

**ATLANTIC COAST PIPELINE, LLC  
ATLANTIC COAST PIPELINE**

**and**

**DOMINION TRANSMISSION, INC.  
SUPPLY HEADER PROJECT**

**Supplemental Filing  
January 27, 2017**

**Karst Terrain Assessment Construction, Monitoring,  
and Mitigation Plan**

January 20, 2017

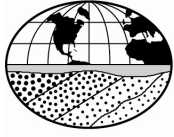
**Karst Terrain Assessment  
Construction, Monitoring  
and Mitigation Plan**

**Atlantic Coast Pipeline  
Randolph and Pocahontas  
Counties in West Virginia  
and Highland, Augusta,  
and Nelson Counties in Virginia**



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January 20, 2017

Ms. Brittany Moody  
Dominion Transmission, Inc.  
445 West Main Street  
Clarksburg, West Virginia 26301

**Subject: Karst Terrain Assessment, Construction, Monitoring and Mitigation Plan, Atlantic Coast Pipeline, Randolph and Pocahontas Counties in West Virginia, and Highland, Augusta, and Nelson Counties in Virginia (Our 15200)**

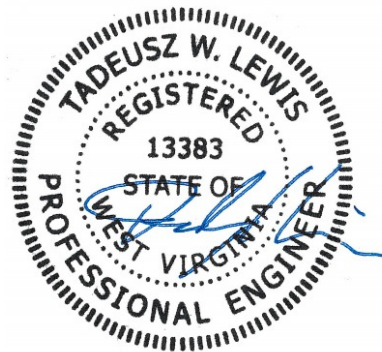
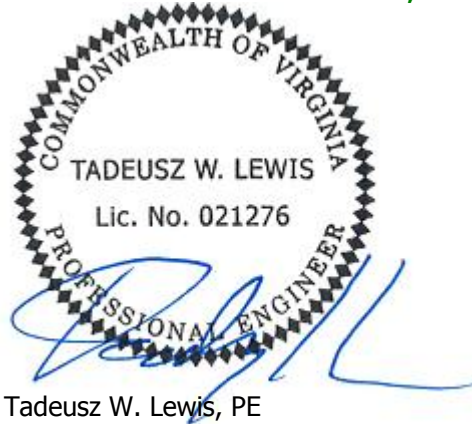
Dear Ms. Moody:

Per your request, GeoConcepts Engineering, Inc. (GeoConcepts) has completed a Karst Terrain Assessment, Construction Monitoring, and Mitigation Plan in support of the development of the Atlantic Coast Pipeline in areas of Randolph and Pocahontas Counties, West Virginia Highland, Augusta, and Nelson Counties, Virginia, and Westmoreland County, PA.

We appreciate the opportunity to serve as your geotechnical consultant on this project. Please do not hesitate to contact me if you have any questions or want to meet to discuss the findings and recommendations contained in the report.

Sincerely,

**GEOCONCEPTS ENGINEERING, INC.**



Tadeusz W. Lewis, PE  
Principal  
tlewis@geoconcepts-eng.com



**ATLANTIC COAST PIPELINE, LLC  
ATLANTIC COAST PIPELINE  
Docket No. PF15-6-000**

**and**



**DOMINION TRANSMISSION, INC  
SUPPLY HEADER PROJECT  
Docket No. PF15-5-000**

**Karst Terrain Assessment, Construction, Monitoring, and  
Mitigation Plan**

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# Plan Outline

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At the request of Atlantic Coast Pipeline, LLC (Atlantic), and Dominion Transmission, Inc. (DTI), GeoConcepts has developed a plan describing the assessment, monitoring, and mitigation activities for the proposed Atlantic Coast Pipeline (ACP) and the Dominion Supply Header Project (SHP) routes through areas of karst terrain. The requested plan is outlined as follows:

## Definitions

This section provides a summary of karst-specific terms used in the plan.

## Geological Overview

This section provides a brief discussion of karst terrain and features and the overall regional karst geology in the general area of the project. It is of note that the plan as written is a “generic” document due to possible changes that may occur in the specific project alignment. However, regardless of reroutes the alignment will need to pass across each of the provinces discussed in the geological overview section of the plan.

## Pre-Construction Assessment and Field Survey

This section describes in detail the pre-construction database and remote sensing review, as well as field survey methods and procedures which are currently being completed.

## Construction Monitoring Protocols

This section describes the methods and procedures to be utilized during the construction phase of the ACP/SHP. It includes:

- a description of the pre-excavation electrical resistivity investigation (ERI) methods and procedures, and the manner in which the ERI data will be analyzed, summarized, and presented; and
- a description of the activities to be conducted by the field geologist during excavation and trenching activities, including how the observations will be made and the reporting format and frequency.

## Karst Mitigation and Conservation Procedures

This section discusses the best management practices (BMPs) to be utilized for mitigating, remediating, and minimizing impacts to karst features that may be encountered during construction activities. This includes features that either are within or receive drainage from the pipeline right-of-way, or features that are intercepted during the excavation and trenching process, as well as access roads, additional temporary workspace areas, or any other areas where land disturbance necessary for pipeline construction is planned. It is noted that these mitigation and conservation procedures will not apply for existing access roads that do not require land disturbance. The format and manner in which the mitigation and remedial activities will be undertaken and reported are addressed in this section of the plan. The intent is to provide agreed upon solutions to the karst features that may be encountered prior to the start of construction so that those features can be protected. However, in some cases, the actual remedial measure employed may be customized to the specific karst features identified.

## Definitions

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**Karst Specialist** – A Licensed Professional Geologist engaged in the practice of engineering geology (or) a Virginia Registered Professional Engineer engaged in the practice of Geotechnical Engineering, with a minimum of 10 years of experience in karst geology characterization and remediation. Practice experience shall be demonstrated by a statement of qualifications.<sup>1</sup>

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<sup>1</sup>Adapted from the VA Cave Board Karst Assessment and Survey Guidelines (and) Denton, et al. 2016. All other definitions adapted from Field, 2002.

**Cave** – A natural hole in the ground, large enough for human entry. This covers the enormous variety of caves that do occur, but eliminates the many artificial tunnels and galleries incorrectly named caves. The size criterion is arbitrary and subjective, but practical, as it eliminates narrow openings irrelevant to explorers but very significant hydrologically, that may be better referred to as *proto-caves*, *sub-conduits*, or *fissures*. A cave may be a single, short length of accessible passage, or an extensive and complex network of tunnels as long as hundreds of kilometers.

**Doline; Sinkhole** – A basin- or funnel-shaped hollow or depression in limestone, dolostone or other soluble bedrock, ranging in diameter from a few meters up to a kilometer and in depth from a few to several hundred meters. Some dolines are gentle grassy hollows or depressions; others are rocky cliff-bounded basins. A distinction may be made by direct solution of the limestone surface zone (solution dolines), and those formed by collapse over a cave (collapse dolines), but it is generally not possible to establish the origin of individual examples. Generally referred to as a "sinkhole" in the United States, the term doline is more widely accepted by the international geology community.

**Throat** – An opening within a sinkhole leading into the subsurface through which material passes or has passed from the sinkhole into underlying solutional voids and conduits, which is generally too small to qualify as a cave and often called a *proto-cave*, *sub-conduit*, or *fissure*. Throats may be "open" (i.e. air-filled or water-filled), or "closed/clogged" (filled with debris including but not limited to: loose-soil; gravel; rock; dead-fall wood or brush; or trash).

**Parapet** – The outer edge or perimeter of a doline (sinkhole).

**Ponor** – a) Hole or opening in the bottom or side of a depression where a surface stream or lake flows either partially or completely underground into the karst groundwater system. b) Hole in the bottom or side of a doline through which water passes to or from an underground channel. Also known as a swallow hole or swallet.

**Solution Cavity** – A natural cavity or depression formed by the dissolution of soluble bedrock, typically not large enough to allow the entry of a human being and, therefore, not classified as a cave.

**Breccia** – Angular fragments of rock commonly, but not always, cemented by finer-grained materials including silica, iron minerals, and calcite to form a new rock. Many fault planes are marked by zones of broken rock, either loose or re-cemented, forming a fault breccia.

**Non-Karst Closed Depression** – A natural or non-natural topographic depression that is not formed by karst processes and is not floored by bedrock. Examples include (but are not limited to) construction-related soil subsidence, silage pits, farm ponds, scour pools, animal wallows, large animal burrows, and pits created by removal of tree stumps.

**Sinking Stream/Swallet** – A perennial or intermittent stream whose bed and bank disappear entirely underground, usually through an open throat sinkhole or cave entrance.

**Losing Stream** – A perennial or intermittent stream which loses flow volume into its bed due to the presence of sub-channel (hyporheic) solution cavities or conduits.

## Geological Overview of the Karst Terrain Sections of the Proposed ACP/SHP

### Overview of regional karst terrain within the project area

The term "karst" refers to a type of landform or terrain, just like "desert", "marsh", "tundra", "steppe" or "montane". It was named for a province in Slovenia where it was first described in the late 17th and early 18th century by geologists of the former Austro-Hungarian Empire. Simply stated, karst terrain is characterized or diagnosed by the presence of sinkholes, caverns, an irregular "pinnacled" bedrock surface,

and many large springs; however, the development of karst terrain is a result of the presence of soluble bedrock such as limestone, dolomite, marble or gypsum. Any landscape that is underlain by soluble bedrock has the potential to develop a karst terrain landform.

As in any region where soluble bedrock is present, a karst landform regime has developed in three known regions of the proposed ACP/SHP. Folding and faulting of the local carbonate rocks has opened up numerous fractures both parallel with the axis of the geologic structures, as well as perpendicular to them. Surface fractures and joints weather differentially, producing a pinnacled or "saw-tooth" profile at the bedrock/soil interface (referred to as the "epikarst" zone). In contrast, rock-enclosed fractures can be secondarily enlarged by the action of carbon dioxide charged groundwater, in some cases forming water-filled or air-filled conduits. As the regional terrain is "mature" karst, nearly all the fractures have undergone successive cycles of sediment filling and flushing. In areas such as the ACP project area, where there is little topographic relief and a relatively minimal groundwater gradient, the great majority of solution fissures are sediment-filled.

