

# **Void Mitigation Plan for Karst Terrain and Underground Mining**

## *Pennsylvania Pipeline Project*

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## TABLE OF CONTENTS

| Section   | Page |
|---|------|
| 1.0 PROJECT DESCRIPTION .....   | 1    |
| 2.0 SURFACE AND GROUNDWATER PROTECTION PLANS .....                              | 1    |
| 3.0 KARST PLAN PURPOSE .....  | 1    |
| 4.0 EXISTING ENVIRONMENT AND PROJECT IMPACTS IN KARST GEOLOGY .....             | 2    |
| 4.1 KARST IN PENNSYLVANIA .....   | 3    |
| 4.2 KARST MAPPING.....  | 3    |
| 4.3 KARST AQUIFER CHARACTERISTICS .....   | 4    |
| 4.4 SITE-SPECIFIC MONTELLO GEOPHYSICS REVIEW .....                              | 5    |
| 4.5 PROJECT IMPACTS .....   | 5    |
| 4.6 BEST MANAGEMENT PRACTICES AND MITIGATION MEASURES.....                      | 6    |
| 5.0 SUBSURFACE MINING .....   | 9    |
| 6.0 MITIGATION IMPLEMENTATION REVIEW.....                                       | 10   |
| 7.0 OPEN-CUT PIPELINE INSTALLATION VOID MITIGATION .....                        | 10   |
| 7.1 VOID MITIGATION PROCEDURES UTILIZING FLOWABLE FILL.....                     | 11   |
| 8.0 SURFACE ENVIRONMENTAL BMPS ASSOCIATED WITH SURFACE VOID<br>MITIGATION ..... | 11   |
| 8.1 PIPELINE INSTALLATION BMPS.....   | 11   |
| 8.2 HYDROSTATIC TESTING .....   | 12   |
| 9.0 CONVENTIONAL BORES INSTALLATION VOID MITIGATION.....                        | 12   |
| 10.0 HDD INSTALLATION VOID MITIGATION.....                                      | 12   |
| 10.1 SMALL VOIDS.....   | 13   |
| 10.2 LARGE VOIDS .....  | 13   |

## TABLES

| Table   | Page |
|---|------|
| Table 1. Aquifer Characteristics by Physiographic Province of Pennsylvania..... | 9    |

## FIGURES

| Figure  | Page |
|---|------|
| Figure 1: Map of Carbonate Rock and Karst Surface Depressions identified within the<br>Project Route..... | 8    |

## LIST OF APPENDICES

|            |  |
|------------|--|
| Appendix A | Summaries of Karst and Mining Areas                                    |
| Appendix B | HDD Alignments   |
|            | B.1 County Maps of HDD Alignments, Carbonate Rocks, and Karst Features |
|            | B.2 Geotechnical Boring Summary Data Tables for HDD Alignments         |
| Appendix C | Geophysical Investigations   |
| Appendix D | Potential Void Mitigation Procedures                                   |
|            | D.1 Sinkhole Mitigation Guidance (West Virginia)                       |
|            | D.2 PADEP Sediment Basins, Design Criteria Summary, Karst Topography   |
|            | D.3 Mitigation Using Micropiles  |
| Appendix E | List of Approved Contractors   |
| Appendix F | References   |



# **VOID MITIGATION PLAN FOR KARST TERRAIN AND UNDERGROUND MINING PENNSYLVANIA PIPELINE PROJECT**

## **1.0 PROJECT DESCRIPTION**

Sunoco Pipeline L.P. (SPLP) proposes to construct and operate the Pennsylvania Pipeline Project (Project or PPP) that would expand existing pipeline systems to provide natural gas liquid (NGL) transportation. The Project involves the installation of two parallel pipelines within an approximately 306.8-mile, 50-foot-wide right-of-way (ROW) from Houston, Washington County, Pennsylvania to SPLP's Marcus Hook facility in Delaware County, Pennsylvania with the purpose of interconnecting with existing SPLP Mariner East pipelines. A 20-inch diameter pipeline will be installed within the ROW from Houston to Marcus Hook (306.8 miles) and a second, 16-inch diameter pipeline, will also be installed in the same ROW. The second line is proposed to be installed from SPLP's Delmont Station, Westmoreland County, Pennsylvania to the Marcus Hook facility, paralleling the initial line for approximately 255.8 miles. For a detailed Project Description see Attachment 9 of the Project's Chapter 105 Joint Application for Permit.

## **2.0 SURFACE AND GROUNDWATER PROTECTION PLANS**

SPLP has developed four plans that accompany the Erosion & Sedimentation Plan (E&S Plan) that are designed to assess the potential impacts and provide for the protection of surface and groundwater from contamination due to project activities, summarized below:

- Prevention, Preparedness, and Contingency Plan (PPC Plan) – Overarching plan designed to address spill prevention in general, and potential impacts to surface waters and public and private water supplies. Includes two supplemental plans, Water Supply Assessment, Prevention, Preparedness, and Contingency Plan (Water Supply Plan) and Inadvertent Return Assessment, Prevention, Preparedness, and Contingency Plan (IR Plan).
- Water Supply Plan – Provides for the assessment of the existing environment in terms of public and private water supplies in or along the project areas and impacted waters, as well as the prevention and preparedness measures to be implemented to protect those supplies.
- IR Plan – Outlines the preconstruction activities implemented to ensure sound geological features are included in the HDD profile, the measures to prevent impact, and the preparedness plan if an impact were to occur.
- Void Mitigation Plan for Karst Terrain and Underground Mining (Karst Plan) – Provided as part of the E&S Plan and provides an assessment of potential impacts and avoidance and mitigation measures that could occur during open-cut and drilling procedures.

The purpose of these plans is to protect surface and groundwater resources project-wide. The PPC Plan is provided as Attachment 12A of the Project's Chapter 105 Joint Application for Permit, and the Water Supply Plan as Attachment 12B, the IR Plan as Attachment 12C, and this Karst Plan as Attachment 12D.

## **3.0 KARST PLAN PURPOSE**

Subsidence is sinking of a landform to a lower level as a result of earth movement, structural loading at or near ground surface, geologic conditions resulting in lowering of

the surface, or mining operations. Subsidence is a potential geologic hazard especially in areas of karst terrain or where underground mining has occurred. Karst terrain forms from dissolution of soluble rocks such as limestone, dolomite, and gypsum. It is generally characterized by topographic depressions at the surface or as subsurface channels, caves, and/or sinkholes. Groundwater aquifers within karst regions can be significantly impacted as a result of their formation. Karst aquifers can be very productive and are used for water supply in Pennsylvania.

Private and public water supply sources from groundwater wells are located along and/or downstream of proposed work areas. Encounters with subsurface voids by the Project activities could potentially impact groundwater resources, if the voids connect to the aquifer or transmit water through the aquifer. However, as detailed in the Water Supply Plan, SPLP has avoided direct impacts to all private water wells. In addition to the information gained from the landowners, SPLP utilized the [Pennsylvania Groundwater Information System \(PAGWIS\)](#) data to identify 22 approximate water well locations within 150 feet of all HDD alignments, including parcels that would be adjacent to, but not directly crossed by the Project. The distance of 150 feet was used based on Federal Energy Regulatory Commission (FERC) guidelines for identification of water wells in the vicinity of their authorized projects. The locations of these wells are kept within the Project files and are not displayed here to protect the rights of the individual owners. Although the PAGWIS data is made available to the public, the accuracy as stated within the metadata is not reliable and what SPLP has or will obtain represents exact well locations. Public water supply areas within one mile of the Project were identified by evaluating all available water supply data obtained from PADEP's eMapPA platform. The analysis resulted in the identification of 50 PWS areas within the 1.0mile buffer. In these correspondences, SPLP requested the locations of the authority's PWS groundwater well and/or surface intakes as well as an assessment of potential impacts. Many authorities did not provide intake locations, but did inform SPLP that impacts were not anticipated.

This Karst Plan addresses mitigation of voids that could be encountered during installation of proposed pipeline in karst-prone areas and historical underground mining operations. This Karst Plan includes mitigation during conventional pipe installation, boring, and horizontal directional drilling (HDD).

#### **4.0 EXISTING ENVIRONMENT AND POTENTIAL PROJECT IMPACTS IN KARST GEOLOGY**

Data and information regarding potential karst and abandoned mining locations were compiled and evaluated from the following sources and reports:

- Background literature research of state databases;
- Geographical Information System (GIS) data from the Commonwealth of Pennsylvania, displaying polygons of abandoned mines and karst features;
- Potential karst and mining areas summarized per land parcel (Appendix A);
- Results from the geotechnical subsurface investigation program at all HDD locations within areas containing carbonate rocks, including field observations during advancement of soil and rock borings, laboratory testing of collected representative soil and bedrock samples, review of regional geology, and provision of summary reports of findings;
- Geophysical investigations at areas of known sinkholes within the right of way (ROW) (Appendix C).

## 4.1 Karst in Pennsylvania

Environmental and engineering problems can arise in areas where natural geologic substrates (i.e. carbonate rock) are subject to solution and erosion, which can generate voids in the subsurface and associated subsidence. Such areas are collectively known as karst. The development of karst is primarily dependent on the presence of soluble rocks such as limestone, dolomite or gypsum. Karst terrain is characterized by disappearing streams, springs, caves, sinkholes, and productive aquifers. Sinkholes and surface depressions form as a result of water transporting residual material and soil through subsurface pathways established by the dissolution process. Both features are typically circular in shape and can vary in size. Sinkholes exhibit an actual break or hole on the land surface, whereas surface depressions are generally bowl-shaped hollows that do not show this land-surface break. Caves are formed as fractures widen by dissolution, creating large openings in the rocks (PADCNr 2015).

Karst aquifers are important sources of groundwater in Pennsylvania for commercial and domestic use and may be contaminated where sinkholes or karst solution openings are present at, or near ground surface. Karst aquifer systems have very low self-purification or filtering capabilities which makes karst groundwater susceptible to impact from erosion of surface materials, surface spills, and surface water runoff (USGS 2014).

Most of the carbonate bedrock occurs in the valleys and lowlands of south-central and southeastern Pennsylvania. Geotechnical and hydrologic attributes that facilitate karst development include the following:

- Low-density limestone/dolomite (low compressibility)
- highly fractured zones with interconnectivity
- flowable water source (surface/subsurface)
- high percentage of calcium carbonate (calcite)

In order to assess the presence of surface/subsurface karst features (voids and fractures) along the project route, a geotechnical boring program was implemented to gather site-specific geologic data along all HDD alignments, and to provide a risk assessment, based on encountered geologic conditions, for each HDD alignment. The boring program identified potential subsurface void space along the original route from Houston, PA through Montello, PA. Supplemental geophysical investigations were performed resulting in a re-route at this location (See Section 4.4 and Appendix C). No evidence of void space was encountered at any other geotechnical boring location within the HDDs. Based on the results of the geotechnical boring program, there is low potential to encounter karst features along the proposed HDD alignments.

## 4.2 Karst Mapping

Efforts to map karst distribution have normally taken a geology-based approach, delineating areas having potential for karst development by identifying areas of soluble rocks from geologic maps. While this approach is representative of karst potential, a complex interaction of many factors determines the formation, localization, and intensity

of karst development. These include the bedrock type and structure, tectonics, climate, sedimentary cover, vegetation, and local hydrologic conditions. The extent of outcrop of soluble rocks provides an approximation of the distribution of karst and potential karst areas, particularly in parts of the United States with a humid climate (USGS 2014).

The USGS Karst Map for Pennsylvania (Figure 1) shows carbonate rocks that are near or at land surface, and thus contain or are susceptible to the development of karst features. Also in Figure 1, the PPP Centerline Corridor and karst features (identified by PADCNr) are overlain. The karst features coincide with the carbonate rock distribution in the southcentral and southeastern portions of the state. The Project route and workspaces overlap with 32 surface depressions identified in the PADCNr database (PADCNr 2016). Appendix B.1 provides county-scale maps of carbonate rock, karst features, and HDD alignments.

#### 4.3 Karst Aquifer Characteristics

The Project from west to east crosses through the Appalachian Plateau, Valley and Ridge, and Piedmont aquifer systems, all of which contain areas of carbonate rock. General characteristics for the carbonate-rock within these aquifer systems are described below, with details associated with groundwater well data for specific carbonate formations (crossed by the Project) summarized in Table 1.

**Appalachian Plateau** – In the Appalachian Plateau, extensive, almost flat-lying confining units of shale, siltstone, clay, and dense limestone impede the vertical movement of water. This is especially true of the Pennsylvanian-age rocks, which cover a large part of the area. The aquifers and confining units are not as intensely fractured in the Appalachian Plateau as in the Valley and Ridge. The fractures also decrease in number with depth, and the circulation of water likewise decreases with depth. Most of the Appalachian Plateau lacks the thick, solution-riddled, carbonate-rock aquifers of the Valley and Ridge (USGS 1997). As shown in Table 1, the following averages (median) were determined for the Monongahela Group (mix of sandstone, silt, and limestone) crossed by the route: water level is 35 feet below grade, well depth of 126 feet, casing length of 21 feet, and well yield of 5 gallons per minute (gpm)(PADCNr 2016b).

**Valley and Ridge** – Most of the more productive aquifers are in carbonate rocks, primarily limestone, and most are in valleys. Although the water-yielding character of the carbonate rocks depends on the degree of fracturing and development of solution cavities in the rock, the limestone formations generally yield moderate to large volumes of water. The sedimentary formations of the Valley and Ridge Province are commonly thick and steeply tilted; thus, a water well usually penetrates only the consolidated rock formation exposed at the surface (USGS 1997). A range of averages (median) were determined for the carbonate formations crossed by the route: water level of 20 to 109 feet below grade, well depth of 104 to 301 feet, casing length of 22 to 94 feet, and well yield of 8 to 90 gallons per minute (gpm)(see Table 1, PADCNr 2016b).

**Piedmont** – The carbonate rocks of the Piedmont and the Blue Ridge Provinces have virtually no primary permeability or porosity, and water in these rocks moves through secondary openings, such as bedding planes, joints, faults, and other partings, within the rock that have been enlarged by dissolution. In rocks that have a large content of sand, clay, or other noncarbonate minerals, dissolution is inhibited and enlargement of openings might not be extensive. In such rocks, all the water might occur in fracture openings similar to those in unweathered crystalline rocks (USGS 1997). A range of averages (median)

were determined for the carbonate formations crossed by the route: water level of 22 to 26 feet below grade, well depth of 132 to 164 feet, casing length of 40 to 45 feet, and well yield of 17 to 39 gallons per minute (gpm)(see Table 1, PADCNR 2016b).

#### **4.4 Site-Specific Montello Geophysics Review**

Seismic refraction and seismic surface-wave geophysical surveys were conducted along proposed alignment and HDD crossings near the Sunoco Montello Terminal, located within an area of documented karst and sinkholes. In addition, soil borings were advanced along survey lines. Borings were advanced by either direct-push technology (DPT) or Standard Penetration Tests (SPT). Purpose of the borings was to compare results from the geophysical investigation to those from collected soil samples in order to correlate soil data with images generated during the geophysical investigation.

Based on information presented in the geophysics report prepared by Advanced Geological Services (AGS) (Appendix C) and subsurface conditions from the geotechnical borings, it does not appear that void spaces are present under the HDD alignments within the areas of the surveys (see map in AGS report). Although areas of low velocity, typically associated with either void spaces or soft soils, were identified during the geophysical survey, voids were not discovered during advancement of the soil borings.

Additional seismic refraction and surface wave geophysical surveys were performed along six survey lines at the Sunoco Montello Terminal to delineate areas of soft soil and potential voids underlying the proposed HDD alignments. For details on the methodology and locations of these surveys, refer to reports prepared by AGS (Appendix C).

After review of results of these investigations, a re-route and conventional design for the pipeline was prepared south of the concentrated area of karst and sinkhole features. Because the general area has a history of sink holes, data acquired during investigations should not be considered representative of the entire area, but only of the areas directly investigated during the study. Geophysical methods applied during the three investigations may be employed if large voids are encountered during pipeline installation.

#### **4.5 Project Impacts**

Potential impacts from construction activity (trenching, conventional bore, and HDD) in karst geology are described below. The project proposes 51 HDD and 85 bores through areas of carbonate rocks. Of these, one HDD (PA-CU-0174\_0001-RD) overlaps with three clustered surface depressions, and one bore overlaps with one surface depression. The rest of the pipeline would be installed by open cut methods in vicinity to the identified surface depressions. Eighteen HDDs are proposed with the Appalachian Plateau karst aquifer, 29 HDDs are proposed in the Valley and Ridge karst aquifer, and 4 HDDs are proposed within the Piedmont karst aquifer. Results and data obtained from the geotechnical boring program for the HDD alignments are summarized in Appendix B.2, and includes a risk assessment designation based on geotechnical lab tests and field observations. None of the HDDs were determined as high or medium-risk; most of the HDDs were determined as very low-risk; with a small number of low-risk HDDs, as shown in Appendix B.2. Spread 2: locations were all determined as very low probabilities.

The low probabilities assigned to HDD locations in Spreads 3 thru 6 were due to the presence of limestone and the vicinity of surface depressions. However, the drills were designed to be either deep in competent bedrock or above the limestone. Low potentials

are summarized below and the geological information is provided in Appendix B.2:

Spread 3: PA-BL-0122.0000-WX, PA-BL-0125.0000-RD, PA-HU-0020.0008-SR, PA-HU-0019.0002-RD, PA-HU-0078.0000-WX.

Spread 4: PA-CU-0136.0000-RD, PA-CU-0136.0002-WX, PA-CU-0136.0003-RD, PA-CU-0136.0012-RD, PA-CU-0136.0020-RR, PA-CU-0174.0001-RD, PA-CU-0174.0014-RD, PA-CU-0174.0019-RD, PA-CU-0189.0000-RD, PA-DA-0030.0000-RR, PA-DA-0039.0000-RD, and PA-DA-0063.0000-RD.

Spread 5: PA-LE-0055.0000-RD and PA-BR-0036.0000-RD.

Spread 6: PA-CH-0212.0000-RD and PA-CH-0219.0000-RDa&b.

#### Conventional Open-Cut – Grading and Trenching of the ROW

- Disturbed and excavated soil from trenching operations, installed at depths of 5 to 7 feet below grade, could be transported into karst surface features through erosion, and could impact local springs or wells, manifested as increased turbidity. Please refer to Erosion and Sediment Control Plan for countermeasures to prevent or mitigate this occurrence.
- Inadvertent spills to karst features from equipment refueling and/or leaks could impact groundwater quality through rapid transport of contaminants to the aquifer or discharge locations such as springs, wells, or surface water bodies. Please refer to the PPC Plan for countermeasures to prevent or mitigate this occurrence.
- Open-cut installation in karst terrain areas can expose karst—prone rocks to air and moisture, thus providing potential for subsurface erosion. Following procedures outlined in this document will minimize this potential.

#### Conventional Bore

- Conventional Bores would excavate and disturb the subsurface to slightly greater depths about 4 to 15 feet below grade; however, the types of impacts are similar to open-cut. Procedures outlined to seal the annulus surrounding the pipe are designed to prevent the migration of fluids beyond the borehole.
- Grout could be introduced into fractures, thereby sealing it; however, due to the relatively shallow depth, should not significantly impact the aquifer.

#### Horizontal Directional Drill

- Should the drill intersect a large fracture in the aquifer there is potential for introduction of drilling fluid (bentonite clay and water) into the aquifer that could manifest as temporarily increased turbidity. See the mitigation procedures in this plan for mitigating small voids and routing around large voids encountered.
- Inadvertent releases of drilling mud could enter surface waterbodies that could manifest as temporarily increased turbidity. See the Inadvertent Return Plan for mitigation countermeasures.

### **4.6 Best Management Practices and Mitigation Measures**

Best Management Practices (BMPs) and mitigation measures are presented in sections 7.1 thru 10.0 of this Void Mitigation Plan for Karst Terrain and Underground Mining, and are summarized below.

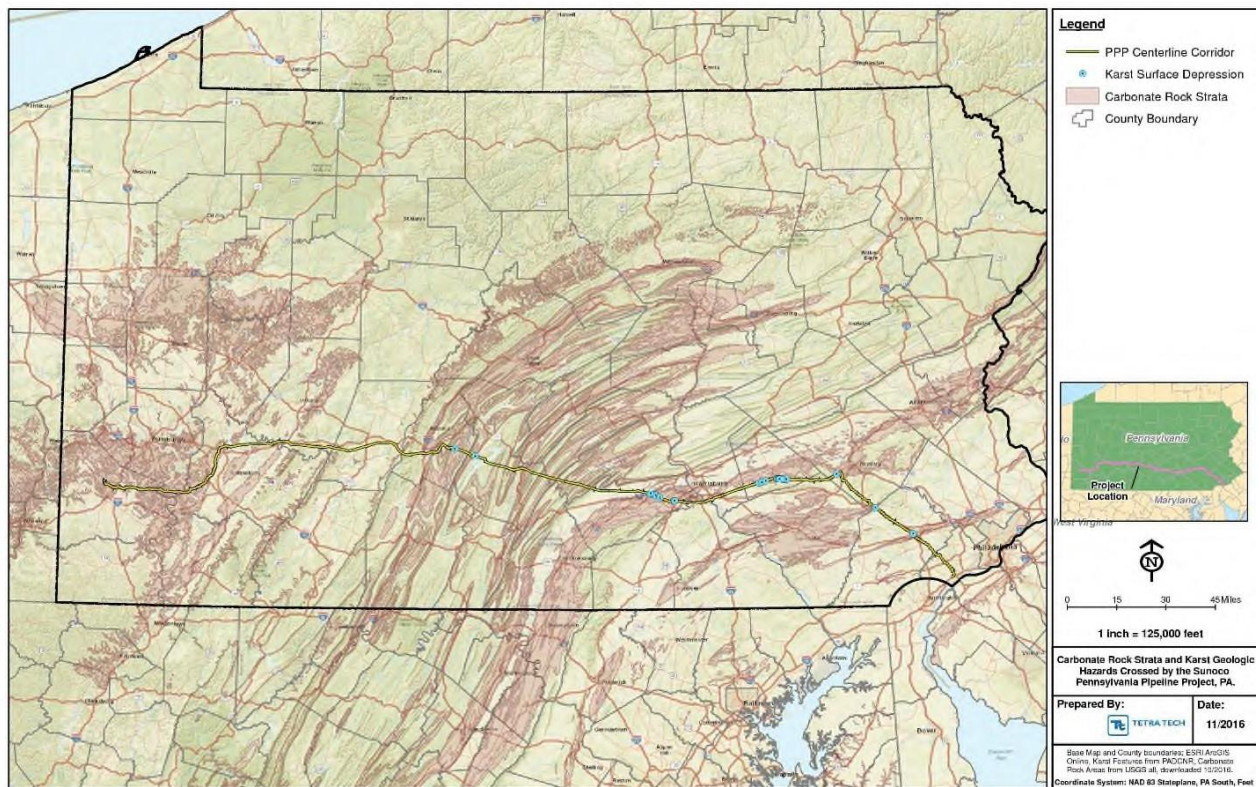
General Pipeline Installation BMPs include the following:

- Stormwater control measures will be implemented to minimize surface water runoff into known or encountered karst
- If voids are encountered, the trench excavation may be backfilled with grout or impermeable plugs, as described in the Void Mitigation Plan.
- Restoration of construction workspace will occur as rapidly as possible following pipeline installation.
- Proper grading at the site will be maintained to minimize diversion of stormwater to areas identified as prone to sinkhole development.
- Post-construction monitoring of identified areas will occur annually to identify any evidence of further sinkhole development, with implementation of any measures necessary to prevent further solution of underlying bedrock.

Open-Cut Installation and Void Mitigation measures are described in Section 7.0 and subsections. BMPs associated with surface construction and planned hydrostatic testing discharges, are described in Section 8.0 and subsections. Conventional bores Installation and Void Mitigation Measures are described in Section 9.0. Horizontal Directional Drilling Installation Void Mitigation Measures are described Section 10.0 and subsections.

The PPC, Water Supply, and IR plans provide for a course of action to protect the local environment and any assets from an event that interrupts the normal operation at the site and could result in a threat to health and/or the environment if not properly addressed. Spill and leak prevention and responses are described in detail in these plans, including encounters with unanticipated impacted soil, and summarized below:

- Petroleum and Petroleum-Related Materials: In dealing with a petroleum spill, the immediate response action is to attempt to eliminate the source of the spill. In the event of an accidental spill, emergency measures will be implemented to isolate the spilled material and prevent the release from entering surface water or groundwater.
- Soil that is impacted as a result of an accidental spill or release will be containerized for subsequent disposal. Clean-up protocol for the spill will be followed.
- Unanticipated discovery of contaminated soil conditions protocols.
- Inadvertent Returns from Horizontal Directional Drilling: The immediate response actions in dealing with an inadvertent return of drilling fluids (primarily bentonite and water) from a horizontal direction drill include discontinuing drilling operations, identifying the area of the inadvertent return, and isolating the inadvertent return. In the event of an inadvertent return, emergency measures will be implemented to isolate the returns and prevent or minimize the extent of the release that will enter surface water.



**Figure 1: Map of Carbonate Rock and Karst Surface Depressions identified within the Project Route**



**Table 1. Aquifer Characteristics by Physiographic Province of Pennsylvania**

| Physiographic Province | Physiographic Section | Aquifer Formation-Carbonate Rock                       | Static Water Level (ft) (median) | Well Depth (ft) (median) | Casing Length(ft) (median) | Well Yield (gal/min) | No. of HDD/No. of Bores | No. of Surface Depression |
|------------------------|-----------------------|--|----------------------------------|--------------------------|----------------------------|----------------------|-------------------------|---------------------------|
| Appalachian Plateaus   | PG                    | Monongahela Group                                      | 35                               | 126                      | 21                         | 5                    | 18/35                   |                           |
| Valley and Ridge       | AM                    | Bellefonte and Axemann Formations, undivided           | 43                               | 180                      | 36.5                       | 9.65                 | 1/0                     | 1                         |
|                        | AM                    | Clinton Group  | 34.8                             | 180                      | 40                         | 12                   | 1/2                     |                           |
|                        | AM                    | Coburn Formation through Loysburg Formation, undivided | 35.4                             | 165                      | 30                         | 7.75                 | 1/1                     |                           |
|                        | AM                    | Gatesburg Formation                                    | 108.5                            | 245                      | 94                         | 10                   | 0/1                     |                           |
|                        | AM                    | Hamilton Group   | 20                               | 106                      | 25                         | 13.5                 | 2/1                     | 1                         |
|                        | AM                    | Keyser and Tonoloway Formations, undivided             | 31.4                             | 147.5                    | 48                         | 15                   | 3/2                     |                           |
|                        | AM                    | Mauch Chunk Formation                                  | 25.2                             | 117.5                    | 29                         | 12                   | 2/0                     |                           |
|                        | AM                    | Nittany and Stonehenge/Larke Formations, undivided     | 72.25                            | 185                      | 53.75                      | 10.5                 | 0/2                     |                           |
|                        | AM                    | Onondaga and Old Port Formations, undivided            | 35.6                             | 140                      | 48                         | 10                   | 5/3                     |                           |
|                        | AM                    | Rockdale Run Formation                                 |                                  | 136                      | 55.5                       | 15                   | 2/2                     | 1                         |
|                        | AM                    | St. Paul Group   | 31.75                            | 150                      | 40                         | 10                   | 5/2                     | 5                         |
|                        | GV                    | Buffalo Springs Formation                              | 45.2                             | 288                      | 57.5                       | 45                   | 0/6                     | 13                        |
|                        | GV                    | Chambersburg Formation                                 | 26.95                            | 162.5                    | 23                         | 10                   | 1/0                     |                           |
|                        | GV                    | Epler Formation  | 52.5                             | 175                      | 60                         | 30                   | 1/1                     |                           |
|                        | GV                    | Millbach and Schaefferstown Formations, undivided      | 31                               | 103.5                    | 51                         | 30                   | 0/2                     |                           |
|                        | GV                    | Millbach Formation                                     | 68.5                             | 301                      | 72.5                       | 90                   | 1/6                     | 1                         |
|                        | GV                    | Pinesburg Station Formation                            | 32.45                            | 107.5                    | 21.5                       | 7.95                 | 1/1                     |                           |
|                        | GV                    | Richland Formation                                     | 38.2                             | 167                      | 55.5                       | 20                   | 0/1                     |                           |
|                        | GV                    | Shadygrove Formation                                   | 48.85                            | 160                      | 52                         | 14.9                 | 1/4                     | 2                         |
|                        | GV                    | Snitz Creek Formation                                  | 43                               | 150                      | 37                         | 8.5                  | 1/10                    | 3                         |
|                        | GV                    | Stonehenge Formation                                   | 38.85                            | 137                      | 40                         | 12                   | 1/1                     |                           |
| Piedmont               | GN                    | Limestone fanglomerate                                 | 22.5                             | 131.5                    | 42.5                       | 35                   | 0/2                     |                           |
|                        | PL                    | Conestoga Formation                                    | 25                               | 163.5                    | 40                         | 17                   | 2/0                     |                           |
|                        | PL                    | Ledger Formation                                       | 25.85                            | 144                      | 45                         | 39                   | 2/0                     | 2                         |
|                        | PU                    | Franklin Marble  | No Data                          | No Data                  | No Data                    | No Data              | 0/1                     |                           |

Source: PADCNr 2016b

## 5.0 SUBSURFACE MINING

The approximate 50-mile ROW from Houston, Pennsylvania to Delmont, Pennsylvania is the same ROW where the previous ME1 pipeline was installed. Although this area is shown as potential abandoned mining area, no voids were encountered during the ME1 pipeline installation. West of Delmont, one mining entry location within project workspace (proposed conventional installation) is mapped in Cambria County. This location was field

verified to not be a mine opening. The proposed Project alignment through abandoned mine land is shown in Appendix B.1.

## **6.0 MITIGATION IMPLEMENTATION REVIEW**

Drilling contractors and engineers experienced in karst and historical mining terrain were consulted to provide proven methods for mitigation of possibly encountered voids. Additionally, the following Reference Documents (Appendix D) will be considered during the mitigation process:

- Appendix D.1: Sinkhole Mitigation Guidance, August 8, 2005. West Virginia Department of Environmental Protection Division of Water and Waste Management Groundwater Protection Program.
- Appendix D.2: PADEP Erosion and Sediment Control Manual, March 2012. "CHAPTER 7 – Sediment Basins, Design Criteria Summary, Karst Topography." "CHAPTER 17 – Areas of Special Concern, Sinkhole Repair."
- Appendix D.3: Penn DOT Pub\_293\_Part\_1: Section 1.6.1.4.5 (Micropiles), Section 1.6.1.6 (Voids), and Section 1.6.1.8 (Temporary Shoring).

The PADEP Manual does not specify mitigation in regards to potential voids in relation to mining. Mine voids of a similar size to surface karst voids will be mitigated in the same manner as referenced in this report for Karst Voids. Mine Voids encountered indicating a potentially more complex problem, will require notification to PADEP. Because of differences among sinkholes and historical underground mines, and to ensure proper execution of the plan to mitigate voids, mitigation will proceed with direct consultation of a professional geologist and/or professional geotechnical engineer. An on-site geotechnical specialist may also be available to identify potential problems with the planned mitigation, and/or provide options to either avoid such problems or adjust the plan when anomalies are encountered. Provision of a professional geologist inspector to oversee HDD installations is provided within the Project's IR Plan.

## **7.0 OPEN-CUT PIPELINE INSTALLATION VOID MITIGATION**

Geotechnical investigations did not occur outside of HDD areas. Possibly present voids will be identified during open-cut pipe trench excavations. Open-cut installation in karst terrain areas can expose carbonate bedrock to air and moisture, thus providing potential for subsurface erosion. Adherence to site erosion and sediment (E&S) plans, construction during dry weather, prompt backfilling of trench with compacted soil, and vegetative stabilization will minimize potential for future subsidence. If a void is encountered during trench excavations, trench boxes and/or an engineered shoring system will be utilized to support sidewalls of the excavation and prevent cave-ins.

If voids are encountered in the subsurface, a professional geotechnical engineer and/or geologist will initially evaluate site conditions. Possible mitigation measures to address voids will include the following:

- West Virginia DEP Sinkhole Mitigation Guidance in WV (Appendix D.1).
- PADEP E&S Manual March 2012, Chapter 17 – Areas of Special Concern – Sinkhole in PA (Appendix D.2).
- In-filling of voids with flowable fill material (grout).

Other sources of mitigation measures also may be consulted—mitigation procedures not discussed in this section are described in Appendices D.1 and D.2.

## **7.1 Void Mitigation Procedures Utilizing Flowable Fill**

1. Excavate void to locate the "throat" of the sink-hole. If the throat cannot be readily located, use water to locate and expose the throat (See Appendix D for depictions).
2. Once the throat is located and excavated out to the extent practicable (removal of most soil and loose rock), design and implement the plugging. Where voids are relatively small it may be appropriate to import and pour a flowable fill (grout) into the void until the void is plugged and filled to 1 foot below the proposed pipe trench bottom elevation. In this case, allow the flowable fill to cure for a minimum of 1 day, ensuring that the top is firm and stable. Where the void is relatively large it may be necessary to implement a design intended to maintain local drainage and groundwater flow patterns. In these cases the design of the plug may be to fill the throat of the void with rip rap, followed finer stone in an upward fining sequence of layers, geofabric, and fine grain compacted soil to the elevation of the trench bottom. The Geotechnical Engineer/Professional Geologist will determine the appropriate design of the plug based on field conditions.
3. Place a 1-foot layer of compacted clay (Unified Soil Classification System [USCS]: CL or CH) over cured flowable fill, bringing top of clay to bottom of pipe trench elevation.
4. At this point, normal pipe installation and trench backfill may proceed, except that the uppermost 1 foot of backfill shall consist of compacted clay (USCS: CL or CH), placed directly below the topsoil layer, to minimize surface water infiltration into backfill.
5. Place a trench plug of clay soil (USCS: CL or CH) along the pipe trench a distance of approximately 10 feet beyond each side of the void area. The trench plug must backfill the entire pipe trench, from bottom to top of trench, including around the pipe (i.e., no bedding sand or gravel). Minimum length of trench plug shall be 5 feet. Purpose of trench plug is to prevent flow into the sink-hole area of water that may be present in upgradient pipe bedding sand/gravel or trench backfill areas.
6. Contractor will defer to specifications for flowable fill of local township and/or Sunoco.

Depending on nature and size of encountered voids, another potential option to support pipeline loads is installation of micropiles. Micropiles are particularly efficient where natural or man-made obstructions occur—in areas of karst geology, where rock surfaces are erratic and large voids are typically present. Micropiles can typically be designed to resist compression, uplift, and lateral loads, and have been used to support a variety of facilities. It is important that installation of the micropile rock socket occur in adequate bedrock to support the proposed loads. (Refer to Appendix D.3 – Penn DOT Geotechnical Engineering Manual, Publication 293, 2014 Edition). The method of mitigation of a sink-hole/void during open-cut excavations will depend on the nature and extent of the void.

## **8.0 SURFACE ENVIRONMENTAL BMPS ASSOCIATED WITH SURFACE VOID MITIGATION**

### **8.1 Pipeline Installation BMPS**

- Stormwater control measures will be implemented to minimize surface water runoff into known or encountered karst or mining areas.
- If voids are encountered, the trench excavation may be backfilled with grout or impermeable plugs (e.g., clay) to minimize flow of water to karst features. Trench plugs would be incorporated prior to backfill operations to prevent or limit subsurface

water flow within the trench or along the pipeline bedding and backfill.

- Restoration of construction workspace will occur as rapidly as possible following pipeline installation. The trench will be backfilled quickly to re-establish vegetative cover and limit time of exposure of the site to concentrated stormwater flow.
- Proper grading at the site will be maintained to minimize diversion of stormwater to areas identified as prone to sinkhole development. Trench plugs may also be used to prevent collection of stormwater within the identified area.
- Post-construction monitoring of identified areas will occur annually to identify any evidence of further sinkhole development, with implementation of any measures necessary to prevent further solution of underlying bedrock.

## **8.2 Hydrostatic Testing**

To reduce potential for sinkhole development during hydrostatic testing, test water from a new pipe will not be discharged directly into the vicinity of a known karst feature open to the surface. The water will be discharged downgradient of identified karst features. If site conditions prevent a downgradient discharge, the water will be discharged as far from the karst feature as practicable, utilizing sediment and erosion control features detailed in the Project E&S Control Plan. Alternatively, a frac tank could be utilized to discharge water off site at a permitted facility. Post-construction monitoring will ensure proper re-vegetation and restoration of these areas.

## **9.0 CONVENTIONAL BORES INSTALLATION VOID MITIGATION**

Conventional bores will be installed with no fluids to depths ranging from approximately 4 to 15 feet below ground surface (bgs). The 20-inch-diameter pipe will be installed in a 22-inch borehole, and pressure grouting will fill the annulus in the borehole surrounding the pipe. Injected grout under pressure should fill any encountered voids, cavities, and/or soft zones within any encountered karst or mining features. Similar procedures will be used for the 16" pipe. If no returns from the injected grout occur, mitigation may follow procedures previously described for open-cut installation and mitigation.

As required by 49 Code of Federal Regulations, Parts 192.613 and 195.204, route surveillance will occur during construction and operation of the facilities, along with training of surveillance personnel, to monitor the pipeline alignment for evidence of subsidence, surface cracks, or depressions that could indicate sinkhole formation. Signs of sinkhole formation, ground subsidence, or surface depressions will be immediately and clearly marked. Work will be temporarily halted and the immediate area around the depression evacuated until it is deemed safe and stable. The project geotechnical engineer will also be notified of the occurrence. Based on direction of the geotechnical engineer, the area may be backfilled with clean sand fill to temporarily stabilize the area pending further evaluation that may include geophysical and/or geotechnical testing. Compaction grouting may be used at one or more points to seal the rock surface, fill void, and push into the loose, weak soil—compacting and strengthening it. Compaction grouting is typically completed in stages, from bottom up. If no returns from the injected grout occur, mitigation may follow the procedures described for open-cut installation and mitigation.

## **10.0 HDD INSTALLATION VOID MITIGATION**

Loss of drilling fluid return to the drilling rig is often an indication of encounter with fractures and/or voids. Mitigation of these depend on the size of the fracture/void, and may include

filling the voids with additional drilling fluid or pulling back drilling equipment and either proceeding deeper or off-setting the HDD. Size of the void encountered during drilling will determine the course of action by the HDD driller. Possible actions in this regard are described in the following paragraphs.

### **10.1 Small Voids**

When smaller voids or open seams are encountered, the driller will usually not experience significant drop in inclination or loss in returns of drilling fluid back to the drilling rig. In these instances, the driller can often fill or seal off the void with additional drilling fluid. By doing so, the driller hopes to build a layer of bentonite in the void and seal the borehole, thus re-establishing circulation of drilling fluid and returns back to the entry/exit pits. Another option in these situations is to adjust composition of the drilling fluid. By mixing natural materials such as wood fibers, or by using special polymer fibers, the driller can thicken the drilling fluid to help seal the void and allow the drill to continue on its current designed path. Materials utilized will be from the PADEP Approved List of thickening additives. When this course of action is chosen, the drilling contractor and the site environmental representative choose the appropriate material and/or product to thicken the drilling fluid.

### **10.2 Large Voids**

When a larger void is encountered, the driller will usually experience a significant drop in inclination, loss in fluid pump differential pressure, and loss in returns to the drilling rig—indicating that the drilling fluid is not circulating back to the pit and is being lost to a big void or seam. When encountering a large void, drilling will stop and the driller will re-group with the project team to evaluate options of how to proceed. The first course of action would be to change the composition of the drill fluid, as detailed above addressing Small voids. If pumping more fluid does not seal the void, the course of action may be to pull back the drill stem and have a geophysicist perform an investigation to evaluate the extent of the void. When this is determined, the applicable course of action may be to either drill deeper into the bed rock or offset 10 feet either direction from the original centerline, but within the ROW, and re-drill the area.

## **APPENDIX A**

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### **Summaries Of Karst And Mining Areas**

## **APPENDIX A – SUMMARIES OF KARST AND MINING AREAS**

### **OPP MINING AND KARST CONSTRUCTABILITY SUMMARY**

#### Geology

No Karst or Natural Geologic Limiting Material other than Coal, discussed under the Mining Category.

#### **Mining within the ROW (OH Mining Inventory) - OHIO**

Mine Openings – OH-JE-0006.0000 (JFN-050)

#### Abandoned Surface Mines

- OH-HA-0031.0000 through OH-HA-0039.0000
- OH-HA-0045.0001
- OH-HA-0048.0001
- OH-HA-0048.0002
- OH-HA-0050.0000
- OH-HA-0052.0000 through to the Ohio River

#### Abandoned Underground Mines

- OH-HA-0045.0001
- OH-HA-0048.0001
- OH-HA-0050.0000
- OH-HA-0051.0000
- OH-HA-0056.0000 through OH-HA-0068.0000

#### **Mining within the ROW (WV Mining Inventory) West Virginia**

#### Abandoned Surface Mines

- WV-BR-0022.0001 through WV-BR-0036.000

#### **Mining within the ROW (PA Mining Inventory) Pennsylvania**

#### Abandoned Mine Land

- PA-WA-0010.0000 through PA-WA-0013.0000
- PA-WA-0038.0000 through PA-WA-0053.0000

### **PPP1 MINING AND KARST CONSTRUCTABILITY SUMMARY (PA Mining Inventory)**

#### Geology

No Karst or Natural Geologic Limiting Material other than Coal which is discussed under the Mining Category. All HDD designs incorporated with geotech borings, which are located on sharepoint.

Pennsylvania Coal Mining (Above and Under Ground)

#### Abandoned Mine Land

- PA-WA-0053.0000 through PA-WM1-0032.0000
- PA-WM1-0058.0000
- PA-WM1-0072.0000 through PA-WM1-0075.0000
- PA-WM1-0110.0000 through PA-WM1-0112.0000
- PA-WM1-0114.0000 through PA-WM1-0133.0000
- PA-WM1-0149.0000 through PA-WM2-0002.0000.

## **PPP2 MINING AND KARST CONSTRUCTABILITY SUMMARY (PA Mining Inventory)**

### **Geology**

No Karst or Natural Geologic Limiting Material other than Coal, discussed under the Mining Category.

### **Pennsylvania Coal Mining (Above and Under Ground)**

- PA-WM2-0004.0000-ABTS
- PA-WM2-0028.0000-ABTE
- PA-IN-0007.0000 through PA-IN-0027.0000
- PA-IN-0030.0000
- PA-IN-0049.0000 through PA-IN-0056.0000
- PA-CA-0004.0000 through PA-CA-0016.0000
- PA-CA-0027.0000 through PA-CA-0047.0000
- PA-CA-0096.0000 through PA-CA-0098.0000
- PA-BL-0001.0001

## **PPP3 MINING AND KARST CONSTRUCTABILITY SUMMARY (PA Mining Inventory)**

### **Geology – Karst Areas**

- PA-BL-0129.0000
- PA-BL-0130.0000
- PA-BL-0137.0000 through PA-BL-0139.0000
- PA-BL-0144.0000
- PA-HU-0020.0008
- PA-CU-0136.0003
- PA-CU-0136.0005
- PA-CU-0136.0007
- PA-CU-0136.0018
- PA-CU-0136.0023
- PA-CU-0136.0020
- PA-CU-0136.0021
- PA-CU-0149.0001 through PA-CU-0149.0003
- PA-CU-0152.0000
- PA-CU-0154.0000
- PA-CU-0157.0000 through PA-CU-0160.0000
- PA-CU-0163.0000
- PA-CU-0167.0000 through PA-CU-0169.0000
- PA-CU-0168.0000
- PA-CU-0170.0000
- PA-CU-0172.0000
- PA-CU-0174.0000
- PA-CU-0176.0000
- PA-CU-0176.0001
- PA-CU-0176.0019
- PA-CU-0176.0020
- PA-CU-0186.0000
- PA-CU-0189.0000
- PA-CU-0194.0000
- PA-DA-0032.0000



Pennsylvania Coal Mining (Above and Under Ground)  
Mine Land

- PA-BL-0001.0001
- PA-BL-0001.0002
- PA-BL-0001.0003

**PPP4 MINING AND KARST CONSTRUCTABILITY SUMMARY (PA Mining Inventory)**

Geology- Karst Area

- PA-CU-0136.0003
- PA-CU-0136.0005
- PA-CU-0136.0006
- PA-CU-0136.0007
- PA-CU-0136.0008
- PA-CU-0136.0023
- PA-CU-0136.0021
- PA-CU-0149.0001
- PA-CU-0149.0002
- PA-CU-0149.0003
- PA-CU-0152.0000
- PA-CU-0154.0000
- PA-CU-0157.0000
- PA-CU-0158.0000
- PA-CU-0159.0000
- PA-CU-0160.0000
- PA-CU-0161.0000
- PA-CU-0162.0000
- PA-CU-0163.0000
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- PA-CU-0169.0000
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- PA-CU-0172.0000
- PA-CU-0174.0000
- PA-CU-0176.0001
- PA-CU-0176.0019
- PA-CU-0176.0020
- PA-CU-0186.0000
- PA-CU-0189.0000
- PA-CU-0194.0000
- PA-DA-0032.0000

Pennsylvania Coal Mining (Not Applicable)

### **PPP5 MINING AND KARST CONSTRUCTABILITY SUMMARY (PA Mining Inventory)**

#### **Geology**

Karst (highly fractured limestone) and resulting surface features such as surface depressions and sinkholes were noted from the PA Mining and Caves Database at the following locations:

- PA-LE-0036.0000 through PA-LE-0082.0000
- PA-BR-0028.0000 through PA-BR-0053.0000
- PA-BR-0189.0001 through PA-BR-0192.0000

Pennsylvania Coal Mining (Not Applicable)

### **PPP6 MINING AND KARST CONSTRUCTABILITY SUMMARY (PA Mining Inventory)**

#### **Geology- Karst Area**

- PA-CH-0004.0000
- PA-CH-0004.0001
- PA-CH-0219.0000
- PA-CH-0223.0000
- PA-CH-0226.0000
- PA-CH-0226.0002
- PA-CH-0262.0000

Pennsylvania Coal Mining (Not Applicable)

## **APPENDIX B**

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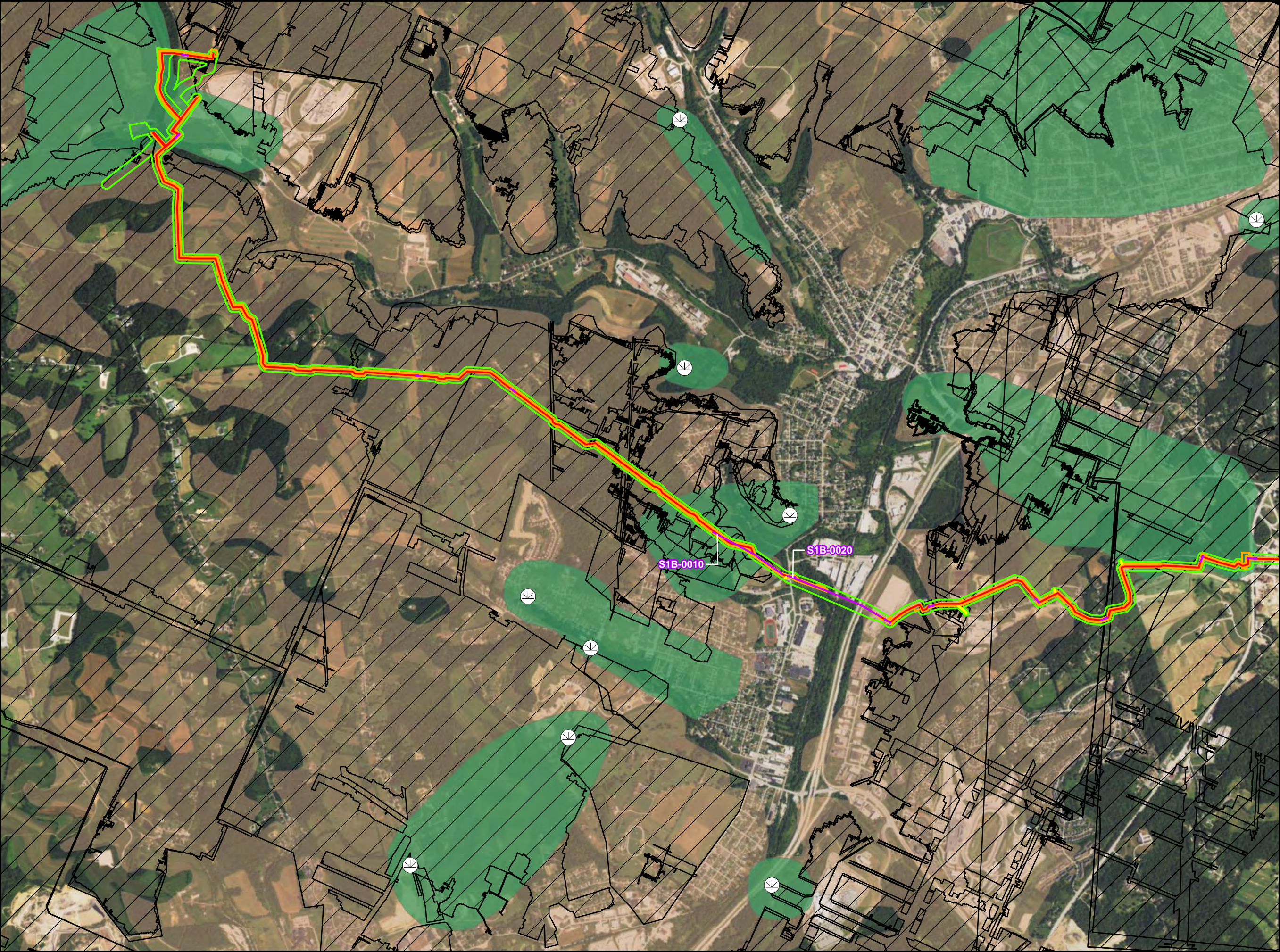
### **HDD Alignments**

## **APPENDIX B.1**

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### **County Maps of HDD Alignments, Carbonate Rocks, and Karst Features**





**Legend**

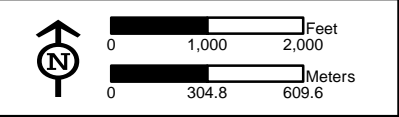
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- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)
- Digitized Mine Area

**Abandoned Mine Land Inventory**

- AML Inventory List

**Geology**

- Limestone

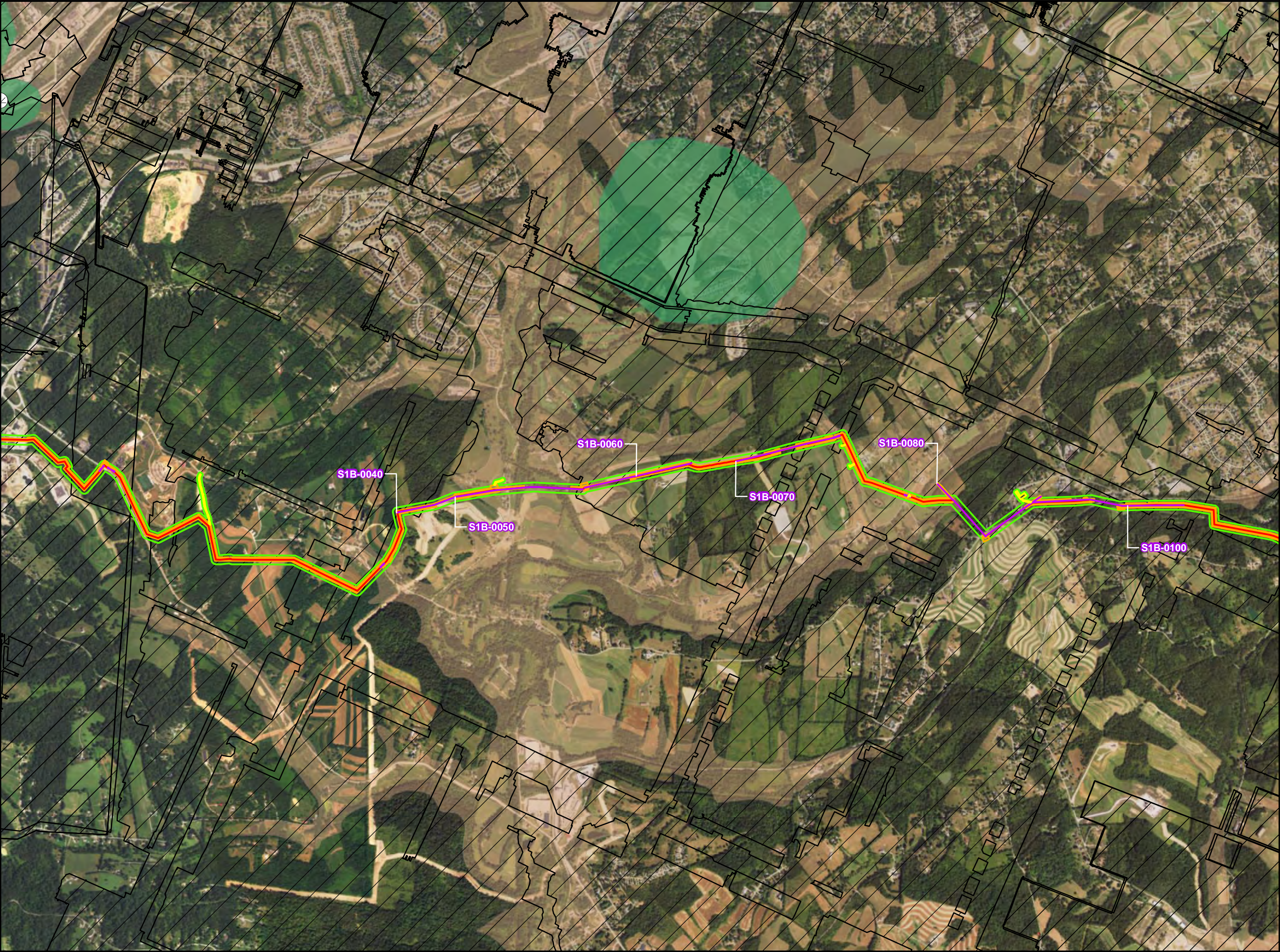


**KARST GEOLOGY MAP  
FIGURE 1  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
WASHINGTON COUNTY,  
PENNSYLVANIA**



**Notes:**  
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**Legend**

- Mine Entry Point/Opening
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)
- Digitized Mine Area

**Abandoned Mine Land Inventory**

- AML Inventory List

**Geology**

- Limestone

**Sheet Identifier**

North arrow and scale bars.

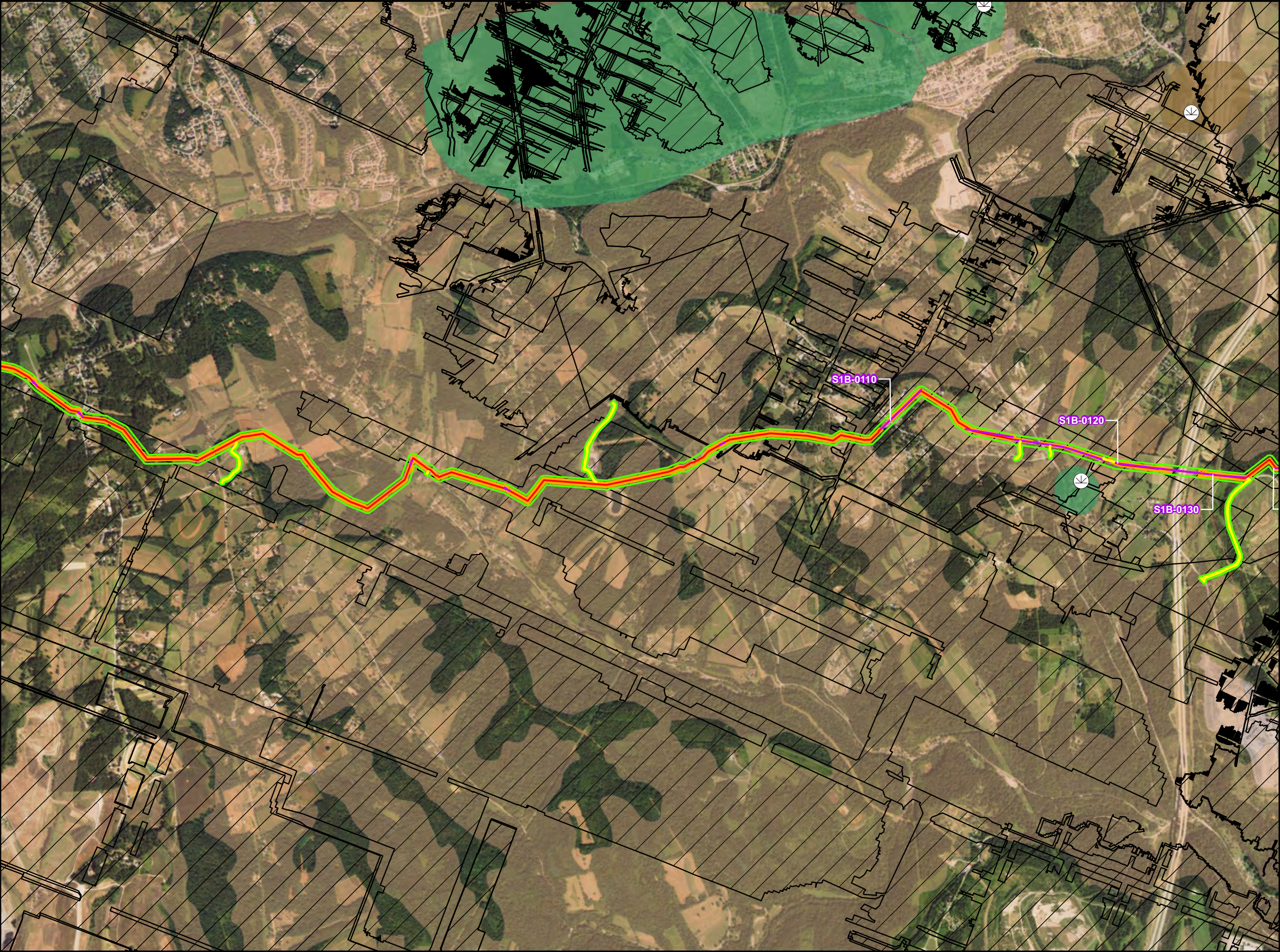
0 1,000 2,000 Feet  
0 304.8 609.6 Meters

**KARST GEOLOGY MAP  
FIGURE 2  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
WASHINGTON COUNTY,  
PENNSYLVANIA**



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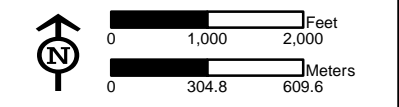
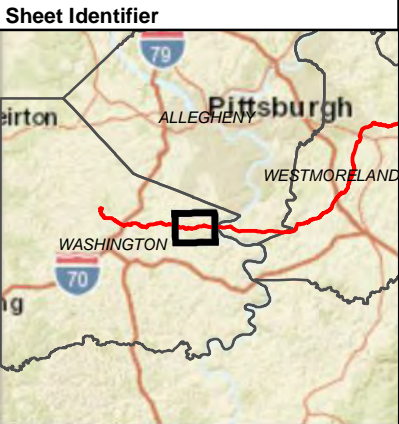
- Mine Entry Point/Opening
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)
- Digitized Mine Area

**Abandoned Mine Land Inventory**

- AML Inventory List
- Reclamation Complete

**Geology**

- Limestone

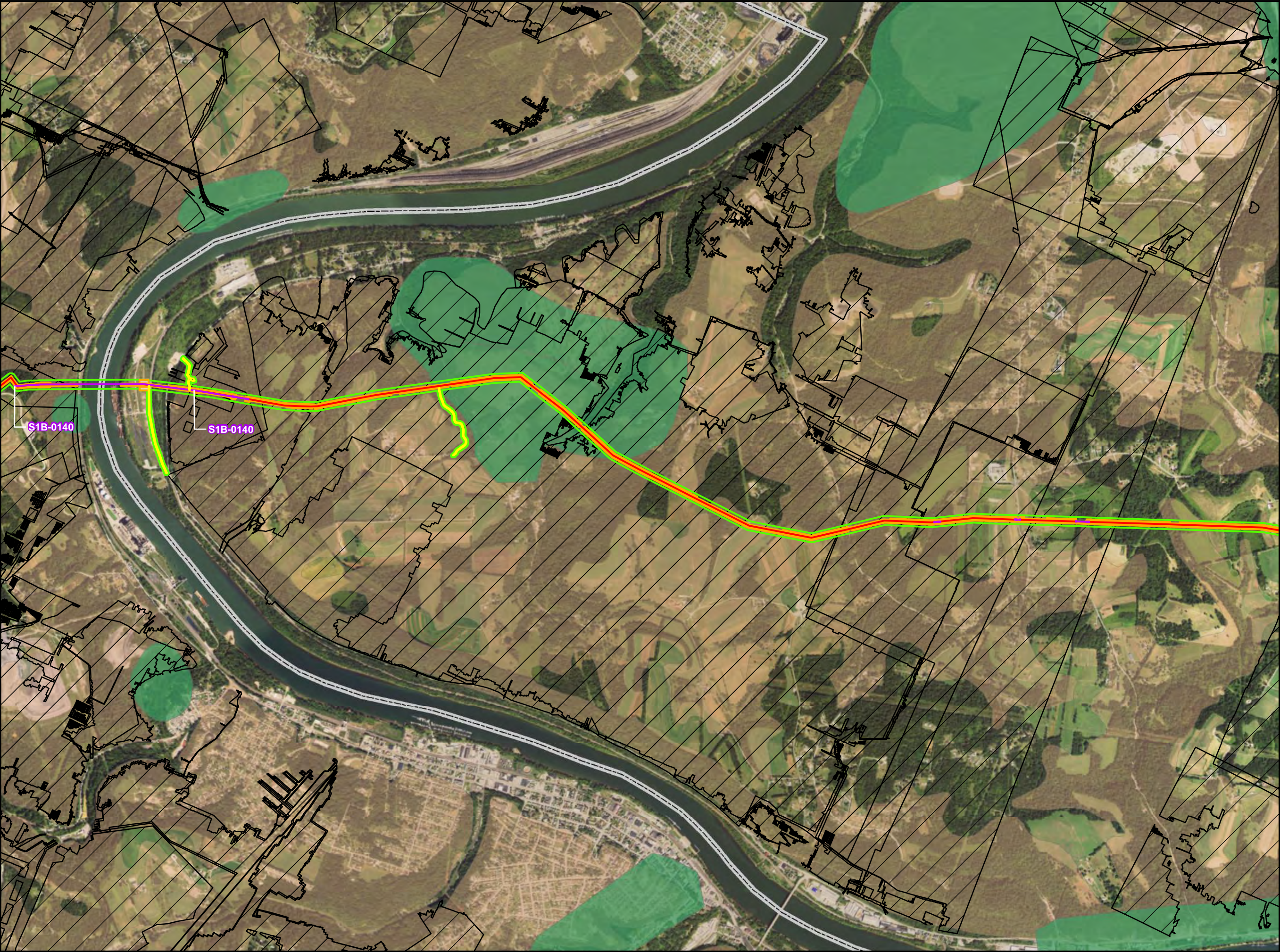


**KARST GEOLOGY MAP  
FIGURE 3  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
WASHINGTON COUNTY,  
PENNSYLVANIA**



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**Legend**

Alignment Centerline

Access Road

HDD Centerline

Limit of Disturbance

Centerline Buffer (100-ft)

Digitized Mine Area

**Abandoned Mine Land Inventory**

AML Inventory List

**Geology**

Limestone



01,0002,000

0304.8609.6

Feet

Meters

**KARST GEOLOGY MAP**

**FIGURE 4**

**PENNSYLVANIA PIPELINE PROJECT**

**NOVEMBER 12, 2016 ALIGNMENT**

**SUNOCO LOGISTICS, L.P.**

**WASHINGTON, ALLEGHENY COUNTY,**

**PENNSYLVANIA**

**TETRA TECH**

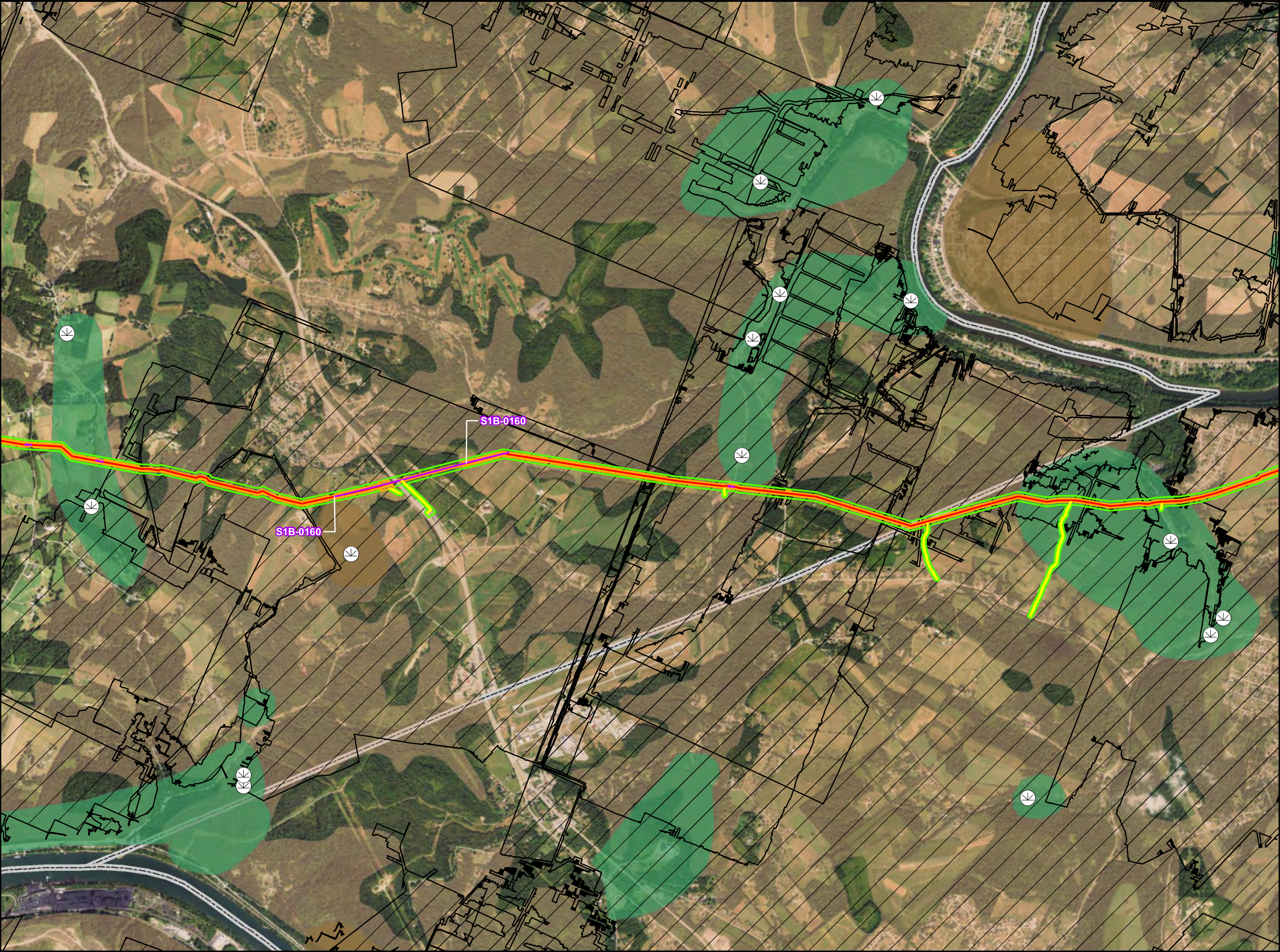
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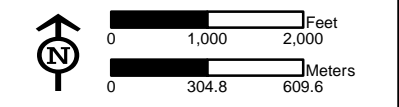
- Mine Entry Point/Opening
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)
- Digitized Mine Area

**Abandoned Mine Land Inventory**

- AML Inventory List
- Reclamation Complete

**Geology**

- Limestone

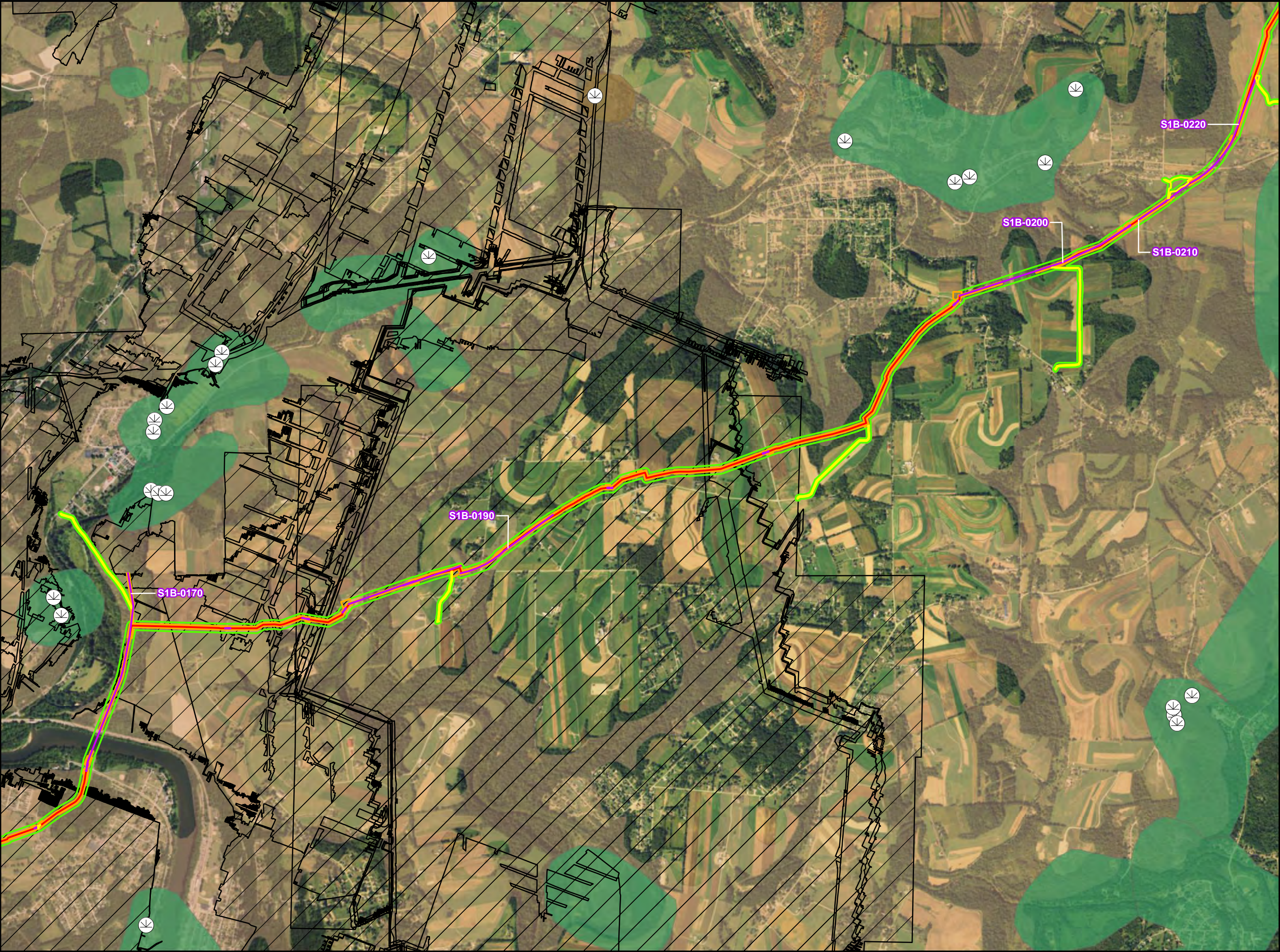


**KARST GEOLOGY MAP  
FIGURE 5  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
ALLEGHENY, WESTMORELAND COUNTY,  
PENNSYLVANIA**



