SUNOCO PIPELINE
An ENERGY TRANSFER Company

535 Fritztown Road
Sinking Spring, PA 19608

May 3, 2019

Via Electronic Mail
Mr. Scott R. Williamson
Program Manager, Waterways & Wetlands Program
Pennsylvania Department of Environmental Protection
Southcentral Regional Office
909 Elmerton Avenue
Harrisburg, PA 17110-8200

Re: Responses to DEP Comments for Hydrogeological HDD Re-Evaluation Report
U.S. Rt. 15 16" Horizontal Directional Drill Location (S2-0247-16)
Permit No. E21-449
Upper Allen Township, Dauphin County

Dear Mr. Williamson:

In compliance with the Corrected Stipulated Order dated August 10, 2017, a Re-evaluation Report on the above-referenced horizontal directional drill (HDD) was submitted to the Pennsylvania Department of Environmental Protection (Department) on March 1, 2019. In a letter dated April 22, 2019, the Department requested further information. Please accept this letter as a response. Your requests are bolded below followed by the response.

1 **As required by Paragraph 4.and 5 of the Environmental Hearing Board's August 10, 2017 Corrected Stipulated Order, SPLP failed to fully utilize information gathered during the HDD of the 20-inch bore as part of the HDD Re-evaluation for the 16-inch pipeline. Examination of the drilling record for the 20-inch pipeline boring indicates a persistent and significant loss of circulation (LOC) at approximately 673 feet and 1525 feet from HDD entry and an inadvertent return (IR) that began when approximately 1768 feet from the HDD entry. The HDD re-evaluation report should discuss the operational or geologic cause of each inadvertent return, the magnitude of the IR(s) and associated loss of circulation, the best management practice used to contain and minimize the IR, and the drilling procedure or technique used to progress the boring.**

SPLP utilized all information obtained during the drilling of the 20-inch HDD in our internal assessment and evaluation of the 16-inch HDD profile as revised; however, we agree that our deductions from review of this information were not fully conveyed in the Re-evaluation Report. The IR information presented graphically on Figure 1 in Attachment 2 presents the plan and cross section views of the June 27, 2017 IR events occurring during completion of this HDD in relation to the depth of profile, and allows for correlation to monitoring data collected during active drilling.

SPLP reviewed the daily drilling reports, the geotechnical investigations, the geophysical survey, and the HDD Inspection Daily Reports, paying attention to intervals/days in which a partial or full loss of returns or an IR occurred. Specifically, the depth of the pilot tool was compared to the geotechnical investigations to determine if the pilot tool was advancing through an interval of bedrock which could be either highly broken, fractured or weathered. Further, the annular pressures were reviewed to identify any sudden changes in pressure while the pilot tool was being advanced, which could be utilized to approximate the competency of the bedrock.

Review of this information identified several areas in which karstified terrane is located with these areas having the potential for IRs. The LOC and loss of returns (LOR) that were reported along the drill path correspond to either reported closed depressions or geophysical results which are indicative of the presence of karst features. Therefore, the LOCs and LORs experienced during the completion of the 20-inch HDD likely resulted from the pilot tool advancing through these karst features. The June 27, 2017 IR resulted from a clogged annulus related to the LOC/LOR observed at approximately 1,525 feet. The pilot tool was located approximately 144 feet to the east of the location of the IR when the drilling fluids surfaced.

To address the LOCs and LORs as they occurred the drilling contractor swabbed the boring and tripped out the pilot tool until circulation was regained. Additionally, the physical qualities of the drilling fluid were altered to increase the carrying capacity to reduce the potential for cuttings to clog the borehole. These procedures were successful at regaining circulation at the LOC reported at approximately 673 feet. However, when these procedures were employed at the LOC reported at approximately 1525 feet, they were only successful while the tooling was tripped back into the borehole. Once new bedrock was being cut, circulation was gradually lost until by the end of the day only 10% of the drilling fluid was returning to the western entry/exit pit. The following day the June 27, 2017, the IR occurred, and all drilling activities were immediately stopped. To avoid further potential LOCs/LORs and IRs, the decision was made to mobilize the drill rig to the eastern entry/exit point and complete the 20-inch HDD by intercepting the borehole advanced from the western entry/exit point. Drilling did not resume until the drill rig and all support equipment were setup at the eastern entry/exit point and the intercept boring was initiated on July 5, 2017. The intercept between the two pilot holes occurred July 13, 2017 and the reaming phase was initiated. Various levels of LOCs occurred intermittently until the 30-inch ream pass was completed on September 22, 2017. Swabbing of the bore concluded on September 25, 2017 and the pipeline was pulled into place on September 26, 21017. No further IRs occurred.

2. **This information should then be used to describe why the chosen bore path for the 16-inch pipeline was determined and how such information has been used to minimize the potential for IRs to occur and as part of the discussion of construction alternatives.**

As discussed in the response to Item #1, karst features were identified along the completed 20-inch and permitted 16-inch HDD. As a result, the depth of the redesigned 16-inch profile was increased so it would be advanced through more competent bedrock as identified in the geophysical survey. However, as indicated by the 2017 geotechnical investigation, bedrock at this depth may still be broken so the potential for an LOC to occur could still exist. As such, the drilling contractor will be monitoring the annular pressure as the pilot tool is being advanced and will modify the drilling fluid accordingly if any unexpected pressure changes are observed. Procedures to address LOCs/LORs or an IR are detailed below in SPLP's response to item #4.

3. **Once the items discussed above are developed and by using the geophysical profiles, please attempt to predict where any operational provisions or changes may be necessary for the intervals where the previous LOCs or IRs occurred. Also, discuss any drilling intervals along the proposed 16-inch drill path where increased vigilance may be warranted, ie: the P.G. working in concert with the HDD contractor as sensitive geologic zones are approached by the drill bit.**

Prior to initiating the 16-inch pilot hole, the drilling contractor, environmental inspector and professional geologist will review the revised 16-inch profile and the 20-inch as built profile to pinpoint areas of potential concern. SPLP will provide the drilling contractor and the inspectors with locations of potential areas of concern for fluid loss and IRs based on previous areas of loss and IRs, as well as areas of potential concern identified in the geophysical survey. As those areas are approached, monitoring efforts will be enhanced which includes, increased monitoring of annular pressure changes and increasing the frequency of drill path surveys to identify any surfacing of air, groundwater, or drilling fluid in the event of a loss of drilling fluids. The drilling contractor will evaluate the need to modify the characteristics of the drilling fluid (i.e., viscosity) and increase the frequency of swabbing the borehole to reduce the potential for cuttings to accumulate within the borehole.

In the event of a LOC/LOR, the drilling contractor will install a loss control materials (LCMs) plug and allow it to cure for an appropriate length of time. Upon restart of the HDD, should the LCM plug be determined to be ineffective at sealing off the LOC/LOR, the drilling contractor will trip the bottom hole assembly (i.e., mud motor, monel and bit/reamer) out of the borehole, and trip in the drilling rods open ended. Once the rods reaches the end of the pilot hole, the driller will commence cement grout injection while backing out the drill rods, to set a low pressure cement grout plug. The cement grout will be allowed to cure 24 hours prior to advancing the pilot bit/reamer through the plug and continue to advance the borehole. If the low pressure plug is ineffective, the driller will install a packer assembly and trip the packer into the interval in which the LOC/LOR occurred and pressure grout (cement-grout) the borehole and surrounding formation. The cement grout will be allowed to cure 24 hours prior to advancing the pilot bit/reamer through the plug and continue to advance the borehole.

In the event of an IR, drilling will be stopped, and an IR Restart report will be prepared and submitted to the Department for review and approval. The specific details regarding the events and the proposed responses will be included in the Restart Report. HDD activity will not resume until Department approval of the Restart Report and proposed responses is received.

4. **In the re-evaluation report, please further discuss SPLP's monitoring procedure for detecting an IR and the standard operating procedures that are implemented upon the loss of circulation**

with special emphasis on how these provisions will minimize the occurrence and magnitude of an inadvertent return.

It should be noted that a LOC is a normal occurrence while advancing an HDD. A portion of the drilling fluid will remain in the formation as it is absorbed into the annulus of the borehole as well as filling microfractures within the annulus and the formation. As noted in the HDD Inadvertent Return Assessment, Preparedness Prevention and Contingency Plan (Revised April 2018), notifications are made (based on occurrence) to the Department; public water suppliers within 450', and every landowner with a private water supply located within 450 feet of the HDD alignment that a LOC occurred and that their water supply may be impacted. If a significant LOC (i.e., greater than 30%) occurs, the drilling contractor will attempt to condition the borehole by modifying the drilling fluids and by swabbing the borehole. This will aid in the removal of any cuttings that may have accumulated in the borehole which could result in increased annular pressure and can lead to fracturing the formation or increasing the magnitude of fractures that are already present. The drilling contractor will modify the advancement rates (i.e., penetration rate and travel speed) to prevent a plunger effect from occurring and will reduce the drilling fluid pumping pressures to the minimum necessary to maintain the borehole and to transport cuttings back to the surface. Finally, the drilling contractor will amend the drilling fluid by adding LCMs to seal off any fractures, voids or zones of lost circulation.

In the event the LOC continues, the drilling contractor will trip out of the boring and initiate a push ream from the entry side to increase the size of the annulus and to regain circulation. By initiating a push ream, the size of the annular space will be increased which will increase the annulus borehole space to decrease annular pressure.

Should the losses continue to be recorded at above-normal levels subsequent to completing the push ream, the drilling contractor will utilize cement grouting of the annulus as discussed in Item 3 above.

5. **Geotechnical Evaluation — Un-named table on p. 7 (RETTEW report) lists the Compressive Strength for boring SB-02 at sample depth 19.0 ft. as 13,320 psi. This is 10x the reported compressive strength of any other boring tested. Please clarify if this value is correct and if so, please provide an explanation for the significant difference in compressive strength considering that the borings are located in the same geologic setting.**

The compressive strength for boring SB-02 is reported in pounds per square inch, while the remaining values for borings B-01 and B-02 should be reported in tons per square feet (tsf). If the result for boring SB-02 is converted to tsf the value would be 959.04 which agrees with the values from borings B-01 and B-02. The un-named table has been revised to reflect the correct units and a revised Re-evaluation Report has been filed.

6. **Figure 1 Topographic Base-map dated 11/17/2018 from the RETTEW report dated January 10, 2019 regarding "Geophysical Survey Sunoco Pipeline, L.P. Pipeline Project Horizontal**

Directional Drill S2-0247 — Highway 15 PA-CU-0176.0019-RD-16 Upper Allen Township, Cumberland County, Pennsylvania" for the HDD is incorrect. Figure 1 shows the location of a HDD in the area of intersection of 1-76 and 1-81. The subject of the report is the HDD in the vicinity of the intersection of 1-76 and State Route 15. Please replace Figure 1 of this report with the correct base-map.

The figure has been replaced and a revised Re-evaluation Report has been filed.

7. Please explain why SPLP considers LCMs to be less effective with increasing depth.

As the depth of a boring increases the annular pressure required to return fluids and cuttings to the entry pit likewise increases. LCMs rely on increasing the body strength and cohesion of the drilling fluid/cutting mix, but LCMs do not solidify the materials. Typically, at a depth of 70 feet or greater, the annular pressure required to maintain returns to the entry pit will exceed the strength and cohesion of the LCM impregnated materials, and result in the loss of the seal.

8. SPLP is reminded that drilling of any sort in a karst environment can induce subsidence sinkholes. The site geologist should be reminded to exercise vigilance for surface indications of sinkhole formation.

The site geologist will be reminded to be vigilant and will look for evidence of sinkhole formation while conducting drill path surveys as required by the HDD Inadvertent Returns Assessment, Preparedness, Prevention and Contingency Plan. Further the Lead Geologist for Spread 4 will periodically conduct surveys looking for evidence of subsidence features while the 16-inch HDD is being completed.

SPLP submits that we have been, and are, in complete compliance with the agreed terms and requirements of analysis of the Order, as agreed to by the Department, and that no further analysis is required for the Department to consent to the start of this HDD. SPLP therefore requests that the Department approve the Reevaluation Report for the U.S. Rt. 15 Crossing Horizontal Directional Drill (S2-0247) as soon as possible.

Sincerely,

Larry J. Gremminger, CWB
Vice-President – Environmental, Health & Safety
Energy Transfer Partners
Mariner East 2 Pipeline Project

HORIZONTAL DIRECTIONAL DRILL ANALYSIS
HIGHWAY 15 CROSSING
PADEP SECTION 105 PERMIT NO.: E21-449
PA-CU-0176.0019-RD-16
(SPLP HDD No. S2-0247-16)

RETTEW

ATTACHMENT 2
SOIL RESOURCES MAP AND PROFILE DESCRIPTIONS

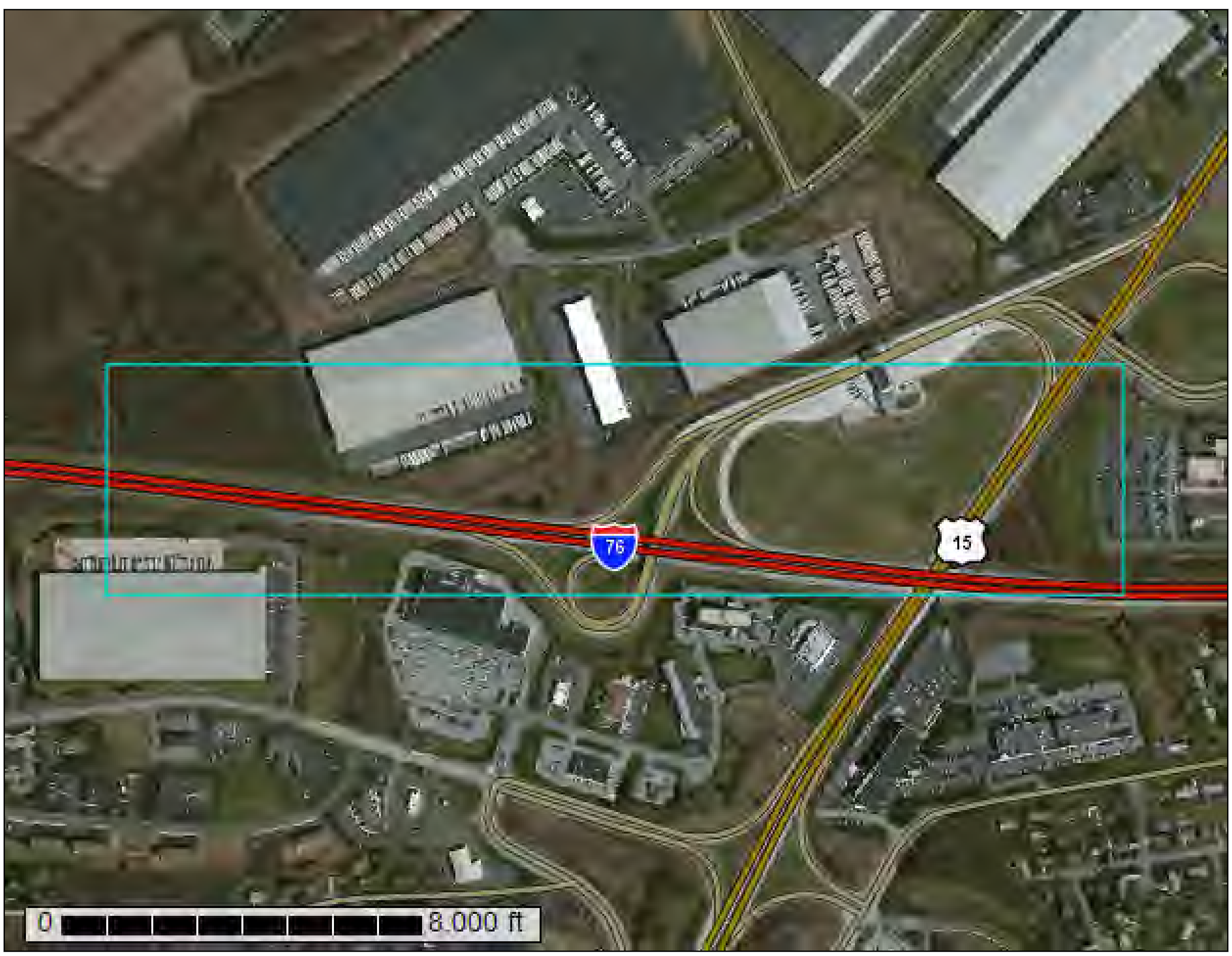
United States Department of Agriculture

Natural Resources Conservation Service

A product of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local participants

Custom Soil Resource Report for Cumberland County, Pennsylvania

HWY 15 HDD



January 25, 2018

Preface

Soil surveys contain information that affects land use planning in survey areas. They highlight soil limitations that affect various land uses and provide information about the properties of the soils in the survey areas. Soil surveys are designed for many different users, including farmers, ranchers, foresters, agronomists, urban planners, community officials, engineers, developers, builders, and home buyers. Also, conservationists, teachers, students, and specialists in recreation, waste disposal, and pollution control can use the surveys to help them understand, protect, or enhance the environment.

Various land use regulations of Federal, State, and local governments may impose special restrictions on land use or land treatment. Soil surveys identify soil properties that are used in making various land use or land treatment decisions. The information is intended to help the land users identify and reduce the effects of soil limitations on various land uses. The landowner or user is responsible for identifying and complying with existing laws and regulations.

Although soil survey information can be used for general farm, local, and wider area planning, onsite investigation is needed to supplement this information in some cases. Examples include soil quality assessments (http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/) and certain conservation and engineering applications. For more detailed information, contact your local USDA Service Center (https://offices.sc.egov.usda.gov/locator/app?agency=nrcs) or your NRCS State Soil Scientist (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/contactus/?cid=nrcs142p2_053951).

Great differences in soil properties can occur within short distances. Some soils are seasonally wet or subject to flooding. Some are too unstable to be used as a foundation for buildings or roads. Clayey or wet soils are poorly suited to use as septic tank absorption fields. A high water table makes a soil poorly suited to basements or underground installations.

The National Cooperative Soil Survey is a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local agencies. The Natural Resources Conservation Service (NRCS) has leadership for the Federal part of the National Cooperative Soil Survey.

Information about soils is updated periodically. Updated information is available through the NRCS Web Soil Survey, the site for official soil survey information.

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Contents

How Soil Surveys Are Made

Soil surveys are made to provide information about the soils and miscellaneous areas in a specific area. They include a description of the soils and miscellaneous areas and their location on the landscape and tables that show soil properties and limitations affecting various uses. Soil scientists observed the steepness, length, and shape of the slopes; the general pattern of drainage; the kinds of crops and native plants; and the kinds of bedrock. They observed and described many soil profiles. A soil profile is the sequence of natural layers, or horizons, in a soil. The profile extends from the surface down into the unconsolidated material in which the soil formed or from the surface down to bedrock. The unconsolidated material is devoid of roots and other living organisms and has not been changed by other biological activity.

Currently, soils are mapped according to the boundaries of major land resource areas (MLRAs). MLRAs are geographically associated land resource units that share common characteristics related to physiography, geology, climate, water resources, soils, biological resources, and land uses (USDA, 2006). Soil survey areas typically consist of parts of one or more MLRA.

The soils and miscellaneous areas in a survey area occur in an orderly pattern that is related to the geology, landforms, relief, climate, and natural vegetation of the area. Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform. By observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they were formed. Thus, during mapping, this model enables the soil scientist to predict with a considerable degree of accuracy the kind of soil or miscellaneous area at a specific location on the landscape.

Commonly, individual soils on the landscape merge into one another as their characteristics gradually change. To construct an accurate soil map, however, soil scientists must determine the boundaries between the soils. They can observe only a limited number of soil profiles. Nevertheless, these observations, supplemented by an understanding of the soil-vegetation-landscape relationship, are sufficient to verify predictions of the kinds of soil in an area and to determine the boundaries.

Soil scientists recorded the characteristics of the soil profiles that they studied. They noted soil color, texture, size and shape of soil aggregates, kind and amount of rock fragments, distribution of plant roots, reaction, and other features that enable them to identify soils. After describing the soils in the survey area and determining their properties, the soil scientists assigned the soils to taxonomic classes (units). Taxonomic classes are concepts. Each taxonomic class has a set of soil characteristics with precisely defined limits. The classes are used as a basis for comparison to classify soils systematically. Soil taxonomy, the system of taxonomic classification used in the United States, is based mainly on the kind and character of soil properties and the arrangement of horizons within the profile. After the soil scientists classified and named the soils in the survey area, they compared the individual soils with similar soils in the same taxonomic class in other areas so that they could confirm data and assemble additional data based on experience and research.

The objective of soil mapping is not to delineate pure map unit components; the objective is to separate the landscape into landforms or landform segments that have similar use and management requirements. Each map unit is defined by a unique combination of soil components and/or miscellaneous areas in predictable proportions. Some components may be highly contrasting to the other components of the map unit. The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The delineation of such landforms and landform segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, onsite investigation is needed to define and locate the soils and miscellaneous areas.

Soil scientists make many field observations in the process of producing a soil map. The frequency of observation is dependent upon several factors, including scale of mapping, intensity of mapping, design of map units, complexity of the landscape, and experience of the soil scientist. Observations are made to test and refine the soil-landscape model and predictions and to verify the classification of the soils at specific locations. Once the soil-landscape model is refined, a significantly smaller number of measurements of individual soil properties are made and recorded. These measurements may include field measurements, such as those for color, depth to bedrock, and texture, and laboratory measurements, such as those for content of sand, silt, clay, salt, and other components. Properties of each soil typically vary from one point to another across the landscape.

Observations for map unit components are aggregated to develop ranges of characteristics for the components. The aggregated values are presented. Direct measurements do not exist for every property presented for every map unit component. Values for some properties are estimated from combinations of other properties.

While a soil survey is in progress, samples of some of the soils in the area generally are collected for laboratory analyses and for engineering tests. Soil scientists interpret the data from these analyses and tests as well as the field-observed characteristics and the soil properties to determine the expected behavior of the soils under different uses. Interpretations for all of the soils are field tested through observation of the soils in different uses and under different levels of management. Some interpretations are modified to fit local conditions, and some new interpretations are developed to meet local needs. Data are assembled from other sources, such as research information, production records, and field experience of specialists. For example, data on crop yields under defined levels of management are assembled from farm records and from field or plot experiments on the same kinds of soil.

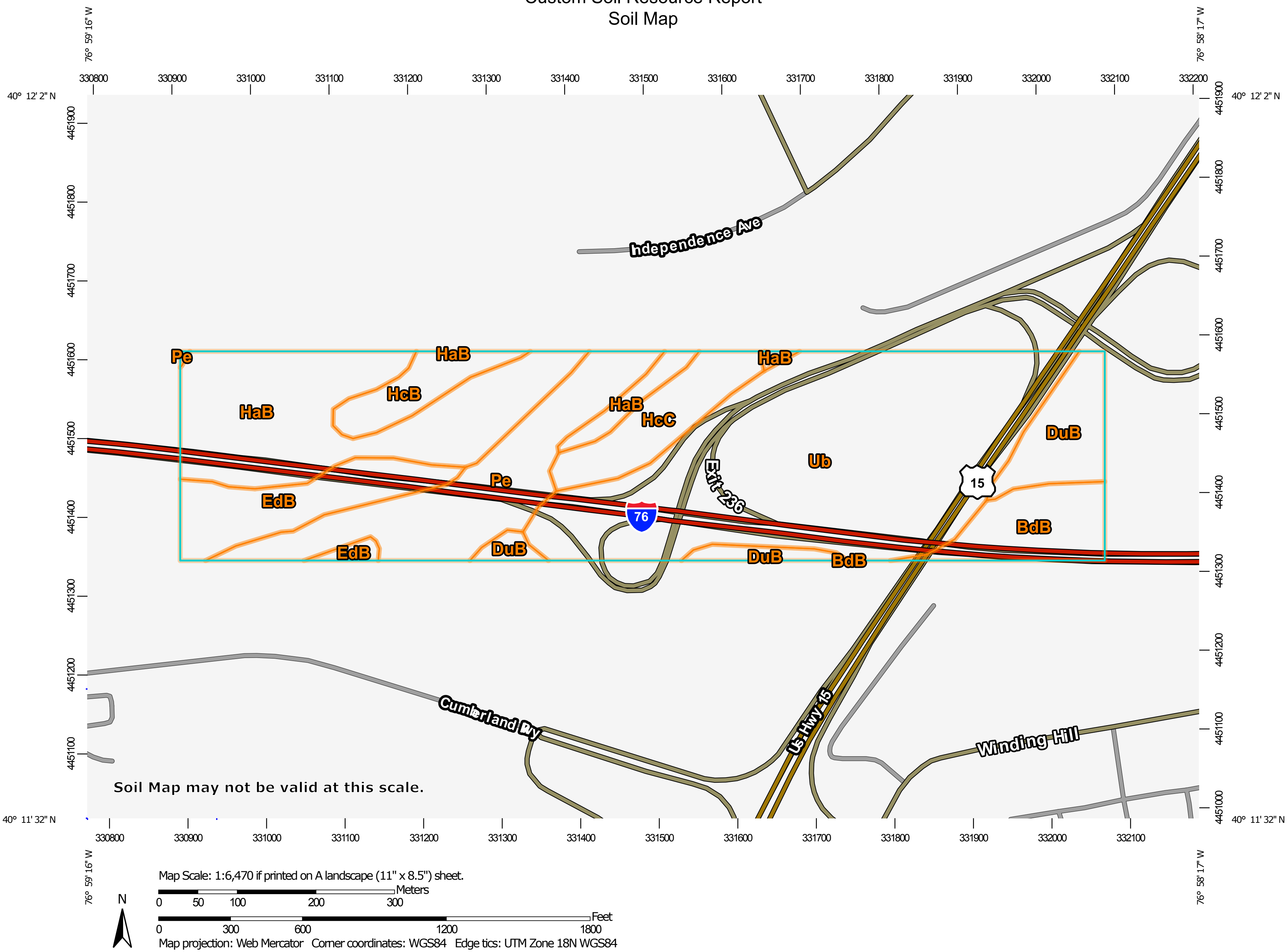
Predictions about soil behavior are based not only on soil properties but also on such variables as climate and biological activity. Soil conditions are predictable over long periods of time, but they are not predictable from year to year. For example, soil scientists can predict with a fairly high degree of accuracy that a given soil will have a high water table within certain depths in most years, but they cannot predict that a high water table will always be at a specific level in the soil on a specific date.

After soil scientists located and identified the significant natural bodies of soil in the survey area, they drew the boundaries of these bodies on aerial photographs and identified each as a specific map unit. Aerial photographs show trees, buildings, fields, roads, and rivers, all of which help in locating boundaries accurately.

Soil Map

The soil map section includes the soil map for the defined area of interest, a list of soil map units on the map and extent of each map unit, and cartographic symbols displayed on the map. Also presented are various metadata about data used to produce the map, and a description of each soil map unit.

Soil Map


76° 59' 16" W
76° 58' 17" W
40° 12' 2" N
40° 11' 32" N
330800
330900
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331200
331300
331400
331500
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4451300
4451200
4451100
4451000
Independence Ave
Pe
HaB
HcB
HaB
HaB
HcC
HaB
DuB
Ub
Exit 236
15
76
EdB
EdB
Pe
DuB
DuB
BdB
BdB
Cumberland Pky
Us Hwy 15
Winding Hill
Soil Map may not be valid at this scale.
Map Scale: 1:6,470 if printed on A landscape (11" x 8.5") sheet.
Meters
0
50
100
200
300
N
Feet
0
300
600
1200
1800
Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 18N WGS84

MAP LEGEND

Area of Interest (AOI)
- Area of Interest (AOI)

Soils
- Soil Map Unit Polygons
- Soil Map Unit Lines
- Soil Map Unit Points

Special Point Features
- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other
- Special Line Features

Water Features
- Streams and Canals

Transportation
- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background
- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:15,800.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Cumberland County, Pennsylvania
Survey Area Data: Version 11, Nov 27, 2017

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Mar 29, 2011—Apr 14, 2011

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
BdB	Bedington shaly silt loam, 3 to 8 percent slopes	4.2	5.4%
DuB	Duffield silt loam, 3 to 8 percent slopes	5.2	6.7%
EdB	Edom silty clay loam, 3 to 8 percent slopes	5.7	7.3%
HaB	Hagerstown silt loam, 3 to 8 percent slopes	15.7	20.3%
HcB	Hagerstown silt loam, rocky, 3 to 8 percent slopes	2.6	3.4%
HcC	Hagerstown silt loam, rocky, 8 to 15 percent slopes	4.3	5.6%
Pe	Penlaw silt loam	9.9	12.8%
Ub	Urban land and Udorthents	29.8	38.5%
Totals for Area of Interest		**77.6**	**100.0%**

Map Unit Descriptions

The map units delineated on the detailed soil maps in a soil survey represent the soils or miscellaneous areas in the survey area. The map unit descriptions, along with the maps, can be used to determine the composition and properties of a unit.

A map unit delineation on a soil map represents an area dominated by one or more major kinds of soil or miscellaneous areas. A map unit is identified and named according to the taxonomic classification of the dominant soils. Within a taxonomic class there are precisely defined limits for the properties of the soils. On the landscape, however, the soils are natural phenomena, and they have the characteristic variability of all natural phenomena. Thus, the range of some observed properties may extend beyond the limits defined for a taxonomic class. Areas of soils of a single taxonomic class rarely, if ever, can be mapped without including areas of other taxonomic classes. Consequently, every map unit is made up of the soils or miscellaneous areas for which it is named and some minor components that belong to taxonomic classes other than those of the major soils.

Most minor soils have properties similar to those of the dominant soil or soils in the map unit, and thus they do not affect use and management. These are called noncontrasting, or similar, components. They may or may not be mentioned in a particular map unit description. Other minor components, however, have properties and behavioral characteristics divergent enough to affect use or to require different management. These are called contrasting, or dissimilar, components. They generally are in small areas and could not be mapped separately because of the scale used. Some small areas of strongly contrasting soils or miscellaneous areas are identified by a special symbol on the maps. If included in the database for a given area, the contrasting minor components are identified in the map unit descriptions along with some characteristics of each. A few areas of minor components may not have been observed, and consequently they are not mentioned in the descriptions, especially where the pattern was so complex that it was impractical to make enough observations to identify all the soils and miscellaneous areas on the landscape.

The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The objective of mapping is not to delineate pure taxonomic classes but rather to separate the landscape into landforms or landform segments that have similar use and management requirements. The delineation of such segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, however, onsite investigation is needed to define and locate the soils and miscellaneous areas.

An identifying symbol precedes the map unit name in the map unit descriptions. Each description includes general facts about the unit and gives important soil properties and qualities.

Soils that have profiles that are almost alike make up a *soil series*. Except for differences in texture of the surface layer, all the soils of a series have major horizons that are similar in composition, thickness, and arrangement.

Soils of one series can differ in texture of the surface layer, slope, stoniness, salinity, degree of erosion, and other characteristics that affect their use. On the basis of such differences, a soil series is divided into *soil phases*. Most of the areas shown on the detailed soil maps are phases of soil series. The name of a soil phase commonly indicates a feature that affects use or management. For example, Alpha silt loam, 0 to 2 percent slopes, is a phase of the Alpha series.

Some map units are made up of two or more major soils or miscellaneous areas. These map units are complexes, associations, or undifferentiated groups.

A *complex* consists of two or more soils or miscellaneous areas in such an intricate pattern or in such small areas that they cannot be shown separately on the maps. The pattern and proportion of the soils or miscellaneous areas are somewhat similar in all areas. Alpha-Beta complex, 0 to 6 percent slopes, is an example.

An *association* is made up of two or more geographically associated soils or miscellaneous areas that are shown as one unit on the maps. Because of present or anticipated uses of the map units in the survey area, it was not considered practical or necessary to map the soils or miscellaneous areas separately. The pattern and relative proportion of the soils or miscellaneous areas are somewhat similar. Alpha-Beta association, 0 to 2 percent slopes, is an example.

An *undifferentiated group* is made up of two or more soils or miscellaneous areas that could be mapped individually but are mapped as one unit because similar interpretations can be made for use and management. The pattern and proportion of the soils or miscellaneous areas in a mapped area are not uniform. An area can be made up of only one of the major soils or miscellaneous areas, or it can be made up of all of them. Alpha and Beta soils, 0 to 2 percent slopes, is an example.

Some surveys include *miscellaneous areas*. Such areas have little or no soil material and support little or no vegetation. Rock outcrop is an example.