The most prevalent type of karst features in the project area are dolines or sinkholes, and these features comprise the greatest potential geohazard risk to any type of construction in karst terrain. Sinkholes fall into two broad categories, "vault-collapse" sinkholes, and "cover-collapse" sinkholes. Vault-collapse type sinkholes (i.e., where a cavern "vault" or roof has failed catastrophically) are rare in the ACP/SHP Project area (Campbell, et al., 2006). Cover-collapse sinkholes, which are common in the ACP project area, develop by the raveling of fines from the soil overburden into solution channels within the bedrock mass, in which water is the transport medium for the movement of the soil fines. The natural raveling process is generally a very slow one, such that sinkhole development generally occurs over a very long time span. However, various changes at a site can sometimes lead to the very sudden development of sinkholes. The most common changes that will exacerbate sinkhole development are:

1. Increase or redirection of overland or subsurface water flow paths, which accelerates the raveling of soil fines;
2. Removal of vegetation cover and topsoil (i.e., stripping and grubbing), which can reduce the cohesive strength of the soils overlying a conduit; and
3. Sudden changes in the elevation of the water table (such as drought, over-pumping of wells, or quarry dewatering), which removes the neutral buoyancy of the water supporting a conduit's soil plug, and can often result in rapid and catastrophic soil collapse.

## Geological Setting

The proposed ACP/SHP will cross three distinct regional provinces of karst geology, from east to west:

1. The **Great Valley subsection of the Valley and Ridge physiographic province**, encompassing the portion of Augusta County, Virginia from the Blue Ridge on the east to Little North Mountain on the west.
2. The **Folded Appalachian subsection of the Ridge and Valley province**, encompassing the westernmost section of Augusta County, and all of Bath County and Highland County, Virginia and extending from the North Mountain area on the east to the Allegheny Mountain on the west.
3. The **Allegheny Front and Appalachian Plateau** provinces of West Virginia, encompassing Pocahontas and Randolph Counties, West Virginia, and the karst section of the SHP located in Westmoreland County, Pennsylvania.



Sequence	AGE	West	FORMATION	East	Thick-ness	DESCRIPTION	Interpretation		
KASKASKIA	Miss.		<b>MAUCH CHUNK</b>			Coarse ss, silt, shale. Channels. Plant fossils common in places. Coal	Begin Alleghenian Orogeny		
			<b>GREENBRIAR</b>			Carbonate dominated (oolites, biosparites)	Orogenic Calm		
			<b>POCONO</b>			300-1700'	Quartz sandstone & conglomerate; coarse, thick, large cross beds	Acadian Orogeny	
		<b>HAMPSHIRE</b>	(Catskill)		2000'	Point Bar Sequences; red			
		<b>GREENLAND GAP GROUP</b>	(former Chemung)	<b>FOREKNOBS SCHEER</b>	2000'	Thick hummocky sequences; at top interbedded red and green fine sands and silts			
		<b>BRALLIER</b>		(Portage in Pa.)	1500-1700'	Bouma sequences			
		<b>MILLBORO</b>	Tully	Harrel Mahantango Marcellus	900' 350-500'	Dark gray to black silts and fine sands			
		<b>NEEDMORE</b>	••• Tioga bentonite •		100-530'	Olive gray fine sands, silts, and shales; fossils abundant in places			
			<i>Wallbridge Unconformity</i>						
			<b>ORISKANY</b>			10-125'	Quartz arenite; white, gray, tan; abundant fossils	Orogenic Calm	
		<b>HELDERBERG GROUP</b>	LICKING CREEK MANDATA NEW SCOTLAND NEW CREEK KEYSER	70-150' 17-50' 70-600'	Carbonates of many kinds; sometimes with cherts, or interbedded with shale or quartz arenites; fossils very abundant				
		(Salina in WVa.)	<b>TONOLOWAY</b>	50-250'	Tidal carbonates; ALM, ALD; mud cracks; salt casts; evaporitic to west				
		<b>WILLS CREEK</b> <b>WILLIAMSPORT</b> <b>McKENZIE</b>	<b>BLOOMSBURG</b>	0-400'	Bloomsburg: red very fine sands/silts/shale				
TIPPECANOE	Silurian				0-75'	Yellow calcareous shale; fossils	Orogenic Calm		
			<b>CLINTON</b>	<b>KEEFER</b> <b>ROSE HILL</b> <b>TUSCARORA</b>	<b>MASSA-NUTTEN</b>	70' 650' 50-250'		700-1200'	Massanutten: coarse friable quartz arenites and conglomerates with large planar X-beds Tuscarora/Keefe: quartz arenites; ripples Skolithus. Rose Hill: red fine - coarse sands and shales; loads, ripples, trace fossils
			<b>JUNIATA</b>	<b>OSWEGO</b>	"Cub ss"	0-200' 0-375'		Red X-bedded ss; Skolithus; bedded w/sh Gray/white, coarse X-bedded sands Hum-mocky	
		<b>REEDSVILLE</b>	<b>MARTINSBURG</b>		3000'	Clastic hummocky sequences Feldspathic/lithic Bouma sequences			
		<b>"TRENTON GROUP"</b>	Oranda (Liberty Hall)	<b>EDINBURG</b> (Lantz Mills)	40-60' 425-600'	Carbonate hummocky sequences Gray silty/shale Black massive micrites and shale	Taconic Orogeny		
		<b>"BLACK RIVER GROUP"</b>	<b>LINCOLNSHIRE</b>		25-170'	Carbonate hummocky sequences Micrites, bio- and pelmicrites, chert			
		<b>NEW MARKET</b>			40-250'	abundant fossils, darkens up section Very pure micrites; tidal features			
			<i>Knox Unconformity</i>						
			<b>BEEKMANTOWN</b>	(Rockdale Run)		2500'	Thick bedded dolomite, black chert; tidal	Divergent Continental Margin	
			<b>STONEHENGE</b>	(Chepultepec)		500'	Thick bedded micrite, blue; tidal features		
		<b>CONOCOCHEAQUE</b>			2500'	LS/dolo/qtz arenite ; abndt tidal structures			
		<b>ELBROOK</b>			2000'	LS/dolo/ blue-gray; tidal features			
		<b>ROME</b>	(Waynesboro)		2000'	Red/green shale/dolo/micrite; very variable			
		<b>SHADY</b>			1600'	Dolomite (granular); LS at top and bottom			
		<b>CHIL-HOWEE</b>	<b>ANTIETAM</b>		500-1500'	Quartz arenite; abndt X-beds Skolithus			
		<b>WEVERTON</b>	<b>HARPERS</b>		2000' 800'	Crs feldspathic shale and graded sandstones Thin bedded			

**Figure 1.** Stratigraphic Column of the central Virginia Great Valley, Folded Appalachians, and eastern Allegheny Front of west central Virginia and eastern West Virginia (Fichter, 2010). (The karst forming units are highlighted in green.)

## The Great Valley (Augusta County, VA)

The Great Valley section is a generally downwarped trough (synclinerium) of Paleozoic limestones, shales, and sandstones that lie between the Blue Ridge Massif on the east and the Allegheny Mountains to the west. The Valley extends between the two mountain uplands from northeast to southwest, parallel with the average strike of the bedrock.

The karst terrain of the Great Valley section of the ACP project area is characterized by numerous circular to oval-shaped sinkholes, ranging in size from a few feet to several hundred feet in diameter, the majority of which are completely vegetated and lack any opening to the subsurface ("throat") at their base. Sinkhole depths can vary, but are usually controlled by the angle of repose of the sediments lining their walls. Steep, rock-walled sinkholes are rare in this section, but generally occur in the small hills and uplands that are erosional remnants of the prior valley floor.

The Great Valley section contains large karst springs in the region. It is also characterized by sinkholes called "estavelles", which are insurgences for water during dry periods, and flood or act as springs (resurgences) during wet seasons. There are also numerous caves (i.e., air-filled voids large enough to permit the entry of a human being and that have an entrance to the surface) and subsurface caverns (air-filled voids large enough for human entry with no connection to the surface) in the region. Most of the caves and caverns range in length from a few feet to several miles; however, the average length rarely exceeds 2,500 feet. This is in contrast to the Folded Appalachian and Appalachian Plateau provinces to the west, where some of the longest caves in the region have been surveyed, many of which are more than 10 miles in length. Nevertheless, though not of great length, some of the most voluminous underground chambers in the region occur in the Great Valley section.

A unique type of karst terrain has developed in the eastern portion of Augusta County along the base of the Blue Ridge Mountains. Here, the characteristic karst terrain has been buried beneath a mantle of alluvial material which was shed off the mountains to the east. This alluvium ranges in age from less than 1 million years (Quaternary Period) to over 50 million years (Paleogene Period). The alluvium thins towards the west, and disappears completely west of Waynesboro, Virginia. Although the primary karst terrain is mantled by the alluvium, numerous shallow broad sinkholes are present and indicate the presence of large karst features in the underlying bedrock.

## Bedrock Geology

Specifically, the proposed ACP project area in the Great Valley section has been extensively studied and mapped as being underlain by a series of karst-forming carbonate and calcareous clastic rocks (Campbell et al., 2006; DMME, 1993; Rader & Gathright, 2001; Rader & Wilkes, 2001; Hubbard, 1988; Southworth, et al., 2013) ranging in age from the Lower Cambrian to Middle Ordovician geological periods as follows:

### Ordovician Period

#### Martinsburg Formation (Om)

The upper 100 to 200 feet of this formation is a brown, medium-to coarse-grained, fossiliferous sandstone. An olive-green silty shale and dark-gray siltstone comprises the middle portion of this formation, along with a medium-to coarse-grained, locally pebbly sandstone. The Stickley Run Member exists as the lower 400 to 900 feet of the formation. This is a medium-gray to grayish-black, very fine-grained (aphanitic), very thin- to thin-bedded, argillaceous limestone with interbedded medium- to dark-gray, calcareous shale.

#### Edinburg Formation (Oeln)

A black, fine-grained to aphanitic limestone with layered black shale that commonly contains pyrite, and medium- to light-gray, fine- to coarse-grained, nodular limestone with thin partings of black shale. This formation lies in thicknesses ranging from 450 to 1,000 feet throughout the three subject areas.

## Lincolnshire Limestone (Oeln)

Gradational contact with the overlying Edinburg. A light- to very dark-gray, fine- to coarse-grained, medium to very thick-bedded limestone with black chert nodules. The Murat Limestone Member, generally found at the top of the formation, is a light colored, coarse-grained limestone composed of fossil fragments. Thicknesses throughout the subject areas range from 50 to 250 feet.