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**Legend**

- Mine Entry Point/Opening
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)
- Digitized Mine Area

**Abandoned Mine Land Inventory**

- AML Inventory List
- Reclamation Complete

**Geology**

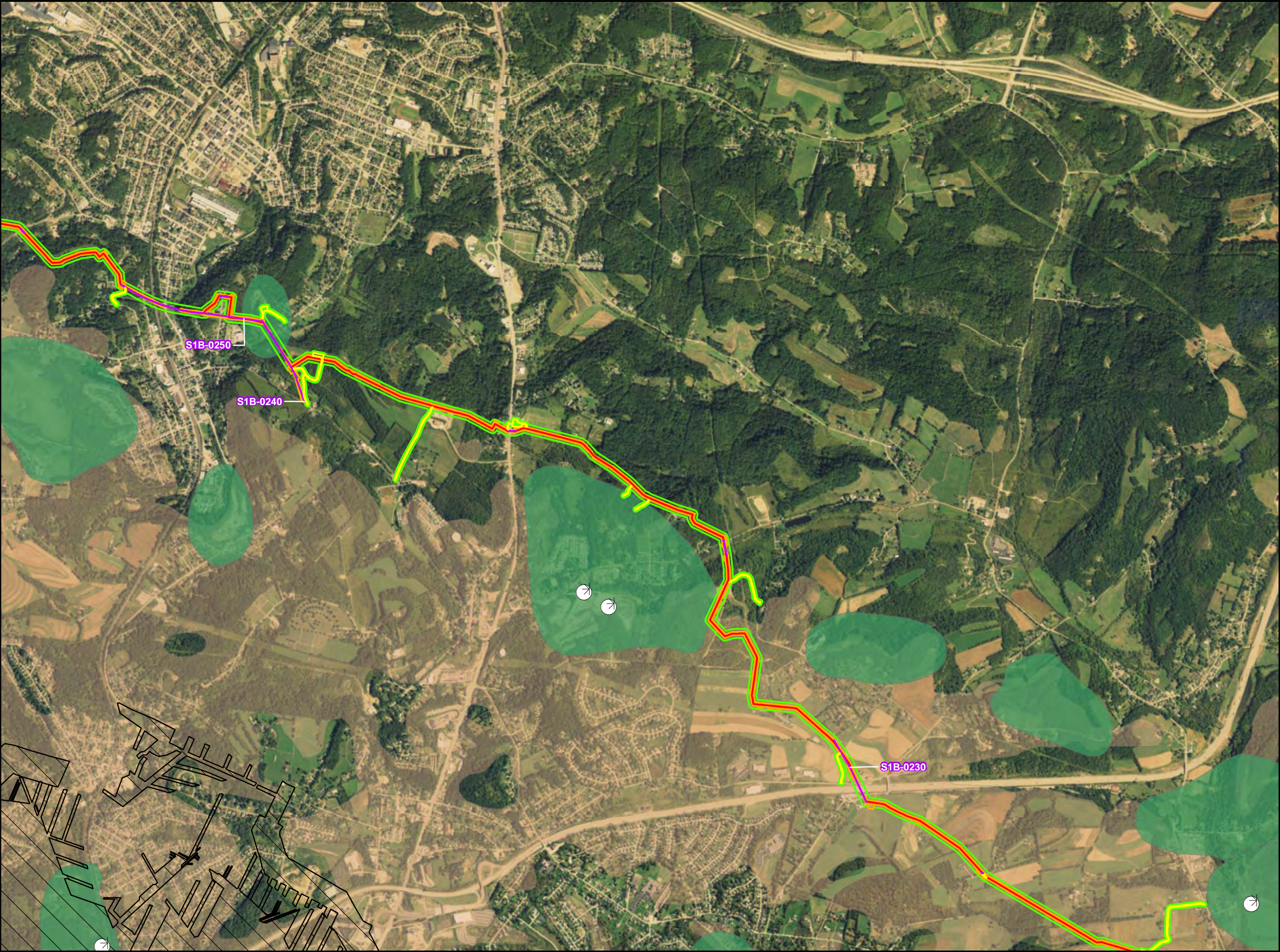
- Limestone

**Sheet Identifier**

**KARST GEOLOGY MAP**  
**FIGURE 6**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**WESTMORELAND COUNTY,**  
**PENNSYLVANIA**

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**Legend**

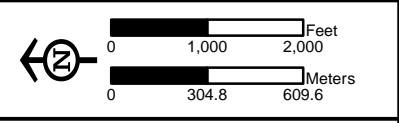
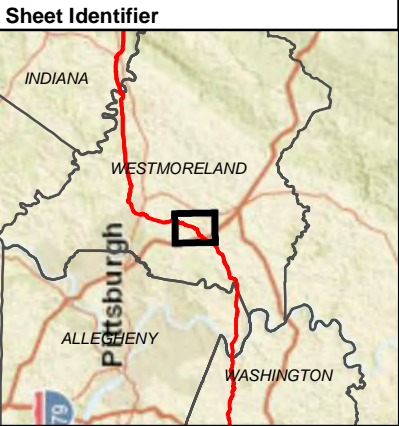
- Mine Entry Point/Opening
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)
- Digitized Mine Area

**Abandoned Mine Land Inventory**

- AML Inventory List

**Geology**

- Limestone

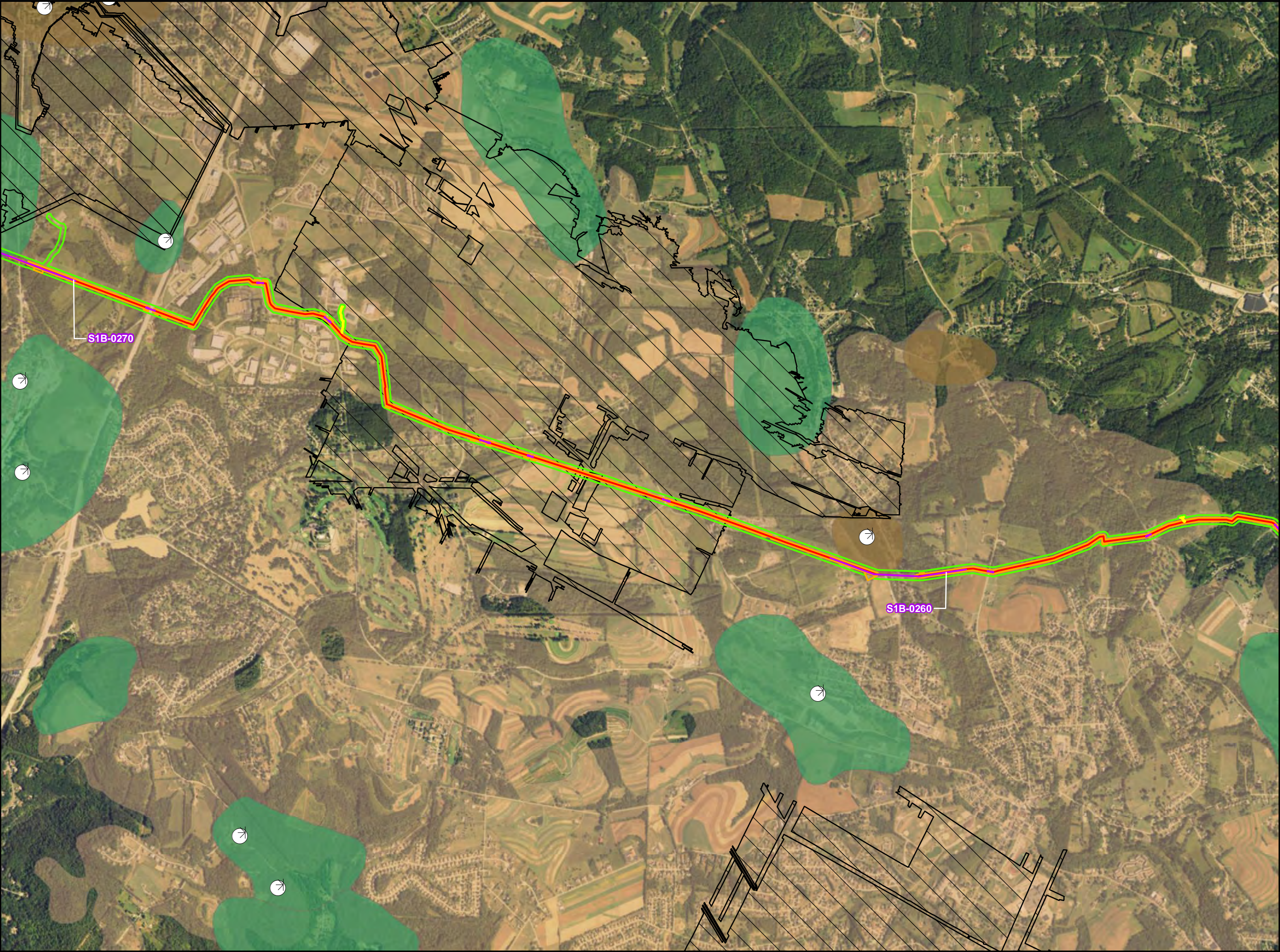


**KARST GEOLOGY MAP  
FIGURE 7  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
WESTMORELAND COUNTY,  
PENNSYLVANIA**



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**Legend**

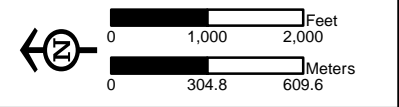
- Mine Entry Point/Opening
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)
- Digitized Mine Area

**Abandoned Mine Land Inventory**

- AML Inventory List
- Reclamation Complete

**Geology**

- Limestone

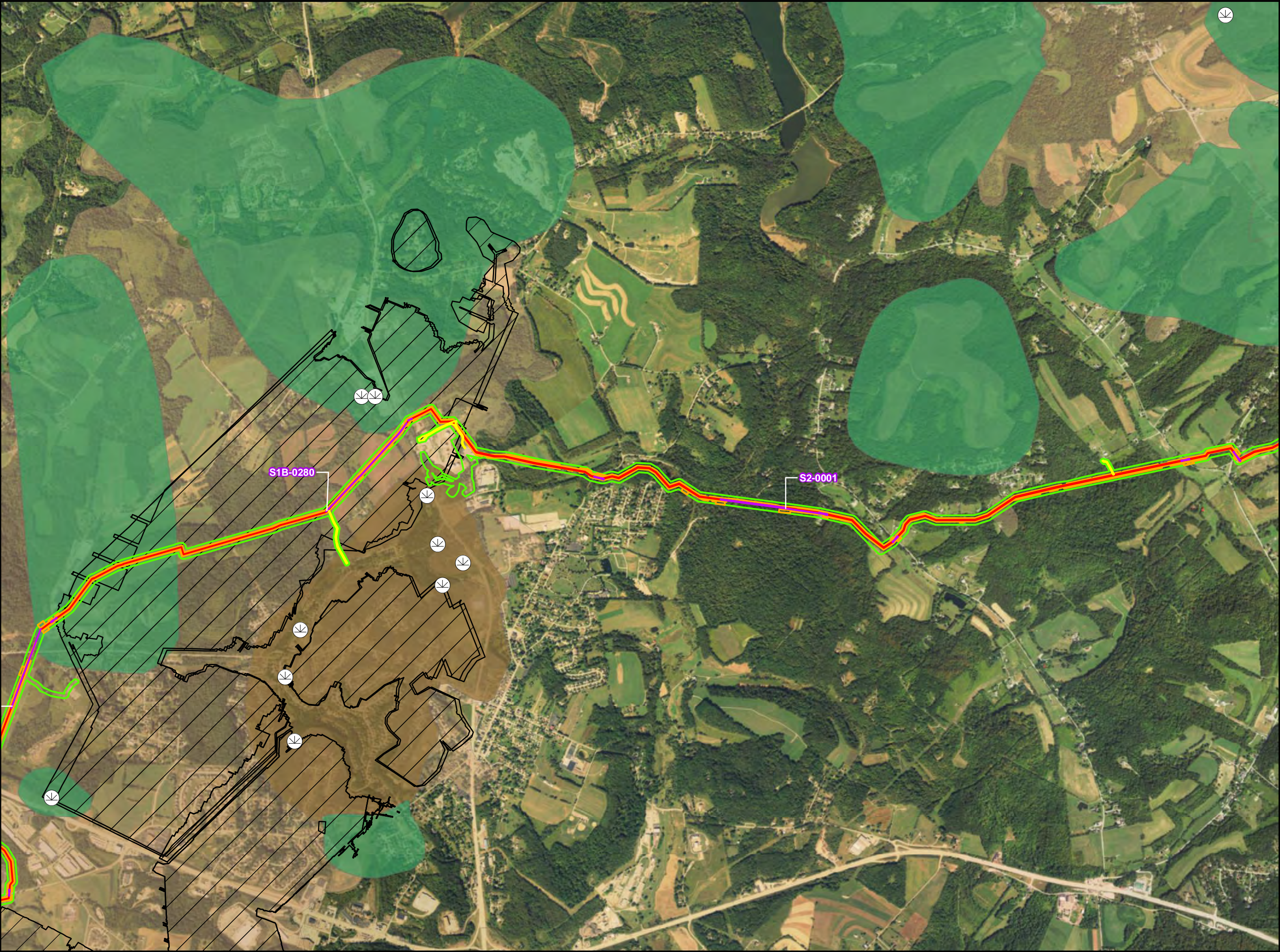


**KARST GEOLOGY MAP  
FIGURE 8  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
WESTMORELAND COUNTY,  
PENNSYLVANIA**



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**Legend**

- Mine Entry Point/Opening
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)
- Digitized Mine Area

**Abandoned Mine Land Inventory**

- AML Inventory List
- Reclamation Complete

**Geology**

- Limestone

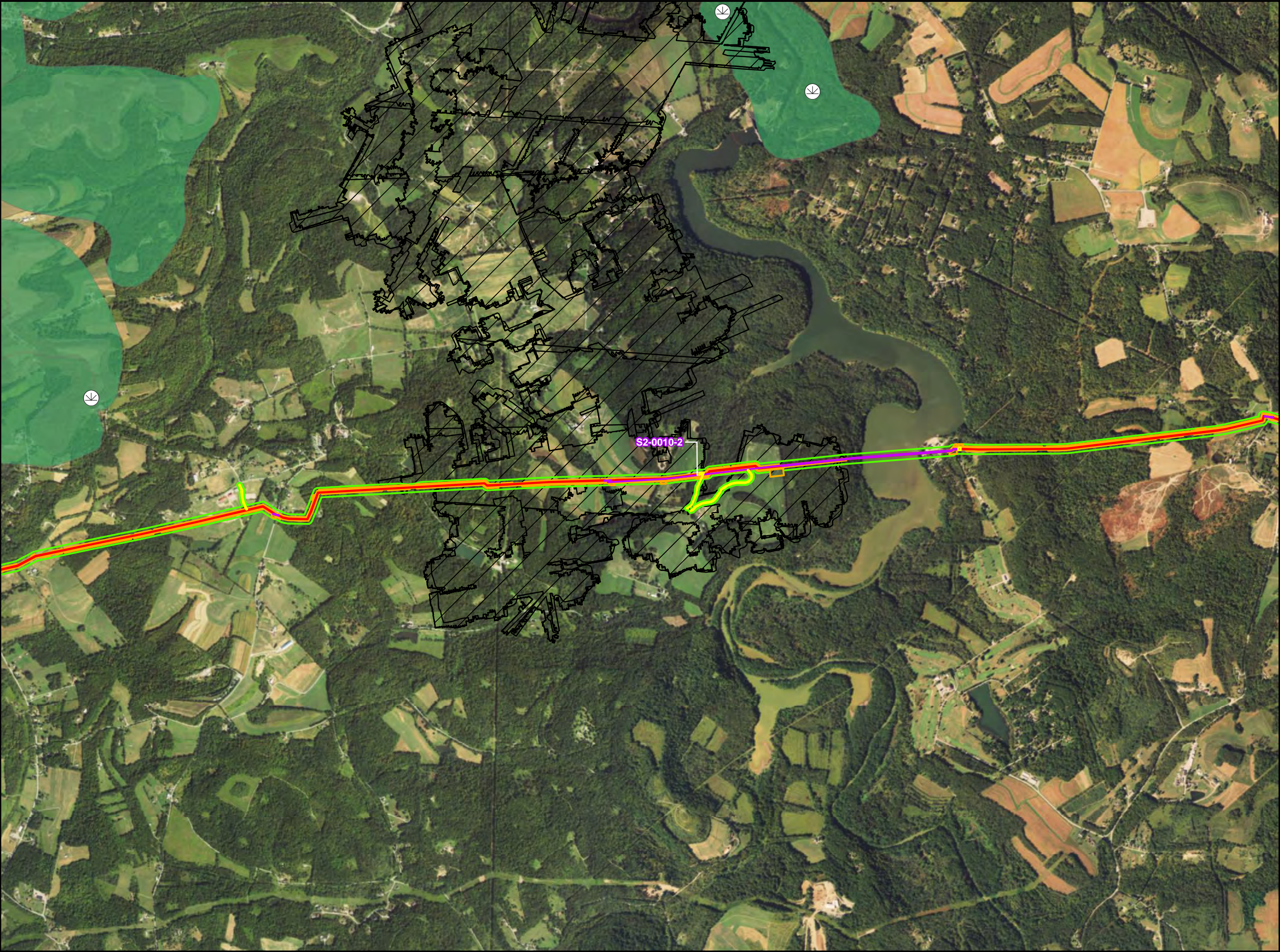
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**KARST GEOLOGY MAP  
FIGURE 9  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
WESTMORELAND COUNTY,  
PENNSYLVANIA**

**TETRA TECH**

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**Legend**

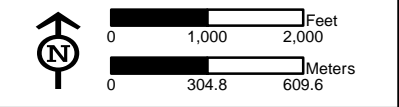
- Mine Entry Point/Opening
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)
- Digitized Mine Area

**Abandoned Mine Land Inventory**

- AML Inventory List

**Geology**

- Limestone



**KARST GEOLOGY MAP**  
**FIGURE 10**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**WESTMORELAND COUNTY,**  
**PENNSYLVANIA**



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**Legend**

Mine Entry Point/Opening

Alignment Centerline

Access Road

HDD Centerline

Limit of Disturbance

Centerline Buffer (100-ft)

**Abandoned Mine Land Inventory**

AML Inventory List

**Geology**

Limestone



01,0002,000

Feet

0304.8609.6

Meters

**KARST GEOLOGY MAP**

**FIGURE 11**

**PENNSYLVANIA PIPELINE PROJECT**

**NOVEMBER 12, 2016 ALIGNMENT**

**SUNOCO LOGISTICS, L.P.**

**WESTMORELAND COUNTY,**

**PENNSYLVANIA**

**TETRA TECH**

Notes:

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**Legend**

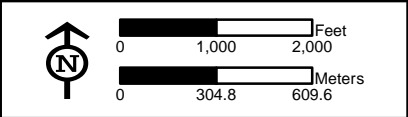
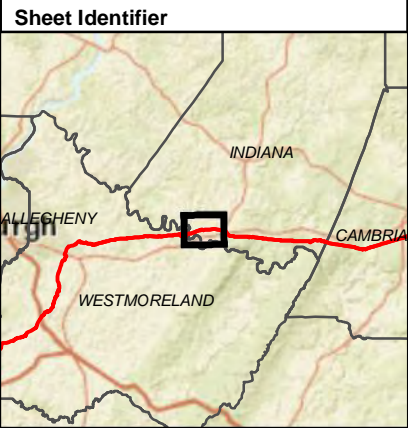
- Mine Entry Point/Opening
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)
- Digitized Mine Area

**Abandoned Mine Land Inventory**

- AML Inventory List
- Abandoned

**Geology**

- Limestone

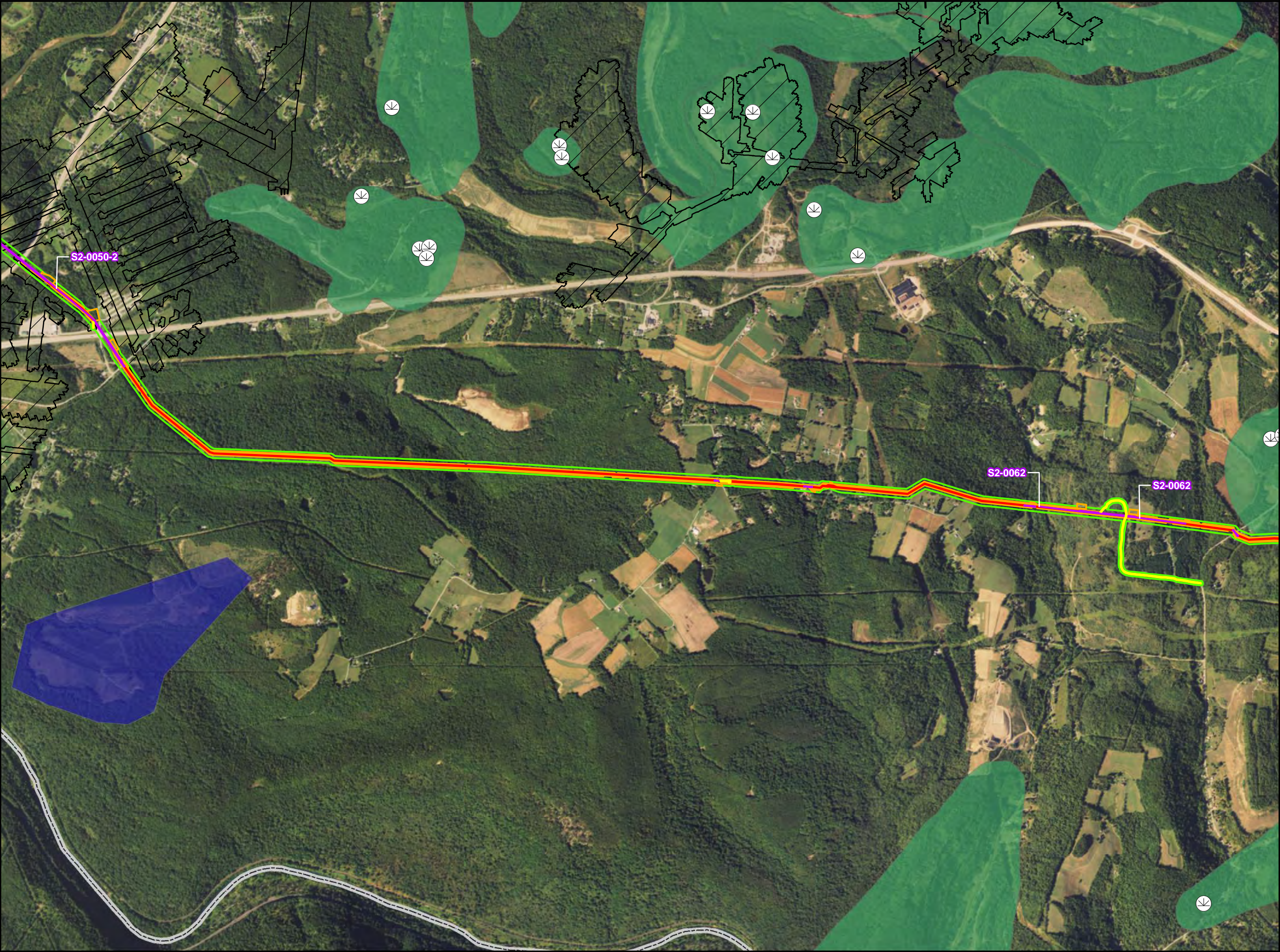


**KARST GEOLOGY MAP  
FIGURE 12  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
WESTMORELAND, INDIANA COUNTY,  
PENNSYLVANIA**



**Notes:**  
Aerial photograph provided by ESRI's  
ArcGIS Online World Imagery map service  
(© 2015 ESRI and its data suppliers).



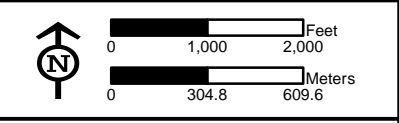


**Legend**

- Mine Entry Point/Opening
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)
- Digitized Mine Area

**Abandoned Mine Land Inventory**

- AML Inventory List
- Abandoned

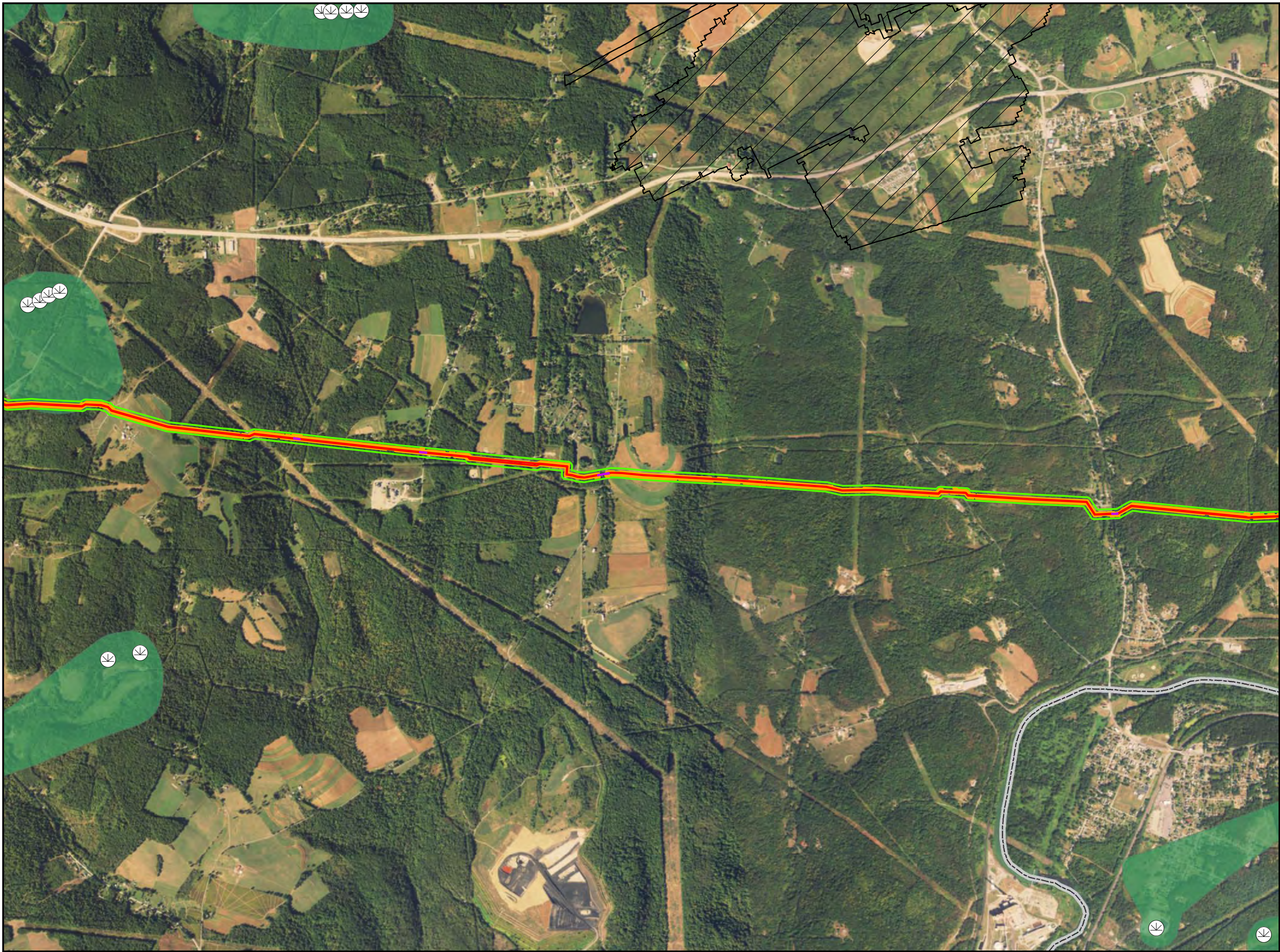


**KARST GEOLOGY MAP  
FIGURE 13  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
INDIANA COUNTY,  
PENNSYLVANIA**



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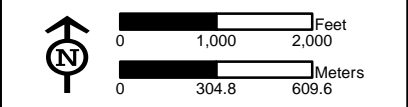
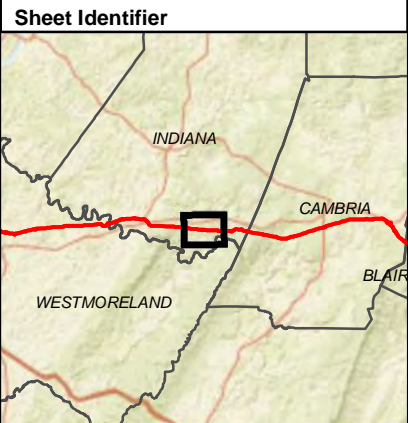


**Legend**

- Mine Entry Point/Opening
- Alignment Centerline
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)
- Digitized Mine Area

**Abandoned Mine Land Inventory**

- AML Inventory List

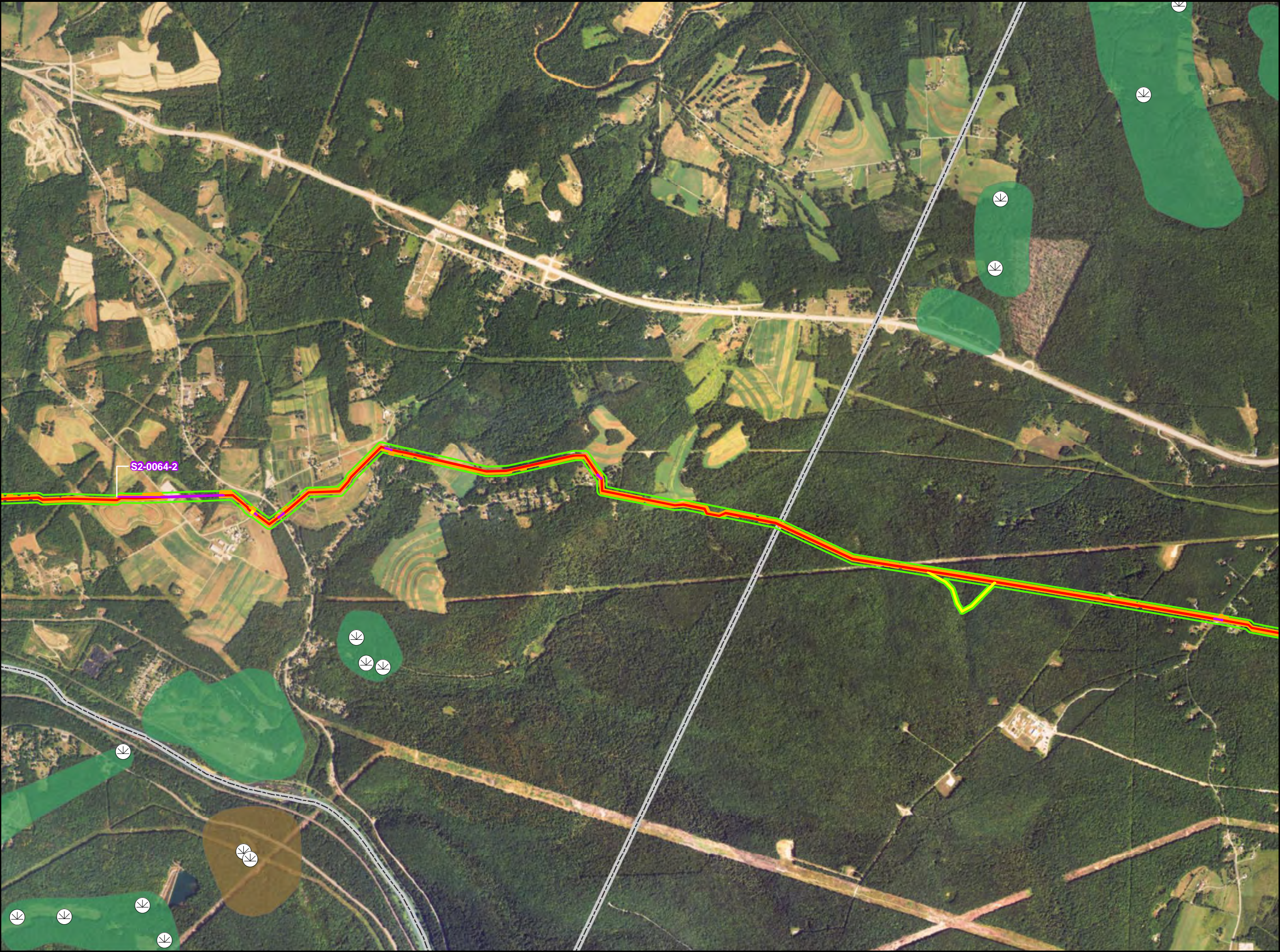


**KARST GEOLOGY MAP  
FIGURE 14  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
INDIANA COUNTY,  
PENNSYLVANIA**



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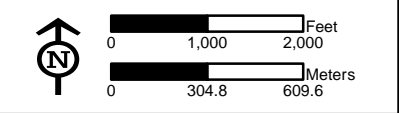
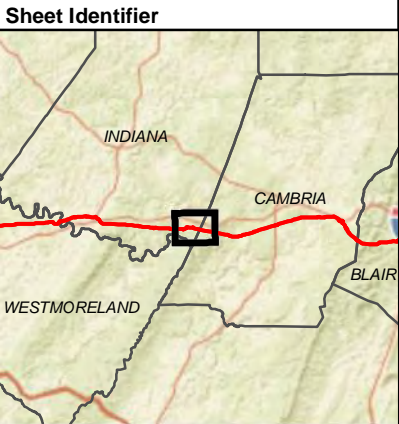


**Legend**

- Mine Entry Point/Opening
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Abandoned Mine Land Inventory**

- AML Inventory List
- Reclamation Complete

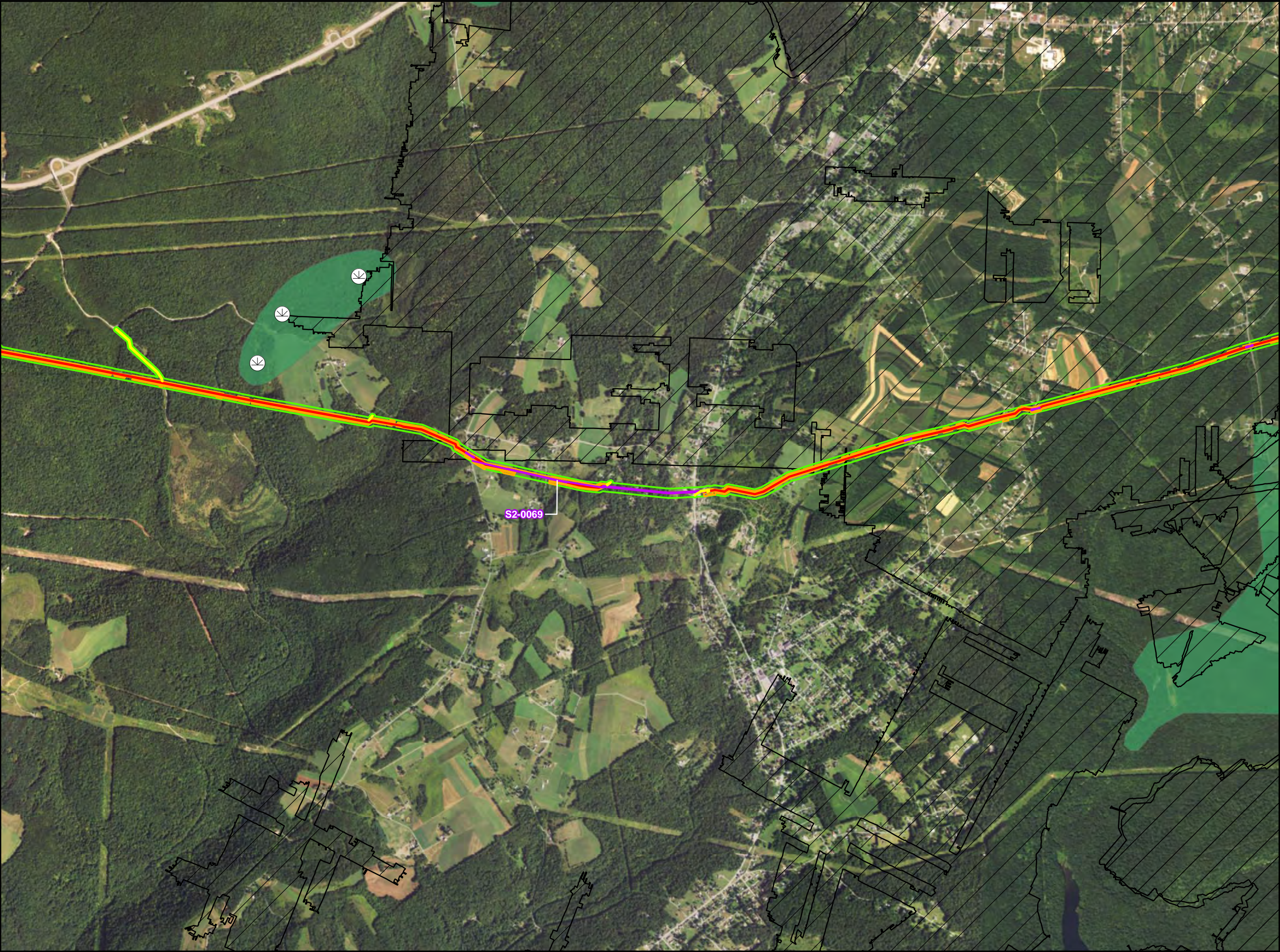


**KARST GEOLOGY MAP  
FIGURE 15  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
INDIANA, CAMBRIA COUNTY,  
PENNSYLVANIA**



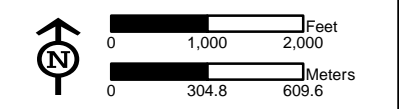
**Notes:**  
Aerial photograph provided by ESRI's  
ArcGIS Online World Imagery map service  
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**Legend**

- Mine Entry Point/Opening
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)
- Digitized Mine Area
- Abandoned Mine Land Inventory**
- AML Inventory List

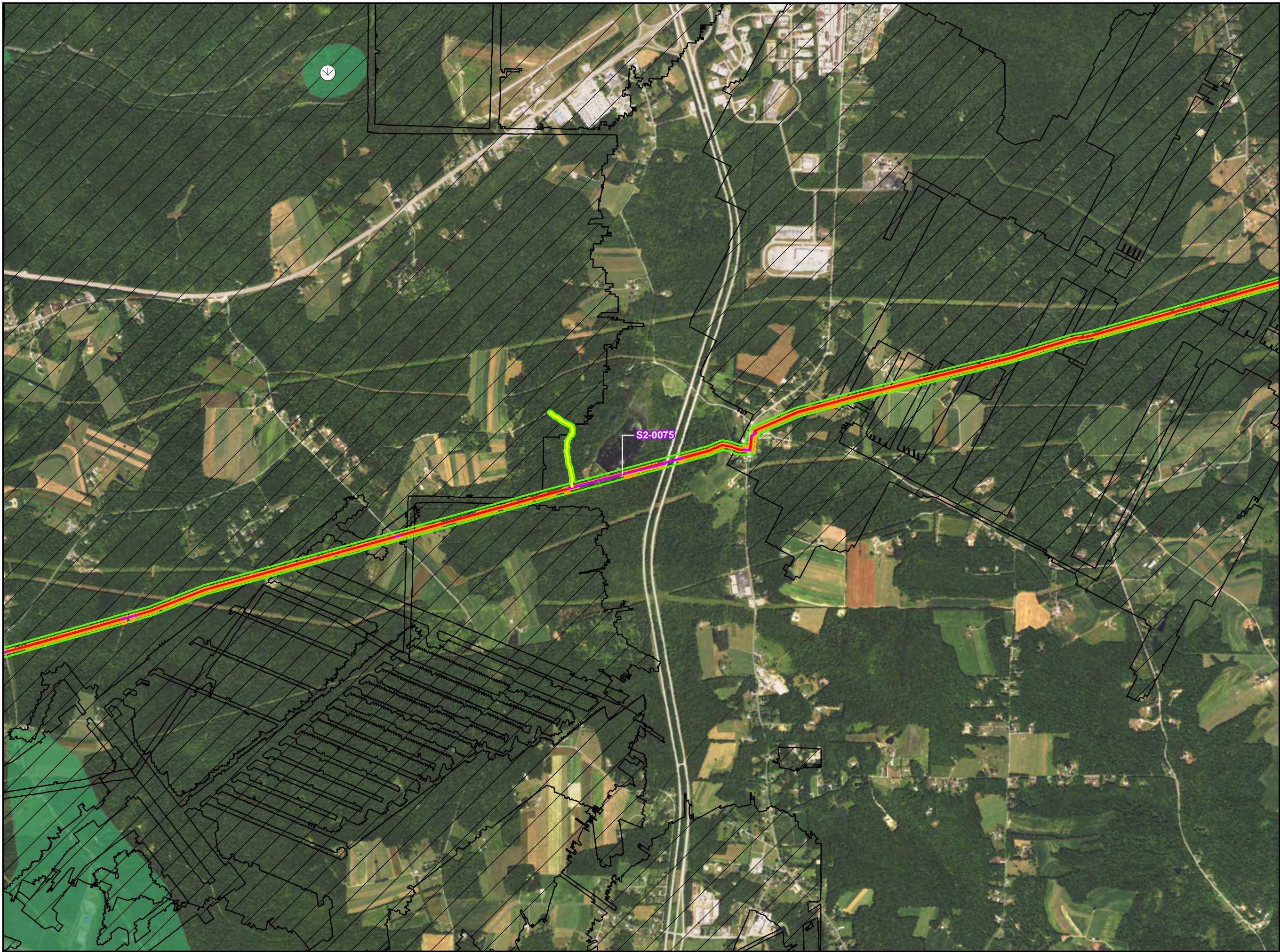


**KARST GEOLOGY MAP**  
**FIGURE 16**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**CAMBRIA COUNTY,**  
**PENNSYLVANIA**



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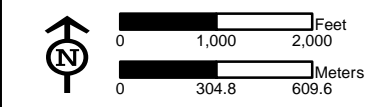


**Legend**

- Mine Entry Point/Opening
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)
- Digitized Mine Area

**Abandoned Mine Land Inventory**

- AML Inventory List

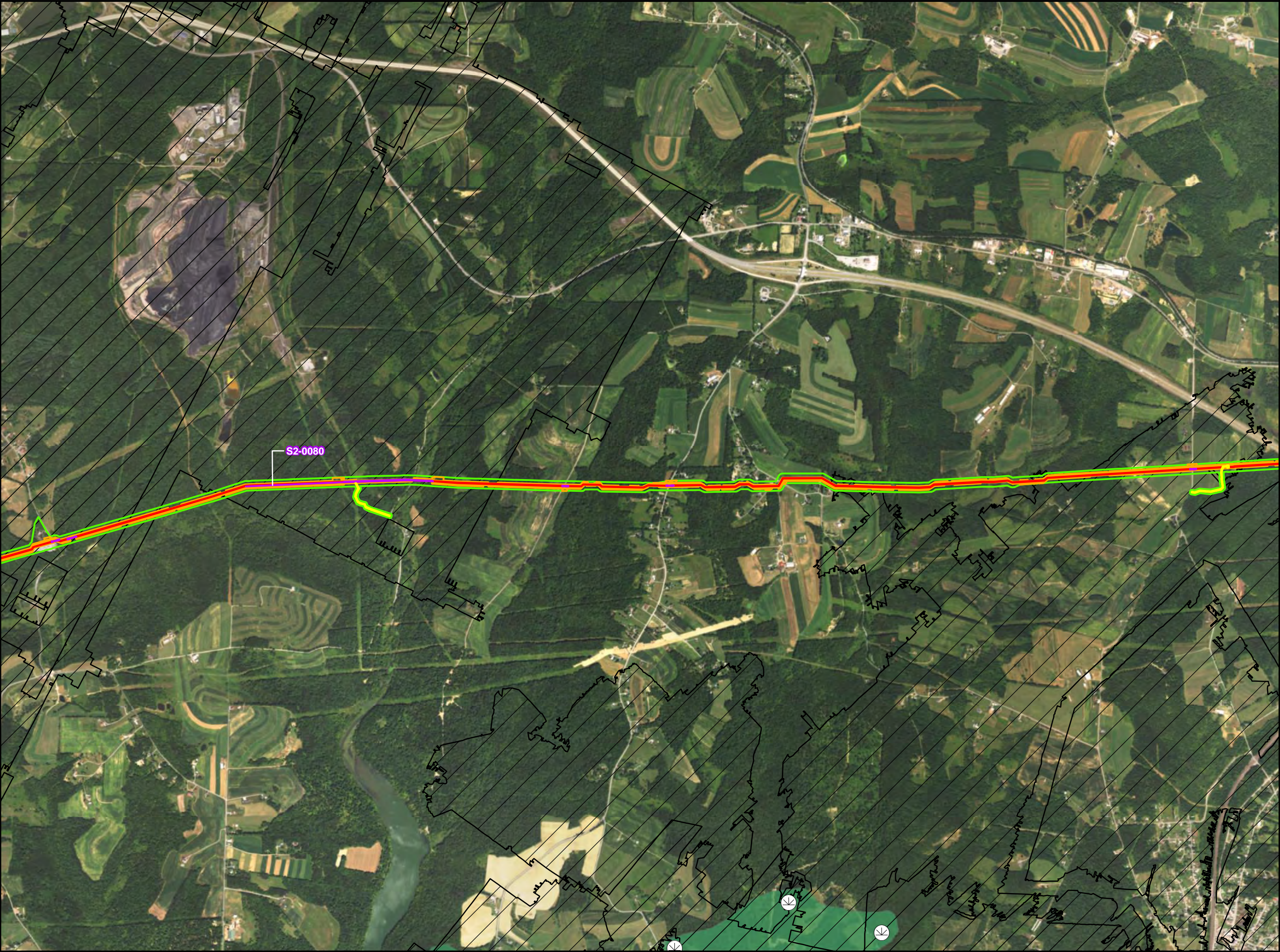


**KARST GEOLOGY MAP  
FIGURE 17  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
CAMBRIA COUNTY,  
PENNSYLVANIA**



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**Legend**

- Mine Entry Point/Opening
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)
- Digitized Mine Area

**Abandoned Mine Land Inventory**

- AML Inventory List

**Sheet Identifier**

INDIANA  
HUNTINGDON  
Altoona  
BLAIR  
CAMBRIA  
WESTMORELAND  
HUNTINGDON

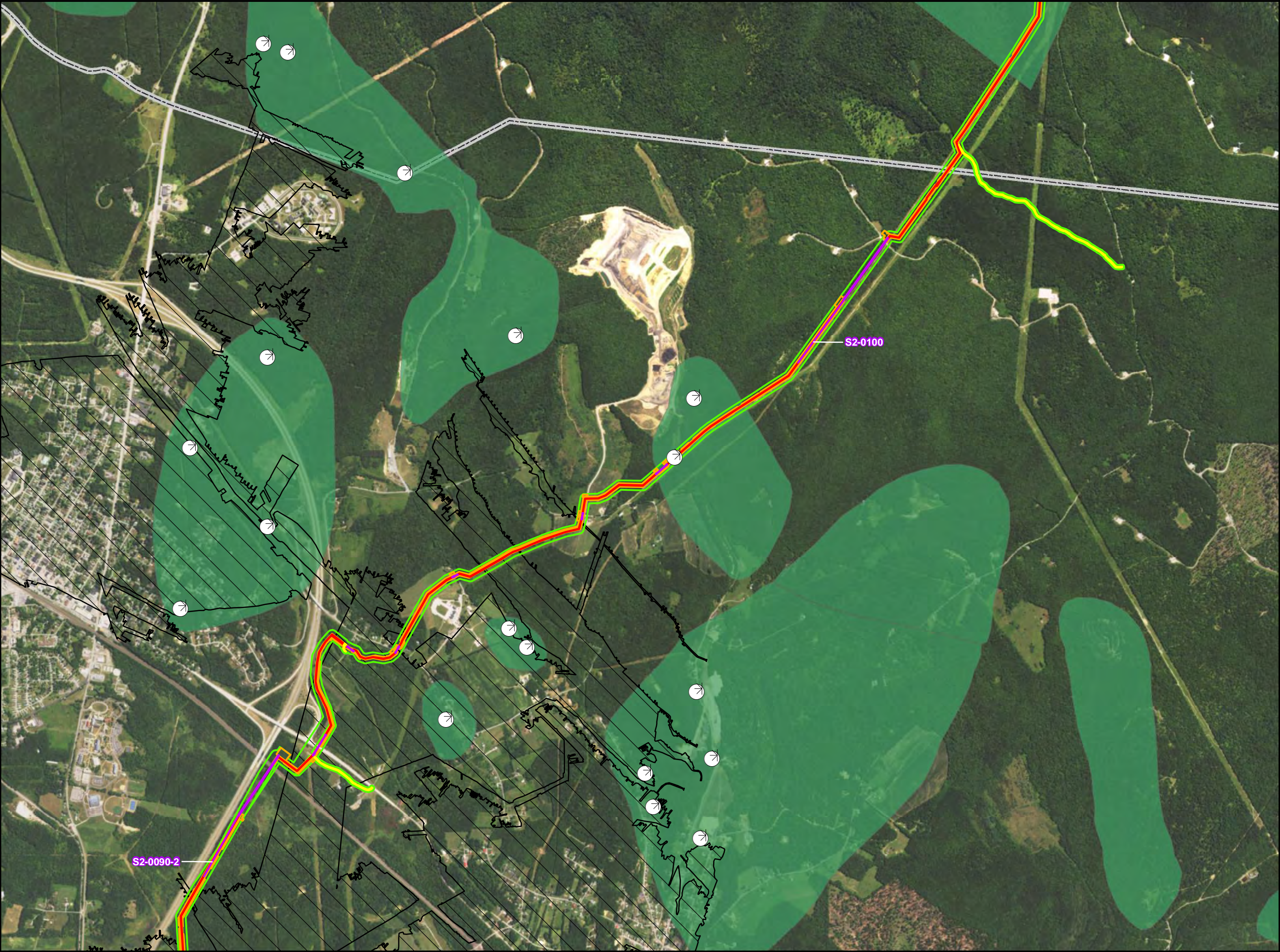
0 1,000 2,000 Feet  
0 304.8 609.6 Meters

**KARST GEOLOGY MAP  
FIGURE 18  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
CAMBRIA COUNTY,  
PENNSYLVANIA**



Notes:  
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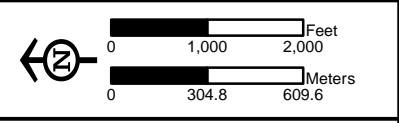
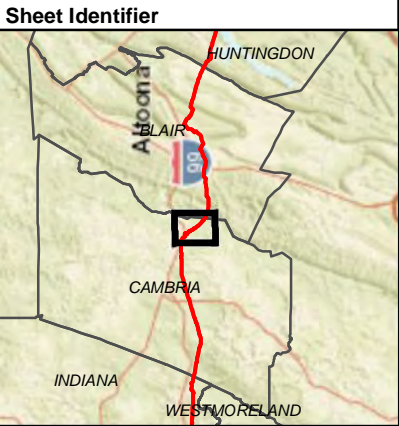


**Legend**

- Mine Entry Point/Opening
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)
- Digitized Mine Area

**Abandoned Mine Land Inventory**

- AML Inventory List

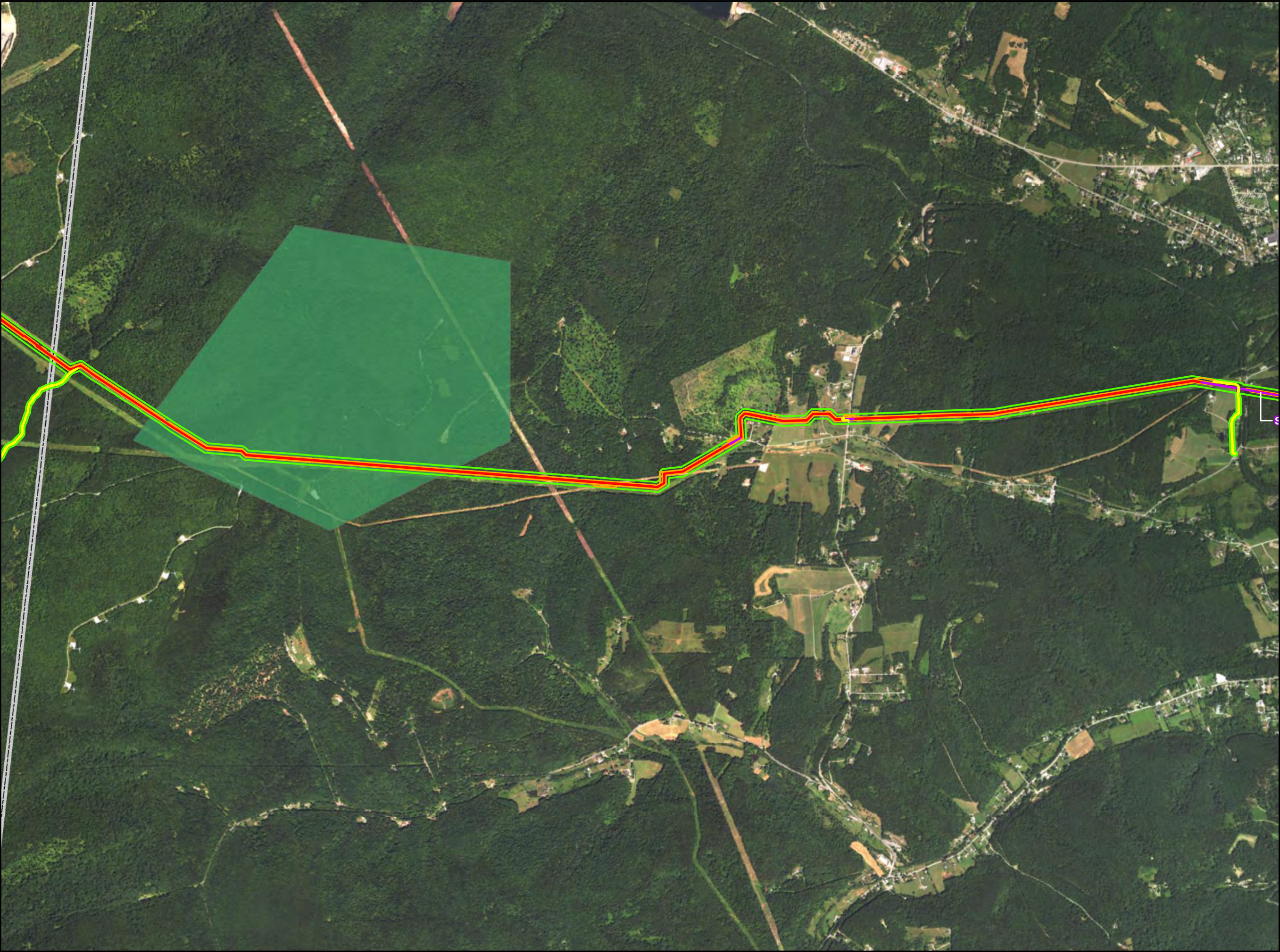


**KARST GEOLOGY MAP  
FIGURE 19  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
CAMBRIA COUNTY,  
PENNSYLVANIA**



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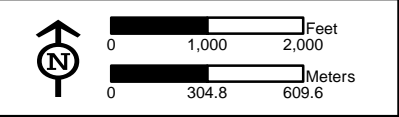
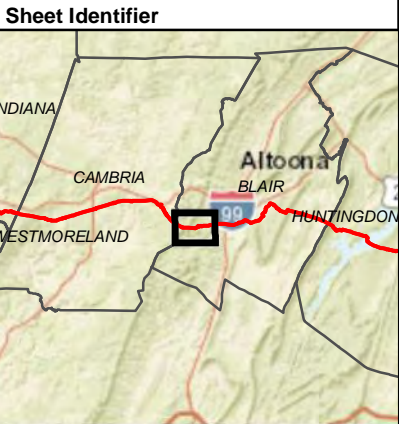


**Legend**

- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Abandoned Mine Land Inventory**

- AML Inventory List

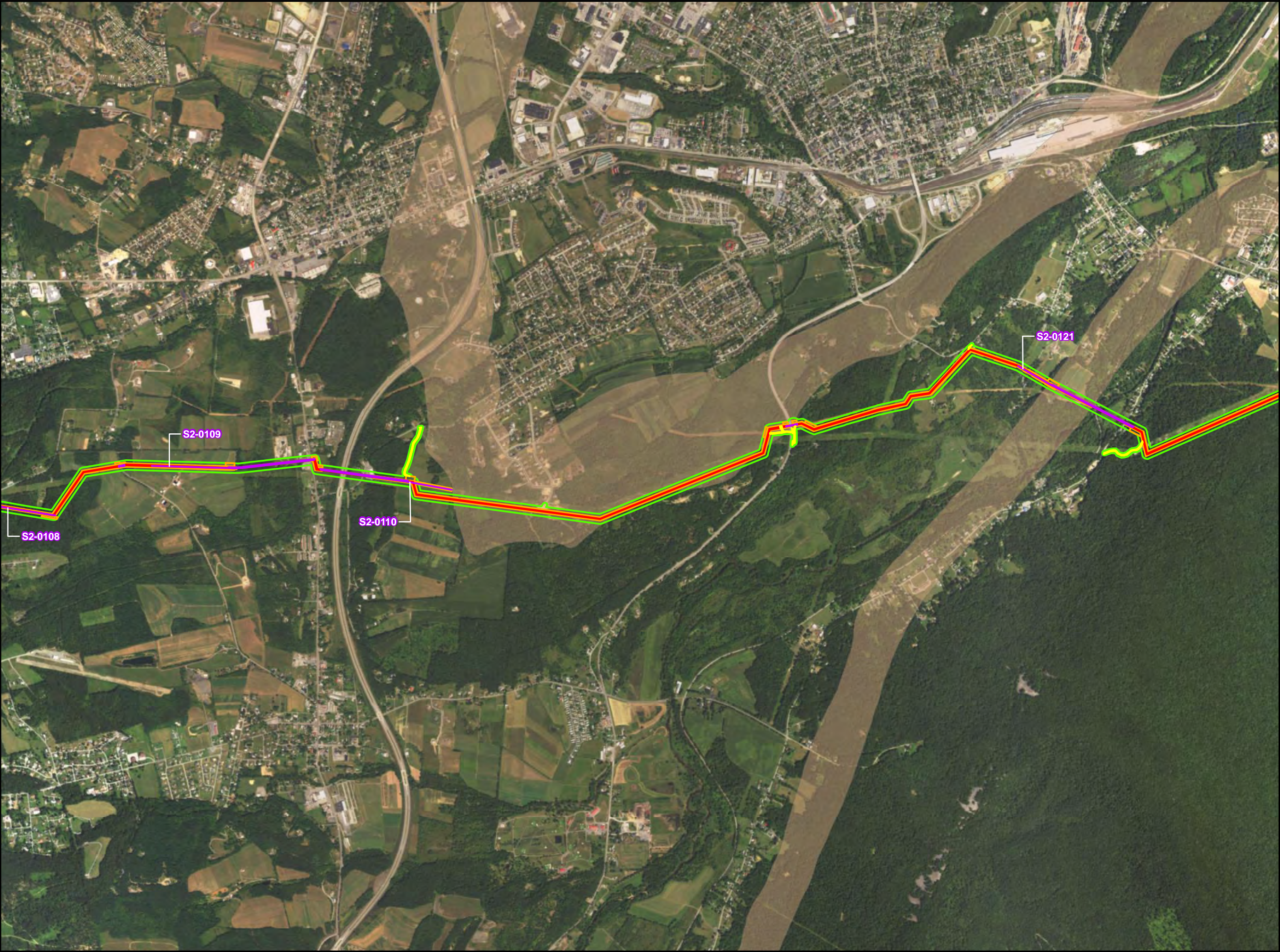


**KARST GEOLOGY MAP  
FIGURE 20  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
BLAIR COUNTY  
PENNSYLVANIA**



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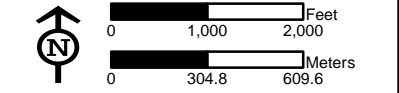
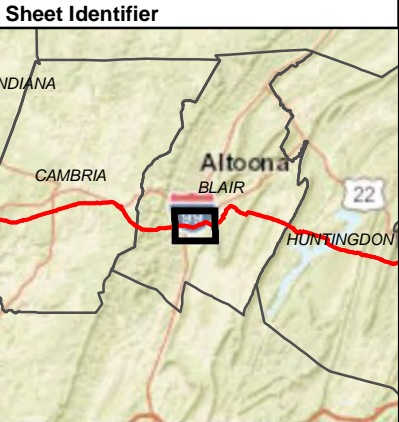


**Legend**

- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Geology**

- Limestone

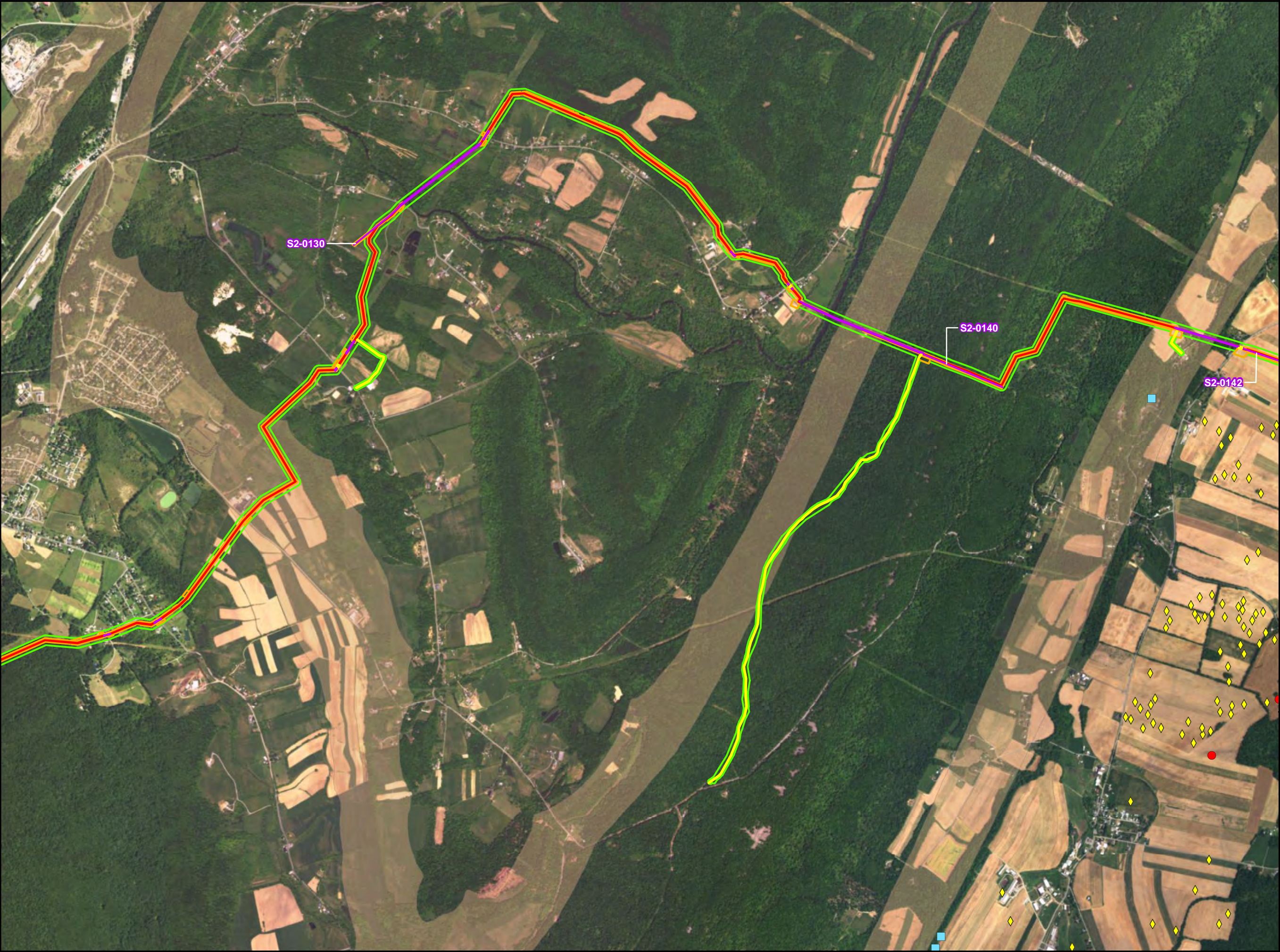


**KARST GEOLOGY MAP  
FIGURE 21  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
BLAIR COUNTY,  
PENNSYLVANIA**



**Notes:**  
Aerial photograph provided by ESRI's  
ArcGIS Online World Imagery map service  
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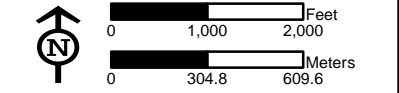
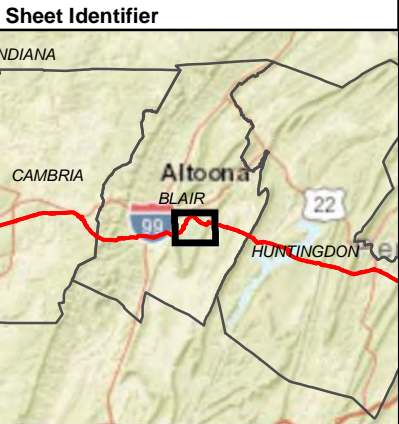
**Legend**

**PA DCNR Karst Points**

- Sinkhole
- ◆ Surface Depression
- Surface Mine
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Geology**

- Limestone

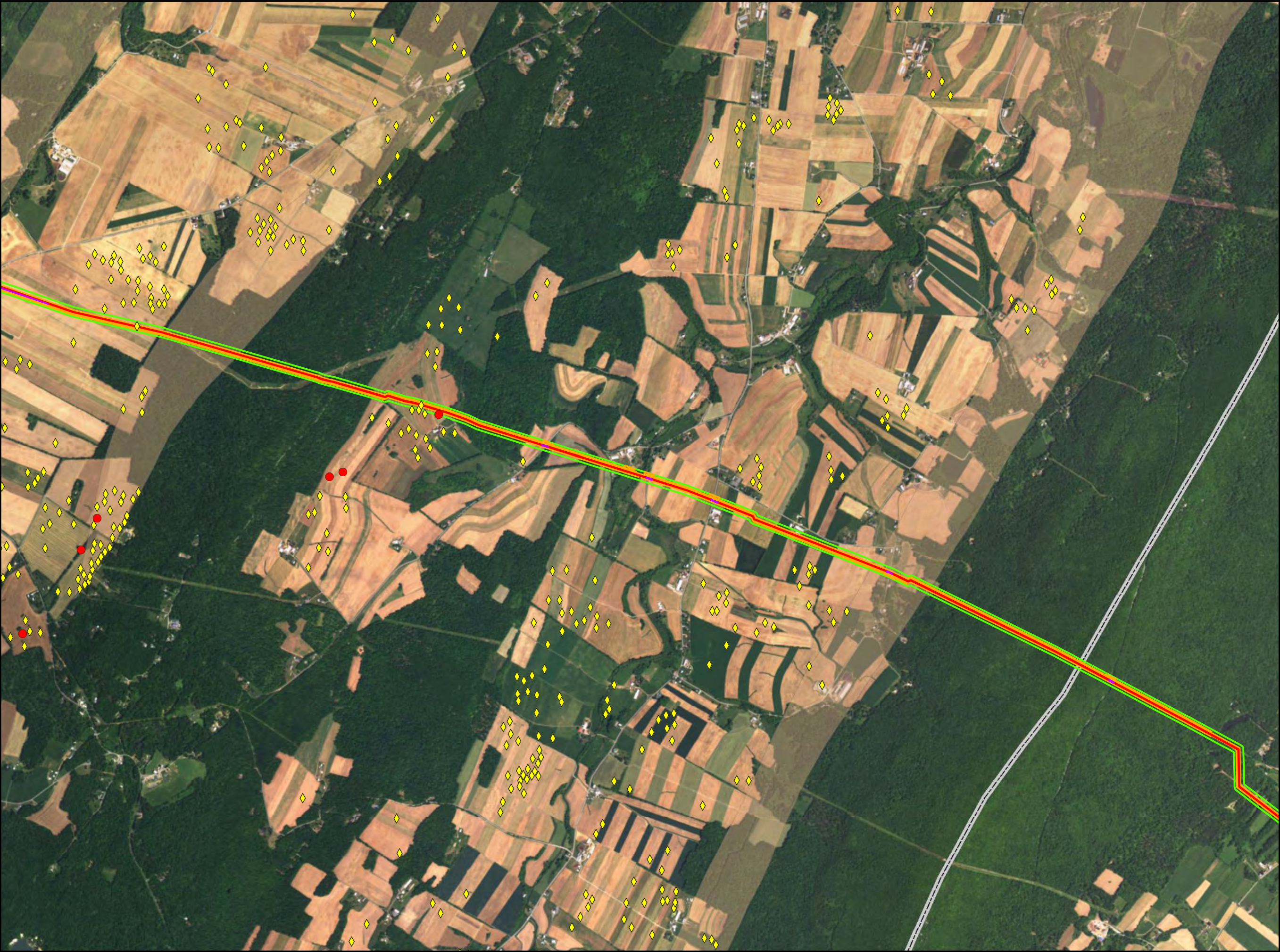


**KARST GEOLOGY MAP  
FIGURE 22  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
BLAIR COUNTY,  
PENNSYLVANIA**



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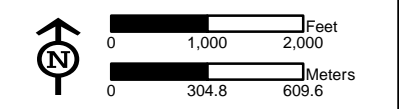
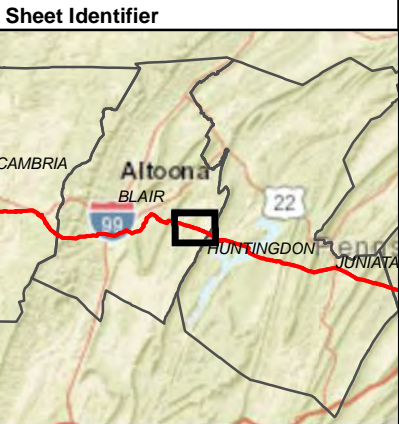
**Legend**

**PA DCNR Karst Points**

- Sinkhole
- Surface Depression
- Alignment Centerline
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Geology**

- Limestone



**KARST GEOLOGY MAP**  
**FIGURE 23**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**BLAIR, HUNTINGDON COUNTY,**  
**PENNSYLVANIA**



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**Legend**

**PA DCNR Karst Points**

- Surface Depression
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Geology**