Cumberland County, Pennsylvania

BdB—Bedington shaly silt loam, 3 to 8 percent slopes

Map Unit Setting

National map unit symbol: r8tt
Elevation: 300 to 1,600 feet
Mean annual precipitation: 35 to 50 inches
Mean annual air temperature: 45 to 57 degrees F
Frost-free period: 120 to 214 days
Farmland classification: All areas are prime farmland

Map Unit Composition

Bedington and similar soils: 85 percent
Minor components: 15 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Bedington

Setting

Landform: Hills
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Interfluve, side slope
Down-slope shape: Linear
Across-slope shape: Concave
Parent material: Acid residuum weathered from sedimentary rock

Typical profile

H1 - 0 to 9 inches: channery silt loam
H2 - 9 to 29 inches: channery silty clay loam
H3 - 29 to 72 inches: very channery silt loam

Properties and qualities

Slope: 3 to 8 percent
Depth to restrictive feature: 60 to 80 inches to lithic bedrock
Natural drainage class: Well drained
Runoff class: Medium
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60 to 2.00 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 6.9 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2e
Hydrologic Soil Group: B
Hydric soil rating: No

Minor Components

Comly

Percent of map unit: 7 percent
Hydric soil rating: No

Berks

Percent of map unit: 5 percent
Landform: Ridges, valleys
Landform position (two-dimensional): Backslope
Landform position (three-dimensional): Side slope
Down-slope shape: Convex, linear
Across-slope shape: Convex, linear
Hydric soil rating: No

Weikert

Percent of map unit: 3 percent
Hydric soil rating: No

DuB—Duffield silt loam, 3 to 8 percent slopes

Map Unit Setting

National map unit symbol: r8vp
Elevation: 300 to 1,500 feet
Mean annual precipitation: 34 to 50 inches
Mean annual air temperature: 46 to 57 degrees F
Frost-free period: 125 to 200 days
Farmland classification: All areas are prime farmland

Map Unit Composition

Duffield and similar soils: 85 percent
Minor components: 15 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Duffield

Setting

Landform: Hills
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Interfluve
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Residuum weathered from limestone

Typical profile

H1 - 0 to 10 inches: silt loam
H2 - 10 to 56 inches: silt loam
H3 - 56 to 65 inches: channery silt loam

Properties and qualities

Slope: 3 to 8 percent
Depth to restrictive feature: 60 to 80 inches to lithic bedrock
Natural drainage class: Well drained
Runoff class: Medium
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60 to 2.00 in/hr)

Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: High (about 10.4 inches)

Interpretive groups
Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2e
Hydrologic Soil Group: B
Hydric soil rating: No

Minor Components

Funkstown
Percent of map unit: 8 percent
Hydric soil rating: No

Clarksburg
Percent of map unit: 5 percent
Hydric soil rating: No

Dryrun
Percent of map unit: 2 percent
Hydric soil rating: No

EdB—Edom silty clay loam, 3 to 8 percent slopes

Map Unit Setting
National map unit symbol: rcp4
Elevation: 480 to 1,100 feet
Mean annual precipitation: 36 to 46 inches
Mean annual air temperature: 48 to 55 degrees F
Frost-free period: 150 to 210 days
Farmland classification: All areas are prime farmland

Map Unit Composition
Edom and similar soils: 100 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Edom

Setting
Landform: Hillslopes, valleys
Landform position (two-dimensional): Backslope
Landform position (three-dimensional): Side slope
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Clayey residuum weathered from limestone and shale

Typical profile
H1 - 0 to 8 inches: silty clay loam
H2 - 8 to 35 inches: silty clay

H3 - 35 to 67 inches: channery silty clay
H4 - 67 to 71 inches: bedrock

Properties and qualities

Slope: 3 to 8 percent
Depth to restrictive feature: 40 to 72 inches to lithic bedrock
Natural drainage class: Well drained
Runoff class: Medium
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.20 to 2.00 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 6.1 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2e
Hydrologic Soil Group: B
Hydric soil rating: No

HaB—Hagerstown silt loam, 3 to 8 percent slopes

Map Unit Setting

National map unit symbol: 2rc98
Elevation: 600 to 1,750 feet
Mean annual precipitation: 37 to 45 inches
Mean annual air temperature: 45 to 55 degrees F
Frost-free period: 155 to 190 days
Farmland classification: All areas are prime farmland

Map Unit Composition

Hagerstown and similar soils: 85 percent
Minor components: 15 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Hagerstown

Setting

Landform: Hills
Landform position (two-dimensional): Backslope, footslope, summit
Landform position (three-dimensional): Side slope, base slope, interfluve
Down-slope shape: Linear, concave
Across-slope shape: Linear, concave
Parent material: Clayey residuum weathered from limestone

Typical profile

Ap - 0 to 10 inches: silt loam
Bt1 - 10 to 21 inches: silty clay loam
Bt2 - 21 to 56 inches: silty clay
C - 56 to 73 inches: silty clay loam
R - 73 to 83 inches: bedrock

Properties and qualities

Slope: 3 to 8 percent
Depth to restrictive feature: 43 to 98 inches to lithic bedrock
Natural drainage class: Well drained
Runoff class: Medium
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60 to 2.00 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 8.7 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2e
Hydrologic Soil Group: B
Hydric soil rating: No

Minor Components

Opequon

Percent of map unit: 5 percent
Landform: Ridges
Landform position (two-dimensional): Shoulder, summit
Landform position (three-dimensional): Side slope, crest
Down-slope shape: Linear, convex
Across-slope shape: Convex, linear
Hydric soil rating: No

Carbo

Percent of map unit: 5 percent
Landform: Hills
Landform position (two-dimensional): Summit, backslope, shoulder
Landform position (three-dimensional): Side slope, crest
Down-slope shape: Linear, convex
Across-slope shape: Linear, convex
Hydric soil rating: No

Funkstown

Percent of map unit: 3 percent
Landform: Valley floors
Landform position (two-dimensional): Toeslope
Landform position (three-dimensional): Base slope
Down-slope shape: Concave
Across-slope shape: Concave, linear
Hydric soil rating: No

Timberville

Percent of map unit: 2 percent
Landform: Hills
Landform position (two-dimensional): Footslope
Landform position (three-dimensional): Head slope, base slope
Down-slope shape: Concave, linear
Across-slope shape: Convex, concave, linear
Hydric soil rating: No

HcB—Hagerstown silt loam, rocky, 3 to 8 percent slopes

Map Unit Setting

National map unit symbol: r8wn
Elevation: 460 to 1,500 feet
Mean annual precipitation: 30 to 45 inches
Mean annual air temperature: 45 to 57 degrees F
Frost-free period: 140 to 200 days
Farmland classification: Not prime farmland

Map Unit Composition

Hagerstown and similar soils: 100 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Hagerstown

Setting

Landform: Ridges
Landform position (two-dimensional): Backslope
Landform position (three-dimensional): Side slope
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Clayey residuum weathered from argillaceous limestone

Typical profile

H1 - 0 to 10 inches: silt loam
H2 - 10 to 19 inches: clay
H3 - 19 to 57 inches: clay

Properties and qualities

Slope: 3 to 8 percent
Depth to restrictive feature: 40 to 84 inches to lithic bedrock
Natural drainage class: Well drained
Runoff class: Medium
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60 to 2.00 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: High (about 10.0 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2s
Hydrologic Soil Group: B
Hydric soil rating: No

HcC—Hagerstown silt loam, rocky, 8 to 15 percent slopes

Map Unit Setting

National map unit symbol: r8wp
Elevation: 460 to 1,500 feet
Mean annual precipitation: 30 to 45 inches
Mean annual air temperature: 45 to 57 degrees F
Frost-free period: 140 to 200 days
Farmland classification: Not prime farmland

Map Unit Composition

Hagerstown and similar soils: 100 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Hagerstown

Setting

Landform: Ridges
Landform position (two-dimensional): Backslope
Landform position (three-dimensional): Side slope
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Clayey residuum weathered from argillaceous limestone

Typical profile

H1 - 0 to 10 inches: silt loam
H2 - 10 to 19 inches: clay
H3 - 19 to 57 inches: clay

Properties and qualities

Slope: 8 to 15 percent
Depth to restrictive feature: 40 to 84 inches to lithic bedrock
Natural drainage class: Well drained
Runoff class: Medium
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60 to 2.00 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: High (about 10.0 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3s
Hydrologic Soil Group: B
Hydric soil rating: No

Pe—Penlaw silt loam

Map Unit Setting

National map unit symbol: r8y8
Elevation: 300 to 1,500 feet
Mean annual precipitation: 34 to 50 inches
Mean annual air temperature: 48 to 57 degrees F
Frost-free period: 140 to 205 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Penlaw and similar soils: 90 percent
Minor components: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Penlaw

Setting

Landform: Swales
Landform position (two-dimensional): Toeslope, footslope
Landform position (three-dimensional): Base slope
Down-slope shape: Concave
Across-slope shape: Concave
Parent material: Colluvium derived from limestone, sandstone, and shale

Typical profile

H1 - 0 to 11 inches: silt loam
H2 - 11 to 30 inches: silty clay loam
H3 - 30 to 45 inches: silty clay loam
H4 - 45 to 69 inches: silty clay

Properties and qualities

Slope: 0 to 3 percent
Depth to restrictive feature: 15 to 30 inches to fragipan; 40 to 72 inches to lithic bedrock
Natural drainage class: Somewhat poorly drained
Runoff class: Very high
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.06 to 0.20 in/hr)
Depth to water table: About 6 to 18 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Low (about 5.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3w
Hydrologic Soil Group: C/D
Hydric soil rating: No

Minor Components

Clarksburg

Percent of map unit: 5 percent
Landform: Swales
Landform position (two-dimensional): Toeslope
Landform position (three-dimensional): Base slope
Down-slope shape: Concave
Across-slope shape: Concave
Hydric soil rating: No

Melvin

Percent of map unit: 5 percent
Landform: Flood plains
Down-slope shape: Concave
Across-slope shape: Concave
Hydric soil rating: Yes

Ub—Urban land and Udorthents

Map Unit Setting

National map unit symbol: r8yg
Mean annual precipitation: 36 to 50 inches
Mean annual air temperature: 46 to 59 degrees F
Frost-free period: 120 to 215 days
Farmland classification: Not prime farmland

Map Unit Composition

Urban land: 90 percent
Minor components: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Urban Land

Setting

Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Pavement, buildings and other artifically covered areas

Properties and qualities

Slope: 0 to 8 percent
Depth to restrictive feature: 10 inches to densic material
Runoff class: Very high

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 8s
Hydric soil rating: No

Minor Components

Udorthents, steep

Percent of map unit: 10 percent
Landform: Mountains
Landform position (two-dimensional): Summit, backslope
Landform position (three-dimensional): Mountaintop
Down-slope shape: Convex
Across-slope shape: Convex
Hydric soil rating: No

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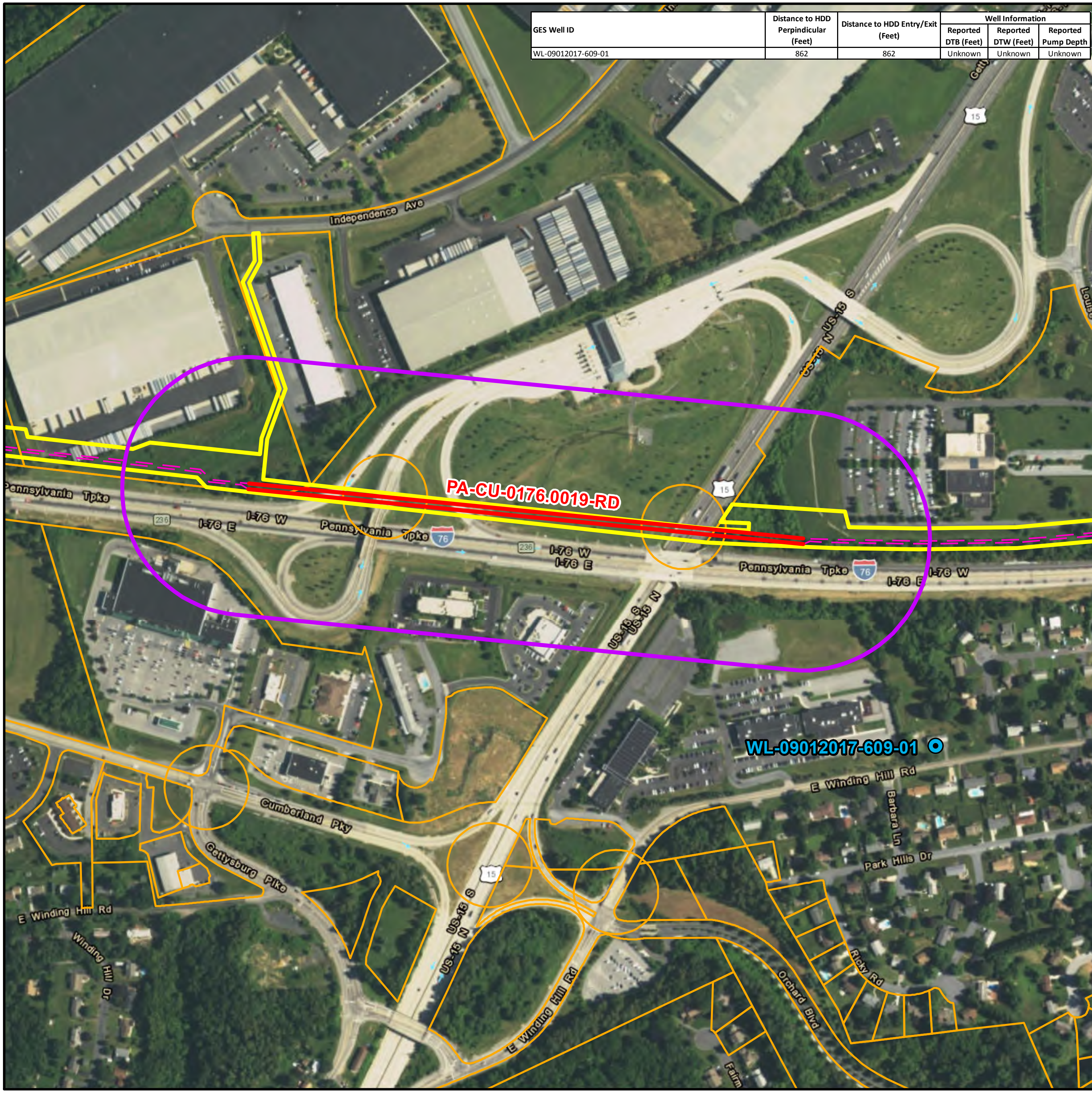
RETTEW

ATTACHMENT 3
450-FOOT WELL SURVEY

GES Well ID	Distance to HDD Perpindicular (Feet)	Distance to HDD Entry/Exit (Feet)	Well Information		
			Reported DTB (Feet)	Reported DTW (Feet)	Reported Pump Depth
WL-09012017-609-01	862	862	Unknown	Unknown	Unknown



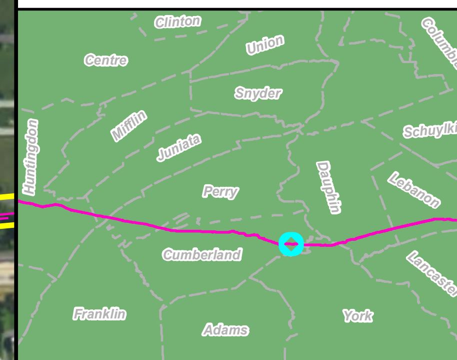
Legend

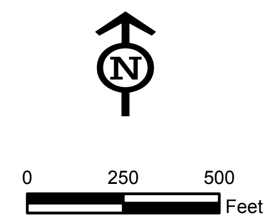
- LOD
- Parcel
- PPP Centerline
- HDD
- 450 foot buffer of HDD alignment

****Testing locations current as of 12/11/2017**

- GES Testing Location

Location





Well Location Map
HDD# PA-CU-0176.0019-RD
Cumberland County, PA.

Prepared By:

Date: 12/12/2017

Base Map;
ESRI World Imagery, 09/24/2015

Coordinate System: NAD 83 Stateplane, PA South, Feet

RETTEW

ATTACHMENT 4
GEOPHYSICAL SURVEY

RETTEW | ENVIROSCAN
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Engineers
Environmental Consultants
Surveyors
Landscape Architects
Safety Consultants
Geophysicists

January 10, 2019
Revised May 1, 2019*

Mr. Larry J. Gremminger
Sunoco Logistics, L.P.
535 Fritztown Road
Sinking Spring, PA 19608

RE: Geophysical Survey
Sunoco Pipeline, L.P. Pipeline Project
Horizontal Directional Drill S2-0247 – Highway 15
PA-CU-0176.0019-RD-16
Upper Allen Township, Cumberland County, Pennsylvania
RETTEW Project No. 096302009

Dear Mr. Gremminger:

RETTEW Associates, Inc. completed a multi-technique geophysical survey at the S2-0247, Highway 15 horizontal directional drill (HDD) location. The purpose of the survey was to detect and delineate subsurface voids or low-density zones beneath three portions of an HDD path that could increase the risk of inadvertent returns (IRs) and/or a loss of returns, and to determine the rock profile and rock rippability for ease-of-excavation. The following report, figures, and attachments describe the methods and results of the investigation.

EXECUTIVE SUMMARY

The multi-technique geophysical survey was completed between November 12 and November 20, 2018. Four different geophysical techniques were utilized to detect and delineate subsurface voids or low-density zones and provide a rock profile. These methods, and their general results are as follows:

- Microgravity delineated low-density zones throughout the three survey areas. These zones could represent minor karst-related air-, water-, or mud-filled voids, or locally deeper rock/thicker soils.
- Seismic refraction confirmed the presence of an irregular bedrock surface or "epikarst" zone.
- Multi-Spectral Analysis of Surface Waves (MASW) identified low-velocity zones above (soft soils) and below (possible voids) the bedrock surface.
- Electrical Resistivity Imaging (ERI) identified conductive features which could represent fractures or wet soils in each of the three areas.

Results from the geophysical techniques are consistent with each other, and with the geology as mapped by the PA Geological Survey, all suggesting that the local bedrock (limestone) is karstified, with potential concentrations of dissolution cavities (of various sizes) indicated by the geophysical anomalies. In the limestone, the top-of-rock is expected to be pinnacled (highly irregular) with interfingered competent rock and residual clay soil as well as potential bedrock voids.

SITE DESCRIPTION

The Highway 15 HDD is located parallel to and just north of the PA Turnpike (I-76), at the I-15 Exit, in Upper Allen Township, Cumberland County, Pennsylvania (see **Figure 1***). A geophysical survey was conducted over accessible lengths of the HDD alignment and encompassed a width of roughly 20 feet (**Figure 2**). Surface conditions as well as the active roadways prohibited full access to the HDD alignment.

The site bedrock geology is karstified and consists of the Ordovician-aged Rockdale Run Formation (Orr) which is predominantly limestone with some dolomite interbeds (Berg, et al., 1980). **Figure 2** shows the mapped contact of the Rockdale Run Formation and Hamburg sequence rocks south of the HDD (Ibid.).

KARST TERRANE

Pinnacled bedrock, closed depressions, and sinkholes are geologic features characteristic of karst terranes — i.e. terranes underlain by soluble carbonate (limestone or dolomite) bedrock in wet climates. In karst terranes, infiltrating precipitation dissolves the carbonate bedrock surface, causing the top-of-rock to retreat downward leaving behind a soil mantle composed of the insoluble clay and/or silica particles formerly bonded in the rock. Within the bedrock, percolating water enlarges fractures, bedding planes, etc. to produce solution openings ranging in size from minor seams to scenic caverns.

The main difference between a sinkhole and a closed depression is that a sinkhole may appear suddenly as a break in the ground surface (revealing a hole), whereas a closed depression typically subsides slowly with no break at the surface. The Pennsylvania Geological Survey (PA DCNR Interactive Map, 2017) records several surface depressions in the vicinity of the survey area (see black dots, **Figure 2**), and many more within a half-mile radius of the site; all within the Rockdale Run Formation (Ibid., see upper right inset to **Figure 2**).

Sinkholes form where particularly enhanced infiltration into a sufficiently-wide solution opening (often called a throat or chimney) washes the soil mantle down into cavities in the underlying rock — a process commonly called soil piping. In areas where the residual soil mantle is clay-rich and cohesive, incipient sinkholes may not display any surficial topographic expression, and are present only as air-, water-, or mud-filled voids which may grow or "stope" upwards. Eventually, the overlying soil arch may collapse under its own weight, or under the weight of an overlying structure or passing vehicle. The resulting collapse feature, or "sinkhole," is commonly filled with the remains of the soil arch and may display rock at its base. In some cases, surficial subsidence may keep pace with soil piping at depth such that a sinkhole forms by progressive deepening of a surficial depression (sometimes called a subsidence sink), rather than by catastrophic collapse of a stoping void. **Appendix A** depicts this process.

MICROGRAVITY SURVEY

Microgravity meters measure very small variations in gravity. Several factors can locally affect the acceleration of gravity. One factor is the local density of the bedrock or soils beneath the meter. Gravity highs (mass excesses) commonly represent locally shallow bedrock pinnacles or float blocks in the soil profile or zones of particularly massive bedrock. Gravity lows (mass deficiencies) may represent locally deep bedrock cutters, or clay seams where soil displaces bedrock; air-, water- or mud-filled voids within bedrock; stoping voids in the soil above bedrock; or zones where soils have been made less dense by removal of fines.

The residual microgravity data for this survey are shown on **Figure 3**. The values depict the general plan-view shallow mass distribution beneath the three accessible survey areas. Lower values (red) represent local mass deficiencies or gravity lows (air- or clay-filled voids or deeper soils). Higher values (blue) represent local mass excesses or gravity highs (bedrock pinnacles or float blocks). Specific microgravity survey parameters are listed in **Appendix B**.

SEISMIC MASW AND REFRACTION SURVEY

Seismic Refraction and MASW methods utilize the speed of seismic waves through various geologic layers and features to characterize subsurface geologic conditions. The methods enable determination of the general material types, and the approximate depth to bedrock and bedrock profile. MASW can detect low-velocity zones in soils that might represent developing sinkholes, or low velocities below the top of rock that might be associated with karst solution features or fractures. The principles of Seismic Refraction are summarized in **Appendix C**.

The seismic survey consisted of three profiles along the HDD center line (see blue triangles, **Figure 2**). Color-contour velocity models of the seismic profiles for the seismic refraction and MASW are presented on **Figures 4** and **5,** respectively. On each, the vertical scale represents relative elevation in feet, and the horizontal axis represents an along-profile distance in feet. The color contours represent average seismic velocity variations (compressional- (P-)wave velocities for refraction, and shear- (S-)wave velocities for MASW), with increasing velocities from blue to green to yellow to orange to brown (refraction, **Figure 4**), and purple to grey to tan to brown (MASW, **Figure 5**). Please note that velocity data along the first and last fifteen feet of any profile have higher uncertainty. Specific seismic refraction and MASW survey parameters are listed in **Appendix B**.

ERI SURVEY

Electrical resistivity measurements involve driving an electrical current in the ground using two electrodes at the ground surface. The apparent resistivity of the subsurface is determined by measuring the potential difference, or voltage, between two potential electrodes with a known separation and position/orientation relative to the current electrodes. The depth and volume of the subsurface zone represented by the measured apparent resistivity is a function of the geometry of the current and potential electrodes. Apparent resistivities are converted to model or true resistivities by performing a joint inversion of all the measured apparent resistivities along a profile.

The resistivity survey consisted of nine profiles; three in each of the accessible areas, all of them parallel to the HDD center line (see orange dotted lines, **Figure 2**). The apparent resistivity data were mathematically inverted using EarthImager2D by AGI to provide a cross-sectional image of each individual profile. These are shown in **Figure 6**. Specific ERI survey parameters are listed in **Appendix B**.

RESULTS

The microgravity data are depicted on **Figure 3** as color contours representing the relative density of the subsurface, with blue for high-density, green for “site normal”, and red for locally low-density areas. The microgravity results delineated low-mass (low-density) areas across the survey grids. This is consistent with either dissolution cavities within rock, or an irregular top-of-rock surface.

The seismic refraction data are presented as cross-sectional profiles on **Figure 4**, which indicate a general three-layer stratigraphy consisting of residual soil mantle, epikarst (or weathered rock interfingered with soil), and competent bedrock. The uppermost layer has average P-wave velocities generally less than

5,000 feet per second (fps) with a thickness of approximately 5-10 feet. This is consistent with the surficial residual clay soil mantle (shaded blue to green). The deepest layers have velocities over 10,000 fps (shaded orange to red) consistent with competent bedrock (Carmichael, R. S., 1989). The zone between roughly the 5,000 and 10,000 fps contours is commonly referred to as the "epikarst" in carbonate rock and is not really a "layer" in the stratigraphic sense. Instead, it contains soil interfingered with rock pinnacles and/or float material. In non-carbonate rock, this zone (if present) is commonly weathered rock with a gradation in properties from soil downwards to competent rock.

The MASW seismic models are presented on **Figure 5**. The MASW velocity model shows velocity changes within the bedrock layer across the profiles, and possible near-vertical low-velocity anomalies of the type commonly associated with significant fractures.

The seismic velocity models from the ray-tracing method (not shown) were compared to standard ripping charts (see **Appendix D**, Caterpillar, Inc., 1995) using the inferred/assumed layer compositions to determine the general rippability of each stratum. In general, the surficial layer down to about the top of the inferred epikarst layer (wavy dashed contour) should be readily to marginally rippable with a D9 multi- or single-shank ripper doing open field ripping, based on a weighted average velocity of about less than 5,000 fps. Below the 5,000-fps contour, ripping will get more difficult with depth, with the transition zone expected to become non-rippable below the 10,000 fps contours (based on the average ray-trace velocity of over 10,000 fps and Caterpillar charts). In carbonates, the transition zone is likely to contain competent rock pinnacles or ridges, and float blocks which may require blasting or hydraulic breaking if excavated (see **Appendix B**). The 5,000-fps contour represents the top of the epikarst/weathered rock (average inferred bedrock surface) and not the actual, likely pinnacled or irregular, surface which is often non-resolvable in karst terranes. Below the solid contour, the basal half-space has a weighted average layer velocity of over 10,000 fps based on the ray-tracing model (not shown) and is well into the non-rippable range. For trenching (as opposed to open field ripping), material **above** the 5,000-fps contour line (as low as 3,500 fps) may become non-rippable (for a CAT-330 tracked excavator or equivalent) as well. The selection of the velocity cut-off for trenching is based on correlations between the ray-tracing models (not shown), material properties, and various excavation strategies investigated by Kirsten (1982). The Limitations section contains additional important information regarding rippability estimation by seismic and other means.

The electrical resistivity results are shown in **Figure 6** as nine cross-sectional profiles, with three over each of the three accessible areas. The electrical profiles show a general two-layer model with a conductive upper layer over a more resistive lower layer, indicative of moist, conductive unconsolidated material over more resistive low-porosity bedrock. The upper layer is laterally variable, which could represent possible near-surface soil disturbances given the site development history. Deep conductive anomalies may represent dissolution features within the bedrock. In general, deep blue and purple shading (low resistivity) should represent damp soil or fill near the ground surface, and mud-filled voids or fractures below the bedrock surface. Green, yellow, orange and brown shading (higher resistivity) should represent non-porous rock.

CONCLUSIONS

In general, the geophysical survey results display anomalies indicative of a karstified terrane with potential for IR at each of the three accessible areas of the HDD. **Figure 7** highlights the areas of concern in each of the three accessible areas. Unsurveyed (inaccessible) areas are expected to be similar. The microgravity data show only mass deficiencies, while the seismic data and ERI show both an irregular inferred bedrock surface and anomalous low-velocity and low-resistivity features consistent with dissolution features within each of the three surveyed areas. If pipeline installation involves open trenching, and rock removal is required, blasting is not recommended since this can produce overshot cracks that provide pathways for soil piping into deeper underlying solution cavities. Once pipeline installation is complete (by any method), since subsidence in karst terranes is driven by infiltrating water, site grading and stormwater control will be key to preventing future subsidence.

LIMITATIONS

The survey described above was completed using standard and/or routinely accepted practices of the geophysical industry, and the equipment employed represents, in RETTEW's professional opinion, the best available technology. RETTEW does not accept responsibility for survey limitations due to inherent technological limitations or unforeseen site-specific conditions. We will notify you of such limitations or conditions, when they are identifiable.

The survey is based on observation of current subsurface conditions. Therefore, while the results of this survey can be used to guide further investigations, RETTEW cannot make any warranties concerning future sinkhole occurrence — particularly under the influence of altered surface and subsurface drainage patterns due to grading and construction activities.

Rippability, while historically closely-correlated with seismic P-wave velocity, also depends on geotechnical properties of the material, on the specific method of excavation, and on the variety and size of equipment employed. For mechanical excavation, the teeth or other cutting elements must be forced into discontinuities of competent rock masses, or penetrate the fabric of weak rocks. Thus, joint or fracture spacing, aperture, and infilling will all play a role in determining whether existing discontinuities in apparently-competent rock masses can allow mechanical excavation. The strength of the intact rock will also control whether fresh discontinuities can be induced during excavation activities. Therefore, while seismic data can provide reliable guidelines, RETTEW recommends that the rocks to be excavated be checked for these other geotechnical characteristics through examination of local outcrops, test pits, or boring logs.

We have enjoyed and appreciated the opportunity to have worked with you. If you have any questions, please do not hesitate to contact the undersigned.

Charles H. Rhine, MSc, PG
Senior Project Manager

Timothy D. Bechtel, PhD, PG
Senior Project Manager

Felicia Kegel Bechtel, MSc, PG
Director of Geophysics

Enclosures
Figure 1: Topographic Basemap
Figure 2: Data Coverage Map and Geologic Setting
Figure 3: Residual Microgravity Results
Figure 4: Seismic Refraction Survey Results
Figure 5: Seismic MASW Survey Results
Figure 6: Electrical Resistivity Survey Results
Figure 7: Geophysical Results Summary
Appendix A: Schematic Karst Processes
Appendix B: Geophysical Survey Parameters
Appendix C: Introduction to Seismic Refraction
Appendix D: Caterpillar Ripping Charts

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Kirsten, HAD (1982). A classification system for excavating in natural materials. Civil Engineering (Siviele Ingenieurswese), 24(7), 293-308.