## New Market Limestone (Oeln)

Unconformable upper contact with the Lincolnshire. The upper unit of this formation is a medium-gray, aphanitic, thick-bedded, limestone with scattered calcite crystals. The lower unit is a medium- to dark-gray, fine-grained, thin-bedded, argillaceous, bioturbated limestone that is dolomitic in parts, with its base being a carbonate pebble conglomerate. Formation thicknesses throughout the subject areas range from 100 to 250 feet.

## Pinesburg Station Dolomite\* (Ob)

This formation is a medium-to light gray, fine-grained, medium- to thick-bedded dolostone, with sparse fossils. When weathered, this dolomite is very light-gray, and exhibits a "butcher-block" structure. A medium-gray, fine-grained limestone exists as the base of this unit. The formation's average thickness is 400 feet.

## Rockdale Run Formation\* (Ob)

The upper contact with the overlying Pinesburg Station is unconformable. This formation is comprised of a medium-gray, fine-grained, fossiliferous limestone and a light- to medium-gray, fine-grained, laminated dolomitic limestone and dolostone with mottled beds. Thin lenses of gray chert are common near the base of the formation. Formation thickness ranges from 1,500 to 2,400 feet.

## Stonehenge Limestone\* (Ob)

Upper contact with the Rockdale Run Formation is gradational. The upper 400 to 500 feet is comprised of a medium- to dark-gray and black, fine- to medium-grained limestone, with thin beds of macerated fossil debris. The lower 50 to 150 feet (Stoufferstown Member) is a dark-gray to black, fine-grained limestone with thin sheet-like, crinkly partings due to cleavage, and thin beds of coarse-grained, bioclastic limestone.

**\*Beekmantown Group (Note – This unit consists of the Pinesburg Station Dolomite, Rockdale Run Formation, and the Stonehenge Limestone)**

## Cambrian Period

### Conococheague Formation (OCco)

The upper contact with the Stonehenge Limestone of the Beekmantown Group is unconformable. The upper 2,000 feet of this formation is a light- to dark-gray, fine-grained, laminated limestone, dolomitic limestone, and dolostone with flat-pebble conglomerate beds. Some cross laminated sandstone beds occur in the uppermost part of this unit. The Lower 200 to 500 feet (Big Spring Station Member) consists of a light-gray, fine-grained dolostone, medium- to dark-gray, fine-grained laminated limestone and dolomitic limestone, and gray, coarse-grained sandstone and dolomitic sandstone. Beds of flat-pebble conglomerate occur in the dolomite.

### Elbrook Formation (Ce)

This unit's thickness ranges from 2,000 to 2,500 feet. The formation is a dark- to medium-gray, fine- to medium-grained limestone, dolomitic limestone, dolostone, and dolomitic shale. These lithologies commonly occur as erosion-surface-bounded sequences of algal limestone overlain by laminated dolomite. Decalcified, ocherous shale-like chips on the ground surface characterize this unit. The lower 300 to 400 feet is green to greenish-gray, fine-grained dolostone, dolomitic limestone, and shale.

## Waynesboro Formation (Cw)

The upper contact with the Elbrook Formation is gradational. A dusky-red to olive-gray, fine- to medium-grained sandstone and dusky-red to gray shale exists as the upper 300 feet. The middle 400 feet is a medium- to dark-gray, saccharoidal dolomite and fine-grained limestone. The lower 500 feet is dusky-red, olive-gray, and dark-gray shale and dusky-red to brownish-gray, fine- to medium-grained sandstone. Overall thickness is approximately 1,200 feet.

## Tomstown Dolomite/Shady Dolomite (Ct/Cs)

The upper 600 feet is light- to dark-gray, fine- to coarse-grained, medium- to thick-bedded, locally laminated dolostone with white chert rosettes and nodules in the upper 50 feet. The middle unit (about 210 feet) is very light- to medium-gray, medium-grained, very thick-bedded dolostone and high-magnesium dolostone. The lower unit (about 325 feet) is dark-gray to black, very fine-grained, thin- to very thin-bedded limestone and dolomitic limestone with argillaceous laminations. The overall unit thickness ranges from 1,100 to 1,200 feet. The Shady Dolomite is the homologous unit in the southeastern Great Valley at the base of the western edge of the Blue Ridge Mountains.

## The Folded Appalachians (Augusta County, Bath County, Highland County, VA)

The western edge of the Great Valley is demarcated by the North Mountain Fault, and the ridges of Little North and Great North Mountain. The rocks underlying this section are younger than those of the Great Valley, dating primarily from the Late Ordovician through the Devonian periods in age. In general, the mountain ridges are underlain by sandstone and siltstone, clastic rocks which are insoluble and not prone to karst terrain development. In contrast, the intervening deep valleys are often floored by carbonate rocks, and a characteristic karst landscape characterized by sinkholes, caves and springs has developed in many cases along the axis and flanks of these valleys (Hubbard, 1988; Rader & Wilkes, 2001; DMME, 1993).

## Bedrock Geology

The regional geology of the Folded Appalachians in the project area has been mapped (DMME, 1993) as being underlain by a series of karst-forming carbonate rocks ranging in age from the Lower Ordovician to Lower Devonian geological periods as follows:

### Devonian – Silurian Periods

#### Helderberg Group (Dh)

This group consists of thick- to massive-bedded, dark gray/black micritic limestone with reef structures. The limestone shows some degree of recrystallization. The uppermost Helderberg is typically silicified near its contact with the overlying Oriskany sandstone. In many areas the Helderberg gives off a distinct petroliferous odor when freshly broken. The contact with the overlying Oriskany Sandstone is poorly exposed regionally, but the contact with the underlying Tonoloway Formation is distinct and often unconformable, where the massive bedding of the Helderberg gives way to the thin-bedding of the Tonoloway Formation. The contact can be identified in places by a lag deposit consisting of flat, packstone rip-ups and pebble conglomerate.

The group is a major cave forming unit of the Folded Appalachian section, however, it is of note that the stratigraphy of this unit has been the subject of a much detailed study in recent years (Haynes, et al., 2014). The Helderberg Group consists of a series of individual formations, from oldest to youngest, respectively: the Keyser Limestone, New Creek Limestone, Corriganville Limestone, and Licking Creek Limestone formations. It should be noted that based on biostratigraphic analysis the Keyser Limestone, the basal formation of the Helderberg Group, is considered to straddle the boundary of the Silurian and Devonian periods (Denkler and Harris, 1988a).

The entire Helderberg Group varies regionally, ranging from 85 feet to over 400 feet in thickness. The Keyser is considered the thickest of the individual formations comprising the group, ranging from 50 to 230 feet in thickness.

## Silurian Period

### Tonoloway Limestone (Sto)

This formation consists of extremely thin-bedded (0.5 inches or less) dark gray micritic limestone interbedded with fissile, calcareous shale. The formation gives off a distinct petroliferous odor when freshly broken. The contact with the overlying Keyser Limestone is distinct; however, it grades into the underlying Wills Creek Limestone. The Tonoloway Formation varies from 150 to 600 feet in thickness.

### Wills Creek Limestone (Swc)

This formation consists of thin-bedded (less than 5 inches) dark gray calcareous shale and fossiliferous micrite, which is poorly exposed in the ACP project area. The thickness is variable, ranging from 3 feet to 230 feet.

## Ordovician Period

### Juniata, Oswego, Reedsville, Dolly Ridge, and Eggleston Formations (Oun)

Karst forming unit present only in the westernmost Valley and Ridge section of the ACP alignment (Highland and Bath Counties). The Dolly Ridge and Eggleston Formations are the only karst-forming units and consist of a medium-gray, fine-grained, thin-bedded, argillaceous limestone with interbedded olive-gray calcareous claystone, silt argillaceous limestone, gray shale, and K-bentonite beds. Thickness is about 400 feet in Bath and Highland Counties. The unit is laterally equivalent to the Middle Ordovician ("Trenton Group") limestones and part of the lower Martinsburg Formation.

### Middle Ordovician Limestones, Undivided (Olm)

These limestones consist of the Edinburg Formation, the Lincolnshire Formation, and the New Market Limestone. The Edinburg is a black, fine-grained to aphanitic limestone with layered black shale that commonly contains pyrite, and medium- to light-gray, fine- to coarse-grained, nodular limestone with thin partings of black shale. Thickness is 400 feet to 500 feet. The Edinburg grades downward into the Lincolnshire Formation, a light- to very dark-gray, fine- to coarse-grained, medium- to very thick-bedded limestone with black chert nodules. Thicknesses throughout the ACP project area range from 25 to 250 feet. This unit is underlain by the New Market Limestone. The upper contact with the Lincolnshire is generally unconformable. The upper unit of this formation is a medium-gray, aphanitic, thick-bedded, limestone with scattered calcite crystals. The lower unit is a medium- to dark-gray, fine-grained, thin-bedded, argillaceous, bioturbated limestone that is dolomitic in parts, with its base being a carbonate pebble conglomerate. Formation thicknesses throughout the ACP project area range from 0 to 150 feet.

### Beekmantown Formation (Ob)

This formation is a medium- to light-gray, fine-grained, medium- to thick-bedded dolostone, with sparse fossils. When weathered, this dolomite is very light-gray, and exhibits a "butcher-block" structure. A medium-gray, fine-grained limestone exists as the base of this unit. This formation is comprised of a medium-gray, fine-grained, fossiliferous limestone and a light- to medium-gray, fine-grained, laminated dolomitic limestone and dolostone with mottled beds. Thin lenses of gray chert are common near the base of the formation. Formation thickness ranges from 1,500 to 2,400 feet. The Beekmantown Formation typically consists of three members, which although distinct in the Great Valley region are hard to distinguish in the Folded Appalachian province.

## The Allegheny Front & Appalachian Plateau (Pocahontas County and Randolph County, WV)

The last section of the folded Appalachian karst is located in eastern Pocahontas County. To the west occurs the relatively flat-bedded geology of the Allegheny Front and Appalachian Plateau provinces. The karst terrain in this area is formed almost exclusively by the carbonate rocks of the Mauch Chunk and Greenbrier Groups.

In general, the Mauch Chunk and Greenbrier Group carbonates exhibit a high density of caves relative to the other two karst sections along the pipeline. There are several factors that contribute to this, the main one being that the units act as a drain system for groundwater infiltrating downward through the fractured clastic rocks above them. Where they are exposed along the mountain flanks, the steep groundwater gradients have enhanced this cavern development. In many places surface water plunges directly into the carbonates via steep-walled, open throat sinkholes (swallets). Most of the caves are linear networks, and exhibit conduit flow, capturing surface streams upgradient which then emerge as springs at the downgradient end.