- Limestone

**Sheet Identifier**

**Scale**

0 1,000 2,000 Feet

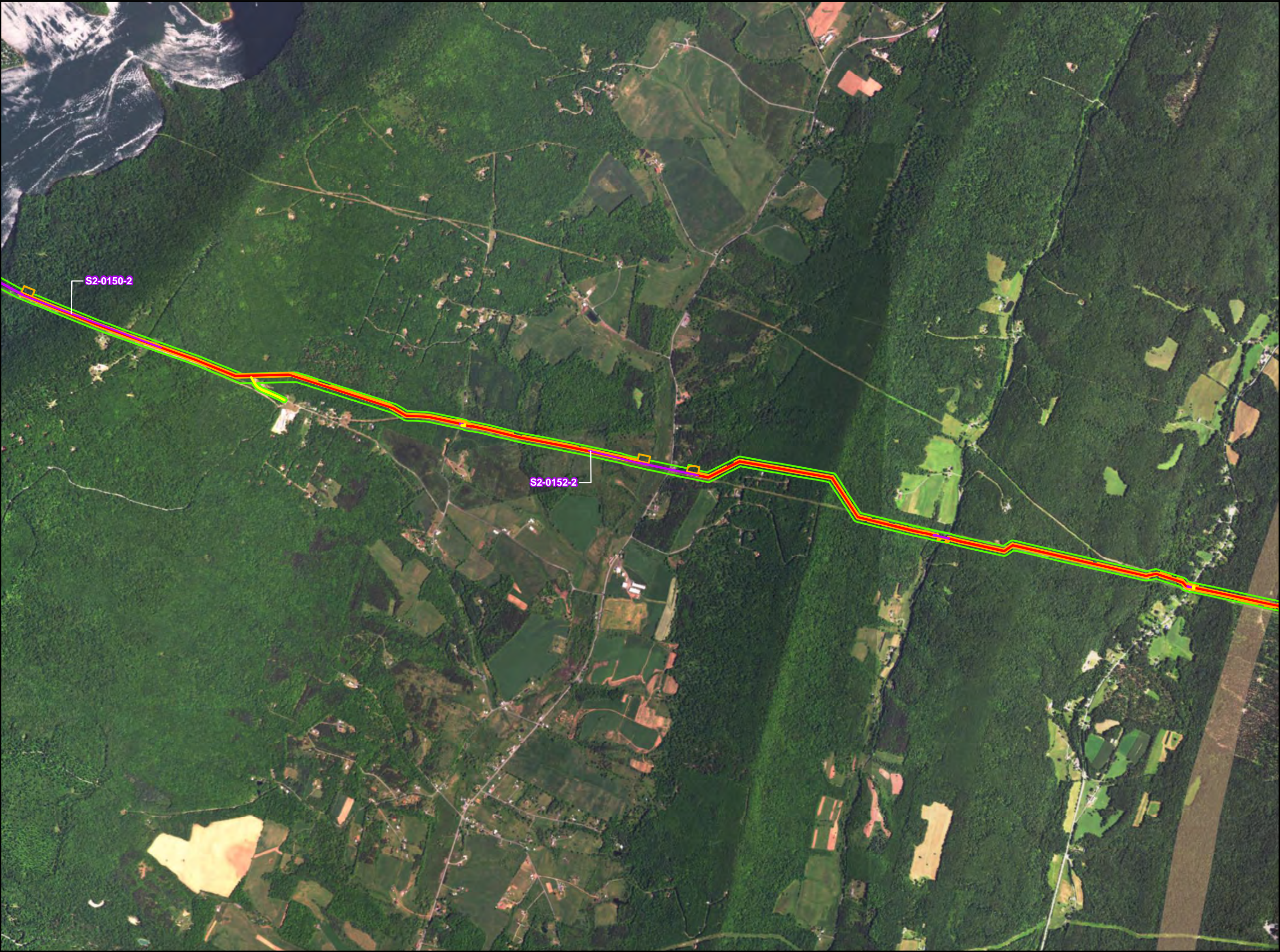
0 304.8 609.6 Meters

**KARST GEOLOGY MAP**  
**FIGURE 24**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**HUNTINGDON COUNTY,**  
**PENNSYLVANIA**



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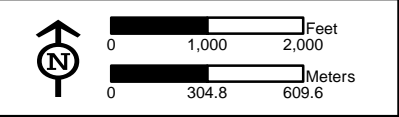
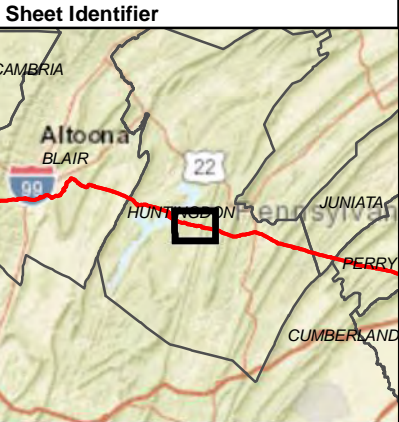


**Legend**

- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Geology**

- Limestone

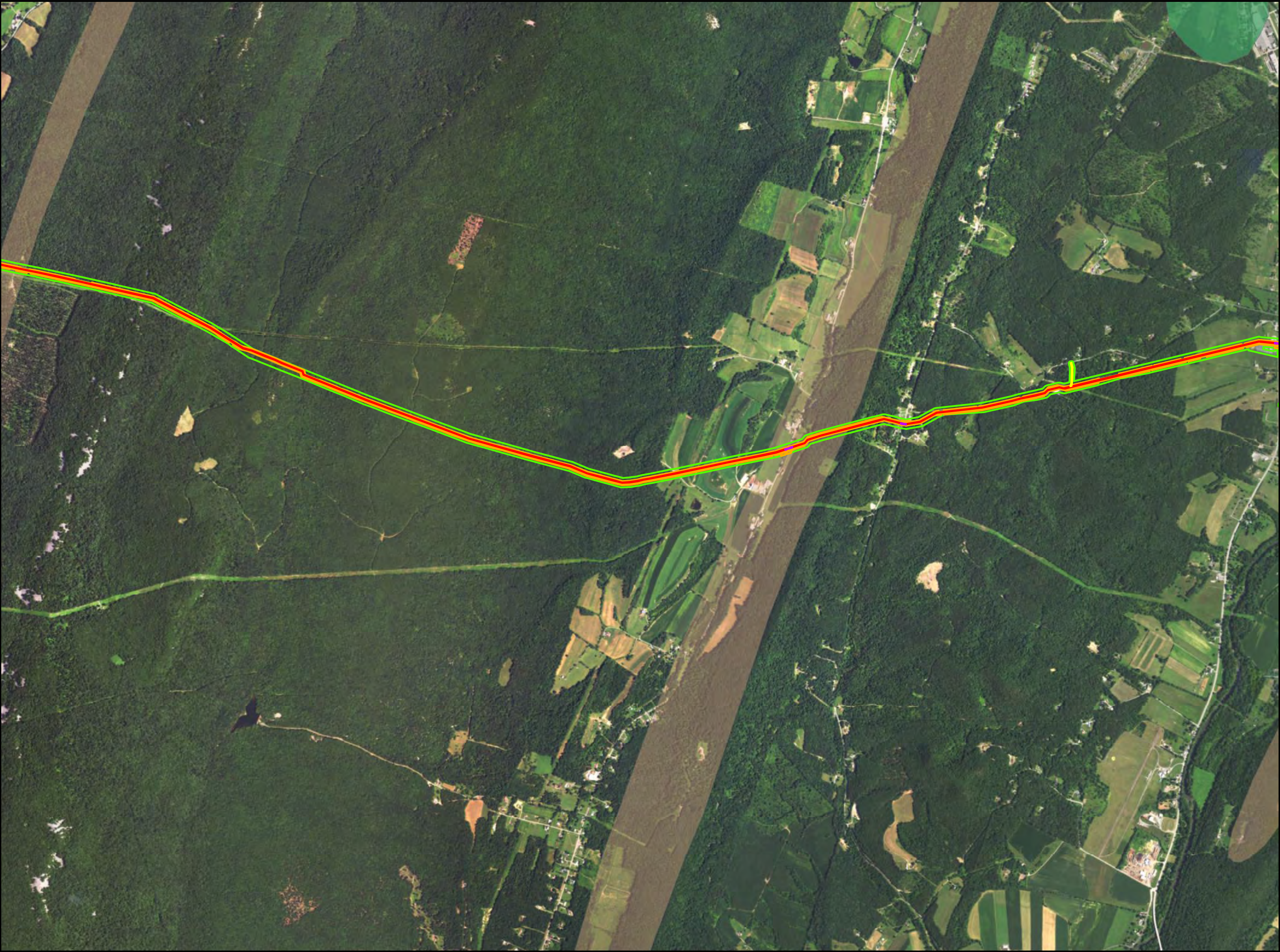


**KARST GEOLOGY MAP  
FIGURE 25  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
HUNTINGDON COUNTY,  
PENNSYLVANIA**



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**Legend**

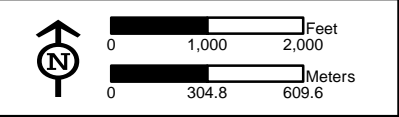
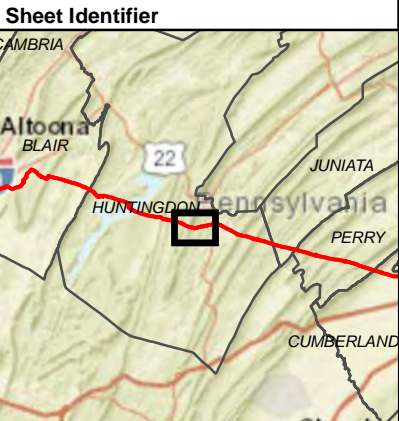
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Abandoned Mine Land Inventory**

- AML Inventory List

**Geology**

- Limestone

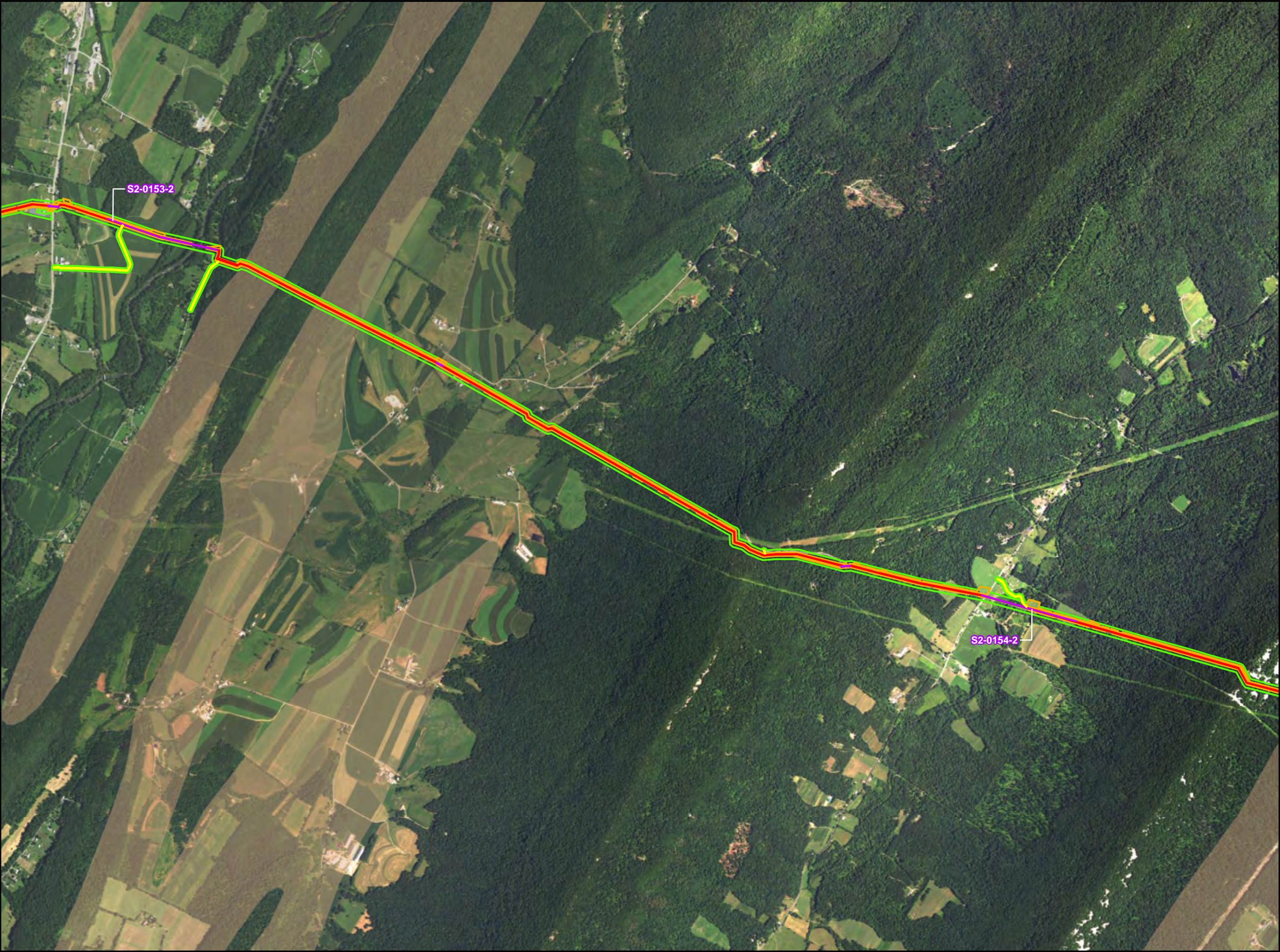


**KARST GEOLOGY MAP  
FIGURE 26  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
HUNTINGDON COUNTY,  
PENNSYLVANIA**



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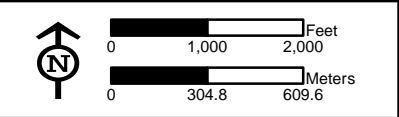
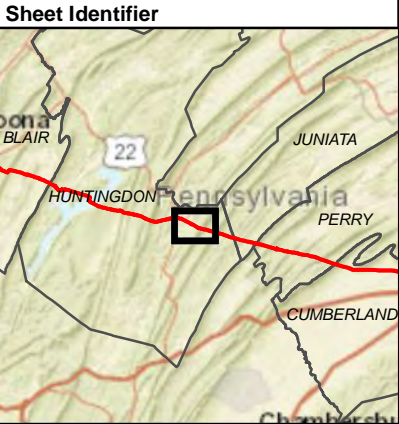


**Legend**

- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Geology**

- Limestone

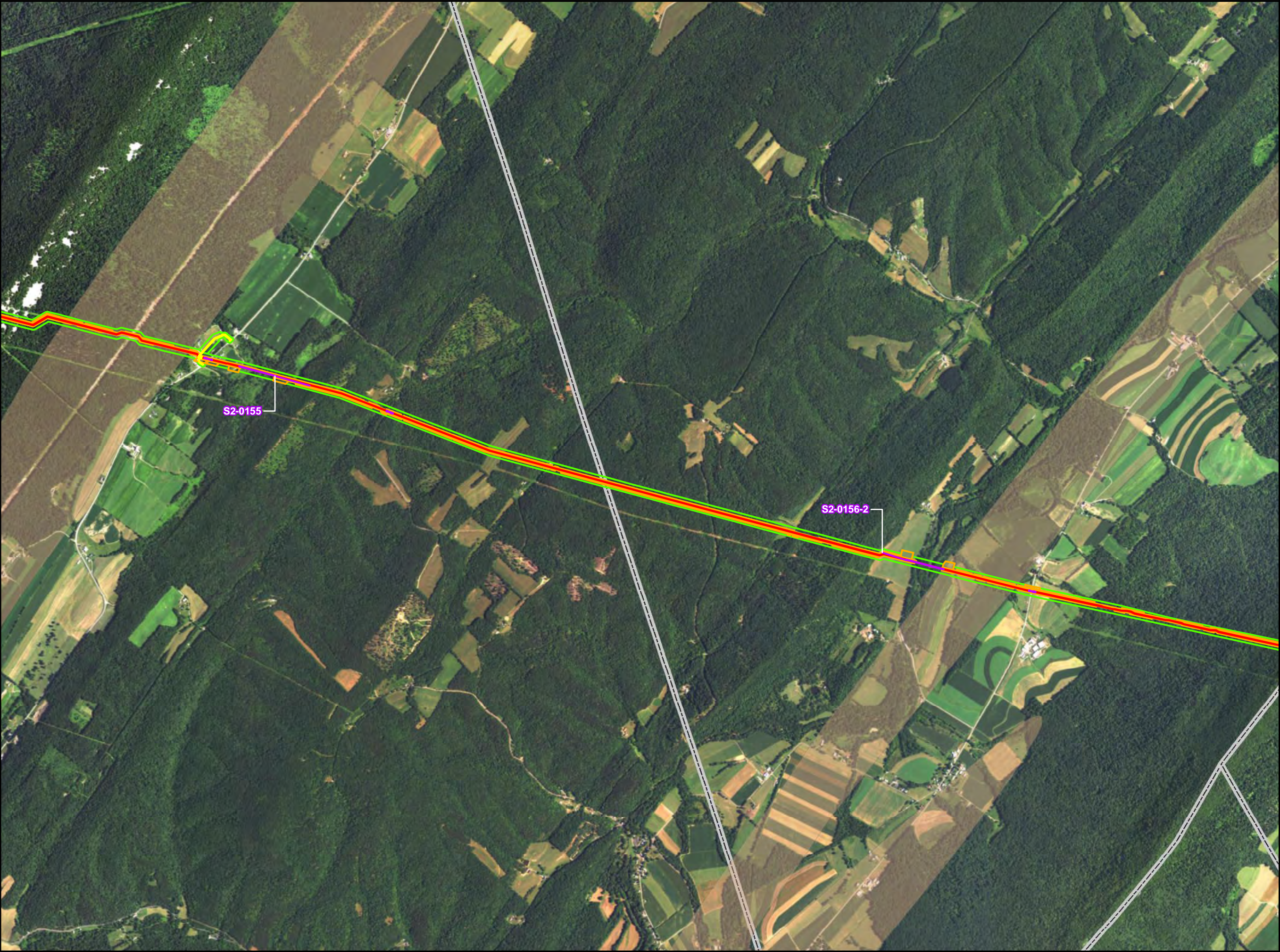


**KARST GEOLOGY MAP  
FIGURE 27  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
HUNTINGDON COUNTY,  
PENNSYLVANIA**



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**Legend**

Alignment Centerline

Access Road

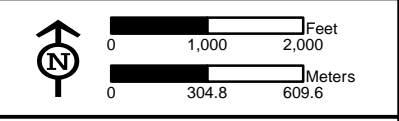
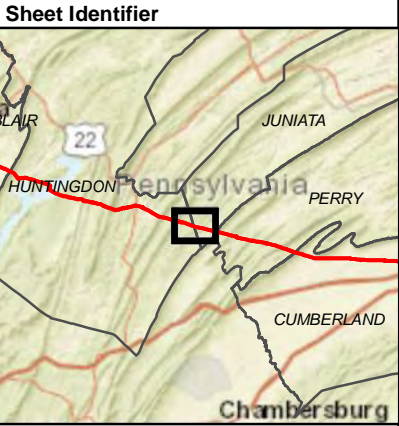
HDD Centerline

Limit of Disturbance

Centerline Buffer (100-ft)

**Geology**

Limestone



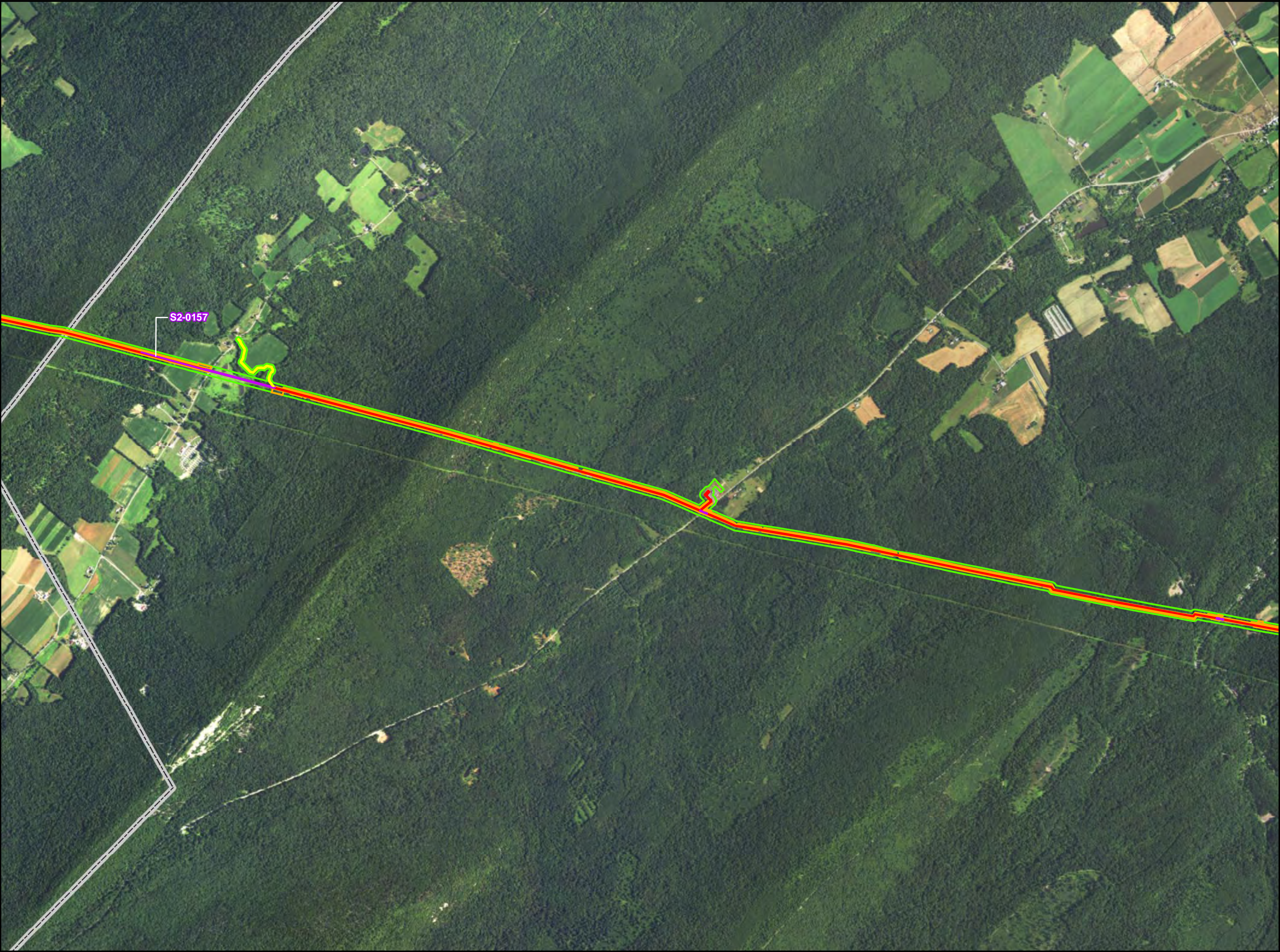
**KARST GEOLOGY MAP**  
**FIGURE 28**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**HUNTINGDON, JUNIATA COUNTY,**  
**PENNSYLVANIA**



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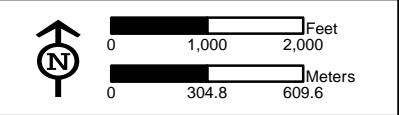
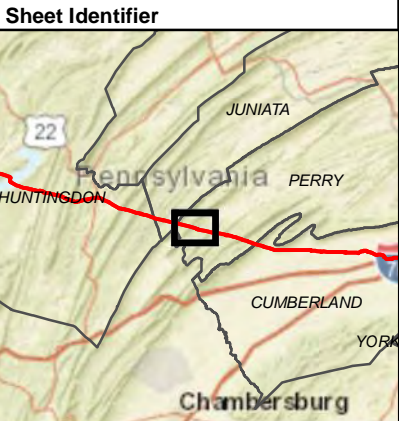


**Legend**

- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Geology**

- Limestone

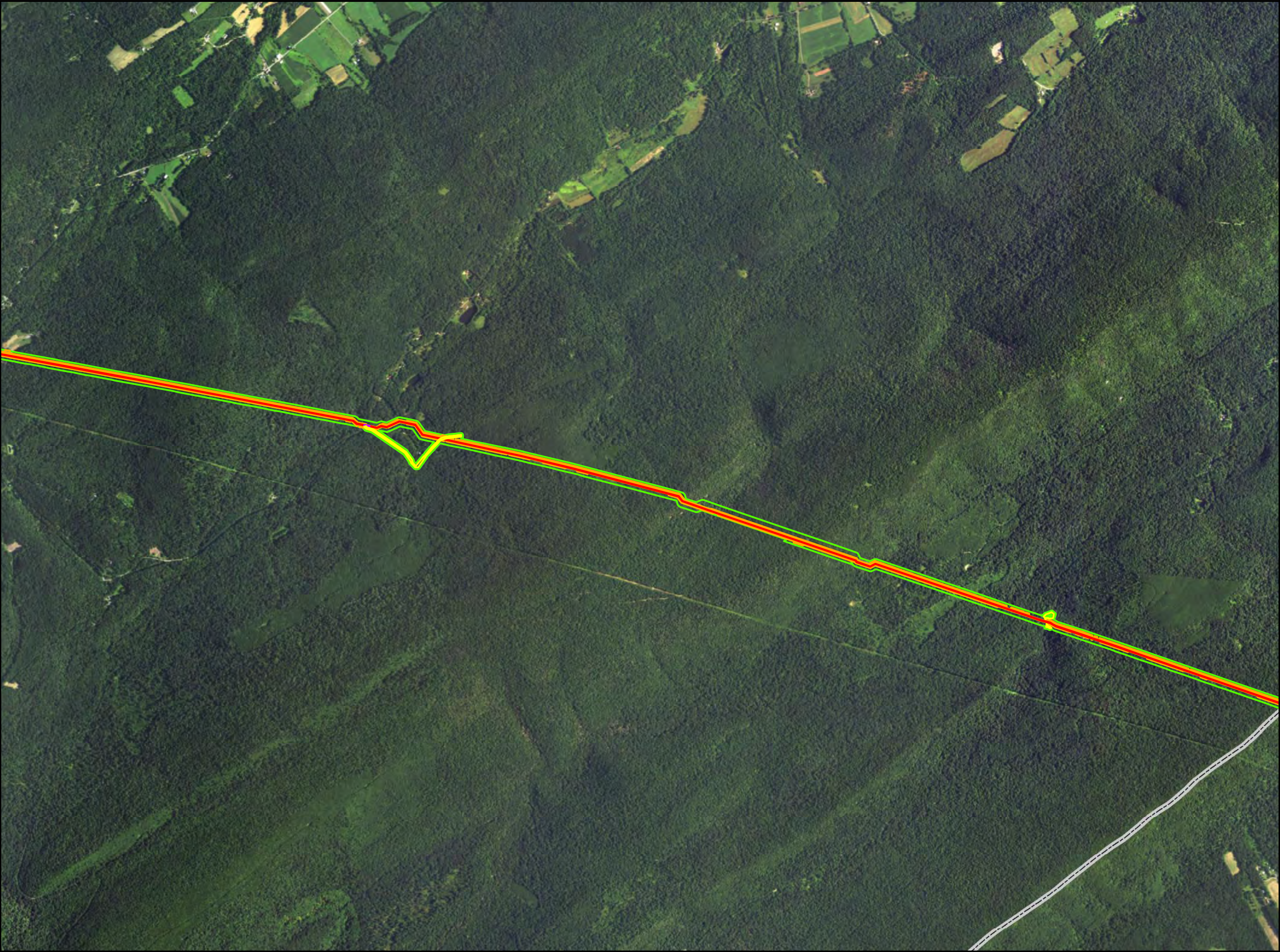


**KARST GEOLOGY MAP  
FIGURE 29  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
JUNIATA, PERRY COUNTY,  
PENNSYLVANIA**



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(© 2015 ESRI and its data suppliers).

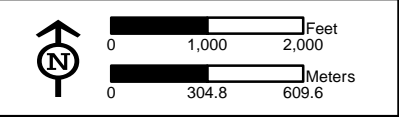
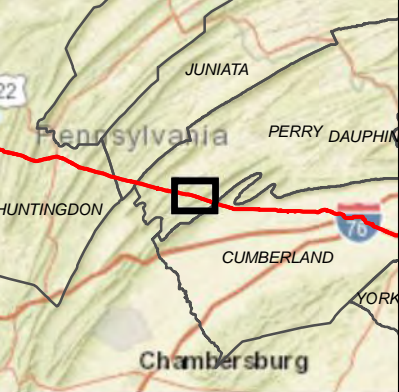




**Legend**

- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Sheet Identifier**



**KARST GEOLOGY MAP  
FIGURE 30  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
PERRY COUNTY,  
PENNSYLVANIA**



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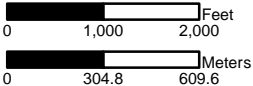
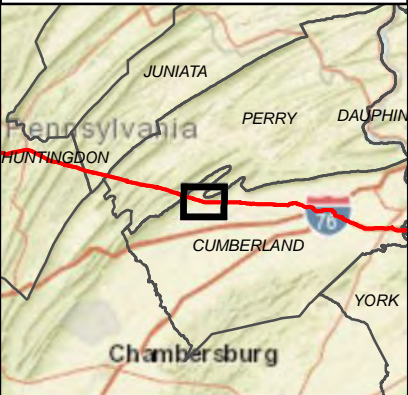




**Legend**

- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Sheet Identifier**

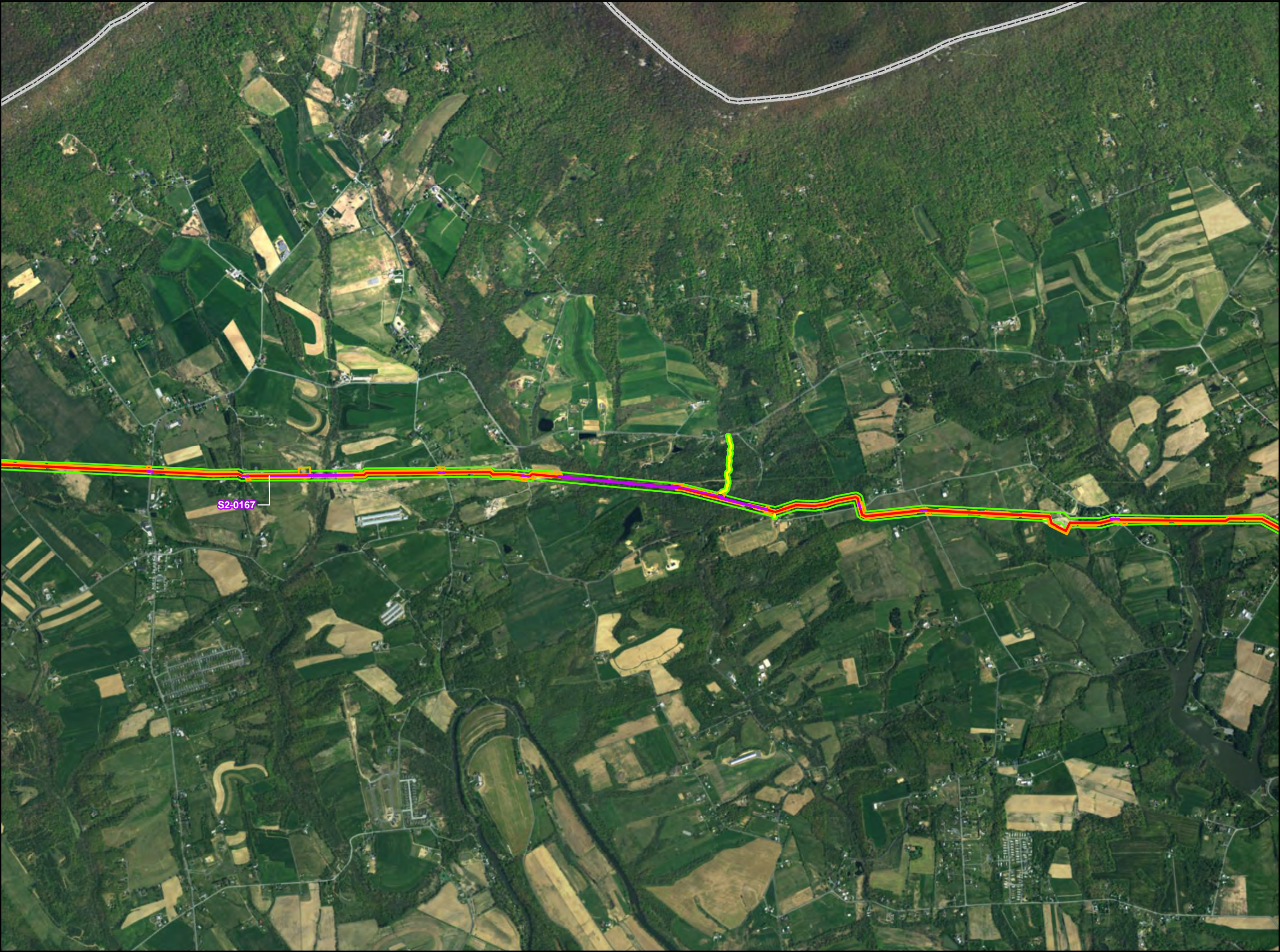


**KARST GEOLOGY MAP  
FIGURE 31  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
CUMBERLAND COUNTY,  
PENNSYLVANIA**

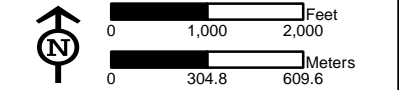
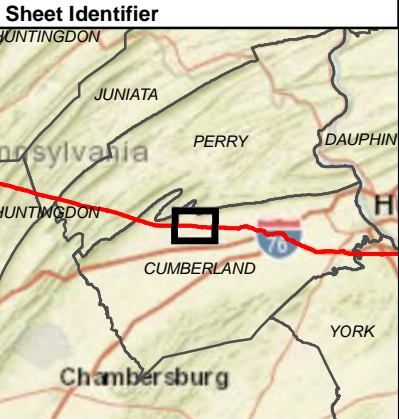


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- Legend**
- Alignment Centerline
  - Access Road
  - HDD Centerline
  - Limit of Disturbance
  - Centerline Buffer (100-ft)

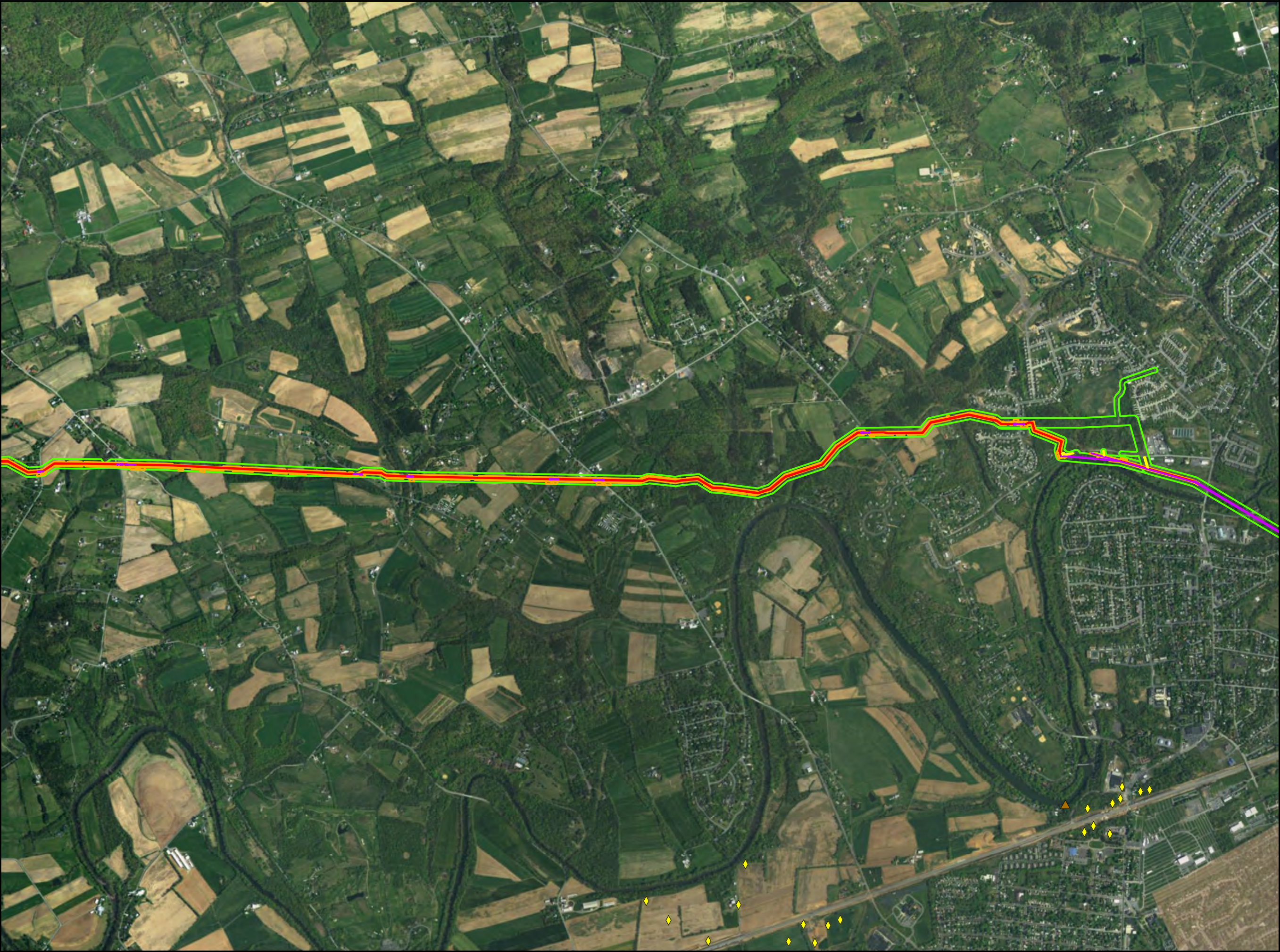


**KARST GEOLOGY MAP  
FIGURE 32  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
CUMBERLAND COUNTY,  
PENNSYLVANIA**




**Notes:**  
Aerial photograph provided by ESRI's  
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**Legend**


**PA DCNR Karst Points**


 Cave


 Surface Depression

 Alignment Centerline


 Access Road

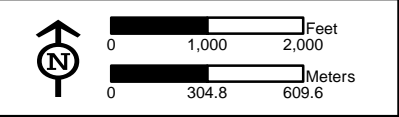
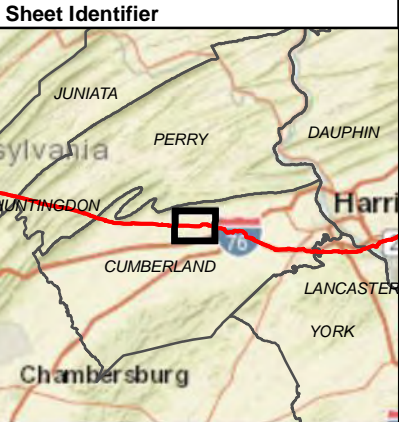
 HDD Centerline

 Limit of Disturbance

 Centerline Buffer (100-ft)

**Geology**

 Limestone

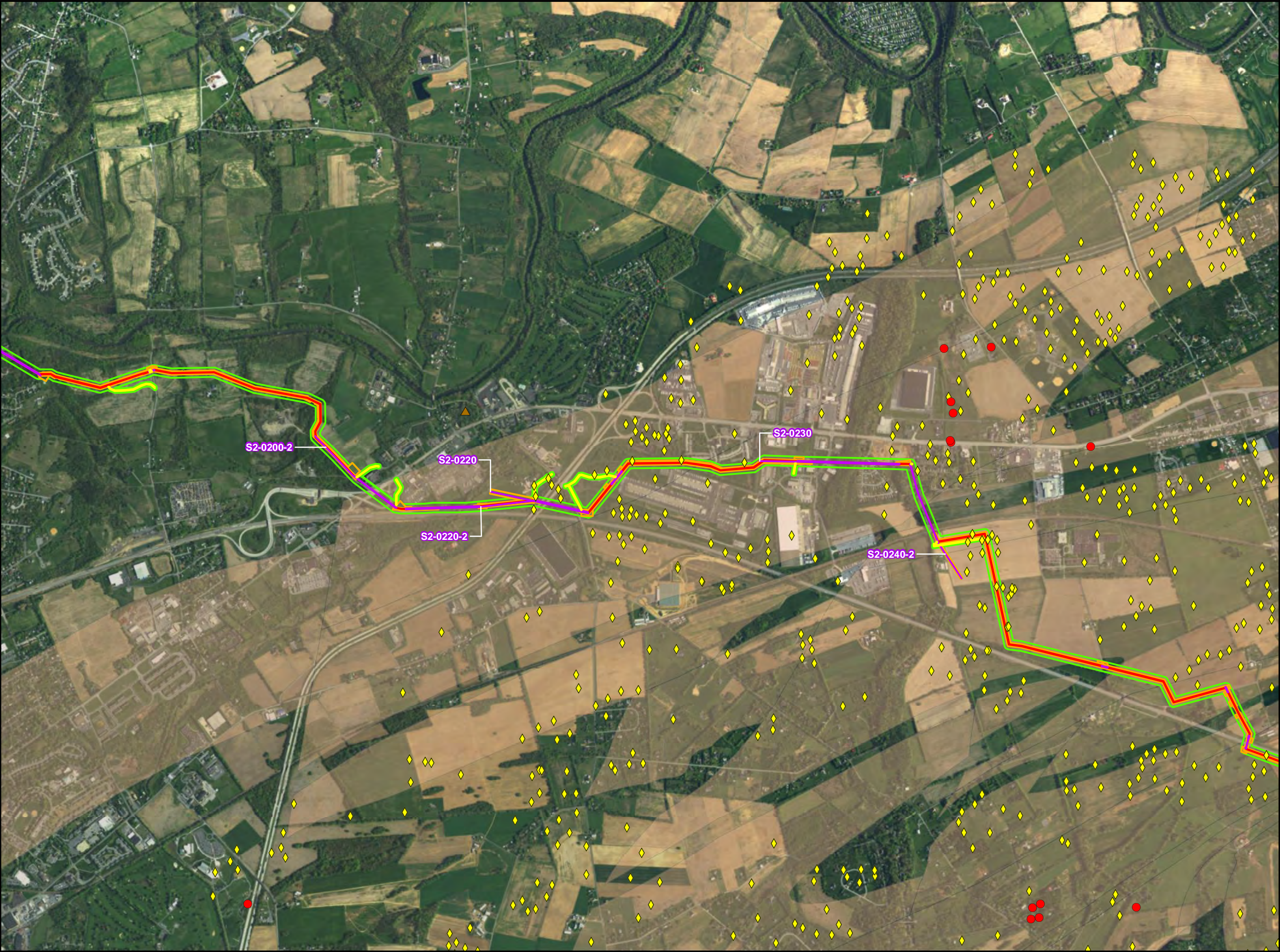


**KARST GEOLOGY MAP**  
**FIGURE 33**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**CUMBERLAND COUNTY,**  
**PENNSYLVANIA**



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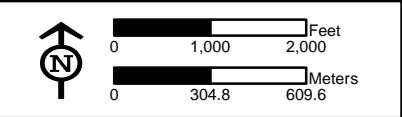
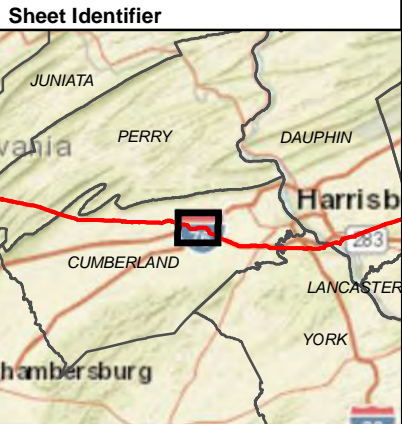
**Legend**

**PA DCNR Karst Points**

- ▲ Cave
- Sinkhole
- ◆ Surface Depression
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Geology**

- Limestone



**KARST GEOLOGY MAP**  
**FIGURE 34**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**CUMBERLAND COUNTY,**  
**PENNSYLVANIA**



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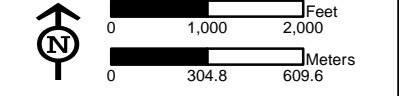
**Legend**

**PA DCNR Karst Points**

- ▲ Cave
- Sinkhole
- ◆ Surface Depression
- Surface Mine
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Geology**

- Limestone



**KARST GEOLOGY MAP**  
**FIGURE 35**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**CUMBERLAND COUNTY,**  
**PENNSYLVANIA**



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**Legend**

**PA DCNR Karst Points**

Sinkhole

Surface Depression

Surface Mine

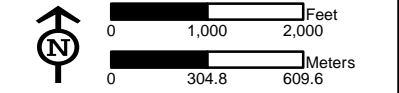
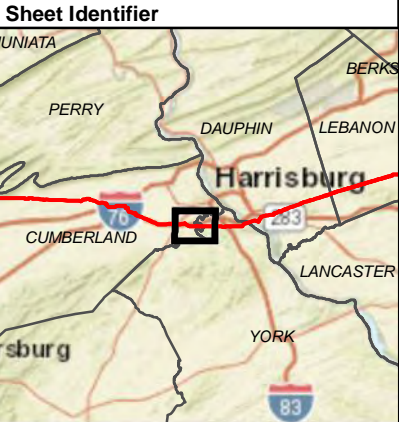
Alignment Centerline

Access Road

HDD Centerline

Limit of Disturbance

Centerline Buffer (100-ft)

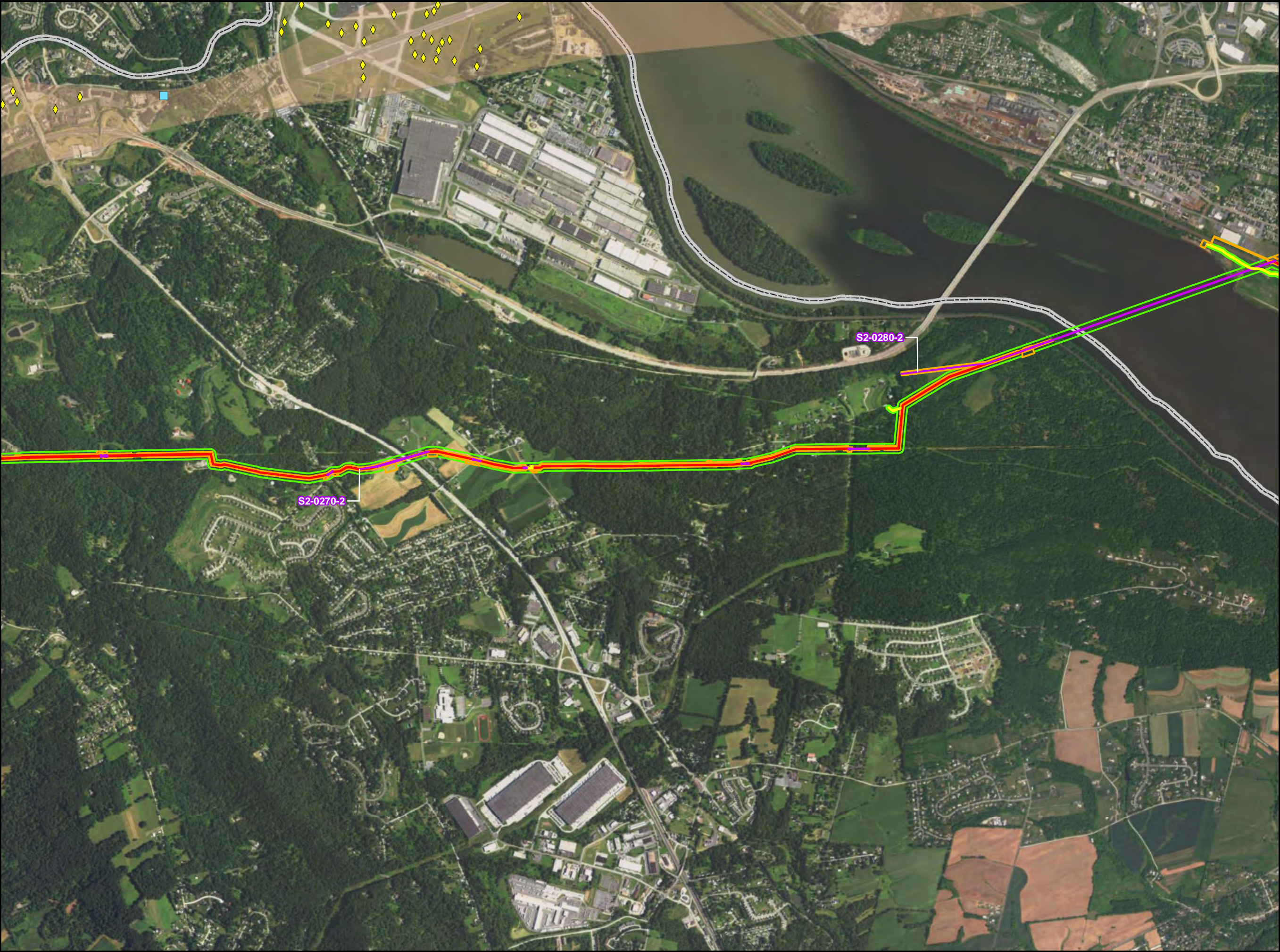
**Geology**Limestone

**KARST GEOLOGY MAP**  
**FIGURE 36**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**CUMBERLAND, YORK COUNTY,**  
**PENNSYLVANIA**



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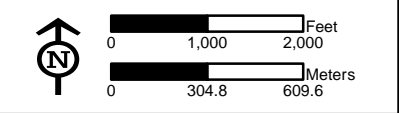
**Legend**

**PA DCNR Karst Points**

- Surface Depression
- Surface Mine
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Geology**

- Limestone

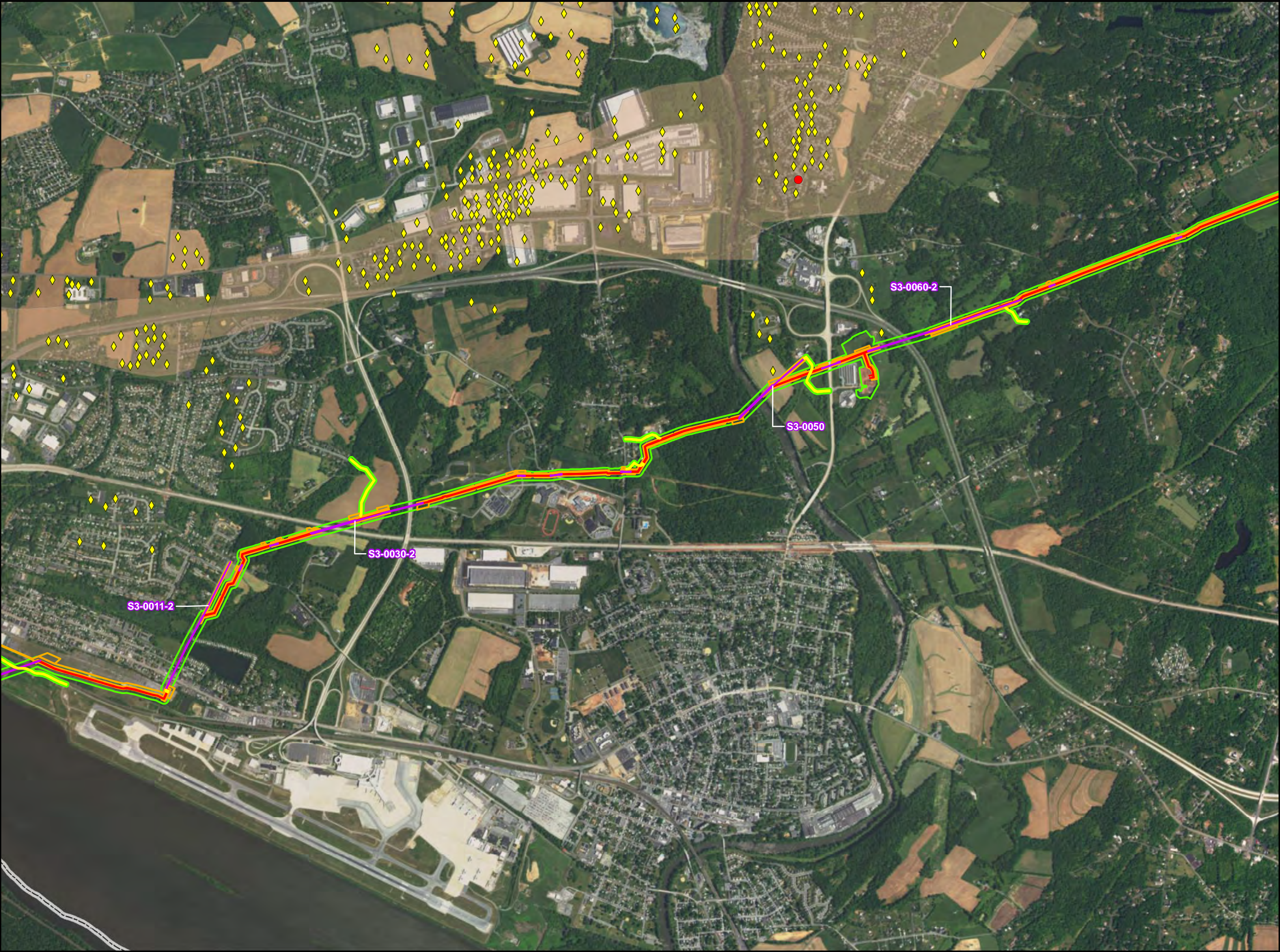


**KARST GEOLOGY MAP**  
**FIGURE 37**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**YORK, DAUPHIN COUNTY,**  
**PENNSYLVANIA**



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**Legend**

**PA DCNR Karst Points**

- Sinkhole
- ◆ Surface Depression
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Geology**

- Limestone

**Sheet Identifier**

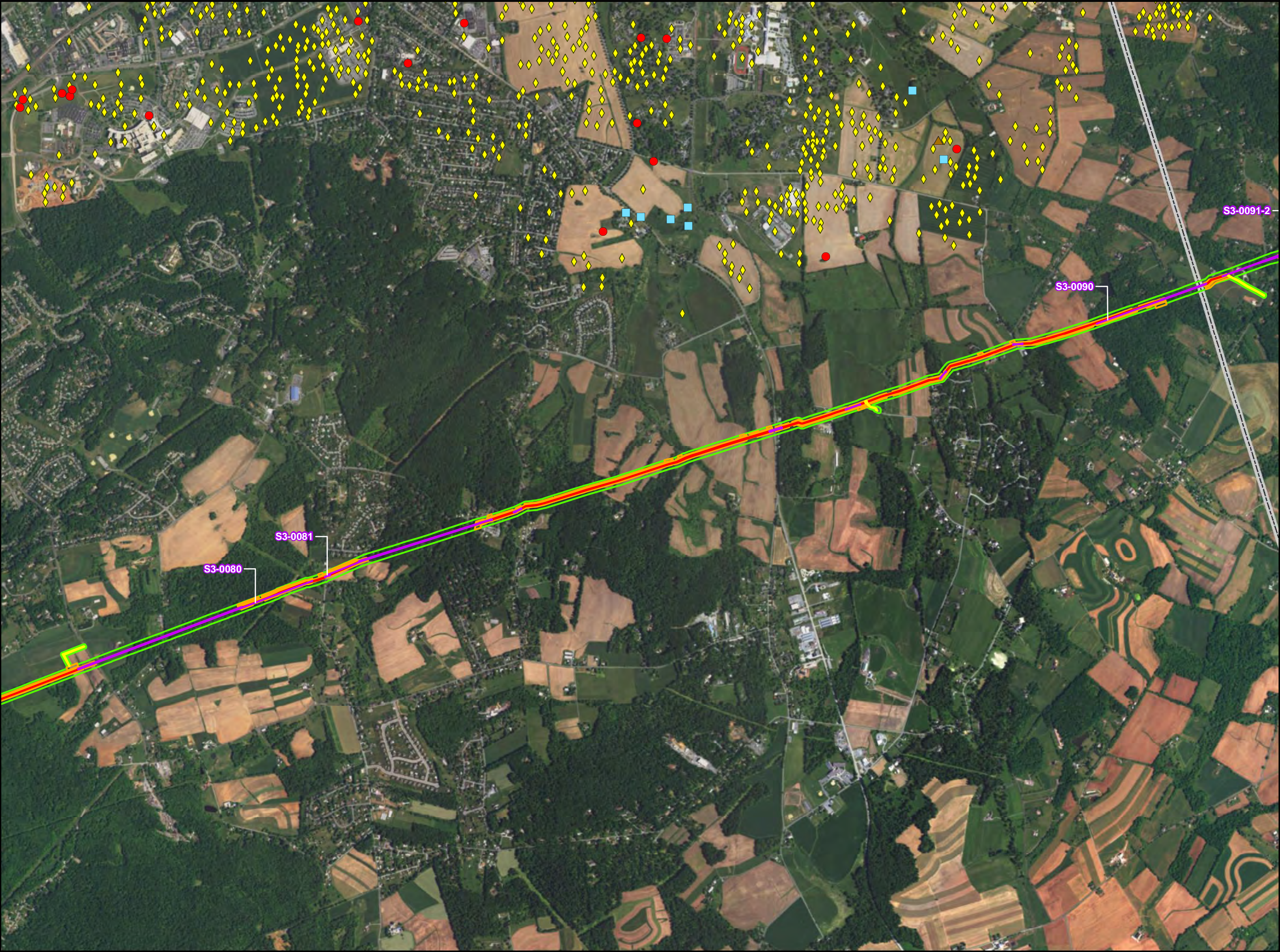
0 1,000 2,000 Feet  
0 304.8 609.6 Meters

**KARST GEOLOGY MAP  
FIGURE 38  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
DAUPHIN COUNTY,  
PENNSYLVANIA**



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**Legend**

**PA DCNR Karst Points**

- Cave
- Sinkhole
- Surface Depression
- Surface Mine
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Sheet Identifier**

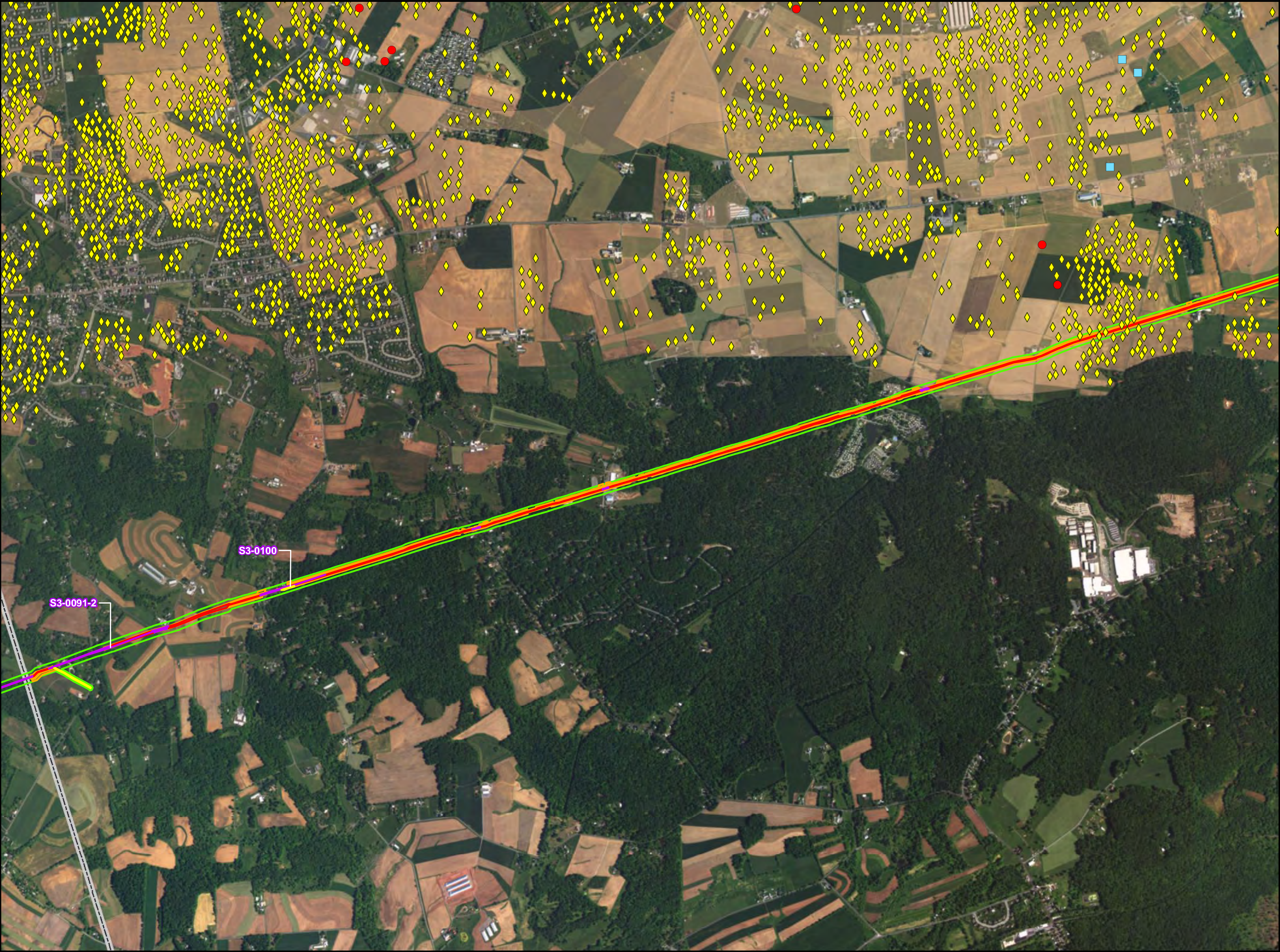
0 1,000 2,000 Feet  
0 304.8 609.6 Meters

**KARST GEOLOGY MAP**  
**FIGURE 39**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**DAUPHIN COUNTY,**  
**PENNSYLVANIA**

**TETRA TECH**

Notes:  
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**Legend**

**PA DCNR Karst Points**

- Sinkhole
- Surface Depression
- Surface Mine

Alignment Centerline

Access Road

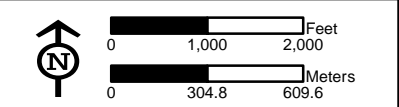
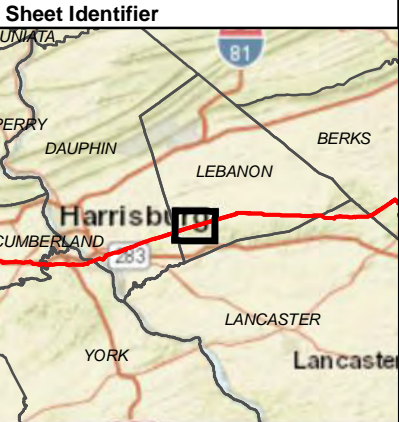
HDD Centerline

Limit of Disturbance

Centerline Buffer (100-ft)

**Geology**

- Limestone



**KARST GEOLOGY MAP**  
**FIGURE 40**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**LEBANON COUNTY,**  
**PENNSYLVANIA**



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**Legend**

**PA DCNR Karst Points**

- Sinkhole
- ◆ Surface Depression
- Surface Mine

— Alignment Centerline

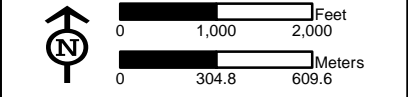
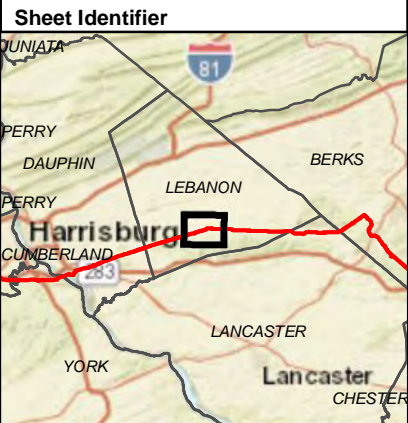
— HDD Centerline

— Limit of Disturbance

— Centerline Buffer (100-ft)

**Geology**

- Limestone



**KARST GEOLOGY MAP**  
**FIGURE 41**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**LEBANON COUNTY,**  
**PENNSYLVANIA**



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**Legend**

**PA DCNR Karst Points**

- Sinkhole
- Surface Depression
- Surface Mine

Alignment Centerline

Access Road

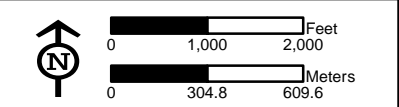
HDD Centerline

Limit of Disturbance

Centerline Buffer (100-ft)

**Geology**

- Limestone

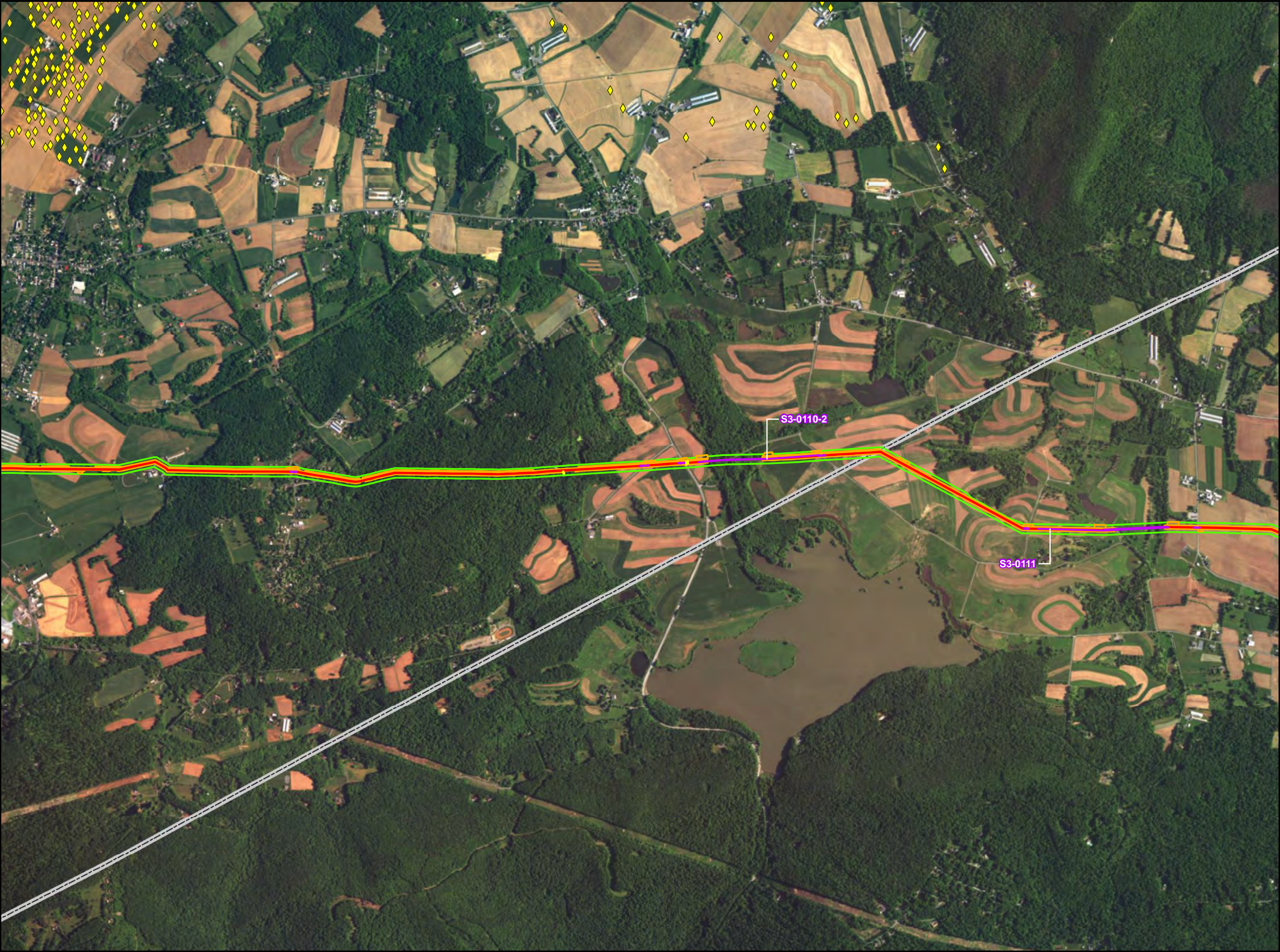


**KARST GEOLOGY MAP**  
**FIGURE 42**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**LEBANON COUNTY,**  
**PENNSYLVANIA**



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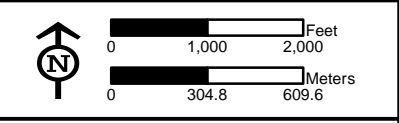
**Legend**

**PA DCNR Karst Points**

- Surface Depression
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Geology**

- Limestone



**KARST GEOLOGY MAP**  
**FIGURE 43**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**LEBANON, LANCASTER COUNTY,**  
**PENNSYLVANIA**

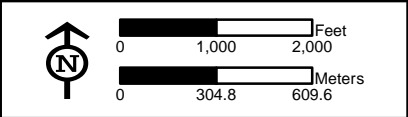
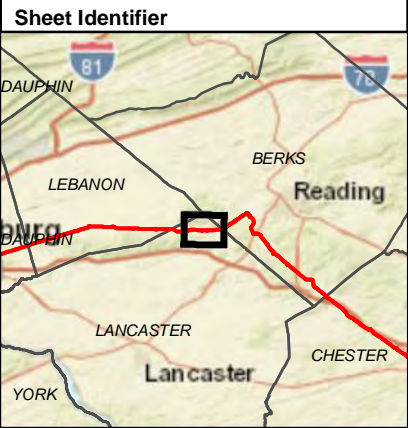


**Notes:**  
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ArcGIS Online World Imagery map service  
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- Legend**
- Alignment Centerline
  - Access Road
  - HDD Centerline
  - Limit of Disturbance
  - Centerline Buffer (100-ft)

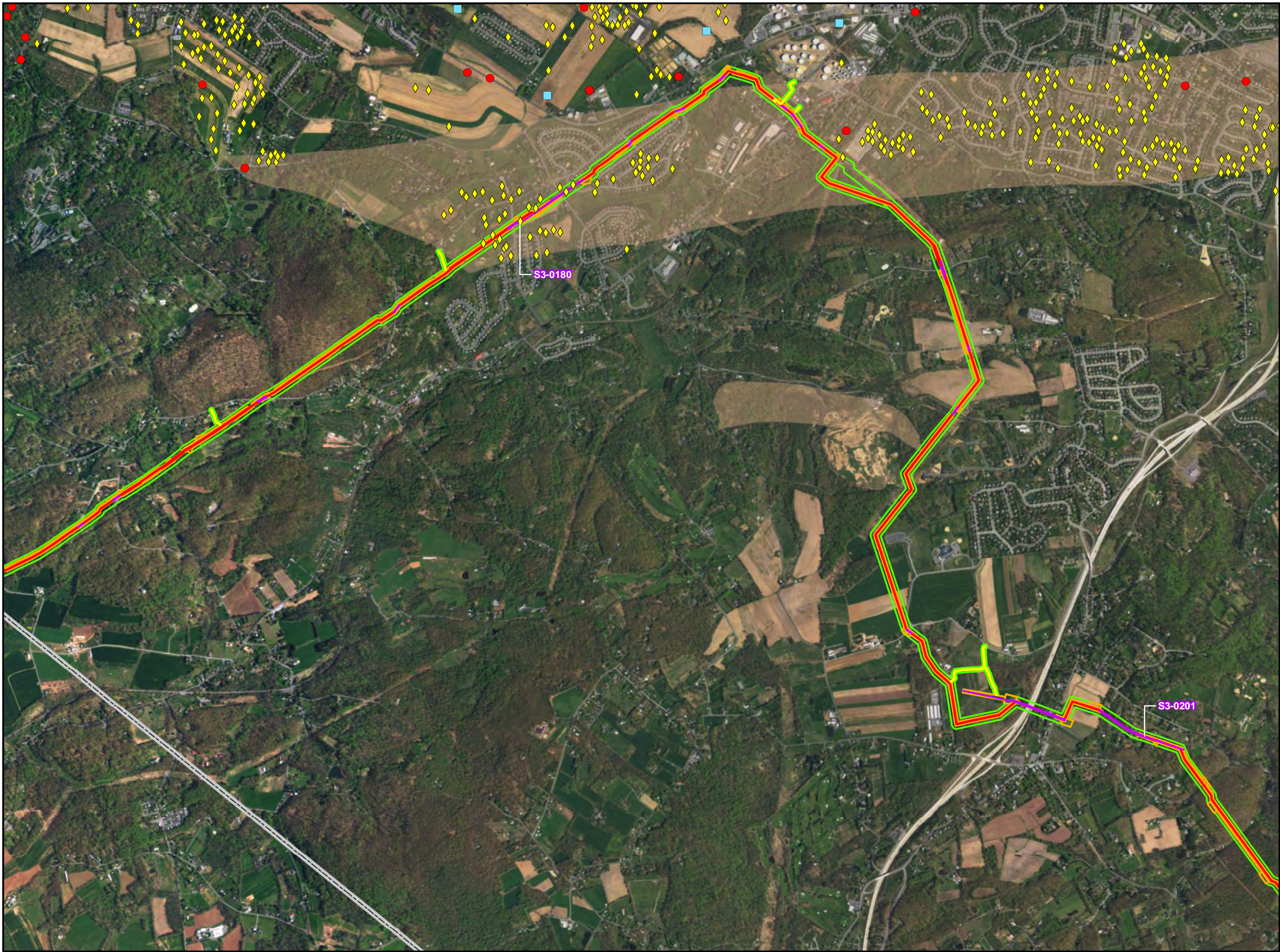


**KARST GEOLOGY MAP  
FIGURE 44  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
LANCASTER COUNTY,  
PENNSYLVANIA**