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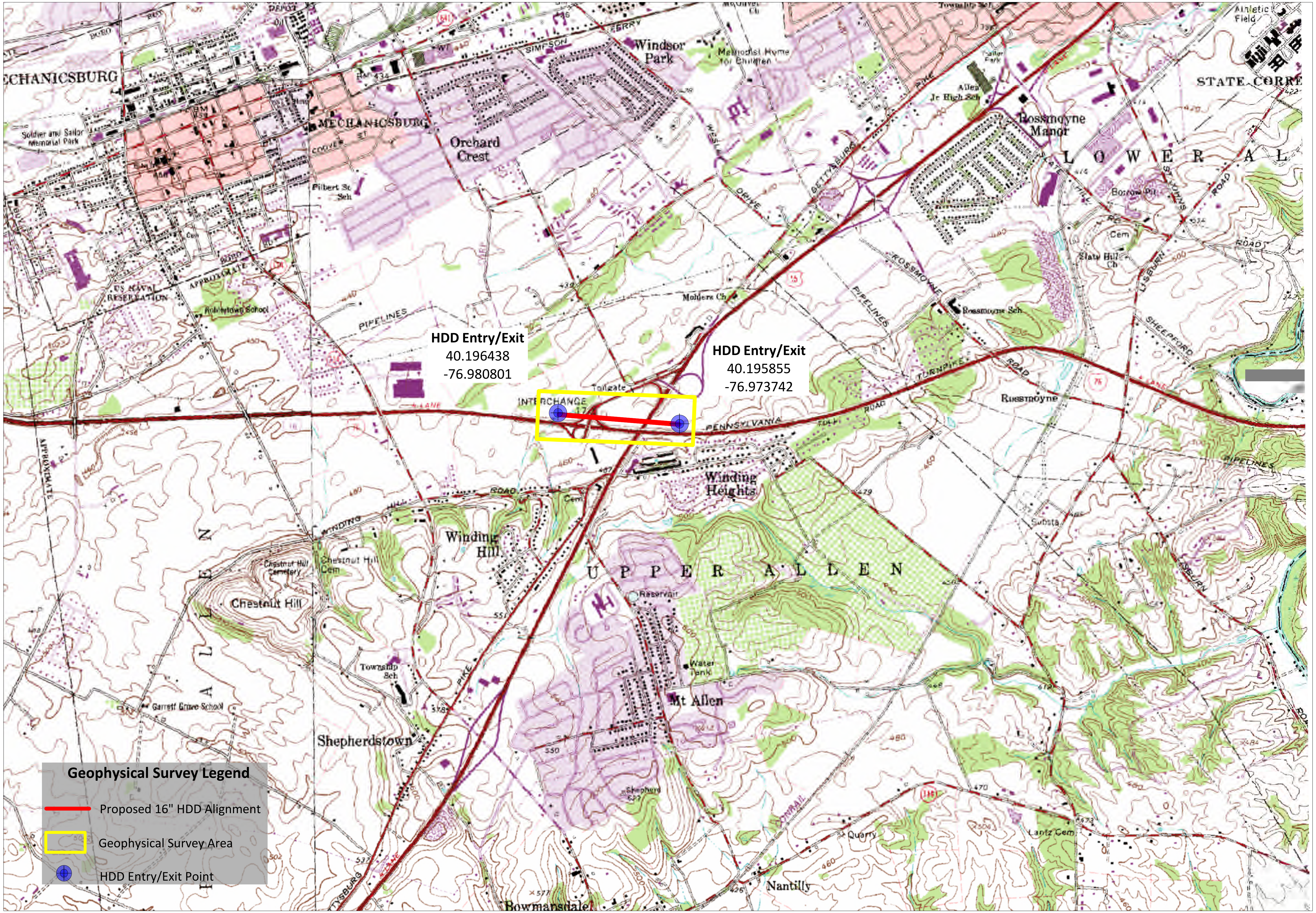
Z:\Shared\Projects\09630\096302009 - Spread 4\GP\S2-0247 Highway 15\Report\Final\HWY 15 Final Geophysic Report 2019-01-10 Revised 2019-05-01.docx

***The original report text submitted on January 10, 2019 has not been changed. The only change to this report is a revision to Figure 1's basemap .**

ENCLOSURES



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Scale (ft)
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RETTEW No.:	096302009
REVIEWED BY:	FKB
DRAWN BY:	CHR
DATE:	05/01/2019
SCALE:	1" = 2000'
FIGURE NO.	1 of 7

RETTEW
ENVIROSCAN

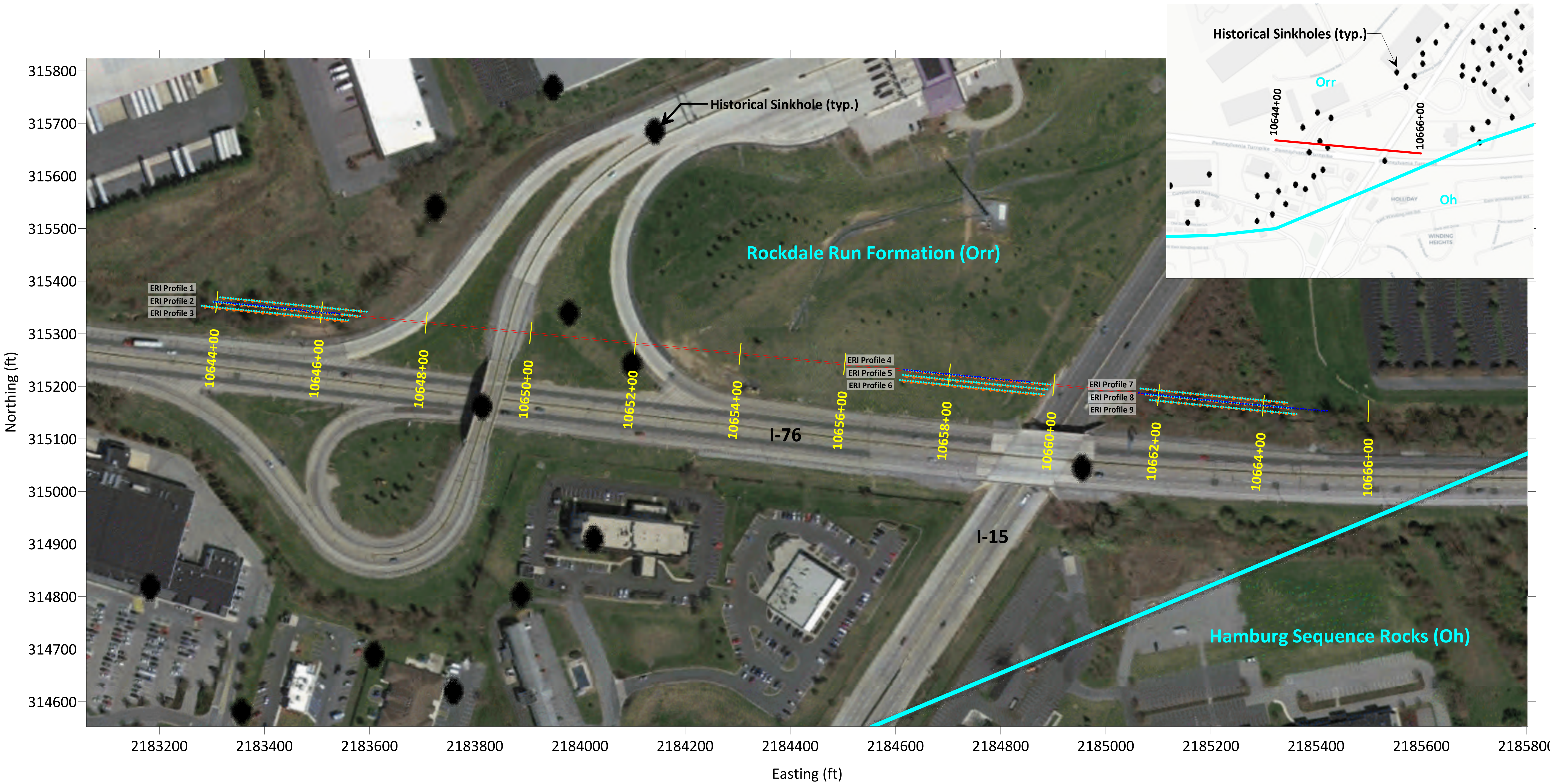
RETTEW Associates, Inc.
3020 Columbia Avenue, Lancaster, PA 17603
Phone (717) 394-3721 Fax (717) 394-1063

Figure 1: Topographic Basemap

Highway 15
S2-0247
PA-CU-0176.0019-RD-16

CUMBERLAND COUNTY, PA

MIDDLESEX TOWNSHIP



Geophysical Survey Legend

- Electrical Resistivity Profile
- Seismic Geophone Location
- Geologic Contact (mapped by others)
- 11638+00 — 16" Product Line with Station Number

N

Scale (ft)

0 100 200 300 400

Notes:

Basemap from Google Earth Pro, extracted 11/2018.

Survey profiles/stations from DGPS survey by RETTEW.

Geologic information from DCNR WMS Server, extracted 11/2018.

SURVEY DATE: 11/17/2018
RETTEW No.: 096302009
REVIEWED BY: FKB
DRAWN BY: CHR
DATE: 01/05/2019
SCALE: 1" = 200"
FIGURE NO. 2 of 7

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Figure 2: Data Coverage Map and Geologic Setting

Highway 15
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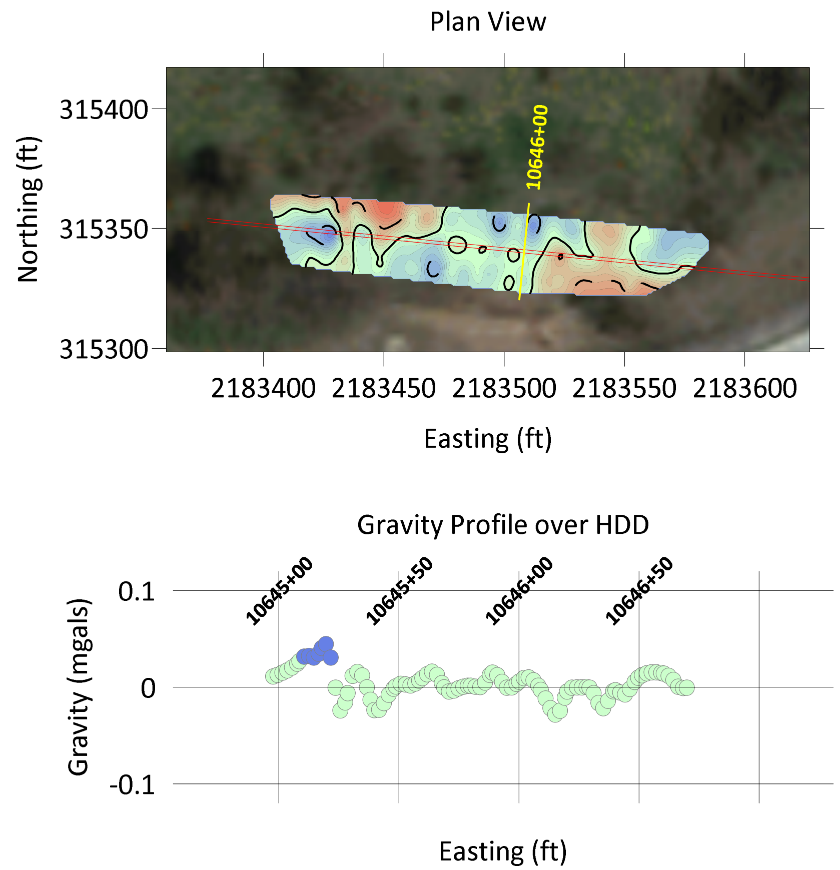
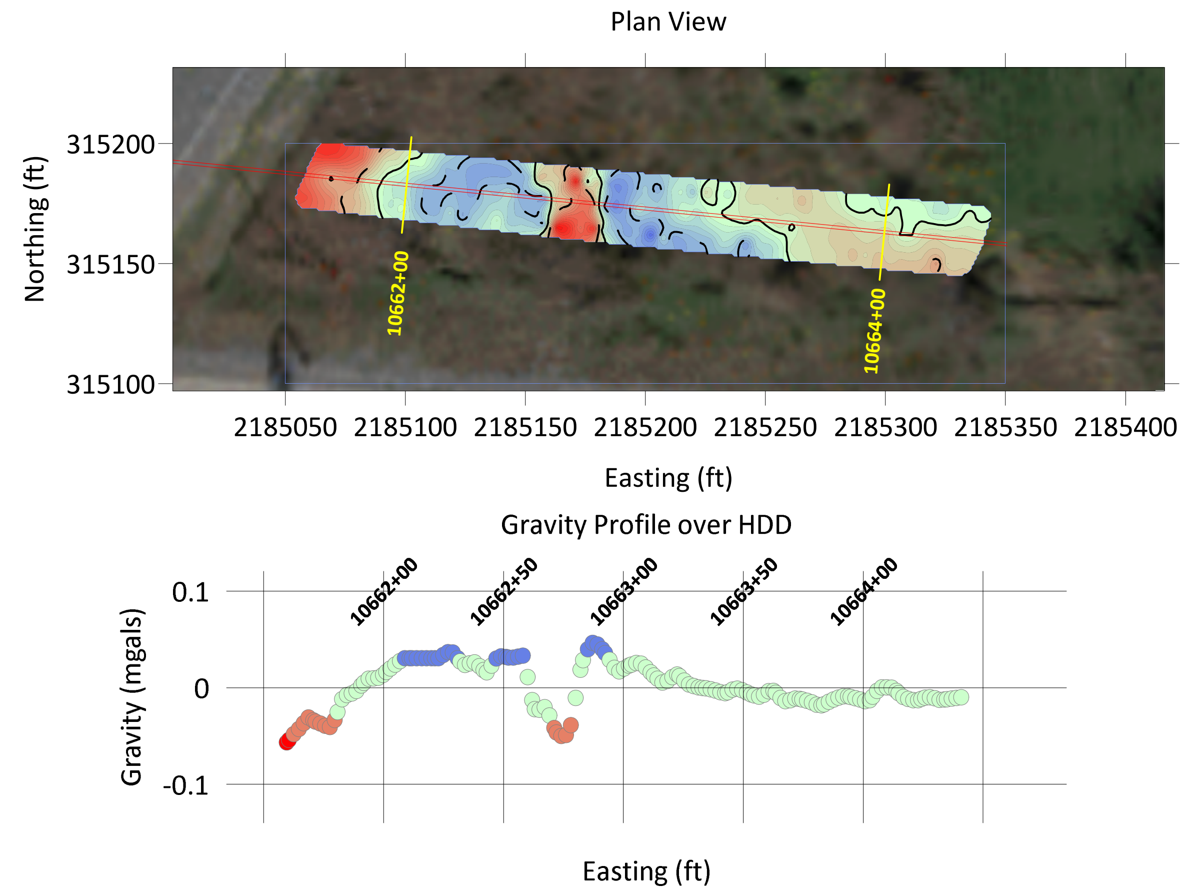
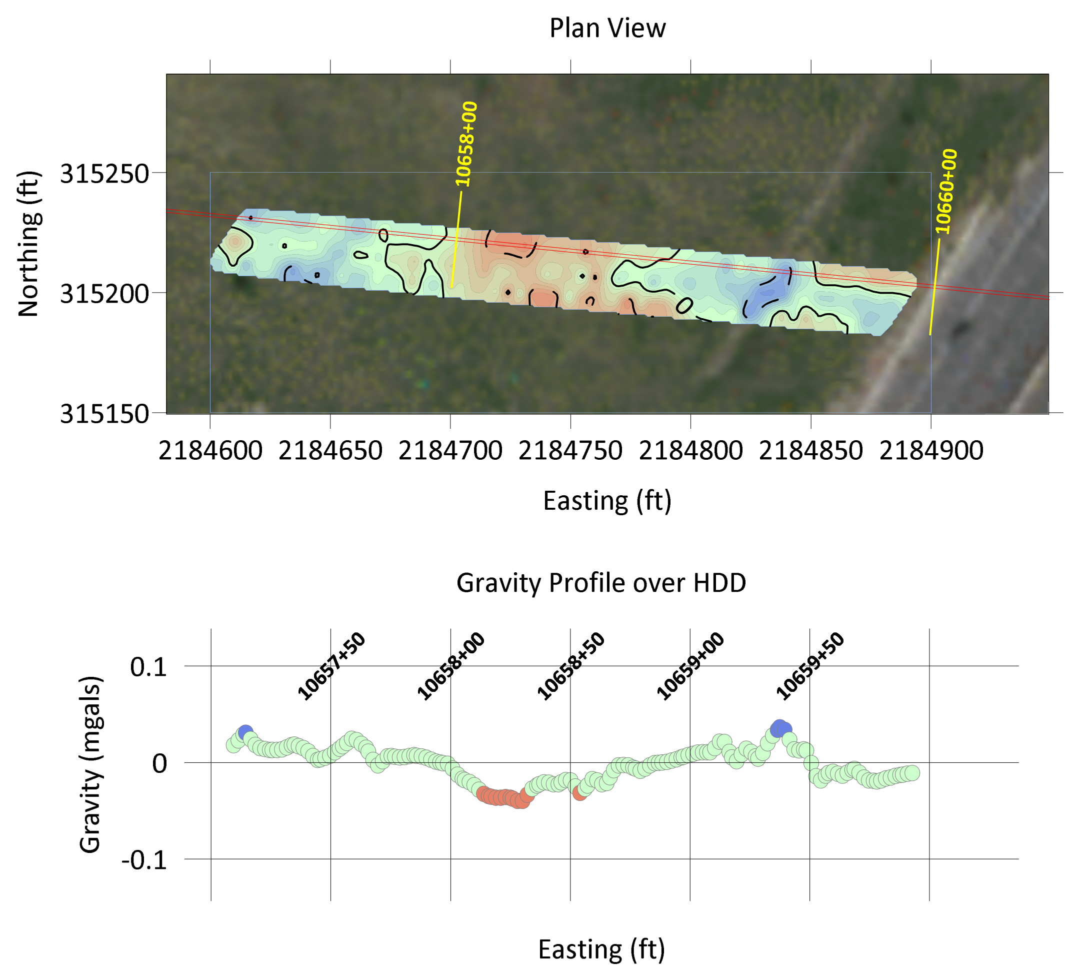
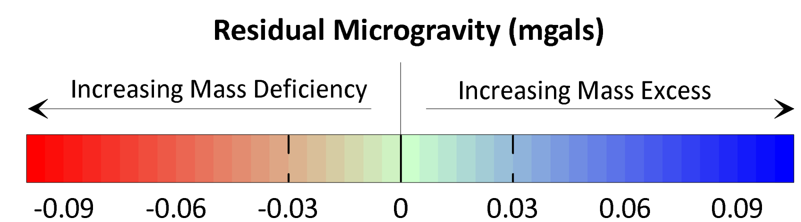
CUMBERLAND COUNTY, PA

MIDDLESEX TOWNSHIP



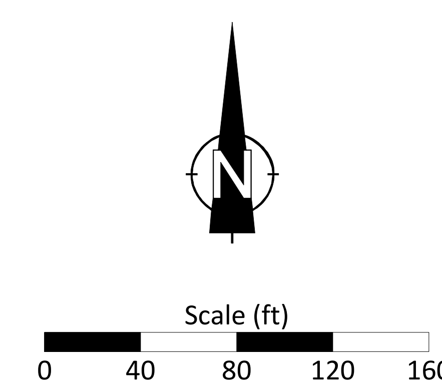






Geophysical Survey Legend

11651+00 — 16" Product Line with Station Number



Notes:

Basemap from Google Earth Pro, extracted 11/2018.

Microgravity data from Scintrex CG-5 gravimeter, with Bouguer correction.

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RETTEW No.:	096302009
REVIEWED BY:	FKB
DRAWN BY:	CHR
DATE:	01/05/2019
SCALE:	1" = 80'
FIGURE NO.	3 of 7

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Figure 3: Residual Microgravity Results

Highway 15
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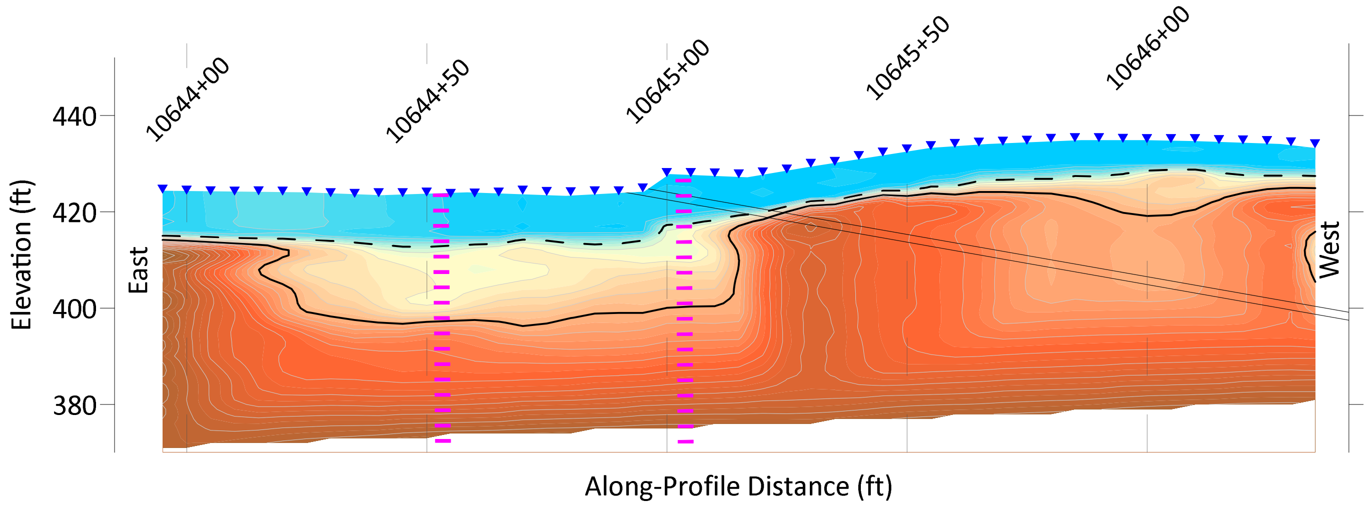
CUMBERLAND COUNTY, PA

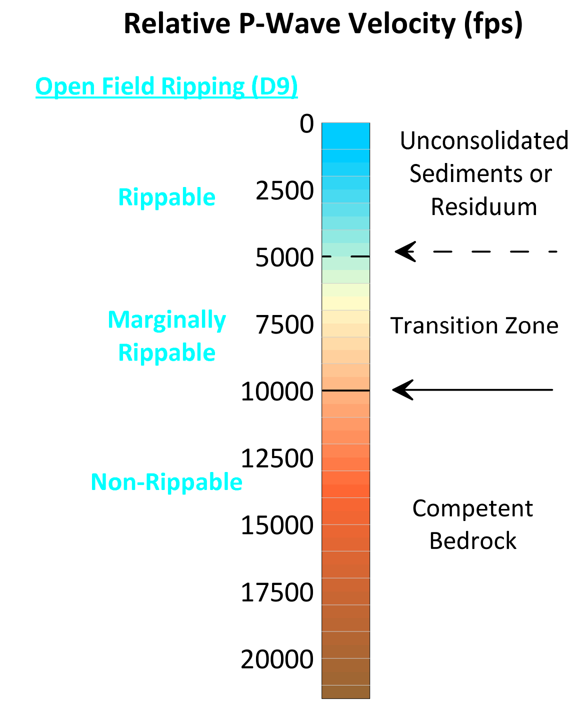
MIDDLESEX TOWNSHIP

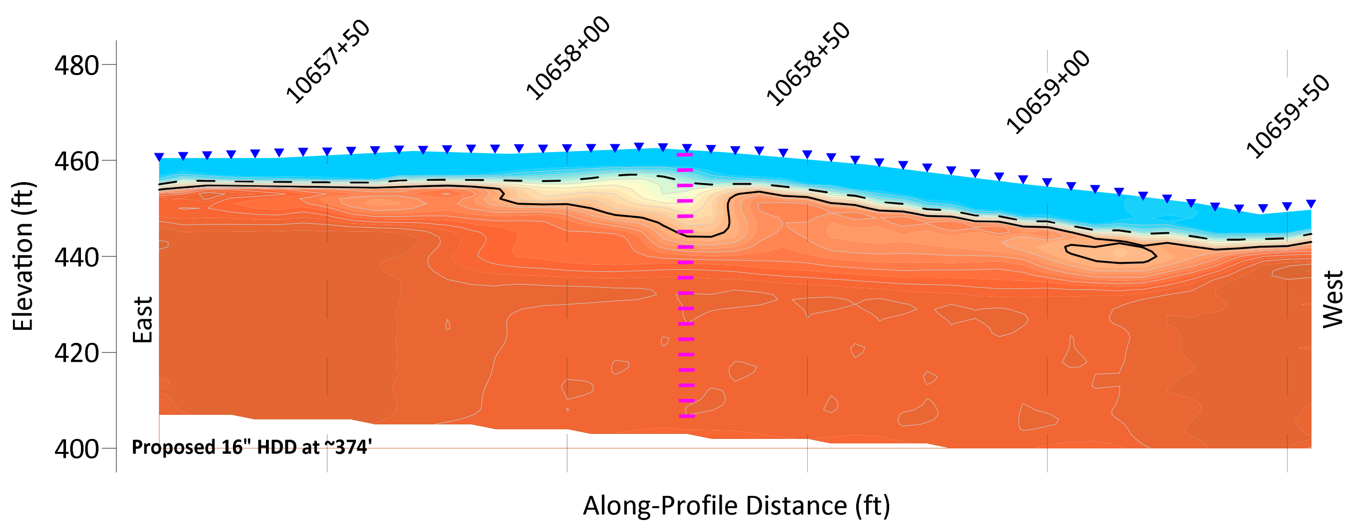


Weighted Average
P-Wave Velocity

V_1 = 1,299 fps

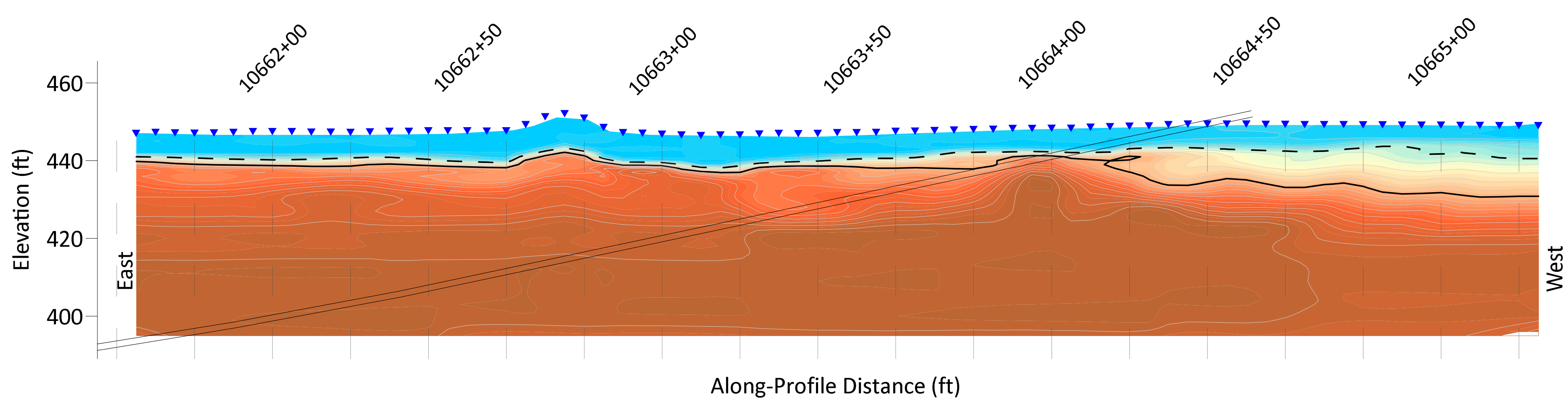
V_2 = 17,172 fps





Geophysical Survey Legend

- ▼ Seismic Geophone Location
- Possible Fracture Zone
- Proposed 16" HDD
- 11627+00 Station Number



Notes:

Seismic data from Geometrics 24-channel Geode with 4.0 Hz geophones.

Relative seismic velocity models from SeisImager (by Oyo Corporation) tomographic and ray-tracing inversions.

SURVEY DATE: 11/17/2018
RETTEW No.: 096302009
REVIEWED BY: FKB
DRAWN BY: CHR
DATE: 01/05/2019
SCALE: NA
FIGURE NO. 4 of 7

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Figure 4: Seismic Refraction Survey Results

Highway 15
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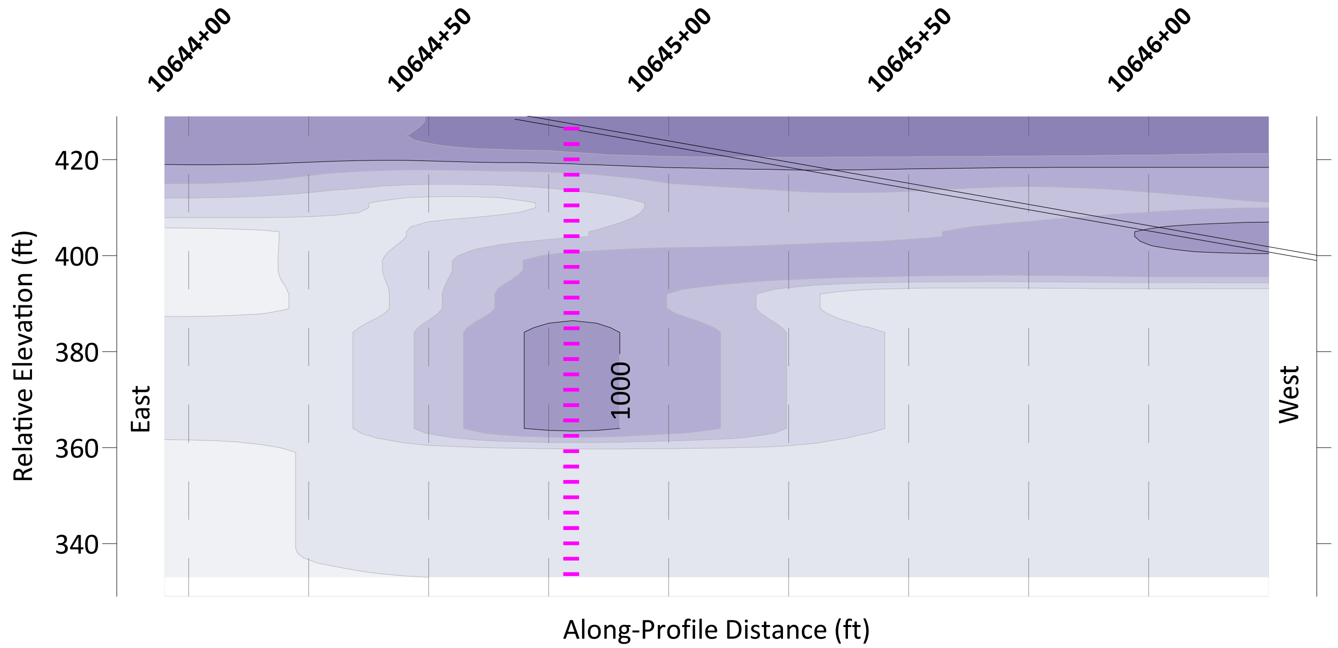
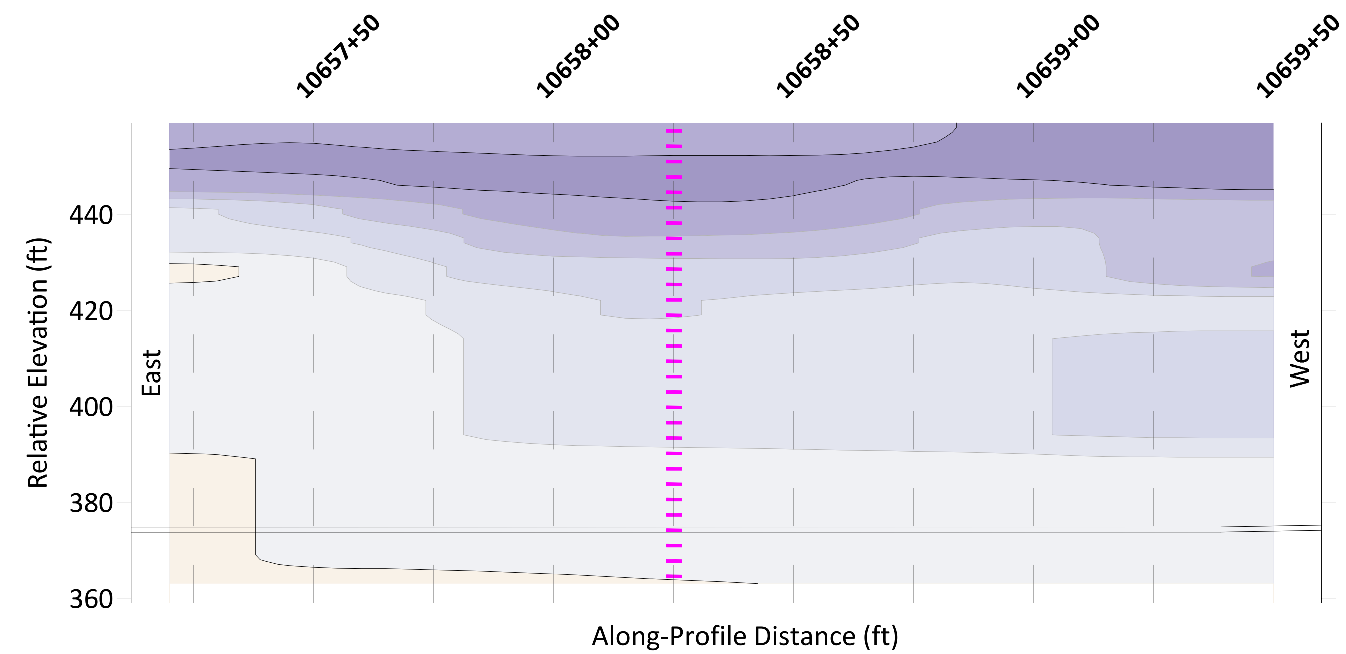
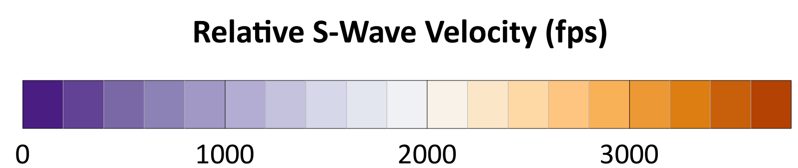
CUMBERLAND COUNTY, PA

MIDDLESEX TOWNSHIP

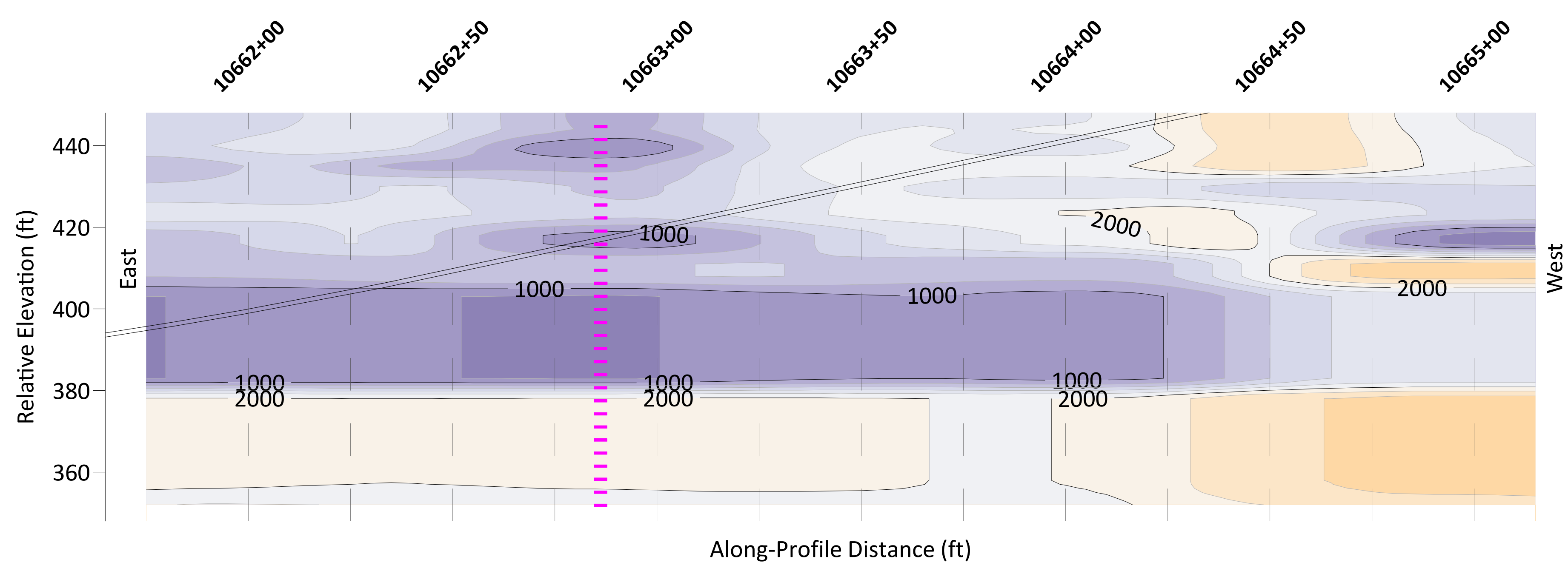






Geophysical Survey Legend

- ▼ Seismic Geophone Location
- Possible Fracture Zone
- Proposed 16" HDD
- 11627+00 Station Number



Notes:

Seismic data from Geometrics 24-channel Geode with 4.0 Hz geophones.