### Bedrock Geology

The Appalachian Plateau section has been mapped (Cardwell, et al., 1968; Davies, 1958) as being underlain by the karst-forming carbonate rocks of the Greenbrier and Mauch Chunk Groups, exclusively. The geology is described from youngest to oldest as follows:

#### Mississippian Period

Mauch Chunk Group – Includes the Bluestone and Princeton Formations (Mbp), Hinton Formation (Mh), and Bluefield Formation (Mbf). The group is predominantly red, green and medium-gray shale and sandstone, with a few thin limestone lenses in each formation. Although the limestone strata in the unit are considered secondary, the topographic position of the Mauch Chunk along the edges of the eroded upland of the Allegheny Plateau where there is a relatively steep downward hydraulic gradient has enhanced water flow through the carbonate lenses, forming karst conduit networks with high transmissivity (Kozar & Mathes, 2001), thus from a karst hydrology viewpoint this unit is significant.

Greenbrier Group (Mg) – In the project area the Greenbrier Group (or “Big Lime” as it is known locally) is up to 400 feet in thickness. It is primarily a gray to dark gray, massively bedded marine limestone, with interbeds of red and green marine and nonmarine shale and thin discontinuous beds of sandstone. The Group is divided into six stratigraphic units; from oldest to youngest they are: the Denmar Limestone, Taggard Shale, Pickaway Limestone, Union Limestone, Greenville Shale, and Alderson Limestone. The principle cave forming units are the Pickaway and Union limestones.

## Pre-Construction Assessment and Field Survey

The proposed ACP/SHP involves the installation of a gas pipeline extending through West Virginia, Virginia, and into southern North Carolina. The currently proposed pipeline construction alignment information shows that the primary route being considered for the pipeline passes across approximately 32.5 miles of karst terrain located in Randolph and Pocahontas Counties in West Virginia, and Highland, Bath, and Augusta Counties in Virginia, based on regional geological mapping.

The “Karst Review Area” (hereinafter referred to as the “KRA”) assessed by data desktop review generally extended 0.25-mile from either side of the centerline of the proposed pipeline and alternate routes, and a 300 foot “study corridor” (300FC) extending 150 feet from either side of the centerline for field review. However, if observed or mapped karst features received drainage from the proposed pipeline work area then these features were delineated to the extent possible, and included in the assessment, even if they were outside of these perimeters.

Thus, the pre-construction assessment and field survey scope can be summarized as follows:

- Located and delineated surface karst features (e.g., sinkholes and karst related subsidence, cave entrances, closed depressions, and sinking and losing streams) within the KRA, with particular emphasis on features that had a direct connection with the phreatic zone such as “open-throat” sinkholes, karst windows, cave entrances, abandoned wells, sinking streams, and areas that could affect the integrity of the pipeline, such as actively forming cover-collapse sinks, areas of soil subsidence, or caves which have passages that extend below the proposed right-of-way at elevations less than 15 feet below the surface. Direct field observations were made by conducting a site reconnaissance over the entire 300FC where access was available.
- Delineated zones of karst terrain, subsidence, and drainages based on the surface karst features assessment.
- Prepared a report summarizing the methods and findings of the assessment.

## Methods and Procedures

The above scope of services was accomplished by the following means:

### Existing Data Review and Analysis

Potential karst features were identified remotely and/or by database review, and then their presence was confirmed in the field. This process helped to focus the actual field location and survey tasks. The following sources were reviewed:

1. The (proprietary) Cave Databases of the Virginia Speleological Survey (VSS) and the West Virginia Speleological Survey (WVSS);
2. Caves of Virginia (Douglas, 1961);
3. Description of Virginia Caves (Holsinger, 1975);
4. Caverns of West Virginia (Davies, 1965);
5. Maps of selected karst features (sinkholes, caves, springs) available from the Virginia Division of Mines and Mineral Resources and the United State Geological Survey (USGS);
6. 2-foot and 4-foot contour interval maps for the KRA (to determine the presence of surface karst features not included in the above listed databases based on the presence of closed, descending contours or other suspect karst “fingerprint” features);
7. LIDAR data (where available);
8. Aerial photographs (both recent and historical);
9. USGS Topographic 7.5-minute topographic quadrangles;
10. Sinkhole and depression locations available from the US Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS) soil studies for the Counties through which the ACP will pass.
11. Weary, D.J. and D.H. Doctor. 2014. Karst in the United States: A digital map compilation and database, USGS open-file report 2014-1156, 23p

In addition, the survey team reviewed the readily available geological literature for bedrock and structural characteristics, relying upon the closest resolution mapping that existed for the particular KRA being examined.

### Field Reconnaissance

Upon completion of the existing data review activities for a specific area, GeoConcepts undertook field reconnaissance and survey activities. Specifically, the field reconnaissance entailed:

1. Location and verification of surface karst features identified in the database review;
2. Location of uncatalogued or previously unidentified surface karst features, specifically sinkholes, cave entrances, dry runs and sinking streams.

The field reconnaissance placed particular emphasis on locations where pathways existed to phreatic groundwater such as open-throat sinkholes, cave entrances, karst “windows”, and sinking streams. Potential reroutes were identified based on the field observation of sensitive karst features, such as significant caves, sinking streams, or open throat sinkholes.

The 300FC was delineated and the path of the 300FC was examined for karst features (both catalogued and previously unidentified) by field survey. This entailed conducting a site reconnaissance over the 300FC (i.e., the proposed pipeline route) in a systematic manner, to observe any existing surface karst features that fit the criteria. The locations and outlines of all relevant features were recorded using a sub-meter accurate Global Positioning System (GPS) device. For the purpose of this study, the outline (parapet) of sinkholes were defined by the last closed descending contour at mapping interval available for the area under study. Cave entrances were identified as single points, unless the entrance was located within a larger sinkhole structure, in which case the cave entrance was indicated as a point within the sinkhole’s parapet. Sinking streams were located as points of entry into the subsurface; however, losing streams were identified as linear features.

All digital data was transmitted in the Universal Transverse Mercator (UTM) Coordinate system. The horizontal datum of reference is NAD83.

## Summary Report

The results of the data review and field survey has been summarized in a final report. The report details the methods and findings, and contains an inventory and contained a delineation of karst features and terrain. The frequency and density of karst features was also correlated with the encompassing geological unit at the formational level (e.g., Elbrook Formation, etc.). The report is accompanied by a data set containing the attributed digital points and polygon data as shapefiles with metadata (maps and/or tables). The results of the karst survey work was used during routing and workspace design. In addition, these data will be used during the construction phase to assist in the pre-construction inspection tasks described in the following sections.

## Construction Monitoring

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The purpose of this section of the plan is to establish a standard set of monitoring protocols for karst features encompassed by the proposed ACP pipeline right-of-way and adjacent areas. The intent of these protocols is to minimize impact to the subterranean environment, ensure water quality, and protect the integrity of the pipeline (Burden, 2012).

### I. Geophysical Survey

To obtain more information about the subsurface conditions, and possible karst development along the proposed ACP pipeline alignment, an electrical resistivity investigation (ERI) will be conducted in the areas that are mapped with limestone bedrock. The ERI will be performed along the entire length of the pipeline centerline in karst terrain prior to any earth-disturbance and/or excavation activity.

### Instrumentation

The geophysical survey instrument which will be used during this survey is an electrical resistivity meter that maps the resistivity changes in the earth. Resistivity refers to the electrical resistance of a material. The ERI survey will be conducted by introducing a measured current into the earth through two electrodes and measuring the resultant voltage (i.e., potential) across two different electrodes. At the low currents used, voltage is proportional to the current. The meter measures the voltage/current ratio or resistance in Ohms.



The ERI survey will be conducted using an earth resistivity meter which measures the apparent conductivity of the subsurface employing an artificial source that is introduced through point electrodes. The automatic electrode system is designed to optimize survey efficiency by gathering maximum information with a minimum of electrodes. The instrument also uses redundancies in the data set to reduce the effects of lateral heterogeneities in the earth and to calculate uncertainties in the data. The survey will be conducted automatically using a dipole-dipole array system.

## Interpretation Method

The ERI data will be converted into a resistivity depth model using a Rapid 2D resistivity inversion model and the least-squares method (RES2DINV). Soundings from each line will be modeled to produce the measured apparent resistivity pseudo-sections. The model will calculate the apparent resistivity pseudo-sections using finite-difference forward modeling. The least-squares optimization technique will be used for the inversion routine that calculates the modeled resistivity section. The generated profiles will include cross-sections that consist of the inverse model resistivity cross-section. The horizontal and vertical scales will be in meters.

The cross-section is the inverse model resistivity pseudo-section. The ER data will be converted into a resistivity depth model (RES2DINV) using a resistivity inversion model by the least-squares method, which will be topographically corrected. RES2DINV will confirm the model reliability by calculating the modeled data into empirical data or the calculated resistivity pseudo-section. The difference between the measured and calculated data is the percent error. The modeled calculated error will be calculated within the five percent range, which is considered very accurate.

Low resistive materials can be caused by certain conductive soils, such as clay, wet silts, and sands, or ionized water. High resistive materials are caused generally by porous soils (i.e., poorly consolidated gravels), laminated bedrock with interstitial clay-filled voids, wood, or large, air-filled cavities. Lower ER anomalies are generally associated with soil-filled voids, saturated sinkhole soils, and water-bearing fractures. High ER anomalies are frequently associated with caverns, buried air filled structures, or weathered, laminated bedrock with air filled cavities.

Resistivity values can vary widely as the geology, mineralogy, and stratigraphy changes from site to site. Therefore, it is important to correlate resistivity results with boring logs for equivalent sections at a specific locality. Typical values are:

<b>Subsurface Material</b>	<b>Resistivity Range (<math>\Omega\text{m}</math>)</b>
Topsoil	1 – 10
Clays	10 – 100
Sands and Gravels (unconsolidated)	600 – 10,000
Fresh Water	3 – 100
Limestone	100 – 10,000
Sandstone	100 – 1,000
Igneous and Metamorphic Rocks	100 – 1,000,000
Open Voids (i.e. caverns, solution conduits)	>10,000

Although the above values are characteristic of various subsurface materials, the absolute resistivity ranges will vary considerably depending on the local geology. Therefore, it is required that the ERI survey is calibrated using soil test/air track borings. In addition, if high ER anomalies are detected, their locations will need to be documented and further investigated. The specific type of investigation will be dictated by the characteristics of each anomaly identified, but typically air track borings will be used to verify anomalies observed during an ERI survey.