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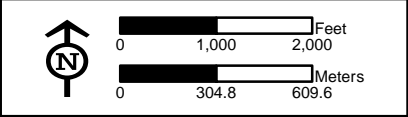
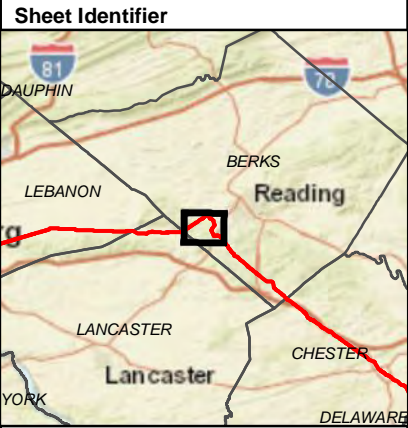
**Legend**

**PA DCNR Karst Points**

- Sinkhole
- ◆ Surface Depression
- Surface Mine
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Geology**

- Limestone

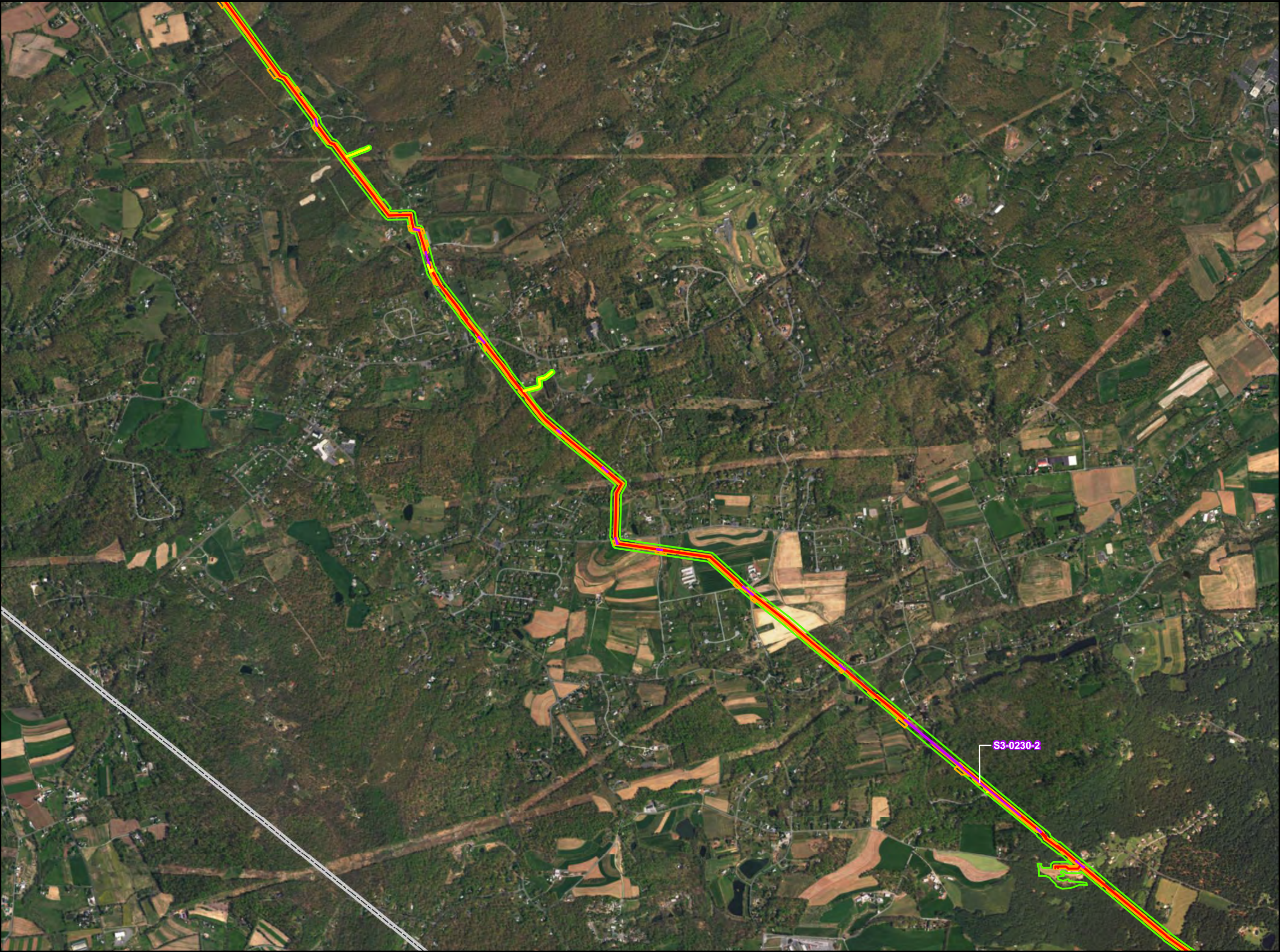


**KARST GEOLOGY MAP  
FIGURE 45  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
BERKS COUNTY,  
PENNSYLVANIA**

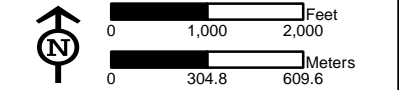


**Notes:**  
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ArcGIS Online World Imagery map service  
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- Legend**
- Alignment Centerline
  - Access Road
  - HDD Centerline
  - Limit of Disturbance
  - Centerline Buffer (100-ft)

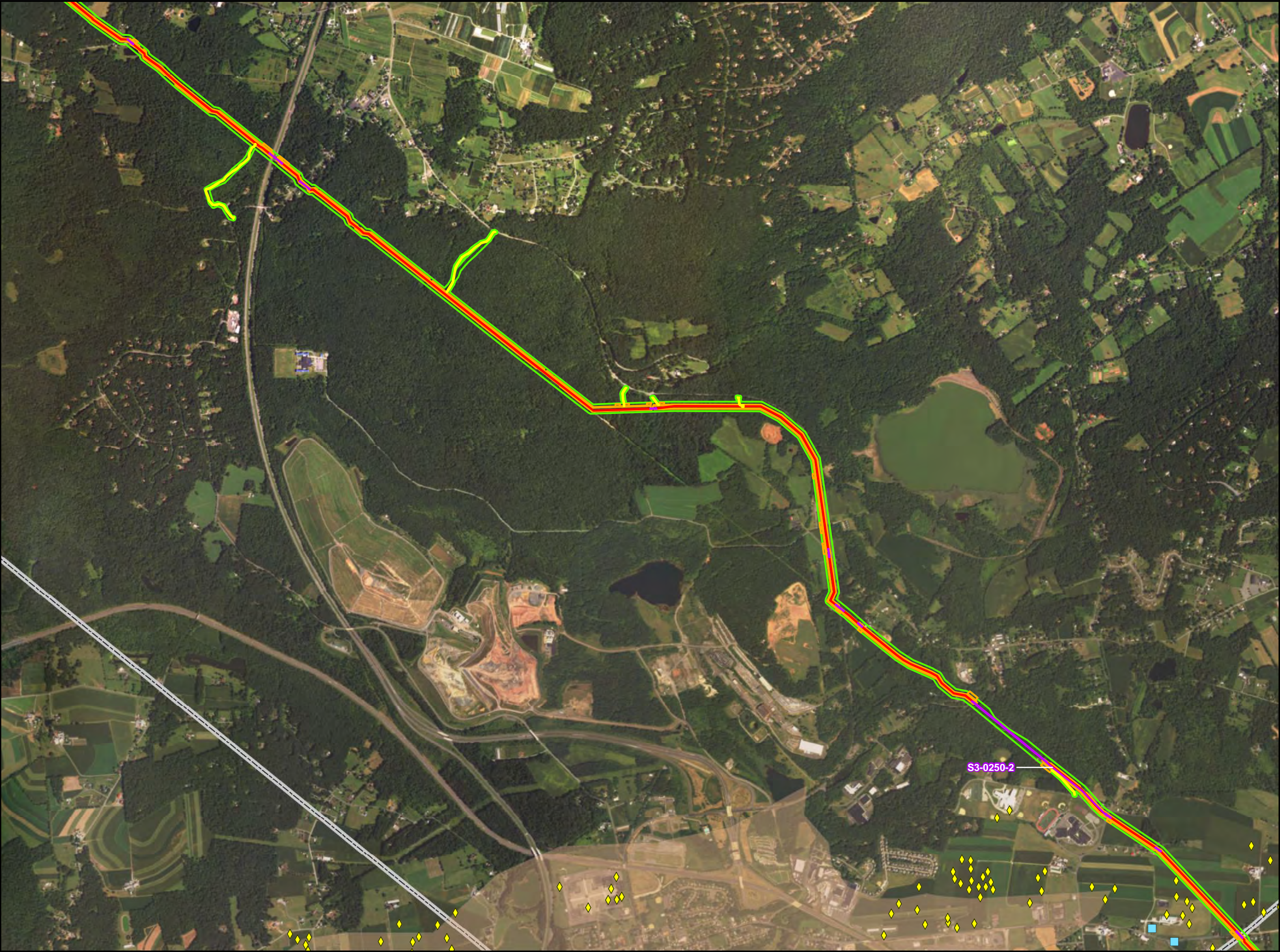


**KARST GEOLOGY MAP  
FIGURE 46  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
BERKS COUNTY,  
PENNSYLVANIA**



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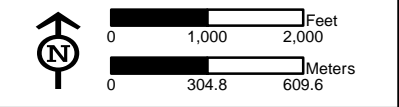
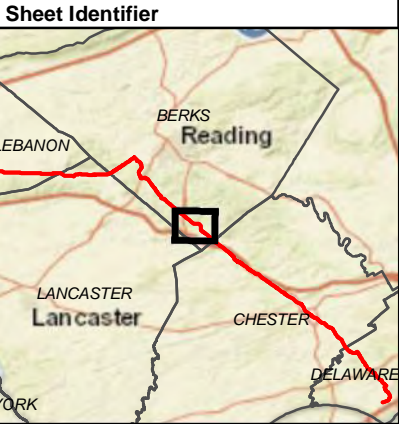
**Legend**

**PA DCNR Karst Points**

- Surface Depression
- Surface Mine
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Geology**

- Limestone



**KARST GEOLOGY MAP**  
**FIGURE 47**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**BERKS COUNTY,**  
**PENNSYLVANIA**

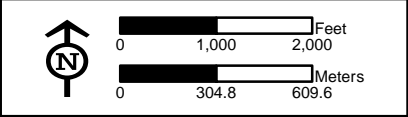
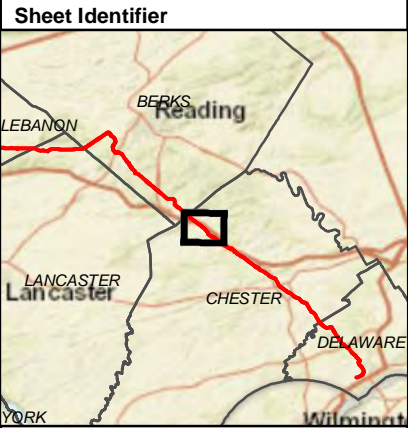


Notes:  
Aerial photograph provided by ESRI's  
ArcGIS Online World Imagery map service  
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- Legend**
- PA DCNR Karst Points**
- Surface Depression
  - Surface Mine
  - Alignment Centerline
  - Access Road
  - HDD Centerline
  - Limit of Disturbance
  - Centerline Buffer (100-ft)

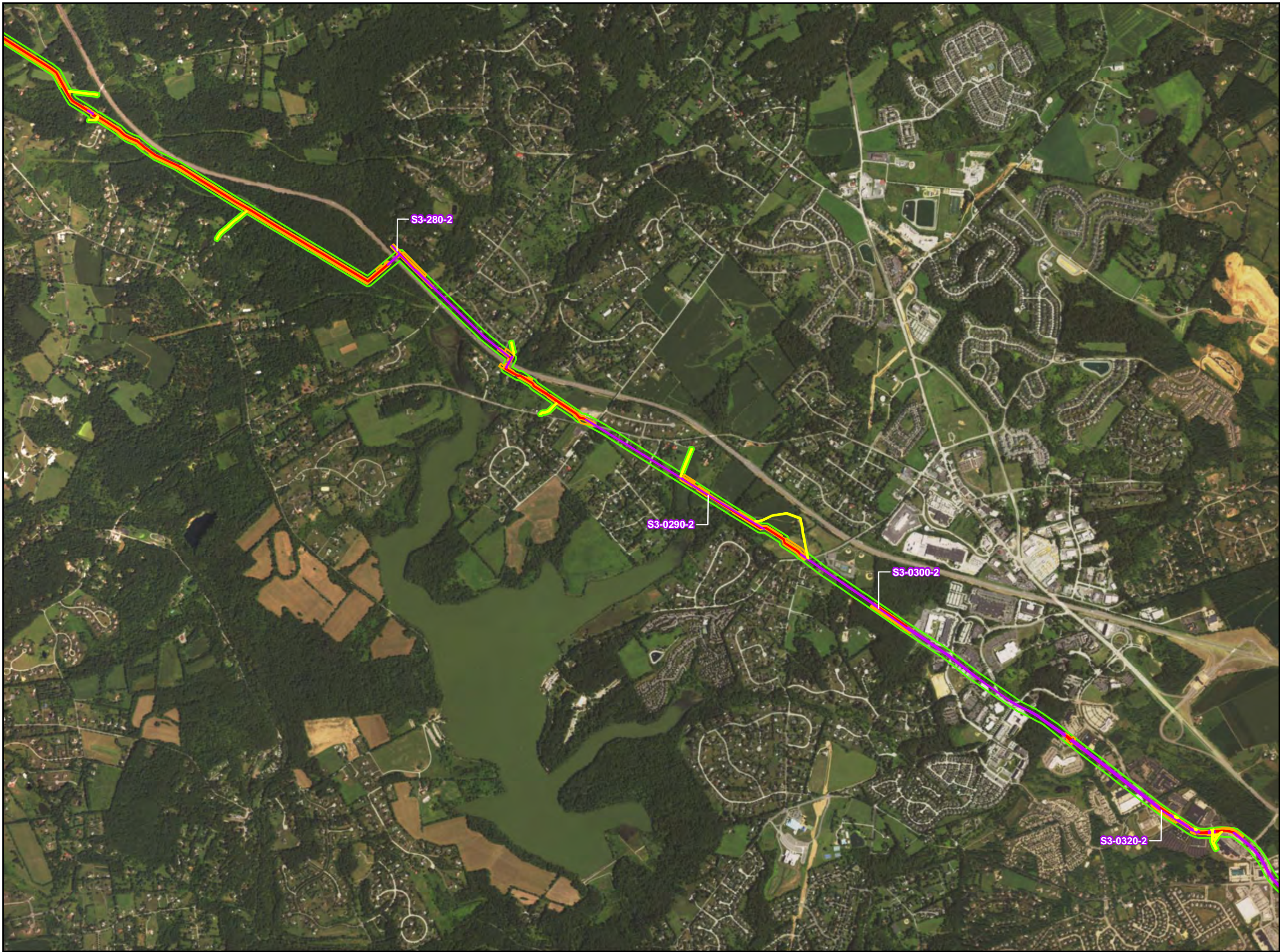


**KARST GEOLOGY MAP**  
**FIGURE 48**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**CHESTER COUNTY,**  
**PENNSYLVANIA**

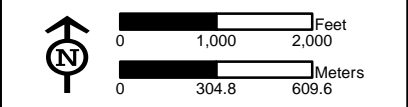
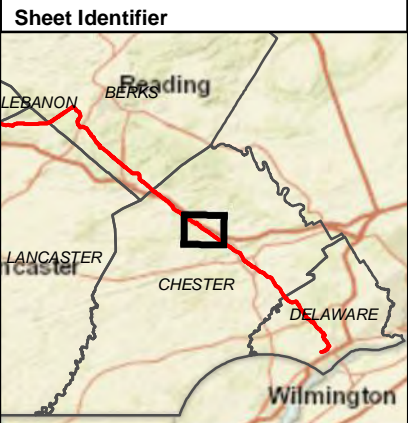


Notes:  
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- Legend**
- Alignment Centerline
  - Access Road
  - HDD Centerline
  - Limit of Disturbance
  - Centerline Buffer (100-ft)

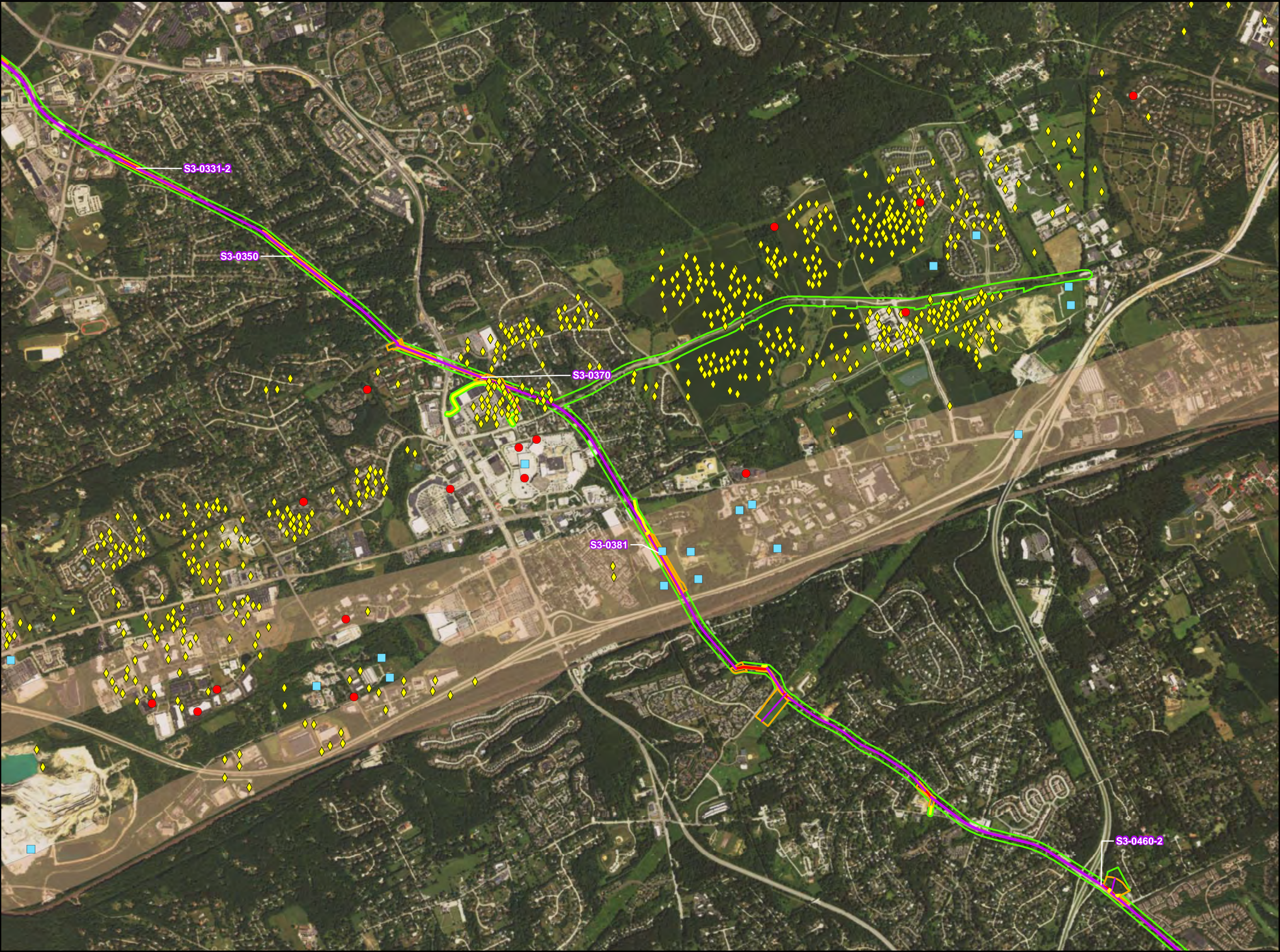


**KARST GEOLOGY MAP  
FIGURE 49  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
CHESTER COUNTY,  
PENNSYLVANIA**



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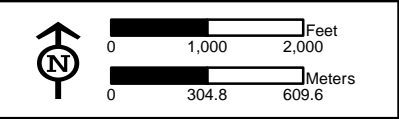
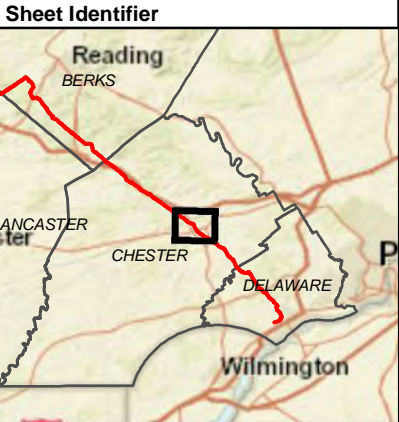
**Legend**

**PA DCNR Karst Points**

- Sinkhole
- ◆ Surface Depression
- Surface Mine
- Alignment Centerline
- Access Road
- HDD Centerline
- Limit of Disturbance
- Centerline Buffer (100-ft)

**Geology**

- Limestone

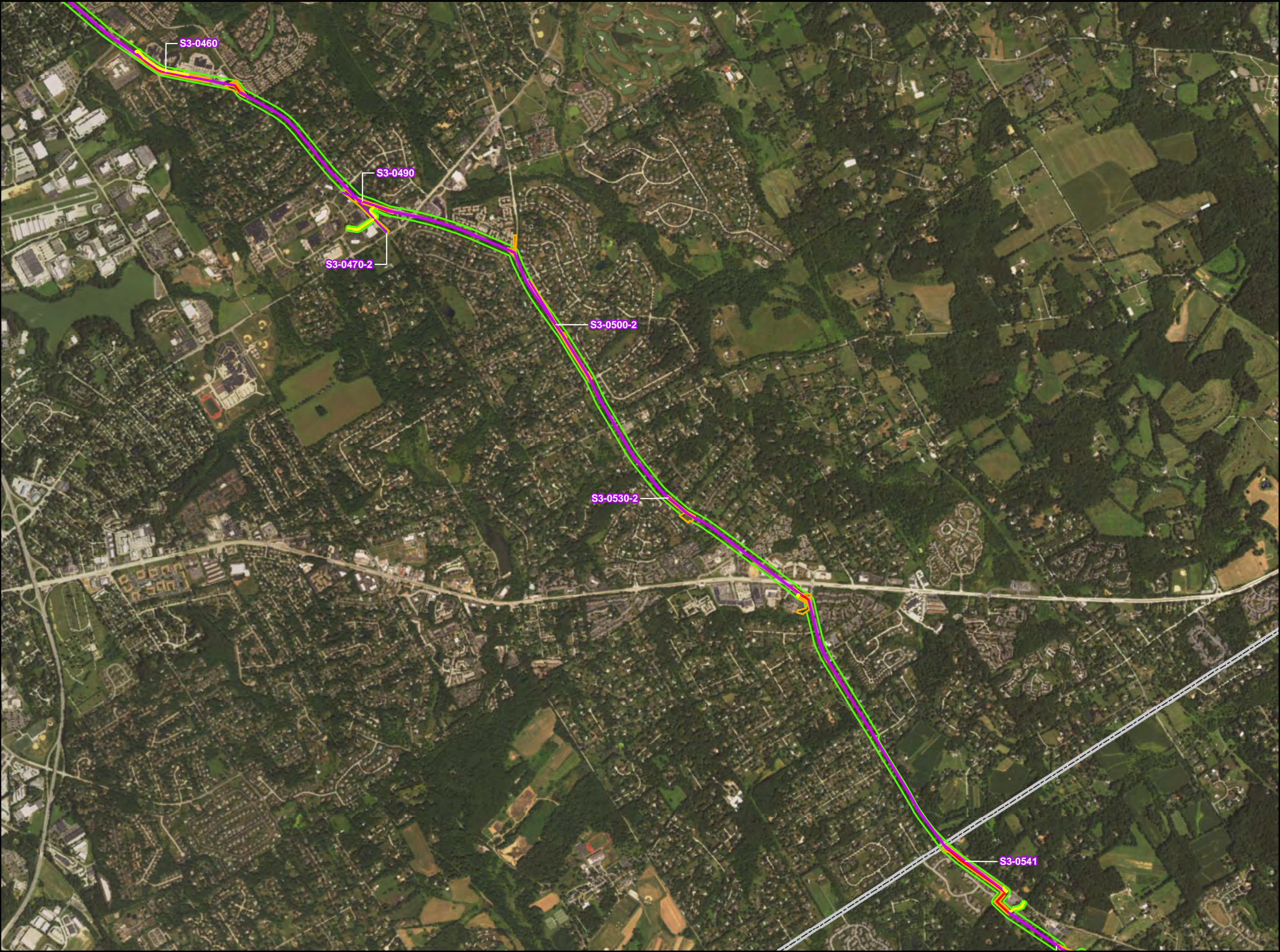


**KARST GEOLOGY MAP  
FIGURE 50  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
CHESTER COUNTY,  
PENNSYLVANIA**



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- Legend**
- Alignment Centerline
  - Access Road
  - HDD Centerline
  - Limit of Disturbance
  - Centerline Buffer (100-ft)

**Sheet Identifier**

**Scale**

0 1,000 2,000 Feet

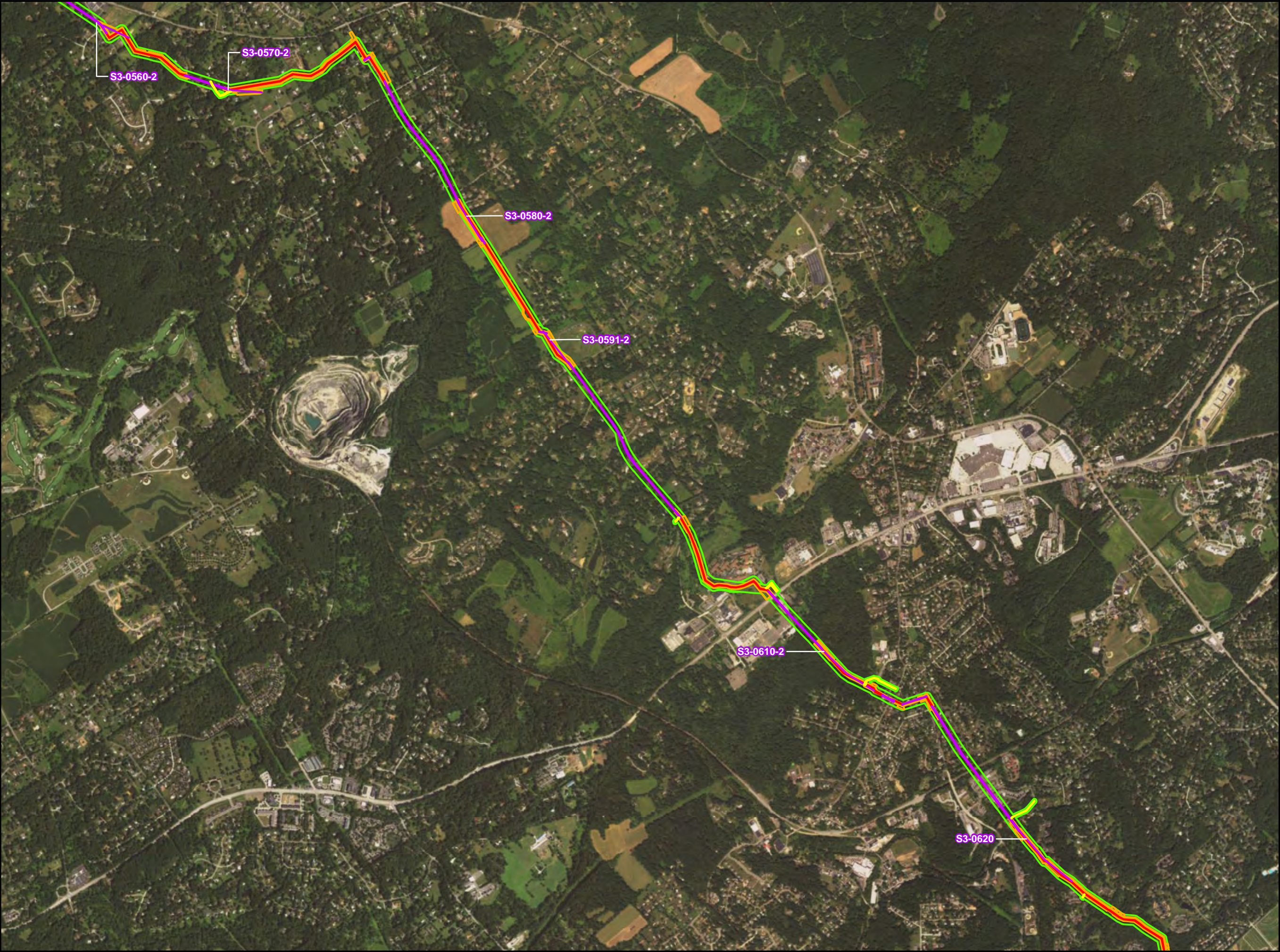
0 304.8 609.6 Meters

**KARST GEOLOGY MAP**  
**FIGURE 51**  
**PENNSYLVANIA PIPELINE PROJECT**  
**NOVEMBER 12, 2016 ALIGNMENT**  
**SUNOCO LOGISTICS, L.P.**  
**CHESTER, DELAWARE COUNTY,**  
**PENNSYLVANIA**

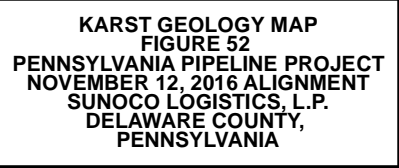
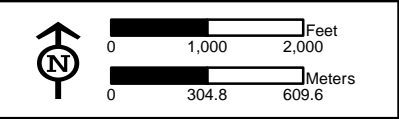
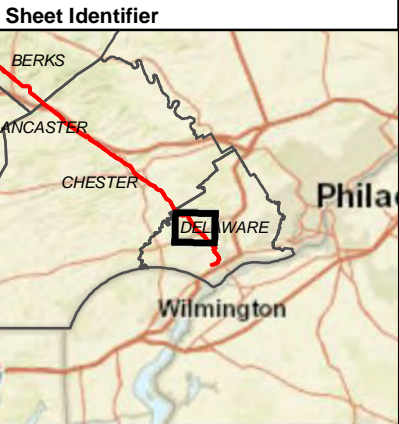


**Notes:**  
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ArcGIS Online World Imagery map service  
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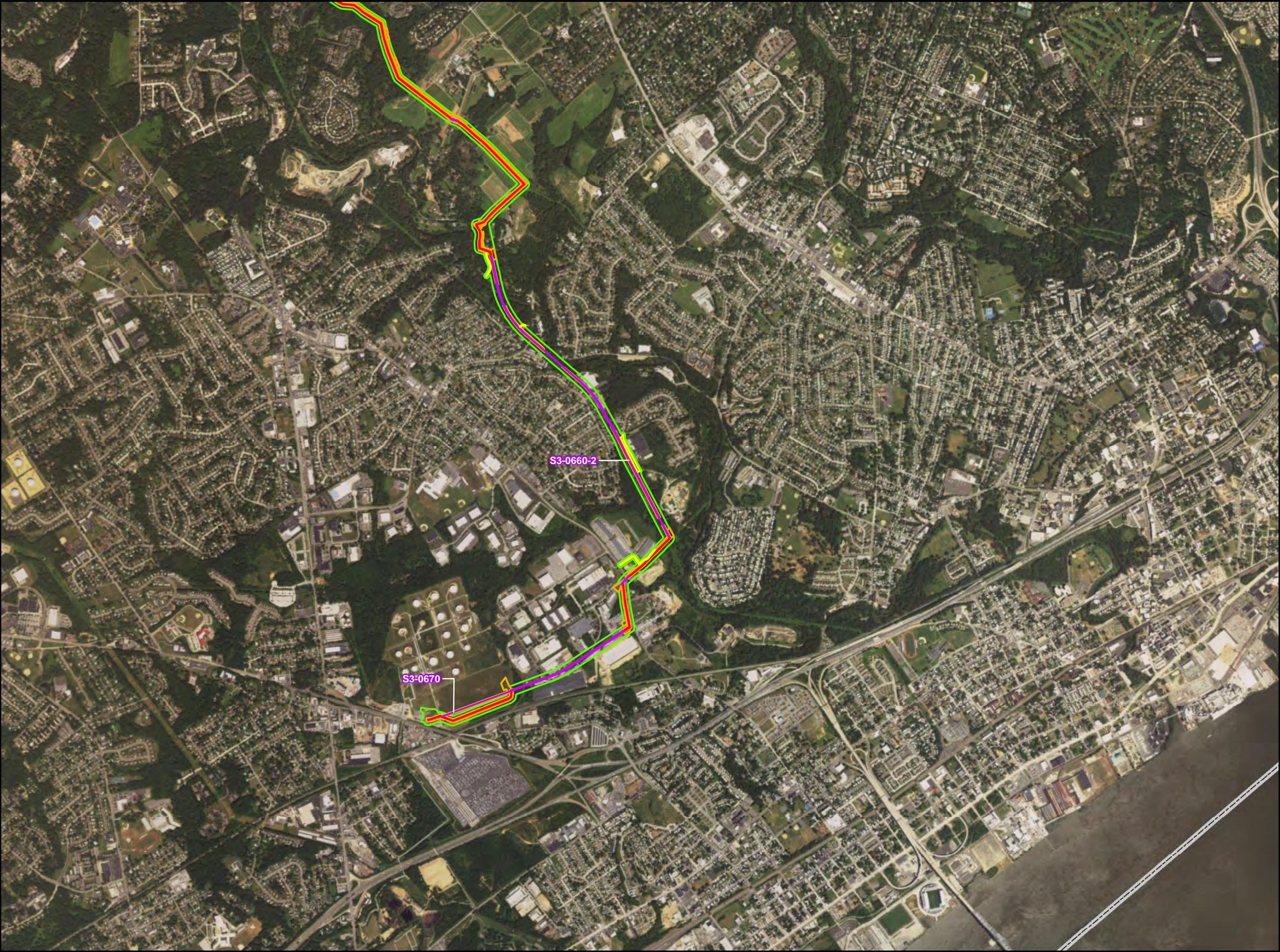


- Legend**
- Alignment Centerline
  - Access Road
  - HDD Centerline
  - Limit of Disturbance
  - Centerline Buffer (100-ft)



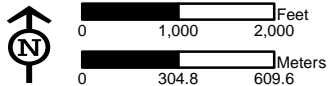
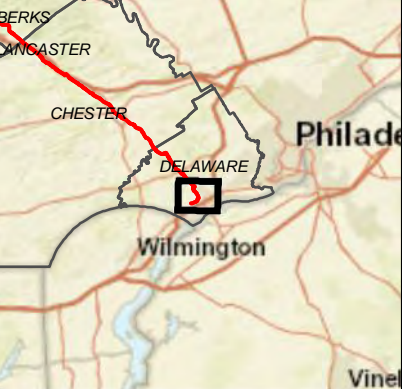
Notes:  
Aerial photograph provided by ESRI's  
ArcGIS Online World Imagery map service  
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- Legend**
- Alignment Centerline
  - Access Road
  - HDD Centerline
  - Limit of Disturbance
  - Centerline Buffer (100-ft)

**Sheet Identifier**



**KARST GEOLOGY MAP  
FIGURE 53  
PENNSYLVANIA PIPELINE PROJECT  
NOVEMBER 12, 2016 ALIGNMENT  
SUNOCO LOGISTICS, L.P.  
DELAWARE COUNTY,  
PENNSYLVANIA**



**Notes:**  
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## **APPENDIX B.2**

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### **Geotechnical Boring Summary Data Tables for HDD Alignments**



| SUNOCO PPP<br>SPREAD 2                | ROCK CORE SAMPLES - COMPRESSIVE STRENGTH LAB TESTING |                   |                   |                         |                      | GEOTECH FIELD OBSERVATIONS |                    |                      |   |                       | REGIONAL GEOLOGY SUMMARY   |                                    |                                   |   |
|---------------------------------------|--|-------------------|-------------------|-------------------------|----------------------|----------------------------|--------------------|----------------------|---|-----------------------|--|------------------------------------|-----------------------------------|---|
| HDD Drawing NO.                       | Geotech<br><br>NO.                                   | BORING<br><br>NO. |                   | Compressive<br>Strength |                      | Bedrock                    |                    |                      | Overburden Summary  | Groundwater (ft. bgs) | REGIONAL GEOLOGY DESCRIPTION   | GENERAL TOPOGRAPHIC<br>SETTING     | APPROX. MAX.<br>THICKNESS<br>(FT) | DEPTH TO ROCK (FT BGS)<br>BASED ON NEARBY WELL<br>DRILLING LOGS |
|                                       |  |                   | DEPTH<br><br>(FT) |                         | Density<br><br>(pcf) | Encountered                | Depth (ft.<br>bgs) | Type                 |   |                       |  |                                    |                                   |   |
| <a href="#">PA-CA-0016.0000-RD</a>    | <a href="#">S2-0069</a>                              | SB-01             |                   |                         |                      | Yes                        | 28                 | Sandstone            | Silty Clay, Sands and Gravels                               | NA                    | <b>Glenshaw Formation</b> - Cyclic sequences of shale, sandstone, red beds, and thin limestone and coal; includes four marine limestone or shale horizons; red beds are involved in landslides; base is at top of Upper Freeport coal.     | Rolling hills, moderate relief     | 280-375                           | 15 to 27  |
| <a href="#">PA-CA-0016.0000-RD-16</a> |  | SB-02             |                   |                         |                      | Yes                        | 30                 | Shale                | Silty Sands, Sands and Gravels                              | 25                    |  |                                    |                                   |   |
| <a href="#">PA-CA-0023.0000-RD</a>    | S2-0070  | SB-01             |                   |                         |                      | Yes                        | 20                 | Sandstone            | Silty Sands, Sands and Gravels                              | 5                     | <b>Glenshaw Formation</b> - Cyclic sequences of shale, sandstone, red beds, and thin limestone and coal; includes four marine limestone or shale horizons; red beds are involved in landslides; base is at top of Upper Freeport coal.     | Plateau                            | 280-375                           | 12 to 27  |
|                                       |  | SB-02             |                   |                         |                      | Yes                        | 5.8                | Sandstone            | Silty Sand  | NA                    |  |                                    |                                   |   |
| <a href="#">PA-CA-0023.0000-RD-16</a> |  | SB-03             | 22.6              | 5,980                   | 158.3                | Yes                        | 19.6               | Sandstone            | Silty Sands, Sands and Gravels                              | 12                    |  |                                    |                                   |   |
| <a href="#">PA-CA-0047.0000-SR</a>    | <a href="#">S2-0075</a>                              | SB-01             |                   |                         |                      | No                         | NA                 | NA                   | Silty Clay, Sands and Gravels                               | NA                    | <b>Glenshaw Formation</b> - Cyclic sequences of shale, sandstone, red beds, and thin limestone and coal; includes four marine limestone or shale horizons; red beds are involved in landslides; base is at top of Upper Freeport coal.     | Upland to mid-ridge                | 280-375                           | 7 to 39   |
| <a href="#">PA-CA-0047.0000-SR-16</a> |  | SB-02             |                   |                         |                      | Yes                        | 28.5               | Shale                | Silty Clay, Sands and Gravels                               | NA                    |  |                                    |                                   |   |
| <a href="#">PA-CA-0069.0000-RD</a>    | <a href="#">S2-0080</a>                              | SB-01             |                   |                         |                      | Yes                        | 24.5               | Siltstone / Shale    | Silty Clay, Sands and Gravels                               | NA                    | <b>Casselman Formation</b> - Cyclic sequences of shale, siltstone, sandstone, red beds, thin, impure limestone, and thin, nonpersistent coal; red beds are associated with landslides; base is at top of Ames limestone.                   | Mid-slope, stream valley           | 236-525                           | 30 to 32  |
|                                       |  | SB-02             |                   |                         |                      | Yes                        | 26                 | Sandstone            | Silty Clay, Sands and Gravels                               | 5                     |  |                                    |                                   |   |
| <a href="#">PA-CA-0069.0000-RD-16</a> |  | SB-03             |                   |                         |                      | Yes                        | 15                 | Limestone/ Sandstone | Silt, Sands and Gravels                                     | NA                    |  |                                    |                                   |   |
| <a href="#">PA-CA-0089.0000-RR</a>    | <a href="#">S2-0090</a>                              | SB-01             |                   |                         |                      | Yes                        | 21                 | Shale                | Silty Clay, Sands and Gravels                               | NA                    | <b>Glenshaw Formation</b> - Cyclic sequences of shale, sandstone, red beds, and thin limestone and coal; includes four marine limestone or shale horizons; red beds are involved in landslides; base is at top of Upper Freeport coal.     | Upland to mid-ridge                | 280-375                           | 10 to 18  |
| <a href="#">PA-CA-0089.0000-RR-16</a> |  | SB-02             |                   |                         |                      | No                         | NA                 | NA                   | <b>Coal spoils, coal seams, silt, clay, sand and gravel</b> | NA                    |  |                                    |                                   |   |
| <a href="#">PA-CA-0091.0016-RD</a>    | <a href="#">S2-0100</a>                              | SB-02             |                   |                         |                      | Yes                        | 13                 | Sandstone            | Silty Clay, Sands and Gravels                               | 6                     | <b>Pottsville Formation</b> - consists mainly of well- to very well cemented, mediumgrained to conglomeratic sandstone beds (ranging in thickness from about 10 to 70 feet), minor amounts of siltstone, claystone, shale, and thin coals. | Upland Plateau                     | 1,600                             | 15 to 20  |
| <a href="#">PA-CA-0091.0016-RD-16</a> |  | SB-03             |                   |                         |                      | Yes                        | 11                 | Sandstone            | Silty Clay, Sands and Gravels                               | 5                     |  |                                    |                                   |   |
| <a href="#">PA-IN-0000.0001-WX</a>    | <a href="#">S2-0020</a>                              | SB-01             |                   |                         |                      | Yes                        | 24                 | Sandstone            | Silty Clay, Sands and Gravels                               | 14                    | <b>Glenshaw Formation</b> - Cyclic sequences of shale, sandstone, red beds, and thin limestone and coal; includes four marine limestone or shale horizons; red beds are involved in landslides; base is at top of Upper Freeport coal.     | Upland ridge sloping down to river | 280-375                           | 12 to 22  |
|                                       |  | SB-02             |                   |                         |                      | Yes                        | 15                 | Sandstone            | Silt, Sands and Gravels                                     | NA                    |  |                                    |                                   |   |
| <a href="#">PA-IN-0002.0000-RR</a>    | <a href="#">S2-0030</a>                              | SB-01             |                   |                         |                      | No                         | NA                 | NA                   | Silty Clay, Sands and Gravels                               | NA                    | <b>Glenshaw Formation</b> - Cyclic sequences of shale, sandstone, red beds, and thin limestone and coal; includes four marine limestone or shale horizons; red beds are involved in landslides; base is at top of Upper Freeport coal.     | Plateau (airport)                  | 280-375                           | 15 to 30  |
| <a href="#">PA-IN-0002.0000-RR-16</a> |  | SB-02             |                   |                         |                      | Yes                        | 10                 | Sandstone            | Sand, Gravel, and Silt                                      | NA                    |  | Field                              |                                   |   |
| <a href="#">PA-IN-0019.0000-RR</a>    | <a href="#">S2-0040</a>                              | SB-01             |                   |                         |                      | Yes                        | 11                 | Sandstone            | Sand, Gravel, and Silt                                      | NA                    | <b>Casselman Formation</b> - Cyclic sequences of shale, siltstone, sandstone, red beds, thin, impure limestone, and thin, nonpersistent coal; red beds are associated with landslides; base is at top of Ames limestone.                   | Upland to mid-ridge                | 236-525                           | 5 to 30   |
| <a href="#">PA-IN-0019.0000-RR-16</a> |  | SB-02             |                   |                         |                      | Yes                        | 25                 | Sandstone            | Silty Clay, Sands and Gravels                               | 10                    |  |                                    |                                   |   |
| <a href="#">PA-IN-0022.0000-RD</a>    | <a href="#">S2-0050</a>                              | SB-01             |                   |                         |                      | Yes                        | 14                 | Sandstone            | Sand, Gravel, and Silt                                      | NA                    | <b>Casselman Formation</b> - Cyclic sequences of shale, siltstone, sandstone, red beds, thin, impure limestone, and thin, nonpersistent coal; red beds are associated with landslides; base is at top of Ames limestone.                   | Rolling hills, moderate relief     | 236-525                           | 10 to 20  |
|                                       |  | SB-02             | 35                | 8,410                   | 166.5                | Yes                        | 29                 | Sandstone            | Silty Clay, Sands and Gravels                               | 18                    |  |                                    |                                   |   |
| <a href="#">PA-IN-0022.0000-RD-16</a> |  | SB-03             |                   |                         |                      | No                         | NA                 | NA                   | Silty Clay, Sands and Gravels                               | 7                     |  |                                    |                                   |   |
| <a href="#">PA-IN-0023.00-RD2-16</a>  |  | SB-01             |                   |                         |                      | Yes                        | 20.5               | Sandstone            | Sand, Gravel, and Silt                                      | NA                    | <b>Glenshaw Formation</b> - Cyclic sequences of shale,   |                                    |                                   |   |



| SUNOCO PPP<br>SPREAD 2                  | ROCK CORE SAMPLES - COMPRESSIVE STRENGTH LAB TESTING |                   |       |                         |         | GEOTECH FIELD OBSERVATIONS |                    |                     |                               |                       | REGIONAL GEOLOGY SUMMARY   |                                |                                   |   |
|---|--|-------------------|-------|-------------------------|---------|----------------------------|--------------------|---------------------|-------------------------------|-----------------------|--|--------------------------------|-----------------------------------|---|
| HDD Drawing NO.                         | Geotech<br><br>NO.                                   | BORING<br><br>NO. | DEPTH | Compressive<br>Strength | Density | Bedrock                    |                    |                     | Overburden Summary            | Groundwater (ft. bgs) | REGIONAL GEOLOGY DESCRIPTION   | GENERAL TOPOGRAPHIC<br>SETTING | APPROX. MAX.<br>THICKNESS<br>(FT) | DEPTH TO ROCK (FT BGS)<br>BASED ON NEARBY WELL<br>DRILLING LOGS |
|   |  |                   | (FT)  | (psi)                   | (pcf)   | Encountered                | Depth (ft.<br>bgs) | Type                |                               |                       |  |                                |                                   |   |
|   | <a href="#">S2-0060</a>                              | SB-02             |       |                         |         | Yes                        | 21                 | Sandstone           | Sand, Gravel, and Silt        | NA                    | sandstone, red beds, and thin limestone and coal; includes four marine limestone or shale horizons; red beds are involved in landslides; base is at top of Upper Freeport coal.  | Upland to mid-ridge            | 280-375                           | 10 to 22  |
| <a href="#">PA-IN-0023.0000-RD2-16</a>  |  | SB-03             |       |                         |         | Yes                        | 25                 | Sandstone           | Sand, Gravel, and Silt        | NA                    |  |                                |                                   |   |
| <a href="#">PA-IN-0047.0000-SR</a>      | <a href="#">S2-0062</a>                              | SB-01             |       |                         |         | Yes                        | 11                 | Sandstone           | Silty Clay, Sands and Gravels | 9                     | <b>Allegheny Formation</b> - composed primarily of cyclic sequences of clay shale, claystone, siltstone, sandstone, limestone, and coal.   | Rolling hills, moderate relief | 270-330                           | 12 to 46  |
| <a href="#">PA-IN-0047.0000-SR-16</a>   |  | SB-02             |       |                         |         | Yes                        | 28                 | Sandstone           | Silty Clay, Sands and Gravels | 23                    |  |                                |                                   |   |
| <a href="#">PA-IN-0086.0000-RD</a>      | <a href="#">S2-0064</a>                              | SB-01             |       |                         |         | No                         | NA                 | NA                  | Silty Clay, Sands and Gravels | NA                    | <b>Glenshaw Formation</b> - Cyclic sequences of shale, sandstone, red beds, and thin limestone and coal; includes four marine limestone or shale horizons; red beds are involved in landslides; base is at top of Upper Freeport coal. | Rolling hills, moderate relief | 280-375                           | 18 to 64  |
| <a href="#">PA-IN-0086.0000-RD-16</a>   |  | SB-02             |       |                         |         | Yes                        | 28                 | Sandstone           | Silty Clay, Sands and Gravels | 25                    |  |                                |                                   |   |
| <a href="#">PA-WM2-0021.0000-RD</a>     | <a href="#">S2-0001</a>                              | SB-01             |       |                         |         | No                         | NA                 | NA                  | NA                            | NA                    | <b>Casselman Formation</b> - Cyclic sequences of shale, siltstone, sandstone, red beds, thin, impure limestone, and thin, nonpersistent coal; red beds are associated with landslides; base is at top of Ames limestone.               | Rolling hills, moderate relief | 236-525                           | 16 to 28  |
| <a href="#">PA-WM2-0021.0000-RD-16</a>  |  | SB-02             |       |                         |         | Yes                        | 13.5               | Sandstone/S<br>hale | Silty Clay, Sands and Gravels | NA                    |  |                                |                                   |   |
| <a href="#">PA-WM2-0064.0000-WXa</a>    | <a href="#">S2-0010</a>                              | SB-01             |       |                         |         | Yes                        | 11.5               | Sandstone           | Sand, Gravel, and Silt        | NA                    | <b>Glenshaw Formation</b> - Cyclic sequences of shale, sandstone, red beds, and thin limestone and coal; includes four marine limestone or shale horizons; red beds are involved in landslides; base is at top of Upper Freeport Coal. | Lake Bottom                    | 280-375                           | 10 to 30  |
| <a href="#">PA-WM2-0064.0000-WXa-16</a> |  | SB-02             | 31.8  | 10,820                  | 157.4   | Yes                        | 28.5               | Sandstone           | Sand, Gravel, and Silt        | NA                    |  |                                |                                   |   |
| <a href="#">PA-WM2-0064.0000-WXb</a>    |  | SB-03             |       |                         |         | Yes                        | 21.4               | Sandstone           | Sand, Clay, Gravel            | NA                    |  |                                |                                   |   |
| <a href="#">PA-WM2-0064.0000-WXb-16</a> |  | SB-04             |       |                         |         | Yes                        | 9                  | Sandstone           | Sand, Gravel, and Silt        | NA                    |  |                                |                                   |   |
| <a href="#">PA-WM2-0090.0000-RD</a>     | <a href="#">S2-0015</a>                              | SB-01             |       |                         |         | Yes                        | 16                 | Sandstone           | Sand, Gravel, and Silt        | NA                    | <b>Casselman Formation</b> - Cyclic sequences of shale, siltstone, sandstone, red beds, thin, impure limestone, and thin, nonpersistent coal; red beds are associated with landslides; base is at top of Ames limestone.               | Rolling hills, moderate relief | 236-525                           | 7 to 14   |
| <a href="#">PA-WM2-0090.0000-RD-16</a>  |  | SB-02             |       |                         |         | Yes                        | 11.5               | Shale               | Sand, Gravel, and Silt        | 25                    |  |                                |                                   |   |
| <a href="#">PA-WM2-0093.0000-RD</a>     | <a href="#">S2-0016</a>                              | SB-01             |       |                         |         | Yes                        | 28                 | Sandstone           | Sand, Gravel, and Silt        | NA                    | <b>Glenshaw Formation</b> - Cyclic sequences of shale, sandstone, red beds, and thin limestone and coal; includes four marine limestone or shale horizons; red beds are involved in landslides; base is at top of Upper Freeport coal. | Downward Slope                 | 280-375                           | 10 to 30  |
| <a href="#">PA-WM2-0093.0000-RD-16</a>  |  | SB-02             |       |                         |         | No                         | NA                 | NA                  | Silty Clay, Sands and Gravels | NA                    | <b>Casselman Formation</b> - Cyclic sequences of shale, siltstone, sandstone, red beds, thin, impure limestone, and thin, nonpersistent coal; red beds are associated with landslides; base is at top of Ames limestone.               | Upland                         | 236-525                           | 7 to 14   |







| SUNOCO PPP<br>SPREAD 3                 | ROCK CORE SAMPLES - COMPRESSIVE STRENGTH LAB TESTING |               |       |                         |         | GEOTECH FIELD OBSERVATIONS |                    |                     |                               |                       | REGIONAL GEOLOGY SUMMARY   |                                |                                   |   | PROBABILITY OF<br>ENCOUNTERING<br>VOIDS |
|--|--|---------------|-------|-------------------------|---------|----------------------------|--------------------|---------------------|-------------------------------|-----------------------|--|--------------------------------|-----------------------------------|---|---|
| HDD Drawing NO.                        | Geotech<br>NO.                                       | BORING<br>NO. | DEPTH | Compressive<br>Strength | Density | Bedrock                    |                    |                     | Overburden Summary            | Groundwater (ft. bgs) | REGIONAL GEOLOGY DESCRIPTION   | GENERAL TOPOGRAPHIC<br>SETTING | APPROX. MAX.<br>THICKNESS (FT)    | DEPTH TO ROCK (FT BGS)<br>BASED ON NEARBY WELL<br>DRILLING LOGS |   |
|  |  |               | (FT)  | (psi)                   | (pcf)   | Encountered                | Depth (ft.<br>bgs) | Type                |                               |                       |  |                                |                                   |   |   |
| <a href="#">PA-HU-0020.0008-SS2</a>    |  | SB-02         |       | 4,200                   | 176.7   | Yes                        | 23.5               | Siltstone           | Sand, Silt, and Clay          | 18                    | Brallier and Harrell formations - (undivided) siltstones and shales  |                                | 1,800                             |   |   |
|  |  | SB-02         | 36.5  | 2,950                   | 170.9   |                            |                    |                     |                               |                       |  |                                |                                   |   |   |
| <a href="#">PA-HU-0020.0008-SS2-16</a> |  | SB-03         |       |                         |         | Yes                        | 6                  | Siltstone           | Sand, Silt                    | NA                    |  |                                |                                   |   |   |
| <a href="#">PA-HU-0019.0002-RD</a>     | <a href="#">S2-0148</a>                              | SB-01         |       |                         |         | Yes                        | 7                  | Shale and Limestone | Sand and Gravel               | 18                    | Brallier and Harrell formations - (undivided) siltstones and shales  | Ridge and Valley (steep        | 1800                              | 14 to 50  | LOW                                     |
| <a href="#">PA-HU-0019.0002-RD-16</a>  |  | SB-02         |       |                         |         | Yes                        | 3.5                | Shale               | Sand and Gravel               | NA                    |  |                                |                                   |   |   |
| <a href="#">Pa-HU-0020.00008-WXa</a>   | <a href="#">S2-0150</a>                              | SB-01         |       |                         |         | Yes                        | 12.5               | Siltstone           | Silt, sand, gravel            | NA                    | Catskill Fm - succession of grennishgray-red sandstone, siltstone, shale, and mudstone, generally in fining upward cycles. | Lake                           | 900-3,900                         | 39 to 46  | VERY LOW                                |
| <a href="#">PA-HU-0020.0008-WXa-16</a> |  |               |       |                         |         |                            |                    |                     |                               |                       |  |                                |                                   |   |   |
| <a href="#">PA-HU-0020.0008-WXb</a>    |  |               |       |                         |         |                            |                    |                     |                               |                       |  |                                |                                   |   |   |
| <a href="#">PA-HU-0020.0008-WXb-16</a> |  | SB-02         | 15.7  | 6,280                   | 167.0   | Yes                        | 5                  | Siltstone           | Silt, sand, gravel            | NA                    |  |                                |                                   |   |   |
|  |  | SB-04         |       |                         |         | No                         | NA                 | NA                  | Silty Clay, Sands and Gravels | NA                    |  |                                |                                   |   |   |
| <a href="#">PA-HU-0025.0000-RD3</a>    | <a href="#">S2-045</a>                               | SB-03         |       |                         |         | Yes                        | 27                 | Siltstone           | Sand, Silt                    | NA                    | Catskill Fm - succession of grennishgray-red sandstone, siltstone, shale, and mudstone, generally in fining upward cycles. | Hilly small peninsula          | 900-3,900                         | Data not available but borings suggest shallow                  | VERY LOW                                |
| <a href="#">PA-HU-0025.0000-RD3-16</a> |  |               |       |                         |         |                            |                    |                     |                               |                       |  |                                |                                   |   |   |
| <a href="#">PA-HU-0047.0000-RD</a>     | <a href="#">S2-0152</a>                              | SB-01         |       |                         |         | Yes                        | 8.5                | Shale               | Clay, silt, sand              | 10                    | Mauch Chunk Formation - shale and siltstone, sandstone, and some conglomerate.   | Rolling hills/ridges           | 500-800                           | 6 to 30   | VERY LOW                                |
| <a href="#">PA-HU-0047.0000-RD-16</a>  |  | SB-02         |       |                         |         | Yes                        | 3.5                | Shale               | Clay, silt, sand              | NA                    |  |                                |                                   |   |   |
| <a href="#">PA-HU-0078.0000-WX</a>     | <a href="#">S2-0153</a>                              | SB-01         |       |                         |         | Yes                        | 6.5                | Sandstone           | Silty Clay, Sands and Gravels | NA                    | Onondaga and Old Port Formation (undivided) upper Limestone and lower Shale.   | Rolling hills/ridges           | 200 Onondaga and 100-200 Old Port | 3 to 67   | LOW                                     |
|  |  | SB-02         | 30.2  | 2,110                   | 161.6   | Yes                        | 21                 | Shale/Limestone     | Silty Clay, Sands and Gravels | NA                    |  |                                |                                   |   |   |
| <a href="#">PA-HU-0078.0000-WX-16</a>  |  | SB-02         | 32.5  | 840                     | 160.2   |                            |                    |                     |                               |                       |  |                                |                                   |   |   |
| <a href="#">PA-HU-0106.0000-RD</a>     | <a href="#">S2-0154</a>                              | SB-01         |       |                         |         | Yes                        | 26                 | Shale               | Silty Clay, Sands and Gravels | NA                    | Reedsville Formation - shale and siltstone interbeds, and it has an upper fossiliferous sandstone.                         | Rolling hills/ridges           | >1,000                            | 18 to 59  | VERY LOW                                |
| <a href="#">PA-HU-0106.0000-RD-16</a>  |  | SB-02         |       |                         |         | Yes                        | 15                 | Shale               | Silty Clay, Sands and Gravels | 11                    |  |                                |                                   |   |   |
| <a href="#">PA-HU-0110.0000-SR</a>     | <a href="#">S2-0155</a>                              | SB-01         |       |                         |         | Yes                        | 29                 | Shale               | Silty Clay, Sands and Gravels | NA                    | Onondaga Formation - shale; limestone of Member at top   | Rolling hills/ridges           | 150                               | 35 to 70  | VERY LOW                                |
|  |  | SB-02         |       |                         |         | Yes                        | 14                 | Shale               | Silty Clay, Sands and Gravels | 11                    | Mahantango Fm - shale; siltstone; and very fine-grained sandstone or claystone   |                                | 1,100                             |   |   |
| <a href="#">PA-HU-0110.0000-SR-16</a>  |  | SB-03         |       |                         |         | Yes                        | 10                 | Shale               | Silt, Sands and Gravels       | 4                     |  |                                |                                   |   |   |
| <a href="#">PA-JU-0004.0000-WX</a>     | <a href="#">S2-0156</a>                              | SB-01         |       |                         |         | Yes                        | 21                 | Shale               | Silt, Sands and Gravels       | 8                     | Mahantango Fm - shale; siltstone; and sandstone or claystone   | Valley                         | 1,100                             | 14 to 38  | VERY LOW                                |
| <a href="#">PA-JU-0004.0000-WX-16</a>  |  | SB-02         |       |                         |         | Yes                        | 17                 | Shale               | Silty Clay, Sands and Gravels | 13                    | Keyser/Tonoloway Fm -limestone Wills Creek Fm -variegated shale with interbedded limestone, dolomite, and sandstone zones  |                                | 270-400                           |   |   |
| <a href="#">PA-PE-0002.0000-RD</a>     | <a href="#">S2-0157</a>                              | SB-01         |       |                         |         | Yes                        | 20                 | Shale               | Silty Clay, Sands and Gravels | 18                    | Martinsburg Fm - shale and slate with thin interbeds of siltstone, metabentonite, and fine-grained sandstone.              | Rolling hills/ridges           | up to 13,000                      | 20 to 59  | VERY LOW                                |
| <a href="#">PA-PE-0002.0000-RD-16</a>  |  | SB-02         |       |                         |         | Yes                        | 15                 | Shale               | Silty Clay, Sands and Gravels | 8                     |  |                                |                                   |   |   |



| SUNOCO PPP<br>SPREAD 4                | ROCK CORE SAMPLES - COMPRESSIVE STRENGTH LAB TESTING |               |                                |                         |         | GEOTECH FIELD OBSERVATIONS |                    |                       |                               |                       | REGIONAL GEOLOGY SUMMARY   |                                |                                |   | PROBABILITY OF<br>ENCOUNTERING VOIDS |
|---------------------------------------|--|---------------|--------------------------------|-------------------------|---------|----------------------------|--------------------|-----------------------|-------------------------------|-----------------------|--|--------------------------------|--------------------------------|---|--------------------------------------|
| HDD Drawing NO.                       | Geotech<br>NO.                                       | BORING<br>NO. | DEPTH                          | Compressive<br>Strength | Density | Bedrock                    |                    |                       | Overburden Summary            | Groundwater (ft. bgs) | REGIONAL GEOLOGY DESCRIPTION   | GENERAL TOPOGRAPHIC<br>SETTING | APPROX. MAX.<br>THICKNESS (FT) | DEPTH TO ROCK (FT BGS)<br>BASED ON NEARBY WELL<br>DRILLING LOGS |                                      |
|                                       |  |               | (FT)                           | (psi)                   | (pcf)   | Encountered                | Depth (ft.<br>bgs) | Type                  |                               |                       |  |                                |                                |   |                                      |
| <a href="#">PA-CU-0015.0000-RD</a>    | <a href="#">S2-0160</a>                              | SB-01         | 32.2                           | 530                     | 165.0   | Yes                        | 25                 | Shale /<br>Dolostone  | Silt, Sands and Gravels       | 16                    | <b>Martinsburg Fm</b> - buff-weathering, darkgray to purple shale and slate with thin interbeds of siltstone, metabentonite, and fine-grained sandstone.   | Valley                         |                                | 20 to 50  | VERY LOW                             |
| <a href="#">PA-CU-0015.0000-RD-16</a> |  | SB-02         |                                |                         |         | No                         | NA                 | NA                    | Silty Clay, Sands and Gravels | NA                    |  |                                |                                |   |                                      |
| <a href="#">PA-CU-0054.0000-RD</a>    | <a href="#">S2-0167</a>                              | SB-01         | 8.9                            |                         |         | Yes                        | 16                 | Shale                 | Silt, Sand,Gavel              | 12                    | <b>Martinsburg Fm</b> - buff- weathering, dark-gray to purple shale and slate with thin interbeds of siltstone, metabentonite, and fine-grained sandstone. | Stream Valley                  |                                |   | VERY LOW                             |
| <a href="#">PA-CU-0054.0000-RD-16</a> |  | SB-02         | Not Completed due to no access |                         |         |                            |                    |                       |                               |                       |  |                                |                                |   |                                      |
| <a href="#">PA-CU-0062.0000-WX</a>    | <a href="#">S2-0170</a>                              | SB-01         | 8.9                            |                         |         | Yes                        | 20                 | Shale                 | Sand, Gravel, Clay            | 11                    | <b>Martinsburg Fm</b> - buff-weathering, darkgray to purple shale and slate with thin interbeds of siltstone, metabentonite, and fine-grained sandstone.   | Gently sloping, valley         |                                | 12 to 18  | VERY LOW                             |
| <a href="#">PA-CU-0062.0000-WX-16</a> |  | SB-02         |                                |                         |         | Yes                        | 18                 | Shale                 | Silt and Gravel               | 8                     |  |                                |                                |   |                                      |
| <a href="#">PA-CU-0067.0000-RD</a>    | <a href="#">S2-0180</a>                              | SB-01         | 20.2                           | 370                     | 164.3   | Yes                        | 20                 | Shale                 | Silt, Sand, Gravel            | NA                    | <b>Martinsburg Fm</b> - buff-weathering, darkgray to purple shale and slate with thin interbeds of siltstone, metabentonite, and fine-grained sandstone.   | Gentle slope, ridge and valley |                                | 12 to 18  | VERY LOW                             |
| <a href="#">PA-CU-0067.0000-RD-16</a> |  | SB-02         |                                |                         |         | Yes                        | 18                 | Shale                 | Silt, Sand, Gravel            | NA                    |  |                                |                                |   |                                      |
| <a href="#">PA-CU-0125.0001-WX</a>    | <a href="#">No Geotech</a>                           |               |                                |                         |         |                            |                    |                       |                               |                       |  |                                |                                |   |                                      |
| <a href="#">PA-CU-0125.0001-WX-16</a> |  |               |                                |                         |         |                            |                    |                       |                               |                       |  |                                |                                |   |                                      |
| <a href="#">PA-CU-0128.0000-WX</a>    | <a href="#">S2-0190</a>                              | SB-01         |                                |                         |         | Yes                        | 18                 | Shale                 | Silty Clay, Sands and Gravels | 11                    | <b>Martinsburg Fm</b> - buff-weathering, darkgray to purple shale and slate with thin interbeds of siltstone, metabentonite, and fine-grained sandstone.   | River Crossing                 |                                | 36 to 52  | VERY LOW                             |
|                                       |  | SB-02         |                                |                         |         | Yes                        | 28.2               | Shale                 | Silty Clay, Sands and Gravels | 17                    |  |                                |                                |   |                                      |
| <a href="#">PA-CU-0128.0000-WX-16</a> |  | SB-03         | 20.5                           | 7,400                   | 168.8   | Yes                        | 14                 | Calcareous Shale      | Silt and Sand                 | NA                    |  | Gently rolling to level        |                                | 12 to 18  |                                      |
|                                       |  | SB-04         |                                |                         |         | Yes                        | Surface            | Shale                 | Weathered shale               | NA                    |  |                                |                                |   |                                      |
| <a href="#">PA-CU-0136.0000-RD</a>    | <a href="#">S2-0200</a>                              | SB-01         |                                |                         |         | Yes                        | 21.5               | Limestone<br>Boulders | Silt and Sand                 | NA                    | <b>Martinsburg Fm</b> - buff-weathering, darkgray to purple shale and slate with thin interbeds of siltstone, metabentonite, and fine-grained sandstone.   | Level Terrain                  | 1,500                          | 9 to 36   | LOW                                  |
| <a href="#">PA-CU-0136.0000-RD-16</a> |  | SB-02         |                                |                         |         | Yes                        | 17.5               | Limestone<br>Boulders | Clay, Silt, Sand              | NA                    |  |                                |                                |   |                                      |
| <a href="#">PA-CU-0136.0002-WX</a>    | <a href="#">S2-0210</a>                              | SB-01         |                                |                         |         | Yes                        | 15                 | Limestone<br>Boulders | Silt and Sand                 | NA                    | <b>St. Paul Group</b> - consists of buff-colored magnesium limestone and very finely crystalline birdseye limestone at its top and base.                   | Level Terrain                  | 1,500                          | 2 to 118  | LOW                                  |
| <a href="#">PA-CU-0136.0002-WX-16</a> |  | SB-02         |                                |                         |         | Yes                        | 28.5               | Limestone<br>Boulders | Silt and Sand                 | 11                    |  |                                |                                |   |                                      |
| <a href="#">PA-CU-0136.0003-RD</a>    | <a href="#">S2-0220</a>                              | SB-01         |                                |                         |         | Yes                        | 17.3               | Limestone<br>Boulders | Silt and Sand                 | NA                    | <b>St. Paul Group</b> - consists of buff-colored magnesium limestone and very finely crystalline birdseye limestone at its top and base.                   | Level Terrain                  | 1,500                          | 2 to 95   | LOW                                  |
| <a href="#">PA-CU-0136.0003-RD-16</a> |  | SB-02         |                                |                         |         | Yes                        | 7.3                | Limestone<br>Boulders | Silt                          | NA                    |  |                                |                                |   |                                      |
| <a href="#">PA-CU-0136.0012-RD</a>    | <a href="#">S2-0230</a>                              | SB-01         |                                |                         |         | Yes                        | 18                 | Limestone<br>Boulders | Silt                          | NA                    | <b>St. Paul Group</b> - consists of buff-colored magnesium limestone and very finely crystalline birdseye limestone at its top and base.                   | Level Terrain                  | 1,500                          | 5 to 50   | LOW                                  |
| <a href="#">PA-CU-0136.0012-RD-16</a> |  | SB-02         |                                |                         |         | Yes                        | 10                 | Limestone<br>Boulders | Silt                          | NA                    |  |                                |                                |   |                                      |
| <a href="#">PA-CU-0136.0020-RR</a>    | <a href="#">S2-0232</a>                              | SB-01         |                                |                         |         | Yes                        | 10                 | Limestone<br>Boulders | Silt and Sand                 | NA                    | <b>St. Paul Group</b> - consists of buff-colored magnesium limestone and very finely crystalline birdseye limestone at its top and base.                   | Gentle upward slope to south   | 580                            | 10 to 25  | LOW                                  |
|                                       |  | SB-02         |                                |                         |         | Yes                        | 10                 | Limestone<br>Boulders | Clay, Silt and Sand           | NA                    |  |                                |                                |   |                                      |
| <a href="#">PA-CU-0136.0020-RR-16</a> |  | SB-03         | 14                             | 15,260                  | 167.4   | Yes                        | 10                 | Limestone<br>Boulders | Clay, Silt and Gravel         | NA                    |  |                                |                                |   |                                      |
| <a href="#">PA-CU-0174.0001-RD</a>    | <a href="#">No Geotech</a>                           |               |                                |                         |         |                            |                    |                       |                               |                       |  |                                |                                |   | LOW                                  |
| <a href="#">PA-CU-0174.0001-RD-16</a> |  |               |                                |                         |         |                            |                    |                       |                               |                       |  |                                |                                |   |                                      |
| <a href="#">PA-CU-0176.0014-RD</a>    |  | SB-01         |                                |                         |         | No                         | NA                 | NA                    | Silt, Clay, Sand              | NA                    |  |                                |                                |   |                                      |