Relative seismic velocity models from SeisImager (by Oyo Corporation).

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RETTEW No.:	096302009
REVIEWED BY:	FKB
DRAWN BY:	CHR
DATE:	01/05/2019
SCALE:	NA
FIGURE NO.	5 of 7

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Figure 5: Seismic MASW Survey Results

Highway 15
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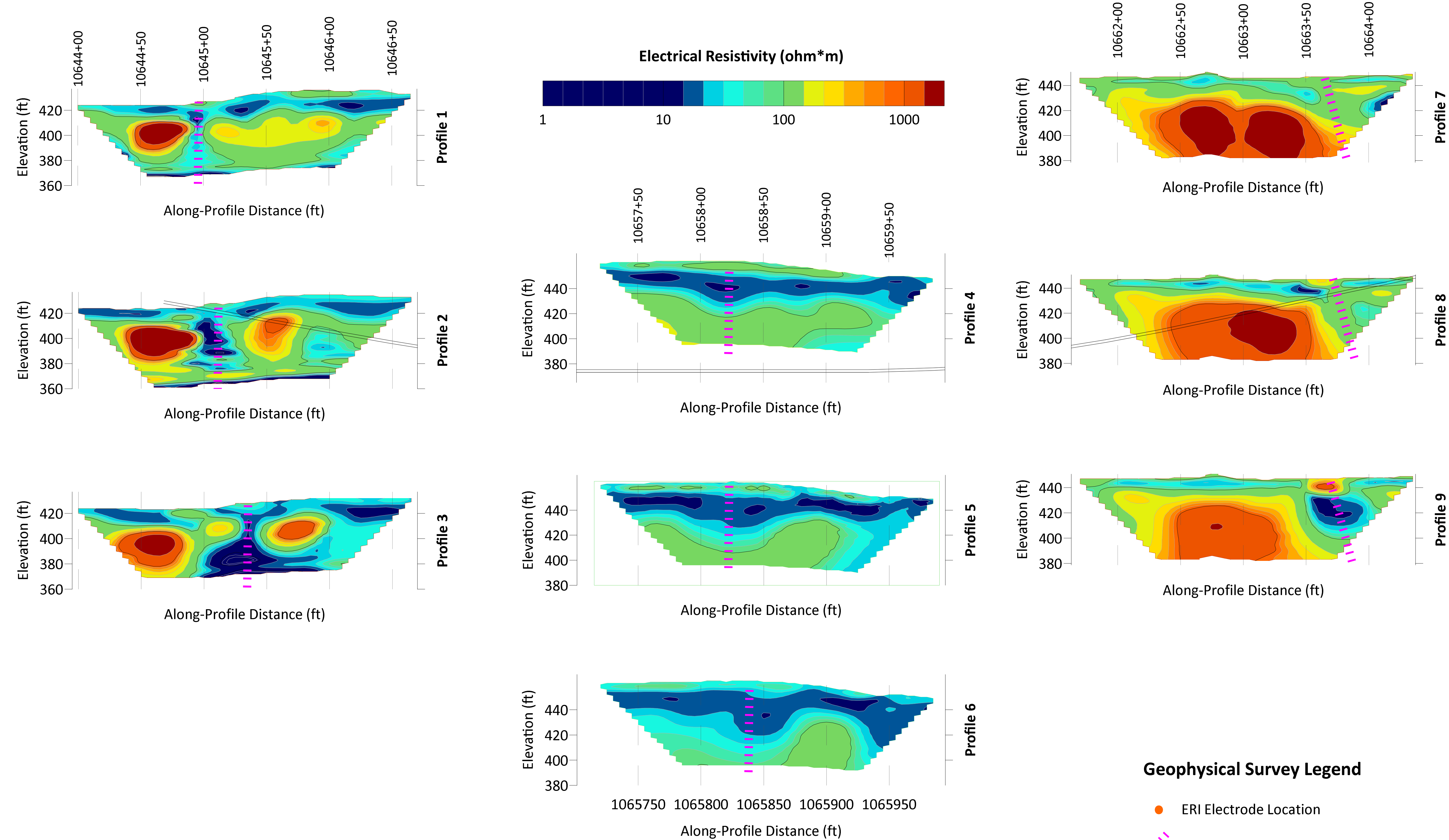
CUMBERLAND COUNTY, PA

MIDDLESEX TOWNSHIP



Geophysical Survey Legend

- ERI Electrode Location
- Possible Fracture Zone
- Proposed 16" HDD
- 11627+00 Station Number

Notes:

Resistivity data from AGI Super Sting 112-channels, 5-ft electrode spacing.

Resistivity models from EarthImager 2D (by AGI Corporation) inversions.

SURVEY DATE:	11/17/2018
RETTEW No.:	096302009
REVIEWED BY:	FKB
DRAWN BY:	CHR
DATE:	01/05/2019
SCALE:	NA
FIGURE NO.	6 of 7

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Figure 6: Electrical Resistivity Survey Results

Highway 15
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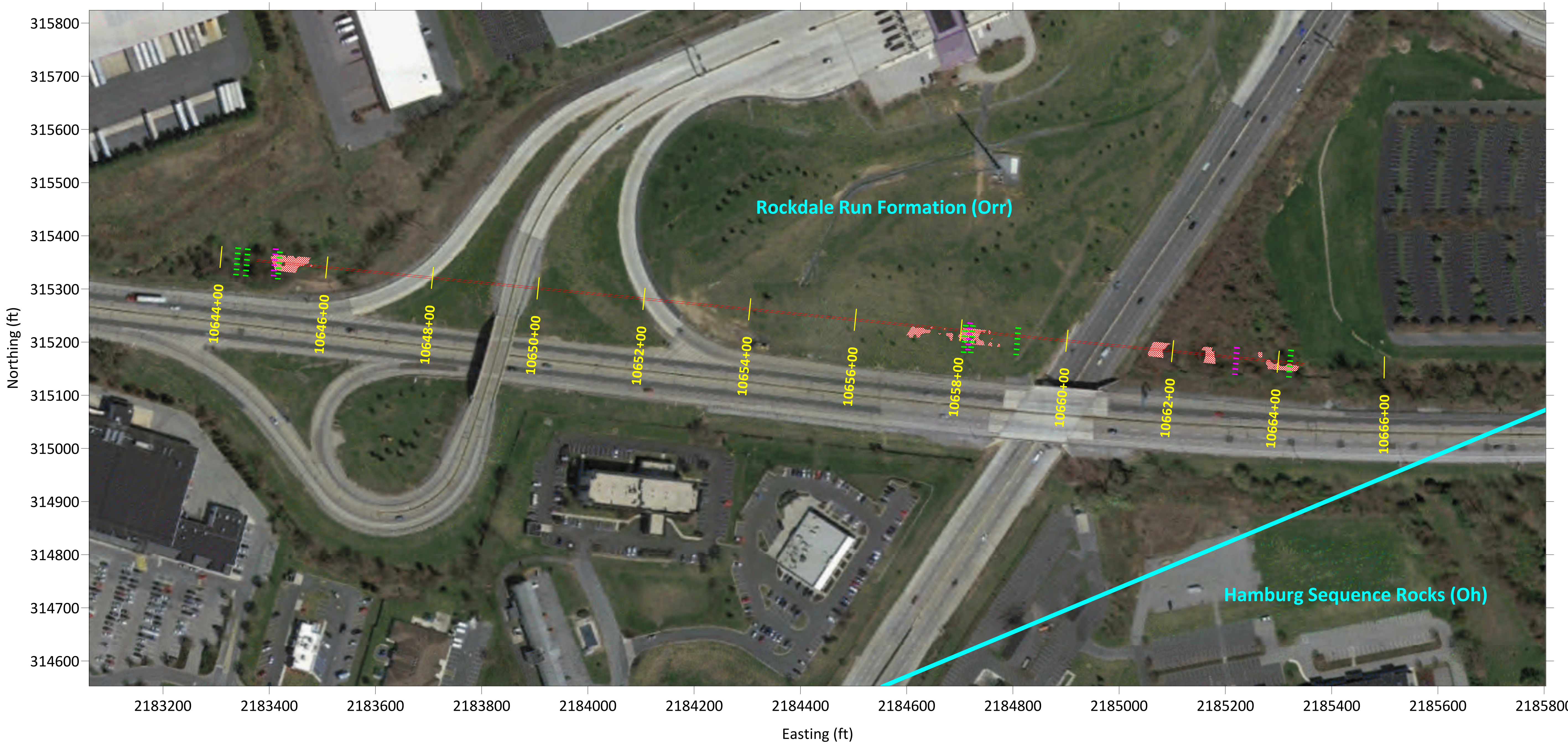
PA-CU-0176.0019-RD-16

CUMBERLAND COUNTY, PA

MIDDLESEX TOWNSHIP



Geophysical Survey Legend

- Electrical Resistivity Suspected Fracture Zone
- Microgravity Low-Density Area
- Seismic Low-Velocity Zone
- 11637+00 Proposed 16" HDD Product Line with Station Number
- Geologic Contact (mapped by others)

N

Scale (ft)
0 100 200 300 400

Notes:

Basemap from Google Earth Pro, extracted 11/2018.

Survey profiles/stations from DGPS survey by RETTEW.

Geologic information from DCNR WMS Server, extracted 11/2018.

SURVEY DATE: 11/17/2018
RETTEW No.: 096302009
REVIEWED BY: FKB
DRAWN BY: CHR
DATE: 01/05/2019
SCALE: NA
FIGURE NO. **7 of 7**

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Figure 7: Geophysical Results Summary

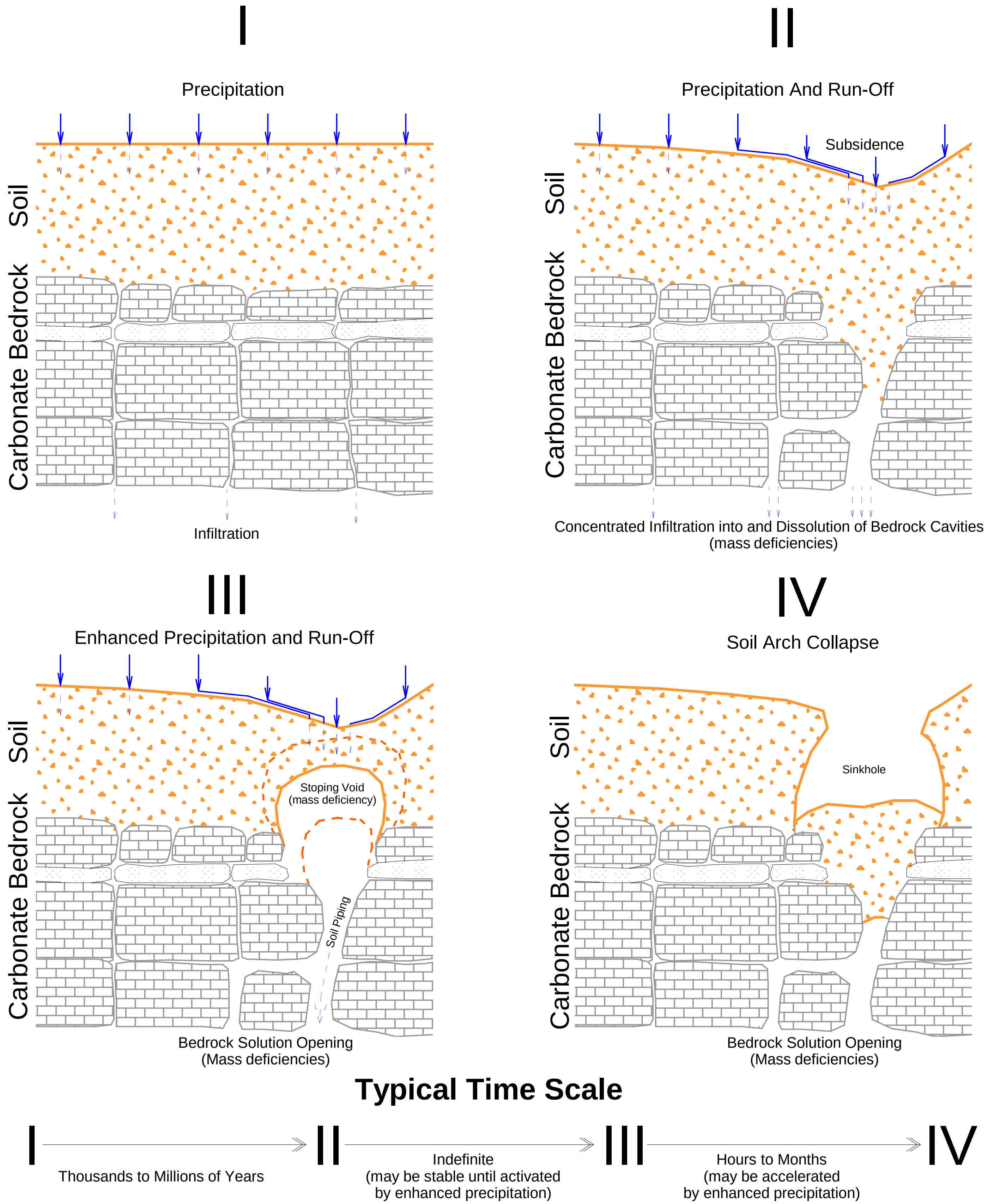
Highway 15
S2-0247
PA-CU-0176.0019-RD-16

CUMBERLAND COUNTY, PA

UPPER ALLEN TOWNSHIP

APPENDIX A

Schematic Karst Processses



Schematic Karst Processes

Rev. 02/2018

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APPENDIX B

Geophysical Survey Parameters

Geophysical Survey Parameters -- I-15

	Spacing[1] (feet)	Shot Interval[2] (feet)	Offset[3] (feet)	Spread Length[4] (feet)	Array Type[5]	Effective Depth[6] (feet)	Lateral Resolution[6] (feet)	Vertical Resolution[6] (percent)	System
Seismic Refraction	5	40	20	120		24	5	15	**Geometrics Geode**
Seismic MASW	5	5	20	120		40	5	25	**Geometrics Geode**
ERI	5		20	280	dipole-dipole	75.6	15	variable	**AGI Sting R-8**
MicroGravity	5		20			size-depth trade-off	depends on depth	depends on depth	**Scintrex CG-5**

[1] geophone, electrode, or station

[2] Seis (27-lb slidehammer source)

[3] distance between parallel profiles

[4] ERI or Seis

[5] ERI

[6] rule-of-thumb only (most depend on site-specific soil properties, sampling interval, depth, and target dimensions)

APPENDIX C

Introduction to Seismic Refraction

3020 Columbia Avenue, Lancaster, PA 17603 ● Phone: (800) 738-8395
E-mail: rettew@rettew.com ● Website: rettew.com

INTRODUCTION TO SEISMIC REFRACTION

BY TIMOTHY D. BECHTEL, PHD, PG

ENERGY

Mechanical elastic (seismic) waves generated by a hammer blow, weight drop, or explosion.

SENSITIVITY

Sensitive to elastic properties or moduli – generally strongly correlated with density.

BASIC EQUIPMENT

Recording Seismograph (generally 24 or more channels); Geophones (one for each channel); Geophone cable; Hammer or weight plus strike plate or explosives; Trigger switch.

COMMON APPLICATIONS

Determination of the depth and dip of soil horizons and bedrock surfaces. Recent processing advances allow some detection and delineation of discrete targets.

PRINCIPLES

In a uniform isotropic earth, the shock wave from a blow or explosion at the surface travels outward and downward in a hemispherical wave front like a three-dimensional ripple from a pebble in a still pond. At any point on the wave front, a straight line from the shock source to the wave front depicts the path of the seismic wave and is called a ray path (see **Figure SR-1**). In reality, there are several independent shock waves; the fast-moving primary, compressional or P wave front; the slower moving secondary, shear or S wave (both of which form hemispherical wavefronts); and several disk-like wave fronts that travel only along the surface of the earth (called surface waves or ground roll). For the purposes of most seismic refraction surveys, only the fastest moving wave front — the P wave — is considered. S-wave refraction is used in selected circumstances where complete determination of elastic moduli is desired – particularly when it may be desirable to eliminate the effects of water saturation.

In a layered earth, the hemispherical P shock wave defined by the radially distributed P ray paths are deflected according to the laws of optics (Snell's Law) at interfaces between materials with differing seismic velocities (i.e. densities or elastic properties). Figure SR-2 depicts the deflection of ray paths due to an increase in P velocity at a bedding plane. The type of deflection that a ray path will undergo is dependent upon the angle at which it strikes the interface, and falls into one of four categories:

Some direct rays (green in **Figures SR-2** and **SR-3**) travel parallel to the ground surface at the seismic velocity of the upper layer, do not strike the underlying interface, and consequently are not deflected.

Reflected rays (purple in **Figures SR-2** and **SR-3**) arise where direct rays strike the interface, and a portion of the energy is reflected symmetrically back towards the surface.

The portion of the energy of the incident direct wave that is not reflected upward is refracted or bent as it crosses the interface – making refracted waves in the lower layer (red in **Figures SR-2** and **SR-3**).

At a precise angle called the critical angle, the incident ray is refracted directly along the interface, and travels at the higher seismic velocity of the lower layer (see Critically Refracted Wave in **Figure SR-3**). As this critically refracted or head wave races along beneath the interface, it generates a secondary elastic disturbance that travels back to the surface along ray paths that define a wave front analogous to the bow wake of a ship. These returning rays again travel at the slower velocity of the upper layer.

To perform a refraction survey, a linear array of ground motion sensors or geophones is spaced out from the seismic source or shot point, forming a geophone spread. Each geophone is connected to a separate channel in a seismograph which records a wiggle trace representing the ground motion resulting from the passage of the various seismic rays.

As depicted in the time-distance (T-X) curve in Figure SR-4, the layered earth structure can be determined by analyzing the seismographic wiggle traces. At distances close to the seismic source, the first wiggle or ground motion (the first arrival after the shot) is due to passage of the direct wave travelling at the velocity of the upper layer. Reflected waves arrive later since they have by definition traveled a greater distance at the same velocity (additional later wiggles are caused by passage of the more slowly travelling S and surface waves). Beyond a distance dictated by the critical angle, the first arrival of seismic energy represents the head wave of the critically refracted ray. These refracted rays also by definition travel a greater distance than the direct wave. However, along part of their path, they have traveled at the higher velocity of the underlying more consolidated layer. At greater distances from the shot point, where the path length in the higher velocity layer becomes significant, the head wave arrivals actually race past the direct wave and become the first arrival (see labeled crossover in **Figure SR-4**). By extension, it can be shown that if a third layer with even greater velocity lies at greater depth, the head wave from this layer will become the first arrival at a sufficient distance from the shot point.

In conventional seismic refraction, only the first P wave arrivals can be reliably selected on a wiggle trace record. The later reflected P wave arrivals are generally obscured by the slower-travelling S and surface waves, and the very slow air blast or sound wave from the shot. To interpret a seismic refraction record, the first arrival travel times are measured for each wiggle trace and plotted at the appropriate point on a time-distance (T-X) curve (see Figure SR-4). In a plane-layered earth, these first arrivals define a series of line segments, each representing a discrete layer. The seismic velocity of each layer is simply the reciprocal of the slope of the associated line segment. The thickness of each layer can be calculated from the distances where the line segments intersect. The mathematics for these calculations are easily derived, and can be found in any introductory geophysics text.

True geologic strata are rarely perfectly horizontal. The effect of a dipping interface on a travel time curve cannot be recognized using a single shot point. Calculations based on a T-X curve from a single shot point should always be considered as producing apparent depths to interfaces and apparent seismic velocities for all but the uppermost layer. To determine the true depths and dips of interfaces and the true seismic velocities, it is necessary to reverse the seismic line; that is, move the shot point to a location at or beyond the farthest geophone in the spread, and repeat the shot. The calculation of true depths, dips and velocities from reversed seismic lines is also readily performed.

CAPABILITIES

Conventional seismic refraction can yield accurate measurements of depths and attitudes of soil horizons, groundwater tables, and other relatively distinct and planar strata. Modern computer analysis of multi-fold seismic refraction data (i.e. with many and overlapping shot points) can provide delineation of undulating or even irregular (as opposed to simply planar) interfaces. The latest generation of computer processing techniques require very high-fold data, but in favorable conditions, are capable of resolving even discrete targets such as foundation elements, tunnels or cavities, and can resolve gradational boundaries as well as distinct interfaces. The seismic P-wave velocities of materials are generally an indication of relative density or compaction. S-wave refraction data (collected using specialized geophones, shock sources and field procedures) can provide S-wave velocities that bear a well-constrained empirical relationship to standard penetration test (SPT) N values and therefore bearing capacity. For surveys where matching P- and S-wave velocities are determined, the dynamic elastic moduli of subsurface materials can be calculated (including Poisson's Ration, Young's or Bulk Modulus, and Shear Modulus or Rigidity).

LIMITATIONS

Seismic data is collected at spaced geophones, and therefore does not provide continuous profile data. If geophones are spaced too widely, thin layers can be missed entirely.

Conventional refraction interpretations are only accurate where the velocity of strata increase with depth. Velocity inversions not only alter the data, but are particularly insidious since the presence of a low velocity zone at depth is not apparent in first arrival data. The latest generation of computer processing techniques do allow detection and delineation of laterally restricted low velocity zones (e.g. tunnels, cavities, gravel lenses, etc.).

Sharp or dramatic interface relief such as limestone pinnacles cannot always be resolved even with very tight geophone spacing. Therefore, refraction profiles of expectedly irregular interfaces should be assumed to represent somewhat smoothed versions of actual relief (see e.g. Figure **SR-5**).

Seismic records can contain noise due to heavy machinery vibrations, vehicular traffic, and sometimes even wind or distant earthquakes. Care must be taken to identify potential sources of seismic noise prior to beginning a survey.

The effective survey depth is limited to approximately 1/5 of the greatest shotpoint to geophone distance. Therefore, very deep surveys may require impractically long lines (requiring consideration of other geophysical techniques such as seismic reflection).