## II. Inspection Protocols

Inspection protocols will be provided to the contractor and will be reviewed at a pre-construction meeting led by the Karst Specialist (KS). In addition, all geologist or engineering staff utilized during construction will have received training from the KS prior to mobilization to the site regarding the identification and mitigation of karst features that have been previously identified within the project boundaries, or that may be identified during construction.

### Pre-Construction Inspection

Prior to the commencement of any earth disturbance activity, the area of the pipeline that will be affected by the planned activities will be inspected by the karst specialist (KS) as follows:

- a. The KS will inspect the entire section of the pipeline ROW (right-of-way) in the designated work area, and note any suspect karst features including sinkholes, caves, areas of soil subsidence, or closed depressions.
- b. The KS shall conduct a final preconstruction field assessment of seeps and springs within 500 feet of construction workspaces in karst terrain. The KS shall subsequently determine if construction activities could have an impact on the seeps and/or springs, and provide construction alternatives to avoid or mitigate impacts where practical.
- c. The locations of observed features will be noted on site drawings and flagged for surveying and/or recorded using sub-meter accuracy GPS instrumentation.
- d. The KS will issue a report summarizing the findings of the inspection. Findings will supplement the summary report and shall include an inventory of feature type(s), drainages, and potential impact to the feature by the planned activities, and recommendations to limit impacts if they are expected. This inspection is intended to supplement the aforementioned pre-construction karst assessment and field survey report, as new features may have developed, or existing features described in identified in the original assessment may have changed.
- e. Features that are considered to have potential impacts are: caves, sinkholes with open throats, ponors, open solution cavities, abandoned wells, and sinking streams. (Note – If a sinkhole throat is filled, the type of fill, i.e. rock, soil, flood debris, etc., will be described in detail).
- f. Features that are not considered to have a potential impact are: soil-bottomed (stable) sinkholes (i.e., no evidence of recent soil raveling or tension cracks along the parapet), karst springs, or non-karst closed depressions. However, it is of note that land disturbance to stable sinkholes can render them unstable. Not structurally unstable in general, but strictly in terms of raveling of surface materials (sediment) and associated contaminants into the subsurface.
- g. The pre-construction inspection will have a “shelf-life” of 1 year from the day of the inspection. If work does not commence within 1 year, a new inspection will need to be completed prior to any earth disturbing activities.
- h. The pre-construction inspection report shall be delivered to Atlantic/DTI no later than 1-month after the completion of the field survey.

### Monitoring of Pre-Identified Features During Construction

Features identified during the pre-construction inspection will be monitored as follows:

- a. If an identified feature with potential impact to the subterranean environment falls within the area designated for earth disturbing activities and cannot be avoided, the feature will be documented by field location and photographs, and then assessed for pre-construction remediation by Atlantic/DTI staff with input and guidance to be provided by the KS. Remediation will be in compliance with the USDA-NRCS’s Conservation Practice Standard Code 527 “Karst Sinkhole Treatment” (2010) and the West Virginia Department of Environmental Protection Division of Water and Waste Management Ground Water Protection Program Sinkhole Mitigation Guidance, August 8, 2005. (see Appendix A)

- b. If a feature that has potential impact falls within the right-of-way but is not intercepted by the excavation, that feature will be monitored during the work by Atlantic/DTI staff for changes such as:
  1. soil subsidence;
  2. rock collapse;
  3. sedimentation;
  4. increased surface water infiltration;
  5. flooding;
  6. clogging; and/or other changes in morphology or function that might indicate potential impact to the epikarst stratum caused by the work.
- c. All features, whether remediated or left in an undisturbed natural state, will be monitored by Atlantic/DTI staff, or their designee, for any changes in appearance, drainage, siltation, etc., at 1 year, 2 year, and 5 year intervals after the completion of the earth disturbing activities. If changes in the features are observed, Atlantic/DTI staff will report the condition to the KS who will provide consultation on potential impacts to the karst environment and possible remedial actions.

## Monitoring of Features That are Intercepted During Construction

Features that are intercepted during construction shall be monitored as follows:

### Level 1 Inspection of Features Intercepted During Construction

If any feature is intercepted during work activities including borings, blasting, and excavation or trenching, the onsite geologist will conduct an initial assessment of the feature to determine if further inspection (Level 2) by the KS will be required. Suspect features shall include:

1. Bedrock enclosed conduits, cave entrances<sup>2</sup> and voids;
2. Solution pockets that extend beyond visual examination range (and therefore may be open);
3. Areas of soft soils;
4. Soil voids;
5. Highly fractured bedrock;
6. Areas of breccia enclosed within the surrounding bedrock.

### Level 2 Inspection of Features Intercepted During Construction

If any of the aforementioned features are observed during the Level 1 inspection, work will stop within a 100-foot radius of the feature, and then the KS will conduct a Level 2 inspection as follows:

- a. The KS will examine the feature and determine if it has potential impact to the subterranean environment based on potential connectivity with the phreatic aquifer via the epikarst stratum (Moore, et al, 2013). The choice of characterization methods will be determined by the KS, and will include any combination of (but not be limited to):
  1. visual assessment;
  2. geophysical survey;
  3. track drill probes;
  4. infiltration or dye trace testing; or
  5. other techniques utilized to facilitate subsurface characterization of karst features.
- b. If the feature is determined to have potential impact to the subterranean environment, the KS will advise Atlantic/DTI staff regarding appropriate remedial actions.

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<sup>2</sup>If an opening to a cave is intercepted during construction activities, there should be immediate coordination with the US Fish and Wildlife Service, US Forest Service (if within Forest Service ownership land) Virginia DCR-NHP Karst Program (or) West Virginia Department of Conservation, for investigation.

- c. If the feature is determined to not have potential impact to the subterranean environment, work will resume as planned.
- d. All features that are intercepted during construction and subsequently remediated will be located by project surveyors exclusively, and monitored by Atlantic/DTI staff, or their designee, for any changes in appearance, drainage, siltation, etc., at 1 year, 2 year, and 5 year intervals after the completion of the earth disturbing activities. If any changes are observed, the KS will provide consultation on potential impact and recommend remedial actions, if necessary.
- e. All Level 2 inspections, findings, and remedial activity will be summarized in a report by the KS, to be delivered to Atlantic/DTI after the completion of the field work.

## Monitoring of Features That Form During Construction

Features that form during construction will be monitored as follows:

### Level 1 Inspection of Features That Form During Construction

If any feature forms during work activities including hydrostatic testing, drilling, blasting, and excavation or trenching, Atlantic/DTI staff will conduct an initial assessment of the feature to determine if further inspection (Level 2) by the KS will be required. Suspect features will include:

- a. Cave entrances<sup>3</sup>
- b. Sinkholes;
- c. Soil subsidence areas; and/or
- d. Rock collapses.

This will apply to any of the above features that may form either within the work area, whether located along the proposed disturbance section or anywhere within a 300-foot radius of the work area.

### Level 2 Inspection of Features That Form During Construction

If any of the aforementioned features are observed during the Level 1 inspection, work will stop in the area of the feature based on the observed site conditions, and then the KS will conduct a Level 2 Inspection as follows:

- a. The KS will examine the feature and determine if it has potential impact to the subterranean environment based on potential hydraulic connectivity with the karst aquifer via the epikarst stratum.
- b. The choice of characterization methods will be determined by the KS, and will include any combination of (but not be limited to) the following:
  - a. visual assessment;
  - b. electrical resistivity survey;
  - c. track drill probes;
  - d. infiltration testing; and/or
  - e. other techniques utilized to perform subsurface characterization of karst features.
- c. If the feature is determined to have potential impact to the subterranean environment, the KS will consult with Atlantic/DTI staff regarding appropriate remedial actions.
- d. If the feature is determined to not have potential impact to the subterranean environment, work will commence as planned.
- e. All features that form during construction, whether remediated or left in an undisturbed natural state, will be located on the site plans by the project surveyors, and will be monitored for any changes in appearance, drainage, siltation, etc. at 1 year, 2 year, and 5 year intervals after the completion of the earth disturbing activities. If any changes are observed, the KS will provide consultation on potential impact to the karst environment and remedial actions, if necessary. This

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<sup>3</sup>If an opening to a cave forms during construction activities, should be immediate coordination with the Virginia DCR-NHP Karst Program (or) West Virginia Department of Conservation for investigation.

monitoring will be carried out on all features that form during work activities, regardless of whether they have a potential impact to the karst environment or not.

### III. Notification and Consultation

Notification of, and consultation with State and Federal regulatory and administrative agencies will be completed for the following:

1. Any planned invasive subsurface exploration, including: geotechnical soil borings; rock coring; air track borings; test pits; or other invasive investigative measures that have the potential for intercepting subsurface voids, conduits, or caverns.
2. Any karst features that were identified and located prior to construction that will require remediation or mitigation.
3. Any karst features that were identified and located prior to construction that will require periodic monitoring, whether remediated or left in an undisturbed natural state. The results of the monitoring shall be documented and reported to the appropriate agencies.
4. Any karst features that are intercepted during construction. Notification and consultation will take place after the performance of the Level I inspection.
5. Any karst features that form during construction. Notification and consultation will take place after the performance of the Level I inspection.
6. Any karst features that form following construction which are observed during the post-construction karst feature monitoring (*see* Level 2 Inspection of Features that form during construction, part e).

#### Federal Agencies to be Notified

**United States Fish and Wildlife Service (USFWS)**  
**Federal Energy Regulatory Agency (FERC)**  
**United States Forest Service (USFS)<sup>4</sup>**

#### State Agencies to be Notified (Virginia)

**Virginia Department of Conservation and Recreation – Natural Heritage Program (DCR-NHP)**  
**Virginia Department of Environmental Quality (VDEQ)**

#### State Agencies to be Notified (West Virginia)

**West Virginia Division of Natural Resources (WVDNR)**  
**West Virginia Department of Environmental Protection (WVDEP)**

## Karst Mitigation and Conservation Procedures

The following procedures will be used to avoid and minimize any impact of pipeline construction and/or O&M activity which might present a risk to environmental receptors, in particular obligate subterranean taxa. Please note that other resource protection measures that may be implemented for the ACP may provide redundancy with regard to the karst mitigation and conservation procedures detailed herein.

### Measures to Avoid Impact to the Karst Aquifer and Environment

These measures shall apply to any karst feature which allows the unfiltered and unimpeded flow of surface drainage into the subsurface environment, including (but not limited to): open throat sinkholes, caves which receive surface drainage, sinking streams, and losing stream segments. These avoidance measures were derived from the NiSource Habitat Conservation Plan, Madison Cave Isopod Avoidance and Minimization Measures, and the Columbia Pipeline Group HCP and non-HCP species Best Management Practices

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<sup>4</sup> Only if within USFS lands.