| SUNOCO PPP<br>SPREAD 4                | ROCK CORE SAMPLES - COMPRESSIVE STRENGTH LAB TESTING |               |               |                                  |                  | GEOTECH FIELD OBSERVATIONS |         |                                   |  |                       | REGIONAL GEOLOGY SUMMARY  |   |                                |   | PROBABILITY OF<br>ENCOUNTERING VOIDS |                                     |
|---------------------------------------|--|---------------|---------------|----------------------------------|------------------|----------------------------|---------|-----------------------------------|--|-----------------------|---|---|--------------------------------|---|--------------------------------------|-------------------------------------|
| HDD Drawing NO.                       | Geotech<br>NO.                                       | BORING<br>NO. | DEPTH<br>(FT) | Compressive<br>Strength<br>(psi) | Density<br>(pcf) | Bedrock                    |         |                                   | Overburden Summary                                     | Groundwater (ft. bgs) | REGIONAL GEOLOGY DESCRIPTION  | GENERAL TOPOGRAPHIC<br>SETTING          | APPROX. MAX.<br>THICKNESS (FT) | DEPTH TO ROCK (FT BGS)<br>BASED ON NEARBY WELL<br>DRILLING LOGS |                                      |                                     |
| <a href="#">PA-CU-0176.0014-RD-16</a> | <a href="#">S2-0247</a>                              | SB-02         | 19            | 13,320                           | 169.9            | Yes                        | 14      | Fractured<br>Calcite<br>Limestone | Silt, Clay, Sand, Gravel                               | NA                    | Rockdale Run - Formation consists of very light gray, finely laminated, fine-grained limestone with pink to brown lenses of chert and a few dolomite beds.  | Level terrain                           | 2,500                          | 15 to 89  | LOW                                  |                                     |
|                                       |  | SB-03         |               |                                  |                  | Yes                        | 12      | Limestone<br>Boulders             | Clay and Gravel  | NA                    |   |   |                                |   |                                      |                                     |
| <a href="#">PA-CU-0176.0019-RD</a>    | <a href="#">S2-0248</a>                              | SB-01         |               |                                  |                  | Yes                        | Surface | Weathered<br>Phyllitic Shale      | Sandy Silt, Gravel Shale<br>Fragments                  | 14                    | Hamburg sequence- phyllitic shale that is silty and siliceous.  | Gently sloping to the<br>east           | <50 to 200                     | 36 to 64  | LOW                                  |                                     |
| <a href="#">PA-CU-0176.0019-RD-16</a> |  | SB-02         |               |                                  |                  | Yes                        | 7.5     | Weathered<br>Phyllitic Shale      | Sandy Silt, Gravel Shale<br>Fragments                  | 22                    | Hershey and Myerstown Formation (undivided) -<br>argillaceous limestone.  |   |                                |   |                                      |                                     |
| <a href="#">PA-CU-0189.0000-RD</a>    | <a href="#">S2-0249</a>                              | SB-01         |               |                                  |                  | Yes                        | 17      | Limestone                         | Silt, Clay, Sand, Gravel                               | NA                    | Epler Fm - consists of very finely crystalline, medium-gray limestone interbedded with gray dolomite  | Gently sloping to the<br>east           | 1000                           | 25 to 30  | LOW                                  |                                     |
| <a href="#">PA-CU-0189.0000-RD-16</a> |  | SB-02         |               |                                  |                  | Yes                        | 17.5    | Phyllite                          | Silt, Sand, Gravel                                     | 11                    | Gettysburg Fm - silty mudstone and shale and sandstone and thin beds of impure limestone. Diabase - occurs primarily as dikes and sheets and forms a complex igneous network that extensively intrudes sedimentary rocks in the Gettysburg basin. |   | 16,000                         |   |                                      |                                     |
| <a href="#">PA-CU-0203.0000-WX</a>    | <a href="#">S2-0250</a>                              | SB-01         |               |                                  |                  | Yes                        | 7       | Sandstone                         | Silt, Clay, Sand                                       | NA                    | Gettysburg Fm - silty mudstone and shale and sandstone and thin beds of impure limestone.   | Steep sloping valley                    |                                | 9 to 43   | VERY LOW                             |                                     |
|                                       |  | SB-02         | 36.5          | 550                              | 160.5            | Yes                        | 34      | Sandstone                         | Silt, Sand, Gravel                                     | NA                    |   |   |                                |   |                                      |                                     |
| <a href="#">PA-CU-0203.0000-WX-16</a> |  | SB-03         |               |                                  |                  | Yes                        | 22.5    | Conglomerate<br>or Sandstone      | Silt, Sand, Gravel                                     | NA                    |   |   |                                |   |                                      |                                     |
| <a href="#">PA-DA-0005.0000-RD</a>    | <a href="#">S3-0010</a>                              | SB-01         |               |                                  |                  | No                         | NA      | NA                                | Historic Fill - Ash/Coal<br>Spoils, Silt, gravel, sand | 18                    | Gettysburg Fm - silty mudstone and shale and sandstone and thin beds of impure limestone.   | Level low area<br>(adjacent to airport) | 16,000                         | 25 to 30  | VERY LOW                             |                                     |
|                                       |  | SB-02         |               |                                  |                  | Yes                        | 44.2    | Sandstone                         | Silt, Sand, Gravel                                     | 19                    |   |   |                                |   |                                      |                                     |
| <a href="#">PA-DA-0005.0000-RD-16</a> |  | SB-03         |               |                                  |                  | No                         | NA      | NA                                | Silt, Clay, Sand, Gravel                               | 30                    |   | Historic Fill - Silt, gravel,<br>sand   |                                |   |                                      | Level area near edge of<br>treeline |
|                                       |  | S3-011 SB-01  |               |                                  |                  | Yes                        | 21      | Shale /<br>Sandstone              |  | 10                    |   |   |                                |   |                                      |                                     |
| <a href="#">PA-DA-0019.0000-RD</a>    | <a href="#">S3-0020</a>                              | SB-01         |               |                                  |                  | No                         | NA      | NA                                | Silt and Sand with<br>conglomerate                     | 21                    | Gettysburg Fm - silty mudstone and shale and sandstone and thin beds of impure limestone.   | Upland (farm field)                     | 16,000                         | 21 to 36  | VERY LOW                             |                                     |
| <a href="#">PA-DA-0019.0000-RD-16</a> |  | SB-02         |               |                                  |                  | No                         | NA      | NA                                | Silt and Sand with<br>conglomerate                     | 27                    |   |   |                                |   |                                      |                                     |
| <a href="#">PA-DA-0020.0000-RD</a>    | <a href="#">S3-0030</a>                              | SB-01         |               |                                  |                  | No                         | NA      | NA                                | Silt, Sand, gravel, and<br>conglomerate                | NA                    | Gettysburg Fm - silty mudstone and shale and sandstone and thin beds of impure limestone.   | Upland (farm field)                     | 16,000                         | 21 to 36  | VERY LOW                             |                                     |
| <a href="#">PA-DA-0020.0000-RD-16</a> |  | SB-02         |               |                                  |                  | Yes                        | 21      | Shale                             | Silt and Sand  | NA                    |   |   |                                |   |                                      |                                     |
| <a href="#">PA-DA-0030.0000-RR</a>    | <a href="#">S3-0050</a>                              | SB-02         |               |                                  |                  | Yes                        | 20      | Sandstone and<br>Conglomerate     | Silt, Sand, gravel, and<br>conglomerate                | 13                    | Gettysburg Fm - silty mudstone and shale and sandstone and thin beds of impure limestone.   | West side of creek                      | 16,000                         | 21 to 62  | LOW                                  |                                     |
| <a href="#">PA-DA-0030.0000-RR-16</a> |  | SB-03         |               |                                  |                  | Yes                        | 23      | Sandstone and<br>Conglomerate     | Silt, Sand, gravel, and<br>conglomerate                | 14                    |   | East side of creek                      |                                |   |                                      |                                     |
| <a href="#">PA-DA-0039.0000-RD</a>    | <a href="#">S3-0060</a>                              | SB-01         |               |                                  |                  | Yes                        | 26      | Sandstone and<br>Conglomerate     | Silt, Sand, gravel, and<br>conglomerate                | NA                    | Gettysburg Fm - silty mudstone and shale and sandstone and thin beds of impure limestone.   | Upland along PA Route<br>283            | 16,000                         | 36 to 135   | LOW                                  |                                     |
| <a href="#">PA-DA-0039.0000-RD-16</a> |  | SB-02         |               |                                  |                  | Yes                        | 36      | Sandstone                         | Silt, Sand, gravel, and<br>conglomerate                | 26                    |   |   |                                |   |                                      |                                     |
|                                       |  | SB-03         |               |                                  |                  | No                         | NA      | NA                                | Clay, Silt, Sand, gravel,<br>and conglomerate          | NA                    |   |   |                                |   |                                      |                                     |
| <a href="#">PA-DA-0056.0000-RD</a>    |  | SB-01         |               |                                  |                  | No                         | NA      | NA                                | Sand, Silt, Gravel                                     | 6                     |   |   |                                |   |                                      |                                     |



| SUNOCO PPP<br>SPREAD 4                 | ROCK CORE SAMPLES - COMPRESSIVE STRENGTH LAB TESTING |                   |       |                         |         | GEOTECH FIELD OBSERVATIONS                       |                    |                          |   |                       | REGIONAL GEOLOGY SUMMARY  |   |                                |   | PROBABILITY OF<br>ENCOUNTERING VOIDS |
|--|--|-------------------|-------|-------------------------|---------|--|--------------------|--------------------------|---|-----------------------|---|---|--------------------------------|---|--------------------------------------|
| HDD Drawing NO.                        | Geotech<br><br>NO.                                   | BORING<br><br>NO. | DEPTH | Compressive<br>Strength | Density | Bedrock  |                    |                          | Overburden Summary                                    | Groundwater (ft. bgs) | REGIONAL GEOLOGY DESCRIPTION  | GENERAL TOPOGRAPHIC<br>SETTING  | APPROX. MAX.<br>THICKNESS (FT) | DEPTH TO ROCK (FT BGS)<br>BASED ON NEARBY WELL<br>DRILLING LOGS |                                      |
|  |  |                   | (FT)  | (psi)                   | (pcf)   | Encountered                                      | Depth (ft.<br>bgs) | Type                     |   |                       |   |   |                                |   |                                      |
| <a href="#">PA-DA-0056.0000-RDa-16</a> | <a href="#">S3-0080</a>                              | SB-02             |       |                         |         | Yes  | 15                 | Sandstone                | Sand, Silt, Gravel                                    | 6                     | Diabase - occurs primarily as dikes and sheets and forms a complex igneous network that extensively intrudes sedimentary rocks in the Gettysburg Basin.   | Moderately sloping rolling hills  |                                | 10 to 62  | VERY LOW                             |
| <a href="#">PA-DA-0056.0000-RDb</a>    |  | SB-03             |       |                         |         | No   | NA                 | NA                       | Clay, Silt, Sand, Gravel                              | 16                    |   |   |                                |   |                                      |
| <a href="#">PA-DA-0056.0000-RDb-16</a> |  |                   |       |                         |         |  |                    |                          |   |                       |   |   |                                |   |                                      |
| <a href="#">PA-DA-0063.0000-RD</a>     | <a href="#">S3-0081</a>                              | SB-01             |       |                         |         | No   | NA                 | NA                       | Clay, Silt, Sand, Gravel                              | 20                    | Gettysburg Fm - silty mudstone and shale and sandstone and thin beds of impure limestone.   | Moderately sloping rolling hills  | 16,000                         | 30 to 65  | LOW                                  |
| <a href="#">PA-DA-0063.0000-RD-16</a>  |  | SB-02             |       |                         |         | Yes  | Mudstone           | 32                       | Clay, Silt, Sand, Gravel                              | 24                    |   |   |                                |   |                                      |
|  |  | SB-03             |       |                         |         | No   | NA                 | NA                       | Clay, Silt, Sand, Gravel                              | NA                    |   |   |                                |   |                                      |
| <a href="#">PA-LE-0001.0000-SR</a>     | S3-0090  | SB-01             | 20.3  |                         |         | Yes  | 20                 | Sandstone                | Sand, Silt, Gravel                                    | NA                    | Gettysburg Fm - reddish-brown to maroon Silty mudstone and shale and soft, red-brown, medium- to fine- grained sandstone, with minor amounts of yellowish-brown shale and sandstone and thibeds of impure limestone | Gently sloping lowland to forested wetlands   |                                | 12 to 22  | VERY LOW                             |
|  | SB-02  | 28.5              |       |                         | Yes     | 31   | Sandstone          | Silty Clay, Sand, Gravel | 20  |                       |   |   |                                |   |                                      |
|  | SB-03  | 24.4              |       |                         | No      | NA   | NA                 | Sand, Silty Clay, Gravel | NA  |                       |   |   |                                |   |                                      |
| <a href="#">PA-YO-0016.0000-RD</a>     | <a href="#">S2-0260</a>                              | SB-01             |       |                         |         | Yes  | 19.7               | Sandstone                | Sand, Silt, Gravel                                    | 14                    | Quartz Conglomerate - consists of coarse conglomerate containing rounded cobbles and boulders of quartzite, sandstone, quartz, and some metarhyolite in a matrix of red sand.                                       |   |                                |   | VERY LOW                             |
| <a href="#">PA-YO-0016.0000-RD-16</a>  |  | SB-02             |       |                         |         | Yes  | 23.3               | Sandstone                | Sand, Silt, Gravel                                    | 14                    |   |   |                                |   |                                      |
|  |  | SB-03             |       |                         |         | Yes  | 18.5               | Sandstone / Conglomerate | Clay, Silt, Sand, Gravel                              | 16                    |   | Gettysburg Fm - silty mudstone and shale and sandstone and thin beds of impure limestone. Diabase - occurs primarily as dikes and sheets and forms a complex igneous network that extensively intrudes sedimentary rocks in the Gettysburg basin. |                                |   |                                      |
| <a href="#">PA-YO-0040.0002-RD</a>     | <a href="#">S2-0270</a>                              | SB-01             |       |                         |         | Yes  | 17                 | Sandstone                | Clay, Silt, Sand, Gravel                              | NA                    | Gettysburg Fm - silty mudstone and shale and sandstone and thin beds of impure limestone.   | Gently sloping to level upland  | 16,000                         | 31 to 45  | VERY LOW                             |
| <a href="#">PA-YO-0040.0002-RD-16</a>  |  | SB-02             |       |                         |         | Yes  | 29                 | Sandstone                | Clay, Silt, Sand, Gravel                              | 27                    |   |   |                                |   |                                      |
|  |  | SB-03             |       |                         |         | Yes  | 17                 | Sandstone                | Clay, Silt, Sand, Gravel                              | NA                    |   |   |                                |   |                                      |
| <a href="#">PA-YO-0063.0000-RRa</a>    | <a href="#">S2-0280</a>                              | SB-01             |       |                         |         | Yes  | 21.5               | Sandstone                | Sand, Silt, Gravel                                    | 13                    | Gettysburg Fm - silty mudstone and shale and sandstone and thin beds of impure limestone.   | Upland to river bank  | 16,000                         | 5 to 10   | VERY LOW                             |
| <a href="#">PA-YO-0063.0000-RRa-16</a> |  | SB-02             |       |                         |         | Not accessible, floodplain of Susquehanna River. |                    |                          |   |                       |   | Floodplain, lowland, west bank of river.  |                                | 20 to 30  |                                      |
| <a href="#">PA-YO-0063.0000-RRb</a>    |  | SB-03             | 49    | 13,090                  | 146.8   | Yes  | 37                 | Siltstone / Sandstone    | Historic Fill - Coal Spoils, Clay, Silt, Gravel, Sand | NA                    |   |   |                                |   |                                      |
| <a href="#">PA-YO-0063.0000-RRb-16</a> |  |                   |       |                         |         |  |                    |                          |   |                       |   |   |                                |   |                                      |



| SUNOCO PPP<br>SPREAD 5 | ROCK CORE SAMPLES - COMPRESSIVE STRENGTH LAB TESTING |                   |       |                         |         | GEOTECH FIELD OBSERVATIONS |                    |                       |                          |                       | REGIONAL GEOLOGY SUMMARY   |   |                                   |   | PROBABILITY OF<br>ENCOUNTERING VOIDS |
|------------------------|--|-------------------|-------|-------------------------|---------|----------------------------|--------------------|-----------------------|--------------------------|-----------------------|--|---|-----------------------------------|---|--------------------------------------|
| HDD Drawing NO.        | Geotech<br><br>NO.                                   | BORING<br><br>NO. | DEPTH | Compressive<br>Strength | Density | Bedrock                    |                    |                       | Overburden Summary       | Groundwater (ft. bgs) | REGIONAL GEOLOGY DESCRIPTION   | GENERAL TOPOGRAPHIC<br>SETTING              | APPROX. MAX.<br>THICKNESS<br>(FT) | DEPTH TO ROCK (FT BGS)<br>BASED ON NEARBY WELL<br>DRILLING LOGS |                                      |
|                        |  |                   | (FT)  | (psi)                   | (pcf)   | Encountered                | Depth (ft.<br>bgs) | Type                  |                          |                       |  |   |                                   |   |                                      |
| PA-LE-0001.0000-SR     | <a href="#">S3-0090</a>                              | SB-01             | 21.5  |                         |         | Yes                        | 21.5               | Sandstone             | Gravel, Sand, Silt       | NA                    | Gettysburg Fm - mudstone and shale and soft sandstone, with thin beds of impure limestone.   | Gently sloping lowland to forested wetlands |                                   | 12 to 22  | VERY LOW                             |
| PA-LE-0001.0000-SR-16  |  | SB-02             | 32.5  |                         |         | Yes                        | 31                 | Sandstone             | Gravel, Sand, Silt, Clay | 20                    |  |   |                                   |   |                                      |
|                        |  | SB-03             | 30    |                         |         | Yes                        | 26                 | Sandstone             | Gravel, Sand, Silt, Clay | NA                    |  |   |                                   |   |                                      |
| PA-LE-0005.0000-RD     | No Geotech   |                   |       |                         |         |                            |                    |                       |                          |                       |  |   |                                   |   | VERY LOW                             |
| PA-LE-0005.0000-RD-16  |  |                   |       |                         |         |                            |                    |                       |                          |                       |  |   |                                   |   |                                      |
| PA-LE-0009.0000-RD     | <a href="#">S3-0100</a>                              | SB-01             | 30    |                         |         | No                         | NA                 | NA                    | Gravel, Sand, Silt, Clay | NA                    | Hammer Creek Conglomerate - very coarse quartz conglomerate having abundant pebbles and cobbles of gray quartzite.   | Upland                                      | 2,580                             | 15 to 69  | VERY LOW                             |
|                        |  | SB-02             | 43.8  |                         |         | Yes                        | 43                 | Sandstone             | Gravel, Sand, Silt       | NA                    |  |   |                                   |   |                                      |
| PA-LE-0009.0000-RD-16  |  | SB-03             | 24    |                         |         | Yes                        | 17                 | Sandstone             | Gravel, Sand, Silt, Clay | NA                    |  |   |                                   |   |                                      |
| PA-LE-0055.0000-RD     | <a href="#">S3-0101</a>                              | SB-01             | 14.5  | 2,960                   | 174.6   | Yes                        | 8                  | Fractured Limestone   | Gravel, Sand, Silt       | NA                    | Snitz Creek Formation - Thick-bedded, medium- to coarsely crystalline dolomite, in part oolitic, containing laminated limestone and sandstone interbeds.         | Gently rolling to level terrain             | 350                               |   | LOW                                  |
|                        |  | SB-02             |       |                         |         | Yes                        | 6                  | Fractured Limestone   | Gravel, Sand, Silt, Clay | NA                    |  |   |                                   |   |                                      |
| PA-LE-0055.0000-RD     |  | SB-03             |       |                         |         | Yes                        | 7                  | Fractured Limestone   | Gravel, Sand, Silt       | NA                    |  |   |                                   |   |                                      |
| PA-LE-0117.0000-WX     | <a href="#">S3-0110</a>                              | SB-01             | 20.2  |                         |         | Yes                        | 20                 | Sandstone             | Gravel, Sand, Silt       | NA                    | Hammer Creek Formation - Gray and pale red, fine- to coarse-grained quartzose sandstone, siltstone, and mudstone   | Lowland, Wetlands area                      | 9,360                             | 32 to 71  | VERY LOW                             |
|                        |  | SB-02             | 68.4  |                         |         | Yes                        | 70                 | Siltstone             | Sand, Silt, Gravel       | 6                     |  |   |                                   |   |                                      |
| PA-LE-0117.0000-WX     |  | SB-03             | 28.8  |                         |         | Yes                        | 30                 | Decomposed Rock       | Gravel, Sand, Silt       | 4                     |  |   |                                   |   |                                      |
| PA-LA-0004.0000-SR     | <a href="#">S3-0111</a>                              | SB-01             | 28.5  |                         |         | No                         | NA                 | NA                    | Sand, Clay, Gravel       | 19                    | Hammer Creek Formation - Gray and pale red, fine- to coarse-grained quartzose sandstone, siltstone, and mudstone, interbeds of red shale and quartz conglomerate | Level to very gently rolling                | 9360                              | 20 to 35  | VERY LOW                             |
|                        |  | SB-02             | 73    |                         |         | No                         | NA                 | NA                    | Sand, Silt, Gravel       | 5                     |  |   |                                   |   |                                      |
| PA-LA-0004.0000-SR     |  | SB-03             | 30    |                         |         | No                         | NA                 | NA                    | Caly, Silt, Sand         | 4                     |  |   |                                   |   |                                      |
| PA-LA-0014.0000-SR-RD  | <a href="#">S3-0160 &amp; S3-0170</a>                | SB-01             | 43.9  |                         |         | Yes                        | 44.6               | Siltstone / Sandstone | Sand, Clay, Gravel       | 17                    | Hammer Creek Formation - Gray and pale red, fine- to coarse-grained quartzose sandstone, siltstone, and mudstone   | Lowland, welands area                       | 9,360                             | 50-75   | VERY LOW                             |
|                        |  | SB-02             | 33.6  |                         |         | Yes                        | 44                 | Siltstone             | Caly, Sand, Rock         | 13                    |  |   |                                   |   |                                      |
| PA-LA-0014.0000-SR-RD  |  | SB-03             | 10.5  |                         |         | No                         | NA                 | NA                    | Sand, Clay, Gravel       | 6                     |  |   |                                   |   |                                      |
| PA-BR-0036.0000-RD     | <a href="#">S3-0180</a>                              | SB-01             | 30    |                         |         | No                         | NA                 | NA                    | Clay, Silt, Sand, Gravel | 16                    | Millback Fm - Limestone and Dolomite   | Level Upland Farmland                       | 1,500                             | 40 to 79  | LOW                                  |
|                        |  | SB-02             | 70    |                         |         | Yes                        | 74                 | Limestone             | Clay, Sand, Gravel       | 30                    |  |   |                                   |   |                                      |
| PA-BR-0036.0000-RD-16  |  | SB-03             | 30    |                         |         | No                         | NA                 | NA                    | Silt, Sand, Gravel,      | 22                    |  |   |                                   |   |                                      |



| SUNOCO PPP<br>SPREAD 5 | ROCK CORE SAMPLES - COMPRESSIVE STRENGTH LAB TESTING |                   |       |                         |         | GEOTECH FIELD OBSERVATIONS |                    |                      |                          |                         | REGIONAL GEOLOGY SUMMARY  |                                    |                                   |   | PROBABILITY OF<br>ENCOUNTERING VOIDS |
|------------------------|--|-------------------|-------|-------------------------|---------|----------------------------|--------------------|----------------------|--------------------------|-------------------------|---|------------------------------------|-----------------------------------|---|--------------------------------------|
| HDD Drawing NO.        | Geotech<br><br>NO.                                   | BORING<br><br>NO. | DEPTH | Compressive<br>Strength | Density | Bedrock                    |                    |                      | Overburden Summary       | Groundwater (ft. bgs)   | REGIONAL GEOLOGY DESCRIPTION  | GENERAL TOPOGRAPHIC<br>SETTING     | APPROX. MAX.<br>THICKNESS<br>(FT) | DEPTH TO ROCK (FT BGS)<br>BASED ON NEARBY WELL<br>DRILLING LOGS |                                      |
|                        |  |                   | (FT)  | (psi)                   | (pcf)   | Encountered                | Depth (ft.<br>bgs) | Type                 |                          |                         |   |                                    |                                   |   |                                      |
| PA-BR-0071.0000-RD     | <a href="#">S3-0200</a>                              | SB-01             | 28.4  |                         |         | No                         | NA                 | NA                   | Sand, Gravel, Silt       | NA                      | Hammer Creek Conglomerate - very coarse quartz conglomerate having abundant pebbles and cobbles of gray quartzite.  | Level-Rolling upland               | 2,580                             | 10 to 60  | VERY LOW                             |
| PA-BR-0071.0000-RD-16  |  | SB-02             | 13.7  |                         |         | Yes                        | 24                 | Comglomerate         | Sand, Gravel, Silt       | NA                      |   |                                    |                                   |   |                                      |
|                        |  | SB-03             | 28.7  |                         |         | No                         | NA                 | NA                   | Sand, Silt, Gravel       | NA                      |   |                                    |                                   |   |                                      |
| PA-BR-0076.0002-RD     | <a href="#">S3-0201</a>                              | SB-01             | 30    |                         |         | No                         | NA                 | NA                   | Sand, Silt, Gravel       | NA                      | Hammer Creek Fm - reddish-brown, coarse grained sandstone with interbeds of red shale and quartz pebble conglomerate  | Level Rolling upland               | 9,360                             | 10 - 30; but some shallow outcrops present                      | VERY LOW                             |
| PA-BR-0076.0002-RD     |  | SB-02             | 34.1  |                         |         | Yes                        | 33.5               | Weathered Sandstone  | Sand, Silt, Clay, gravel | NA                      | Hammer Creek Conglomerate - very coarse quartz conglomerate having abundant pebbles and cobbles of gray quartzite.  |                                    | 2580                              |   |                                      |
|                        |  | SB-03             | 29    |                         |         | No                         | NA                 | NA                   | Sand, Silt, Gravel       | NA                      | Hammer Creek Conglomerate - very coarse quartz conglomerate having abundant pebbles and cobbles of gray quartzite.  |                                    |                                   |   |                                      |
| PA-BR-0134.0001-RD     | <a href="#">S3-0230</a>                              | SB-01             |       |                         |         | Yes                        | 20                 | Weathered Limestone  | Silt                     | Perched Water may exist | St. Paul Group - consists of buff-colored magnesium limestone and very finely crystalline birdseye limestone at its top and base.                                   | Level terrain                      | 1,500                             | 5 to 50   | VERY LOW                             |
| PA-BR-0134.0001-RD-16  |  | SB-02             |       |                         |         | Yes                        | 8.5                | Bouldering may exist | Limestone                | NA                      |   |                                    |                                   |   |                                      |
| PA-BR-0181.0000-RD     | <a href="#">S3-0250</a>                              | SB-01             | 27    |                         |         | Yes                        | 26.5               | Sandstone            | Gravel, Silty Clay       | NA                      | Stockton Formation -Light-gray to buff, coarse-grained, arkosic sandstone; includes reddish-brown to grayish purple sandstone, siltstone, and mudstone.             | Gently-moderately sloping lowlands | NA                                | 35 -53  | VERY LOW                             |
| PA-BR-0181.0000-RD-16  |  | SB-02             | 15    |                         |         | Yes                        | 16                 | Granite or Basalt    | Clay, Sand               | 8                       | Diabase - Boccurs primarily as dikes and sheets and forms a comles igneous network that extensively intrudes sedimentary rocks in the gettysburg and Newark basins. |                                    |                                   | 13  |                                      |
|                        |  | SB-03             | 18.9  | 1,510                   | 187.3   | Yes                        | 18.5               | Weathered Diabase    | Silty Clay, Sand         | 13                      |   |                                    |                                   |   |                                      |



| SUNOCO PPP<br>SPREAD 6                | ROCK CORE SAMPLES - COMPRESSIVE STRENGTH LAB TESTING |                   |           |                         |             | GEOTECH FIELD OBSERVATIONS |                    |        |                              |                              | REGIONAL GEOLOGY SUMMARY  |  |   |   | PROBABILITY OF<br>ENCOUNTERING VOIDS |
|---------------------------------------|--|-------------------|-----------|-------------------------|-------------|----------------------------|--------------------|--------|------------------------------|------------------------------|---|--|---|---|--------------------------------------|
| HDD Drawing NO.                       | Geotech<br><br>NO.                                   | BORING<br><br>NO. | DEPTH     | Compressive<br>Strength | Density     | Bedrock                    |                    |        | Overburden Summary           | Groundwater (ft. bgs)        | REGIONAL GEOLOGY DESCRIPTION  | GENERAL TOPOGRAPHIC SETTING                    | APPROX. MAX.<br>THICKNESS (FT)              | DEPTH TO ROCK (FT BGS)<br>BASED ON NEARBY WELL<br>DRILLING LOGS |                                      |
|                                       |  |                   | (FT)      | (psi)                   | (pcf)       | Encountered                | Depth (ft.<br>bgs) | Type   |                              |                              |   |  |   |   |                                      |
| <a href="#">PA-CH-0085.0005-RD</a>    | <a href="#">S3-0280</a>                              | SB-01             |           |                         |             | Yes                        | 12                 | Gneiss | Sand, Silt, and Gravel       | NA                           | <b>Graphitic felsic gneiss</b> - predominantly feldspar and quartz.   |  |   | 4 to 46 feet bgs  | VERY LOW                             |
|                                       |  | SB-02             |           |                         |             | Yes                        | 25                 | Gneiss | Sand, Silt, and Gravel       | NA                           | <b>Graphitic felsic gneiss</b> - predominantly feldspar and quartz.   |  |   | 6 to 102 feet bgs   |                                      |
|                                       |  | SB-03             |           |                         |             | Yes                        | 24                 | Gneiss | Sand, Silt, and Gravel       | NA                           | <b>Banded mafic gneiss</b> - includes rocks of probable sedimentary origin.   |  |   | 6 to 75 feet bgs  |                                      |
| <a href="#">PA-CH-0085.0005-RD-16</a> |  | SB-04             | 35.0-35.7 | 1,520                   | 173.8       | Yes                        | 31.4               | Gneiss | Sand, Silt, and Gravel       | NA                           | <b>Banded mafic gneiss</b> - includes rocks of probable sedimentary origin.   |  |   | 6 to 75 feet bgs  |                                      |
|                                       |  | SB-05             | 7.0-8.0   | 7,688                   | 161.1       | Yes                        | 4.4                | Gneiss | Sand, Silt, and Gravel       | NA                           | <b>Graphitic felsic gneiss</b> - predominantly feldspar and quartz.   |  |   | 4 to 46 feet bgs  |                                      |
|                                       |  | SB-06             |           |                         |             | No                         | NA                 | NA     | Sand, Silt, and Gravel       | 23                           | <b>Metadiabase</b> - Dark-gray, fine-grained intrusives; locally, mineralogy is altered and unit has greenish color.                |  | Mostly in thin dikes, but a few over 100 ft | 4 to 50 feet bgs  |                                      |
| <a href="#">PA-CH-0100.0000-RD</a>    | <a href="#">S3-0290</a>                              | SB-01             |           |                         |             | No                         | NA                 | NA     | Sand, Silt, and Gravel       | NA                           | <b>Graphitic felsic gneiss</b> - Includes Pickering Gneiss and small areas of marble; dominantly quartz and feldspar                | Gently sloping to the north                    |   | 4 to 50 feet bgs  | VERY LOW                             |
| <a href="#">PA-CH-0100.0000-RD-16</a> |  | SB-02             | 7.7-11.5  | 3,360-5,690             | 160.8-172.8 | Yes                        | 7                  | Gneiss | Sand, Silt, and Gravel       | NA                           |   | Generally level, slightly sloping to the south |   | 10 to 50 feet bgs   |                                      |
|                                       |  | SB-03             |           |                         |             |                            | No                 | NA     | NA                           | Clay, Sand, Silt, and Gravel |   | 16   |   | Generally level   |                                      |
| <a href="#">PA-CH-0111.0000-RD</a>    | <a href="#">S3-0300</a>                              | SB-01             |           |                         |             | No                         | NA                 | NA     | Sand, Silt, and Gravel       | 16                           | <b>Graphitic felsic gneiss</b> - Includes Pickering Gneiss and small areas of marble; dominantly quartz and feldspar                | Gently sloping to the north                    |   | 25 feet bgs   | VERY LOW                             |
| <a href="#">PA-CH-0111.0000-RD-16</a> |  | SB-02             |           |                         |             | No                         | NA                 | NA     | Sand, Silt, and Gravel       | 18                           |   | Generally level, slightly sloping to the west  |   |   |                                      |
| <a href="#">PA-CH-0124.0000-RD</a>    | <a href="#">S3-0310</a>                              | SB-01             | 47-47.5   | 5,390                   | 159.5       | Yes                        | 45                 | Gneiss | Sand, Silt, and Gravel       | 31                           | <b>Graphitic felsic gneiss</b> - Includes Pickering Gneiss and small areas of marble; dominantly quartz and feldspar                | Gently sloping to the west                     |   | 30 to 95 feet bgs   | VERY LOW                             |
| <a href="#">PA-CH-0124.0000-RD-16</a> |  | SB-02             |           |                         |             | No                         | NA                 | NA     | Clay, Sand, Silt, and Gravel | 18                           |   | Generally level                                |   |   |                                      |
|                                       |  | SB-03             |           |                         |             | No                         | NA                 | NA     | Sand, Silt, and Gravel       | NA                           |   | Gently sloping to the south                    |   |   |                                      |
| <a href="#">PA-CH-0127.0000-RD</a>    | <a href="#">S3-0320</a>                              | SB-01             |           |                         |             | Yes                        | 55                 | Gneiss | Sand, Silt, and Gravel       | 25                           | <b>Felsic and intermediate gneiss</b> - largely quartz, feldspar, and mica; commonly gneissic, ; interfingers with gabbroic gneiss. | Generally level, slight slope to the west      |   | 30 to 57 feet bgs   | VERY LOW                             |
| <a href="#">PA-CH-0127.0000-RD-16</a> |  | SB-02             |           |                         |             | Yes                        | 24                 | Gneiss | Sand, Silt, and Gravel       | NA                           | <b>Felsic and intermediate gneiss</b> - largely quartz, feldspar, and mica; commonly gneissic, ; interfingers with gabbroic gneiss. | Gently sloping to the NW                       |   | 25 to 50 feet bgs   |                                      |
|                                       |  | SB-03             |           |                         |             | Yes                        | 19                 | Gneiss | Sand, Silt, and Gravel       | NA                           | <b>Banded mafic gneiss</b> - includes rocks of probable sedimenta   | Generally level, slightly sloping to the north |   | 25 to 50 feet bgs   |                                      |
| <a href="#">PA-CH-0138.0000-RD</a>    | <a href="#">S3-0330</a>                              | SB-01             |           |                         |             | Yes                        | 16.5               | Gneiss | Sand, Silt, and Gravel       | NA                           | <b>Felsic and intermediate gneiss</b> - Medium grained, interfingers with <b>gabbroic gniess</b>                                    | Generally level                                |   | 20 to 50 feet bgs   | VERY LOW                             |
|                                       |  | SB-02             |           |                         |             | Yes                        | 11                 | Gneiss | Sand, Silt, and Gravel       | NA                           |   |  |   | 10 to 65 feet bgs   |                                      |
|                                       |  | SB-03             |           |                         |             | No                         | NA                 | NA     | Clay, Sand, Silt, and Gravel | 15                           |   |  |   | 10 to 65 feet bgs   |                                      |
| <a href="#">PA-CH-0138.0000-RD-16</a> | <a href="#">S3-0340</a>                              | SB-01             |           |                         |             | No                         | NA                 | NA     | Clay, Sand, Silt, and Gravel | 16                           | <b>Felsic and intermediate gneiss</b> - Medium grained, interfingers with <b>gabbroic gneiss</b>                                    | Generally level                                |   | 10 to 65 feet bgs   | VERY LOW                             |
|                                       |  | SB-03             |           |                         |             | No                         | NA                 | NA     | Sand, Silt, and Gravel       | 15                           |   |  |   | 10 to 65 feet bgs   |                                      |
| <a href="#">PA-CH-0167.0000-RD</a>    |  | SB-01             |           |                         |             | Yes                        | 20                 | Gneiss | Clay, Sand, Silt, and Gravel | 12                           | <b>Felsic and intermediate gneiss</b> - Medium grained, interfingers with gabbroic gneiss   | Generally level, slight slope to the SE        |   | 10 to 65 feet bgs   |                                      |
|                                       |  | SB-02             | 46.0-46.5 | 5,910                   | 163.1       | Yes                        | 40                 | Gneiss | Sand, Silt, and Gravel, Mica | 32                           |   | Generally level                                |   | 10 to 65 feet bgs   |                                      |



| SUNOCO PPP<br>SPREAD 6                 | ROCK CORE SAMPLES - COMPRESSIVE STRENGTH LAB TESTING |                   |  |                         |                 | GEOTECH FIELD OBSERVATIONS |                 |                    |                              |                       | REGIONAL GEOLOGY SUMMARY  |  |                                |   | PROBABILITY OF<br>ENCOUNTERING VOIDS |
|--|--|-------------------|--|-------------------------|-----------------|----------------------------|-----------------|--------------------|------------------------------|-----------------------|---|--|--------------------------------|---|--------------------------------------|
| HDD Drawing NO.                        | Geotech<br><br>NO.                                   | BORING<br><br>NO. | DEPTH  | Compressive<br>Strength | Density         | Bedrock                    |                 |                    | Overburden Summary           | Groundwater (ft. bgs) | REGIONAL GEOLOGY DESCRIPTION  | GENERAL TOPOGRAPHIC SETTING                    | APPROX. MAX.<br>THICKNESS (FT) | DEPTH TO ROCK (FT BGS)<br>BASED ON NEARBY WELL<br>DRILLING LOGS |                                      |
|  |  |                   | (FT)   | (psi)                   | (pcf)           | Encountered                | Depth (ft. bgs) | Type               |                              |                       |   |  |                                |   |                                      |
|  | S3-0350  | SB-03             |  |                         |                 | Yes                        | 47.5            | Gneiss             | Sand, Silt, and Gravel, Mica | 28                    |   | Generally level                                |                                | 10 to 65 feet bgs   | VERY LOW                             |
| <a href="#">PA-CH-0167.0000-RD-16</a>  |  | SB-04             |  |                         |                 | Yes                        | 64              | Gneiss             | Sand, Silt, and Gravel       | 30                    | Chickies Formation - Light-gray, hard, massive, Scolithus-bearing quartzite and quartz schist; thin, interbedded dark slate at top; conglomerate (Hellam Member) at base. | Generally level, slight slope to the NE        | 600                            | 35 to 70 feet bgs   |                                      |
| <a href="#">PA-CH-0199.0000-RD</a>     | S3-0360  | SB-01             |  |                         |                 | No                         | NA              | NA                 | Sand, Silt, and Gravel       | NA                    | Chickies Formation - Light-gray, hard, massive, Scolithus-bearing quartzite and quartz schist; thin, interbedded dark slate at top; conglomerate (Hellam Member) at base. | Gentle slope to the SW                         | 600                            | 20 to 78 feet bgs   | VERY LOW                             |
|  |  | SB-02             | 35.0-36.0  | 3,130                   | 149             | Yes                        | 34              | Quartzite          | Sand, Silt, and Gravel       | NA                    | Gentle slope to the SW  | 35 to 70 feet bgs                              |                                |   |                                      |
| <a href="#">PA-CH-0199.0000-RD-16</a>  |  | SB-03             |  |                         |                 | No                         | NA              | NA                 | Sand, Silt, and Gravel       | NA                    | Gentle slope to the South   | 20 to 78 feet bgs                              |                                |   |                                      |
| <a href="#">PA-CH-0212.0000-RD</a>     | S3-0370  | SB-01             | 30-30.5  | 2,040                   | 152.9           | Yes                        | 29              | Dolomite           | Sand, Silt, and Gravel       | 12                    | Chickies Formation - Light-gray, hard, massive, Scolithus-bearing quartzite and quartz schist; thin, interbedded dark slate at top; conglomerate (Hellam Member) at base. | Generally level, slight slope to the west      | 600                            | 20 to 78 feet bgs   | LOW                                  |
|  |  | SB-02             |  |                         |                 | No                         | NA              | NA                 | Sand, Silt, and Gravel       | 28                    | Ledger Formation - crystalline dolomite; siliceous in middle part.  | Generally level, slight slope to the west      | 2,000                          |   |                                      |
| <a href="#">PA-CH-0212.0000-RD-16</a>  |  | SB-03             |  |                         |                 | No                         | NA              | NA                 | Sand, Silt, and Gravel       | 28                    | Chickies Formation - Light-gray, hard, massive, Scolithus-bearing quartzite and quartz schist; thin, interbedded dark slate at top; conglomerate (Hellam Member) at base. | Generally level, slight slope to the south     | 600                            |   |                                      |
| <a href="#">PA-CH-0219.0000-RDa</a>    | S3-0381  | SB-01             |  |                         |                 | No                         | NA              | NA                 | Sand, Silt, and Gravel       | NA                    | Chickies Formation - Light-gray, hard, massive, Scolithus-bearing quartzite and quartz schist; thin, interbedded dark slate at top; conglomerate (Hellam Member) at base. | Generally level, slight slope to the west      | 600                            | 7 to 65 feet bgs  | LOW                                  |
|  |  | SB-02             |  |                         |                 | Yes                        | 47.5            | Dolomite/Limestone | Sand, Silt, and Gravel       | 38                    | Chickies Formation - Light-gray, hard, massive, Scolithus-bearing quartzite and quartz schist; thin, interbedded dark slate at top; conglomerate (Hellam Member) at base. | Generally level                                | 600                            | 20 to 78 feet bgs   |                                      |
| <a href="#">PA-CH-0219.0000-RDb</a>    |  | SB-03             | Few sinkholes mapped in this area, mostly depressions (potential soft soils) |                         |                 | Yes                        | 23              | Dolomite           | Sand, Silt, and Gravel       | 7                     | Ledger Formation - crystalline dolomite; siliceous in middle part.  | Generally level, slight slope to the south     | 2,000                          | 7 to 65 feet bgs  |                                      |
|  |  | SB-04             | 20 to 20.5   | 13,700                  | 170.9           | Yes                        | 19              | Dolomite           | Sand, Silt, and Gravel       | 15                    | Ledger Formation - crystalline dolomite; siliceous in middle part.  | Generally level, slight slope to the north     | 2,000                          | 7 to 65 feet bgs  |                                      |
| <a href="#">PA-CH-0219.0000-RDa-16</a> |  | SB-05             | Few sinkholes mapped in this area, mostly depressions (potential soft soils) |                         |                 | Yes                        | 16.5            | Limestone          | Sand, Silt, and Gravel       | NA                    | Conestoga Formation - limestone with some shale; alternating dolomite and limestone in lower part.  | Generally level, slight slope to the west      | 300+                           | 7 to 65 feet bgs  |                                      |
| <a href="#">PA-CH-0256.0000-RR</a>     | S3-0400  | SB-01             | Few sinkholes mapped in this area, mostly depressions (potential soft soils) |                         |                 | No                         | NA              | NA                 | Sand, Silt, and Gravel       | 27                    | Conestoga Formation - limestone with some shale; alternating dolomite and limestone in lower part.  | Gently sloping to the north/northwest.         | 300+                           |   | VERY LOW                             |
|  |  | SB-02             |  |                         |                 | No                         | NA              | NA                 | Sand, Silt, and Gravel       | 38                    |   |  |                                |   |                                      |
| <a href="#">PA-CH-0256.0000-RR-16</a>  |  | SB-03             |  |                         |                 | No                         | NA              | NA                 | Sand, Silt, and Gravel       | NA                    | Octoraro Formation - Includes albitechlorite schist, phyllite, some hornblende gneiss, and granitized members.  |  |                                |   |                                      |
| <a href="#">PA-CH-0277.0000-Rda</a>    | S3-0410  | SB-01             |  |                         |                 | No                         | NA              | NA                 | Sand, Silt, and Gravel       | NA                    | Octoraro Formation - Includes albitechlorite schist, phyllite, some hornblende gneiss, and granitized members.  | Moderately sloping to the north                | Several miles thick            | 3 to 65 feet bgs  | VERY LOW                             |
| <a href="#">PA-CH-0277.0000-RDb</a>    |  | SB-02             |  |                         |                 | Yes                        | 50              | Phyllite           | Sand, Silt, and Gravel       | 27                    |   | Gently to moderately sloping to the north      |                                |   |                                      |
| <a href="#">PA-CH-0277.0000-RDa-16</a> |  | SB-03             |  |                         |                 | Yes                        | 56              | Schist             | Sand, Silt, and Gravel       | 53                    |   | Generally level                                |                                |   |                                      |
|  |  | SB-04             |  |                         |                 | Yes                        | 29              | Schist             | Sand, Silt, and Gravel       | NA                    |   | Generally level, slightly sloping to the north |                                |   |                                      |
|  |  | SB-05             |  |                         |                 | Yes                        | 23.5            | Schist             | Sand, Silt, and Gravel       | 8                     |   | Generally level, slightly sloping to the south |                                |   |                                      |
|  |  | SB-06             |  |                         |                 | Yes                        | 16              | Phyllite           | Sand, Silt, and Gravel       | 25                    |   | Generally level, slightly sloping to the north |                                |   |                                      |
|  |  | SB-07             |  |                         |                 | Yes                        | 15              | Phyllite           | Sand, Silt, and Gravel       | NA                    |   | Generally level, slightly sloping to the south |                                |   |                                      |
| <a href="#">PA-CH-0290.0000-RDa</a>    | S3-0421  | SB-01             |  |                         | Petroleum odors | Yes                        | 65              | Schist/Gneiss      | Sand, Silt, and Mica         | 8                     | Glenarm Wissahickon - mafic gneiss and schist; other types: amphibolite   | Generally level, slightly sloping to the south | Several miles thick            | 4 to 58 bgs   | VERY LOW                             |
| <a href="#">PA-CH-0290.0000-RDb</a>    |  | SB-02             | 20 to 20.5   | 4,040                   | 154.5           | Yes                        | 14              | Schist/Gneiss      | Sand, Silt, and Mica         | 23                    |   | Generally level, slightly sloping to the west  |                                |   |                                      |
| <a href="#">PA-CH-0290.0000-RDa-16</a> |  | SB-03             |  |                         | Petroleum odors | No                         | NA              | NA                 | Sand, Silt, and Mica         | NA                    |   | Generally level                                |                                |   |                                      |
| <a href="#">PA-CH-0290.0000-RDb-16</a> |  | SB-04             |  |                         |                 | No                         | NA              | NA                 | Sand, Silt, and Mica         | NA                    |   | Generally level, slightly sloping to the south |                                |   |                                      |
| <a href="#">PA-CH-0326.0000-RD</a>     | S3-0460  | SB-01             |  |                         |                 | Yes                        | 34              | Schist             | Sand, Silt, and Gravel       | NA                    | Glenarm Wissahickon - mafic gneiss and schist; other types: amphibolite   | Generally level                                | Several miles thick            | 1 to 72 feet bgs  | VERY LOW                             |
|  |  | SB-02             |  |                         |                 | No                         | NA              | NA                 | Sand, Silt, and Gravel       | NA                    |   | Generally level                                |                                |   |                                      |



| SUNOCO PPP<br>SPREAD 6                  | ROCK CORE SAMPLES - COMPRESSIVE STRENGTH LAB TESTING |                   |           |                         |         | GEOTECH FIELD OBSERVATIONS |                    |               |                                  |                       | REGIONAL GEOLOGY SUMMARY   |  |                                |   | PROBABILITY OF<br>ENCOUNTERING VOIDS |
|---|--|-------------------|-----------|-------------------------|---------|----------------------------|--------------------|---------------|----------------------------------|-----------------------|--|--|--------------------------------|---|--------------------------------------|
| HDD Drawing NO.                         | Geotech<br><br>NO.                                   | BORING<br><br>NO. | DEPTH     | Compressive<br>Strength | Density | Bedrock                    |                    |               | Overburden Summary               | Groundwater (ft. bgs) | REGIONAL GEOLOGY DESCRIPTION   | GENERAL TOPOGRAPHIC SETTING                    | APPROX. MAX.<br>THICKNESS (FT) | DEPTH TO ROCK (FT BGS)<br>BASED ON NEARBY WELL<br>DRILLING LOGS |                                      |
|   |  |                   | (FT)      | (psi)                   | (pcf)   | Encountered                | Depth (ft.<br>bgs) | Type          |                                  |                       |  |  |                                |   |                                      |
| <a href="#">PA-CH-0326.0000-RD-16</a>   |  | SB-03             |           |                         |         | No                         | NA                 | NA            | Sand, Silt, and Gravel           | 28                    |  | Generally level, slightly sloping to the north |                                |   |                                      |
| <a href="#">PA-CH-0326.0004-SR</a>      | <a href="#">S3-0461</a>                              | SB-01             |           |                         |         | No                         | NA                 | NA            | Sand, Silt, and Gravel           | NA                    | Ultramafic rocks - serpentine, steatite, and peridotites and pyroxenites | Gently sloping to the southeast                |                                |   | VERY LOW                             |
| <a href="#">PA-CH-0326.0004-SR-16</a>   |  | SB-02             |           |                         |         | No                         | NA                 | NA            | Sand, Silt, and Gravel           | NA                    | Felsic Gneiss  | Generally level                                |                                |   |                                      |
| <a href="#">PA-CH-0326.0006-RDa</a>     | <a href="#">S3-0470</a>                              | SB-01             |           |                         |         | No                         | NA                 | NA            | Sand, Silt, and Gravel           | NA                    | Felsic Gneiss  | Generally level                                |                                | 10 to 78 feet bgs   | VERY LOW                             |
| <a href="#">PA-CH-0326.0006-RDb</a>     |  | SB-02             |           |                         |         |                            |                    |               |                                  |                       |  |  |                                |   |                                      |
| <a href="#">PA-CH-0326.0006-RDa-16</a>  | S3-0480  | SB-01             |           |                         |         | No                         | NA                 | NA            | Sand, Silt, and Mica             | NA                    | Felsic Gneiss  | Gently sloping to the southwest                |                                | 10 to 78 feet bgs   | VERY LOW                             |
|   |  | SB-02             | 37-37.5   | 4693                    | 164     | Yes                        | 31                 | Felsic Gneiss | Sand, Silt, and Mica             | 30                    |  | Gently sloping to the west                     |                                |   |                                      |
| <a href="#">PA-CH-0326.0006-RDb-16</a>  |  | SB-03             |           |                         |         | No                         | NA                 | NA            | Sand, Silt, and Mica             | NA                    |  | Generally level                                |                                |   |                                      |
| <a href="#">PA-CH-0355.0000-RD</a>      | <a href="#">S3-0490</a>                              | SB-01             |           |                         |         | No                         | NA                 | NA            | Sand, Silt, and Gravel           | 8                     | Felsic Gneiss  | Generally level                                |                                | 19 to 110   | VERY LOW                             |
| <a href="#">PA-CH-0355.0000-RD-16</a>   |  | SB-02             |           |                         |         | Yes                        | 46                 | Schist        | Sand, Silt, and Gravel           | 28                    | Felsic Gneiss  | Generally level, slightly sloping to the north |                                | 30 to 50  |                                      |
| <a href="#">PA-CH-0370.0000-RD</a>      | S3-0500  | SB-01             |           |                         |         | No                         | NA                 | NA            | Sand, Silt, and Gravel           | NA                    | Felsic Gneiss  | Generally level, slightly sloping to the north |                                | 30 to 50  | VERY LOW                             |
| <a href="#">PA-CH-0370.0000-RD-16</a>   |  | SB-02             | 30.5-31   | 8,267 PSI               | 165     | Yes                        | 29                 | Gneiss        | Sand, Silt, and Gravel           | NA                    | Felsic Gneiss  | Generally level, slightly sloping to the south |                                | 30 to 50  |                                      |
| <a href="#">PA-CH-0383.0003-ABTE</a>    | S3-0510  | SB-01             |           |                         |         | Yes                        | 14                 | Schist        | Sand, Silt, and Gravel           | NA                    | Felsic Gneiss  | Generally level, slightly sloping to the south |                                | 30 to 50  | VERY LOW                             |
| <a href="#">PA-CH-0383.0003-ABTE-16</a> |  | SB-02             |           |                         |         | No                         | NA                 | NA            | Sand, Silt, and Gravel           | 15                    | Felsic Gneiss  | Generally level, slightly sloping to the south |                                | 30 to 50  |                                      |
| <a href="#">PA-CH-0413.0000-RD</a>      | <a href="#">S3-0520</a>                              | SB-01             |           |                         |         | Yes                        | 53                 | Gneiss        | Sand, Silt, and Gravel           | 25                    | Felsic Gneiss  | Generally level, slightly sloping to the south |                                | 30 to 50  | VERY LOW                             |
|   |  | SB-02             |           |                         |         | Yes                        | 56                 | Gneiss        | Sand, Silt, and Gravel, and Clay | 30                    | Felsic Gneiss  | Generally level                                |                                |   |                                      |
| <a href="#">PA-CH-0413.0000-RD-16</a>   |  | SB-03             |           |                         |         | No                         | NA                 | NA            | Silt and Sand                    | 28                    | Felsic Gneiss  | Generally level, slightly sloping to the south |                                |   |                                      |
| <a href="#">PA-CH-0420.0000-RD</a>      | <a href="#">S3-0530</a>                              | SB-01             |           |                         |         | Yes                        | 36                 | Gneiss        | Sand, Silt, and Gravel           | NA                    | Felsic Gneiss  | Generally level                                |                                | 9 to 70   | VERY LOW                             |
|   |  | SB-02             |           |                         |         | Yes                        | 15                 | Gneiss        | Sand, Silt, and Gravel, and Clay | NA                    | Felsic Gneiss  | Generally level, slightly sloping to the NE    |                                |   |                                      |
| <a href="#">PA-CH-0420.0000-RD-16</a>   |  | SB-03             |           |                         |         | Yes                        | 18.5               | Gneiss        | Sand, Silt, and Gravel, and Clay | NA                    | Felsic Gneiss  | Generally level                                |                                |   |                                      |
| <a href="#">PA-CH-0421.0000-RDa</a>     | S3-0541  | SB-01             |           |                         |         | No                         | p                  | NA            | Sand, Silt, Gravel, and Mica     | 25                    | Felsic Gneiss  | Generally level                                |                                | 5 to 40 feet bgs  | VERY LOW                             |
|   |  | SB-02             | 39.0-29.5 | 13,333                  | 162.8   | No                         | 32                 | Gneiss        | Sand, Silt, Gravel, and Mica     | NA                    | Felsic Gneiss  | Generally level, slightly sloping to the south |                                |   |                                      |
| <a href="#">PA-CH-0421.0000-RDb</a>     |  | SB-03             |           |                         |         | No                         | 68                 | Gneiss        | Sand, Silt, Gravel, and Mica     | 39                    | Felsic Gneiss  | Generally level, slightly sloping to the south |                                |   |                                      |
| <a href="#">PA-CH-0421.0000-RDa-16</a>  |  | SB-04             |           |                         |         | No                         | 42                 | Gneiss        | Sand, Silt, Gravel, and Mica     | 21                    | Felsic Gneiss  | Generally level, slightly sloping to the sw    |                                |   |                                      |
| <a href="#">PA-CH-0421.0000-RDb-16</a>  |  | SB-05             |           |                         |         | No                         | NA                 | NA            | Sand, Silt, Gravel               | NA                    | Felsic Gneiss  | Generally level                                |                                |   |                                      |
| <a href="#">PA-DE-0008.0000-RD</a>      | <a href="#">S3-0560</a>                              | SB-01             |           |                         |         | No                         | NA                 | NA            | Sand and Silt                    | NA                    | Felsic Gneiss  | Generally level, slightly dipping to the north |                                | 4 to 95 ft bgs  | VERY LOW                             |
| <a href="#">PA-DE-0008.0000-RD-16</a>   |  | SB-02             |           |                         |         | No                         | NA                 | NA            | Silt, Clay, and Sand             | 13                    |  | Generally level                                |                                |   |                                      |
| <a href="#">PA-DE-0016.0000-RD</a>      | <a href="#">S3-0570</a>                              | SB-01             |           |                         |         | No                         | NA                 | NA            | Silt and Clay                    | 14                    | Felsic Gneiss  | Gently sloping to the SE                       |                                | 15 to 40 ft bgs   | VERY LOW                             |
| <a href="#">PA-DE-0016.0000-RD-16</a>   |  | SB-02             |           |                         |         | Yes                        | 22                 | Gneiss        | Sand and Silt                    | 10                    |  | Generally level                                |                                |   |                                      |
| <a href="#">PA-DE-0032.0000-RD</a>      | S3-0580  | SB-01             |           |                         |         | Yes                        | 14                 | Gneiss        | Silt, Clay, and Sand, and gravel | NA                    | Felsic Gneiss  | Generally level, slightly sloping to the south |                                | 45 to 55 ft bgs   | VERY LOW                             |
|   |  | SB-02             | 29.0-29.5 | 11,076                  | 176     | Yes                        | 16                 | Gneiss        | Sand and Silt and gravel         | NA                    |  | Generally level, slightly sloping to the west  |                                |   |                                      |
| <a href="#">PA-DE-0032.0000-RD-16</a>   |  | SB-03             | 12.5-13.0 | 12,574                  | 158.4   | Yes                        | 8                  | Gneiss        | Sand and Silt                    | NA                    | Felsic Gneiss  | Generally level                                |                                |   |                                      |
|   |  | SB-04             |           |                         |         | No                         | NA                 | NA            | Sand and Silt                    | 16                    |  | Generally level                                |                                |   |                                      |
| <a href="#">PA-DE-0046.0000-RDa</a>     | S3-0591  | SB-01             |           |                         |         | No                         | NA                 | NA            | Sand, Silt, Gravel               | NA                    | Felsic Gneiss  | Generally level, slightly sloping to the south |                                | 14 to 75 ft bgs   | VERY LOW                             |
|   |  | SB-02             |           |                         |         | Yes                        | 18.5               | Gneiss        | Silt                             | 10                    |  | Generally level, slightly sloping to the south |                                |   |                                      |
| <a href="#">PA-DE-0046.0000-RDb</a>     |  | SB-03             |           |                         |         | Yes                        | 40                 | Gneiss        | Sand, Silt, Gravel               | 35                    |  | Generally level, slightly sloping to the SE    |                                |   |                                      |



| SUNOCO PPP<br>SPREAD 6 | ROCK CORE SAMPLES - COMPRESSIVE STRENGTH LAB TESTING |                   |           |                         |         | GEOTECH FIELD OBSERVATIONS |       |             |                                  |                       | REGIONAL GEOLOGY SUMMARY   |  |                                |   | PROBABILITY OF<br>ENCOUNTERING VOIDS |                    |
|------------------------|--|-------------------|-----------|-------------------------|---------|----------------------------|-------|-------------|----------------------------------|-----------------------|--|--|--------------------------------|---|--------------------------------------|--------------------|
|                        | Geotech  | BORING<br><br>NO. | DEPTH     | Compressive<br>Strength | Density | Bedrock                    |       |             | Overburden Summary               | Groundwater (ft. bgs) | REGIONAL GEOLOGY DESCRIPTION   | GENERAL TOPOGRAPHIC SETTING                    | APPROX. MAX.<br>THICKNESS (FT) | DEPTH TO ROCK (FT BGS)<br>BASED ON NEARBY WELL<br>DRILLING LOGS |                                      |                    |
| HDD Drawing NO.        |  |                   | NO.       |                         | (FT)    | (psi)                      | (pcf) | Encountered |                                  |                       |  |  |                                |   |                                      | Depth (ft.<br>bgs) |
| PA-DE-0046.0000-RDa-16 |  | SB-04             | 31.5-32.0 | 6,170                   | 160.7   | Yes                        | 31    | Gneiss      | Sand, Silt, Gravel               | 38                    |  | Generally level, slightly sloping to the west  |                                |   |                                      |                    |
| PA-DE-0046.0000-RDb-16 |  | SB-05             |           |                         |         | No                         | NA    | NA          | Sand, Silt, Gravel               | NA                    |  | Generally level, slightly sloping to the south |                                |   |                                      |                    |
| PA-DE-0074.0000-RD     | S3-0610  | SB-01             |           |                         |         | No                         | NA    | NA          | Sand, Silt, and Gravel           | NA                    | Felsic Gneiss  | Gently sloping to the south                    |                                | 8 to 24   | VERY LOW                             |                    |
| PA-DE-0074.0000-RD-16  |  | SB-02             |           |                         |         | Yes                        | 22    | Gneiss      | Sand, Silt, and Gravel           | NA                    |  | Gently sloping to the west                     |                                |   |                                      |                    |
| PA-DE-0100.0000-RRa    | S3-0620  | SB-01             |           |                         |         | No                         | NA    | NA          | Sand, Silt, and Gravel, and Mica | 23                    | Ultramafic rocks - Includes serpentine, steatite, and other products of alteration of peridotites and pyroxenites. | Generally level                                |                                | 10 to 70 ft bgs   | VERY LOW                             |                    |
| PA-DE-0100.0000-RRb    |  | SB-02             | 39.0-39.5 | 8,325                   | 163.4   | No                         | NA    | NA          | Sand, Silt, and Gravel           | 38                    |  | Gently sloping to the East                     |                                |   |                                      |                    |
| PA-DE-0100.0000-RRa-16 |  | SB-03             |           |                         |         | Yes                        | 31    | Gneiss      | Sand, Silt, and Gravel           | 28                    |  | Gently sloping to the SE                       |                                |   |                                      |                    |
| PA-DE-0100.0000-RRb-16 |  | SB-04             |           |                         |         | Yes                        | 12    | Gneiss      | Sand, Silt, and Gravel           | 4                     |  | Generally level                                |                                |   |                                      |                    |
| PA-DE-0104.0008-WXa    | S3-0631  | SB-01             |           |                         |         | Yes                        | 22.5  | Gneiss      | Sand, Silt, and Gravel           | NA                    | Glenarm Wissahickon - mafic gneiss and schist; other types: amphibolite  | Gently sloping to the west                     |                                | 20-38 ft bgs  | VERY LOW                             |                    |
| PA-DE-0104.0008-WXb    |  | SB-02             |           |                         |         | Yes                        | 15    | Schist      | Sand, Silt, Gravel               | 8                     |  | Gently sloping to the south                    |                                |   |                                      |                    |
| PA-DE-0104.0008-WXa-16 |  | SB-03             | 38.0-38.5 | 11,268                  | 168     | Yes                        | 24    | Gneiss      | Sand, Silt, Gravel               | 32                    |  | Generally level                                |                                |   |                                      |                    |
| PA-DE-0104.0008-WXb-16 |  | SB-04             | 23.5-24   | 5,320                   | 162.6   | Yes                        | 22.5  | Gneiss      | Sand, Silt, Gravel               | NA                    | Mafic Gneiss   | Gently sloping to the south                    |                                |   |                                      |                    |
|                        |  | SB-05             |           |                         |         | No                         | NA    | NA          | Sand, Silt, Gravel               | 26                    | Pensauken and Bridgeton Formations - undifferentiated formations, unlikely rock.                                   | Gently sloping to the west                     | 30+                            |   |                                      | 38 bgs             |
| PA-DE-0104.0025-RD     | S3-0660  | SB-01             |           |                         |         | No                         | NA    | NA          | Sand, Silt, Gravel               | NA                    | Pensauken and Bridgeton Formations - undifferentiated formations, unlikely rock.                                   | Moderately sloping to the south                | 30+                            |   | VERY LOW                             |                    |
| PA-DE-0104.0025-RD-16  |  | SB-02             |           |                         |         | Yes                        | 15.5  | Schist      | Sand, Silt, Gravel               | NA                    | Mafic Gneiss   | Gently to Moderately sloping to the west       |                                |   |                                      |                    |
| PA-DE-0104-0023-RD     | S3-0670  | SB-01             |           |                         |         |                            |       |             |                                  |                       |  |  | 30+                            |   | VERY LOW                             |                    |
|                        |  | SB-02             | 47.0-47.5 | 5,690                   | 159.5   | Yes                        | 46    | Schist      | Sand, Silt, and Gravel, and Mica | 10                    | Pensauken and Bridgeton Formations and Mafic Gneiss  | Generally level                                |                                |   |                                      | 11 to 25 ft bgs    |
| PA-DE-0104-0023-RD-16  |  | SB-03             |           |                         |         | No                         | NA    | NA          | Sand, Silt, and Gravel, and Mica | 13                    |  |  |                                |   |                                      |                    |



Notes:



Lab Analysis of bedrock core samples

Summary of Properties of Common Rocks in Pennsylvania

|                |                                    |  |                                     | Shear Strength                 |                             |                     |
|----------------|------------------------------------|--|-------------------------------------|--------------------------------|-----------------------------|---------------------|
| Rock Type      | Unit dry weight lb/ft <sup>3</sup> | Unconfined compressive strength lb/in <sup>2</sup> | Tensile strength lb/in <sup>2</sup> | Angle of internal friction (°) | Cohesion lb/in <sup>2</sup> | Source              |
| Shale          | 134-165                            | 30-1,000   | 250-1,480                           | 6 to 33                        | 95-1,500                    | Mellinger, 1969     |
|                |                                    | 1,000-2,950  |                                     |                                |                             |                     |
| Silty Shale    | 145-169                            | 370-1,000  | 720-3,200                           | 10 to 54                       | 200-1,970                   |                     |
|                |                                    | 1,000-6,300  |                                     |                                |                             |                     |
| Sandy Shale    | 154-167                            | 4,850-13,580                                       | 1,400-3,140                         | 29 to 60                       | 310-2,660                   |                     |
| Indurated Clay | 131-170                            | 55-1,000   | 790-1,090                           | 10 to 60                       | 18-600                      |                     |
|                |                                    | 1,000-3,520  |                                     |                                |                             |                     |
| Claystone      | 148-164                            | 420-1,000  |                                     | 24 to 60                       | 0-600                       |                     |
|                |                                    | 1,000-6,000  |                                     |                                |                             |                     |
| Siltstone      | 149-166                            | 2,000-11,300                                       | 1,380-3,160                         | 19 to 48                       | 590-2,930                   |                     |
| Granite        |                                    | 23,000-42,600                                      |                                     |                                |                             | Bolz and Tuve, 1973 |
| Basalt         |                                    | 11,800-52,000                                      |                                     |                                |                             |                     |
| Marble         |                                    | 6,700-34,500                                       |                                     |                                |                             |                     |
| Gneiss         |                                    | 22,200-36,400                                      |                                     |                                |                             |                     |
| Quartzite      |                                    | 21,100-91,200                                      |                                     |                                |                             |                     |
| Limestone      |                                    | 5,300-37,600                                       |                                     |                                |                             |                     |
| Sandstone      |                                    | 4,800-34,100                                       |                                     |                                |                             |                     |



## **APPENDIX C**

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### **Geophysical Investigations**



David S. Kane, P.G., Geology and Environmental Sciences  
Tetra Tech  
240 Continental Drive, Suite 200  
Newark, DE 19713

Subject: Report  
Seismic Refraction and Seismic Surface-wave Surveys  
Sunoco Montello Terminal  
Sinking Springs, Pennsylvania

Dear Mr. Kane:

## 1.0 INTRODUCTION

This letter presents the results of Advanced Geological Services, Inc. (AGS) seismic refraction and seismic surface-wave surveys in support of Tetra Tech's geotechnical investigation along a proposed pipeline route through the Sunoco Montello Terminal in Sinking Springs, Pennsylvania (Figure 1). The investigation objective was to look for potential voids and/or areas of soft sediments along the proposed pipeline route. AGS understands that soft sediments were encountered in a well close to the proposed route.

AGS performed the investigation using the seismic refraction and seismic surface-wave methods. The two methods were used to look for disturbed subsurface layering and areas exhibiting relatively low seismic velocity indicative of potential soft sediment; refraction was used to assess the compressional (P-) wave velocity of subsurface materials and the associated layering, and the surface-wave method was used to assess shear (S-) wave velocity and layering. The surface-wave survey was performed to augment the refraction work due to the expected noisy site conditions, which would reduce the effectiveness of the refraction method (the surface-wave method uses ambient noise as a signal source). The investigation was performed between March 10 and March 25, 2015 by AGS senior geophysicist Peter Miller and AGS project geophysicist Christopher Call.



**Figure 1 - Survey Area Locations- Sinking Springs, PA**



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## 2.0 SUMMARY OF FINDINGS

- Overall, five areas exhibiting low P-wave velocity were identified (see Figures 2 and 3):
  1. eastern end of Line 2 (between 220 and 400 ft)
  2. western end of Line 3 (40 and 230 ft)
  3. northern end of Line 12 (between 160 and 230 ft)
  4. eastern end of Line 16 (between 280 and 360 ft)
  5. the center of Line 22 (between 220 and 340 ft)
- Of these five low P-wave velocity areas, four areas also exhibit corresponding lower S-wave velocity; as such, these areas represent the most likely locations of voids and/or soft sediments:
  1. Line 2, between 220 and 400 ft
  2. Line 12, between 160 and 230 ft
  3. Line 16, between 280 and 360 ft
  4. Line 22, between 220 and 340 ft
- Lines 9, 10, 11, 18, 19 and 20 exhibit overall low P-wave velocity. In general, lower P-wave velocity is indicative of weaker, less-compacted material; however, due to the high noise levels, the P-wave refraction results may not accurately depict subsurface conditions along these lines.
- Given the overall relatively low P-wave velocities observed (generally less than 5,000 fps), bedrock was likely not detected.
- Undulations in velocity layering observed on some P-wave velocity models (*e.g.*, Lines 6 and 7 on Figure 6) could represent actual distortions in sediment layering, artifacts of the noisy seismic records, or a combination of both factors.
- It is worth noting that other areas of voids/soft sediments not detected by this investigation may also be present.

## 3.0 SITE DESCRIPTION

The investigation was performed in two areas— site S3-0180, which is an open, grass-covered area that runs through a residential neighborhood, and site S3-0190, which is a highly developed area that includes the main terminal, residential housing, and active roadways. It is worth noting that S3-0190 exhibited extremely high levels of seismic noise that severely degraded the quality of the seismic refraction data obtained at that site.

## 4.0 FIELD PROCEDURES

The refraction work was performed as a high-resolution seismic refraction tomography survey



using seven shotpoints per spread; some lines were composed of multiple geophone spreads. First, AGS laid a fiberglass tape measure along the ground surface to mark the first seismic refraction line. AGS then placed 24 geophones in the ground at 10-foot spacings to form a linear, 230-foot-long geophone array. The geophones were coupled to the ground surface by means of 4-inch spikes. Seven shotpoints were used for each array—two “off-end” shotpoints, each one placed 30 feet beyond each end of the array; two “end” shotpoints, one at each end of the array; and three shotpoints within the array, one in the center and two at the array “quarter points.” The combination of the geophone array and associated shotpoints is referred to as a “spread.”

AGS produced seismic energy through multiple impacts with a 16-lb sledge hammer against a metal plate placed on the ground surface at each shotpoint location. In general, seven hammer blows were struck at the end- and off-end shotpoints and three to five blows were struck at the mid-line shotpoints. The seismic energy produced by the hammer impacts was detected using Geospace 10-Hz geophones, and the detected seismic signals were recorded using a DAQLink II seismic system connected to a laptop computer. Recording parameters included a record length of 0.5 seconds with a 0.125-millisecond sample rate.

After the refraction data were collected, AGS obtained the surface-wave data. Surface-wave data were collected using the refraction microtremor (“Remi”) technique, whereby the ambient seismic signals produced by wind, wave motion and cultural sources such as factory machinery and vehicle traffic are recorded; no hammer blows are struck. For each geophone array, AGS collected ten 30-second records with a 2-millisecond sample rate.

After the seismic data were collected for the first spread, AGS moved the tape measure to mark the next spread, repositioned the geophones, and collected refraction and surface-wave data in the same manner as with the first spread. All told, AGS obtained seismic data along 22 lines. Most lines were 230 feet long and comprised one spread. Two lines were 410 feet long (two spreads); one line was 590 feet long (three spreads), and one line, L-22, was 810 feet long (four spreads). For the longer lines, AGS overlapped the geophone arrays by 50 feet to facilitate continuity of results between the spreads.

AGS mapped the line locations using a Global Positioning System (GPS) as the survey progressed.

## **5.0 GEOPHYSICAL METHOD OVERVIEW**

### **5.1 Seismic Refraction**

The seismic refraction method uses compressional (P-) wave energy to delineate seismic velocity layers within the subsurface. Interpretation entails correlating the velocity layers to geologic features such as soil, sediment, and bedrock. Distortions in the layering can indicate the presence of geologic faults and potential sinkholes. To perform a refraction survey, an elastic wave (compressional, or P-wave) is generated at certain locations (shotpoints) along a survey line. The P-wave energy is usually produced with a small explosion or by striking the ground with a sledgehammer. As the P-wave propagates through the ground it is refracted along boundaries between geologic layers with different seismic velocities.