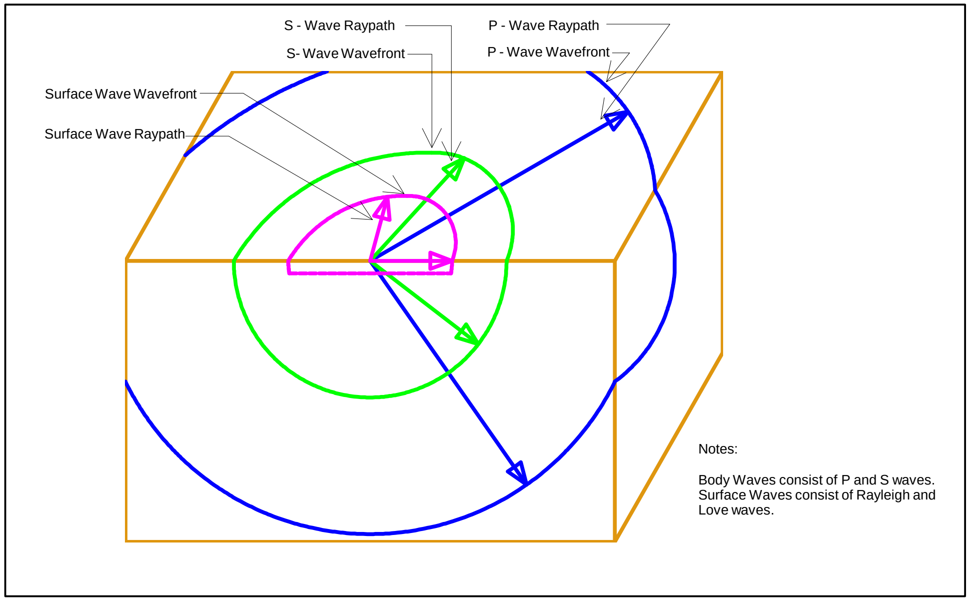


Figure SR-1 Seismic Wave Types Rev. 04/2018

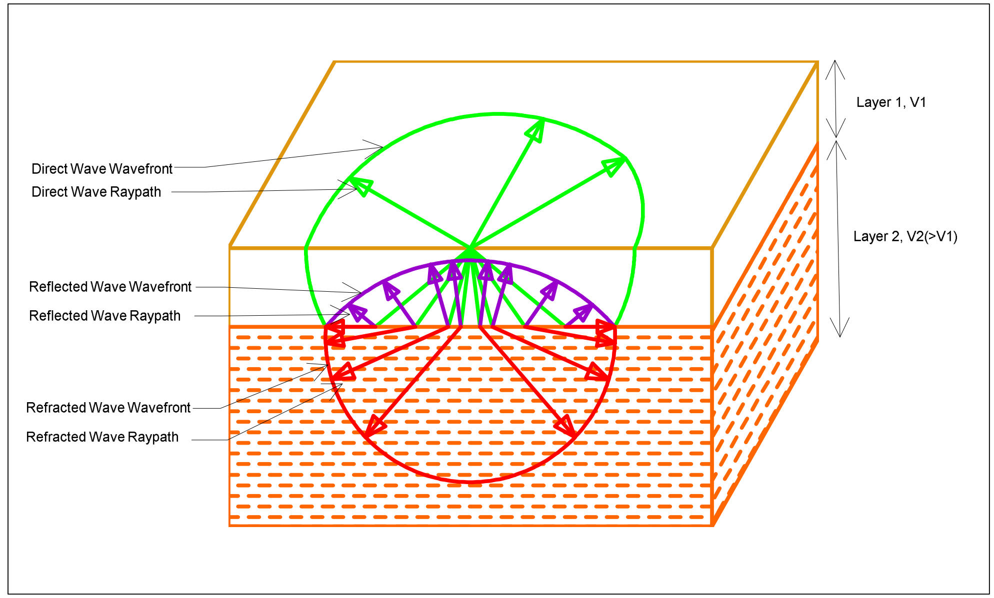


Figure SR-2 Effect of Layering on Body Wave Raypath Rev. 04/2018

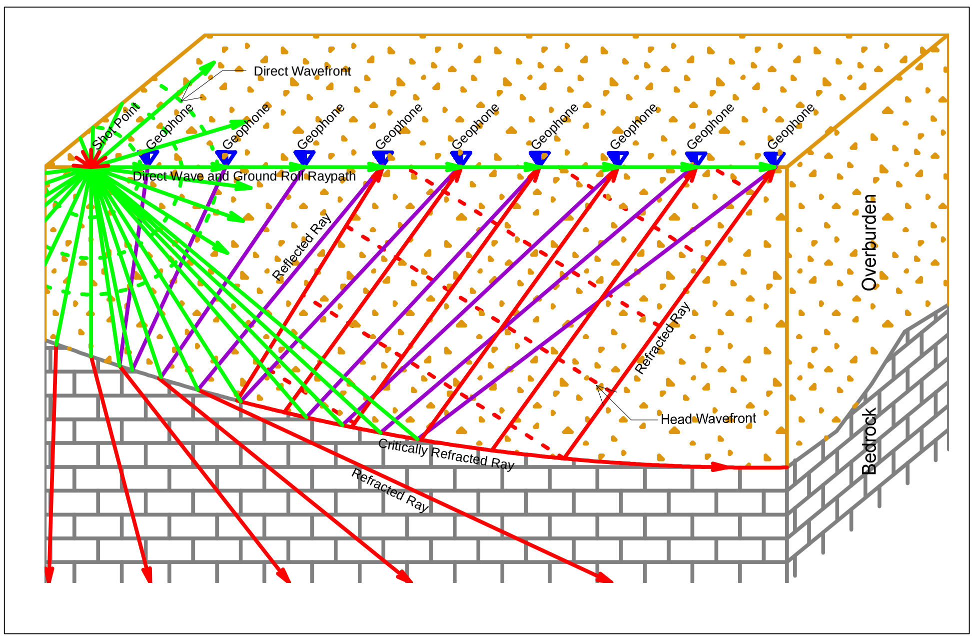


Figure SR-3 Seismic Ray Path Geometry Rev. 04/2018

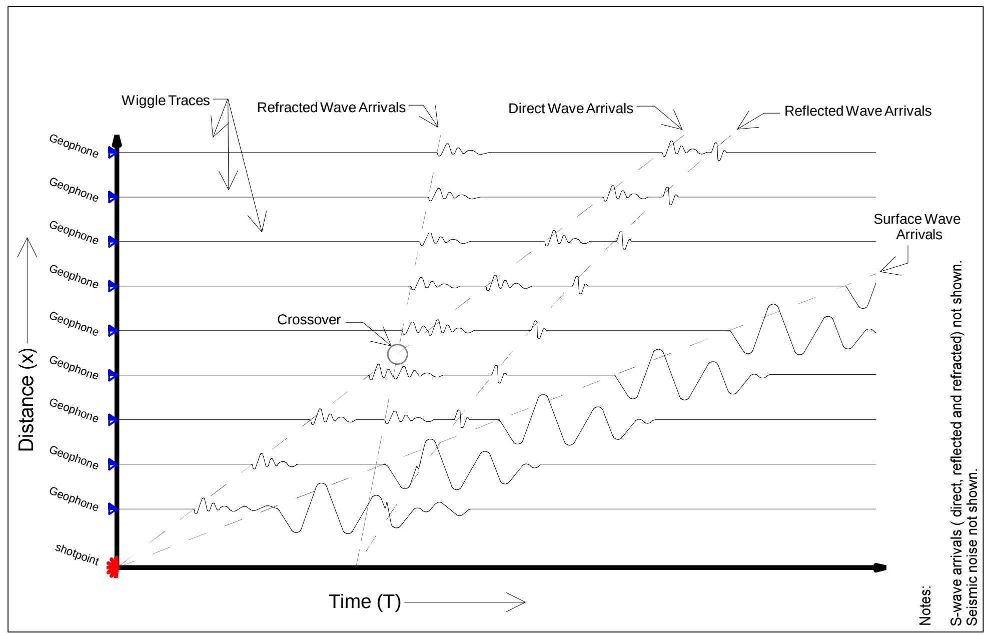


Figure SR-4 Idealized Seismic Record and T- X Graph Rev. 04/2018

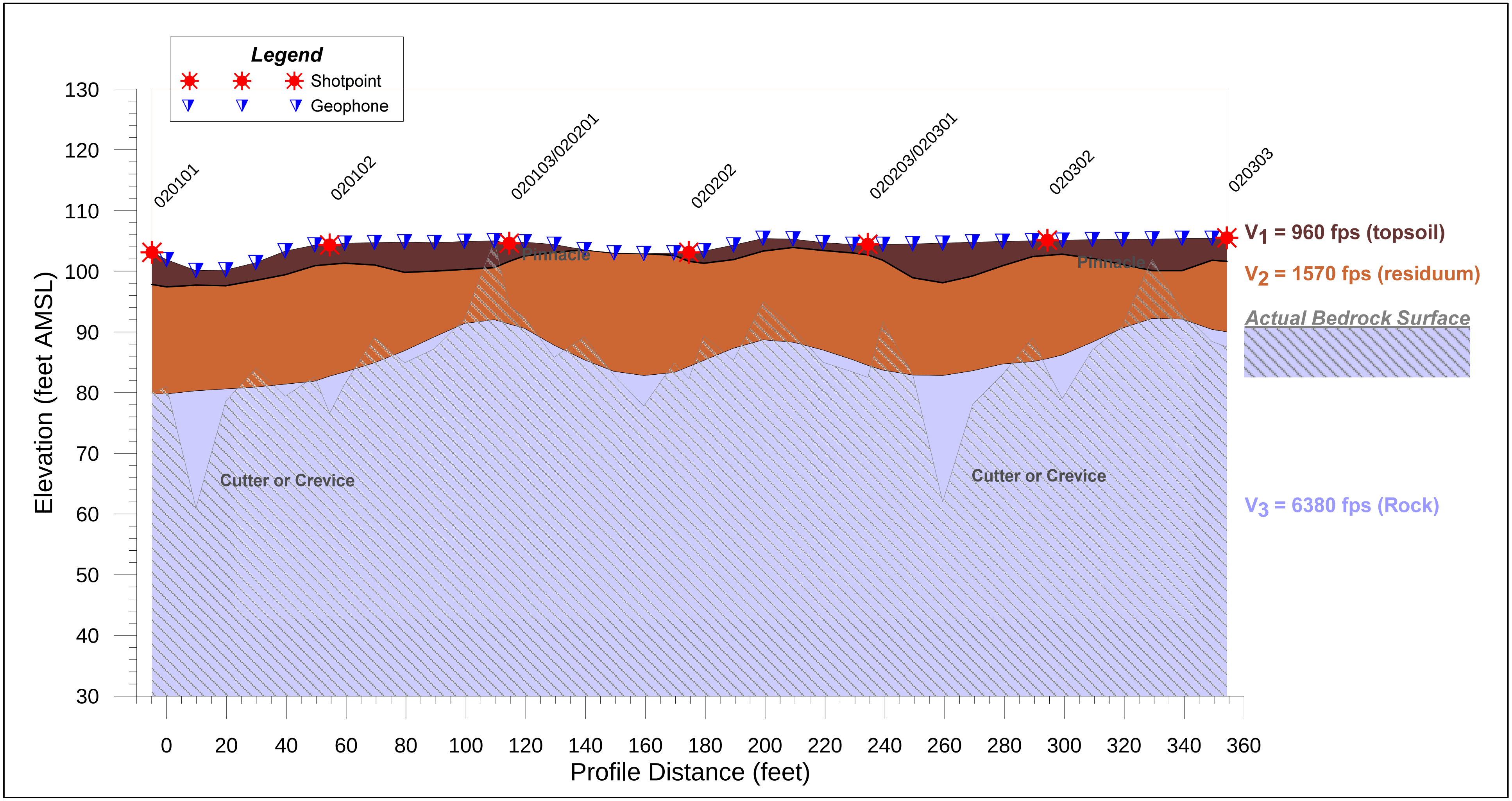


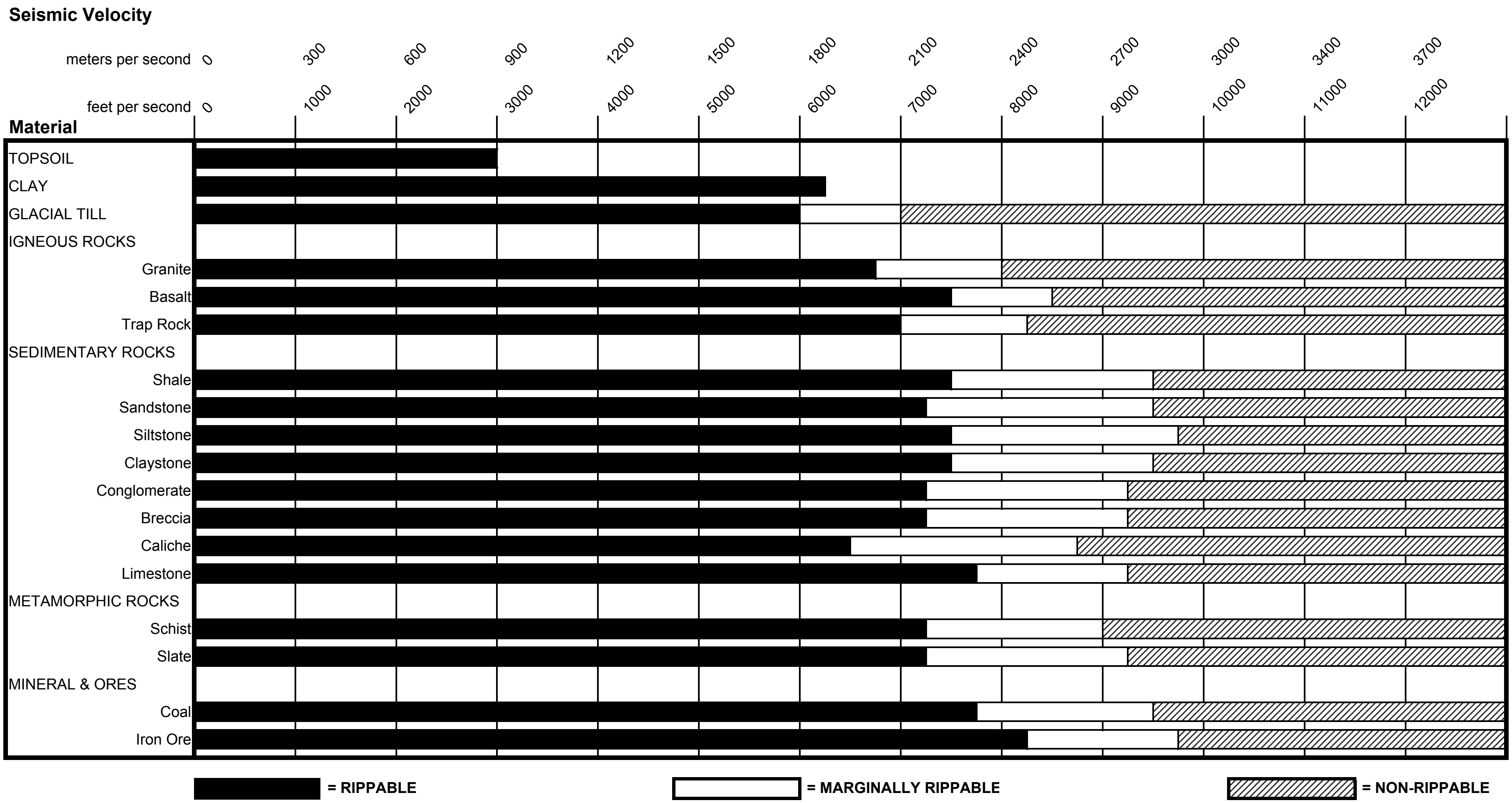
Figure SR-5 **Example Karst Terrane Seismic Profile** **Revised 04/2018**

RETTEW

APPENDIX D

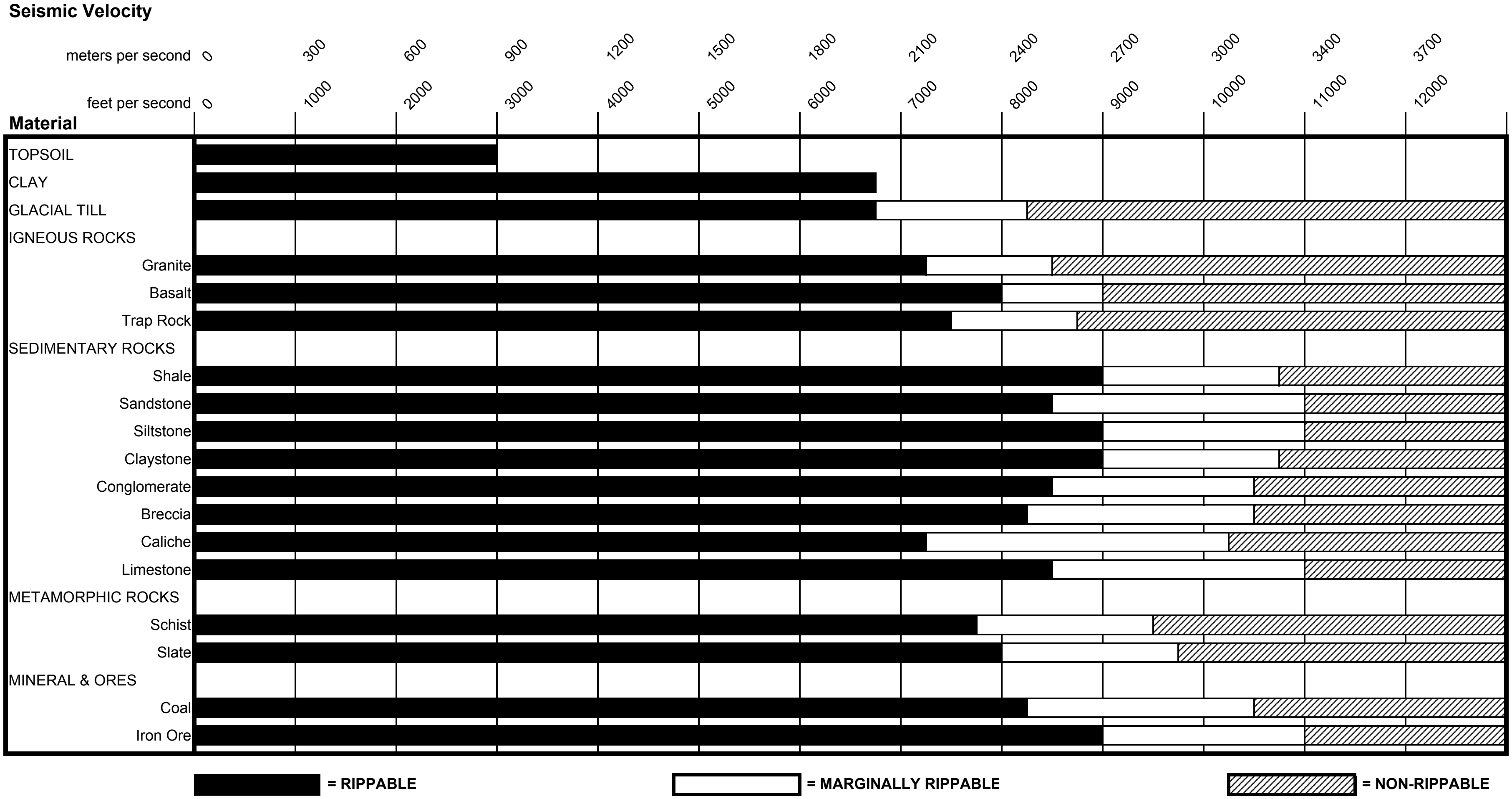
Caterpillar Ripping Charts

Ripping Chart *
D9R
Multi or Single Shank No. 9 Ripper
Estimated by Seismic P-Wave Velocities



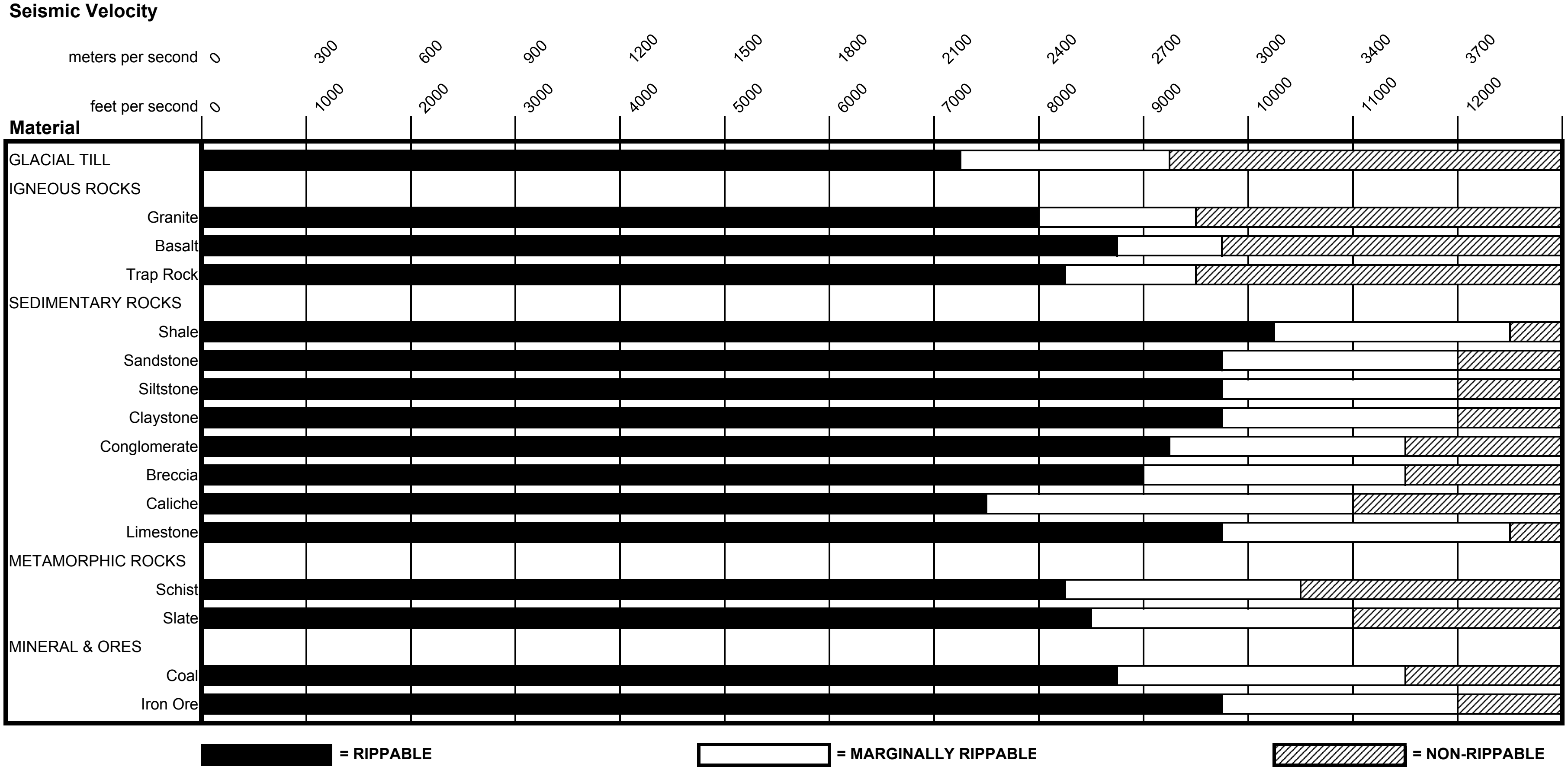
* Caterpillar Performance Handbook, Edition 26, Caterpillar, Inc., Peoria, Illinois

Ripping Chart *
D10N
Multi or Single Shank No. 10 Ripper
Estimated by Seismic P-Wave Velocities



* Caterpillar Performance Handbook, Edition 26, Caterpillar, Inc., Peoria, Illinois

Ripping Chart *
D11N
Multi or Single Shank No. 11 Ripper
Estimated by Seismic P-Wave Velocities

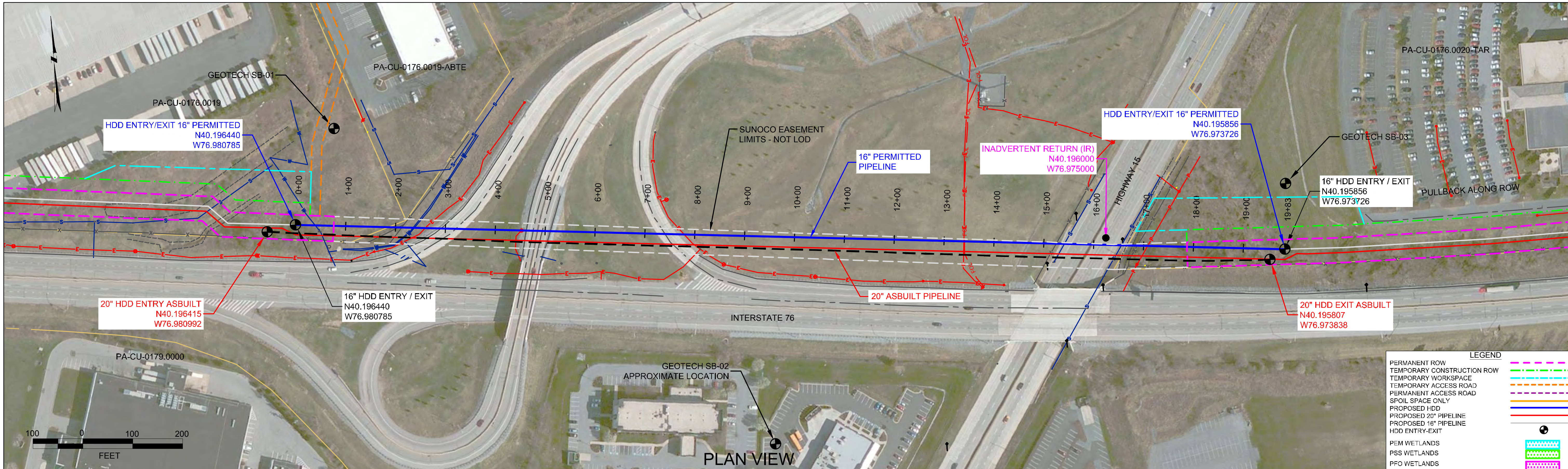


* Caterpillar Performance Handbook, Edition 26, Caterpillar, Inc., Peoria, Illinois

HIGHWAY 15 CROSSING
PADEP SECTION 105 PERMIT NO. E21-449
PA-CU-0176.0019-RD-16
(SPLP HDD No. S2-0247-16)

ATTACHMENT 2

HORIZONTAL DIRECTIONAL DRILL PLAN AND PROFILES



CUMBERLAND COUNTY PENNSYLVANIA, UPPER ALLEN TOWNSHIP
S2-0247-16

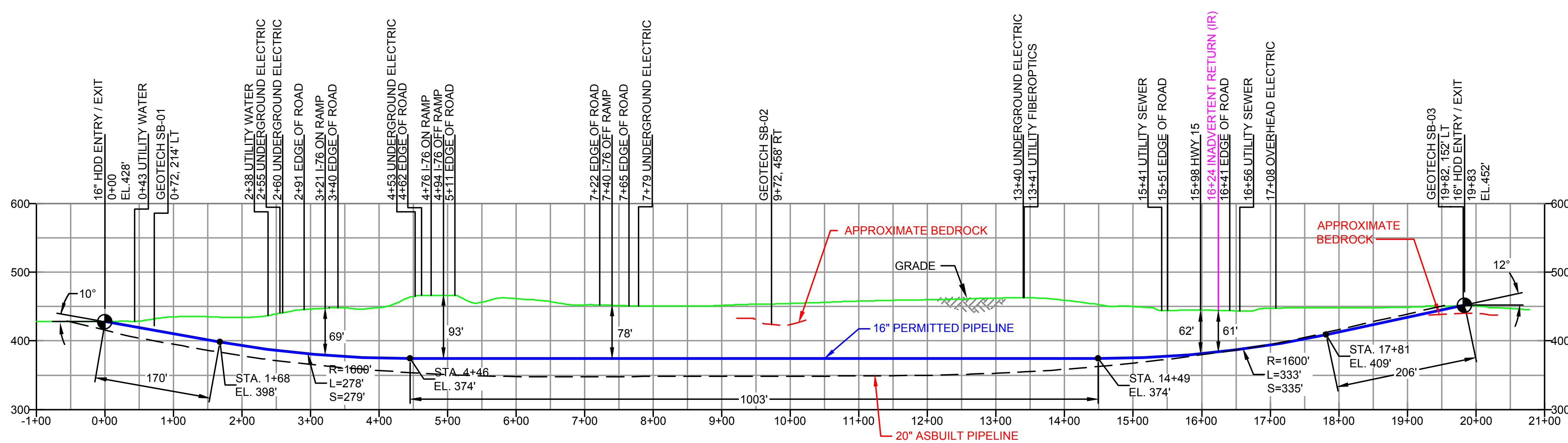
PROFILE VIEW

GEOTECH SB-01
- NG EL. 422'
- TOPSOIL (0' - 0.3')
- CL (0.3' - 30.0')
- COMPLETION DEPTH EL. 392'

GEOTECH SB-02
- NG EL. 458'
- TOPSOIL (0' - 0.3')
- CL (0.3' - 13.5')
- WEATHERED LIMESTONE (13.5' - 13.9')
- AUGER REFUSAL (14.0')
- FRACTURED LIMESTONE (14.0' - 21.4')
- COMPLETION DEPTH EL. 437'

GEOTECH SB-03
- NG EL. 445'
- TOPSOIL (0' - 0.3')
- CLAY / LIMESTONE FRAGMENTS (USCS:CH) (0.3' - 12.0')
- LIMESTONE FRAGMENTS (12.0' - 12.1')
- AUGER REFUSAL (12.0')
- COMPLETION DEPTH EL. 433'

NOTE: REFER TO TEST BORING LOG S2-0247 FOR COMPLETE SOIL MATERIAL DESCRIPTION



DESIGN AND CONSTRUCTION:

1. CONTRACTOR SHALL FIELD VERIFY DEPTH OF ALL EXISTING UTILITIES SHOWN OR NOT SHOWN ON THIS DRAWING.
2. THE MINIMUM SEPARATION DISTANCE FROM EXISTING SUBSURFACE UTILITIES SHALL NOT BE LESS THAN 10 FEET AS MEASURED FROM THE OUTSIDE EDGE OF THE UTILITY TO OUTSIDE OF PROPOSED PIPELINE.
3. DESIGNED IN ACCORDANCE WITH CFR 49 195 & ASME B31.4
4. CROSSING PIPE SPECIFICATION:
   HDD HORZ. LENGTH (L=):1983'
   HDD PIPE LENGTH (S=):1993'
   16" x 0.438" W.T., X-70, API5L, PSL2, ERW, BFW
   COATING: 14-16 MILS FBE WITH 30-35 MIL ARO (POWERCRETE OR ENGINEER APPROVED EQUAL)
5. INTERNAL DESIGN PRESSURE 1480 PSIG (SEAM FACTOR 1.0, DESIGH FACTOR 0.50).
6. INSTALLATION METHOD: HORIZONTAL DIRECTIONAL DRILL (HDD).
7. PIPELINE WARNING MARKERS SHALL BE INSTALLED ON BOTH SIDES OF ALL ROAD, RAILWAY, AND STREAM CROSSINGS.
8. CARRIER PIPE NOT ENCASED.
9. PIPE / AMBIENT TEMPERATURE MUST BE NO LESS THAN 30°F DURING PULLBACK WITHOUT PRIOR WRITTEN APPROVAL FROM THE ENGINEER.
10. CONDUCT 4-HOUR PRE-INSTALLATION HYDROTEST OF HDD PIPE STRING TO MINIMUM 1850 PSIG.
11. SEE SUNOCO PENNSYLVANIA PIPELINE PROJECT ESRI WEBMAP FOR ACCESS ROAD ALIGNMENT.
12. SUNOCO PIPELINE, L.P.'S HORIZONTAL DIRECTIONAL DRILL INADVERTENT RETURN CONTINGENCY PLAN WILL BE IMPLEMENTED AT ALL TIMES.
13. SUNOCO PIPELINE, L.P.'S EROSION AND SEDIMENTATION CONTROL PLAN WILL BE IMPLEMENTED AT ALL TIMES.

Figure 1. Permitted 16-inch HDD Plan and Profile with 20-Inch IR Data

NOTES

1. ALL COORDINATES SHOWN ARE IN LATITUDE AND LONGITUDE. ALL MSL ELEVATIONS ARE NAD83
2. STATIONING IS BASED ON HORIZONTAL DISTANCES.
3. ROONEY ENGINEERING, INC. AND SUNOCO PIPELINE, LP ARE NOT RESPONSIBLE FOR LOCATION OF FOREIGN UTILITIES SHOWN IN PLOT PLAN OR PROFILE. THE INFORMATION SHOWN HEREON IS FURNISHED WITHOUT LIABILITY ON THE PART OF ROONEY ENGINEERING, INC. AND SUNOCO PIPELINE, LP, FOR ANY DAMAGES RESULTING FROM ERRORS OR OMISSIONS THEREIN.
4. CONTRACTOR IS RESPONSIBLE FOR LOCATING ALL UTILITIES. CONTACT ONE CALL AT 811 PRIOR TO DIGGING.
5. SUNOCO EMERGENCY HOTLINE NUMBER IS #1-800-786-7440.

REVISIONS

NO.	DESCRIPTION	BY	DATE	CHK	DATE	APP	DATE
5	DRILL ENTRY/EXIT LAT LONG UPDATE	DLM	04/03/17	RMB	04/03/17	CAG	04/03/17
4	REVISED PROFILE WITH 2017 LIDAR	MRS	02/24/17	RMB	02/24/17	CAG	02/24/17
3	REVISED PER ENGINEERING COMMENTS	MRS	08/31/16	RMB	08/31/16	AAW	08/31/16
2	REVISED PER COMMENTS FROM REI REVIEW	MRS	02/19/16	RMB	02/19/16	AAW	02/19/16
1	DESIGN CHANGE	DLM	02/19/16	RMB	02/19/16	AAW	02/19/16
0	ISSUED FOR CONSTRUCTION	MRS	01/19/16	RMB	01/19/16	AAW	01/19/16

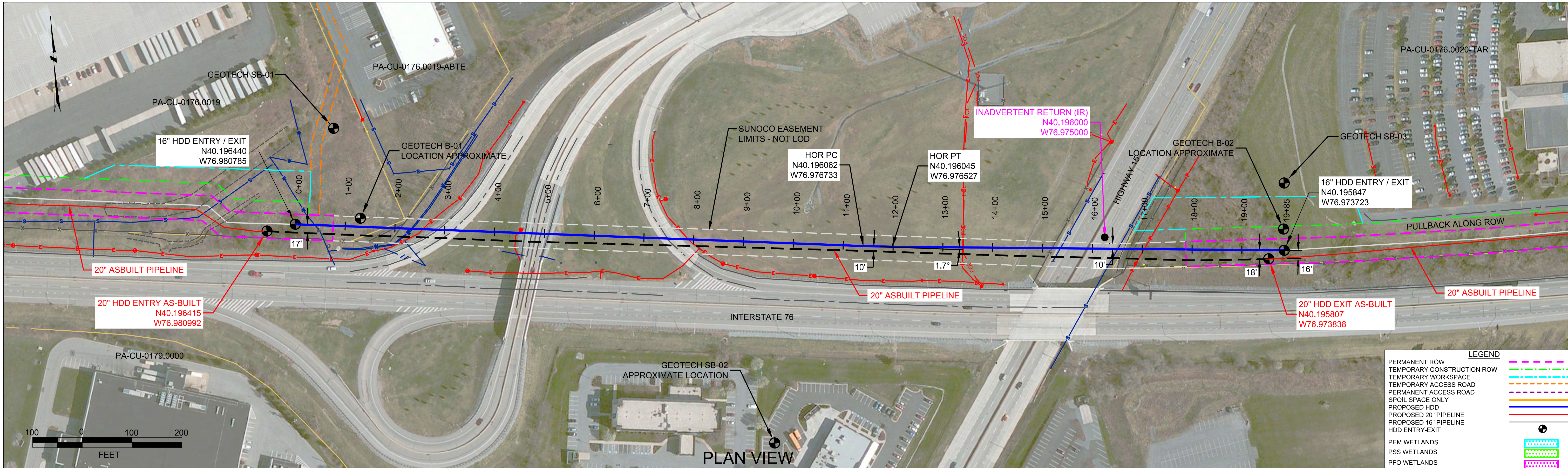
Sunoco Logistics Partners L.P.

TETRA TECH ROONEY
(303) 792-5911

SUNOCO PIPELINE, L.P.

HORIZONTAL DIRECTIONAL DRILL
HWY 15
PENNSYLVANIA PIPELINE PROJECT

SCALE: 1"=200'
DWG. NO: PA-CU-0176.0019-RD-16



CUMBERLAND COUNTY PENNSYLVANIA, UPPER ALLEN TOWNSHIP
S2-0247-16

PROFILE VIEW

GEOTECH SB-01

- NG EL. 422'
- TOPSOIL (0' - 0.3')
- CL (0.3' - 30.0')
- COMPLETION DEPTH EL. 392'

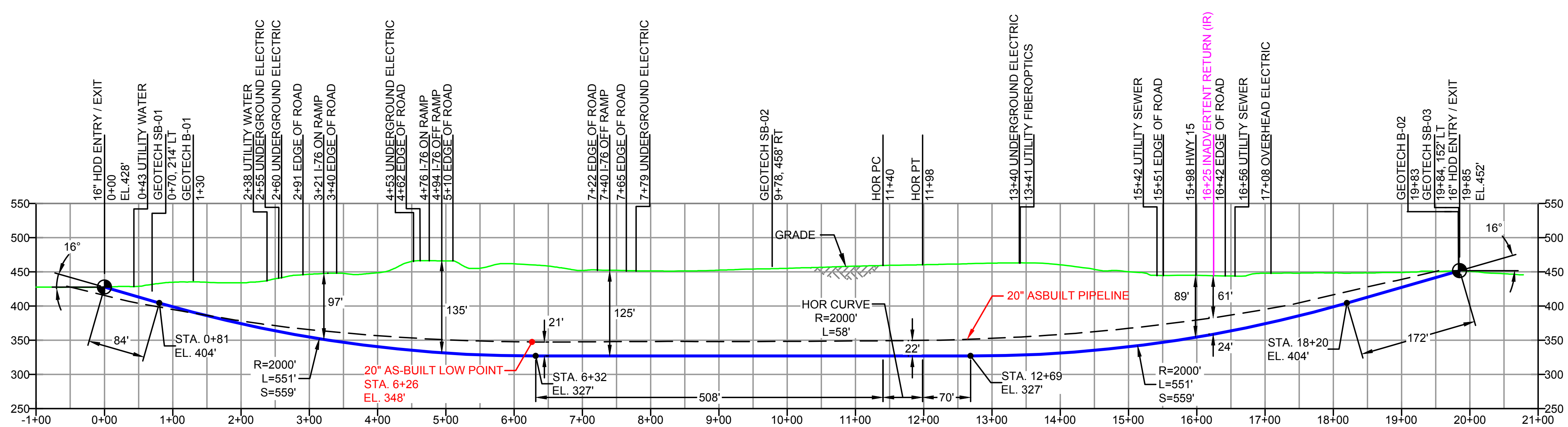
GEOTECH SB-02

- NG EL. 458'
- TOPSOIL (0' - 0.3')
- CL (0.3' - 13.5')
- WEATHERED LIMESTONE (13.5' - 13.9')
- AUGER REFUSAL (14.0')
- FRACTURED LIMESTONE (14.0' - 21.4')
- COMPLETION DEPTH EL. 437'

GEOTECH SB-03

- NG EL. 445'
- TOPSOIL (0' - 0.3')
- CLAY / LIMESTONE FRAGMENTS (USCS:CH) (0.3' - 12.0')
- LIMESTONE FRAGMENTS (12.0' - 12.1')
- AUGER REFUSAL (12.0')
- COMPLETION DEPTH EL. 433'

NOTE: REFER TO TEST BORING LOG S2-0247 FOR COMPLETE SOIL MATERIAL DESCRIPTION



GEOTECH B-01

- NG EL. 437'
- RESIDUUM SILT ML (0.0' - 8.5')
- GROUNDWATER (17.3')
- HIGHLY WEATHERED LIMESTONE (8.5' - 10.0')
- LIMESTONE/DOLOMITE (10.0' - 85.0')
- BORING TERMINATED EL.352'

NOTE: REFER TO TEST BORING LOG B-01 INTERTEK PROJECT #04911465 FOR COMPLETE SOIL MATERIAL DESCRIPTION

GEOTECH B-02

- NG EL. 449'
- PROBABLE FILL CL (0.0' - 2.5')
- RESIDUUM CLAYEY SAND SC (2.5' - 6.5')
- RESIDUUM CLAY CL (6.5' - 9.75')
- RESIDUUM CLAYEY GRAVEL GC (9.75' - 10.5')
- GROUNDWATER (27.8')
- LIMESTONE/DOLOMITE (10.5' - 111.0')
- BORING TERMINATED EL.338'

NOTE: REFER TO TEST BORING LOG B-02 INTERTEK PROJECT #04911465 FOR COMPLETE SOIL MATERIAL DESCRIPTION

DESIGN AND CONSTRUCTION:

1. CONTRACTOR SHALL FIELD VERIFY DEPTH OF ALL EXISTING UTILITIES SHOWN OR NOT SHOWN ON THIS DRAWING.
2. THE MINIMUM SEPARATION DISTANCE FROM EXISTING SUBSURFACE UTILITIES SHALL NOT BE LESS THAN 10 FEET AS MEASURED FROM THE OUTSIDE EDGE OF THE UTILITY TO OUTSIDE OF PROPOSED PIPELINE.
3. DESIGNED IN ACCORDANCE WITH CFR 49 195 & ASME B31.4
4. CROSSING PIPE SPECIFICATION:
   HDD HORZ. LENGTH (L=):1985'
   HDD PIPE LENGTH (S=):2010'
   16" x 0.438" W.T., X-70, API5L, PSL2, ERW, BFW
   COATING: 14-16 MILS FBE WITH 30-35 MIL ARO (POWERCRETE OR ENGINEER APPROVED EQUAL)
5. INTERNAL DESIGN PRESSURE 2100 PSIG (SEAM FACTOR 1.0, DESIGH FACTOR 0.50).
6. INSTALLATION METHOD: HORIZONTAL DIRECTIONAL DRILL (HDD).
7. PIPELINE WARNING MARKERS SHALL BE INSTALLED ON BOTH SIDES OF ALL ROAD, RAILWAY, AND STREAM CROSSINGS.
8. CARRIER PIPE NOT ENCASED.
9. PIPE / AMBIENT TEMPERATURE MUST BE NO LESS THAN 30°F DURING PULLBACK WITHOUT PRIOR WRITTEN APPROVAL FROM THE ENGINEER.
10. CONDUCT 4-HOUR PRE-INSTALLATION HYDROTEST OF HDD PIPE STRING TO MINIMUM 2625 PSIG.
11. SEE SUNOCO PENNSYLVANIA PIPELINE PROJECT ESRI WEBMAP FOR ACCESS ROAD ALIGNMENT.
12. SUNOCO PIPELINE, L.P.'S HORIZONTAL DIRECTIONAL DRILL INADVERTENT RETURN CONTINGENCY PLAN WILL BE IMPLEMENTED AT ALL TIMES.
13. SUNOCO PIPELINE, L.P.'S EROSION AND SEDIMENTATION CONTROL PLAN WILL BE IMPLEMENTED AT ALL TIMES.