Guidance Document. They are intended to prevent impact to the karst aquifer and the subsurface habitat of obligate stygobiont species through protection of groundwater quantity and quality (Burden, 2012).

1. Protect known and/or future mapped recharge areas of cave streams and other karst features by following relevant conservation standards, specifically the FERC 2013 Upland Erosion Control, Revegetation and Maintenance Plan, the FERC 2013 Wetland and Waterbody Construction and Mitigation Procedures, and the ACP Spill Prevention, Containment, and Control (SPCC) plan.
2. Buffers of 300 feet around karst features in all work areas (within and off-ROW including discharge areas) must be clearly marked in the field with signs and/or highly visible flagging until construction related ground disturbing activities are completed. If a karst feature or its 300-ft buffer falls within the 125-ft wide workspace the following steps should be taken:
  - a. The workspace should be narrowed (if practicable) to impact as little of the buffer as possible.
  - b. No spraying of insecticides or herbicides shall be allowed within the 300-ft buffer.
  - c. No refueling, repair or maintenance of vehicle or equipment shall be allowed within the 300-ft buffer.
  - d. Soil disturbance within the buffer (i.e. trenching) shall be performed in a manner which prevents sediment from entering the subsurface through the use of carefully designed and continuously maintained sediment and erosion control measures, and shall follow the procedures and BMPs specified in the FERC plans and procedures mentioned in section 1, above.
  - e. If the karst feature is located downgradient from the area of soil disturbance, drainage shall be directed away from the karst feature and its 300-ft buffer through the use of diversion trenches, water breaks, or other engineered methods. This shall apply even if the feature itself is located outside of the 125-ft workspace, but the workspace intercepts the 300-ft buffer.
  - f. No activity of any kind shall be allowed within the parapet of a sinkhole or within a 25-ft buffer around the parapet, which should remain in an undisturbed, natural state. The sinkhole and the 25-ft parapet buffer should be delineated using temporary fencing.
3. Earth disturbing activities will be conducted in a manner that minimizes alteration of existing grade and hydrology of existing surficial karst features. Pre-existing flow channels will be stabilized but will not otherwise be altered. Concentrated flow caused by construction activities will be dispersed with a suitable spreading or diversion technique. Surface water flow volume will be maintained at historic (or predevelopment) levels as changes to the volume of surface water flow can disturb the subsurface hydrology.
4. Any open-throat sinkholes and cave entrances within 300 feet of the workspace, located downgradient from the centerline which receives drainage from the workspace will be carefully protected using silt fences, diversion trenches, constructed temporary berms around the parapet, or water breaks. If the feature receives flow via a discreet drainage channel, the channel will be equipped with absorptive boom and a double row of silt fences.
5. In addition to the aforementioned requirements, the following will be implemented in construction workspace areas:
  - a. If a new open throat, cover-collapse sinkhole forms within the ROW or construction work space, work in that area will stop and the sinkhole will be isolated from the rest of the work area with sandbags or other suitable materials. The sinkhole will be inspected by the KS and appropriate action taken (e.g., pipeline relocated, sinkhole remediated, etc.) to ensure pipeline integrity and protection of the aquatic resource and subterranean habitat. The preferred method for remediation will be the graded/inverted filter method (Ralstein and Oweis, 1999). This technique involves excavation and cleaning out collapsed, soft soils in the weakened zone to limit further soil raveling, and placing rocks or boulders large enough to bridge the bedrock conduit or "throat" at the bottom of the excavation. Progressively finer rock and gravel are then placed and compacted above the base course, above which is placed a layer of permeable

- geotextile fabric and soil to the final grade which is then seeded. The advantage of this method is that it allows surface water to continue to infiltrate into the subsurface, but prevents further soil raveling (which is the root cause of cover-collapse sinkholes). The vegetated soil stratum and underlying gravel acts as a natural filter for the water infiltrating to the underlying solution enlarged conduits and fracture system. (see Appendix A).
- b. If a subsurface void or conduit should open or be intersected in the process of excavation and/or trenching, work in that area will stop and the void will be isolated from the rest of the work area with sandbags or other suitable materials. The void will be inspected by the KS and the most appropriate remedial method will be determined on a case-by-case basis. Soil voids will be backfilled using the graded filter method as described above. Small conduits (< 1 foot in diameter) may be closed with low mobility grout and/or flowable fill. Large conduits (>1 foot in diameter) will require specific remedial actions (capping, void bridging, or plugging) based on the location and geometry of the conduit (i.e. whether the conduit is located at the bottom, one side, or both sides of the trench).
  - c. If a subsurface void or conduit should open or be intersected in the process of excavation and/or trenching through which water is flowing (i.e. an underground stream) work in that area will stop, and the void will be isolated from the rest of the work area with sandbags or other suitable materials. The void will be inspected by the KS, and the most appropriate remedial method will be determined on a case-by-case basis. All efforts will be made to ensure that the existing flow path is not interrupted by isolating the stream using trench breakers, and backfilling the location of the saturated karst feature or stream with permeable material such as well-graded stone or other material which will not interfere with the continued flow of water from one side of the trench to the other.
  - d. In linear excavations adjacent to karst features, spoils will be placed on the upgradient side of the excavation so that if any erosion takes place the stockpiled soil will flow back into the excavation and not downgradient towards the karst feature.
  - e. Surface water control measures, including, but not limited to: diversion (direct water flow into trench or off right-of-way areas past the area of concern), detention or collection and transportation, will be utilized to prevent construction-influenced surface water from free flowing into open throated surface karst features, and eventually into the subsurface.
  - f. Open throat surface karst features will not be utilized for the disposal of water. This shall include, but not be limited to: hydrostatic test water, water from trench dewatering, or any other water generated by, or utilized in, construction activities.
6. Blasting will be conducted in a manner that will not compromise the structural integrity or alter the karst hydrology of known or inferred subsurface karst structures. If blasting or hammering is deemed necessary then the following parameters will be adhered to:
- a. The excavation will be carefully inspected for any voids, openings or other tell-tale signs of solution activity.
  - b. If the rock removal intercepts an open void, channel, or cave, the work in that area will be stopped until a remedial assessment can be carried out by a qualified geologist or engineer with experience in karst terrain.
  - c. All use of explosives will be limited to low-force charges that are designed to transfer the explosive force only to the rock which is designated for removal (e.g., maximum charge of 2 inches per second ground acceleration).
  - d. If the track drill used to prepare the hole(s) for the explosive charge(s) encounters a subsurface void larger than 6 inches within the first 10 feet of bedrock, or a group of voids totaling more than 6 inches within the first 10 feet of bedrock, then explosives should not be used (or) a subsurface exploration should be conducted to determine if the voids have connectivity with a deeper structure. The subsurface exploration can be carried out with track drill probes, coring drill, electrical resistivity, or other techniques capable of resolving open voids in the underlying

- bedrock. If a track drill or coring rig is used, then all open holes will be grouted shut after the completion of the investigation.
7. Horizontal Directional Drilling (HDD) will not be used in karst terrain.
  8. If authorized by the landowner, block (e.g. gate) all access roads and ROWs leading to cave entrances or open throat sinkhole structures to prevent unauthorized access.
  9. Comply with requirements of project SPCC plan.
  10. A Spill Prevention, Control, and Countermeasures Plan (SPCC) has been developed for the proposed ACP/SHP which will further avoid and minimize potential impact of spills by implementing the following measures:
    - g. equipment refueling will not be performed within flagged or marked buffer areas of streambeds, sinkholes, fissures, or areas draining into these or other karst features, except by hand-carried cans (5 gallon maximum capacity) when necessary;
    - h. equipment servicing and maintenance areas will be sited outside of flagged or marked buffer areas of streambeds, sinkholes, fissures, or areas draining into these or other karst features;
    - i. prevent runoff resulting from construction equipment washing operations to directly enter any karst feature by locating these operations outside of the buffer area;
    - j. construction equipment vehicles, materials, hazardous materials, chemicals, fuels, lubricating oils, and petroleum products will not be parked, stored, or serviced within 300 feet of any karst feature;
    - k. all equipment will be checked by a construction inspector daily for leaks prior to beginning work in karst areas; damaged or defective equipment will be removed or repaired; and
    - l. if a reportable spill has impacted a karst feature:
      - i. follow the SPCC Plan and
      - ii. call the National Response Center (800-424-8802) and the Virginia Department of Environmental Quality (800-469-8892) or the West Virginia Department of Environmental Protection (304-558-5938), as appropriate.
  11. Hydrostatic test water will not be obtained from karst features (only free-flowing streams).
  12. Hydrostatic testing water from new pipe installations shall not be discharged into flagged or marked buffer areas of sinkholes, fissures, or other karst features or channels or surface features that flow towards those features. Discharging of hydrostatic testing water shall be performed in the following manner (in order of priority and preference):
    - a. Discharge hydrostatic test water downgradient of flagged or marked buffer areas of sinkholes, fissures, or other karst features unless on-the-ground circumstances (e.g., man-made structures, terrain, or other sensitive resources) prevent such discharge.
    - b. If water cannot be discharged downgradient as described in 12a, discharge water into uplands greater than 300 feet from flagged or marked buffer areas of sinkholes, fissures, or other karst features unless on-the-ground circumstances (e.g. man-made structures, terrain, other sensitive resources) prevent such discharge.
    - c. If the conditions listed in either 12a or 12b are not practicable, discharge water as far from flagged or marked sinkholes, fissures, or other karst features as is practical and utilize additional sediment and water flow control devices to minimize effects.

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## Appendix A – Sinkhole Mitigation Guidance Documents

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**West Virginia Department of Environmental Protection  
Division of Water and Waste Management  
Groundwater Protection Program**

**Sinkhole Mitigation Guidance**

**August 8, 2005**

**Purpose:**

These sinkhole mitigation designs serve to allow the filling of sinkholes while maintaining recharge to the aquifer, reducing potential contamination threats to groundwater, and eliminating safety hazards at sinkhole entries.

**General:**

Consideration should be given to the method used for removing contaminated materials from sinkholes and reducing or eliminating direct inflow of surface water into sinkholes. Land treatment methods that improve the filtration and infiltration of surface water before it enters the sinkhole should be used along with the mitigation of the sinkhole.