Part of the refracted P-wave energy returns to the ground surface where it is detected by vibration-sensitive devices called geophones, which are placed in a co-linear array along the seismic survey line. The geophone data are fed to a seismograph, where they are recorded, and then to a computer, where they are processed using inversion software to produce models that depict the depth and velocities of the subsurface layers detected. Key data for refraction analysis are the positions of the geophones and shotpoints along a seismic line, and the amount of time it takes for the refracted wave to travel from the shotpoint to each geophone location. Because the P-wave is the fastest traveling of all types of seismic waves, it can be readily identified as the first deflection (“first break”) on a seismic trace.

Additional discussion of the refraction method, its limitations, and the relationship between seismic velocity and geologic materials is presented in Appendix A.

## **5.2 Seismic Surface-Wave**

Seismic surface-wave surveys use essentially the same field set-up as a refraction survey, but a different part of the recorded seismic signal—the Rayleigh (surface) wave—is analyzed instead of the P-wave. Briefly, a surface-wave survey entails measuring the velocity of surface waves using an array of motion detectors (geophones) placed on the ground surface. Because surface-wave velocity closely follows shear-wave velocity (90 to 95% of  $V_s$ ), surface-wave velocity data can be used to estimate shear wave velocity ( $V_s$ ). Surface-waves are seismic waves that travel along or near the surface of the earth; they are generated by both natural (e.g., wind, ocean waves) and man-made (e.g., hammer blow, traffic noise, factory vibration) sources. Surface-waves travel in assemblages of frequencies, with each frequency having a corresponding wavelength. Because surface-waves are influenced by subsurface material to a depth approximately equal to the surface-wave’s wavelength, a velocity vs. depth profile can be generated by measuring the velocity of surface-waves of varying wavelengths. Short wavelengths (higher frequencies) respond to the material properties (e.g., stiffness) of shallower materials while longer wavelengths (lower frequency) respond to deeper materials.

Specialized computer software is used to identify surface-waves in the recorded data and prepare a ‘velocity spectrum’ image, which the geophysical analyst interprets to produce a ‘dispersion curve’ to depict how velocity varies with frequency. The geophysicist then prepares a velocity layer model from which a synthetic dispersion curve is produced. The analyst then adjusts the model to obtain a ‘best fit’ between the synthetic dispersion curve and the actual dispersion curve that was interpreted from the velocity spectrum. The degree or closeness of the fit between the interpreted and synthetic curves provides an indication of how well the model represents actual subsurface conditions. The final output from a surface-wave survey is a one-dimensional (1-D) profile showing S-wave velocity variations with depth at a point that is taken to be at the center of the geophone array. Multiple 1-D profiles can be combined to produce cross-sections showing how S-wave velocity varies both laterally and with depth.

## **6.0 DATA PROCESSING AND ANALYSIS**

The seismic refraction data quality for this project ranged from good to poor. The quality of the surface-wave data was good. In general, the refraction data obtained at the Residential site (S3-



0180) was of good quality and first break picks were made with high confidence, while the refraction data at the Terminal site (S3-0190) exhibited high noise levels that obscured the P-wave arrivals to such a degree that first-break picks could not be made in many instances, particularly at the more distant (from the shotpoint) geophones. Refraction data quality was enhanced by “stacking,” which entailed using multiple hammer blows at each shotpoint location to improve the signal-to-noise ratio. The additive affect of stacking of multiple hammer blows at the same location enhances or increases the amplitude of the signal (i.e., the refracted wave arrival) while amplitude of the background noise, which, being random in nature, tends to cancel itself on successive hammer blows and remains largely unchanged. Stacking was made necessary by the vibratory noise from the terminal. AGS stacked seven hammer blows at the end-of-line and off-end shotpoints and three-to-five blows at the mid-line shotpoints.

### **6.1 Refraction Processing and Analysis**

The refraction data were processed using the *SeisImager* software from Geometrics, Inc. Briefly, *SeisImager* is a computer inversion program that generates an initial velocity layer model, produces synthetic data from the model, and then adjusts the model so that the synthetic data better matches the observed field data. The agreement between the synthetic and observed data provides an indication of how well the model represents the true subsurface conditions. For each seismic line, AGS first used the *SeisImager* module *PickWin* to interpret (“pick”) the P-wave arrivals (“first breaks”) for each of the seven shotpoint data sets (“shot gathers”) per line. *PickWin* was also used to check (against the geophysicist’s field log) that the proper locations were assigned to the geophones and shotpoints. Next, the first break files were fed to the *SeisImager* module *PlotRefra*, which was used review time-distance (TD) plots for the seismic lines and assign a seismic layer to each arrival time. For the initial refraction analysis, each P-wave arrival (“first break”) is considered to have refracted from a distinct seismic layer. The number of layers resolved by the seismic survey, and their thickness and average velocity, are revealed by straight line segments on the TD plot; because these straight-line segments represent a constant velocity condition within the subsurface, they are usually considered to represent a distinct geologic layer. The topographic elevation files were incorporated into the analysis at this point. Next, a time-term inversion was performed to produce models showing the velocity layering along each seismic line.

The layered velocity models were then used as starting models for the tomographic inversion process that produced the velocity models presented on Figures 4 through 11 of this Report. Briefly, tomographic inversion is a grid-based modeling process wherein the subsurface is divided into rectangular cells based on the geophone spacing. The tomography software assigns a velocity to each cell, produces a synthetic arrival time data set based on seismic raypaths projected through the velocity grid, and then compares the synthetic data to the real data recorded in the field. The cell velocities are then adjusted and re-adjusted until the synthetic data achieve a “best fit” with the observed field data. Tomographic modeling is often used to complement layered modeling at sites where gradual velocity transitions, such as those often seen within thick layers of sediment and between weathered and unweathered bedrock, are expected. Tomographic modeling can also depict lateral velocity variations within the subsurface more accurately than a layered modeling approach.

For the analysis of the refraction survey results, AGS examined the models for anomalous low-



velocity zones and distortions in the velocity layering that could indicate potential soft sediment and void areas. In addition, AGS examined the time-distance (TD) plots for “jumps” and “sags” and other distortions in the arrival-time curves that might indicate subsurface disruptions that were not expressed in the models. The locations of any such features observed were annotated on the site maps (Figures 2 and 3) and velocity layer models (Figures 4 through 11)

## 6.2 Surface-Wave Processing and Analysis

Surface-wave data processing was performed using *SeisOpt Remi* software by Optim Software. In general, surface wave data processing entails first producing a velocity spectrum image, which shows the phase velocity for the various frequencies of surface waves detected. This image is used as the basis for interpreting (“picking”) a dispersion curve, which is a graph that depicts how surface-wave velocity varies with frequency (hence, depth). The dispersion curve is then used to prepare an initial 1D model of surface-wave velocity versus depth using a one-third wavelength approximation (i.e., a given phase velocity is assigned to a depth that is one-third of the wavelength of the corresponding surface-wave). The initial velocity layer model is then adjusted using an inversion process until the corresponding synthetic dispersion curve achieves a “best-fit” match to the original dispersion curve that was interpreted from the observed data (i.e., the velocity spectrum image). The degree or closeness of the fit between the interpreted and synthetic curves provides an indication of how well the model represents actual subsurface conditions.

Accordingly, AGS first used the *SeisOpt Remi Vspect* module to produce a velocity spectrum image, which shows how surface-wave velocity varies with frequency, and pick a dispersion curve. Next, AGS used the *Dispr* module to perform the inversion that produced 1-D models showing S-wave ( $V_s$ ) velocity variations with depth. To produce the 2-D S-wave velocity cross sections (Figures 4 through 11), AGS separately processed and analyzed sub-sets of each 24-channel data set (i.e., the data from a each array of 24 geophones). For each array of 24 geophones, AGS separately processed the data from geophones 1 through 12, 6 through 18, and 12 through 24 to produce three 1-D profiles, which were then assembled into 2-D cross section. Cross sections for the longer lines with multiple geophone arrays were composed of from six to twelve 1-D profiles.

For the analysis of the surface-wave survey results, AGS examined the 2-D cross sections for anomalous low-velocity zones that could indicate potential soft sediment areas. In particular, AGS looked for correlations between low S-wave velocity area and distortions in the P-wave velocity layer models. The locations of any such features were annotated on the site maps (Figures 2 and 3) and velocity layer models (Figures 4 through 11).

## 7.0 RESULTS

The investigation results are presented on Figures 2 through 11 and are summarized in Table 1, below. Figures 2 and 3 show the seismic line locations at the Terminal (S3-0190) and Residential (S3-0180) sites, respectively; in addition, low-velocity areas identified from the seismic results are highlighted. Figures 4 through 11 show the P- and S-wave velocity layer models generated from the refraction and surface-wave data, respectively. The P-wave and S-wave models are placed together on the figures to facilitate correlation, although it is worth



noting that the P- and S-wave displays have opposite color scales. In other words, on the P-wave models “cool” (blue) colors indicate higher velocity while on the S-wave models cool (blue-indigo) colors indicate lower velocity.

Overall, five localized zones of low P-wave velocity were observed as follows (Figures 2 and 3):

1. at the eastern end of Line 2
2. at the western end of Line 3
3. at the eastern end of Line 12
4. at the eastern end of Line 16
5. at the center of Line 22

Of these five low P-wave velocity areas, four areas also exhibit corresponding lower S-wave velocities. As such these four areas represent the most likely of voids and/or soft sediments.

1. Line 2, between 220 and 400 ft
2. Line 12, between 160 and 230 ft
3. Line 16, between 280 and 360 ft
4. Line 22, between 220 and 340 ft

In addition, Lines 9, 10, 11, 18, 19 and 20 exhibit an overall lower P-wave velocity than the other lines. In general, lower P-wave velocity is indicative of weaker, less-compacted material; however, the high noise levels in the refraction data from these lines, many of which were located in the Terminal area, may have obscured the refracted arrivals in seismic traces and led to erroneous first-break picks and inaccurate velocity calculations. Accordingly, the P-wave refraction results may not accurately depict subsurface conditions along these lines.

Examination of the of the time-distance (TD) plots from the refraction data and the resulting velocity models indicates that, in general, two subsurface layers were detected— an upper layer exhibiting P-wave velocities less than 2,000 feet per second (fps) representing soil and loosely consolidated sediment, and a lower layer exhibiting P-wave velocities ranging between 2,000 and 5,100 fps that represents more consolidated sediment, which may be saturated in some areas. For some lines, particularly the noisy ones, only one layer was detected, largely because first-break picks could not be made on seismic traces from the more distant (from the shotpoints) geophones.

The investigation depth for the refraction survey varied according to the amount of noise, ranging from 50 or 60 feet below ground surface (bgs) in the quieter areas to about 30 feet bgs in the noisy areas. It is worth noting that, given the overall low P-wave velocities observed, “bedrock” was likely not detected. AGS understands that the investigation area is underlain by limestone bedrock. Such bedrock, if detected, would exhibit extremely high P-wave velocity, probably in excess of 8,000 fps. Finally, the undulations observed on the P-wave velocity models (e.g., *Figure 6*, Lines 6 and 7) could represent actual distortions in sediment layering, artifacts of irregular arrival-time picks on the noisy seismic records, or a combination of both factors.



The investigation depth for the surface-wave survey was in excess of 100 feet bgs; however, the surface-wave survey lacked the lateral resolution of the refraction survey. This is because surface-wave surveys use a single long geophone array on the ground surface to obtain information about bulk properties (S-wave velocity) of subsurface materials beneath the array. Although surface-wave surveys provide information about S-wave velocity variations with depth at a single point (the center of the geophone array), they are more suited for assessing Vs30, the average S-wave velocity of the upper 100 feet (30 meters), for seismic site classification. In general, Vs30 at the Montello sites ranged between 1,000 and 1,200 fps (seismic site class “D”—stiff soil), with the lower-velocity zones exhibiting Vs30 values between 700 and 900 fps.

The Montello seismic investigation was performed using a series of overlapping 230-foot long arrays, each consisting of 24 geophones. Surface-waved data were processed by gathering and processing separately data from 12 geophones at a time to produce a series of 1D S-wave soundings spaced approximately 60 feet apart, which were then combined to produce the 2D cross sections shown on the Report figures. Hence, the surface-wave survey lacked the lateral resolution of the refraction survey, which provided subsurface information at each 10-foot spaced geophone location. This explains the smoother-looking appearance of the S-wave cross sections as compared to the refraction models.

Table 1 – Summary of Seismic Survey Results

| Line | Figure | Localized Low P-wave ( $V_p$ ) velocity Zone Observed? | Location of Low P-wave velocity zone(s) | Correlate with Low S-wave Velocity? | P-wave Velocity of “basement” (fps) | Comments  |
|------|--------|--|---|-------------------------------------|-------------------------------------|---|
| 1    | 4      | n  |   |                                     | 3700                                | Good refraction data                              |
| 2    | 4      | Y  | 220-400 ft                              | Y                                   | 5100                                | Void/Soft Sediment area?                          |
| 3    | 5      | Y  | 40-230 ft                               | N                                   | 3500                                | High S-wave velocities observed in low $V_p$ area |
| 4    | 5      | n  |   |                                     | 4100                                | Good refraction data                              |
| 5    | 5      | n  |   |                                     | 3500                                | Good refraction data                              |
| 6    | 6      | n  |   |                                     | 2600                                | Slow $V_p$  |
| 7    | 6      | n  |   |                                     | 4400                                | Good refraction data                              |
| 8    | 6      | n  |   |                                     | 9000                                | TD plot dislocations                              |
| 9    | 6      | n  |   |                                     | 1700                                | Extremely noisy line                              |
| 10   | 7      | n  |   |                                     | 1700                                | Slow $V_p$  |
| 11   | 7      | n  |   |                                     | 1700                                | Slow $V_p$  |
| 12   | 7      | Y  | 160-230 ft                              | Y                                   | 2300                                | Void/Soft Sediment area?                          |
| 13   | 7      | n  |   |                                     | 4100                                | Good refraction data                              |
| 14   | 8      | n  |   |                                     | 3200                                | Good refraction data                              |
| 15   | 8      | n  |   |                                     | 4100                                | Thick top layer                                   |
| 16   | 8      | Y  | 280-360 ft                              | Y                                   | 5200                                | Void/Soft Sediment area?                          |
| 17   | 9      | n  |   |                                     | 3200                                | Good refraction data                              |
| 18   | 9      | n  |   |                                     | 1400                                | Slow $V_p$  |
| 19   | 9      | n  |   |                                     | 1400                                | Slow $V_p$  |
| 20   | 10     | n  |   |                                     | 2000                                | Slow $V_p$  |
| 21   | 10     | n  |   |                                     | 2700                                | Good refraction data                              |
| 22   | 11     | Y  | 220-340 ft                              | Y                                   | 5000                                | Void/Soft Sediment area?                          |



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## 8.0 CLOSING

All geophysical data and field notes collected as a part of this investigation will be archived at the AGS office. The data collection and interpretation methods used in this investigation are consistent with standard practices applied to similar geophysical investigations. The correlation of geophysical responses with probable subsurface features is based on the past results of similar surveys although it is possible that some variation could exist at this site. Due to the nature of geophysical data, no guarantees can be made or implied regarding the targets identified or the presence or absence of additional objects or targets.

AGS appreciates working for you on this project and we look forward to working with you again.

Sincerely,



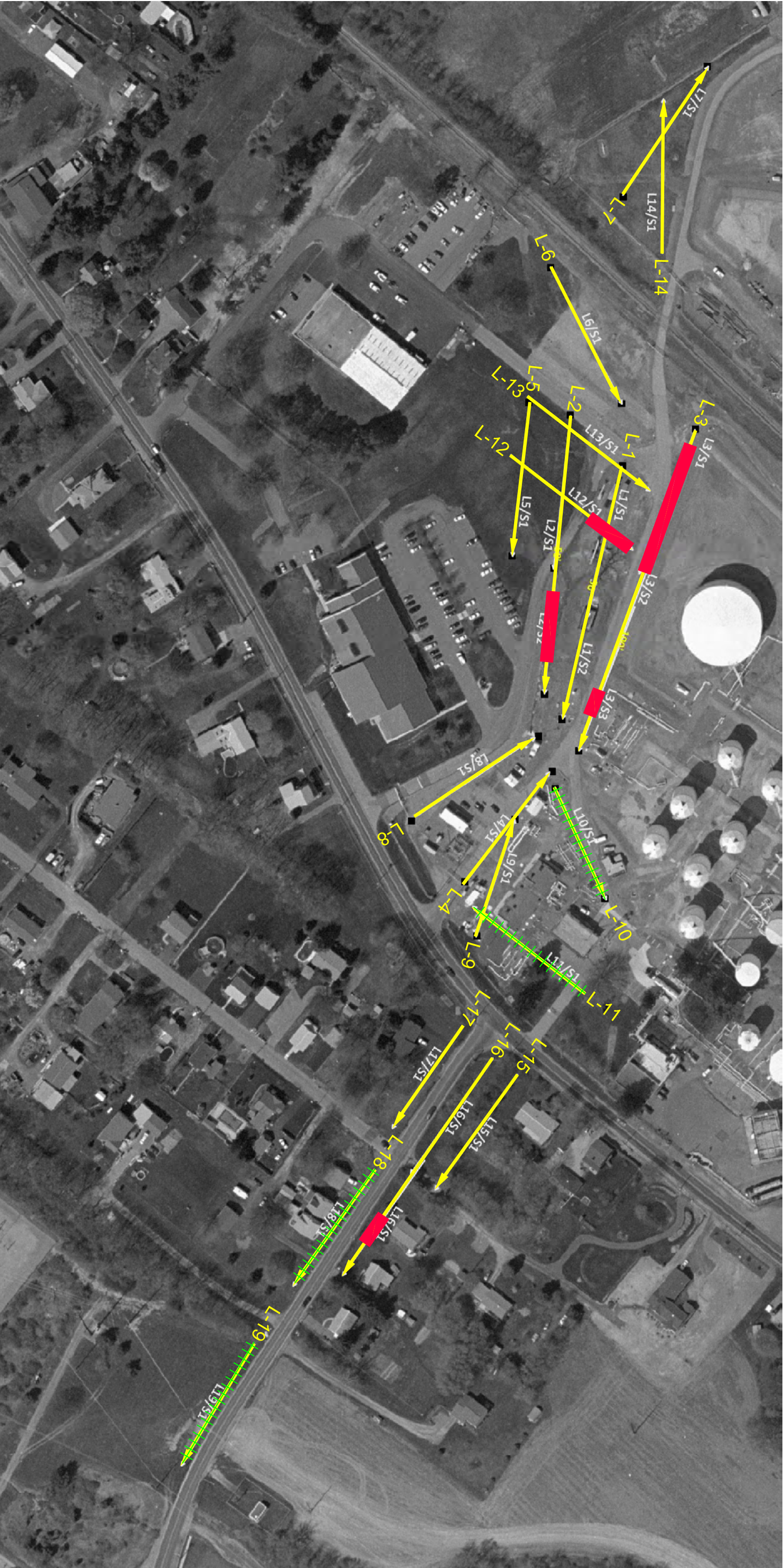
Roark W. Smith  
Senior Geophysicist  
Advanced Geological Services, Inc.

### Figures:




|           |   |
|-----------|---|
| Figure 1  | Site Location (imbedded in Report text, above)                            |
| Figure 2  | Seismic Line Locations and Low-Velocity Areas, Terminal Site (S3-0190)    |
| Figure 3  | Seismic Line Locations and Low-Velocity Areas, Residential Site (S3-0180) |
| Figure 4  | Seismic Survey Results, Lines 1 and 2                                     |
| Figure 5  | Seismic Survey Results, Lines 3, 4 and 5                                  |
| Figure 6  | Seismic Survey Results, Lines 6, 7, 8 and 9                               |
| Figure 7  | Seismic Survey Results, Lines 10, 11, 12 and 13                           |
| Figure 8  | Seismic Survey Results, Lines 14, 15, and 16                              |
| Figure 9  | Seismic Survey Results, Lines 17, 18 and 19                               |
| Figure 10 | Seismic Survey Results, Lines 20 and 21                                   |
| Figure 11 | Seismic Survey Results, Line 22   |

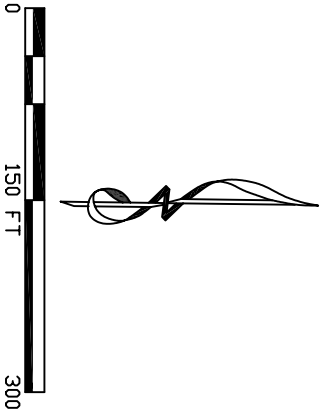
Attachments: Appendix A: Seismic Velocity and Limitations of the Refraction Method

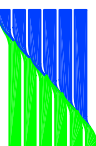




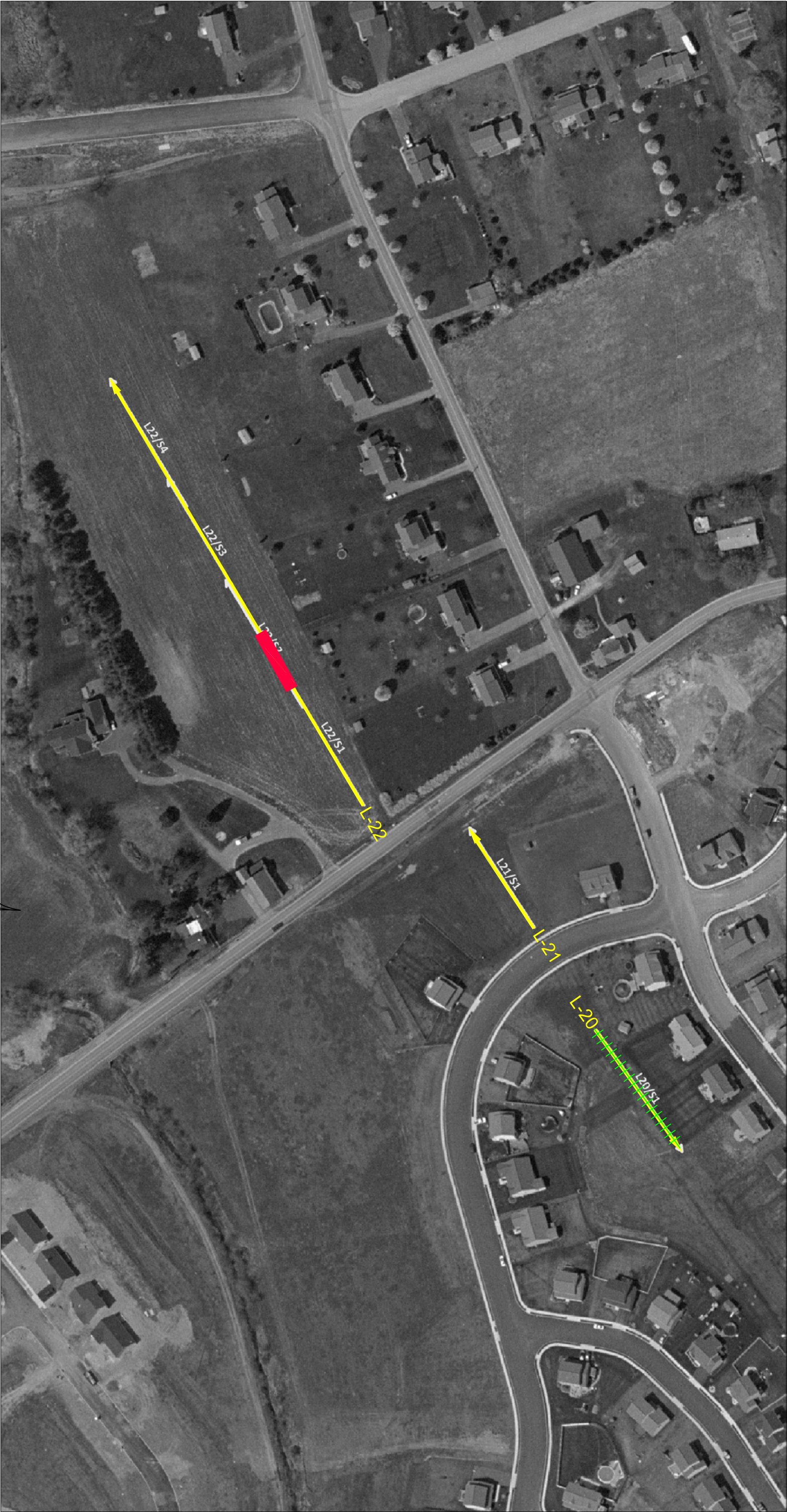
EXPLANATION

-  L-14 SEISMIC LINE LOCATION
-  LOW-VELOCITY ZONE INDICATIVE OF POTENTIAL VOIDS OR SOFT SEDIMENT
-  ENTIRE SEISMIC LINE EXHIBITS LOW VELOCITY



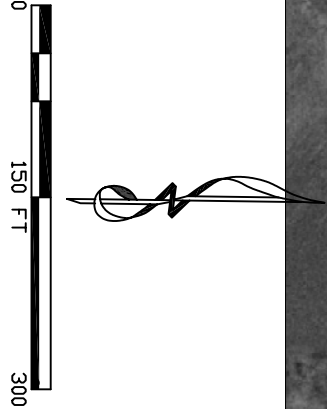
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| 3 Mystic Lane<br>Malvern, PA 19355<br>(925) 808-8965  |  | LOCATION: Sinking Springs, PA  |                    |
|   |  | CLIENT: Tetra Tech   |                    |
|   |  | PROJECT #: 15-122-1PA  |                    |
|   |  | DATE: Apr 24, 2015   | DRAWN BY: R. SMITH |
|   |  | FIGURE<br><b>2</b>   |                    |





- EXPLANATION
- L-21

SEISMIC LINE LOCATION
- LOW-VELOCITY ZONE INDICATIVE OF  
POTENTIAL VOIDS OR SOFT SEDIMENT
- ENTIRE SEISMIC LINE EXHIBITS LOW VELOCITY



Seismic Line Locations  
Site S3-0180 - Residential Area  
Sunoco Montello Terminal

LOCATION: Sinking Springs, PA

CLIENT: Tetra Tech

3 Mystic Lane  
Malvern, PA 19355  
(925) 808-8965

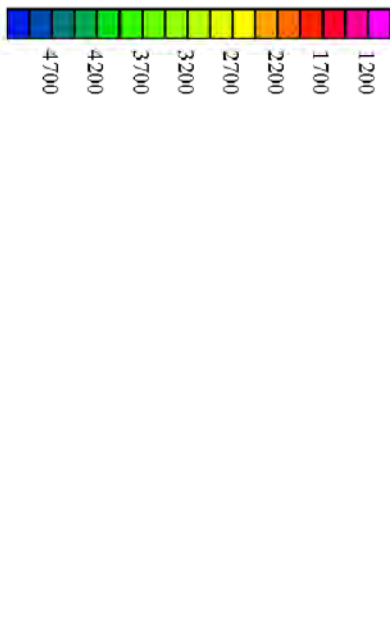
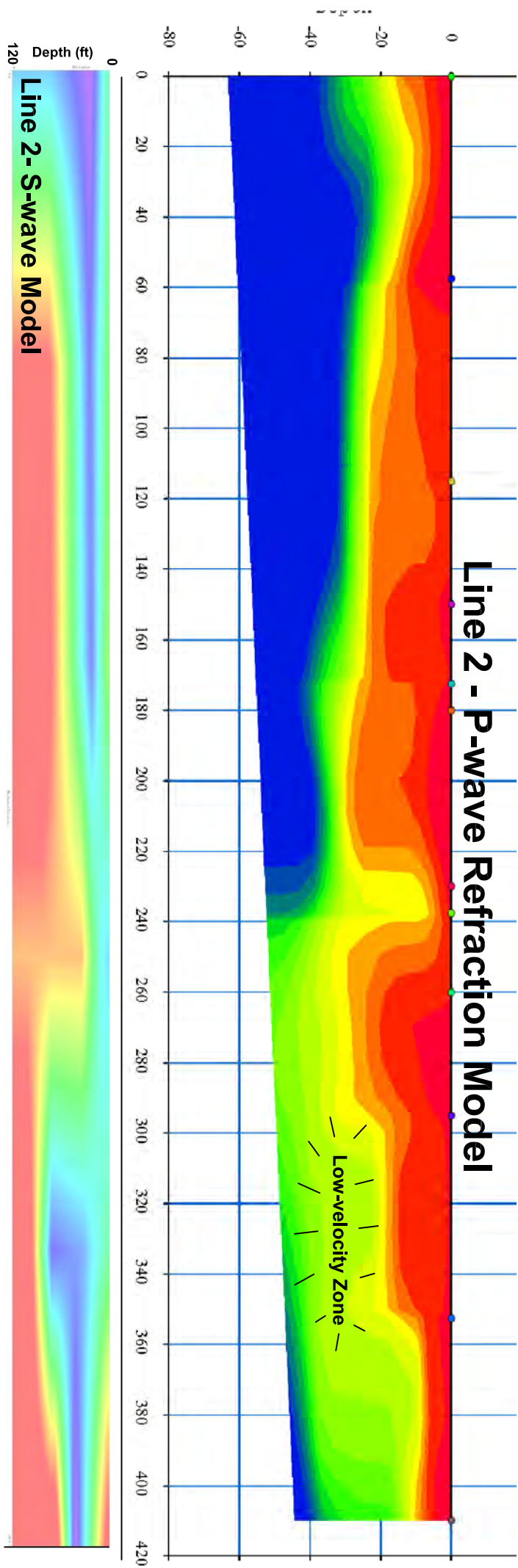
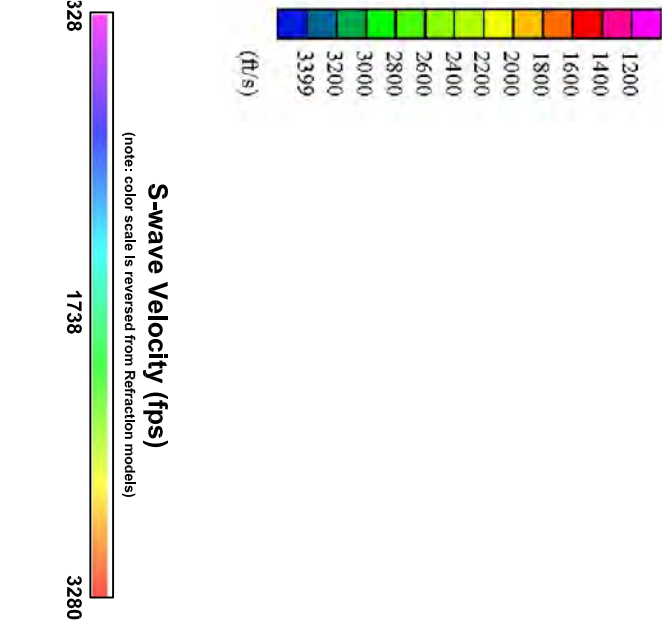
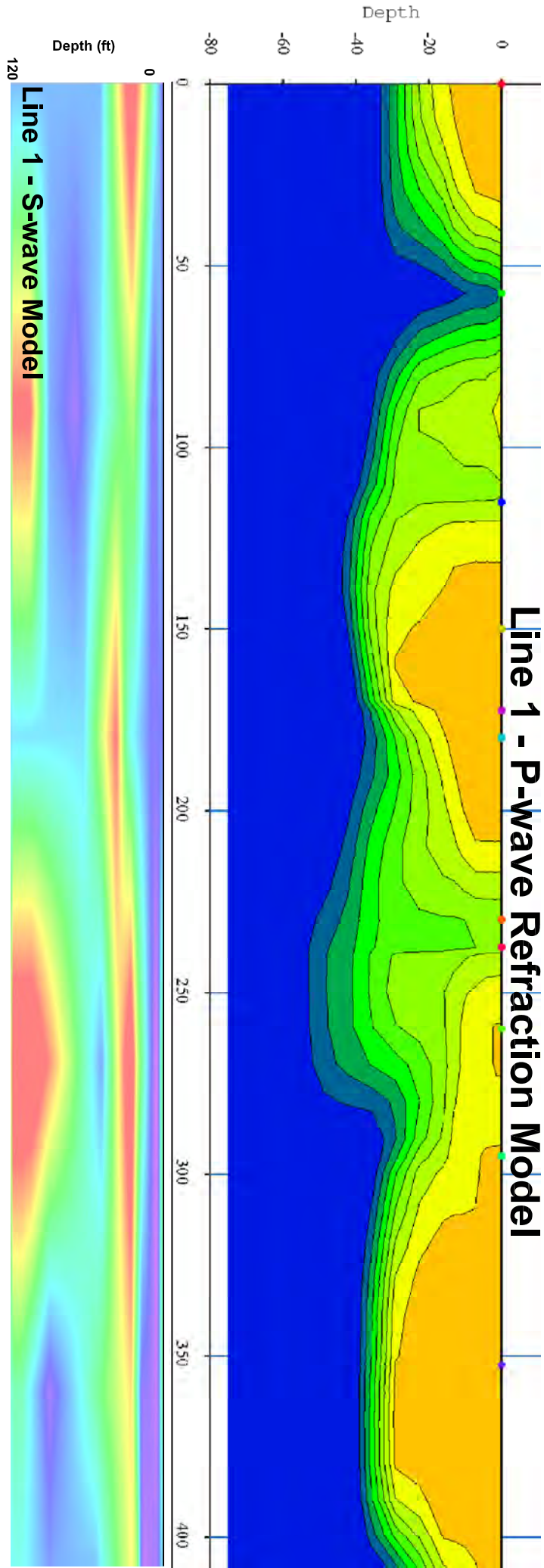
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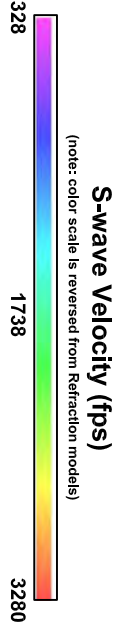
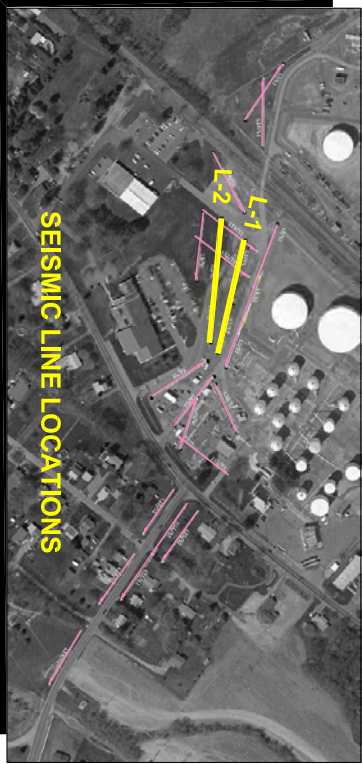
FIGURE

3





Line 2 - S-wave Model



Seismic Survey Results  
L-1, L-2  
Site S3-0190 - Terminal Area

LOCATION: Sinking Springs, PA

CLIENT: Tetra Tech

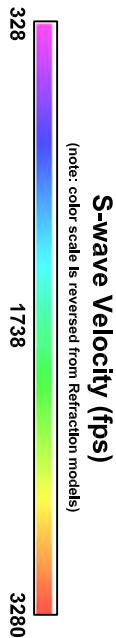
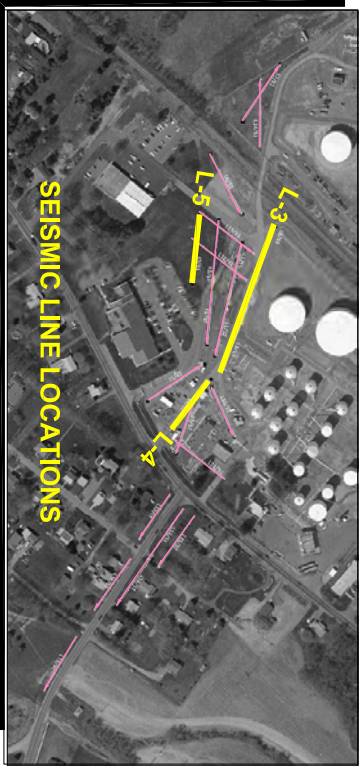
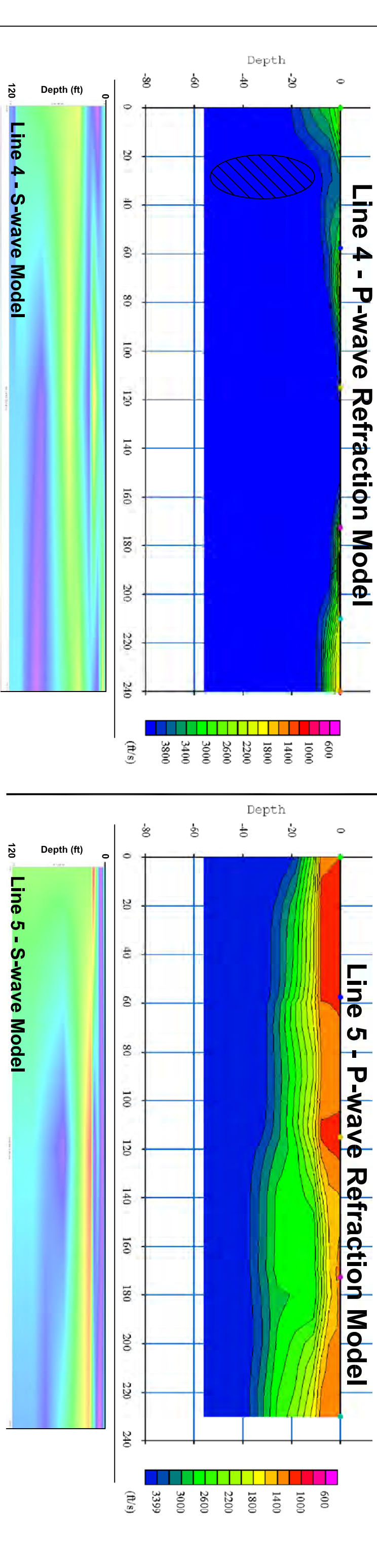
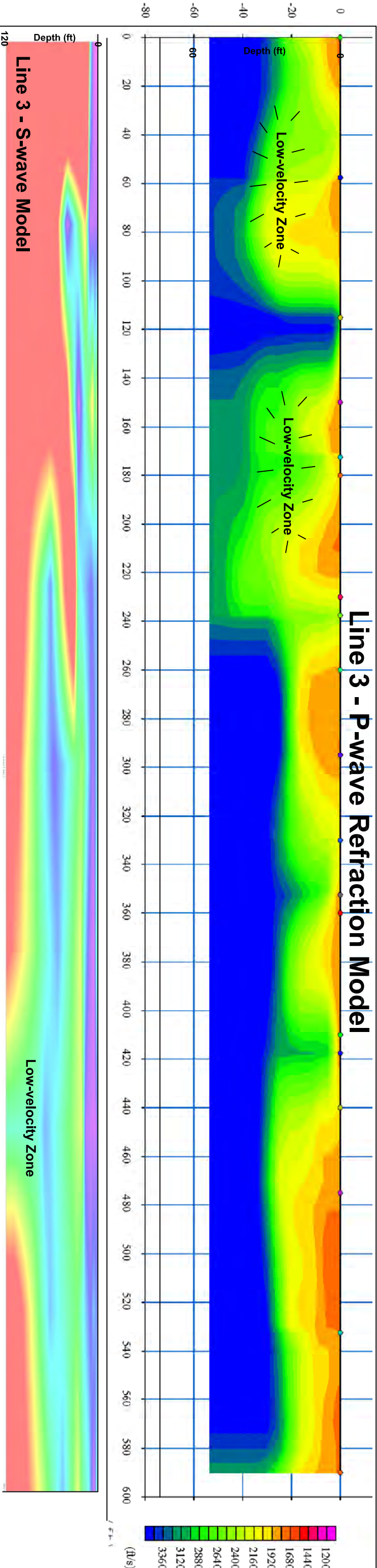
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DATE: Apr 24, 2015 DRAWN BY: R. SMITH

FIGURE

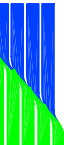
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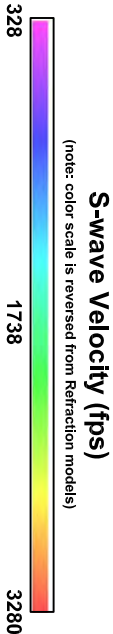
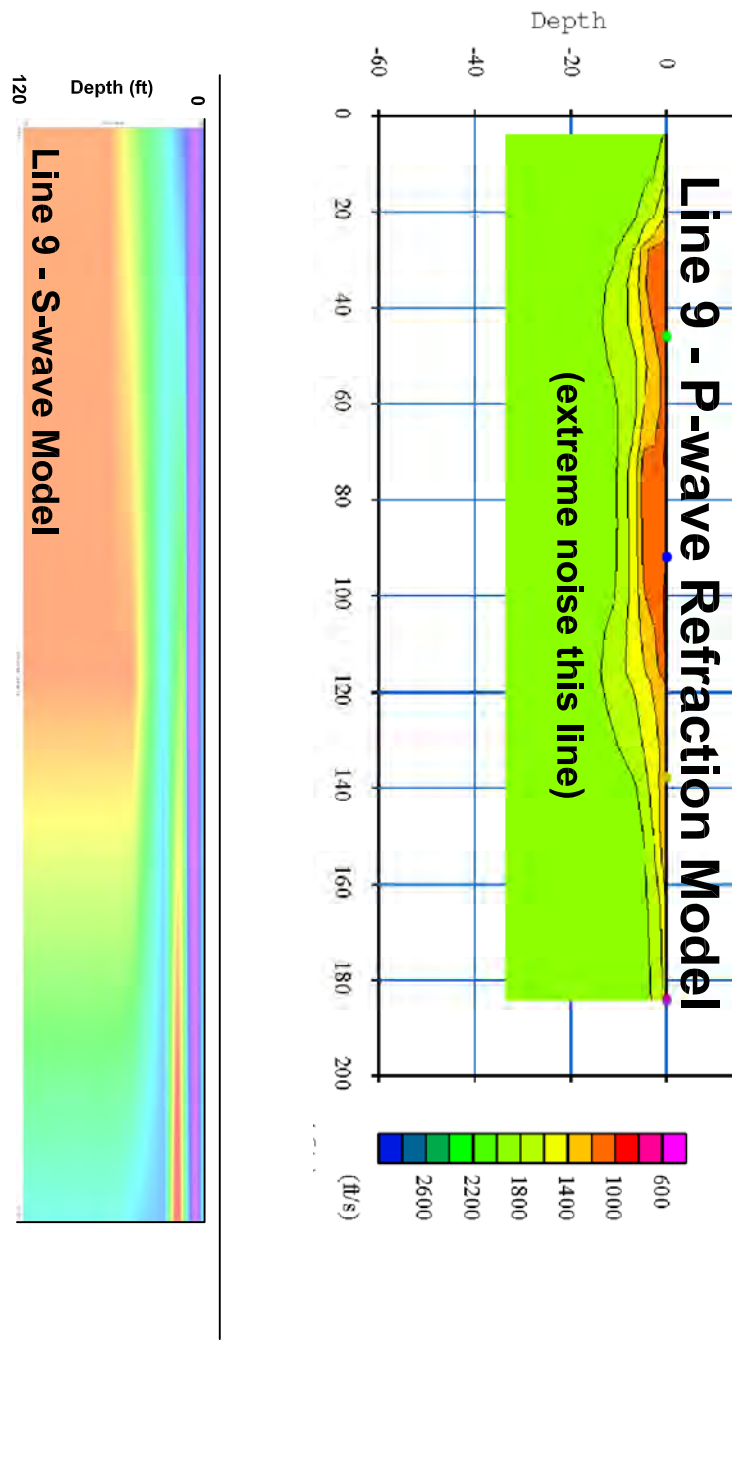
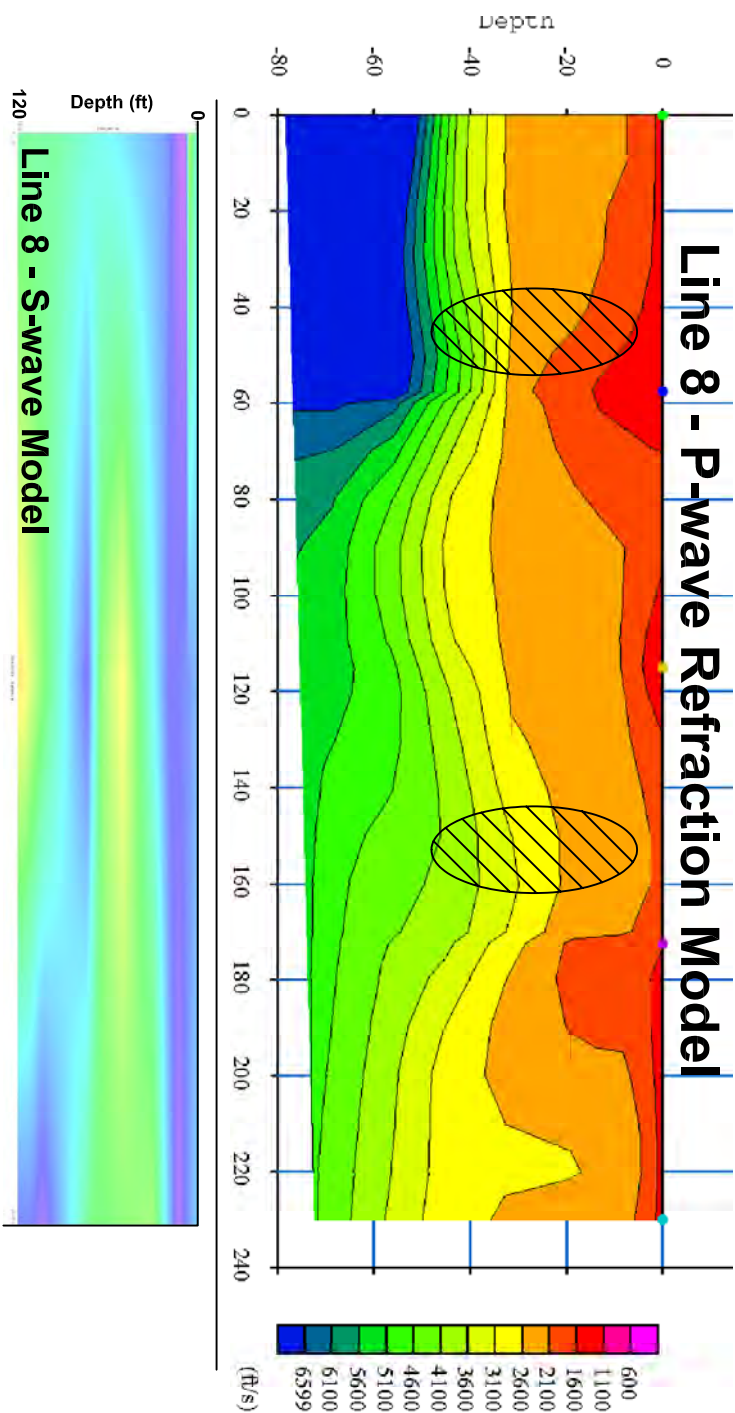
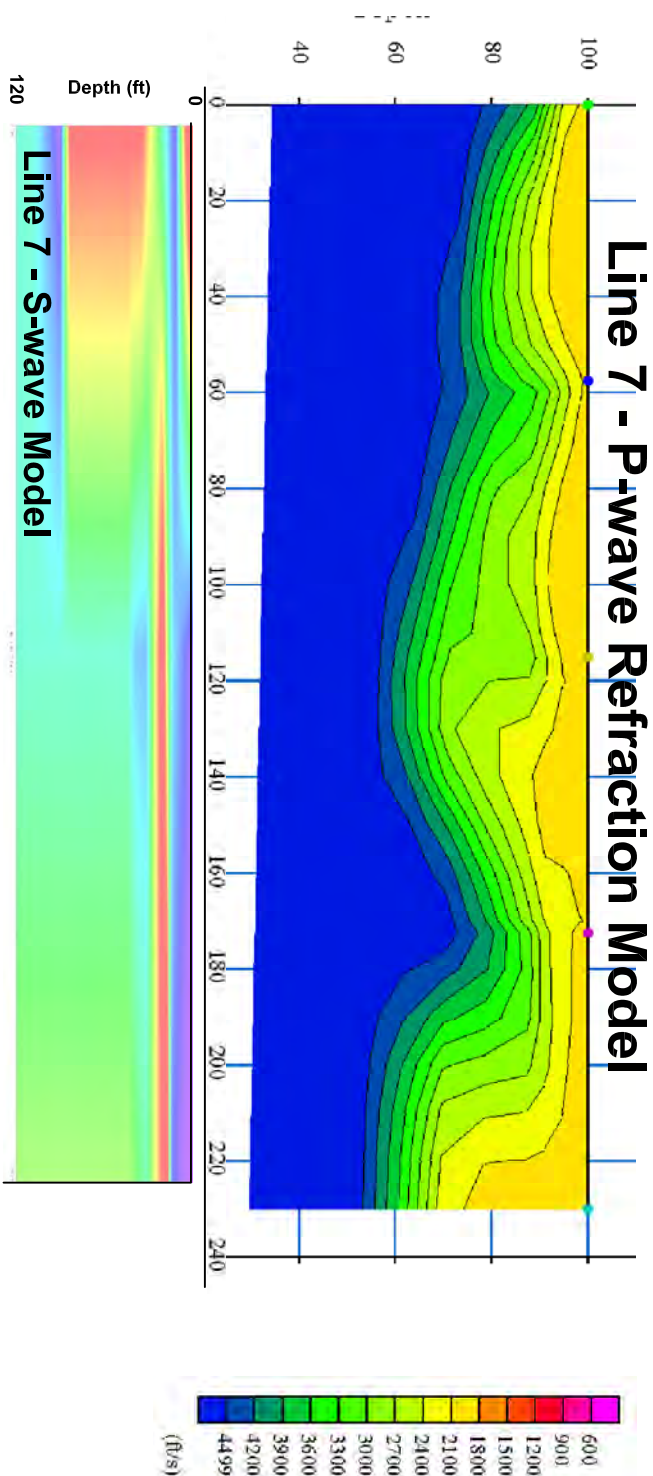
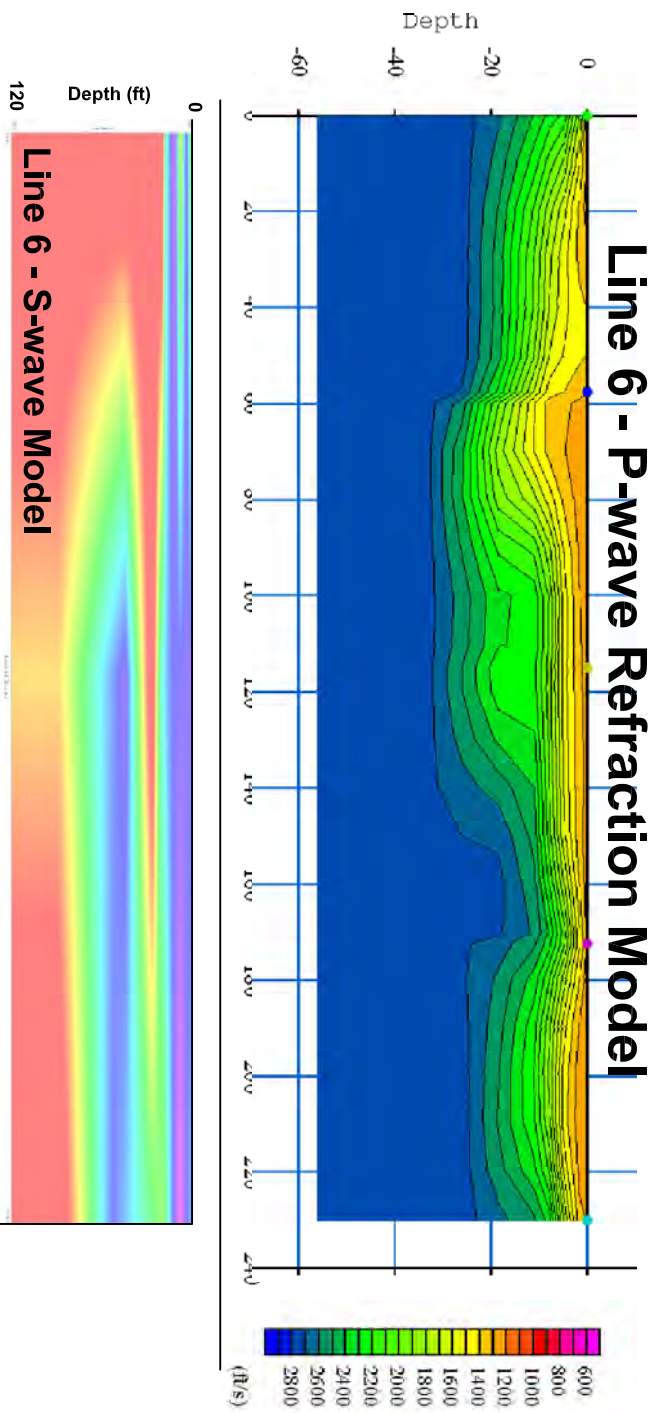


**EXPLANATION**

**TD PLOT DISRUPTION**

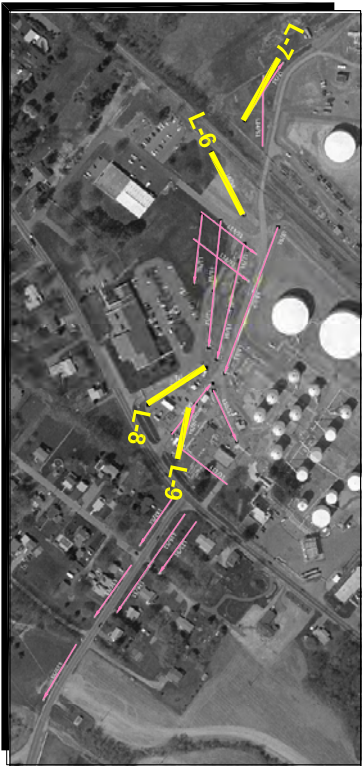
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|  | LOCATION: Sinking Springs, PA   |                    |        |  |
|  | CLIENT: Tetra Tech  |                    | FIGURE |  |
|  | PROJECT #: 15-122-1PA   |                    |        |  |
| 3 Mystic Lane<br>Malvern, PA 19355<br>(925) 808-8965   | DATE: Apr 24, 2015  | DRAWN BY: R. SMITH | 5      |  |



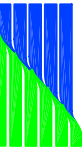


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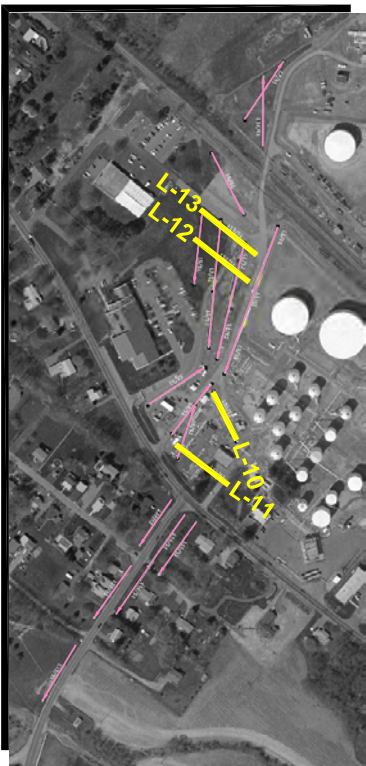
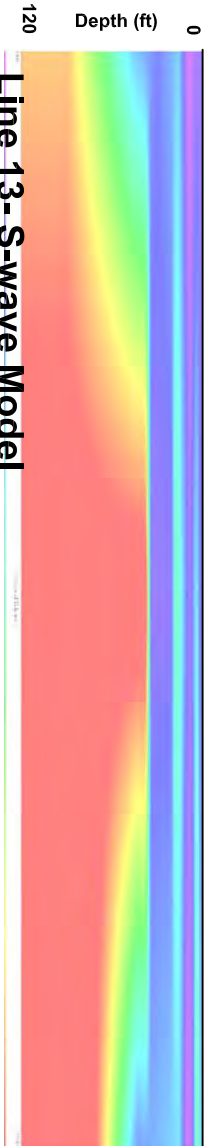
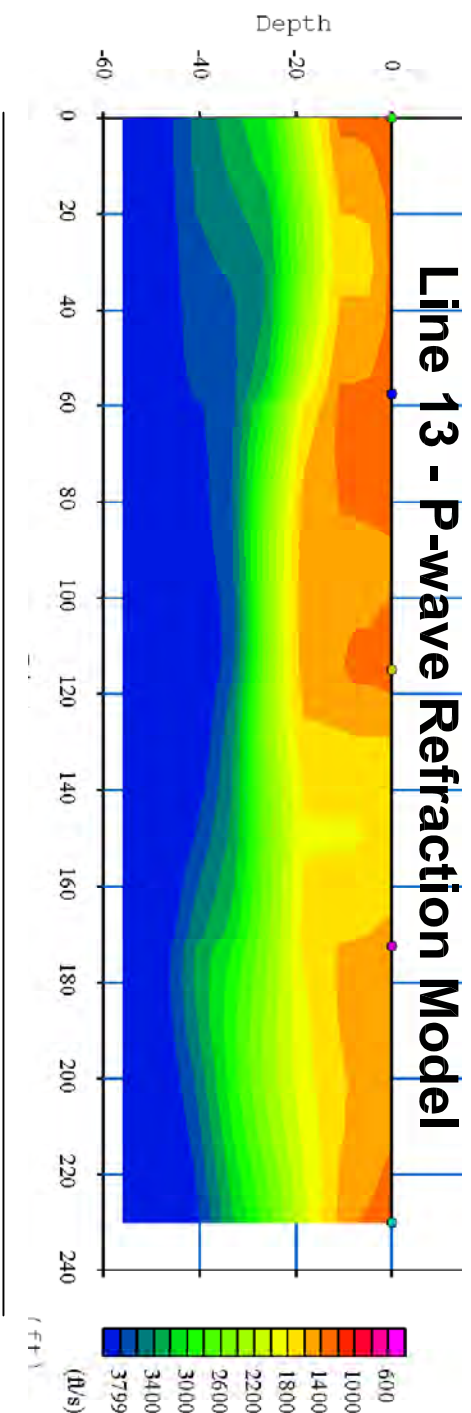
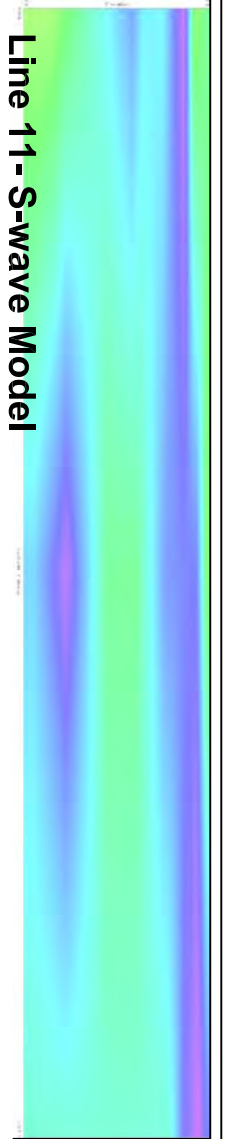
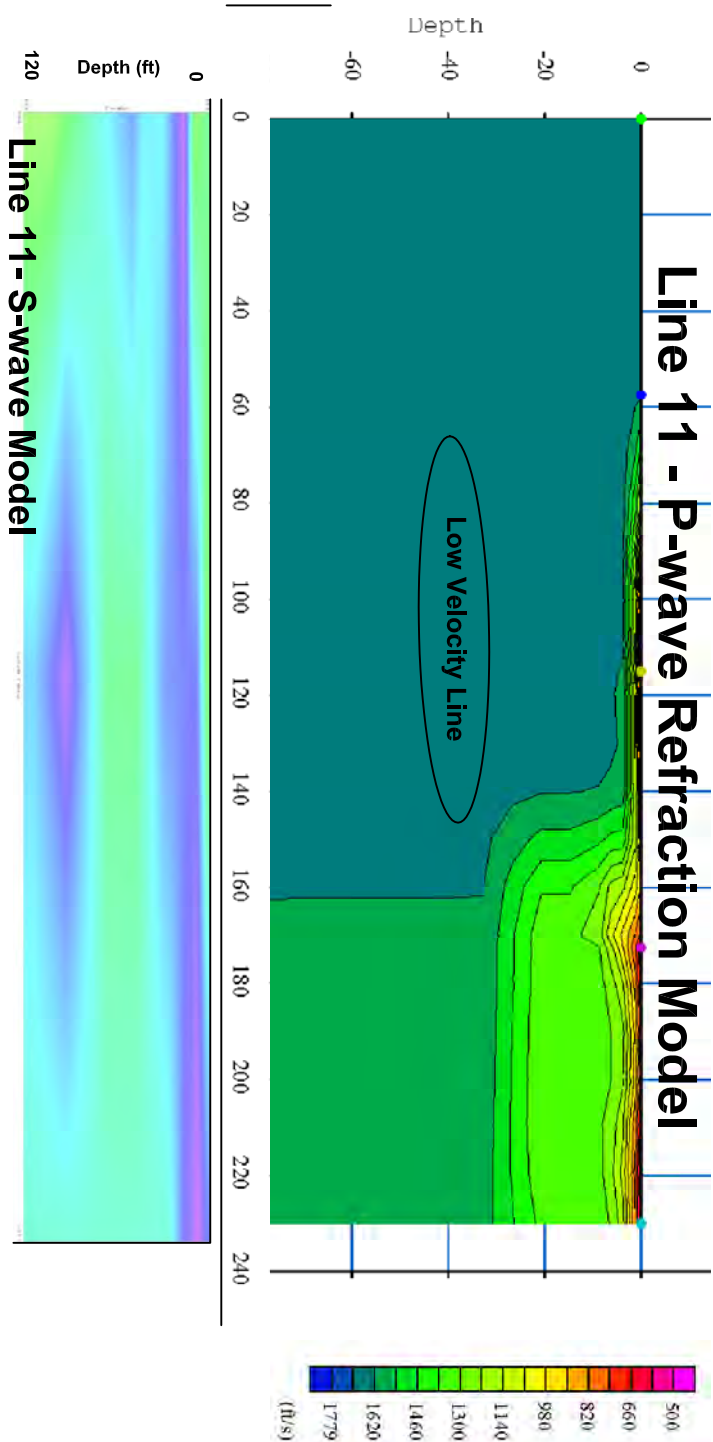
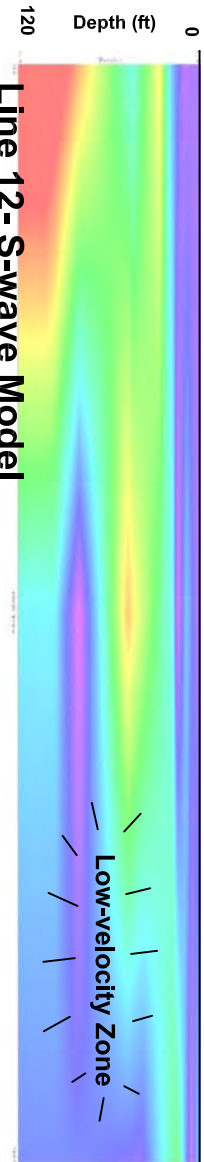
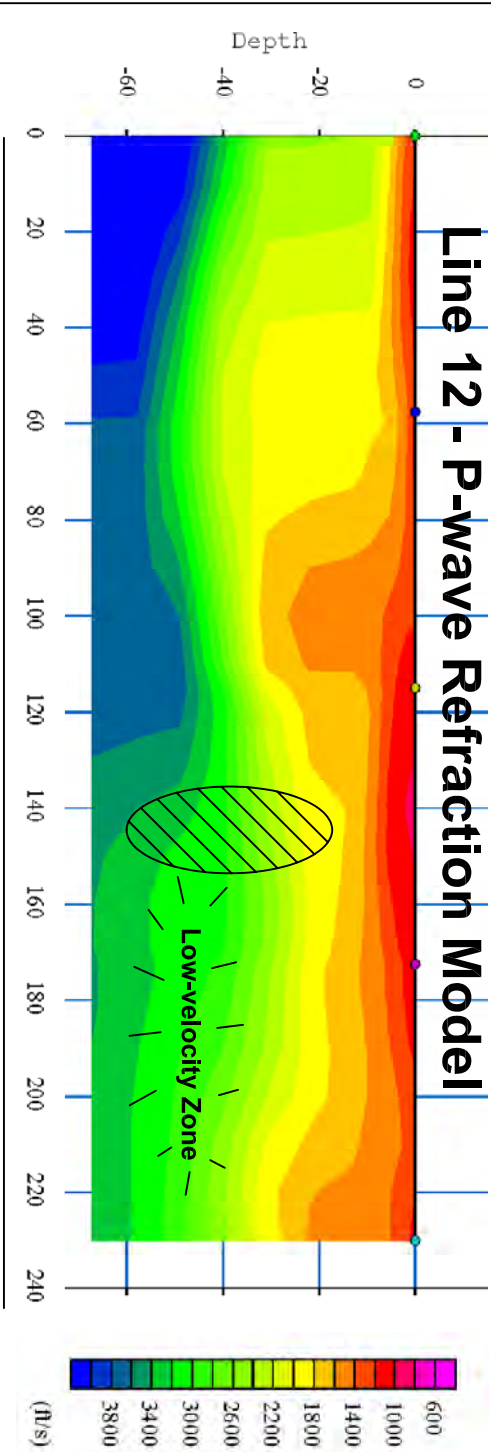
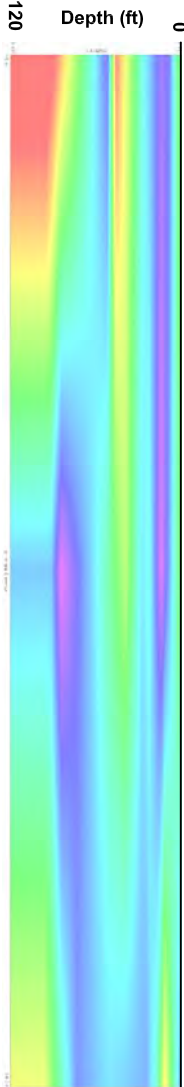
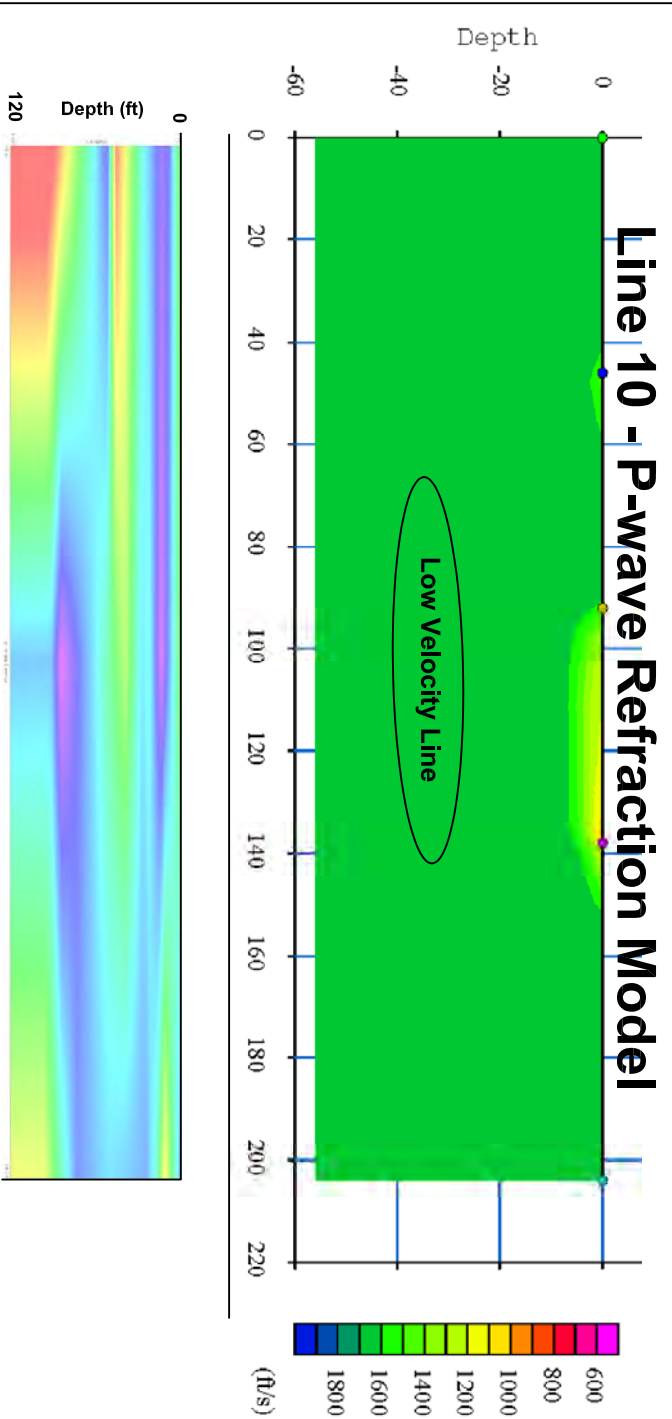
**TD PLOT DISRUPTION**



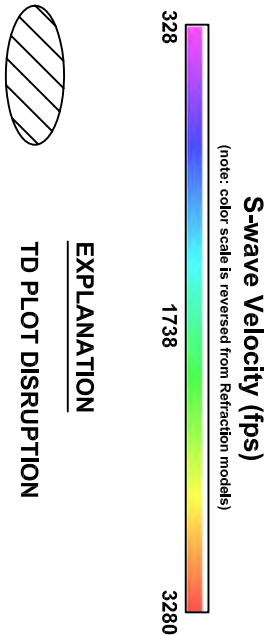
SEISMIC LINE LOCATIONS

|  |  |                    |                        |
|--|--|--------------------|------------------------|
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|  | LOCATION: Sinking Springs, PA  |                    | FIGURE<br><br><b>6</b> |
|  | CLIENT: Tetra Tech   |                    |                        |
|  | PROJECT #: 15-122-1PA  |                    |                        |
|  | DATE: Apr 24, 2015   | DRAWN BY: R. SMITH |                        |
| 3 Mystic Lane<br>Malvern, PA 19355<br>(925) 808-8965   |  |                    |                        |