Figure 2. Redesigned 16-Inch HDD Plan and Profile

NOTES

1. ALL COORDINATES SHOWN ARE IN LATITUDE AND LONGITUDE. ALL MSL ELEVATIONS ARE NAD83
2. STATIONING IS BASED ON HORIZONTAL DISTANCES.
3. ROONEY ENGINEERING, INC. AND SUNOCO PIPELINE, LP ARE NOT RESPONSIBLE FOR LOCATION OF FOREIGN UTILITIES SHOWN IN PLOT PLAN OR PROFILE. THE INFORMATION SHOWN HEREON IS FURNISHED WITHOUT LIABILITY ON THE PART OF ROONEY ENGINEERING, INC. AND SUNOCO PIPELINE, LP, FOR ANY DAMAGES RESULTING FROM ERRORS OR OMISSIONS THEREIN.
4. CONTRACTOR IS RESPONSIBLE FOR LOCATING ALL UTILITIES. CONTACT ONE CALL AT 811 PRIOR TO DIGGING.
5. SUNOCO EMERGENCY HOTLINE NUMBER IS #1-800-786-7440.

REF. DRAWING

DWG NO		DWG NO	DESCRIPTION
ES-4.89	TO	ES-4.90	EROSION & SEDIMENT PLAN
SHEET 54	TO	SHEET 54	AERIAL SITE PLAN

REVISIONS

NO.	DESCRIPTION	BY	DATE	CHK	DATE	APP	DATE
EP3	DESIGN CHANGE - LOWERED DRILL AND ADDED GEOTECH	MRS	01/30/19	RMB	01/30/19	AMC	01/30/19
EP2	REVISED PER PADEP COMMENTS RECEIVED 09-06-16	MRS	10/07/16	RMB	10/07/16	AAW	10/07/16
EP1	REVISED PER PADEP COMMENTS	MRS	05/11/16	RMB	05/11/16	AAW	05/11/16
EP		JTW	11/23/15	RMB	11/23/15	AAW	11/23/15
B	ADDED GEOTECH INFO	MRS	09/18/15	RMB	09/18/15	AAW	09/18/15
A	ISSUED FOR BID	DLM	08/31/15	RMB	08/31/15	AAW	08/31/15

Sunoco Logistics Partners L.P.

TETRA TECH ROONEY
(303) 792-5911

SUNOCO PIPELINE, L.P.

HORIZONTAL DIRECTIONAL DRILL
HWY 15
PENNSYLVANIA PIPELINE PROJECT

SCALE: 1"=200' DWG. NO: PA-CU-0176.0019-RD-16

HIGHWAY 15 CROSSING
PADEP SECTION 105 PERMIT NO. E21-449
PA-CU-0176.0019-RD-16
(SPLP HDD No. S2-0247-16)

This reevaluation of the horizontal directional drill (HDD) installation of a 16-inch diameter pipeline that traverses Highway 15 in Upper Allen Township, Cumberland County, Pennsylvania, is in accordance with the Stipulated Order issued under Environmental Hearing Board Docket No. 2017-009-L for HDDs listed on Exhibit 3 of the Stipulated Order. This HDD is number 10 on the list of HDDs included on Exhibit 3 of the Order.

The first pipeline HDD had one inadvertent return (IR), which was remediated in conjunction with the installation of the 20-inch diameter pipeline.

The 16-inch pipeline HDD is referred to herein as HDD S2-0247-16.

PIPE INFORMATION

16-Inch: 0.438 wall thickness; X-70.

Pipe stress allowances are an integral part of the design calculations performed for each HDD.

ORIGINAL HORIZONTAL DIRECTIONAL DRILL DESIGN SUMMARY: 16-INCH

- Horizontal length: 1,983 foot (ft)
- Entry/Exit angle: 10-12 degrees
- Maximum Depth of cover: 93 ft
- Pipe design radius: 1,600 ft

ROOT CAUSE ANALYSIS FOR THE 20-INCH PIPELINE INSTALLATION INADVERDENT RETURNS

The 20-inch HDD pilot was initiated in June of 2017. Based upon analysis of the drilling profile, location of the IR, phase of drilling (pilot hole) and interviews with supervisory personnel on site during this HDD, SPLP drilling specialists conclude that a clogged annulus behind the pilot drilling tool induced the IR event. Craft inspectors who were on-site during this HDD recall several Loss of Circulation events after the pilot tool had progressed from west to east and passed under the entry-exit roadway interchange between Highway 15 and Interstate 76. Furthermore, it was noted that the materials under the interchange roads appeared to be un-compacted fill based upon the behavior of the pilot tool while passing through this section of the profile. These observations about conditions when the pilot tool passed under the interchange support the clogged annulus conclusion.

GEOLOGIC AND HYDROGEOLOGIC ANALYSIS

Based upon publications by the Pennsylvania Bureau of Topographic and Geologic Survey (PABTGS), the site is in the Great Valley Section of the Ridge and Valley Physiographic Province of Pennsylvania and is underlain by very finely crystalline limestone with minor occurrences of dolomite and chert. The site geology for the redesigned 16-inch HDD profile is mapped as the Orr: Rockdale Run Formation. The Rockdale Run Formation contains a very light gray, very fine-grained pure limestone in the lower part of the formation, while the middle and upper portions of the formation consist mostly of light-gray limestone, commonly containing abundant fine carbonate grains and fossil fragments. Dolomite is sparsely distributed throughout the formation but is primarily concentrated towards the top of the unit (Becher and Root, 1981). The formation also contains lenses of pink to brown chert and white quartz rosettes are found near the top of the formation. The lower third of the formation is medium bedded, while the upper two thirds are thickly bedded. Joints tend to have a blocky pattern, are moderately well developed, moderately abundant, and regularly spaced. Fractures in the formation tend to have a moderate distance between them, are open and steeply dipping. The Rockdale Run Formation tends to be moderately resistant to weathering and is moderately weathered to a deep depth. The weathered product consists of irregular and blocky-shaped fragments resulting from prolonged weathering. From an engineering stand point, the formation is considered difficult to excavate, due to the degree and extent of bedrock pinnacle development, while drilling rates are expected to be fast but may be slowed by chert and quartz lenses.

Karst geology is present in the immediate vicinity of this HDD location. RETTEW completed a multi-technique geophysical survey at the Highway 15 HDD site from November 12-20, 2018. The purpose of the survey was to provide supplemental information to the geotechnical investigations to aid in detecting and delineating subsurface voids or low-density zones. Results from these geophysical techniques are consistent with each other, and with the geology as mapped by the PA Geological Survey, all suggesting that the local bedrock (limestone) is karstified, with potential concentrations of dissolution cavities (of various sizes) indicated by the geophysical anomalies detected. In the limestone, the top-of-rock is expected to be pinnacled (highly irregular) with interfingered competent rock and residual clay soil as well as potential bedrock voids.

This HDD was near completion before the Stipulated Order, and as a result there are no logs by the monitoring geologists to verify the reported geology to the geologic materials and conditions drilled through during installation of the 20-inch pipeline.

Attachment 1 provides an extensive discussion on the geology and results of the geotechnical and geophysical investigations performed at this location.

HYDROGEOLOGY, GROUND WATER, AND WELL PRODUCTION ZONES

Groundwater at the site occurs in a fractured, solution-prone, carbonate bedrock aquifer system within the Rockdale Run Formation. In carbonate rocks, water-bearing zones generally occur in solution-enhanced secondary openings that form along bedding planes, joints, faults and fractures. Most of the water-bearing zones penetrated by supply wells occur in individual fractures or groups of interconnected fractures that are sufficiently enlarged by dissolution of bedrock to provide pathways for the transport of groundwater. Groundwater flow paths within the karstic limestone beneath the site have both local and regional components. Locally, shallow groundwater discharges to the gaining portions of nearby streams and deeper regional groundwater flow is toward points of regional groundwater discharge such as the Susquehanna River. Groundwater divides may be different for each zone of groundwater flow and, therefore, may not coincide with surface water divides.

Of the 91 yielding zones reported within the Rockdale Run Formation, 58 are at depths of less than 100 feet and only seven occur below 250 feet. No large specific-capacity or high-yielding wells produce from zones below 200 feet (Becher and Root, 1981). The median depth of water supply wells in the Rockdale Run Formation is reported to be 82 feet bgs with a median depth to water of 30 feet bgs. Well records for 8 individual water supply wells within a 0.5-mile radius of the Highway 15 HDD were obtained from the Pennsylvania Groundwater Information System (PaGWIS). Well construction details were not reported for all of the wells; however, the majority of the identified wells were completed as 6-inch-diameter open-rock wells with total depths ranging from 200 to 280 feet bgs. Reported well yields range from 5 to 150 gpm, while the reported water levels ranged from 21 to 54 feet bgs.

Attachment 1 provides an extensive discussion on the hydrogeology and results of the geotechnical investigation performed at this location.

HIGHWAY 15 CROSSING
PADEP SECTION 105 PERMIT NO. E21-449
PA-CU-0176.0019-RD-16
(SPLP HDD No. S2-0247-16)

INADVERTENT RETURN (IR) DISCUSSION

As discussed above, the SPLP drilling specialist have concluded that a clogged annulus behind the pilot drilling tool induced the IR event.

As outlined below in the Conclusions Section, SPLP will require the implementation of the drilling BMP's as listed. The implementation of these drilling tool, procedures, and corrective actions significantly reduce the probability of an IR during drilling and installation of the 16-inch pipeline.

ADJACENT FEATURES ANALYSIS

This HDD location is located 1.8 miles southeast of the Town of Mechanicsburg in Cumberland County, Pennsylvania. The pipeline alignment and HDD crosses under Highway 15 and a clover-leaf interchange to Interstate 76. This HDD location is set within an urban area. No aquatic resources are crossed by this HDD.

SPLP performed a preconstruction survey of landowners within 450 feet and greater from the alignment. SPLP sent each of these landowners a notice letter via both certified and first-class mail that included an offer to sample the landowner's private water supply/well in accordance with the terms of the Order and the Water Supply Assessment, Preparedness, Prevention and Contingency Plan. The letter also requested that each landowner contact the Right-of-Way agent for the local area and provide SPLP with information regarding: (1) whether the landowner has a well; (2) where that well is located, and its depth and size if known; and (3) whether the landowner would like to have the well sampled. In accordance with paragraph 10 of the Order, copies of the certified mail receipts for the letters sent to landowners have been provided to Karyn Yordy, Executive Assistant, Office of Programs at the Department's Central Office.

As a result of these communications, no known private water wells were identified within 450 radius of the HDD profile.

In accordance with the requirements of the Stipulated Order, SPLP will transmit a copy of this HDD analysis to all landowners having a property line within 450 ft of any direction of the revised HDD alignment.

ALTERNATIVES ANALYSIS

As part of the PADEP Chapter 105 permit process for the Mariner II East Project, SPLP developed and submitted for review a project-wide Alternatives Analysis. During the development and siting of the Project, SPLP considered several different routings, locations, and designs to determine whether there was a practicable alternative to the proposed impact. SPLP performed this determination through a sequential review of routes and design techniques, which concluded with an alternative that has the least environmental impacts, taking into consideration cost, existing technology, and logistics. The baseline route provided for the pipeline construction was to cross every wetland and stream on the project by open cut construction procedures. The Alternatives Analysis submitted to PADEP conceptually analyzed the potential feasibility of any alternative to baseline route trenched resource crossings (e.g., reroute, conventional bore, HDD). The decision-making processes for selection of the HDD instead of an open cut crossing methodology is discussed thoroughly in the submitted alternatives analysis and was an important part of the overall PADEP approval of HDD plans as currently permitted. As described below, the open cut and re-route analyses have confirmed the conclusions reached in the previously submitted Alternatives Analysis.

HIGHWAY 15 CROSSING
PADEP SECTION 105 PERMIT NO. E21-449
PA-CU-0176.0019-RD-16
(SPLP HDD No. S2-0247-16)

Open-cut Analysis

Sunoco Pipeline, L.P. (SPLP) specifications require a minimum of 48-inches of cover over the installed pipelines. The Pennsylvania Department of Transportation (PennDOT) cover requirements under public roadways is 60-inches of cover. As discussed above, this HDD crosses under Highway 15, and an entry-exit interchange to Interstate 76. The profile of the HDD is bound by Highway 15 to the east, Interstate 76 to the south, and the interstate entry-exit interchange to Highway 15 to the west and north.

An open cut of the linear footage for the entire length of the HDD is not possible to due interruption it would cause to public users of the roadways. A subset of this length can be open cut as is discussed below.

Use of Conventional Auger Bore

Planning for a conventional bore must account for the extent or width of the feature (road, stream, etc.) being bored under, as well as the length and width of the setup-entry pit for setting the boring equipment within while operating, and the receiving pit through which the product pipeline is pulled back through after the boring machinery exits.

Based on experience gained during construction of the Mariner II Pipeline project, conventional auger bores should be limited to approximately 200 linear foot at a time, or less, varying by the underlying substrate. Conventional auger bores for the 20-inch pipeline, attempted at longer distances, have at times had alignment drift and elevation deflections occur which have complicated installation.

A conventional bore crossing of the interstate entry-exit roadways would require a bore of approximately 540 ft in length and is not a recommended action due to the nature of the soils and geology underlying the construction area.

Assuming PennDOT approval, a combination of conventional bore under Highway 15, an open cut of the grounds between Highway 15 and the interstate entry-exit, and a guided bore (or mini-HDD) under the interstate entry-exit is potentially feasible. This approach, however, would require a large permitted area of disturbance within the open lands between all the roadways along with a vehicle entry-exit to Highway 15 that could accommodate semi-truck/trailer use, and a truck turnaround area. The open land area would be used for pipe and equipment staging, equipment operations, worker parking, and receiving pits for the bore under Highway 15 and guided bore under the interstate entry-exit. Due to the logistics of traffic management on Highway 15, and since a large portion of the HDD footage would be replaced with a shallow guided bore or mini-HDD and risks associated with this construction method in a weak shallow zone between road surfaces; the impact to the public’s use of the roadways from construction traffic, and high probability of one or more IRs during the guided bore make this alternative undesired.

Re-Route Analysis

This HDD is set within an area bounded by public roadway and surrounding commercial development. There are no existing utility corridors to the north or south that provide a practical alternative route. Any alternate route considered to the north or south would require a significant deviation many miles in extent to avoid developments and establishment of a new “greenfield” corridor through existing agricultural land, woodlands, potentially encounter stream crossings, and possibly encroach on additional private residences before it could rejoin the current route.

In summary, due to the setting surrounding the overall route of the Mariner II pipelines in this area, there is no practical alternative route that could avoid conflicts with existing development. Since SPLP possesses no prior rights for multiple utility lines in any nearby existing corridor, nor any new corridor that could be developed, SPLP anticipates significant legal action to acquire a new easement.

This re-route analysis conducted for the Highway 15 HDD confirms the conclusions reached in the previously submitted alternatives analysis.

REVISED HORIZONTAL DIRECTIONAL DRILL DESIGN SUMMARY: 16-INCH

Additional geologic investigations have been completed, and the "as built" record for the 20-inch pipeline has been utilized in the redesign of the planned 16-inch HDD. The redesign adjusts the HDD profile deeper to minimize the risk of drilling fluid loss, drilling difficulties, and IRs. A summary of the redesign factors is provided below. The original and redesigned 16-inch HDD plan and profile drawings are provided in Attachment 2.

- Horizontal length: 1,985 ft
- Entry/Exit angle: 16 degrees
- Maximum Depth of cover: 135 ft
- Pipe design radius: 2000 ft

CONCLUSION

As shown on Figure 2, the redesigned HDD profile for the 16-inch pipeline increases the entry-exit angles to allow for a profile depth that is 42 ft deeper than the permitted design. The redesign of the HDD will not prevent all IRs. IRs are common on entry and exit of the drilling tool and other measures are required to minimize IR potential. In particular, upon the start of this HDD, SPLP will employ the following HDD best management practices:

- The drilling contractor, craft inspector, and monitoring geologists will be provided an orientation on the IR that occurred during drilling of the 20-inch pipeline installation, and the contractor will be required to utilize low drilling fluid pressure during pilot entry down to the bedrock face, and will monitor pilot tool progress on the exit radius to attempt to cut drilling fluid pressures immediately upon exiting out of bedrock into overburden;

- SPLP will mandate annular pressure monitoring during the drilling of the pilot hole, which assists in immediate identification of pressure changes indicative of loss of return flows or over pressurization of the annulus, to help manage development pressures that can induce an IR;

- SPLP inspectors will ensure that an appropriate diameter pilot tool, relative to the diameter of the drilling pipeline, is used to ensure adequate "annulus spacing" around the drilling pipeline exits to allow good return flows during the pilot drilling;

- SPLP will implement short-tripping of the reaming tools, as indicated by monitoring of return flows, to ensure an open annulus is maintained to manage the potential inducement of IRs;

- SPLP will require monitoring of the drilling fluid viscosity, such that fissures and fractures in the subsurface are sealed during the drilling process;

- During all drilling phases, the use of Loss Control Materials (LCMs) will be implemented upon detection of a Loss of Circulation (LOC) or indications of a potential IR are noted or an IR is observed. The use of LCMs, however, is less effective below 70 ft of the ground surface.

Accordingly, the preferred corrective action needed to address the presence of fractures or LOC at greater depths below ground will require grouting of the HDD annulus. Two types of grouting may be utilized for corrective actions to seal fractures. These are: 1) grouting using “neat cement”; and 2) grouting using a sand/cement mix. Neat cement grout is a slurry of Portland cement and water which is highly reactive to bentonite and induces solidification. The sand/cement grout mix is a slurry of mostly sand with a small percentage of Portland cement and activators that after setup results in a material having the competency of a friable sandstone or mortar. Both grouting actions require tripping out the drilling tool, and then tripping in with an open-ended drill stem to apply or inject the grout mixes. Either of these grouting actions may be implemented upon the first detection of an LOC with the selection of the treatment based upon the circumstances of the LOC, being small or large in magnitude.

HIGHWAY 15 CROSSING
PADEP SECTION 105 PERMIT NO. E21-449
PA-CU-0176.0019-RD-16
(SPLP HDD No. S2-0247-16)

FEASIBILITY DETERMINATION

Based on the information reviewed by the Geotechnical Evaluation Leader, Professional Geologists, Professional Engineers, and HDD specialists, the HDD Reevaluation Team's opinion is that the proposed HDD design and implementation of the management measures contained within this re-revaluation report will minimize the risk of IRs

Pertaining to Horizontal Directional Drilling Practices and Procedures; Conventional Construction; Alternatives; and Environmental Effects

Larry J. Gremminger, CWB
Vice President – Environmental
Geotechnical Evaluation Leader
Mariner East 2 Pipeline Project

2-28-2019
Date

Pertaining to the practice of geology

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3/1/2019
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Pertaining to the pipeline stress and HDD geometry

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HIGHWAY 15 CROSSING
PADEP SECTION 105 PERMIT NO. E21-449
PA-CU-0176.0019-RD-16
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ATTACHMENT 1

GEOLOGY AND HYDROGEOLOGICAL EVALUATION REPORT

RETTEW

We answer to you.

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Engineers

Environmental Consultants

Surveyors

Landscape Architects

Safety Consultants

March 1, 2019
Revised May 3, 2019

Mr. Matthew Gordon
Sunoco Pipeline, LP
535 Fritztown Road
Sinking Spring, PA 19608

RE: Sunoco Pipeline, LP Pipeline Project - Mariner East II
Highway 15 HDD (S2-0247), PA- CU-0176.0019-RD-16
Hydrogeological Re-Evaluation Report for the 16-inch Pipeline
Upper Allen Township, Cumberland County, Pennsylvania
RETTEW Project No. 096302011

EXECUTIVE SUMMARY

1. The Corrected Stipulated Order dated August 10, 2017, requires a re-evaluation of the Highway 15 horizontal directional drill (HDD) location S2-0247, including a geologic report. This HDD is listed as No. 10 of the HDDs in Exhibit 3. Due to the occurrence of an inadvertent return (IR) during HDD operations for the 20-inch pipeline, this hydrogeological report was also prepared to address the potential for IRs during the proposed 16-inch HDD operations.
2. The site is underlain by limestone of the Ordovician age Rockdale Run Formation (Orr). Geologic mapping, published reports, geophysical surveys, and field observations indicate steeply south-southeasterly dipping beds with regularly spaced jointing and fracturing with karst features.
3. Water-bearing zones generally occur in secondary openings along bedding planes, joints, faults, fractures and karst features. The permeability of these features is enhanced by dissolution of the limestone and dolomite bedrock.
4. Water-bearing zones in the Rockdale Run Formation are typically within 200 feet of the ground surface. 91 groundwater yielding zones are reported within the Rockdale Run Formation, with 58 of them being at depths of less than 100 feet and only seven occur below 250 feet. The calculated median sustained groundwater yield for the formation is 405 gallons per minute.
5. The HDD profile for the permitted 16-inch drill has been redesigned to increase the amount of cover under Highway 15.
6. Based on the hydro-structural characteristics of the underlying geology, results of the geotech investigations, geophysical survey, and the occurrence of an IR during the installation of the 20-inch pipeline pilot hole, the Highway HDD is susceptible to an IR of drilling fluid during HDD operations for the planned 16-inch drill. The redesigned 16-inch HDD profile along with engineering controls and proactive HDD best management practices during drilling operations will be used to reduce the risk of an IR.

1.0 INTRODUCTION

The purpose of this report is to describe the geologic and hydrogeologic setting of the Highway 15 S2-0247 horizontal directional drill (HDD) location on the Sunoco Pipeline, LP (SPLP) Pennsylvania Pipeline Project - Mariner East II (PPP-ME2) Project. The Highway 15 HDD is located in Upper Allen Township, Cumberland County, Pennsylvania as shown on **Figure 1**. The HDD will be drilled under the Pennsylvania Turnpike (Interstate 76) and Highway (State Route) 15. This re-evaluation report is part of the response to the Corrected Stipulated Order dated August 10, 2017 related to the potential for IRs of drilling fluids during proposed drilling operations. This re-evaluation report was also prepared as a result of an IR that occurred on June 27, 2017, as the 20-inch pilot hole was being advanced.

The original 16-inch HDD profile was redesigned on January 30, 2019. The overall boring length of the proposed HDD was increased and the inclination of the entry and exit angles has been increased to increase the amount of cover at the location of the June 27, 2017 IR and to install the boring into bedrock quicker than the original, shallower profile. The redesigned western HDD entry/exit is at a surface elevation of approximately 428 feet above mean sea level (AMSL) and the redesigned eastern entry/exit is at an elevation of approximately 452 feet AMSL. The inclination of the eastern and western entry/exit angles has been increased to 16° to install the pipe through the soils and bedrock in closer proximity to the entry and exit points, and to deepen the profile to approximately 89 feet at Highway 15 (approximately 25 feet deeper than the 20-inch pipe) and 85 feet at the June 27, 2017 IR location. The horizontal length and the boring/pipe length are 1,985 and 2,010 feet, respectively. The locations of the as-built 20-inch and proposed 16-inch, Highway 15 HDD locations are shown on **Figure 1**, and the redesigned 16-inch profile detail is included as **Attachment 1.**

2.0 GEOLOGY AND SOILS

Based upon publications by the Pennsylvania Bureau of Topographic and Geologic Survey (PABTGS), the site is in the Great Valley Section of the Ridge and Valley Physiographic Province of Pennsylvania and is underlain by very finely crystalline limestone with minor occurrences of dolomite and chert. Local topography is characterized by rolling valleys of low relief and natural slopes that are gentle and relatively stable. Geologic structures are characterized as thrust sheets, nappes, overturned folds and steeply inclined faults (Sevon, 2000). Areas underlain by these rock units typically have good subsurface drainage and poor surface drainage where bedrock dissolution results in the development of bedrock pinnacles and solution cavities (e.g., sinkholes, voids, caves). Based on the United States Geological Survey (USGS) 7.5-Minute Mechanicsburg and Lemoyne Topographic Quadrangle Maps as shown on **Figure 1**, the site is situated at an approximate elevation of 460 to 440 feet AMSL. Surface topography at the site generally slopes towards the north/northeast towards the un-named tributary to Cedar Run Run. The major surface water feature is the unnamed tributary to Cedar Run that flows northeast to Cedar Run which ultimately discharges into Yellow Breeches Creek.

The site geology for the redesigned 16-inch HDD profile is mapped as the Orr as shown on **Figure 2**. The Rockdale Run Formation contains a very light gray, very fine-grained pure limestone in the lower part of the formation, while the middle and upper portions of the formation consist mostly of light-gray limestone, commonly containing abundant fine carbonate grains and fossil fragments. Dolomite are sparsely distributed throughout the formation but are primarily concentrated towards the top of the unit (Becher and Root, 1981). The formation also contains lenses of pink to brown chert and white quartz rosettes are found near the top of the formation.

The lower third of the formation is medium bedded, while the upper two thirds are thickly bedded. Joints tend to have a blocky pattern, are moderately well developed, moderately abundant, and regularly spaced. Fractures in the formation tend to have a moderate distance between them, are open and steeply dipping. The Rockdale Run Formation tends to be moderately resistant to weathering and is moderately weathered to a deep depth. The weathered product consists of irregular and blocky-shaped fragments resulting from prolonged weathering. The overlying mantle is moderately thick and in most places the bedrock-mantle interface is characterized by bedrock pinnacles. From an engineering stand point, the formation is considered difficult to excavate, due to the degree and extent of bedrock pinnacle development, while drilling rates are expected to be fast but may be slowed by chert and quartz lenses. Cut slope stability is good, provided solution opening and local intense pinnacle development are investigated. Subsurface drainage is good but there is little surface drainage. Secondary porosity provided by interconnections between joints and solution cavities is moderate to high in magnitude; while permeability for the formation is low to moderate (Geyer and Wilshusen, 1982).

According to the United States Department of Agriculture (USDA) (2018) Soil Survey of Cumberland County, Pennsylvania, soils in the vicinity of the Highway 15 HDD consist of eight separate soil units. A USDA soils map depicting the mapped area, along with the soil profile descriptions, is included as **Attachment 2**.

3.0 HYDROGEOLOGY

Groundwater at the site occurs in a fractured, solution-prone, carbonate bedrock aquifer system within the Rockdale Run Formation. In carbonate rocks, water-bearing zones generally occur in solution-enhanced secondary openings that form along bedding planes, joints, faults and fractures. Most of the water-bearing zones penetrated by supply wells occur in individual fractures or groups of interconnected fractures that are sufficiently enlarged by dissolution of bedrock to provide pathways for the transport of groundwater.

Groundwater flow paths within the karstic limestone beneath the site have both local and regional components. Locally, shallow groundwater discharges to the gaining portions of nearby streams and deeper regional groundwater flow is toward points of regional groundwater discharge such as the Susquehanna River. Groundwater divides may be different for each zone of groundwater flow and, therefore, may not coincide with surface water divides. Based on our review of available reference sources, no regional water table mapping is available for the site or surrounding area. As a result, no water table mapping was available for review or inclusion with this HDD re-evaluation report.

The median depth of water supply wells in the Rockdale Run Formation is reported to be 82 feet bgs with a median depth to water of 30 feet bgs. A medium specific capacity of 12 gallons per minute (gpm) per foot was calculated from 43 water supply wells in the Rockdale Run Formation. This medium specific capacity is nearly double that of the other carbonate aquifers within the Cumberland Valley, with the exception of the Tomstown Formation. The calculated median sustained yield of 405 gpm attributed to well-developed fractures and solution openings. Sustained yields of 500 gpm and 600 gpm are the reported maximum yields for this formation. Of the 91 yielding zones reported within the Rockdale Run Formation, 58 are at depths of less than 100 feet and only seven occur below 250 feet. No large specific-capacity or high-yielding wells produce from zones below 200 feet (Becher and Root, 1981).

Well records for 8 individual water supply wells within a 0.5-mile radius of the Highway 15 HDD were obtained from the Pennsylvania Groundwater Information System (PaGWIS). The well locations are shown on **Figures 2** and **3**. Well construction details were not reported for all of the wells; however, the majority of the identified wells were completed as 6-inch-diameter open-rock wells with total depths ranging from 200 to 280 feet bgs. Reported well yields range from 5 to 150 gpm, while the reported water levels ranged from 21 to 54 feet bgs. The information obtained from these well records is summarized in the following table:

Well No.	Well Use	Casing Depth (feet)	Total Depth (feet)	Water Level (feet)	Yield (gpm)
99126	DOMESTIC	63	280	40	5
99108	DOMESTIC	NOT REPORTED	NOT REPORTED	21	NOT REPORTED
99023	INSTITUTIONAL	64	200	54	150
561774	DOMESTIC	NOT REPORTED	NOT REPORTED	NOT REPORTED	NOT REPORTED
561772	DOMESTIC	NOT REPORTED	NOT REPORTED	NOT REPORTED	NOT REPORTED
561770	DOMESTIC	NOT REPORTED	NOT REPORTED	NOT REPORTED	NOT REPORTED
262303	IRRIGATION	105	250	43	24
17095	DOMESTIC	NOT REPORTED	NOT REPORTED	21.4	NOT REPORTED

In January 2019, other Sunoco subcontractors provided a map depicting the locations of researched private water supplies located within a 450-foot radius of the Highway 15 HDD. No private water supply wells were identified within the 450-foot radius as shown on **Attachment 3**. However, one private water well was identified approximately 876 feet southeast of the eastern HDD entry/exit point. No specific information pertaining to the total depth, depth to water or pump depth could be obtained.