Before selecting a treatment option the following should be considered:

- Land use
- Existing and planned land treatment
- Sinkhole drainage area
- Dimensions of the sinkhole opening
- Safe outlet for diverted surface water
- Environmentally safe disposal of sinkhole “clean out” material
- Availability and quality of filter material
- Safety of equipment and operators and laborers during installation

Treatment selection should be based on the dimensions of the sinkhole drainage area and include direct sinkhole treatment with surface water control measures and filter strips. Whichever treatment option is chosen, it should avoid surface water ponding or the creation of high soil moisture conditions in excess of 72 hours.

Treatment designs apply to sinkholes with excavated depths of 5 to 25 feet and with drainage areas up to 15 acres. Excavations up to 5 feet are sufficient for most sinkholes. Sinkholes with excavation depths of greater than 25 feet or with uncontrolled drainage areas greater than 15 acres may require adjustments to the treatment measure(s) and/or surface water control measure(s). In these cases, geologic and engineering assistance must be obtained and a site-specific treatment design prepared.

### **Treatment for Sinkholes with Drainage Areas Less than 5 Acres**

Treat the sinkhole using the mitigation design in Figure 1 of this guidance document. The treatment site should be inspected after periods of heavy precipitation because some material may run into adjacent sinkhole voids causing a surface depression. In this case, maintenance will include adding soil material at the surface. The existing land use or practice may continue over the treated sinkhole as long as the treatment is maintained.

### **Treatment for Sinkholes with Drainage Areas of 5 Acres or More and Having a Safe Outlet**

The following additional treatment criteria are applicable to sinkholes with drainage areas of 5 acres or more where a safe outlet can be provided to divert surface water away from the sinkhole. A safe outlet is one that does not erode, divert surface water to another sinkhole or injection well, or cause flood damage to crops, property, buildings, or highways/roads.

Surface water control measures should be situated to reduce the internal drainage area around the sinkhole to less than 5 acres. The choice of surface water control measures is generally based on site-specific conditions.

### **Treatment for Sinkholes with Drainage Areas of 5 to 15 acres and Having No Safe Outlet**

Treat the sinkhole using the mitigation design in Figure 2 of this guidance document. The site should be inspected after periods of heavy precipitation because some material may run into adjacent sinkhole voids causing a surface depression. In this case, maintenance will include adding soil material at the surface. The sinkhole should remain as unused land.

### **Vegetated Buffer Area**

A vegetated buffer area should be installed around the sinkhole to improve runoff water quality by filtration and adsorption of contaminants. The vegetated buffer area should be installed within the sinkhole drainage area and should begin at the treated sinkhole.

The minimum width (in feet) of the vegetated buffer area is determined by multiplying the sinkhole drainage area (in acres) by seven. This width should provide beneficial filtering for some distance outside the sinkhole because surface water runoff may be temporarily held before reaching the treated sinkhole.

Appropriate vegetation should be used for the buffer area. Use native vegetation as much as possible. **DO NOT** use noxious plants or weeds. It is recommended that a plant nursery be consulted for the appropriate vegetation.

### **Acceptable Materials**

Engineering fabric - must meet the applicable requirements of AASHTO M-288.

Aggregates – fine aggregates, gravel, or rock rip rap that conforms to the West Virginia Department of Highways, Standard Specifications for Roads and Bridges, Sections 702, 703, and 704.

### **Specifications**

Use the following guidance for installing a mitigation design for sinkholes and sinkhole areas with drainage areas of less than 5 acres:

1. Remove and properly dispose of materials dumped in and around the sinkhole in accordance with applicable federal, state, and local laws.
2. Excavate loose material from the sinkhole and try to expose the solution void(s) in the bottom. Enlarge the sinkhole, as necessary, to allow for installation of the filter material.

3. Select stone that is approximately 1.5 times larger than the solution void(s). Place the stone into the void(s) forming a competent bridge. Stone used for the bridge should have rock strength equal to, at least, moderately hard (*e.g.*, resistant to abrasion or cutting by a knife blade but can be easily dented or broken by light blows with a hammer). Shale or similar soft and non-durable rock is not acceptable.
4. Place a layer of filter material over the bridge to a minimum thickness of 24 inches. Approximately 35 percent of the material should be larger than the opening between the bridge and the void(s). There should be no discernable large openings around the bridge. The material should be either gabion stone, stone for rip rap, or stone for special rock fill that conforms to West Virginia Department of Highways, *Standard Specification Roads and Bridges*, Section 704.
5. Place a layer of smaller size filter material over the previous layer to a minimum thickness of 10 inches. The size of the material should be  $\frac{1}{4}$  to  $\frac{1}{2}$  the size of that used in the previous layer. The material should be No. 57 aggregate, which conforms to West Virginia Department of Highways, *Standard Specifications Roads and Bridges*, Sections 703.1.1, 703.1.2, 703.1.3, 704.1.4, and 703.2.1. Unacceptable filter material consists of pea gravel or slags (steel, electromagnetic, or power plant).
6. Place a layer of sand-sized filter material over the previous layer at to a minimum thickness of 10 inches. The sand must be compatible in size with the previous layer to prevent piping. The material should be fine aggregate that conforms to West Virginia Department of Highways, *Standard Specification Roads and Bridges*, Sections 702.1.1, 702.1.2, and 702.1.3.
7. Engineering fabric conforming to AASHTO M 288 may be substituted for the stone and sand filter materials discussed in 5 and 6.
8. Backfill over the top filter layer or engineering fabric with soil material to the surface. This should be mineral soil with at least 12 percent fines. Reuse soil material excavated from the sinkhole as much as possible and place any available topsoil over the backfill. Overfill by about 5 percent to allow for settling.

9. Establish vegetation on the mitigated sinkhole and other disturbed areas of the site.

Use the following guidance for installing a mitigation design for sinkholes and sinkhole areas with drainage areas of 5 to 15 acres:

1. Remove and properly dispose of materials dumped in and around the sinkhole.
2. Excavate loose material from the sinkhole.
3. Place a layer of filter material into the sinkhole, allowing the stone to fill the void(s) below the bottom of excavated sinkhole. The size should be  $\frac{1}{4}$  to  $\frac{1}{2}$  the size of the void(s). This material can be WVDOH gabion stone, rip rap stone, or special rock fill stone.
4. Place a layer of the same size filter material to a thickness of about  $\frac{3}{4}$  TD (TD = total depth) above the sinkhole bottom.
5. Place a layer of smaller size filter material over the previous layer to a thickness of about  $\frac{1}{4}$  D. Bring this layer to surface level. The size should be  $\frac{1}{4}$  to  $\frac{1}{2}$  the size of the previous layer. The material should be No. 57 aggregate, which conforms to West Virginia Department of Highways, *Standard Specification Roads and Bridges*, Sections 703.1.1, 703.1.2, 703.1.3, 703.2.1, and 704.1.4. Unacceptable stone consists of pea gravel or slags (steel, electrometallurgical, or power plant).
6. Shale or similar soft and non-durable rock is not acceptable.
7. Establish vegetation on the mitigated sinkhole and disturbed areas of the site.

### **Engineering Fabric Requirements for Subsurface Drainage**

Engineering fabric used in the mitigation of sinkholes should meet the applicable requirements of AASTHO M 288, Section 7.2

## **Engineering Fabric Installation**

Proper construction and installation techniques are essential to ensure that the intended function of the engineering fabric is fulfilled.

When sewn seams are necessary, the seam strength must be equal to or greater than 90 percent of the specified grab strength, as measured in accordance with ASTM D 4632.

When sewn seams are used for the seaming of the engineering fabric, the thread must be high strength polypropylene, or polyester. Nylon thread is unacceptable.

For Sinkhole Mitigation Design A, place the engineering fabric loosely, with no wrinkles or folds, and with no void spaces between the fabric and the bridge. Overlap successive sheets of engineering fabric a minimum of 12 inches, with the upstream sheet overlapping the downstream sheet.

Prior to covering, the engineering fabric should be inspected to ensure that it has not been damaged (*e.g.* holes, tears, rips) during installation. An engineer or the engineer's designated representative should conduct the inspection. The designated representative should be a certified field inspector.

Damaged fabric must be repaired immediately. Cover the damaged area with an engineered fabric patch that overlaps to 12 inches beyond the damaged area.

Any damaged engineering fabric that cannot be repaired shall be replaced as directed by the engineer.

Place material over the engineering fabric in such a manner as to avoid stretching and subsequently tearing the fabric. Do not drop stone and soil placement from a height greater than one meter. Do not allow stone with a mass of more than 100 kg to roll down the slope of the sinkhole.

Grading the sinkhole slope is not permitted if the grading will result in the movement of the stone directly above the engineering fabric.



## **Operation and Maintenance**

The owner/operator is responsible for maintaining the mitigated sinkhole and sinkhole area. At a minimum, the following maintenance practices should be performed:

1. Mow grass and plantings as necessary to promote vigorous growth.
2. Inspect mitigation measures at least twice a year and after all major rain events. Repairs to the sinkhole mitigation measures should be made promptly were warranted.