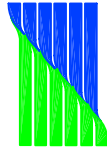


SEISMIC LINE LOCATIONS

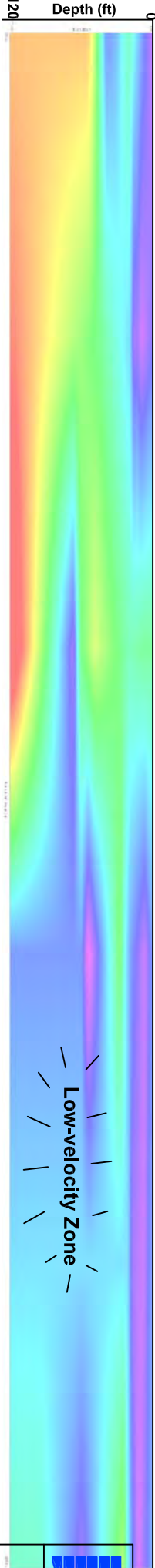
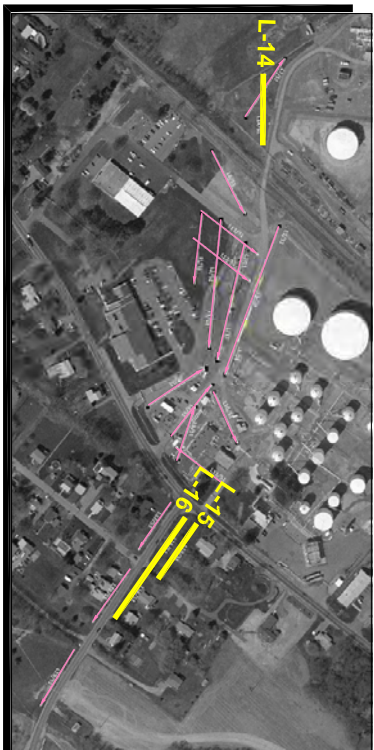
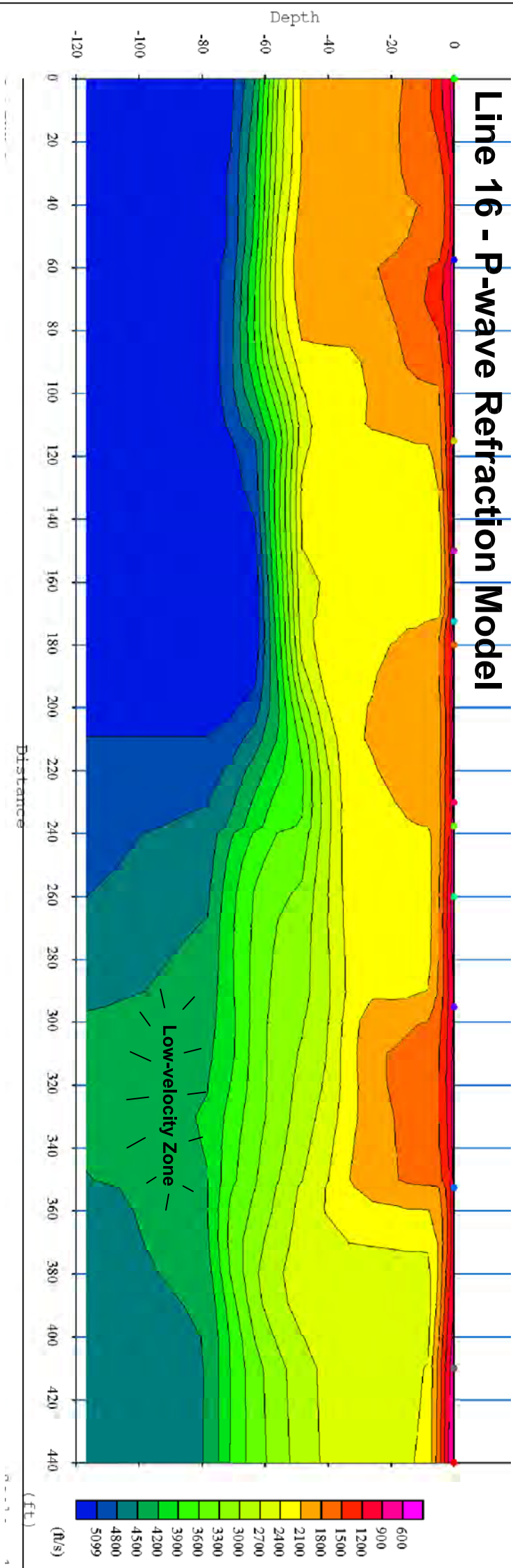
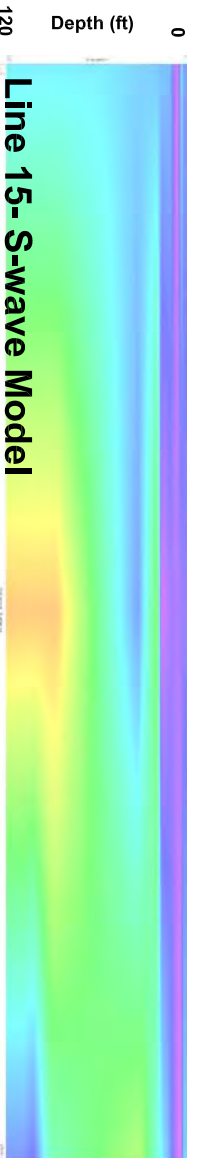
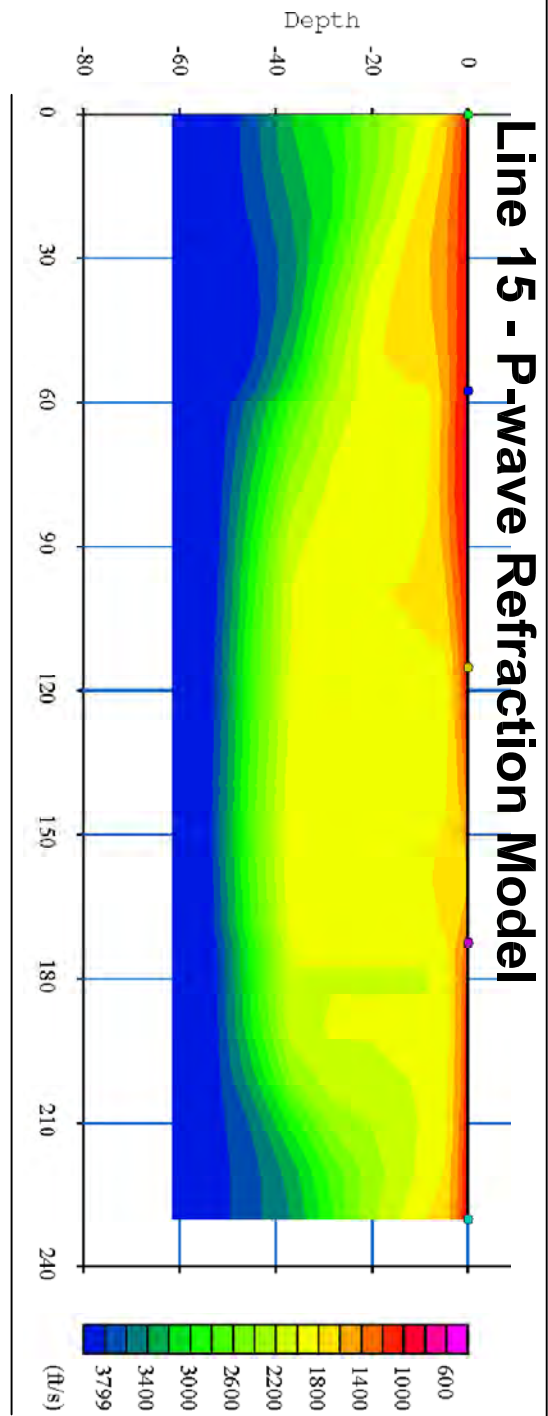
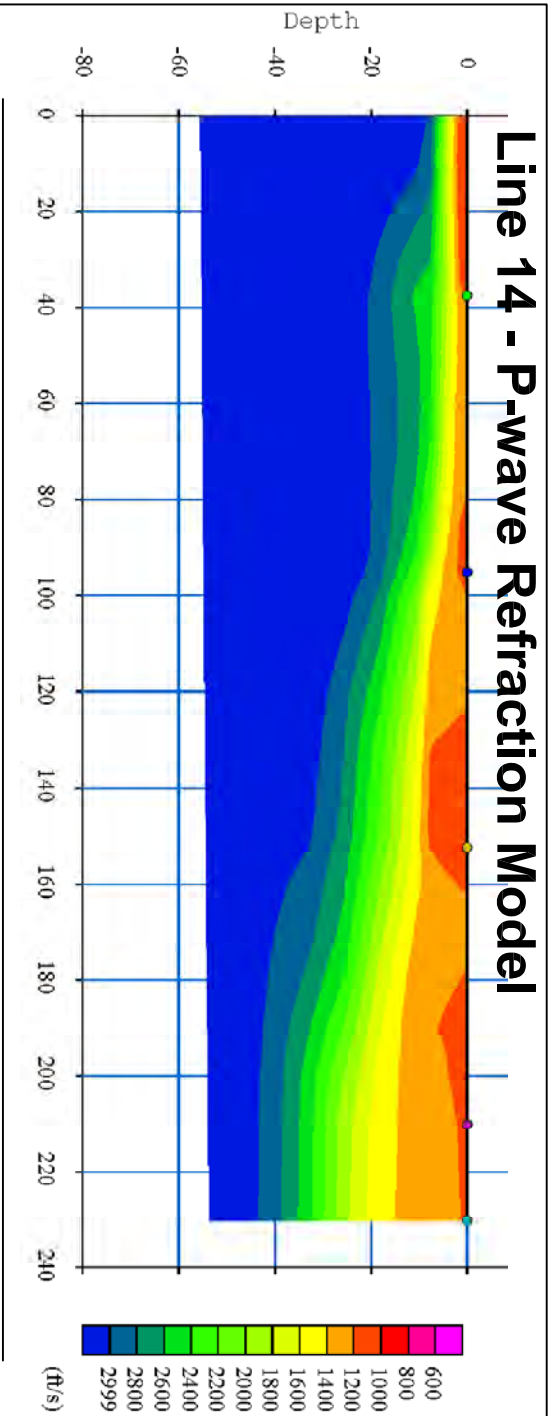


EXPLANATION

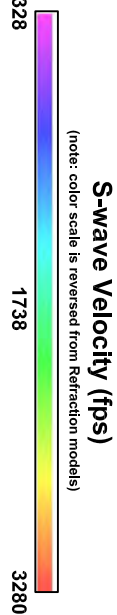
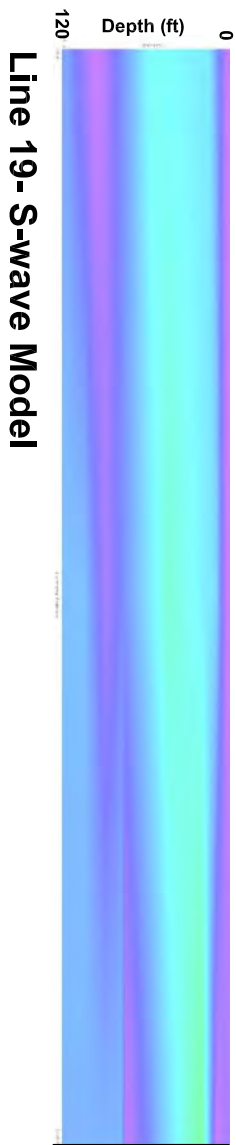
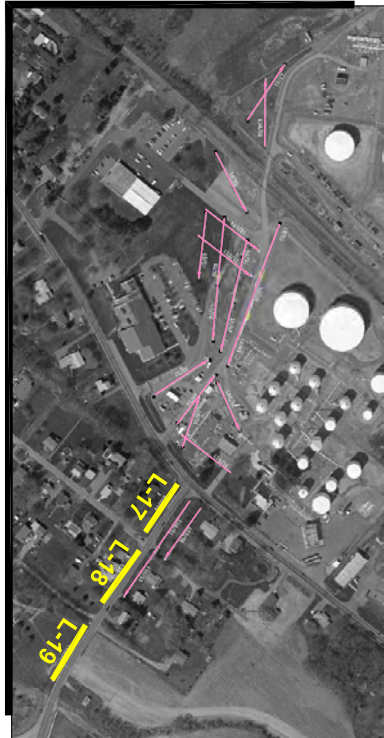
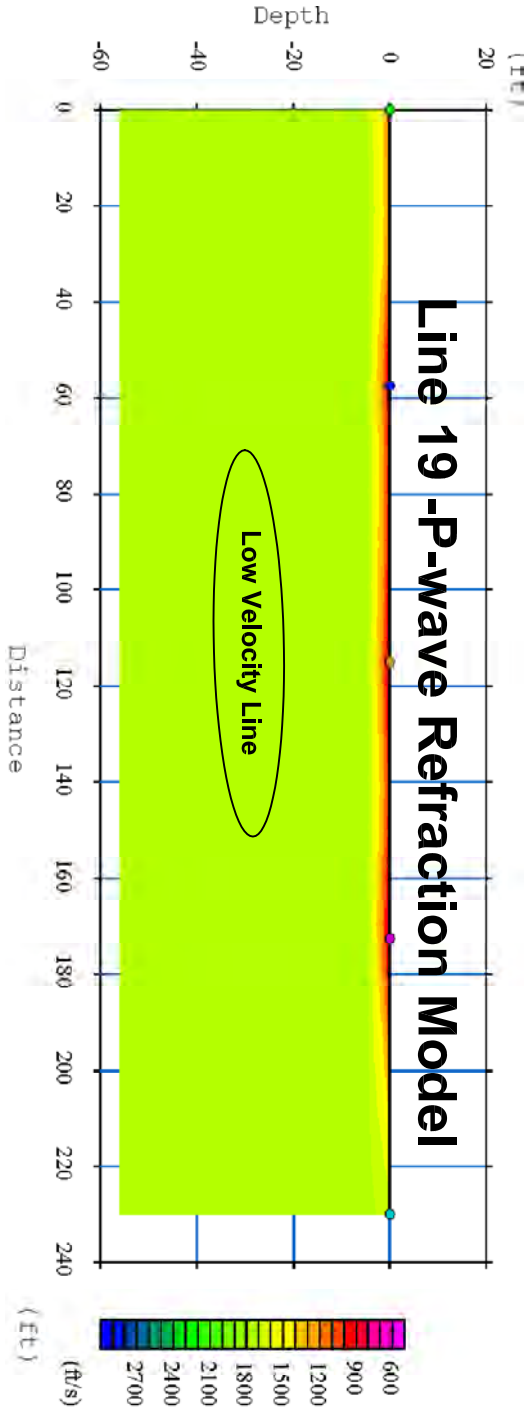
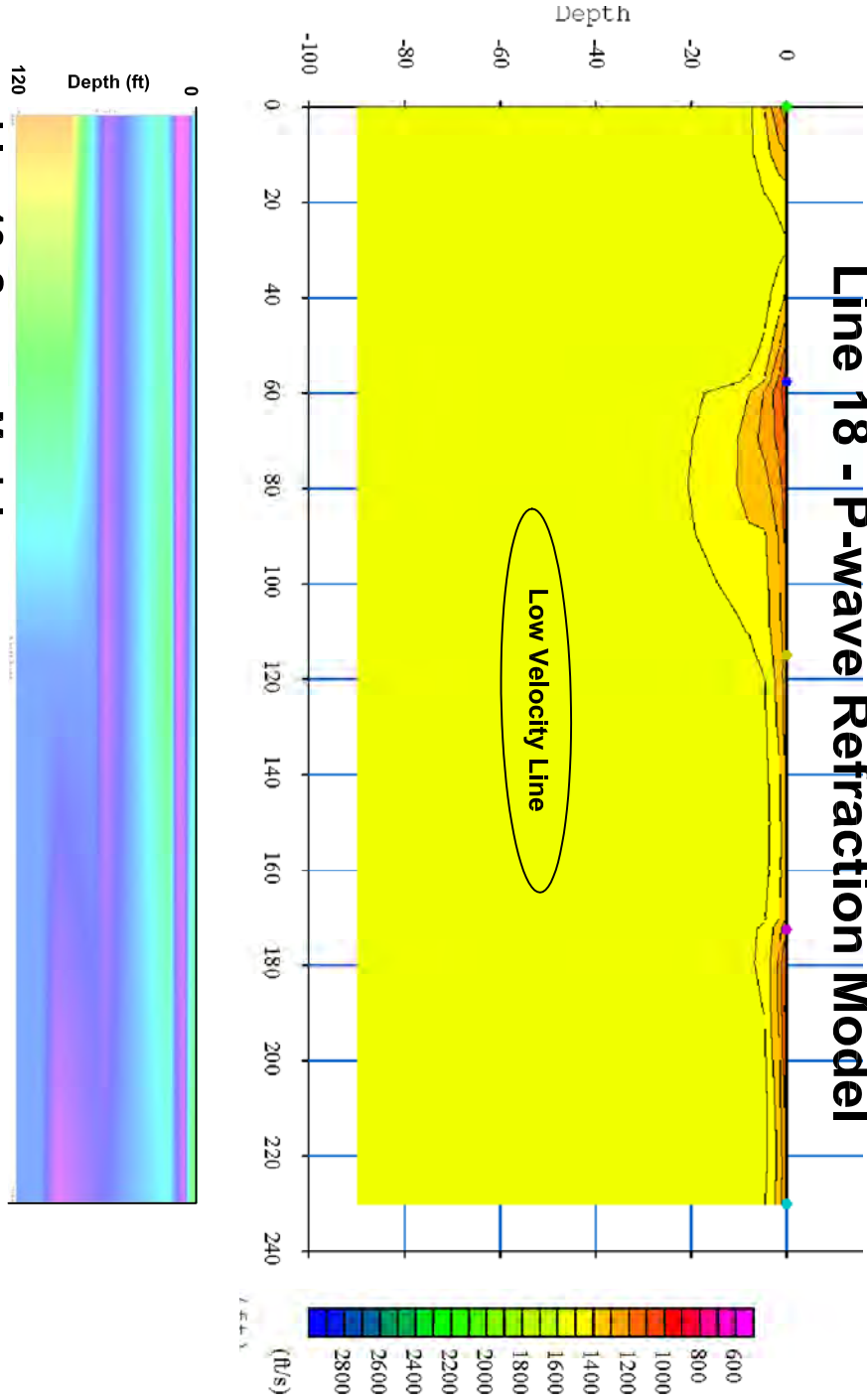
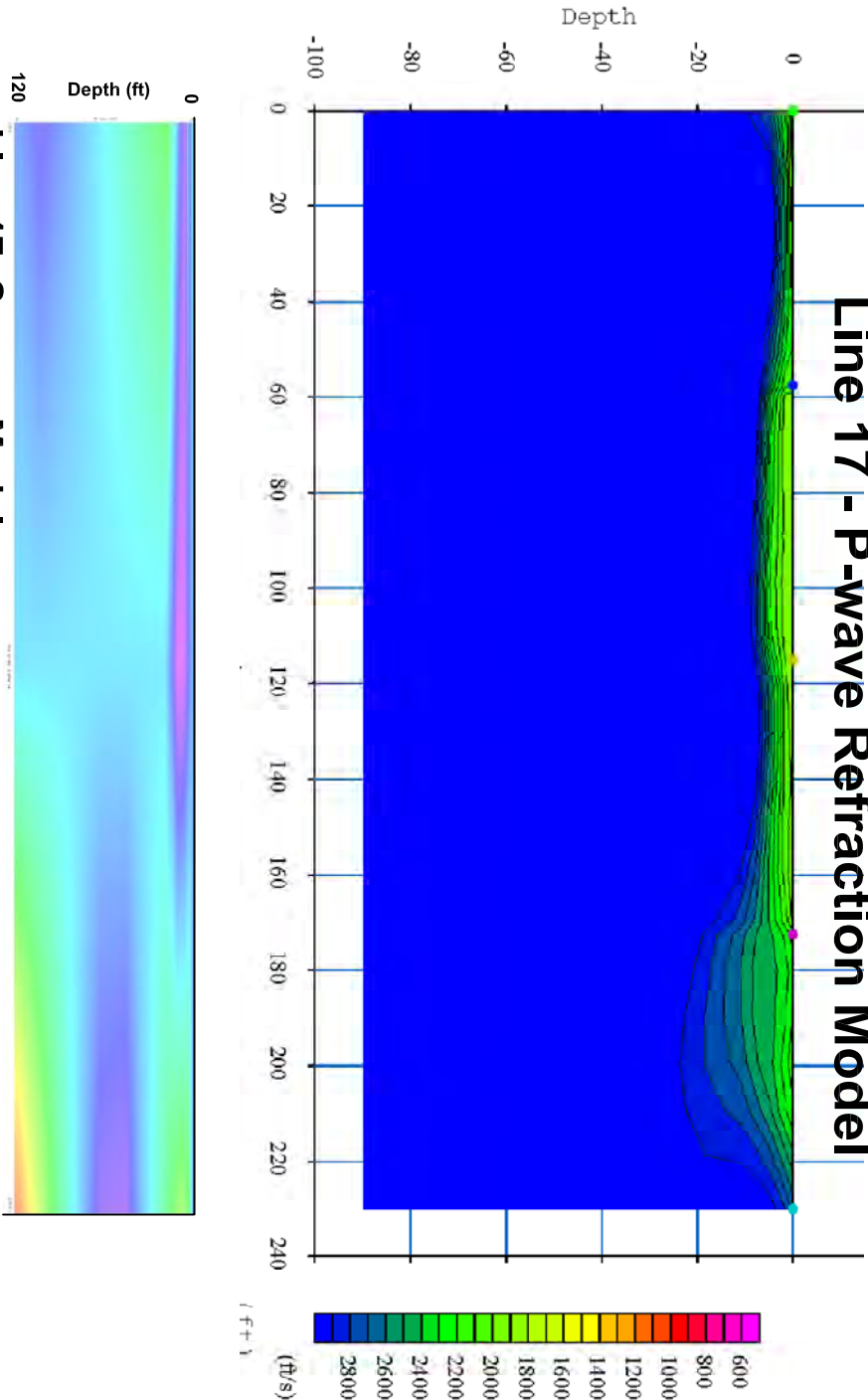
TD PLOT DISRUPTION


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|  <div>ADVANCED<br/>GEOLOGICAL<br/>SERVICES</div> | <div>Seismic Survey Results<br/>L-10, L-11 L-12, L-13<br/>Site S3-0190 - Terminal Area</div>   |                    |                        |                       |                    |                    |  |
| <div>3 Mystic Lane<br/>Molvern, PA 19355<br/>(925) 808-8965</div>   | <div>LOCATION: Sinking Springs, PA</div> <table><tr><td>CLIENT: Tetra Tech</td><td rowspan="3">FIGURE<br/><div>7</div></td></tr><tr><td>PROJECT #: 15-122-1PA</td></tr><tr><td>DATE: Apr 24, 2015</td></tr><tr><td>DRAWN BY: R. SMITH</td><td></td></tr></table> | CLIENT: Tetra Tech | FIGURE<br><div>7</div> | PROJECT #: 15-122-1PA | DATE: Apr 24, 2015 | DRAWN BY: R. SMITH |  |
| CLIENT: Tetra Tech  | FIGURE<br><div>7</div>   |                    |                        |                       |                    |                    |  |
| PROJECT #: 15-122-1PA   |  |                    |                        |                       |                    |                    |  |
| DATE: Apr 24, 2015  |  |                    |                        |                       |                    |                    |  |
| DRAWN BY: R. SMITH  |  |                    |                        |                       |                    |                    |  |



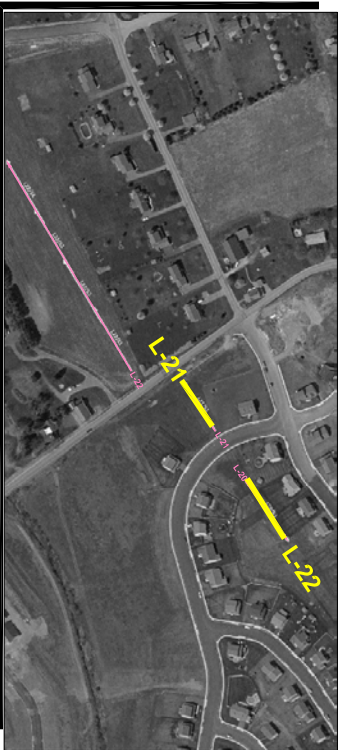
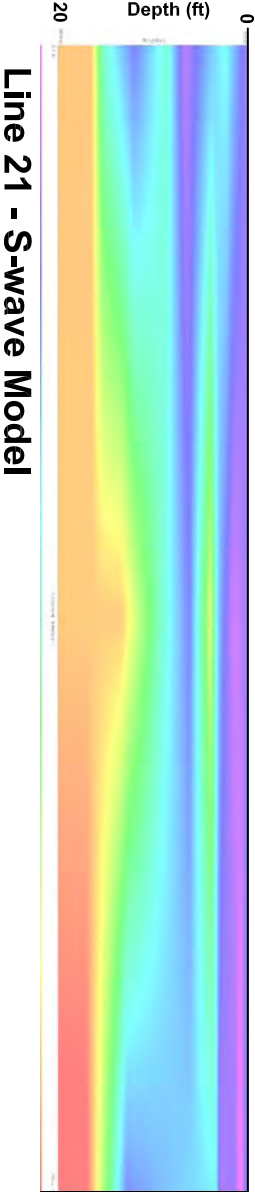
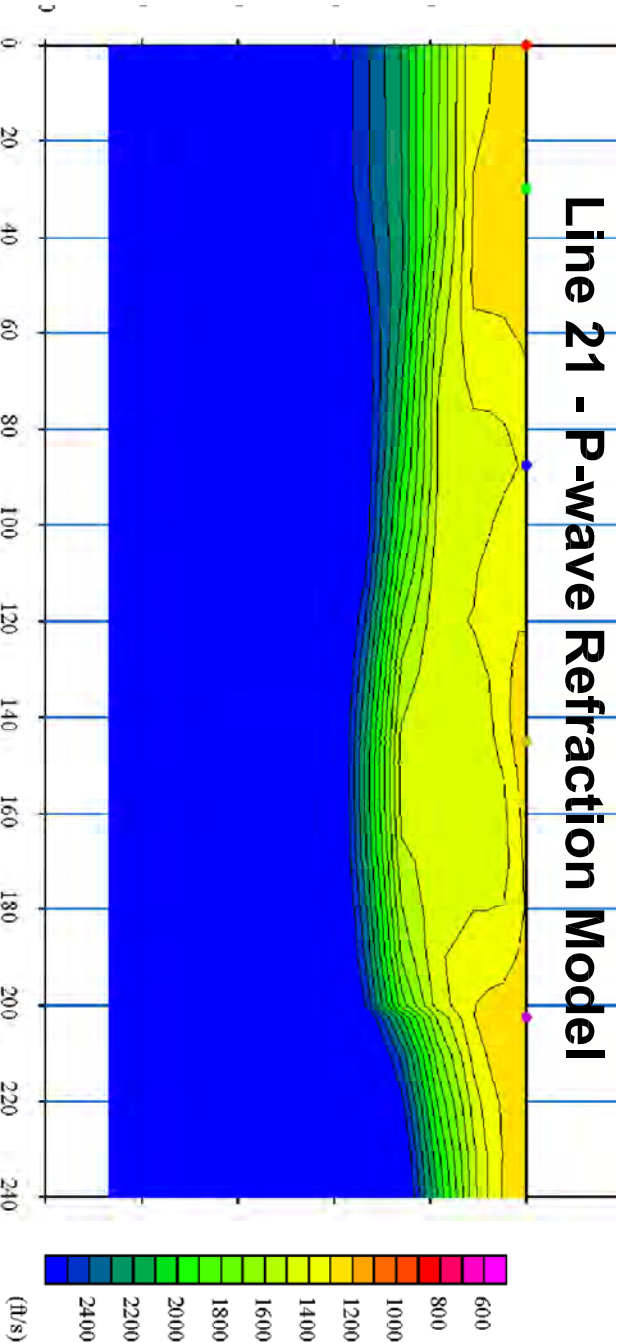
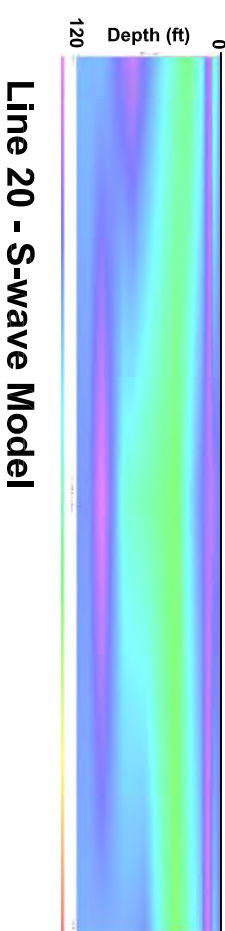
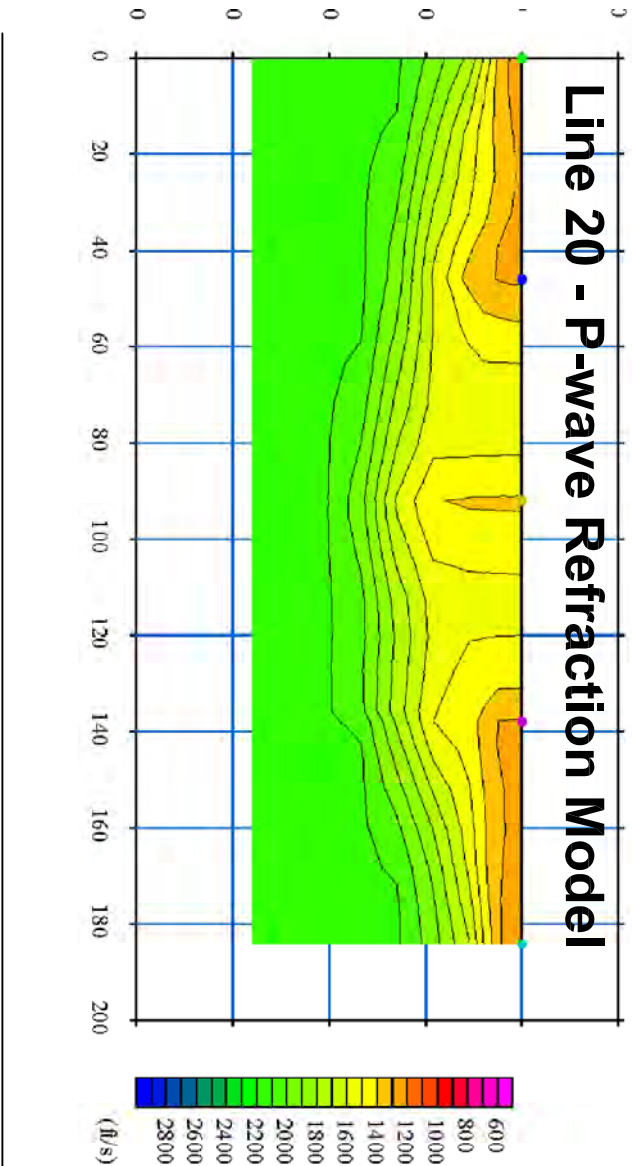






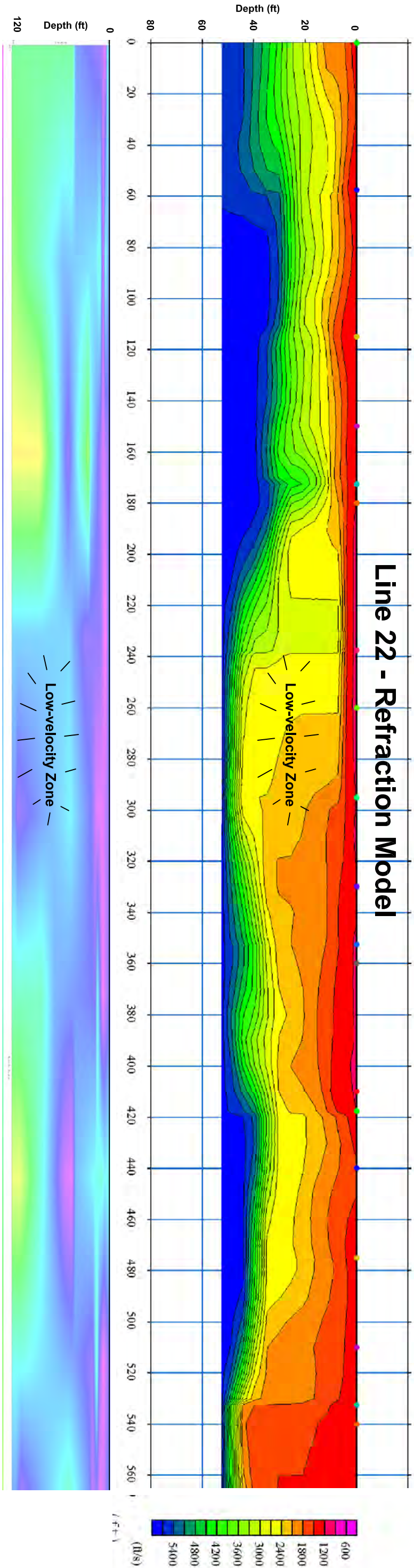
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|   | LOCATION: Sinking Springs, PA  |                       | FIGURE<br><b>9</b> |
|   | CLIENT: Tetra Tech   | PROJECT #: 15-122-1PA |                    |
| 3 Mystic Lane<br>Malvern, PA 19355<br>(925) 808-8965  |  | DATE: Apr 24, 2015    | DRAWN BY: R. SMITH |



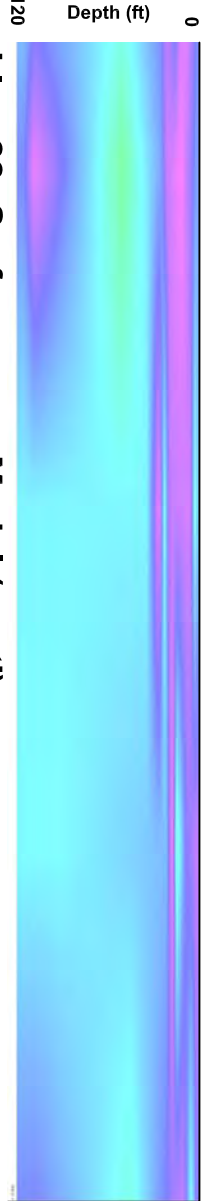
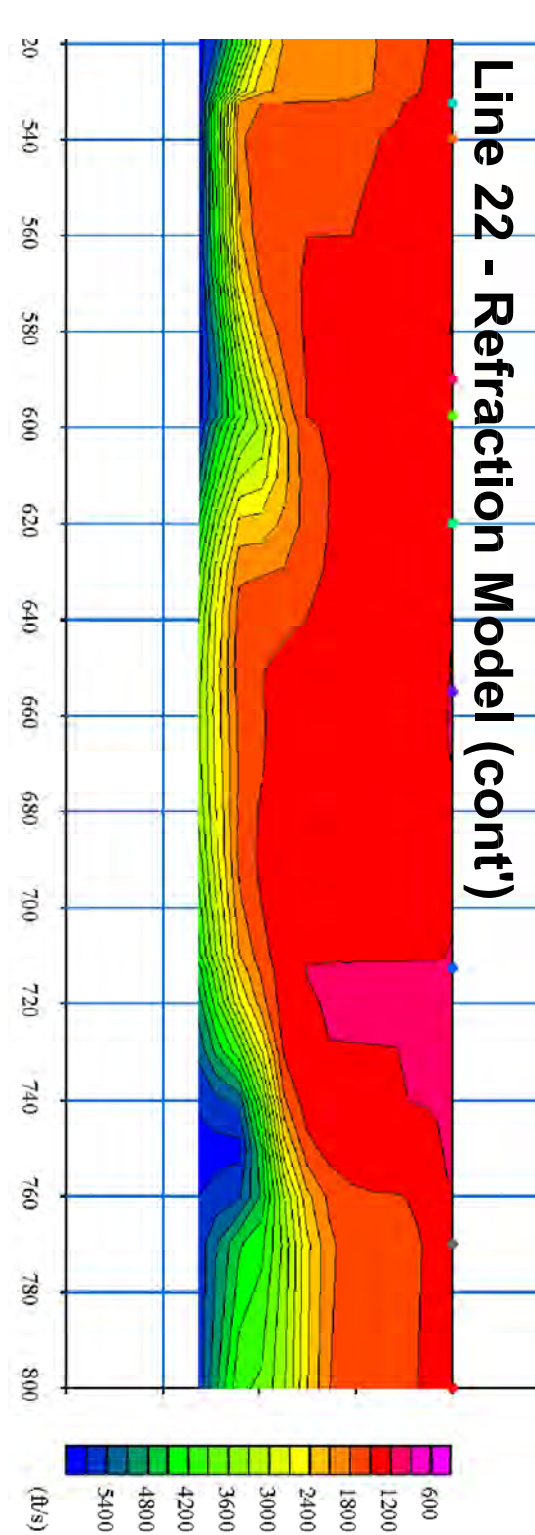


SEISMIC LINE LOCATIONS






Line 22- Surface-wave Model



SEISMIC LINE LOCATION



|   |  |                        |        |
|---|--|------------------------|--------|
|  |  | Seismic Survey Results |        |
| Site S3-0180 - Residential Area   |  | L-22                   |        |
| LOCATION: Sinking Springs, PA   |  | CLIENT: Tetra Tech     | FIGURE |
| 3 Mystic Lane<br>Malvern, PA 19355<br>(925) 808-8965                                |  | PROJECT #: 15-122-1PA  |        |
| DATE: Apr 24, 2015  |  | DRAWN BY: R. SMITH     |        |
| 11  |  |                        |        |



## **APPENDIX A**

### **SEISMIC VELOCITY AND LIMITATIONS OF THE REFRACTION METHOD**

The physical properties of earth materials (fill, sediment, rock) such as compaction, density, hardness, and induration dictate the corresponding seismic velocity of the material. Additionally, other factors such as bedding, fracturing, weathering, and saturation can also affect seismic velocity. In general, low velocities indicate loose soil, poorly compacted fill material, poorly to semi-consolidated sediments, deeply weathered, and highly fractured rock. Conversely, high velocities are indicative of competent rock or dense and highly compacted sediments and fill. The highest velocities are measured in unweathered and little fractured rock.

There are certain limitations associated with the seismic refraction method as applied for this investigation. These limitations are primarily based on assumptions that are made by the data analysis routine. The data analysis routine assumes that the velocities along the length of each spread are uniform. If there are localized zones within each layer where the velocities are higher or lower than indicated, the analysis routine will interpret these zones as changes in the surface topography of the underlying layer. A zone of higher velocity material would be interpreted as a low in the surface of the underlying layer. Zones of lower velocity material would be interpreted as a high in the underlying layer. The data analysis routine also assumes that the velocity of subsurface materials increase with depth. Therefore, if a layer exhibits velocities that are slower than those of the material above it, the slower layer will not be resolved. Also, a velocity layer may simply be too thin to be detected.

The quality of the field data is critical to the construction of an accurate depth and velocity profile. Strong, clear “first-break” information from refracted interfaces will make the data processing, analysis, and interpretation much more accurate and meaningful. Vibrational noise or poor subsurface conditions can decrease the ability to accurately locate and pick seismic waves from the interfaces.

Due to these and other limitations inherent to the seismic refraction method, resultant velocity cross-sections should be considered only as approximations of the subsurface conditions. The actual conditions may vary locally.



David S. Kane, P.G., Geology and Environmental Sciences  
Tetra Tech  
240 Continental Drive, Suite 200  
Newark, DE 19713

Subject: Draft Report  
Phase II Seismic Refraction and Seismic Surface-wave Surveys  
Sunoco Montello Terminal  
Sinking Springs, Pennsylvania

Dear Mr. Kane:

## 1.0 INTRODUCTION

This letter presents the results of Advanced Geological Services, Inc. (AGS) seismic refraction and seismic surface-wave surveys in support of Tetra Tech's geotechnical investigation along a proposed pipeline route through the Sunoco Montello Terminal in Sinking Springs, Pennsylvania (Figure 1). The investigation objective was to look for potential voids and/or areas of soft sediments along the proposed pipeline route. AGS understands that soft sediments were encountered in a well close to the proposed route.

AGS performed the investigation using the seismic refraction and seismic surface-wave methods. The two methods were used to look for disturbed subsurface layering and areas exhibiting relatively low seismic velocity indicative of potential soft sediment; refraction was used to assess the compressional (P-) wave velocity of subsurface materials and the associated layering, and the surface-wave method was used to assess shear (S-) wave velocity and layering. The surface-wave survey was performed to augment the refraction work due to the expected noisy site conditions, which would reduce the effectiveness of the refraction method (the surface-wave method uses ambient noise as a signal source). The investigation was performed on May 27, 2015 by AGS project geophysicist Christopher Call and staff geophysicist Gregory Fournier.



**Figure 1 - Phase II Seismic Line Location-  
Sinking Springs, PA (Phase I areas shown in grey)**



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## 2.0 SUMMARY OF FINDINGS

- A zone of relatively low P-wave and S-wave velocity indicative of potential voids/soft sediments was observed along the easternmost 150 feet of Line 1 (see Figures 2 and 3).
- Line 2, north of the railroad tracks, exhibited much higher P- and S-wave velocity than Line 1, indicating shallower bedrock and/or the presence of more compacted alluvium in that area.
- It is worth noting that other areas of voids/soft sediments not detected by this investigation may also be present.

## 3.0 SITE DESCRIPTION

The investigation was performed along an approximately 920 foot alignment running northwest from Fitztown road alongside a paved access road for a nearby garage and office complex (Figure 2). The alignment includes an approximately 85-foot wide gap associated with a railroad line. The ground surface along the alignment comprised a mixture of grass, gravel, and asphalt pavement. AGS recognized a minor topographic variation (approximately 25-foot increase in elevation, per Google Earth) along the southern portion of the alignment; we will incorporate topographic data into the analysis if and when it becomes available.

## 4.0 FIELD PROCEDURES

The refraction work was performed as a high-resolution seismic refraction tomography survey using four co-linear 230-foot long, 24-channel geophone spreads. One spread was located north of the railroad tracks and the remaining three spreads were located south of the tracks. The three southern spreads were combined into one seismic line, L-1, while the fourth spread, north of the railroad tracks formed line L-2. For each spread, AGS laid a fiberglass tape measure along the ground surface and placed 24 geophones in the ground at 10-foot spacings to form a 230-foot-long geophone array. The geophones were coupled to the ground surface by means of 4-inch spikes. Five shotpoints were used for each array— two “end” shotpoints, each located five feet beyond the geophone array, and three shotpoints within the array— one in the center and two at the array “quarter points.” The combination of the geophone array and associated shotpoints is referred to as a “spread.”

AGS produced seismic energy through multiple impacts with a 16-lb sledge hammer against a metal plate placed on the ground surface at each shotpoint location. In general, 10 hammer blows were struck at the end shotpoints and five blows were struck at the shotpoints within the geophone array. The seismic energy produced by the hammer impacts was detected using Geospace 10-Hz geophones, and the detected seismic signals were recorded using a DAQLink II seismic system connected to a laptop computer. Recording parameters included a record length of 0.5 seconds with a 0.125-millisecond sample rate.

After the refraction data were collected, AGS obtained the surface-wave data. Surface-wave data were collected using the refraction microtremor (“Remi”) technique, whereby the ambient



seismic signals produced by wind, wave motion and cultural sources such as factory machinery and vehicle traffic are recorded; no hammer blows are struck. For each geophone array, AGS collected ten 30-second records with a 2-millisecond sample rate.

After the seismic data were collected for the first spread, AGS moved the tape measure to mark the next spread, repositioned the geophones, and collected refraction and surface-wave data in the same manner as with the first spread. All told, AGS obtained seismic data along four spreads.

AGS mapped the shotpoint locations using a Global Positioning System (GPS) as the survey progressed.

## **5.0 GEOPHYSICAL METHOD OVERVIEW**

### **5.1 Seismic Refraction**

The seismic refraction method uses compressional (P-) wave energy to delineate seismic velocity layers within the subsurface. Interpretation entails correlating the velocity layers to geologic features such as soil, sediment, and bedrock. Distortions in the layering can indicate the presence of geologic faults and potential sinkholes. To perform a refraction survey, an elastic wave (compressional, or P-wave) is generated at certain locations (shotpoints) along a survey line. The P-wave energy is usually produced with a small explosion or by striking the ground with a sledgehammer. As the P-wave propagates through the ground it is refracted along boundaries between geologic layers with different seismic velocities.

Part of the refracted P-wave energy returns to the ground surface where it is detected by vibration-sensitive devices called geophones, which are placed in a co-linear array along the seismic survey line. The geophone data are fed to a seismograph, where they are recorded, and then to a computer, where they are processed using inversion software to produce models that depict the depth and velocities of the subsurface layers detected. Key data for refraction analysis are the positions of the geophones and shotpoints along a seismic line, and the amount of time it takes for the refracted wave to travel from the shotpoint to each geophone location. Because the P-wave is the fastest traveling of all types of seismic waves, it can be readily identified as the first deflection (“first break”) on a seismic trace.

Additional discussion of the refraction method, its limitations, and the relationship between seismic velocity and geologic materials is presented in Appendix A.

### **5.2 Seismic Surface-Wave**

Seismic surface-wave surveys use essentially the same field set-up as a refraction survey, but a different part of the recorded seismic signal—the Rayleigh (surface) wave—is analyzed instead of the P-wave. Briefly, a surface-wave survey entails measuring the velocity of surface waves using an array of motion detectors (geophones) placed on the ground surface. Because surface-wave velocity closely follows shear-wave velocity (90 to 95% of  $V_s$ ), surface-wave velocity data can be used to estimate shear wave velocity ( $V_s$ ). Surface-waves are seismic waves that travel along or near the surface of the earth; they are generated by both natural (e.g., wind, ocean waves) and man-made (e.g., hammer blow, traffic noise, factory vibration) sources. Surface-



waves travel in assemblages of frequencies, with each frequency having a corresponding wavelength. Because surface-waves are influenced by subsurface material to a depth approximately equal to the surface-wave's wavelength, a velocity vs. depth profile can be generated by measuring the velocity of surface-waves of varying wavelengths. Short wavelengths (higher frequencies) respond to the material properties (e.g., stiffness) of shallower materials while longer wavelengths (lower frequency) respond to deeper materials.

Specialized computer software is used to identify surface-waves in the recorded data and prepare a 'velocity spectrum' image, which the geophysical analyst interprets to produce a 'dispersion curve' to depict how velocity varies with frequency. The geophysicist then prepares a velocity layer model from which a synthetic dispersion curve is produced. The analyst then adjusts the model to obtain a 'best fit' between the synthetic dispersion curve and the actual dispersion curve that was interpreted from the velocity spectrum. The degree or closeness of the fit between the interpreted and synthetic curves provides an indication of how well the model represents actual subsurface conditions. The final output from a surface-wave survey is a one-dimensional (1-D) profile showing S-wave velocity variations with depth at a point that is taken to be at the center of the geophone array. Multiple 1-D profiles can be combined to produce cross-sections showing how S-wave velocity varies both laterally and with depth.

## **6.0 DATA PROCESSING AND ANALYSIS**

The seismic refraction data quality for this project ranged from good to fair. The quality of the surface-wave data was good. Refraction data quality was enhanced by "stacking," which entailed using multiple hammer blows at each shotpoint location to improve the signal-to-noise ratio. The additive affect of stacking of multiple hammer blows at the same location enhances or increases the amplitude of the signal (i.e., the refracted wave arrival) while amplitude of the background noise, which, being random in nature, tends to cancel itself on successive hammer blows and remains largely unchanged. Stacking was made necessary by the vibratory noise from the terminal. In general, AGS stacked 10 hammer blows at the end-of-spread shotpoints and five blows at the mid-spread shotpoints.

### **6.1 Refraction Processing and Analysis**

The refraction data were processed using the *SeisImager* software from Geometrics, Inc. Briefly, *SeisImager* is a computer inversion program that generates an initial velocity layer model, produces synthetic data from the model, and then adjusts the model so that the synthetic data better matches the observed field data. The agreement between the synthetic and observed data provides an indication of how well the model represents the true subsurface conditions. For each seismic line, AGS first used the *SeisImager* module *PickWin* to interpret ("pick") the P-wave arrivals ("first breaks") for each of the seven shotpoint data sets ("shot gathers") per line. *PickWin* was also used to check (against the geophysicist's field log) that the proper locations were assigned to the geophones and shotpoints. Next, the first break files were fed to the *SeisImager* module *PlotRefra*, which was used review time-distance (TD) plots for the seismic lines and assign a seismic layer to each arrival time. For the initial refraction analysis, each P-wave arrival ("first break") is considered to have refracted from a distinct seismic layer. The number of layers resolved by the seismic survey, and their thickness and average velocity, are revealed by straight line segments on the TD plot; because these straight-line segments represent



a constant velocity condition within the subsurface, they are usually considered to represent a distinct geologic layer. The topographic elevation files were incorporated into the analysis at this point. Next, a time-term inversion was performed to produce models showing the velocity layering along each seismic line.

The layered velocity models were then used as starting models for the tomographic inversion process that produced the velocity models presented on Figure 3 this Report. Briefly, tomographic inversion is a grid-based modeling process wherein the subsurface is divided into rectangular cells based on the geophone spacing. The tomography software assigns a velocity to each cell, produces a synthetic arrival time data set based on seismic raypaths projected through the velocity grid, and then compares the synthetic data to the real data recorded in the field. The cell velocities are then adjusted and re-adjusted until the synthetic data achieve a “best fit” with the observed field data. Tomographic modeling is often used to complement layered modeling at sites where gradual velocity transitions, such as those often seen within thick layers of sediment and between weathered and unweathered bedrock, are expected. Tomographic modeling can also depict lateral velocity variations within the subsurface more accurately than a layered modeling approach.

For the analysis of the refraction survey results, AGS examined the models for anomalous low-velocity zones and distortions in the velocity layering that could indicate potential soft sediment and void areas. In addition, AGS examined the time-distance (TD) plots for “jumps” and “sags” and other distortions in the arrival-time curves that might indicate subsurface disruptions that were not expressed in the models. The locations of any such features observed were annotated on the velocity layer models (Figure 3).

## **6.2 Surface-Wave Processing and Analysis**

Surface-wave data processing was performed using *SeisOpt Remi* software by Optim Software. In general, surface wave data processing entails first producing a velocity spectrum image, which shows the phase velocity for the various frequencies of surface waves detected. This image is used as the basis for interpreting (“picking”) a dispersion curve, which is a graph that depicts how surface-wave velocity varies with frequency (hence, depth). The dispersion curve is then used to prepare an initial 1D model of surface-wave velocity versus depth using a one-third wavelength approximation (i.e., a given phase velocity is assigned to a depth that is one-third of the wavelength of the corresponding surface-wave). The initial velocity layer model is then adjusted using an inversion process until the corresponding synthetic dispersion curve achieves a “best-fit” match to the original dispersion curve that was interpreted from the observed data (i.e., the velocity spectrum image). The degree or closeness of the fit between the interpreted and synthetic curves provides an indication of how well the model represents actual subsurface conditions.

Accordingly, AGS first used the *SeisOpt Remi Vspect* module to produce a velocity spectrum image, which shows how surface-wave velocity varies with frequency, and pick a dispersion curve. Next, AGS used the *Dispr* module to perform the inversion that produced 1-D models showing S-wave ( $V_s$ ) velocity variations with depth. To produce the 2-D S-wave velocity cross sections (Figures 4 through 11), AGS separately processed and analyzed sub-sets of each 24-channel data set (i.e., the data from a each array of 24 geophones). For each array of 24



geophones, AGS separately processed the data from geophones 1 through 12, 6 through 18, and 12 through 24 to produce three 1-D profiles, which were then assembled into 2-D cross section.

For the analysis of the surface-wave survey results, AGS examined the 2-D cross sections for anomalous low-velocity zones that could indicate potential soft sediment areas. In particular, AGS looked for correlations between low S-wave velocity area and distortions in the P-wave velocity layer models. The locations of any such features were annotated on the site map (Figure 2) and velocity layer models (Figure 3).

## 7.0 RESULTS

The investigation results are presented on Figures 2 and 3. Figure 2 shows the seismic line locations; in addition, a low-velocity zone identified from the seismic results is highlighted. Figure 3 shows the P- and S-wave velocity layer models generated from the refraction and surface-wave data, respectively. The P-wave and S-wave models are placed together on the figures to facilitate correlation, although it is worth noting that the P- and S-wave displays have opposite color scales. In other words, on the P-wave models “cool” (blue) colors indicate higher velocity while on the S-wave models cool (blue-indigo) colors indicate lower velocity.

Overall, one zone of low P-wave and S-wave velocity indicative of potential voids/soft sediments was observed along the easternmost 150 feet of Line 1 (see Figures 2 and 3).

Examination of the of the time-distance (TD) plots from the refraction data and the resulting velocity models indicates that, in general, two subsurface layers were detected— an upper layer exhibiting P-wave velocities less than 1,500 feet per second (fps) representing soil and loosely consolidated sediment, and a lower layer exhibiting P-wave velocities ranging between 3,100 and 8,000 fps that represents more consolidated sediment, which may be saturated in some areas, and possibly bedrock. It is worth noting that Line 2, north of the railroad tracks, exhibited much higher P- and S-wave velocity than Line 1, indicating shallower bedrock and/or the presence of more compacted alluvium in that area.

The investigation depth for the refraction survey ranged between 50 and 80 feet below ground surface (bgs). It is worth noting that the undulations observed on the P-wave velocity models could represent actual distortions in sediment layering, artifacts of irregular arrival-time picks on the noisy seismic records, or a combination of both factors.

The investigation depth for the surface-wave survey was in excess of 100 feet bgs; however, the surface-wave survey lacked the lateral resolution of the refraction survey. This is because surface-wave surveys use a single long geophone array on the ground surface to obtain information about bulk properties (S-wave velocity) of subsurface materials beneath the array. Although surface-wave surveys provide information about S-wave velocity variations with depth at a single point (the center of the geophone array), they are more suited for assessing Vs30, the average S-wave velocity of the upper 100 feet (30 meters), for seismic site classification. In general, Vs30 in the Phase II survey area ranged between 1,060 and 1,590 fps, which places it between seismic site classes “D”(stiff soil) and “C” (very dense soil and soft rock), with 1,200 fps being the boundary between classes D and C.



The Phase II Montello seismic investigation was performed using a series of 230-foot long arrays, each consisting of 24 geophones. Surface-waved data were processed by gathering and processing separately data from 12 geophones at a time to produce a series of 1D S-wave soundings spaced approximately 60 feet apart, which were then combined to produce the 2D cross sections shown on the Figure 3. Hence, the surface-wave survey lacked the lateral resolution of the refraction survey, which provided subsurface information at each 10-foot spaced geophone location. This explains the smoother-looking appearance of the S-wave cross sections as compared to the refraction models.

## 8.0 CLOSING

All geophysical data and field notes collected as a part of this investigation will be archived at the AGS office. The data collection and interpretation methods used in this investigation are consistent with standard practices applied to similar geophysical investigations. The correlation of geophysical responses with probable subsurface features is based on the past results of similar surveys although it is possible that some variation could exist at this site. Due to the nature of geophysical data, no guarantees can be made or implied regarding the targets identified or the presence or absence of additional objects or targets.

AGS appreciates working for you on this project and we look forward to working with you again.

Sincerely,



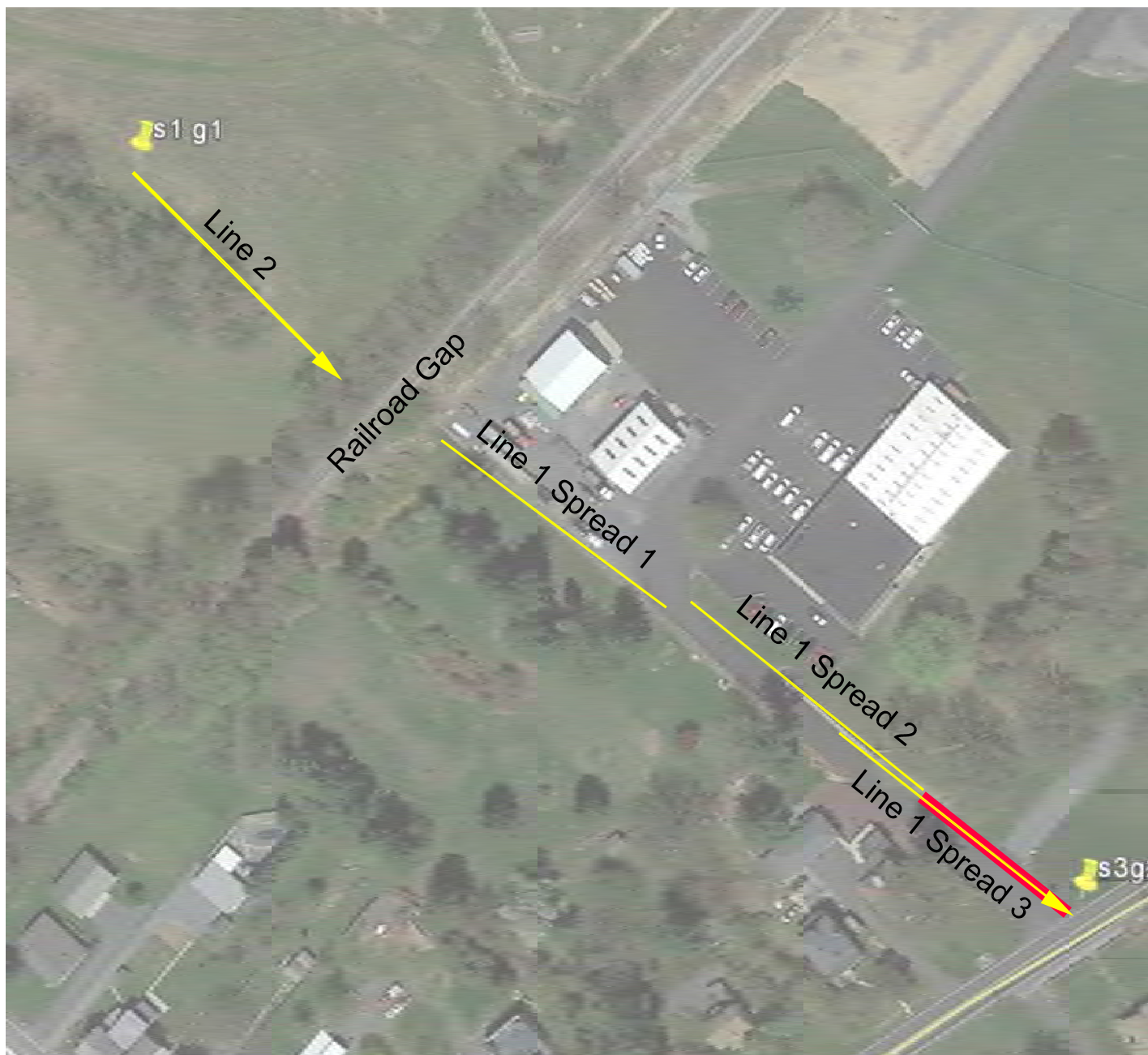
Roark W. Smith  
Senior Geophysicist  
Advanced Geological Services, Inc.

Figures:

- |          |  |
|----------|--|
| Figure 1 | Site Location (imbedded in Report text, above) |
| Figure 2 | Seismic Line Locations and Low-Velocity Area   |
| Figure 3 | Seismic Survey Results                         |

Attachments: Appendix A: Seismic Velocity and Limitations of the Refraction Method





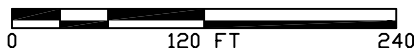
# EXPLANATION



SEISMIC LINE LOCATION



LOW-VELOCITY ZONE INDICATIVE OF  
POTENTIAL VOIDS OR SOFT SEDIMENT



3 Mystic Lane  
Malvern, PA 19355  
(925) 808-8965

Seismic Line Locations  
Phase II Seismic Investigation  
Sunoco Montello Terminal

LOCATION: Sinking Springs, PA

CLIENT: Tetra Tech

PROJECT #: 15-122-2PA

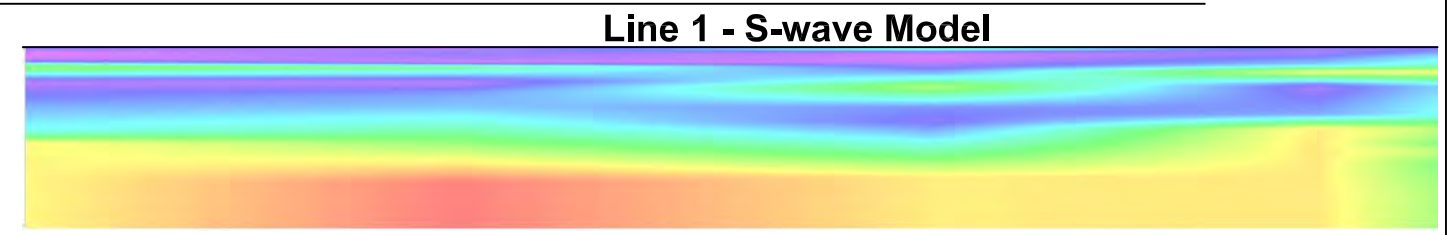
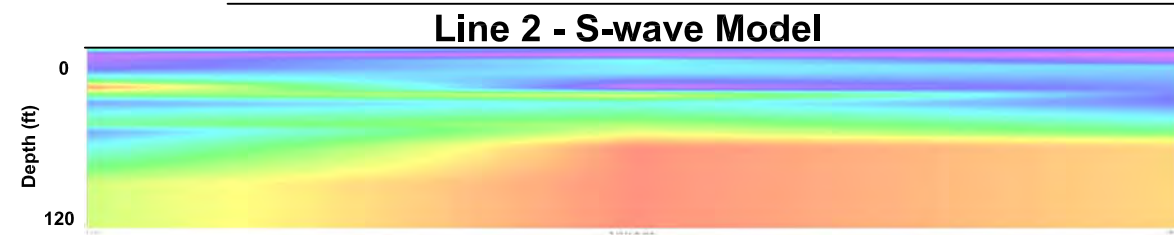
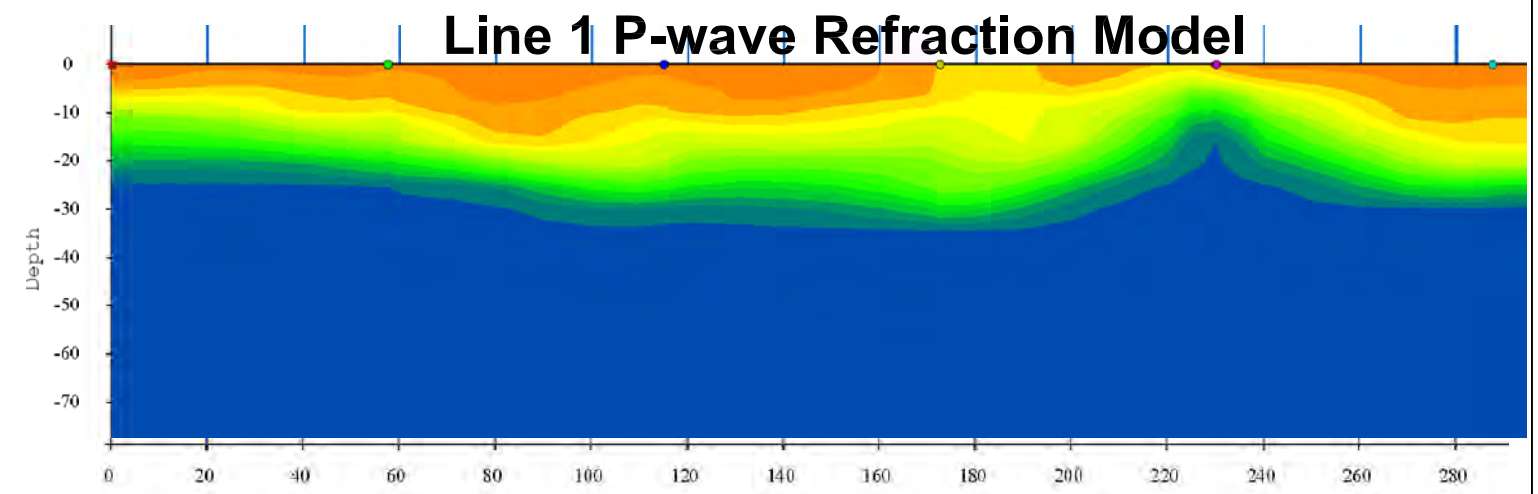
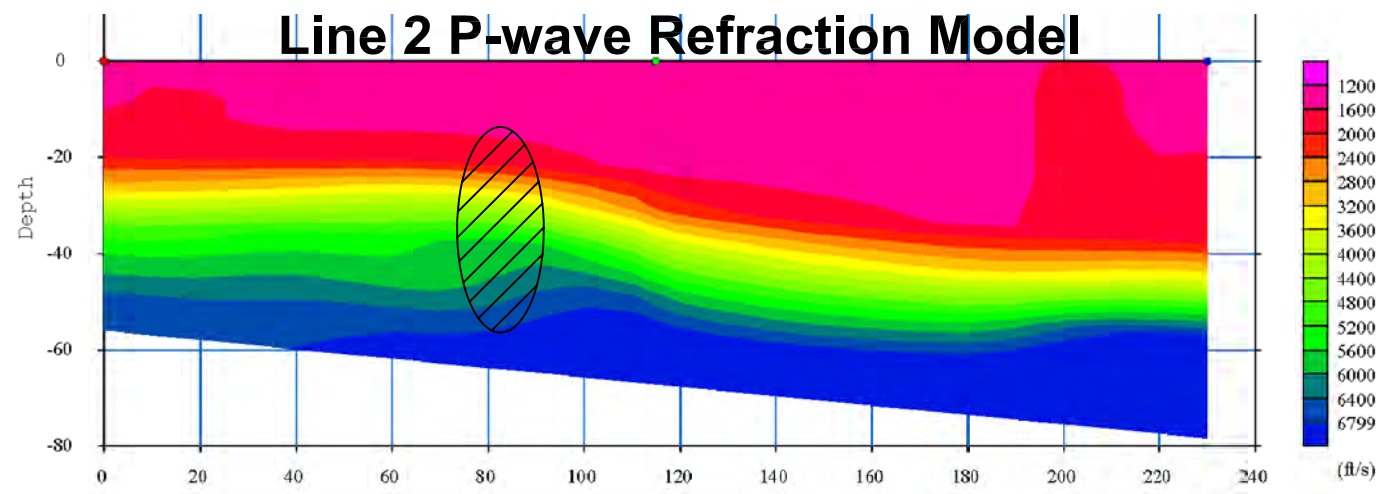
DATE: June 2, 2015

DRAWN BY: R. SMITH

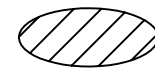
FIGURE

2

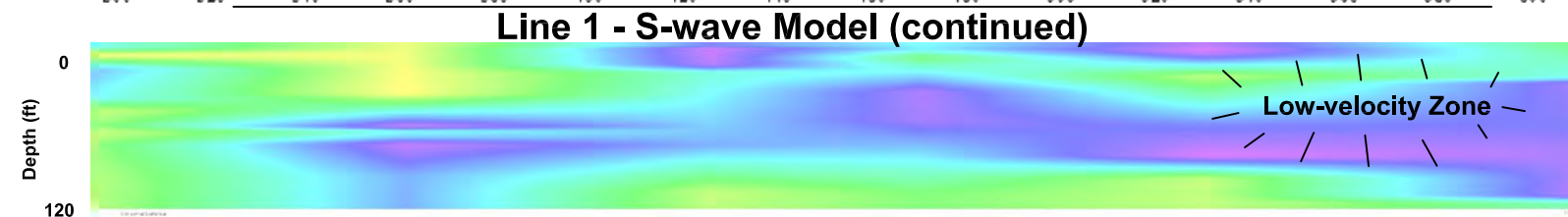
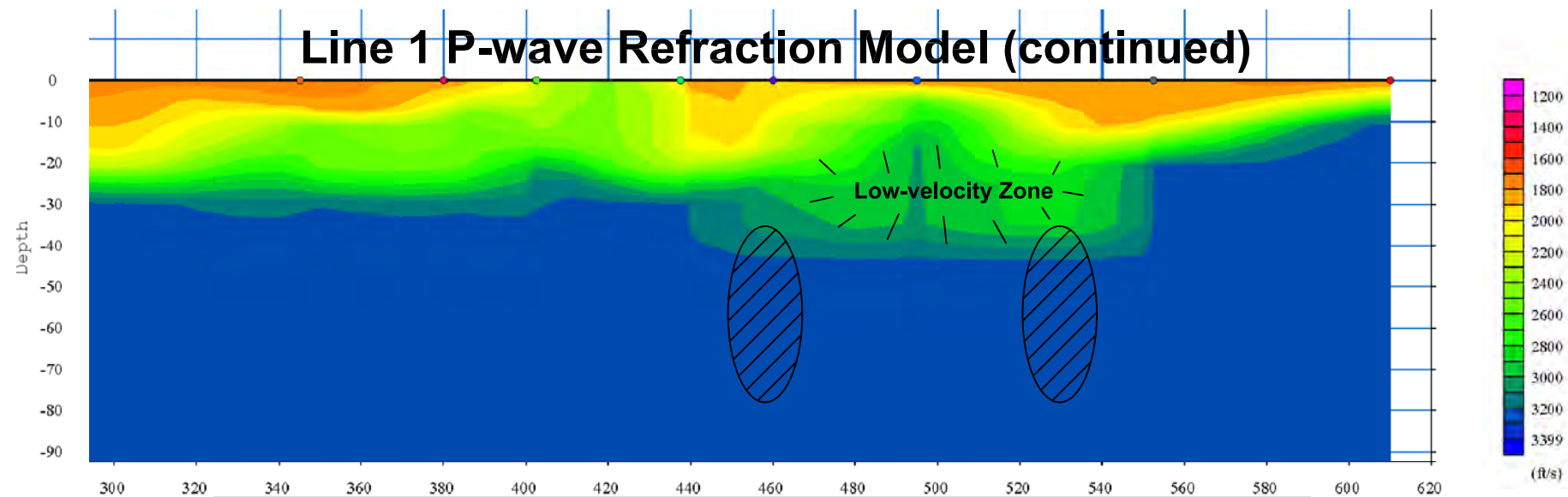




Railroad Gap



**EXPLANATION**  
TD PLOT DISRUPTION



|  |  |                    |
|--|--|--------------------|
|  | Phase II Seismic Survey Results<br>Line 1 and Line 2 |                    |
|  | LOCATION: Sinking Springs, PA                        |                    |
|  | CLIENT: Tetra Tech                                   | FIGURE<br><b>3</b> |
|  | PROJECT #: 15-122-2PA                                |                    |
| 3 Mystic Lane<br>Malvern, PA 19355<br>(925) 808-8965 |  | DATE: Jun 2, 2015  |
|  |  | DRAWN BY: R. SMITH |



## **APPENDIX A**

### **SEISMIC VELOCITY AND LIMITATIONS OF THE REFRACTION METHOD**

The physical properties of earth materials (fill, sediment, rock) such as compaction, density, hardness, and induration dictate the corresponding seismic velocity of the material. Additionally, other factors such as bedding, fracturing, weathering, and saturation can also affect seismic velocity. In general, low velocities indicate loose soil, poorly compacted fill material, poorly to semi-consolidated sediments, deeply weathered, and highly fractured rock. Conversely, high velocities are indicative of competent rock or dense and highly compacted sediments and fill. The highest velocities are measured in unweathered and little fractured rock.

There are certain limitations associated with the seismic refraction method as applied for this investigation. These limitations are primarily based on assumptions that are made by the data analysis routine. The data analysis routine assumes that the velocities along the length of each spread are uniform. If there are localized zones within each layer where the velocities are higher or lower than indicated, the analysis routine will interpret these zones as changes in the surface topography of the underlying layer. A zone of higher velocity material would be interpreted as a low in the surface of the underlying layer. Zones of lower velocity material would be interpreted as a high in the underlying layer. The data analysis routine also assumes that the velocity of subsurface materials increase with depth. Therefore, if a layer exhibits velocities that are slower than those of the material above it, the slower layer will not be resolved. Also, a velocity layer may simply be too thin to be detected.

The quality of the field data is critical to the construction of an accurate depth and velocity profile. Strong, clear “first-break” information from refracted interfaces will make the data processing, analysis, and interpretation much more accurate and meaningful. Vibrational noise or poor subsurface conditions can decrease the ability to accurately locate and pick seismic waves from the interfaces.

Due to these and other limitations inherent to the seismic refraction method, resultant velocity cross-sections should be considered only as approximations of the subsurface conditions. The actual conditions may vary locally.



## **APPENDIX D**

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### **Potential Void Mitigation Procedures**



David S. Kane, P.G., Geology and Environmental Sciences  
Tetra Tech  
240 Continental Drive, Suite 200  
Newark, DE 19713

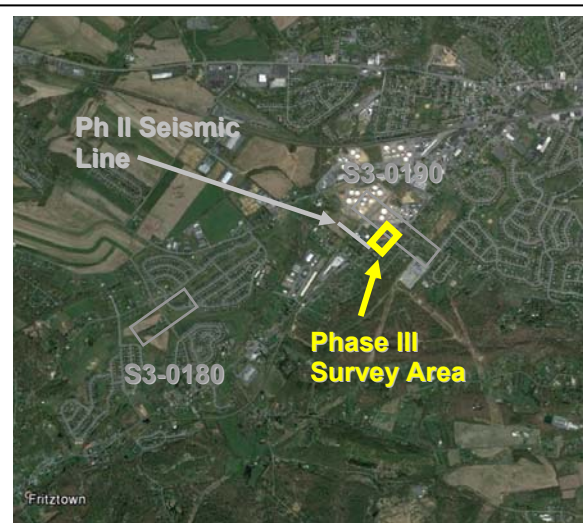
Subject: Draft Report  
Phase III Seismic Refraction and Seismic Surface-wave Surveys  
Sunoco Montello Terminal  
Sinking Springs, Pennsylvania

Dear Mr. Kane:

## 1.0 INTRODUCTION

This letter presents the results of Advanced Geological Services, Inc. (AGS) seismic refraction and seismic surface-wave surveys in support of Tetra Tech's geotechnical investigation along a proposed pipeline route through the Sunoco Montello Terminal in Sinking Springs, Pennsylvania (Figure 1). The investigation objective was to look for potential voids and/or areas of soft sediments along the proposed pipeline route. AGS understands that soft sediments were encountered in a well close to the proposed route.