4.0 FRACTURE TRACE ANALYSIS

Fracture traces underlying, or in close proximity to, the Highway 15 HDD were evaluated using historical aerial photographs from the years 1993 through 2016 (Google Earth, 2019), the Mechanicsburg and Lemoyne, PA USGS 7.5 Minute Quadrangle Topographic Map and the Geologic Map of the Mechanicsburg Quadrangle (Root, 1978) and the Geologic Map of the Harrisburg West Area (Root, 1977). The aerial photographs and maps were used to approximate locations of natural linear features or lineaments expressed on the ground surface. The linear features may be the surficial representation of deeper fractures, joints, faults or bedding planes within the subsurface which can transmit groundwater through the fractured bedrock aquifer underlying the Highway 15 HDD.

Figures 2 and **3** show the results of the fracture trace analysis overlain on the geologic map and aerial base map, respectively. Three fracture traces were identified in close proximity to the proposed Highway 15 HDD. Two of the fracture traces trend approximately north/northeast-south/southwest, parallel to geologic strike. The remaining fracture trace, which is almost perpendicular to and intercepting the other two fracture traces, trends east-west.

5.0 GEOTECHNICAL EVALUATION

Two geotechnical drilling investigations were performed at the Highway HDD site. The initial investigation was performed in February and April, during the preliminary investigation for the Highway 15 HDD and prior to initiating the 20-inch HDD operations. A second phase of geotechnical drilling was performed in September of 2017. The 2015 test borings were advanced by hollow-stem auger drilling to auger refusal or a maximum depth of 30 feet bgs was reached. NQ-sized wireline rock coring was utilized in the boring that was advanced past auger refusal. These borings are designated as SB-01, SB-02 and SB-03. The second phase test borings completed in 2017 were advanced using hollow-stem auger drilling and NQ-sized wireline rock coring methods. The 2017 borings were designated as B-01 and B-02. Soil, residual soil and weathered bedrock collected during both investigations were sampled using split-spoon sampling techniques. Geotechnical boring logs are included in **Attachment 1**.

Boring SB-01 was located approximately 200 feet northeast of the HDD entry point near the western end of the profile. Boring SB-02 was located approximately 1,100 feet southeast of the HDD entry point (in the parking lot of the Cracker Barrel Restaurant) and near the midpoint of the profile. Boring SB-03 was located approximately 150 feet north of the exit point near the eastern end of the profile. Boring B-01 was located approximately 100 feet northeast of the HDD entry point and B-02 was located approximately 75 feet north of the HDD exit point. The locations of the borings are identified on **Figure 2** and **Figure 3.**

The generalized subsurface profile at the site, as observed in the borings, is described as follows:

- Residual soil depths vary boring from boring; 30.0 feet bgs at SB-01, 13.9 feet bgs at SB-02, 12.1 feet bgs at SB-03, 10.0 feet bgs at B-01, and 10.5 feet bgs at B-02. The residual soils are described as follows:
    - **Boring SB-01**: Topsoil, mottled silty CLAY (CL) and fine sand, trace unweathered fine rock fragments; silty CLAY (CL) with some fine sand, soft. The boring was terminated at 30.0 feet bgs. Groundwater was not encountered in the boring.
    - **Boring SB-02**: Topsoil, mottled silty CLAY (CL) and fine sand, trace fine gravel, silty CLAY (CL), gray partially weathered LIMESTONE. Auger refusal was encountered at 14.0 feet bgs. Groundwater was not encountered in the boring.
    - **Boring SB-03**: Topsoil, CLAY (CH) of high plasticity, trace fine limestone fragments, gray LIMESTONE fragments. Auger refusal was encountered at 12.0 feet bgs. Groundwater was not encountered in the boring.
    - **Boring B-01**: Medium stiff, SILT (ML) with sand, moist to moist/wet, highly weathered LIMESTONE. Split spoon refusal occurred at 10 feet bgs and the remainder of the boring was cored with NQ-sized wireline rock coring methods. Groundwater was encountered at 7.8 feet bgs.
    - **Boring B-02:** Probable fill consisting of lean CLAY (CL) with sand, trace gravel, moist, medium dense, clayey SAND (SC) with gravel, moist/wet, very soft, lean CLAY (CL) trace sand,

moist/wet, very loose, clayey GRAVEL (GC) with sand, moist/wet, highly weathered gravel sized LIMESTONE fragments. Casing refusal occurred at 10.3 feet bgs and the remainder of the boring was cored with NQ-sized wireline rock coring methods. Groundwater was not encountered in the residual soil.

- At depths of auger or split-spoon refusal, and to the total depth of the NQ cores, weathered bedrock and bedrock were encountered and are described as follows:
  - **Boring SB-01:** Rock coring was not completed at this location.
  - **Boring SB-02:** Boring SB-02 was completed to a total depth of 21.4 feet bgs. From 14.0 to 21.4 feet, light gray, moderately to intensely fractured LIMESTONE with calcite was encountered. Rock recoveries ranged from 92% to 100% and Rock quality designations (RQDs) ranged from very poor (13) to poor (49).
  - **Boring SB-03:** Rock coring was not completed at this location.
  - **Boring B-01:** B-01 was completed to a total depth of 85.0 feet bgs. From 10.0 to approximately 24 feet bgs, light-gray to black, very fine-grained, slightly weathered, very broken to massive, hard to very hard LIMESTONE was encountered. Rock recoveries were 100% and RQDs ranged from 97 to 100 (excellent). From approximately 24 to 30.0 feet bgs, gray to dark gray, very fine-grained, slightly weathered, massive, very hard DOLOMITE was encountered. Rock recovery was 98% and RQD value was excellent (98). From 30.0 to 85.0 feet bgs, light gray to black, very fine-grained slightly weathered, very broken to massive, hard to very hard LIMESTONE was encountered. A broken seam (approximately 1.5-inch thick) was observed at 54.2 feet bgs., and an approximately 2.5-inches thick weathered seam was observed at 62.5 feet bgs. A nearly vertical fracture was observed at 70.2 feet bgs. Rock recoveries were 100% and RQD values ranged from good (82) to excellent (100). Groundwater was observed at a depth of 17.3 feet at the completion of coring operations.
  - **Boring B-02:** B-02 was completed to a depth of 110.0 feet bgs. From 10.5 feet bgs to approximately 31 feet bgs, light gray to black, very fine-grained, slightly weathered, broken to massive, moderately hard to very hard LIMESTONE with trace calcite stringers was encountered. A weathered fracture was observed at 11.9 feet bgs. Rock recoveries ranged from 81% to 100% and the RQDs ranged from good (81) to excellent (100). From approximately 31 to 34.5 feet bgs, light gray to dark gray, very fine grained, slightly weathered, very broken to massive, hard to very hard DOLOMITE with trace calcite stringers was encountered. From 34.5 to 57.5 feet bgs, light gray to black, very fine grained, slightly weathered, broken to massive, moderately hard to very hard, LIMESTONE with trace calcite stringers was observed. An approximately 2.25-inch thick broken seam was observed at 42.7 feet bgs, while a weathered seam, approximately 2-inch thick, was observed at 47.8 feet bgs. From 57.5 feet bgs to 110.0 feet below bgs, alternating layers of LIMESTONE and DOLOMITE, as previously described, were observed. Broken layers ranging in thickness from 4- to 4.5-inches thick were observed at 59.5, 92.2 and 103.3 feet bgs, while approximately 2.25-inch thick broken seams were observed at 71.7 and 104.5 feet bgs. A vertical fracture was observed from 87.1 to 87.8 feet bgs. Rock recoveries were 100% and RQD values ranged from fair (73) to excellent (100). Groundwater was observed at 27.8 feet bgs at the completion of coring operations.

Unconfined compressive strength testing was performed on the core samples, and these testing results are summarized in the table below.

Boring	Sample Depth (feet bgs)	Compressive Strength (pounds per square inch)
SB-02	19.0	13,320
Boring	**Sample Depth (feet bgs)**	**Compressive Strength (tons per square foot)**
B-01	11	495.04
B-01	22.1	552.79
B-01	28.4	1319.18
B-01	34.9	301.38
B-01	40.6	695.34
B-01	57	503.52
B-01	67.4	564.48
B-01	78.2	290.38
B-02	11.1	546.32
B-02	21.5	666.23
B-02	31.7	853.51
B-02	40.8	229.87
B-02	47.5	1336.64
B-02	58.7	992.64
B-02	67.8	578.50
B-02	79.9	513.45
B-02	88.5	668.55
B-02	102.6	791.47

Please note that RETTEW Associates, Inc. (RETTEW) and Skelly and Loy did not oversee or direct the geotechnical drilling program associated with the Highway 15 HDD including, but not limited to, the selection of boring locations and target depths, observations of rock cores during drilling operations, or preparation of boring logs. The geotechnical reports, boring logs, and core photographs that resulted from these programs were generated by other Sunoco Pipeline, L.P. contractors. RETTEW and Skelly and Loy relied on these reports and incorporated the data into the general geologic and hydrogeologic framework included in this report.

6.0 GEOPHYSICAL SURVEY

RETTEW completed a multi-technique geophysical survey at the Highway 15 HDD site from November 12-20, 2018, and the report is included as **Attachment 4**. The purpose of the survey was to provide supplemental information to the geotechnical investigations to aid in detecting and delineating subsurface voids or low-density zones beneath three portions of the HDD path that could increase the risk of IRs and/or a loss of returns, and to determine the rock profile and rock rippability for ease-of-excavation.

Four different geophysical techniques were utilized to detect and delineate subsurface voids or low-density zones and to develop a rock profile. These analytical methods, and their general results are summarized as follows:

- A microgravity survey delineated low-density zones throughout the three survey areas. These zones could represent minor karst-related air-, water-, or mud-filled voids, or locally deeper rock and thicker soils.
- A seismic refraction survey confirmed the presence of an irregular bedrock surface or “epikarst” zone.
- A multi-spectral analysis of surface waves survey identified low-velocity zones above (soft soils) and below (possible voids) the bedrock surface.
- An electrical resistivity imaging survey identified conductive features which could represent fractures or wet soils in each of the three areas.

Results from these geophysical techniques are consistent with each other, and with the geology as mapped by the PA Geological Survey, all suggesting that the local bedrock (limestone) is karstified, with potential concentrations of dissolution cavities (of various sizes) indicated by the geophysical anomalies detected. In the limestone, the top-of-rock is expected to be pinnacled (highly irregular) with interfingered competent rock and residual clay soil as well as potential bedrock voids.

7.0 FIELD OBSERVATIONS

RETTEW staff were on-site during all 20-inch HDD operations which began on June 12, 2017. An IR occurred while the pilot hole was being advanced on June 27, 2017 with drilling fluid surfacing in the northbound lanes of Highway 15 at the location shown on **Figures 2 and 3** and identified on the profile included as **Attachment 1**. The events that occurred during the 20-inch HDD pipeline installation are summarized below.

- **June 12, 2017:** Michels Directional Crossings (Michels) spudded in the 20-inch pilot hole from the western entry/exit point.
- **June 19, 2017:** Michels reported a partial loss of circulation (LOC) at a trajectory length of 673 feet. Michels began to trip out drill rods and swab the boring, in conjunction with increasing the drilling fluid viscosity. After tripping out four drill rods, full circulation was regained, and pilot hole advancement was resumed.
- **June 24, 2017:** Michels reported a LOC at an approximate trajectory length of 1,525 feet and tripped out/swabbed the boring in an effort to regain full circulation. After regaining full circulation Michels began to trip the pilot bit back to the face of the boring.
- **June 26, 2017:** After tripping the pilot bit back to the face of the boring and resuming pilot hole advancement, Michels reported LOCs for the rest of the day ranging from 50% to 90% losses.

- **June 27, 2017:** Michels regained full circulation and continued to advance the pilot bit from an approximate trajectory length of 1,587 feet. At a trajectory length of 1,768.49 feet and a depth of approximately 32 feet, an IR was observed in the northbound lanes of Highway 15. All drilling activities were immediately suspended and after traffic control was established, cleanup efforts were initiated.
- **June 28 – July 3, 2017:** Michels tripped out of the boring and mobilized the drill rig to the eastern end of the profile to initiate an intercept boring.
- **July 5, 2017:** Michels completed rigging up the drill rig and initiated an interceptor boring from the eastern end of the HDD profile.
- **July 7, 2017:** Michels reports loss of drilling returns ranging from a full loss of returns (LOR) to 50% loss of drilling fluids. Pilot bit reaches trajectory length for intercept, but appeared to be too deep. Michels began efforts to adjust borehole to the proper depth for intercept.
- **July 8, 2017:** Michels appeared to have encountered a void at an approximate trajectory length of 1,722 feet and a depth of 40 feet. Michels tripped out to an approximate trajectory length of 100 feet and a depth of 19 feet to re-orient the boring to make another attempt at intersecting the pilot hole from the western end of the profile.
- **July 13, 2017:** Michels completed intercept of the eastern and western pilot borings and tripped drill rods through the boring to initiate the reaming phase.
- **July 15, 2017:** Michels initiated the 30-inch ream pass from the western end of the boring (pull ream). A 20% to 25% LOC was observed after the reamer had been advanced to an approximate trajectory length of 70 feet. No IRs were observed.
- **July 16 – July 25, 2017:** Michels continued the 30-inch ream to a trajectory length of 764.2 feet on July 25th, 2017 when all HDD activities across the MEII Project were suspended pending legal action.
- **August 28, 2017:** Michels resumed the 30-inch reaming phase and advanced the reamer to a trajectory length of 864.8 feet.
- **August 29, 2017:** Michels reported a LOC of approximately 20% to 30% and suspended reaming until an IR survey/patrol was completed. When no IR was observed Michels resumed the 30-inch ream and increased the viscosity of the drilling fluid to regain full circulation.
- **August 30, 2017:** Michels reported a full LOR and suspended drilling until an IR survey/patrol could be completed. Michels tripped the 30-inch reamer out of the boring to fully clear the borehole of cuttings when no IRs were observed.
- **August 31 – September 1, 2017:** Michels continued to trip the 30-inch reamer in and out of the borehole.
- **September 2, 2017:** Michels resumed the 30-inch ream pass.
- **September 5 – 8, 2017**: Michels advanced the 30-inch reamer from an approximate trajectory length of 985 to 1,327 feet.
- **September 9, 2017:** Michels reported a full LOR at a trajectory length of 1,407 feet.
- **September 11 – 13, 2017:** Michels tripped the 30-inch reamer in and out of the boring in conjunction with a clean out tool to remove cuttings that had accumulated in the borehole.
- **September 14, 2017:** Michels resumed the 30-inch ream pass from the eastern end of the boring (push ream).

- **September 15 – 21 2017:** Michels continued the 30-inch ream pass.
- **September 22, 2017:** Michels completed the 30-inch ream pass and initiated the 30-inch swab pass.
- **September 23, 2017:** Michels completed the first swab pass and initiated the second and final swab pass.
- **September 25, 2017:** Second swab pass was completed.
- **September 26, 2017:** The 20-inch product pipe pull was completed.

A field investigation was performed by RETTEW staff on February 19, 2018, to identify rock outcrops for fracture fabric analysis, evaluation and ground-truthing of fracture traces identified during the desktop exercise, to collect additional bedrock strike and dip measurements to accompany published data, and to identify potential sensitive receptors to IRs. Readily accessible bedrock outcrops were not observed. No additional sensitive receptors to IRs were identified during the site reconnaissance.

8.0 CONCEPTUAL HYDROGEOLOGIC MODEL AND CONCLUSION

Based on published geologic and hydrogeologic information, results of geotechnical investigations, geophysical surveys, and field observations during completion of the 20-inch HDD, the Highway 15 HDD site is underlain by slightly weathered limestone and dolomite of the Rockdale Run Formation. The hydrogeologic setting is dominated by groundwater flow in secondary openings along geologic features including bedding planes, fractures, and joints. In this formation, secondary openings may be enlarged by solutioning to form karst features (e.g., pinnacled bedrock, sinkholes). Water-bearing zones in the Rockdale Run Formation are typically within 200 feet of the ground surface. 91 groundwater yielding zones are reported within the Rockdale Run Formation, with 58 of them being at depths of less than 100 feet and only seven occur below 250 feet. Geotechnical core observations indicate that the uppermost bedrock along the proposed 16-inch HDD profile is slightly weathered and fractured.

The originally proposed 16-inch HDD profile was relatively shallow at the western entry and eastern exit points and passed through both the unconsolidated overburden and fractured bedrock for an extended period. Based on the hydro-structural characteristics of the underlying geology described in this report and the previous occurrence of an IR during installation of the 20-inch pipe, the Highway 15 HDD site is susceptible to an IR of drilling fluids during HDD operations. As a result, the 16-inch HDD profile was redesigned to allow for deeper crossings beneath Highway 15 and the location of the June 27, 2017 IR. The revised 16-inch HDD profile is approximately 89 and 85 feet beneath Highway 15 and the IR location (approximately 24 feet deeper than the as-built 20-inch pipe), respectively. The inclination of the eastern and western entry angle was increased to allow the pipe to be installed through protective soils, residual soils, and bedrock, and in closer proximity to the entry point than the original profile. From a geologic perspective, the deeper profile, in conjunction with the proposed proactive engineering controls and drilling best management practices (BMPs), will be used to reduce the risk of an IR and/or a loss of drilling fluid. Drilling BMPs are described in the Horizontal Directional Drill Analysis component of the overall re-evaluation package.

9.0 REFERENCES

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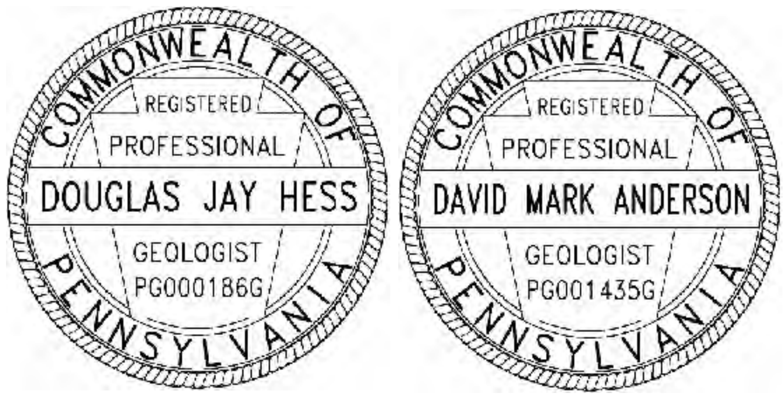
10.0 CERTIFICATION

The studies and evaluations presented in this report (other than Section 5.0) were completed under the direction of a licensed professional geologist (PG) and are covered under the PG seals that follow.

By affixing my seal to this document, I am certifying that, to my knowledge and belief, the information herein is true and correct. I further certify, that I am licensed to practice in the Commonwealth of Pennsylvania and that it is within my professional expertise to verify the correctness of the information herein.

Douglas J. Hess, PG
License No. PG000186G

David M. Anderson, PG
License No. PG001435G



Enclosures

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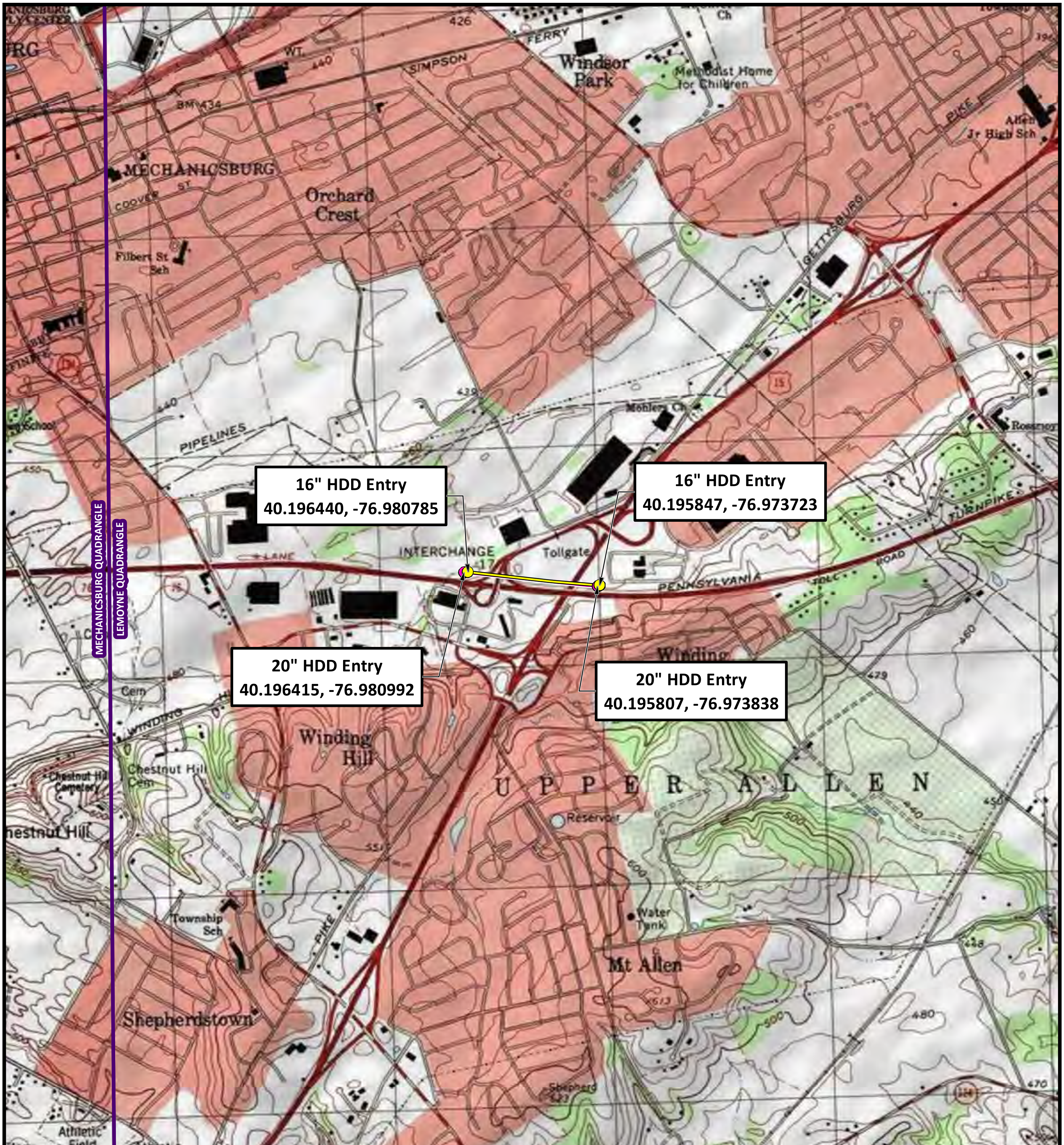
RETTEW

FIGURES



16" HDD Entry/Exit

20" HDD Entry/Exit

16" HDD Profile

20" HDD Profile

Lemoyne, PA USGS 7.5' Topographic Quadrangle 2/21/2019

Sunoco Pipeline, L.P.

Highway 15 HDD Location

Figure 1 - Topographic Basemap

Upper Allen Township, Dauphin County, PA

Project No. 096302011

0 2,000 Feet

1 inch = 2,000 feet

Service Layer Credits: Copyright:© 2013 National Geographic Society, i-cubed

Sunoco Logistics Partners L.P.

RETTEW

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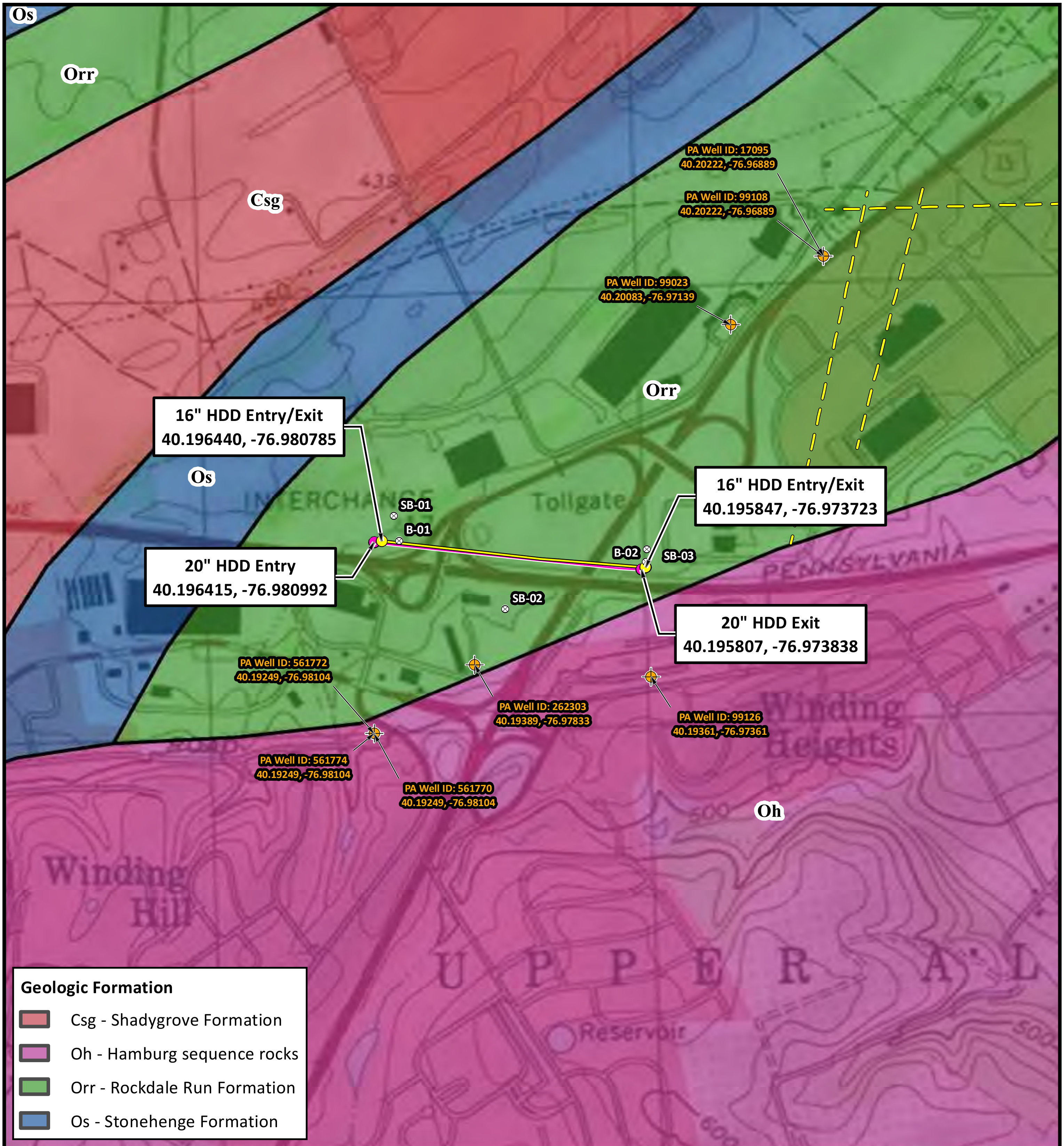

Residential Well
Soil Boring
16" HDD Entry/Exit
20" HDD Entry/Exit
16" HDD Profile
20" HDD Profile
Inferred Fracture Trace

Sunoco Pipeline, L.P.

Highway 15 HDD Location

Figure 2 - Geologic Map

Upper Allen Township, Dauphin County, PA
Project No. 096302011

0 1,000 Feet
1 inch = 1,000 feet

Service Layer Credits: Copyright:© 2013 National Geographic Society, i-cubed

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Lemoyne, PA USGS 7.5' Topographic Quadrangle

2/20/2019

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▲	Inadvertent Return	—	20" HDD Profile
⊕	Residential Well	- -	Inferred Fracture Trace
⊗	Soil Boring	—	NHD Stream
●	16" HDD Entry/Exit	—	Road
●	20" HDD Entry/Exit	▭	Municipal Boundary
—	16" HDD Profile		

2/21/2019

Sunoco Pipeline, L.P.

Highway 15 HDD Location

Figure 3 - Aerial Basemap

Upper Allen Township, Dauphin County, PA
Project No. 096302011

N E S W

0 1,000 Feet

1 inch = 1,000 feet

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Sunoco Logistics Partners L.P.