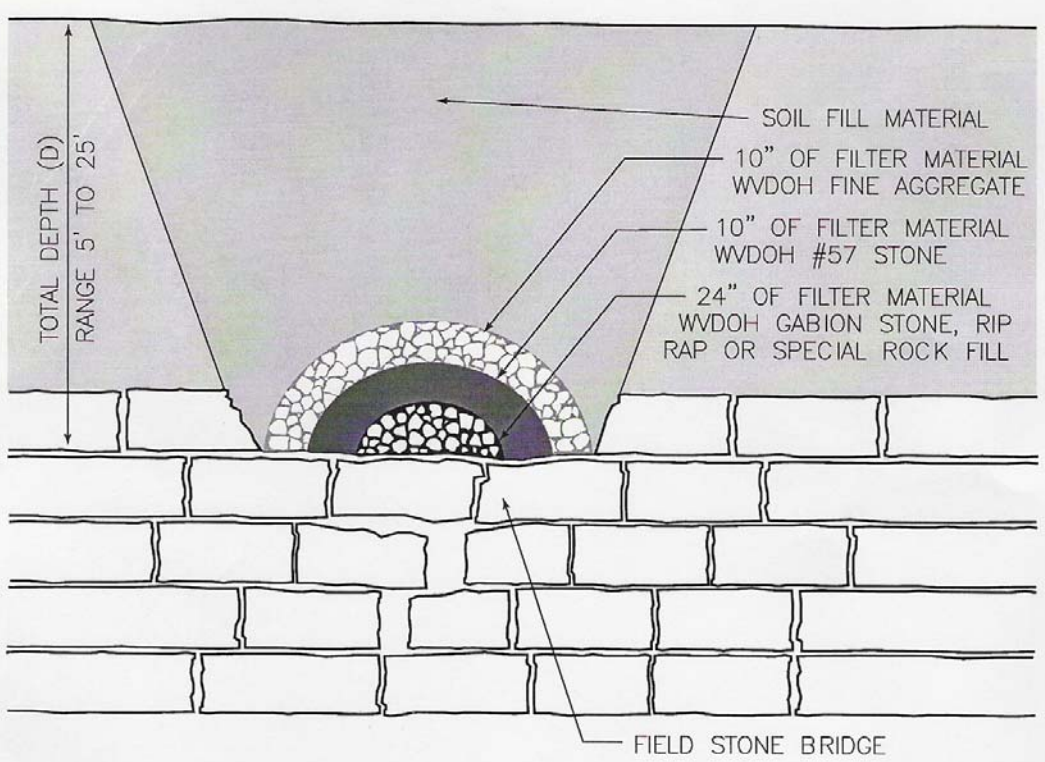
## **References:**

USDA Natural Resources Conservation Center, January 2004. *Maryland Conservation Practice Standard, Sinkhole and Sinkhole Area Treatment, Code 725.*

West Virginia Department of *Highways, Standard Specifications Roads and Bridges*, 2000, Section 702, “Fine Aggregates”, Section 703, “Coarse Aggregates”, Section 704, “Stone and Crushed Aggregate”, Section 715, “Miscellaneous Materials”.

WEST VIRGINIA DEPARTMENT OF ENVIRONMENTAL PROTECTION  
SINKHOLE MITIGATION GUIDANCE

FIGURE 1



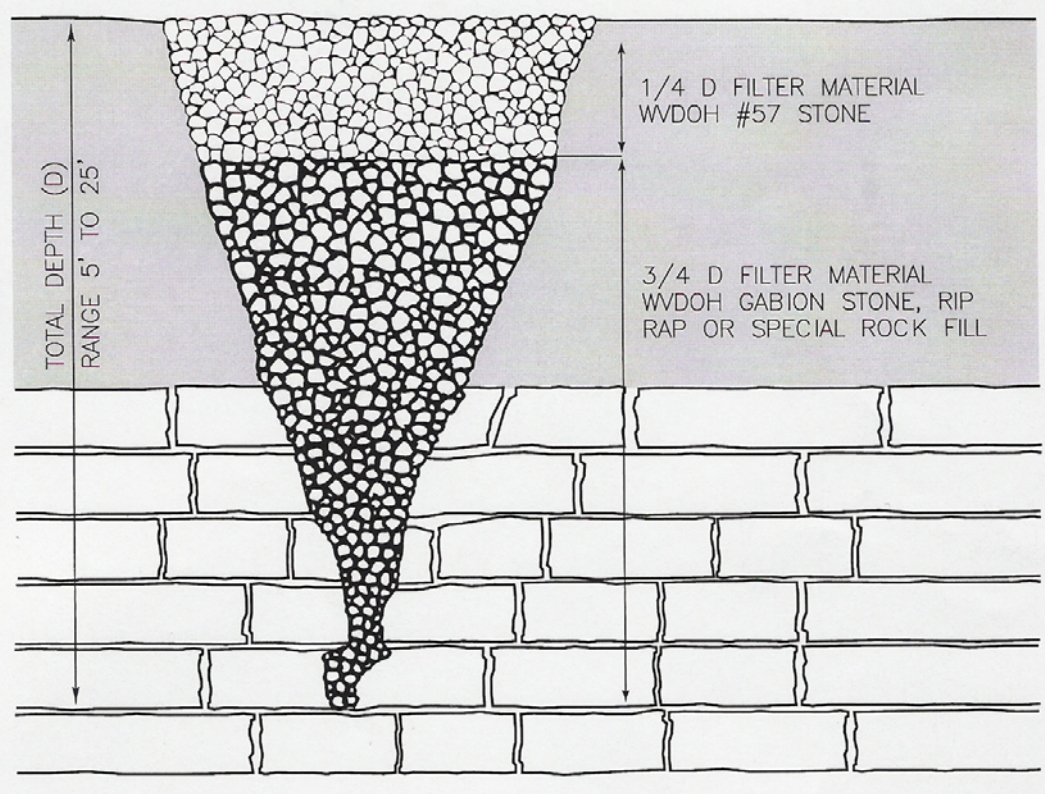
NOTE:  
A NONWOVEN GEOTEXTILE MEETING AASHTO M288,  
SECTIONS 7.1+7.2 MAY BE SUBSTITUTED FOR THE  
WVDH #57 STONE AND WVDH FINE AGGREGATE

# SINKHOLE MITIGATION

(DRAINAGE AREA LESS THAN 5 ACRES)

WEST VIRGINIA DEPARTMENT OF ENVIRONMENTAL PROTECTION  
SINKHOLE MITIGATION GUIDANCE

FIGURE 2



SINKHOLE MITIGATION

(DRAINAGE AREA 5 TO 15 ACRES)

**NATURAL RESOURCES CONSERVATION SERVICE  
CONSERVATION PRACTICE STANDARD**

**KARST SINKHOLE TREATMENT**

(No.)

**CODE 527**

**DEFINITION**

The treatment of sinkholes in karst areas to reduce contamination of groundwater resources, and/or to improve farm safety.

**PURPOSE**

This practice may be applied as part of a conservation management system in karst topography, which is an area underlain by solutioned carbonate bedrock with sinkholes and caverns. The practice supports one or more of the following purposes:

- Improve water quality
- Improve farm safety

**CONDITIONS WHERE PRACTICE APPLIES**

On any land surface or in conjunction with any existing practice where the soils and geologic conditions are characterized by sinkholes or karst topography.

This practice does not apply to erosional or collapse features caused by failure or leakage of underground pipes or constructed surface drainage features (e.g., canals), or due to piping of unstable soil materials, or due to poorly compacted or poorly constructed features.

This practice does not apply to sinkholes that may appear in or beneath structures or in flowing streams. Treatment of sinkholes in these areas will be determined through engineering investigations and structural design solutions.

**CRITERIA**

**General Criteria Applicable to all Purposes**

The installation and operation of karst sinkhole treatment(s) will comply with all Federal, State, and local laws, rules, and regulations.

A geologic investigation of the potential impact of the treatment on groundwater, surface water run-in, and the karst features will be conducted by a qualified geologist.

Trash and other material will be removed from the sinkhole and disposed of in an environmentally sound manner.

Excess surface water caused by construction activities will be diverted from the sinkhole area.

Nutrient and pest management plans will be developed for the drainage area of the sinkhole controlled by the landowner.

**Vegetative Treatment.** All sinkholes treated will have a vegetated buffer established and/or maintained. The buffer will be a minimum of 25-foot wide measured from the rim of the sinkhole. The buffer area may be extended to prevent concentrated flow channels from occurring and entering the sinkhole. The width of the vegetated buffer will be established and maintained in accordance with the type of buffer chosen. The sinkhole and surrounding buffer area will be fenced.

Livestock will be excluded from the vegetative buffer except when grazing would be beneficial to maintenance of the buffer.

Nutrients, herbicides, pesticides, and animal waste will not be applied within an established buffer area. Only mechanical treatments shall be used for weed control.

Appropriate erosion and sediment control measures will be used to reduce the amount of sediment entering sinkhole openings during the establishment of the vegetative buffer.

**Surface Water Control.** Changes to the volume of surface water that enters a sinkhole may disturb the underground hydrology. To the extent possible, the surface water flow should be maintained at historic (or predevelopment) volumes.

Pre-existing concentrated flow channels will be stabilized but should not otherwise be altered. If a plug or inverted filter is used, the area to be protected will be characterized by a qualified Geologist to enable a suitable design. Concentrated flow caused by construction activities will be dispersed with a suitable spreading or diversion technique.

**Sinkhole Treatment/Closing.** Adequate protection of most sinkhole and sinkhole areas can be achieved by the use of vegetative buffers and livestock exclusion. However, if an open sinkhole is a safety hazard, it may be treated with a rock filter, gabions, or other methods approved by the State Conservation Engineer or delegated authority.

Sinkholes to be treated or closed via a reverse filter or plug shall be excavated to stable, unweathered bedrock, if possible, prior to construction.

Sinkholes that open into caves shall not be filled under any circumstances. Gated openings may be used for safety reasons.

## CONSIDERATIONS

Current and planned land use should be considered. In particular, structures, septic drain fields, wells, feedlots, ponds, and animal waste storage systems should not be located over a sinkhole site or within the impact area.

Sinkholes may be natural conveyances of organic material and nutrients important to cave fauna.

For a sinkhole receiving contaminated overland flow, every effort should be made to first treat the source of the contamination. Although it is important to maintain the hydrology of the karst system, it may be more beneficial to the groundwater quality to divert the contaminated water away from the sinkhole. In some cases, it may be necessary to completely plug a sinkhole with sealing materials rather than treat it with an inverted filter. Acceptable sealing materials are provided in ASTM D 5299, part 6.4. An example of this would be a sinkhole in a feedlot or a site that is difficult to protect by any other method.

The sinkhole treatment should not result in excessive surface water ponding or high soil

moisture conditions over an extended period of time.

When filling a sinkhole, mounding of the fill material may be needed to offset future settlement due to consolidation and migration of the fill material into subsurface voids. Additional fill may be required as treatment ages.

Treatment of one sinkhole may have an effect on other sinkholes or solution features in the vicinity.

The use of a conservation easement for the buffer and sinkhole should be considered.

## PLANS AND SPECIFICATIONS

Plans and specifications for Sinkhole and Sinkhole Area Treatment will be in keeping with this standard and will describe the requirements for applying the practice to achieve its intended purpose.

Plans and specifications shall include the following:

- Plan view showing sinkhole and sinkhole area Include topographic information and photographs
- The geologic investigation will include a study of potential impacts on the karst resource
- Depth to stable, unweathered bedrock
- Description of planned treatment measures
- The drainage area of sinkhole delineated on a topographic map
- Availability of safe outlet for surface water, if applicable
- Operation and Maintenance requirements
- Special safety requirements

## OPERATION AND MAINTENANCE

An operation and maintenance (O&M) plan will provide specific instructions for maintaining the sinkhole and sinkhole area treatment, including reference to periodic inspections and the prompt repair and/or replacement of damaged components.