AGS performed the investigation using the seismic refraction and seismic surface-wave methods. The two methods were used to look for disturbed subsurface layering and areas exhibiting relatively low seismic velocity indicative of potential soft sediment; refraction was used to assess the compressional (P-) wave velocity of subsurface materials and the associated layering, and the surface-wave method was used to assess shear (S-) wave velocity and layering. The surface-wave survey was performed to augment the refraction work due to the expected noisy site conditions, which would reduce the effectiveness of the refraction method (the surface-wave method uses ambient noise as a signal source). The investigation was performed on June 10 and 11, 2015 by AGS project geophysicist Christopher Call and staff geophysicist Gregory Fournier; it was the third phase of seismic work performed by AGS at this site.



**Figure 1 - Phase III Seismic Survey Area**  
(Phase I & II areas shown in grey)



## **2.0 SUMMARY OF FINDINGS**

- Small zones of low S-wave velocity were observed on five of the six seismic lines (Figures 2 through 6); only Line 4 did not exhibit a significant low S-wave velocity zone.
- Small disruptions were observed on the TD plots for Lines 4 and 5; however, no significant P-wave velocity anomalies were observed.
- It is worth noting that other areas of voids/soft sediments not detected by this investigation may also be present.

## **3.0 SITE DESCRIPTION**

The investigation was performed along six seismic lines located near the intersection of Fritztown Road and Old Fritztown road (Figure 2). Lines 1 through 5 were on private property, mostly grass-covered yards. Line 6 was on a gravel-covered area inside the plant boundary fence. It is worth noting that Line 6 was located near a large generator, which produced high levels of background noise. Because roadways within the survey area were heavily trafficked, data were collected during periods of lower vehicle traffic, to the extent possible, in order to minimize ambient noise.

## **4.0 FIELD PROCEDURES**

The refraction work was performed as a high-resolution seismic refraction tomography survey along six seismic lines (Figure 2). Five of the six lines comprised single 24-channel seismic spreads, which varied from 115 to 230 feet in length as dictated by site conditions. Line 1 was 320 feet long and comprised two overlapping 230-foot seismic spreads. For each spread, AGS laid a fiberglass tape measure along the ground surface and placed 24 geophones in the ground at spacings that ranged from 5 to 10 feet apart, depending on the overall spread length. The geophones were coupled to the ground surface by means of 4-inch spikes. Five shotpoints were used for each spread—two “end” shotpoints, each located five feet beyond the geophone array, and three shotpoints within the array—one in the center and two at the array “quarter points.” The combination of the geophone array and associated shotpoints is referred to as a seismic “spread.”

AGS produced seismic energy through multiple impacts with a 16-lb sledge hammer against a metal plate placed on the ground surface at each shotpoint location. In general, 10 hammer blows were struck at the end shotpoints and five blows were struck at the shotpoints within the geophone array. The seismic energy produced by the hammer impacts was detected using Geospace 10-Hz geophones, and the detected seismic signals were recorded using a DAQLink II seismic system connected to a laptop computer. Recording parameters included a record length of 0.5 seconds with a 0.125-millisecond sample rate.

After the refraction data were collected, AGS obtained the surface-wave data. Surface-wave data were collected using the refraction microtremor (“Remi”) technique, whereby the ambient



seismic signals produced by wind, wave motion and cultural sources such as factory machinery and vehicle traffic are recorded; no hammer blows are struck. For each geophone array, AGS collected ten 30-second records with a 2-millisecond sample rate.

After the seismic data were collected for the first spread, AGS moved the tape measure to mark the next spread, repositioned the geophones, and collected refraction and surface-wave data in the same manner as with the first spread. All told, AGS obtained seismic data along seven spreads (two spreads for Line 1 and one spread for Lines 2 through 5).

AGS mapped the shotpoint locations using a Global Positioning System (GPS) as the seismic survey progressed.

## **5.0 GEOPHYSICAL METHOD OVERVIEW**

### **5.1 Seismic Refraction**

The seismic refraction method uses compressional (P-) wave energy to delineate seismic velocity layers within the subsurface. Interpretation entails correlating the velocity layers to geologic features such as soil, sediment, and bedrock. Distortions in the layering can indicate the presence of geologic faults and potential sinkholes. To perform a refraction survey, an elastic wave (compressional, or P-wave) is generated at certain locations (shotpoints) along a survey line. The P-wave energy is usually produced with a small explosion or by striking the ground with a sledgehammer. As the P-wave propagates through the ground it is refracted along boundaries between geologic layers with different seismic velocities.

Part of the refracted P-wave energy returns to the ground surface where it is detected by vibration-sensitive devices called geophones, which are placed in a co-linear array along the seismic survey line. The geophone data are fed to a seismograph, where they are recorded, and then to a computer, where they are processed using inversion software to produce models that depict the depth and velocities of the subsurface layers detected. Key data for refraction analysis are the positions of the geophones and shotpoints along a seismic line, and the amount of time it takes for the refracted wave to travel from the shotpoint to each geophone location. Because the P-wave is the fastest traveling of all types of seismic waves, it can be readily identified as the first deflection (“first break”) on a seismic trace.

Additional discussion of the refraction method, its limitations, and the relationship between seismic velocity and geologic materials is presented in Appendix A.

### **5.2 Seismic Surface-Wave**

Seismic surface-wave surveys use essentially the same field set-up as a refraction survey, but a different part of the recorded seismic signal—the Rayleigh (surface) wave—is analyzed instead of the P-wave. Briefly, a surface-wave survey entails measuring the velocity of surface waves using an array of motion detectors (geophones) placed on the ground surface. Because surface-wave velocity closely follows shear-wave velocity (90 to 95% of  $V_s$ ), surface-wave velocity data can be used to estimate shear wave velocity ( $V_s$ ). Surface-waves are seismic waves that travel along or near the surface of the earth; they are generated by both natural (e.g., wind, ocean waves) and man-made (e.g., hammer blow, traffic noise, factory vibration) sources. Surface-



waves travel in assemblages of frequencies, with each frequency having a corresponding wavelength. Because surface-waves are influenced by subsurface material to a depth approximately equal to the surface-wave's wavelength, a velocity vs. depth profile can be generated by measuring the velocity of surface-waves of varying wavelengths. Short wavelengths (higher frequencies) respond to the material properties (e.g., stiffness) of shallower materials while longer wavelengths (lower frequency) respond to deeper materials.

Specialized computer software is used to identify surface-waves in the recorded data and prepare a 'velocity spectrum' image, which the geophysical analyst interprets to produce a 'dispersion curve' to depict how velocity varies with frequency. The geophysicist then prepares a velocity layer model from which a synthetic dispersion curve is produced. The analyst then adjusts the model to obtain a 'best fit' between the synthetic dispersion curve and the actual dispersion curve that was interpreted from the velocity spectrum. The degree or closeness of the fit between the interpreted and synthetic curves provides an indication of how well the model represents actual subsurface conditions. The final output from a surface-wave survey is a one-dimensional (1-D) profile showing S-wave velocity variations with depth at a point that is taken to be at the center of the geophone array. Multiple 1-D profiles can be combined to produce cross-sections showing how S-wave velocity varies both laterally and with depth.

## **6.0 DATA PROCESSING AND ANALYSIS**

The seismic refraction data quality for this project ranged from good to fair. The quality of the surface-wave data was good. Refraction data quality was enhanced by "stacking," which entailed using multiple hammer blows at each shotpoint location to improve the signal-to-noise ratio. The additive affect of stacking of multiple hammer blows at the same location enhances or increases the amplitude of the signal (i.e., the refracted wave arrival) while amplitude of the background noise, which, being random in nature, tends to cancel itself on successive hammer blows and remains largely unchanged. Stacking was made necessary by the vibratory noise from the terminal. In general, AGS stacked 10 hammer blows at the end-of-spread shotpoints and five blows at the mid-spread shotpoints.

### **6.1 Refraction Processing and Analysis**

The refraction data were processed using the *SeisImager* software from Geometrics, Inc. Briefly, *SeisImager* is a computer inversion program that generates an initial velocity layer model, produces synthetic data from the model, and then adjusts the model so that the synthetic data better matches the observed field data. The agreement between the synthetic and observed data provides an indication of how well the model represents the true subsurface conditions. For each seismic line, AGS first used the *SeisImager* module *PickWin* to interpret ("pick") the P-wave arrivals ("first breaks") for each of the seven shotpoint data sets ("shot gathers") per line. *PickWin* was also used to check (against the geophysicist's field log) that the proper locations were assigned to the geophones and shotpoints. Next, the first break files were fed to the *SeisImager* module *PlotRefra*, which was used review time-distance (TD) plots for the seismic lines and assign a seismic layer to each arrival time. For the initial refraction analysis, each P-wave arrival ("first break") is considered to have refracted from a distinct seismic layer. The number of layers resolved by the seismic survey, and their thickness and average velocity, are revealed by straight line segments on the TD plot; because these straight-line segments represent



a constant velocity condition within the subsurface, they are usually considered to represent a distinct geologic layer. The topographic elevation files were incorporated into the analysis at this point. Next, a time-term inversion was performed to produce models showing the velocity layering along each seismic line.

The layered velocity models were then used as starting models for the tomographic inversion process that produced the velocity models presented on Figures 3 through 6 of this Report. Briefly, tomographic inversion is a grid-based modeling process wherein the subsurface is divided into rectangular cells based on the geophone spacing. The tomography software assigns a velocity to each cell, produces a synthetic arrival time data set based on seismic raypaths projected through the velocity grid, and then compares the synthetic data to the real data recorded in the field. The cell velocities are then adjusted and re-adjusted until the synthetic data achieve a “best fit” with the observed field data. Tomographic modeling is often used to complement layered modeling at sites where gradual velocity transitions, such as those often seen within thick layers of sediment and between weathered and unweathered bedrock, are expected. Tomographic modeling can also depict lateral velocity variations within the subsurface more accurately than a layered modeling approach.

For the analysis of the refraction survey results, AGS examined the models for anomalous low-velocity zones and distortions in the velocity layering that could indicate potential soft sediment and void areas. In addition, AGS examined the time-distance (TD) plots for “jumps” and “sags” and other distortions in the arrival-time curves that might indicate subsurface disruptions that were not expressed in the models. The locations of any such features observed were annotated on the velocity layer models (Figures 3 through 6).

## **6.2 Surface-Wave Processing and Analysis**

Surface-wave data processing was performed using *SeisOpt Remi* software by Optim Software. In general, surface wave data processing entails first producing a velocity spectrum image, which shows the phase velocity for the various frequencies of surface waves detected. This image is used as the basis for interpreting (“picking”) a dispersion curve, which is a graph that depicts how surface-wave velocity varies with frequency (hence, depth). The dispersion curve is then used to prepare an initial 1D model of surface-wave velocity versus depth using a one-third wavelength approximation (i.e., a given phase velocity is assigned to a depth that is one-third of the wavelength of the corresponding surface-wave). The initial velocity layer model is then adjusted using an inversion process until the corresponding synthetic dispersion curve achieves a “best-fit” match to the original dispersion curve that was interpreted from the observed data (i.e., the velocity spectrum image). The degree or closeness of the fit between the interpreted and synthetic curves provides an indication of how well the model represents actual subsurface conditions.

Accordingly, AGS first used the *SeisOpt Remi Vspect* module to produce a velocity spectrum image, which shows how surface-wave velocity varies with frequency, and pick a dispersion curve. Next, AGS used the *Dispr* module to perform the inversion that produced 1-D models showing S-wave ( $V_s$ ) velocity variations with depth. To produce the 2-D S-wave velocity cross sections (Figures 3 through 6), AGS separately processed and analyzed sub-sets of each 24-channel data set (i.e., the data from a each array of 24 geophones). For each array of 24



geophones, AGS separately processed the data from geophones 1 through 12, 6 through 18, and 12 through 24 to produce three 1-D profiles, which were then assembled into 2-D cross section.

For the analysis of the surface-wave survey results, AGS examined the 2-D cross sections for anomalous low-velocity zones that could indicate potential soft sediment areas. In particular, AGS looked for correlations between low S-wave velocity area and distortions in the P-wave velocity layer models. The locations of any such features were annotated on the site map (Figure 2) and velocity layer models (Figures 3 through 6).

## 7.0 RESULTS

The investigation results are presented on Figures 2 through 6. Figure 2 shows the seismic line locations; in addition, low-velocity zones identified from the seismic results are highlighted. Figures 3 through 6 show the P- and S-wave velocity layer models generated from the refraction and surface-wave data, respectively. The P-wave and S-wave models are placed together on the figures to facilitate correlation, although it is worth noting that the P- and S-wave displays have opposite color scales. In other words, on the P-wave models “cool” (blue) colors indicate higher velocity while on the S-wave models cool (blue-indigo) colors indicate lower velocity.

Overall, small zones of low S-wave velocity were observed on five of the six seismic lines (Figure 2); only Line 4 did not exhibit a significant low S-wave velocity zone.

Although small disruptions were observed on the TD plots for lines 4 and 5, no significant P-wave velocity anomalies were observed. Examination of the time-distance (TD) plots from the refraction data and the resulting velocity models indicates that two subsurface layers were detected along most of the lines— a thin upper layer exhibiting P-wave velocities less than 1,500 feet per second (fps) representing soil and loosely consolidated sediment, and a lower layer exhibiting P-wave velocities ranging between 2,100 and 2,800 fps representing more consolidated sediment. Indications of a third, higher-velocity layer were observed on Lines 3 and 5. The third layer on Line 3 exhibits a P-wave velocity in excess of 8,000 fps, which is indicative of the limestone bedrock that reportedly exists in the area; this layer occurs at approximately 70 feet below ground surface (bgs) along Line 3. The third layer on Line 5 exhibits a velocity of about 4,900 fps, which is indicative of saturated sediment; it occurs at a depth of about 50 feet bgs along Line 5.

The investigation depth for the refraction survey ranged between 40 and 80 feet below ground surface (bgs), depending on the seismic spread lengths and the amount of noise present on the seismic records. It is worth noting that the undulations observed on the P-wave velocity models could represent actual distortions in sediment layering, artifacts of irregular arrival-time picks on the noisy seismic records, or a combination of both factors.

The investigation depth for the surface-wave survey was in excess of 100 feet bgs; however, the surface-wave survey lacked the lateral resolution of the refraction survey. This is because surface-wave surveys use a single long geophone array on the ground surface to obtain information about bulk properties (S-wave velocity) of subsurface materials beneath the array. Although surface-wave surveys provide information about S-wave velocity variations with depth



at a single point (the center of the geophone array), they are more suited for assessing Vs30, the average S-wave velocity of the upper 100 feet (30 meters), for seismic site classification. In general, Vs30 in the Phase III survey area ranged between 890 and 1,500 fps, with most values clustering around 1,200 fps, which places it between seismic site classes “D” (*stiff soil*) and “C” (*very dense soil and soft rock*); 1,200 fps is the boundary between classes D and C.

The Phase III Montello seismic investigation was performed using a series seismic spreads comprised of 24 geophones. Surface-waved data were processed by gathering and processing separately data from 12 geophones at a time to produce a series of 1D S-wave soundings spaced approximately 60 feet apart, which were then combined to produce the 2D cross sections shown on Figures 3 through 6. Hence, the surface-wave survey lacked the lateral resolution of the refraction survey, which provided subsurface information at each 10-foot spaced geophone location. This explains the smoother-looking appearance of the S-wave cross sections as compared to the refraction models.

## 8.0 CLOSING

All geophysical data and field notes collected as a part of this investigation will be archived at the AGS office. The data collection and interpretation methods used in this investigation are consistent with standard practices applied to similar geophysical investigations. The correlation of geophysical responses with probable subsurface features is based on the past results of similar surveys although it is possible that some variation could exist at this site. Due to the nature of geophysical data, no guarantees can be made or implied regarding the targets identified or the presence or absence of additional objects or targets.

AGS appreciates working for you on this project and we look forward to working with you again.

Sincerely,



Roark W. Smith  
Senior Geophysicist  
Advanced Geological Services, Inc.

Figures:

- |          |   |
|----------|---|
| Figure 1 | Site Location (imbedded in Report text, above)      |
| Figure 2 | Seismic Line Locations and Low-Velocity Areas       |
| Figure 3 | Phase III Seismic Survey Results, Line 1            |
| Figure 4 | Phase III Seismic Survey Results, Line 3            |
| Figure 5 | Phase III Seismic Survey Results, Line 4            |
| Figure 6 | Phase III Seismic Survey Results, Lines 2, 5, and 6 |



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Attachments: Appendix A: Seismic Velocity and Limitations of the Refraction Method





0 150 FT 300

#### EXPLANATION



SEISMIC LINE LOCATION



LOW-VELOCITY ZONE INDICATIVE OF  
POTENTIAL VOIDS OR SOFT SEDIMENT



3 Mystic Lane  
Malvern, PA 19355  
(925) 808-8965

#### Seismic Line Locations Phase III Seismic Investigation Sunoco Montello Terminal

LOCATION: Sinking Springs, PA

CLIENT: Tetra Tech

PROJECT #: 15-122-2PA

DATE: Jun 29, 2015

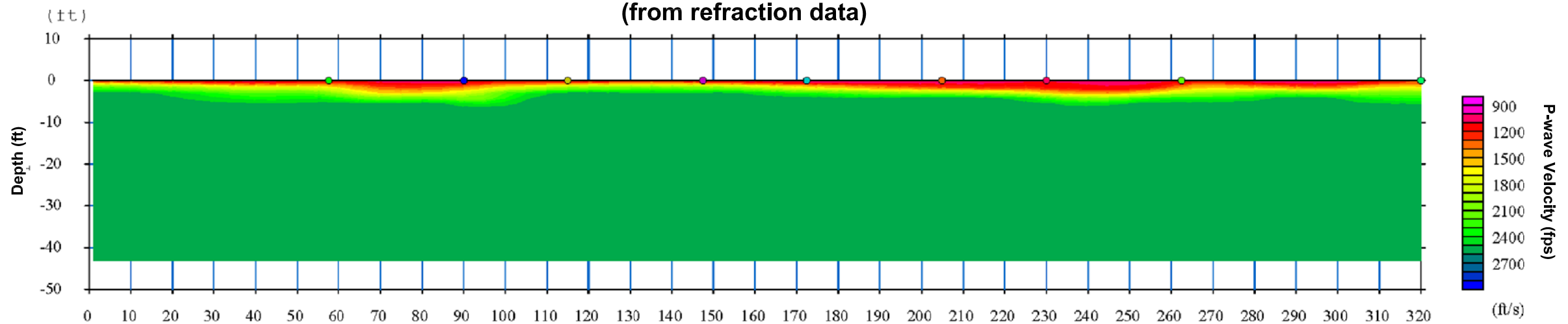
DRAWN BY: R. SMITH

FIGURE

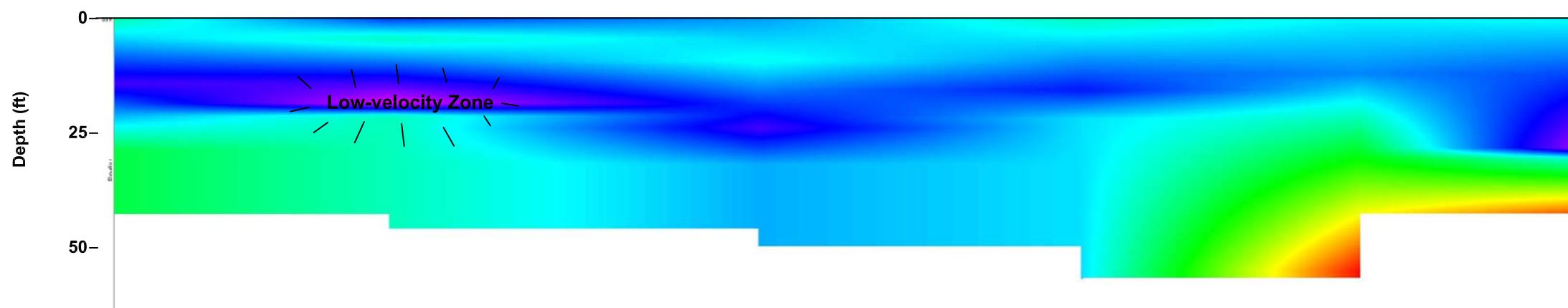
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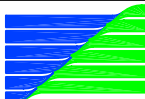


# Line 1 P-wave Model (from refraction data)



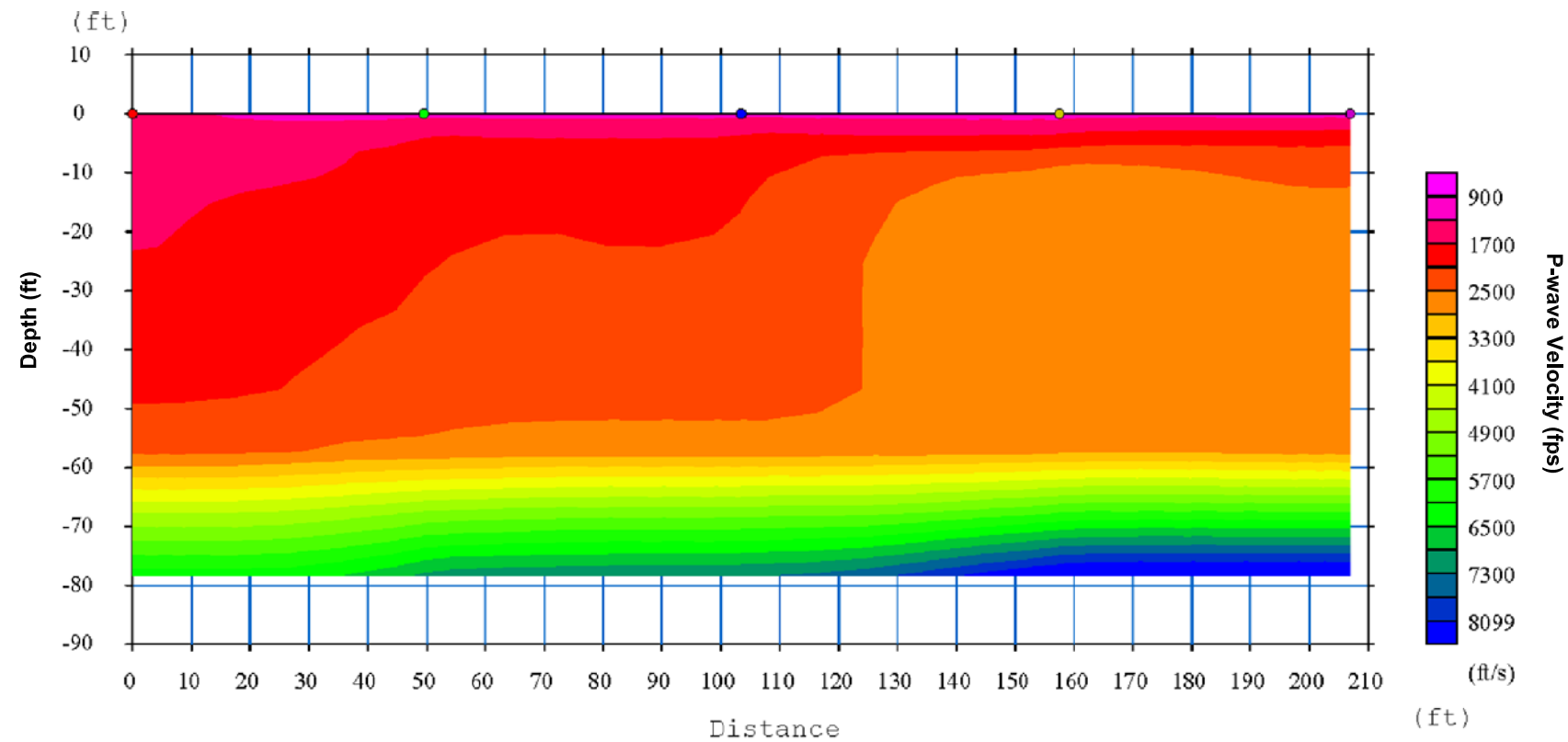
# S-wave Model (from surface-wave data)



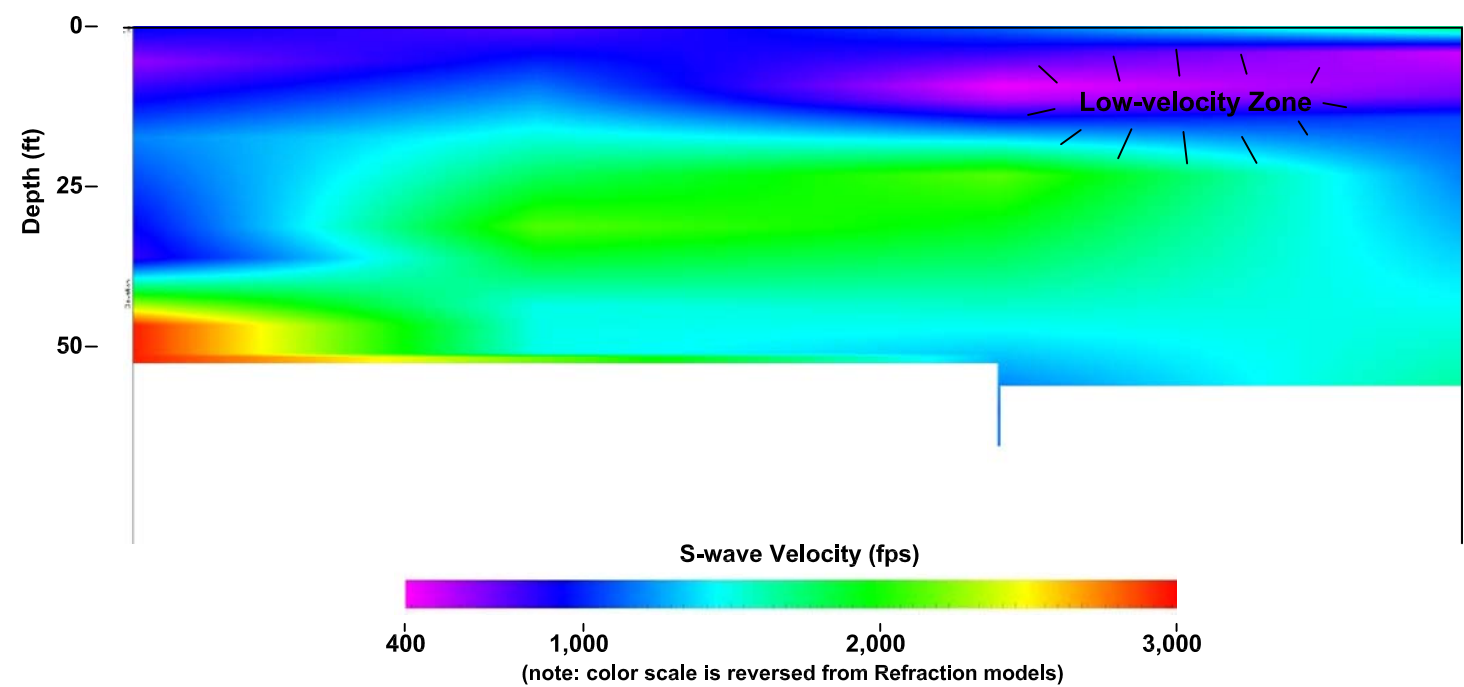
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| <div>3 Mystic Lane<br/>Malvern, PA 19355<br/>(925) 808-8965</div>   | LOCATION: Sinking Springs, PA              |                    | <div>FIGURE</div> <div>3</div> |
|   | CLIENT: Tetra Tech                         |                    |                                |
|   | PROJECT #: 15-122-2PA                      |                    |                                |
|   | DATE: Jun 29, 2015                         | DRAWN BY: R. SMITH |                                |

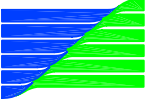


Line 3  
P-wave Model  
(from refraction data)



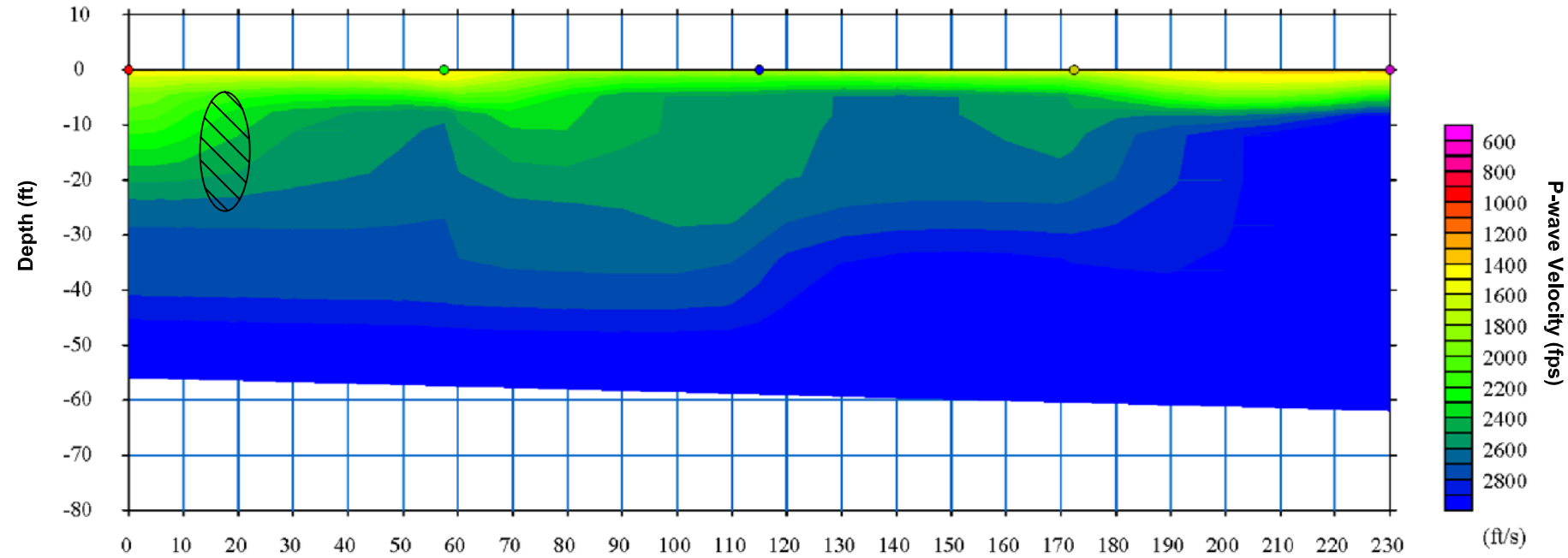
S-wave Model  
(from surface-wave data)



|   |  |                    |
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|  <b>ADVANCED<br/>GEOLOGICAL<br/>SERVICES</b> | Phase III Seismic Survey Results<br>Line 3 |                    |
|   | LOCATION: Sinking Springs, PA              |                    |
|   | CLIENT: Tetra Tech                         | FIGURE<br><b>4</b> |
|   | PROJECT #: 15-122-2PA                      |                    |
| 3 Mystic Lane<br>Malvern, PA 19355<br>(925) 808-8965  |  | DATE: Jun 29, 2015 |
|   |  | DRAWN BY: R. SMITH |

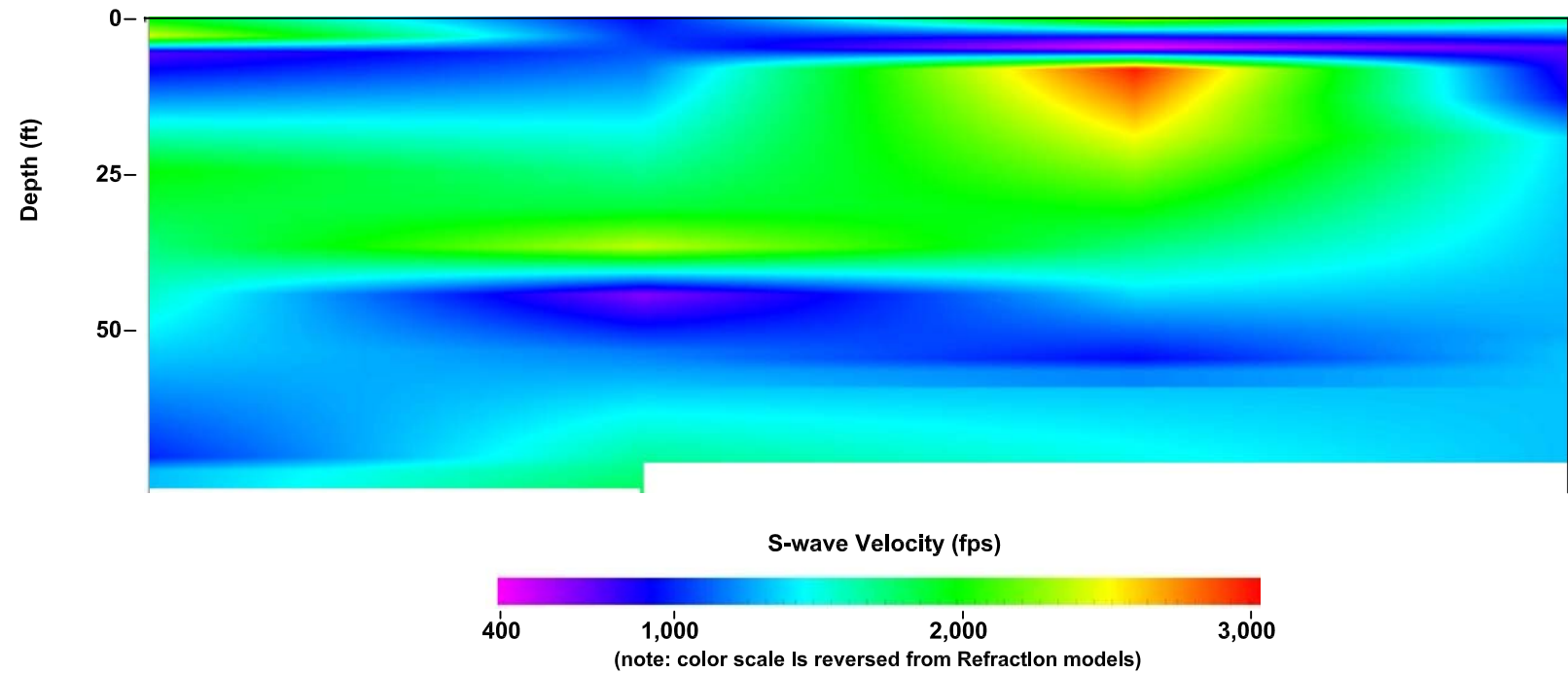


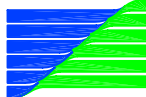
Line 4  
P-wave Model  
(from refraction data)



**EXPLANATION**  
TD PLOT DISRUPTION

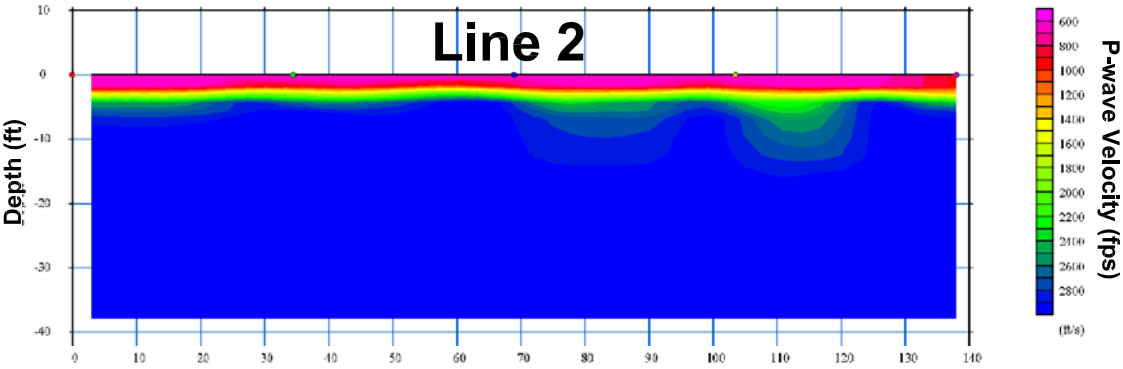
S-wave Model  
(from surface-wave data)



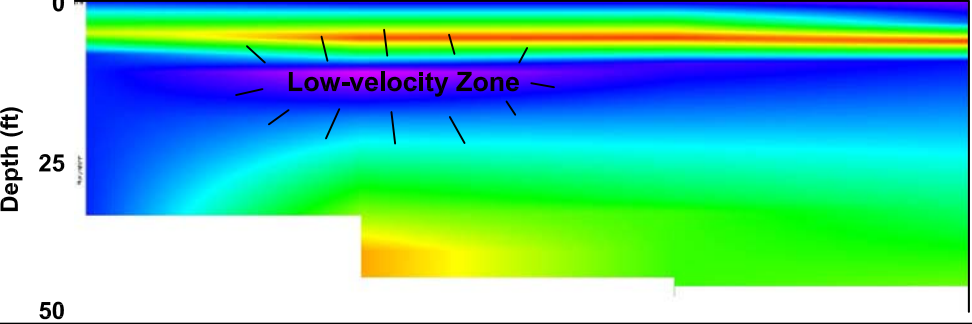
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|  <b>ADVANCED<br/>GEOLOGICAL<br/>SERVICES</b> | Phase III Seismic Survey Results<br>Line 4 |                    |                        |
|   | LOCATION: Sinking Springs, PA              |                    | FIGURE<br><br><b>5</b> |
|   | CLIENT: Tetra Tech                         |                    |                        |
|   | PROJECT #: 15-122-2PA                      |                    |                        |
| 3 Mystic Lane<br>Malvern, PA 19355<br>(925) 808-8965  | DATE: Jun 29, 2015                         | DRAWN BY: R. SMITH |                        |



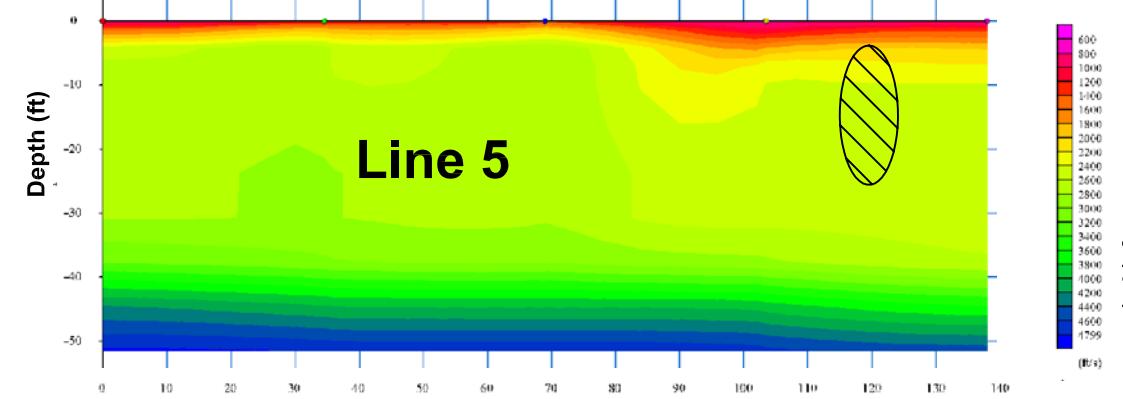
**P-wave Model (from refraction data)**



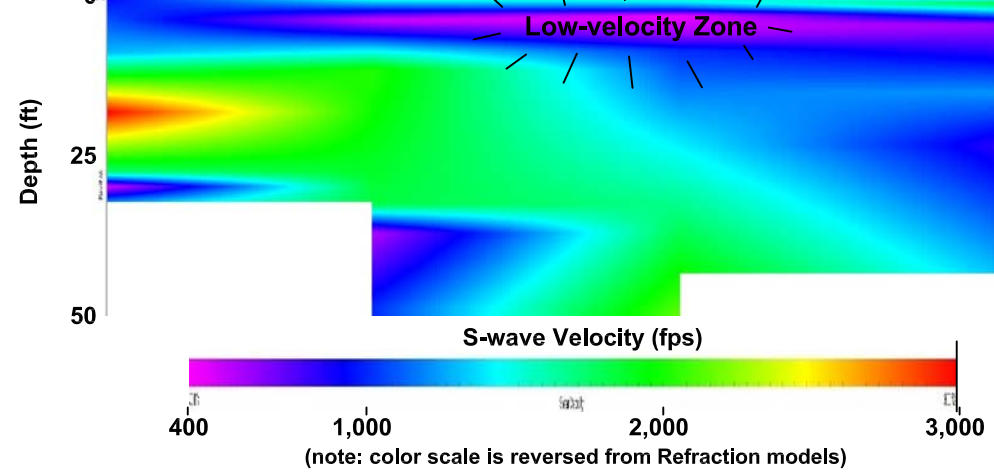
**S-wave Model (from surface-wave data)**



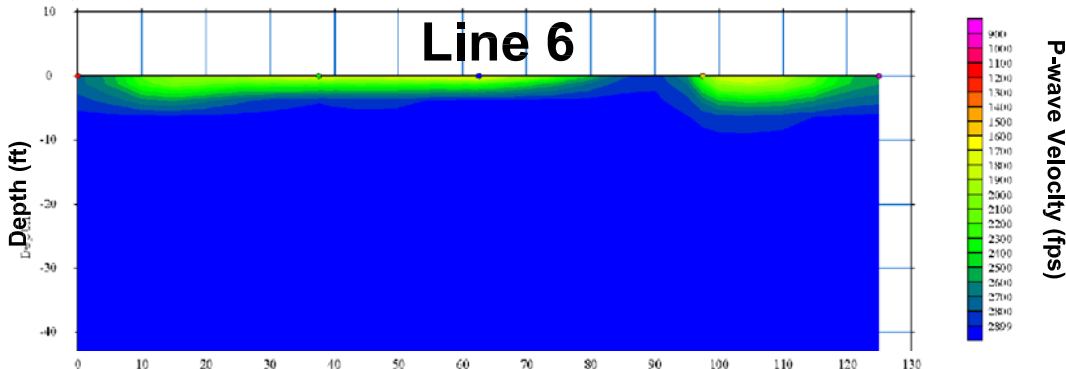
**P-wave Model (from refraction data)**



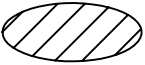
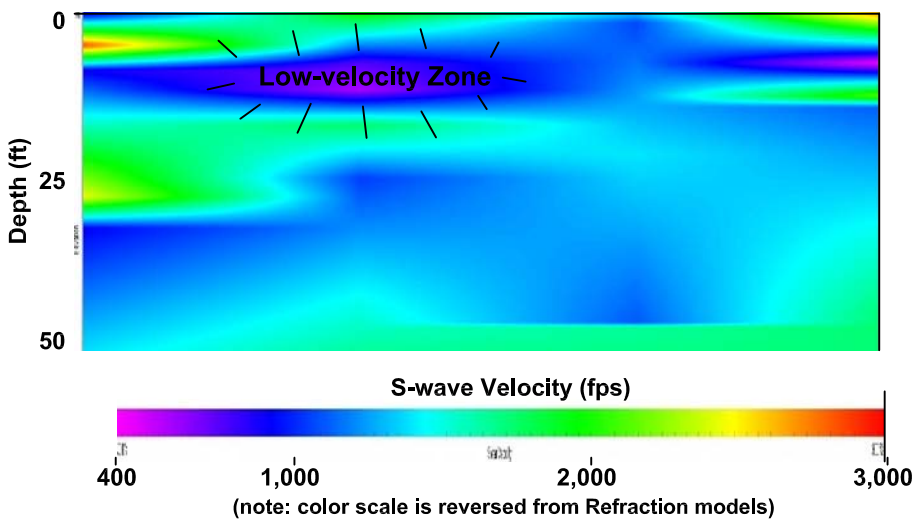
**S-wave Model (from surface-wave data)**



**P-wave Model (from refraction data)**

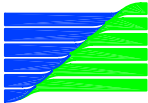


**S-wave Model (from surface-wave data)**



**EXPLANATION**  
TD PLOT DISRUPTION



|   |  |  |                               |
|---|--|--|-------------------------------|
|  <b>ADVANCED<br/>GEOLOGICAL<br/>SERVICES</b> | Phase III Seismic Survey Results<br>Line 2, Line 5, Line 6 |  |                               |
|   | LOCATION: Sinking Springs, PA                              |  | <b>FIGURE</b><br><br><b>6</b> |
|   | CLIENT: Tetra Tech   |  |                               |
|   | PROJECT #: 15-122-2PA                                      |  |                               |
| DATE: Jun 29, 2015   DRAWN BY: R. SMITH   |  |  |                               |
| 3 Mystic Lane<br>Malvern, PA 19355<br>(925) 808-8965  |  |  |                               |



## **APPENDIX A**

### **SEISMIC VELOCITY AND LIMITATIONS OF THE REFRACTION METHOD**

The physical properties of earth materials (fill, sediment, rock) such as compaction, density, hardness, and induration dictate the corresponding seismic velocity of the material. Additionally, other factors such as bedding, fracturing, weathering, and saturation can also affect seismic velocity. In general, low velocities indicate loose soil, poorly compacted fill material, poorly to semi-consolidated sediments, deeply weathered, and highly fractured rock. Conversely, high velocities are indicative of competent rock or dense and highly compacted sediments and fill. The highest velocities are measured in unweathered and little fractured rock.

There are certain limitations associated with the seismic refraction method as applied for this investigation. These limitations are primarily based on assumptions that are made by the data analysis routine. The data analysis routine assumes that the velocities along the length of each spread are uniform. If there are localized zones within each layer where the velocities are higher or lower than indicated, the analysis routine will interpret these zones as changes in the surface topography of the underlying layer. A zone of higher velocity material would be interpreted as a low in the surface of the underlying layer. Zones of lower velocity material would be interpreted as a high in the underlying layer. The data analysis routine also assumes that the velocity of subsurface materials increase with depth. Therefore, if a layer exhibits velocities that are slower than those of the material above it, the slower layer will not be resolved. Also, a velocity layer may simply be too thin to be detected.

The quality of the field data is critical to the construction of an accurate depth and velocity profile. Strong, clear “first-break” information from refracted interfaces will make the data processing, analysis, and interpretation much more accurate and meaningful. Vibrational noise or poor subsurface conditions can decrease the ability to accurately locate and pick seismic waves from the interfaces.

Due to these and other limitations inherent to the seismic refraction method, resultant velocity cross-sections should be considered only as approximations of the subsurface conditions. The actual conditions may vary locally.



## **APPENDIX D.1**

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### **Sinkhole Mitigation Guidance (West Virginia)**



**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:**

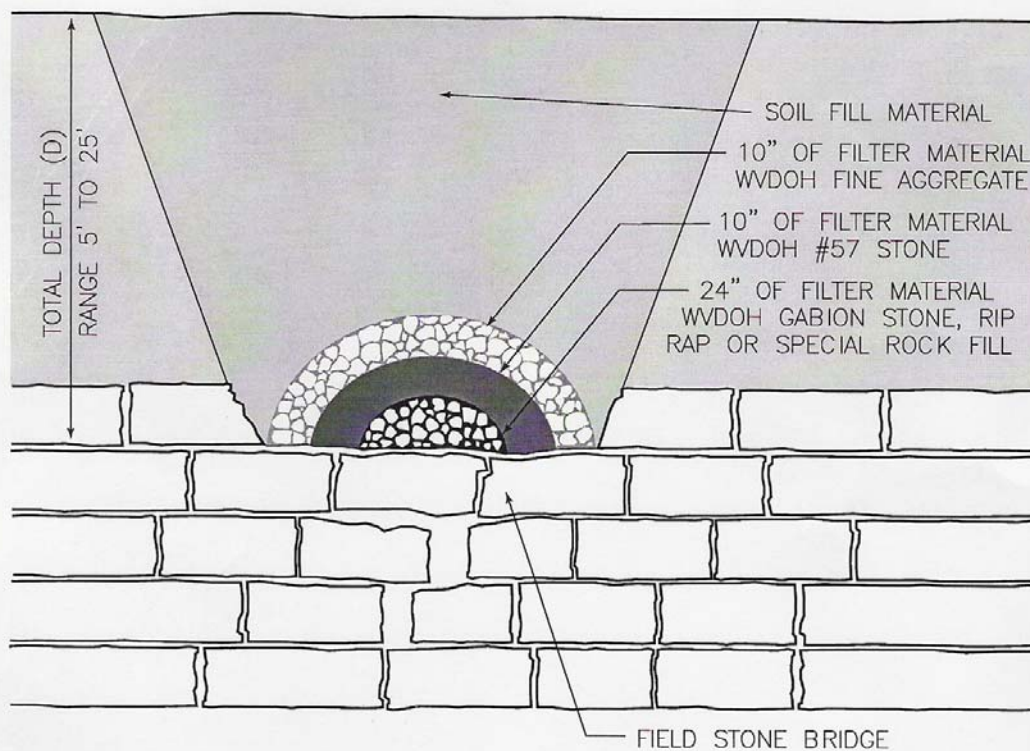
USDA Natural Resources Conservation Center, January 2004. *Maryland Conservation Practice Standard, Sinkhole and Sinkhole Area Treatment, Code 725.*

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

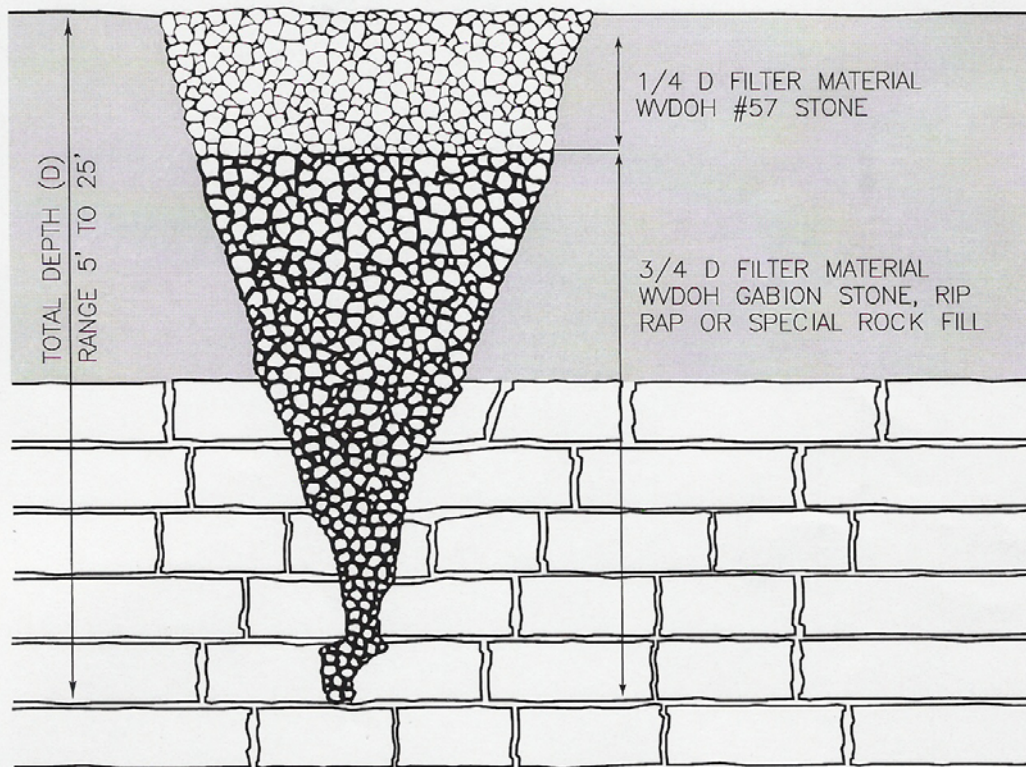
## SINKHOLE MITIGATION

(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)



## APPENDIX D.2

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### PADEP Sediment Basins, Design Criteria Summary, Karst Topography



**CHAPTER 7 - SEDIMENT BASINS**  
DESIGN CRITERIA SUMMARY

2. In **karst topography**, impounded water causes soil saturation and loss of cohesion, and produces stress from the weight of the water. Differences in hydraulic head and steep hydraulic gradients can result in sinkhole development. To ensure that these facilities are kept small and shallow, it is recommended that drainage areas be kept to 5 acres or less and that sediment traps be utilized to the maximum extent practicable so that the total depth is kept below 5 feet (see Chapter 8 – Sediment Traps for more information). For areas where a sediment basin cannot be avoided, the designer should keep the depth to the minimum (4 feet to the top of the settling volume). At the discretion of the designer, it may be necessary to install an impermeable liner based on geotechnical testing, known occurrences of sinkhole development, and whether the basin will be converted to a permanent stormwater management facility. Maintenance instructions should emphasize the importance of ensuring the integrity of all pipes. Pipe leakage or sagging can become the focus of soil loss into subsurface voids leading to subsidence and the development of sinkholes. Should sinkholes develop, they should be promptly and properly repaired. **Please see Chapter 17, Areas of Special Concern, for information regarding sinkhole repair.** Information regarding sinkhole repair should be placed on the plan drawings.

**CHAPTER 17 - AREAS OF SPECIAL CONCERN**  
**SINKHOLE REPAIR**

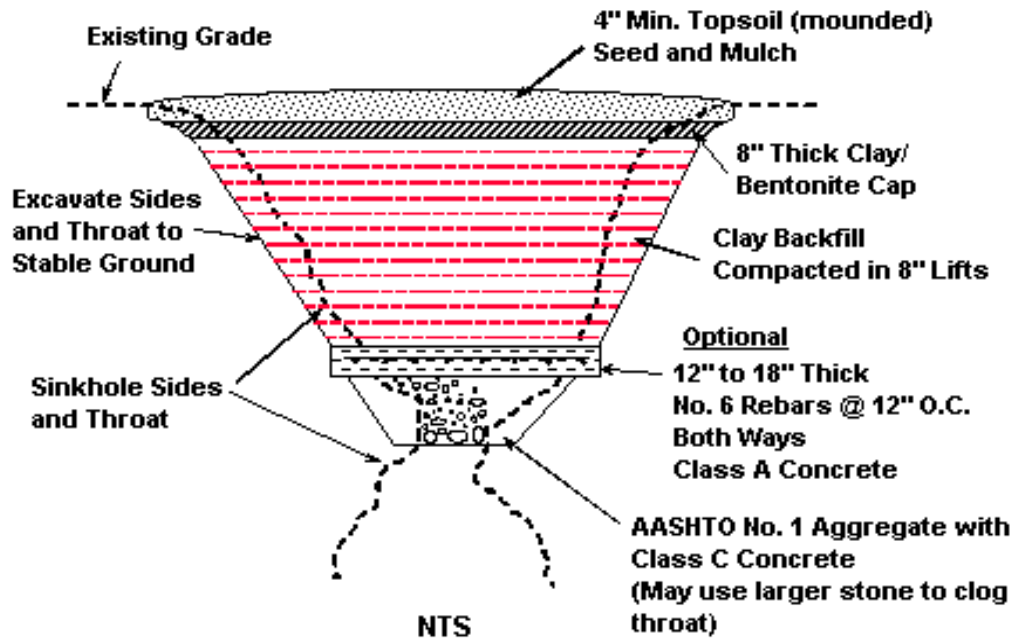
Sinkholes vary greatly in size and nature. Therefore, specific methods of repairing sinkholes will depend on site conditions including but not necessarily limited to:

- Sinkhole diameter and depth
- Surface slope
- Presence or absence of surface runoff
- Soil type
- Connectivity to public or private water supplies
- Proximity of surface waters
- Ease of access by construction equipment
- Potential danger to the public or damage to structures

Due to the variable nature of sinkholes, they should be repaired under the direct observation and supervision of a professional geologist or licensed geotechnical engineer. Figures 17.1 through 17.4 are provided as general guidelines for the repair of sinkholes. They may be modified as necessary to accommodate specific site conditions. Site specific sinkhole repair plans will be reviewed on a case-by-case basis.



**FIGURE 17.1**  
**Sinkhole Repair with a Bentonite Cap**



PA DEP

Loose material shall be excavated from the sinkhole and expose solution void(s) if possible. Enlarge sinkhole if necessary to allow for installation of filter materials. Occupational Safety and Health Administration (OSHA) regulations must be followed at all times during excavation.

Stones used for the "bridge" and filters shall have a moderately hard rock strength and be resistant to abrasion and degradation. Shale and similar soft and/or non-durable rock are not acceptable.



**FIGURE 17.2**  
**Sinkhole Repair with a Pervious Cover**

**GEOTEXTILE BETWEEN  
R-3 ROCK & AASHTO  
#57 STONE**

**6" TO 12" TOPSOIL**

**1/4 D FILTER  
MATERIAL  
(AASHTO#57 STONE)**

**~1' ABOVE  
COMPETENT  
ROCK**

**GEOTEXTILE BLANKET  
IN AREAS ADJACENT  
TO FINE-GRAINED  
MATERIAL**

**3/4 D FILTER MATERIAL  
(R-3 ROCK)**

**STONES 1/4 TO 1/2 VOID DIA.**

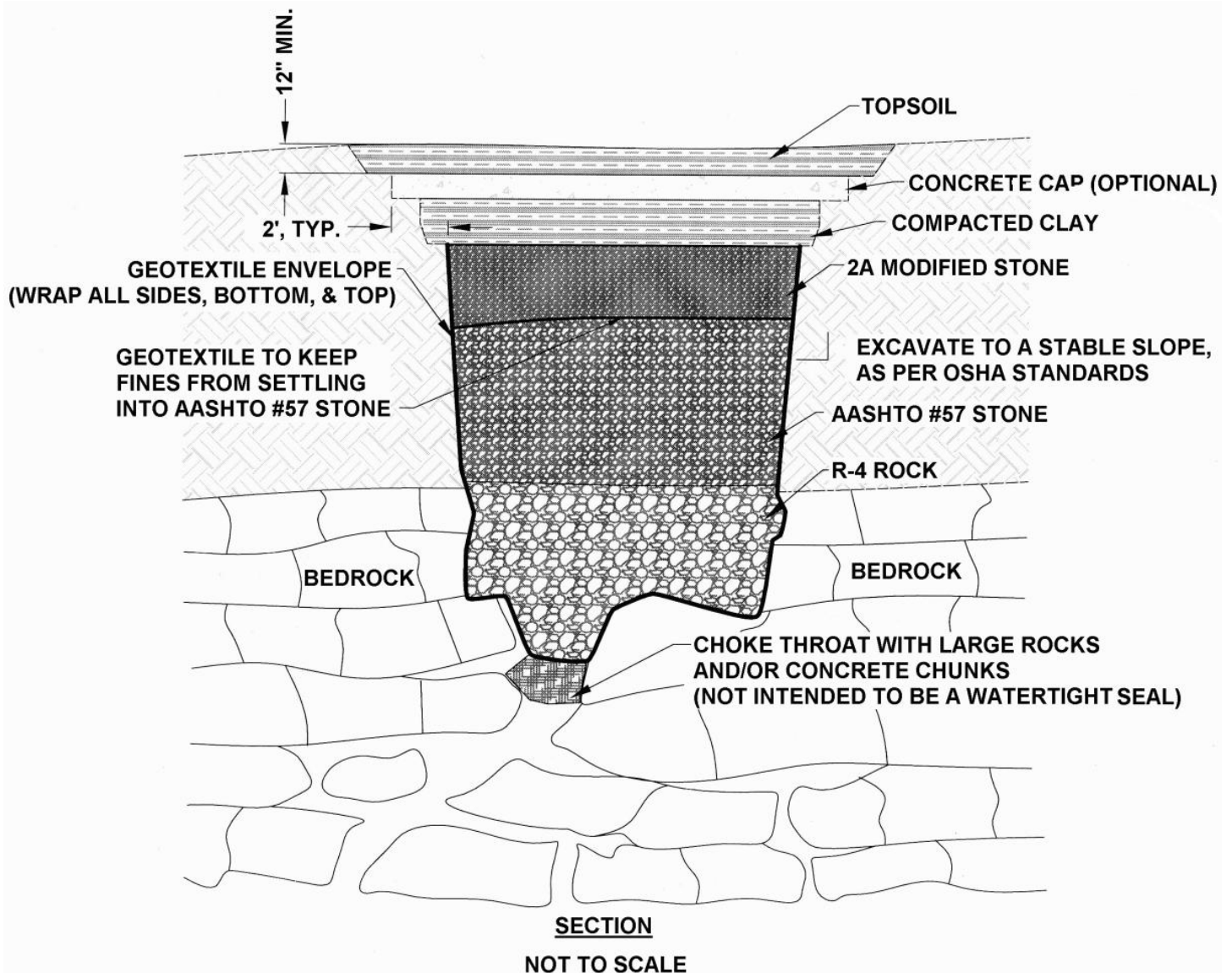
**SECTION**  
**NOT TO SCALE**

Loose material shall be excavated from the sinkhole and expose solution void(s) if possible. Enlarge sinkhole if necessary to allow for installation of filter materials. OSHA regulations must be followed at all times during excavation.

Stones used for the "bridge" and filters shall have a moderately hard rock strength and be resistant to abrasion and degradation. Shale and similar soft and/or non-durable rock are not acceptable.



**FIGURE 17.3**  
**Sinkhole Repair with an Impervious Cover**



Loose material shall be excavated from the sinkhole and expose solution void(s) if possible. Enlarge sinkhole if necessary to allow for installation of filter materials. OSHA regulations must be followed at all times during excavation.

Geotextile shall be non-woven with a burst strength between 100 and 200 psi.

Select field stone(s) about 1.5 times larger than solution void(s) to form "bridge." Place rock(s) so no large openings exist along the sides. Stones used for the "bridge" and filters shall have a moderately hard rock strength and be resistant to abrasion and degradation. Shale and similar soft and/or non-durable rock are not acceptable.

Minimum thickness of R-4 rock is 18." AASHTO #57 stone thickness shall be  $\frac{1}{4}$  to  $\frac{1}{2}$  that of the R-4 rock.

Minimum thickness of 2A modified crushed stone shall be 9". AASHTO #57 stone and 2A modified crushed stone shall be compacted after each placement.

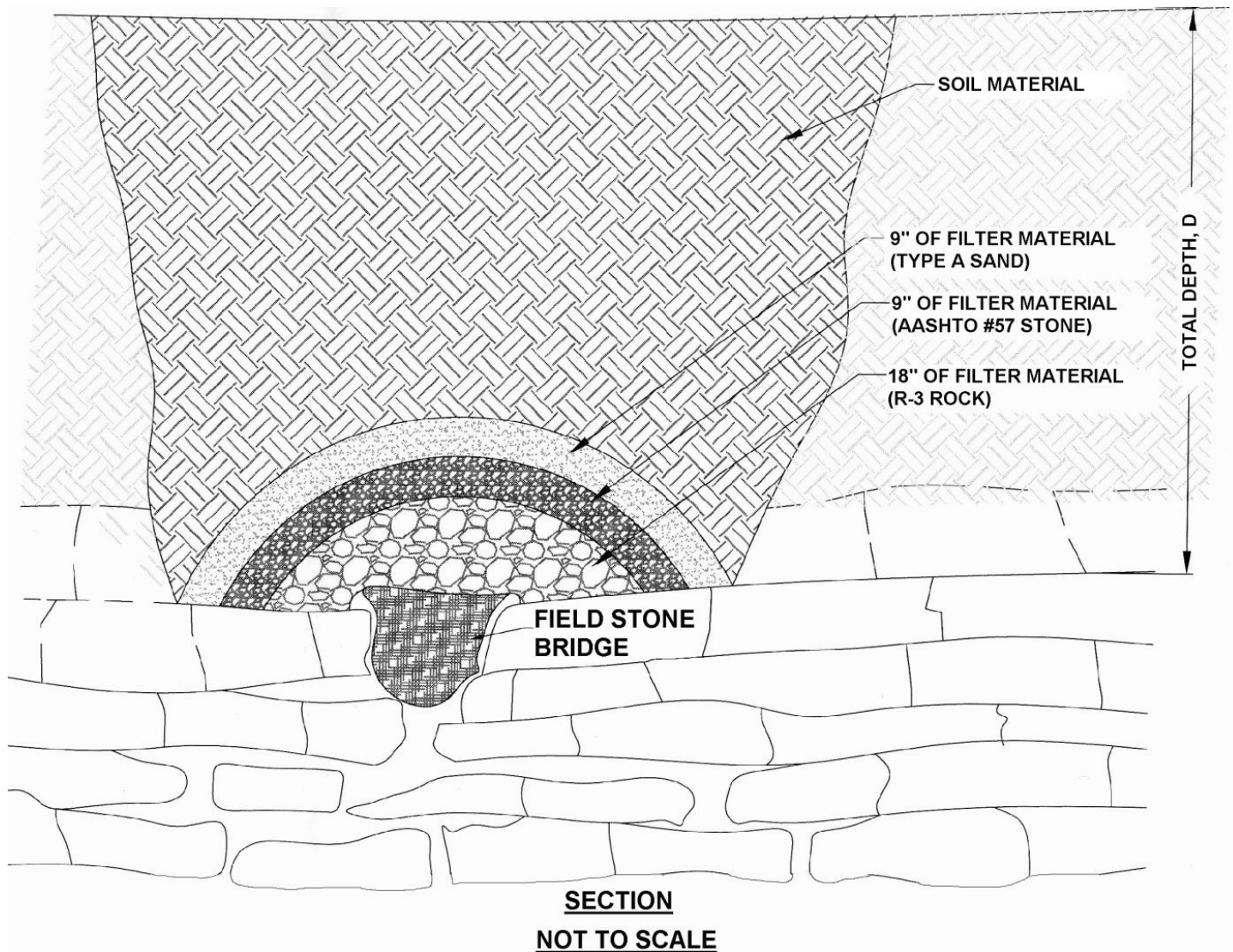
Compacted clay seal shall be a minimum of 12" thick. Clay shall be placed in 6" to 9" lifts and thoroughly compacted.

Concrete cap, which is optional, shall be a minimum of 8" thick. Use 4,000 psi concrete with 6" X 6" - 6 gauge welded wire fabric, or # 3 rebar on 18" O.C. both ways.

Topsoil shall be a minimum of 12" thick. Grade for positive drainage away from sinkhole area.



**FIGURE 17.4**  
**Sinkhole Repair with Soil Cover**



Loose material shall be excavated from the sinkhole and expose solution void(s) if possible. Enlarge sinkhole if necessary to allow for installation of filter materials. OSHA regulations must be followed at all times during excavation.

Select field stone(s) about 1.5 times larger than solution void(s) to form "bridge." Place rock(s) so no large openings exist along the sides. Stones used for the "bridge" and filters shall have a moderately hard rock strength and be resistant to abrasion and degradation. Shale and similar soft and/or non-durable rock are not acceptable.

Minimum thickness of R-3 rock is 18." AASHTO #57 stone thickness shall be a minimum of 9" thick. Minimum thickness of type A sand shall be 9". NOTE: A non-woven geotextile with a burst strength between 100 and 200 psi may be substituted for the AASHTO#57 stone and type A sand.

Soil shall be mineral soil with at least 12 % fines and overfilled by 5% to allow for settlement. Suitable soil from the excavation may be used. Any available topsoil shall be placed on top surface.



## APPENDIX D.3

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### Mitigation Using Micropiles



**Penn DOT Geotechnical Engineering Manual, Publication 293, 2014 Edition.**

**1.6.1.4.5 Micropiles**

Micropiles used on PennDOT project typically require a rock socket to provide axial and lateral resistance, and micropiles are often used where voids, soil seams, weak rock layers, etc., underlie a project site. It is therefore important that the micropile rock socket be installed in adequate bedrock to support the proposed loads. Determining the adequacy of the rock socket is typically based on the response of the drill rig (i.e., rate of drill stem advancement, down pressure, water pressure, sound, etc.) and the type of cuttings that exit the drill hole. The drill operator is often relied upon heavily to evaluate these conditions due to their experience installing micropiles. For proper QA assessment, a geotechnical specialist should observe and document all conditions during installation, communicating with the drill operator to assure that an adequate, suitable rock socket is obtained for foundation installation. With close observation of the drilling, the geotechnical specialist can prevent excessive pile lengths (i.e., reduce cost) and can track quantities, depths and/or socket lengths necessary to satisfy design requirements, and fully document pile installation (including item quantities for quality control and assurance, or for payment calculation).

**1.6.1.6 Voids**

Voids beneath a project site, either naturally occurring from the solutioning of soluble bedrock (i.e., limestone, dolomite, marble) or manmade from mining, will require treatment if they are known or anticipated to impact the proposed construction, or have an impact on long term performance. Whether or not to treat voids will typically be determined during the design phase, although often times the exact extent/limits of the void are not known at this time. Additionally, voids not identified by the design subsurface exploration may be encountered during construction. Whatever the situation the geotechnical specialist can provide assistance and a level of assurance that:

1. The locations of anticipated voids are properly identified.
2. The existence and extent of the anticipated voids are verified.
3. Proposed mitigation of anticipated voids is properly monitored and executed.
4. Unforeseen voids are identified and delineated.
5. Effective mitigation proposals for the unforeseen voids are developed.
6. Mitigation of unforeseen voids is properly monitored and executed.
7. Quantities required for payment are tracked.
8. Voids are adequately filled, and verification of such is provided (assuming means or measures exist to assess the adequacy of void filling operations).

**1.6.1.8 Temporary Shoring**

Contractor submittals are required for temporary shoring conditions. Submittals are required to document the proposed design, materials, and methods to be used for the temporary shoring. Review of these submissions by a geotechnical specialist, either in house or by consultant reviewer, having knowledge and experience with design and proposed construction of the temporary shoring is required.



## APPENDIX E

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### List of Approved Contractors



## **LIST OF APPROVED VOID MITIGATION GEOTECHNICAL AND GEOPHYSICAL CONTRACTORS**

### **Approved Geotechnical Contractor**

Ralph Boedeker, P.E. (DE, PA, MD, VA, OH, WV)  
Manager, Geotechnical Engineering and Construction Services  
Direct: 302.283.2274 | Mobile: 302-275-4506 | Main: 302.738.7551 | Fax: 302.454.5988  
ralph.boedeker@tetrattech.com

Tetra Tech | Manager-Senior Engineer  
240 Continental Drive, Suite 200 | Newark, DE 19713

### **List of Approved Geophysical Contractors**

Suggested Notification to get on Contract and possible Standby prior to Drilling in concentrated Karst/Sinkhole Areas and Abandoned Subsurface Mines.

- 1) Advanced Geological Services  
3 Mystic Lane  
Malvern, PA 19355  
(610) 722-5500  
(610) 722-0250 Fax
- 2) Advanced Geological Services  
P.O. 349  
Chillicothe, Ohio 45601  
(740) 600-0276
- 3) Enviroskan  
1051 Columbia Avenue  
Lancaster, PA 17603  
(717) 283-4715



## APPENDIX F

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## REFERENCES



## **REFERENCES**

Appendix D.1: Sinkhole Mitigation Guidance, August 8, 2005. West Virginia Department of Environmental Protection Division of Water and Waste Management Groundwater Protection Program.

Appendix D.2: PADEP Erosion and Sediment Control Manual, March 2012. "CHAPTER 7 - Sediment Basins, Design Criteria Summary, Karst Topography". "CHAPTER 17 - Areas of Special Concern, Sinkhole Repair".

Appendix D.3: Penn DOT Pub 293 Part 1: Section 1.6.1.4.5 (Micropiles), Section 1.6.1.6 (Voids), and Section 1.6.1.8 (Temporary Shoring).

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