RETTEW

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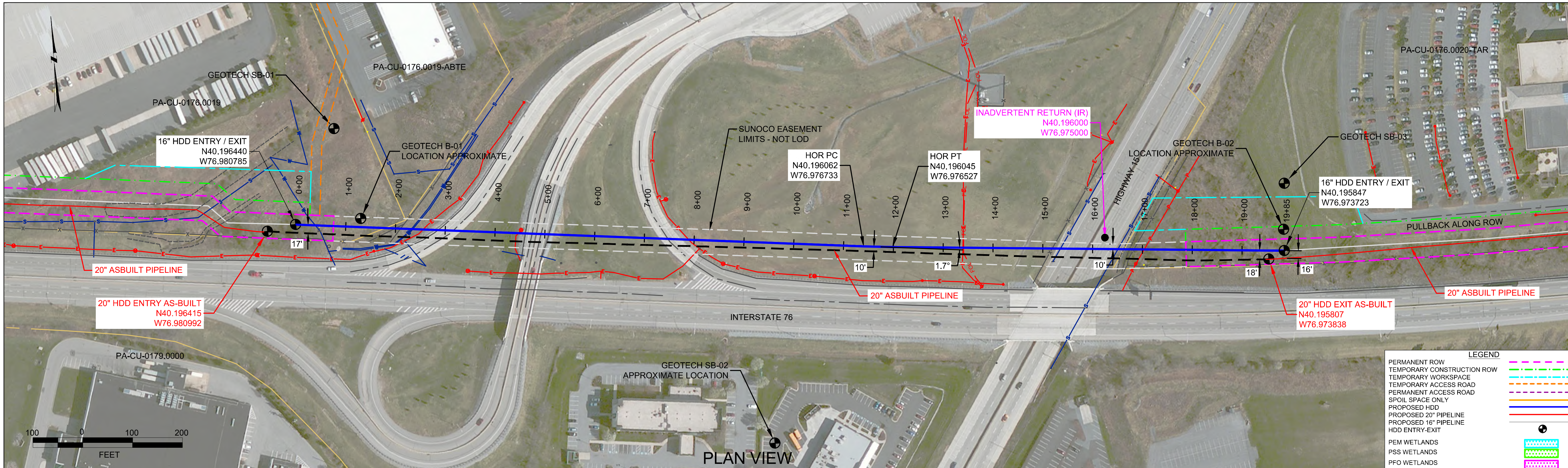
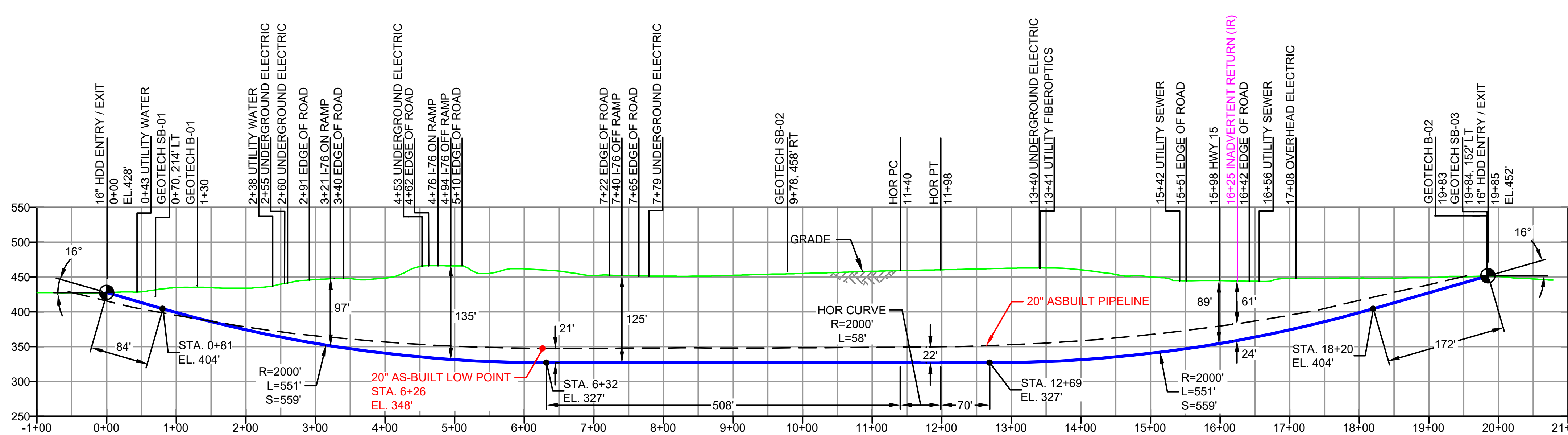
ATTACHMENT 1
HDD PROFILES AND GEOTECHNICAL BORING LOGS



CUMBERLAND COUNTY PENNSYLVANIA, UPPER ALLEN TOWNSHIP
S2-0247-16

PROFILE VIEW



GEOTECH SB-01

- NG EL. 422'
- TOPSOIL (0' - 0.3')
- CL (0.3' - 30.0')
- COMPLETION DEPTH EL. 392'

GEOTECH SB-02

- NG EL. 458'
- TOPSOIL (0' - 0.3')
- CL (0.3' - 13.5')
- WEATHERED LIMESTONE (13.5' - 13.9')
- AUGER REFUSAL (14.0')
- FRACTURED LIMESTONE (14.0' - 21.4')
- COMPLETION DEPTH EL. 437'

GEOTECH SB-03

- NG EL. 445'
- TOPSOIL (0' - 0.3')
- CLAY / LIMESTONE FRAGMENTS (USCS:CH) (0.3' - 12.0')
- LIMESTONE FRAGMENTS (12.0' - 12.1')
- AUGER REFUSAL (12.0')
- COMPLETION DEPTH EL. 433'

NOTE: REFER TO TEST BORING LOG S2-0247 FOR COMPLETE SOIL MATERIAL DESCRIPTION

GEOTECH B-01

- NG EL. 437'
- RESIDUUM SILT ML (0.0' - 8.5')
- GROUNDWATER (17.3')
- HIGHLY WEATHERED LIMESTONE (8.5' - 10.0')
- LIMESTONE/DOLOMITE (10.0' - 85.0')
- BORING TERMINATED EL.352'

NOTE: REFER TO TEST BORING LOG B-01 INTERTEK PROJECT #04911465 FOR COMPLETE SOIL MATERIAL DESCRIPTION

GEOTECH B-02

- NG EL. 449'
- PROBABLE FILL CL (0.0' - 2.5')
- RESIDUUM CLAYEY SAND SC (2.5' - 6.5')
- RESIDUUM CLAY CL (6.5' - 9.75')
- RESIDUUM CLAYEY GRAVEL GC (9.75' - 10.5')
- GROUNDWATER (27.8')
- LIMESTONE/DOLOMITE (10.5' - 111.0')
- BORING TERMINATED EL.338'

NOTE: REFER TO TEST BORING LOG B-02 INTERTEK PROJECT #04911465 FOR COMPLETE SOIL MATERIAL DESCRIPTION

DESIGN AND CONSTRUCTION:

1. CONTRACTOR SHALL FIELD VERIFY DEPTH OF ALL EXISTING UTILITIES SHOWN OR NOT SHOWN ON THIS DRAWING.
2. THE MINIMUM SEPARATION DISTANCE FROM EXISTING SUBSURFACE UTILITIES SHALL NOT BE LESS THAN 10 FEET AS MEASURED FROM THE OUTSIDE EDGE OF THE UTILITY TO OUTSIDE OF PROPOSED PIPELINE.
3. DESIGNED IN ACCORDANCE WITH CFR 49 195 & ASME B31.4
4. CROSSING PIPE SPECIFICATION:
   HDD HORZ. LENGTH (L=): 1985'
   HDD PIPE LENGTH (S=): 2010'
   16" x 0.438" W.T., X-70, API5L, PSL2, ERW, BFW
   COATING: 14-16 MILS FBE WITH 30-35 MIL ARO (POWERCRETE OR ENGINEER APPROVED EQUAL)
5. INTERNAL DESIGN PRESSURE 2100 PSIG (SEAM FACTOR 1.0, DESIGN FACTOR 0.50).
6. INSTALLATION METHOD: HORIZONTAL DIRECTIONAL DRILL (HDD).
7. PIPELINE WARNING MARKERS SHALL BE INSTALLED ON BOTH SIDES OF ALL ROAD, RAILWAY, AND STREAM CROSSINGS.
8. CARRIER PIPE NOT ENCASED.
9. PIPE / AMBIENT TEMPERATURE MUST BE NO LESS THAN 30°F DURING PULLBACK WITHOUT PRIOR WRITTEN APPROVAL FROM THE ENGINEER.
10. CONDUCT 4-HOUR PRE-INSTALLATION HYDROTEST OF HDD PIPE STRING TO MINIMUM 2625 PSIG.
11. SEE SUNOCO PENNSYLVANIA PIPELINE PROJECT ESRI WEBMAP FOR ACCESS ROAD ALIGNMENT.
12. SUNOCO PIPELINE, L.P.'S HORIZONTAL DIRECTIONAL DRILL INADVERTENT RETURN CONTINGENCY PLAN WILL BE IMPLEMENTED AT ALL TIMES.
13. SUNOCO PIPELINE, L.P.'S EROSION AND SEDIMENTATION CONTROL PLAN WILL BE IMPLEMENTED AT ALL TIMES.

NOTES

1. ALL COORDINATES SHOWN ARE IN LATITUDE AND LONGITUDE. ALL MSL ELEVATIONS ARE NAD83
2. STATIONING IS BASED ON HORIZONTAL DISTANCES.
3. ROONEY ENGINEERING, INC. AND SUNOCO PIPELINE, LP ARE NOT RESPONSIBLE FOR LOCATION OF FOREIGN UTILITIES SHOWN IN PLOT PLAN OR PROFILE. THE INFORMATION SHOWN HEREON IS FURNISHED WITHOUT LIABILITY ON THE PART OF ROONEY ENGINEERING, INC. AND SUNOCO PIPELINE, LP, FOR ANY DAMAGES RESULTING FROM ERRORS OR OMISSIONS THEREIN.
4. CONTRACTOR IS RESPONSIBLE FOR LOCATING ALL UTILITIES. CONTACT ONE CALL AT 811 PRIOR TO DIGGING.
5. SUNOCO EMERGENCY HOTLINE NUMBER IS #1-800-786-7440.

REF. DRAWING

DWG NO		DWG NO	DESCRIPTION
ES-4.89	TO	ES-4.90	EROSION & SEDIMENT PLAN
SHEET 54	TO	SHEET 54	AERIAL SITE PLAN

REVISIONS

NO.	DESCRIPTION	BY	DATE	CHK	DATE	APP	DATE
EP3	DESIGN CHANGE - LOWERED DRILL AND ADDED GEOTECH	MRS	01/30/19	RMB	01/30/19	AMC	01/30/19
EP2	REVISED PER PADEP COMMENTS RECEIVED 09-06-16	MRS	10/07/16	RMB	10/07/16	AAW	10/07/16
EP1	REVISED PER PADEP COMMENTS	MRS	05/11/16	RMB	05/11/16	AAW	05/11/16
EP		JTW	11/23/15	RMB	11/23/15	AAW	11/23/15
B	ADDED GEOTECH INFO	MRS	09/18/15	RMB	09/18/15	AAW	09/18/15
A	ISSUED FOR BID	DLM	08/31/15	RMB	08/31/15	AAW	08/31/15

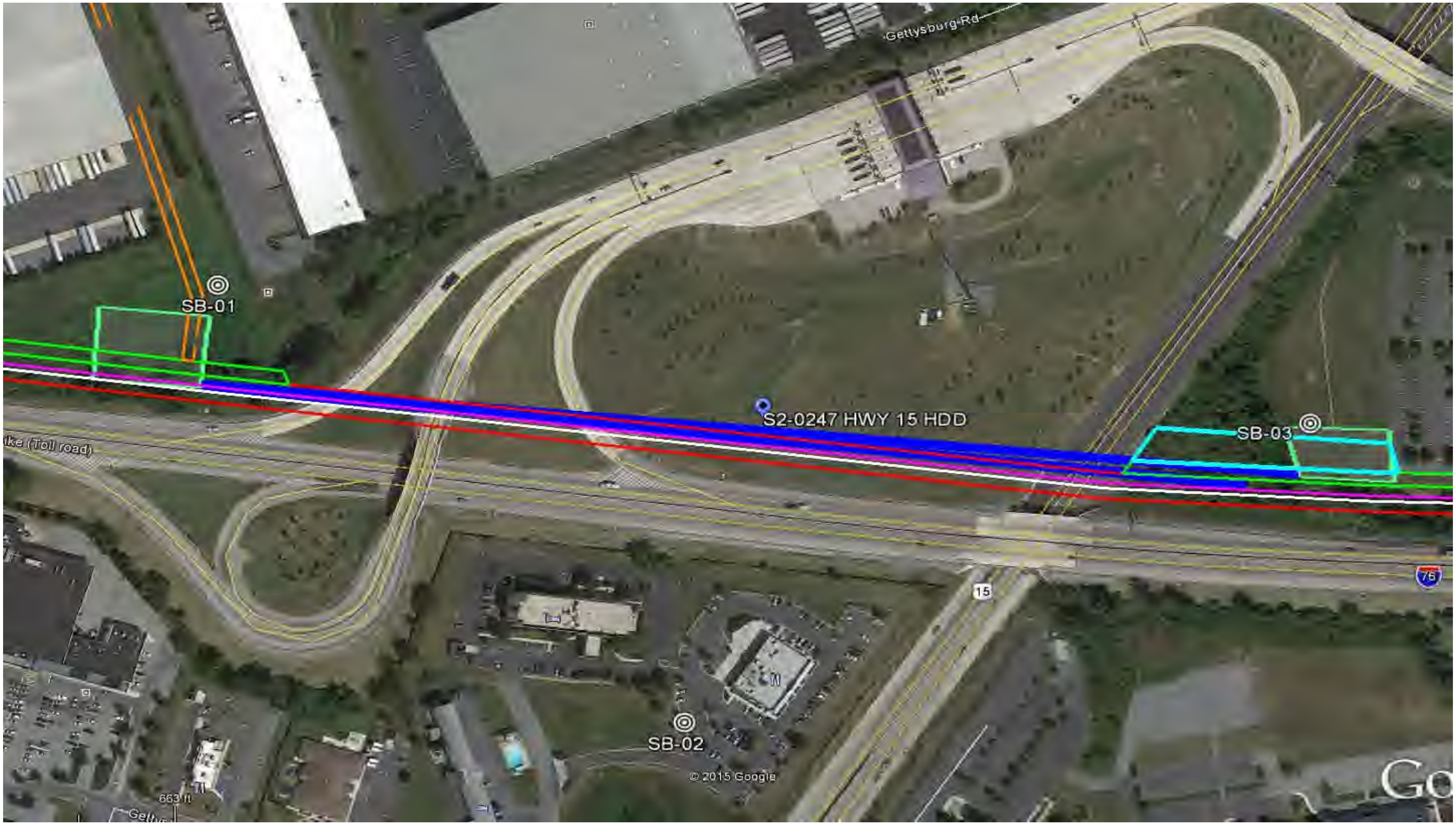
Sunoco Logistics Partners L.P.

TETRA TECH ROONEY
(303) 792-5911

SUNOCO PIPELINE, L.P.

HORIZONTAL DIRECTIONAL DRILL
HWY 15
PENNSYLVANIA PIPELINE PROJECT

SCALE: 1"=200' DWG. NO: PA-CU-0176.0019-RD-16



LEGEND:

Geotechnical Soil Boring (SB) Locations

TETRA TECH

GEOTECHNICAL BORING LOCATIONS
HDD S2-0247 HWY 15
CUMBERLAND COUNTY, UPPER ALLEN TOWNSHIP, PA
SUNOCO PENNSYLVANIA PIPELINE PROJECT

TEST BORING LOG

TETRA TECH
240 Continental Drive, Suite 200
Newark, Delaware 19713
302.738.7551
fax: 302.454.5988

Project Name:	SUNOCO PENNSYLVANIA PIPELINE PROJECT	Project No.: 103IP3406	
Project Location:	INDEPENDENCE AVENUE, MECHANICSBURG, PA	Page 1 of 1	
HDD No.:	S2-0247	Dates(s) Drilled: 02-03-15	Inspector: E. WATT
Boring No.:	SB-01	Drilling Method: SPT - ASTM D1586	Driller: S. HOFFER
Drilling Contractor:	HAD DRILLING	Groundwater Depth (ft): NOT ENCOUNTERED	Total Depth (ft): 30.0
Boring Location Coordinates:		40° 11' 49.015" N	76° 58' 49.632" W

Sample No.	Sample Depth (ft)		Strata Depth (ft)		Recov. (in)	Strata (USCS)	Description of Materials	6" Increment Blows *				N
	From	To	From	To								
			0.0	0.3			TOPSOIL (4")					
1	3.0	5.0	0.3		19		MOTTLED BROWN AND GRAY SILTY CLAY.	3	3	7	10	**10**
2	8.0	10.0			24		MOTTLED BROWN AND GRAY SILTY CLAY AND FINE SAND, TRACE	5	8	11	12	**19**
							UNWEATHERED FINE ROCK FRAGMENTS. (USCS: CL).					
3	13.0	15.0			24		MOTTLED BROWN AND GRAY SILTY CLAY, TRACE UNWEATHERED	2	4	5	5	**9**
						CL	FINE ROCK FRAGMENTS.					
4	18.0	20.0			24		BROWN SILTY CALY.	2	4	6	6	**10**
5	23.0	25.0			24		BROWN SILTY CLAY, SOFT, WITH SOME FINE SAND.	1	2	3	3	**5**
							(USCS: CL).					
6	28.0	30.0		30.0	24		BROWN SILTY CLAY, SOFT.	1	1	2	4	**3**
							DRY AND CAVED AT 30'.					

Notes/Comments:

<u>Pocket Pentrometer Testing</u>

S1: 3 TSF	S4: 0.5 TSF
S2: 2.5 TSF	S5: 0.5 TSF
S3: 2.5 TSF	S6: 0.5 TSF

Strata (USCS) Designations are approximated based on visual review, except where indicated in Description of Materials.

* Number of blows of 140 lb. Hammer dropped 30 in. required to drive 2 in. split-spoon sampler in 6 in. increments.
N: Number of blows to drive spoon from 6" to 18" interval.

TETRA TECH
240 Continental Drive, Suite 200
Newark, Delaware 19713
302.738.7551
fax: 302.454.5988

TEST BORING LOG

Project Name:	SUNOCO PENNSYLVANIA PIPELINE PROJECT			Project No.: 103IP3406	
Project Location:	CRAKER BARREL PROPERTY, SOUTH SIDE OF I-76, MECHANICSBURG, PA			Page 1 of 1	
HDD No.:	S2-0247	Dates(s) Drilled: 04-28-15		Inspector:	E. WATT
Boring No.:	SB-02	Drilling Method: SPT - ASTM D1586		Driller:	S. HOFFER
Drilling Contractor:	HAD DRILLING	Groundwater Depth (ft): NOT ENCOUNTERED		Total Depth (ft):	21.4
Boring Location Coordinates:		40° 11' 40.770" N		76° 58' 39.169" W	

Sample No.	Sample Depth (ft) From	Sample Depth (ft) To	Strata Depth (ft) From	Strata Depth (ft) To	Recov. (in)	Strata (USCS)	Description of Materials	6" Increment Blows *				N
			0.0	0.3			TOPSOIL (4")					
1	3.0	5.0	0.3		13	CL	MOTTLED REDDISH BROWN, TAN, GRAY SILTY CLAY AND FINE SAND,	1	2	4	6	**6**
							TRACE FINE GRAVEL.					
2	8.0	10.0			12		REDDISH BROWN SILTY CLAY (USCS: CL).	2	8	10	14	**18**
				13.5								
3	13.0	13.9	13.5	13.9	5		GRAY PARTIALLY WEATHERED LIMESTONE.	5	50/5"			**>50**
							AUGER REFUSAL AT 14'.					
							<u>ROCK CORING</u>					
RUN 1	14.0	18.0	14.0	18.2	44	LIMESTONE ROCK	LIGHT GRAY INTENSELY FRACTURED LIMESTONE WITH CALCITE.	TCR: 92%, SCR: 18%, RQD: 13%				
RUN 2	18.0	21.4	18.2	20.4	41		LIGHT GRAY MODERATELY FRACTURED LIMSTONE WITH CALCITE.	TCR: 100%, SCR: 65%, RQD: 49%				
			20.4	21.4			LIGHT GRAY INTENSELY FRACTURED LIMESTONE WITH CALCITE.					
							<u>CORE TESTING RESULTS (DEPTH 19'):</u>					
							COMPRESSIVE STRENGTH: 13,320 PSI					
							UNIT WEIGHT: 169.9 PCF					

Notes/Comments:

<u>Pocket Pentrometer Testing</u>
4': 3.25 TSF
10': > 4 TSF

Strata (USCS) Designations are approximated based on visual review, except where indicated in Description of Materials.

* Number of blows of 140 lb. Hammer dropped 30 in. required to drive 2 in. split-spoon sampler in 6 in. increments.
N: Number of blows to drive spoon from 6" to 18" interval.

TETRA TECH
240 Continental Drive, Suite 200
Newark, Delaware 19713
302.738.7551
fax: 302.454.5988

TEST BORING LOG

Project Name:	SUNOCO PENNSYLVANIA PIPELINE PROJECT		Project No.: 103IP3406
Project Location:	DELTA DRIVE, MECHANICSBURG, PA		Page 1 of 1
HDD No.:	S2-0247	Dates(s) Drilled: 02-03-15	Inspector: E. WATT
Boring No.:	SB-03	Drilling Method: SPT - ASTM D1586	Driller: S. HOFFER
Drilling Contractor:	HAD DRILLING	Groundwater Depth (ft): NOT ENCOUNTERED	Total Depth (ft): 12.1
Boring Location Coordinates:		40° 11' 46.376" N	76° 58' 25.257" W

Sample No.	Sample Depth (ft)		Strata Depth (ft)		Recov. (in)	Strata (USCS)	Description of Materials	6" Increment Blows *				N
	From	To	From	To								
			0.0	0.3			TOPSOIL (3")					
1	3.0	5.0	0.3		10	CH	ORANGE BROWN CLAY OF HIGH PLASTICITY, TRACE FINE ROCK FRAGMENTS.	1	6	8	10	**14**
2	8.0	10.0		12.0	22		MOTTLED ORANGE AND YELLOWISH BROWN CLAY, HIGH PLASTICITY, TRACE FINE LIMESTON ROCK FRAGMENTS. (USCS: CH).	5	6	8	10	**14**
3	12.0	12.1	12.0	12.1	<1		GRAY LIMESTONE FRAGMENTS.	50/.5"				**0**
							AUGER REFUSAL AT 12'. OFF-SET BORING 15' SOUTH AND AUGERED TO REFUSAL AT 11'. OFF-SET AGAIN AND AUGERED TO REFUSAL AT 11.5'.					
							REFUSAL MATERIAL MIGHT BE A RESULT OF BOULDERY SUBSURFACE CONDITIONS.					
							DRY AND CAVED AT 12'.					

Notes/Comments:

Pocket Pentrometer Testing
S1: 3.5 TSF
S2: 2.5 TSF

Strata (USCS) Designations are approximated based on visual review, except where indicated in Description of Materials.

* Number of blows of 140 lb. Hammer dropped 30 in. required to drive 2 in. split-spoon sampler in 6 in. increments.
N: Number of blows to drive spoon from 6" to 18" interval.

GEOTECHNICAL LABORATORY TESTING SUMMARY
SUNOCO PENNSYLVANIA PIPELINE PROJECT
HDD S2-0247 Hwy 15

HDD No.	Test Boring No.	Sample No.	Depth of Sample (ft.)		Water Content, % (ASTM D2216)	Percent Silts/Clays, % (ASTM D1140)	Atterburg Limits (ASTM D4318)			USCS Classif. (ASTM D2487)
			From	To			Liquid Limit, %	Plastic Limit, %	Plasticity Index, %	
S2-0247	SB-01	1	3.0	5.0	23.7	99.2	-	-	-	-
		2	8.0	10.0	16.2	55.5	36	21	15	CL
		4	18.0	20.0	37.2	95.5	-	-	-	-
		5	23.0	25.0	39.6	74.1	46	26	20	CL
		6	28.0	30.0	40.5	99.0	-	-	-	-
	SB-02	1	3.0	5.0	22.5	59.8	-	-	-	-
		2	8.0	10.0	28.8	99.9	49	27	22	CL
	SB-03	1	3.0	5.0	25.4	97.7	-	-	-	-
		2	8.0	10.0	29.5	99.4	60	27	33	CH

Rock Core Testing Results				
Boring No.	Core Run	Approximate Depth (ft)	Compressive Strength (psi)	Unit Weight (pcf)
SB-02	Run 2	19.0	13,320	169.9

Notes:

1) Sample depths based on feet below grade at time of exploration.

ROCK CORE DESCRIPTION SUMMARY
SUNOCO PENNSYLVANIA PIPELINE PROJECT
HDD S2-0247 HYW 15

<table>
<tr><th rowspan="2">Location</th><th rowspan="2">Boring No.</th><th rowspan="2">Core Run</th><th colspan="2">Core Depth (ft)</th><th rowspan="2">TCR (%)</th><th rowspan="2">SCR (%)</th><th rowspan="2">RQD (%)</th><th colspan="2">Depth (ft)</th><th rowspan="2">Weathering</th><th rowspan="2">Classification</th><th rowspan="2">Bedding Thickness (ft)</th><th rowspan="2">Color</th><th rowspan="2">Discontinuity Data</th></tr>
<tr><th>From</th><th>To</th><th>From</th><th>To</th></tr>
<tr><td rowspan="2">S2-0247</td><td rowspan="2">SB-2</td><td>1</td><td>14</td><td>18</td><td>92</td><td>18</td><td>13</td><td rowspan="2">14</td><td rowspan="2">21.4</td><td rowspan="2">Slight</td><td rowspan="2">Limestone</td><td rowspan="2">Massive</td><td rowspan="2">Alternating light and dark gray, darker with depth</td><td rowspan="2">Visible laminations with varying coloration, likely due to changes in depositional chemistry, bedding not visible; Fracturing along laminations, ranging from 30° to 50°, Avg. 37°; Large eroded vertical fracture from 16.5 to 18 ft</td></tr>
<tr><td>2</td><td>18</td><td>21.4</td><td>100</td><td>65</td><td>49</td></tr>
</table>

REGIONAL GEOLOGY SUMMARY
SUNOCO PENNSYLVANIA PIPELINE PROJECT
HDD S2-0247 HWY 15

HDD No.	NAME	BORING NO.	REGIONAL GEOLOGY DESCRIPTION	GENERAL TOPOGRAPHIC SETTING	BEDROCK FORMATION	GENERAL ROCK TYPE	APPROX MAX FM THICKNESS (FT)	DEPTH TO ROCK (Ft bgs) based on nearby well drilling logs	NOTES / COMMENTS
S2-0247	Highway 15	SB-01 SB-02 SB-03	**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	Rockdale Run	Limestone with dolomite and chert	2,500	Variable; 15-89 ft bgs, average DTB ~30 ft bgs	500 ft section of pinkish, marbley limestone and chert. Some stromatolies in the chert in middle of fm

<u>Note</u> : Source of well log data - http://www.dcnr.state.pa.us/topogeo/groundwater/pagwis/records/index.htm. All other sources as referenced in comments section.

FIELD DESCRIPTION AND LOGGING SYSTEM FOR SOIL EXPLORATION

GRANULAR SOILS

(Sand, Gravel & Combinations)

Density	***N (blows)****
Very Loose	5 or less
Loose	6 to 10
Medium Dense	11 to 30
Dense	31to 50
Very Dense	51 or more

Relative Proportions

Description Term	*Percent*
Trace	1 - 10
Little	11 - 20
Some	21 - 35
And	36 - 50

Particle Size Identification

Boulders	8 in. diameter or more	
Cobbles	3 to 8 in. diameter	
Gravel	Coarse (C)	3 in. to ¾ in. sieve
	Fine (F)	¾ in. to No. 4 sieve
Sand	Coarse (C)	No. 4 to No. 10 sieve (4.75mm-2.00mm)
	Medium (M)	No. 10 to No. 40 sieve (2.00mm – 0.425mm)
	Fine (F)	No. 40 to No. 200 sieve (0.425 – 0.074mm)
Silt/Clay	Less Than a No. 200 sieve (<0.074mm)	

COHESIVE SOILS

(Silt, Clay & Combinations)

Consistency	***N (blows)****
Very Soft	3 or less
Soft	4 to 5
Medium Stiff	6 to 10
Stiff	11 to 15
Very Stiff	16 to 30
Hard	31 or more

Plasticity

Degree of Plasticity	*Plasticity Index*
None to Slight	0 - 4
Slight	5 - 7
Medium	8- 22
High to Very High	> 22

ROCK

(Rock Cores)

Rock Quality Designation (RQD), %	***Rock Quality Description***
0-25	Very Poor
25-50	Poor
50-75	Fair
75-90	Good
90-100	Excellent

****N - Standard Penetration Resistance.*** Driving a 2.0" O.D., 1-3/8" I.D. sampler a distance of 18 inches into undisturbed soil with a 140 pound hammer free falling a distance of 30.0 inches. The number of hammer blows to drive the sampler through each 6 inch interval is recorded; the number of blows required to drive the sampler through the final 12 inch interval is termed the Standard Penetration Resistance (SPR) N-value. For example, blow counts of 6/8/9 (through three 6-inch intervals) results in an SPR N-value of 17 (8+9).

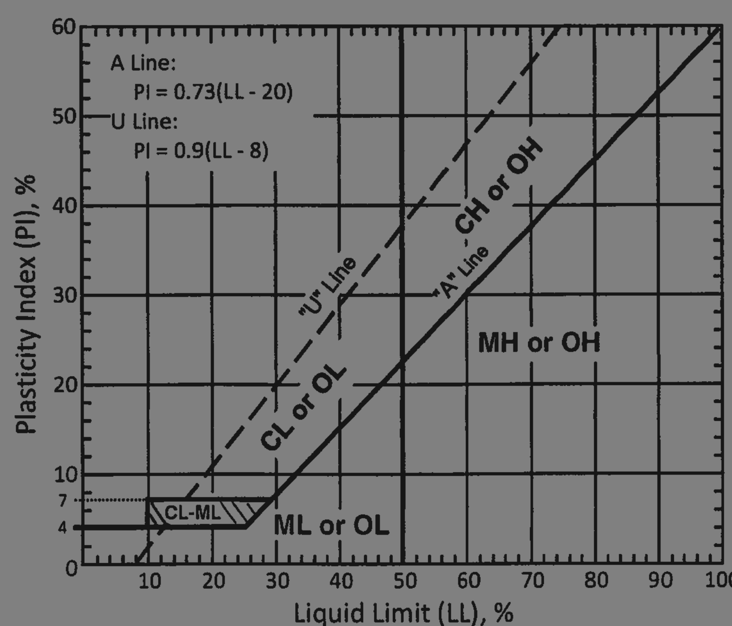
Groundwater observations were made at the times indicated. Groundwater elevations fluctuate throughout a given year, depending on actual field porosity and variations in seasonal and annual precipitation.

UNIFIED SOIL CLASSIFICATION SYSTEM [Casagrande (1948)]

Major Divisions			Group Symbols	Typical Descriptions	Laboratory Classifications		
Coarse Grained Soils (More than half of material is larger than No. 200 sieve)	Gravels More than half of coarse fraction is larger than No. 4 sieve size	Clean gravel (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines	Determine Percentage of sand and gravel from grain size curve. Depending on Percentage of fines (fraction smaller than No. 200 sieve), coarse-grained soils are classified as follows: Less than 5 percent GW, GP, SW, SP; More than 12 percent GM. GC, SM, SC; 5 to 12 percent Borderline cases requiring dual symbols[1]	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4: $C_c = \frac{(D_{30})2}{D_{10} \text{ x } D_{60}}$ between 1 and 3	
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines		Not meeting C_u or C_c requirements for GW	
		Gravel with fines (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixtures		Atterberg limits below A Line or I_p less than 4	Limits plotting in hatched zone with I_p between 4 and 7 are borderline cases requiring use of dual symbols
			GC	Clayey gravels, gravel-sand-clay mixtures		Atterberg limits above A line with I_p greater than 7	
	Sands (More than half of coarse fraction is smaller than No. 4 Sieve)	Clean sands (Little or no fines)	SW	Well graded sands, gravely sands, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ greater than 6 $C_c = \frac{(D_{30})2}{D_{10} \text{ x } D_{60}}$ between 1 and 3	
			SP	Poorly graded sands, gravelly sands, little or no fines		Not meeting C_u or C_c requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures		Atterberg limits below A Line or I_p less than 4	Limits Plotting in hatched zone with I_p between 4 and 7 are borderline cases requiring use of dual symbols
			SC	Clayey sands, sand-clay mixtures		Atterberg limits above A line with I_p greater than 7	

Major Divisions		Group Symbols	Typical Descriptions
Fine–grained soils (More than half of material is smaller than No. 200 sieve)	Silts and clays (Liquid limit less than 50)	ML	norganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity
		CL	Inorganic clays of low to medium plasticity, gravelly clays , sandy clays, silty clays, lean clays
		OL	Organic silts and organic silty clays of low plasticity
	Silts and Clays (Liquid limit greater than 50)	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
		CH	Inorganic clays of high plasticity, fat clays
		OH	Organic clays of medium to high plasticity, organic silts
	Highly organic soils	Pt	Peat and other highly organic soils

For soils plotting nearly on A line use dual symbols i.e ., I_p = 29.5, w_L=60 gives CH-MH. When w_L is near 50 use CL-CH or ML-MH. Take near as ± 2 percent.



(1) Borderline classifications, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. For example GW-GC. well-graded gravel-sand mixture with clay binder.

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Figure 1: Site Vicinity Plan

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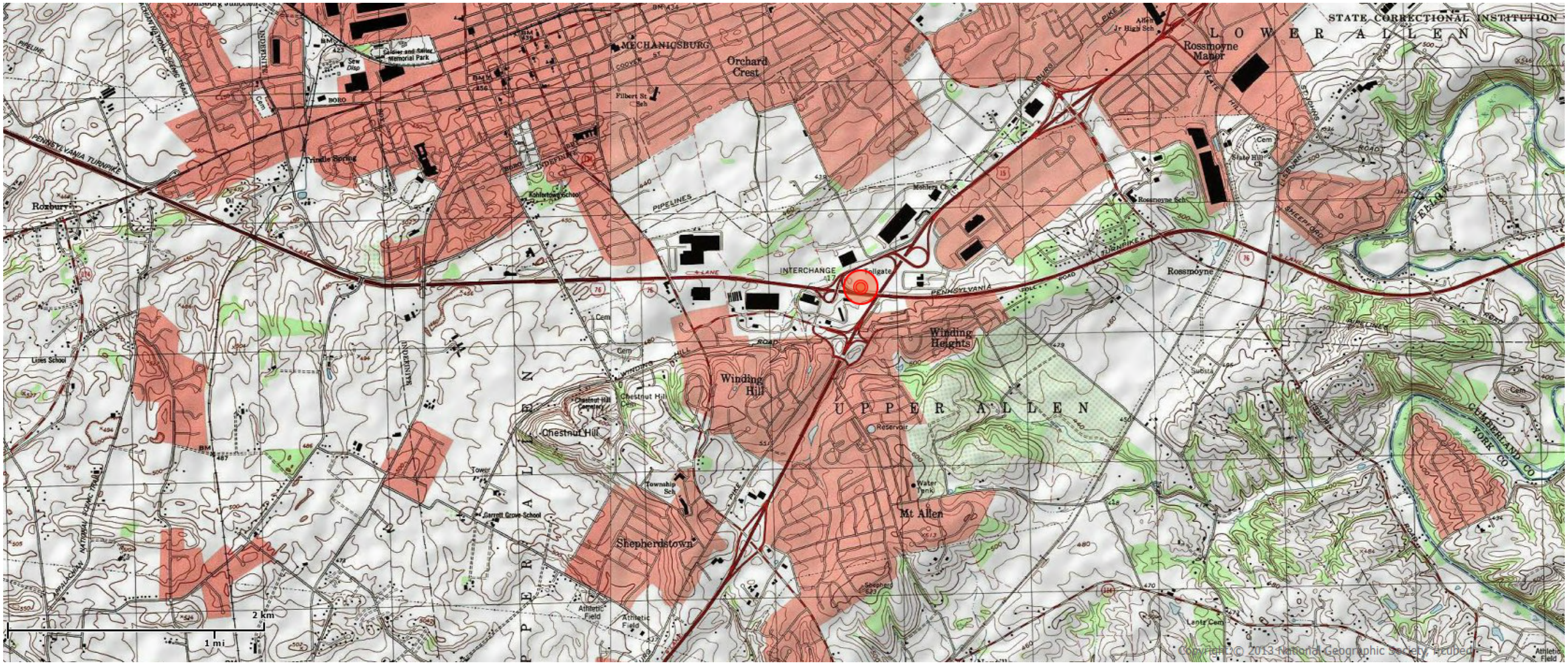
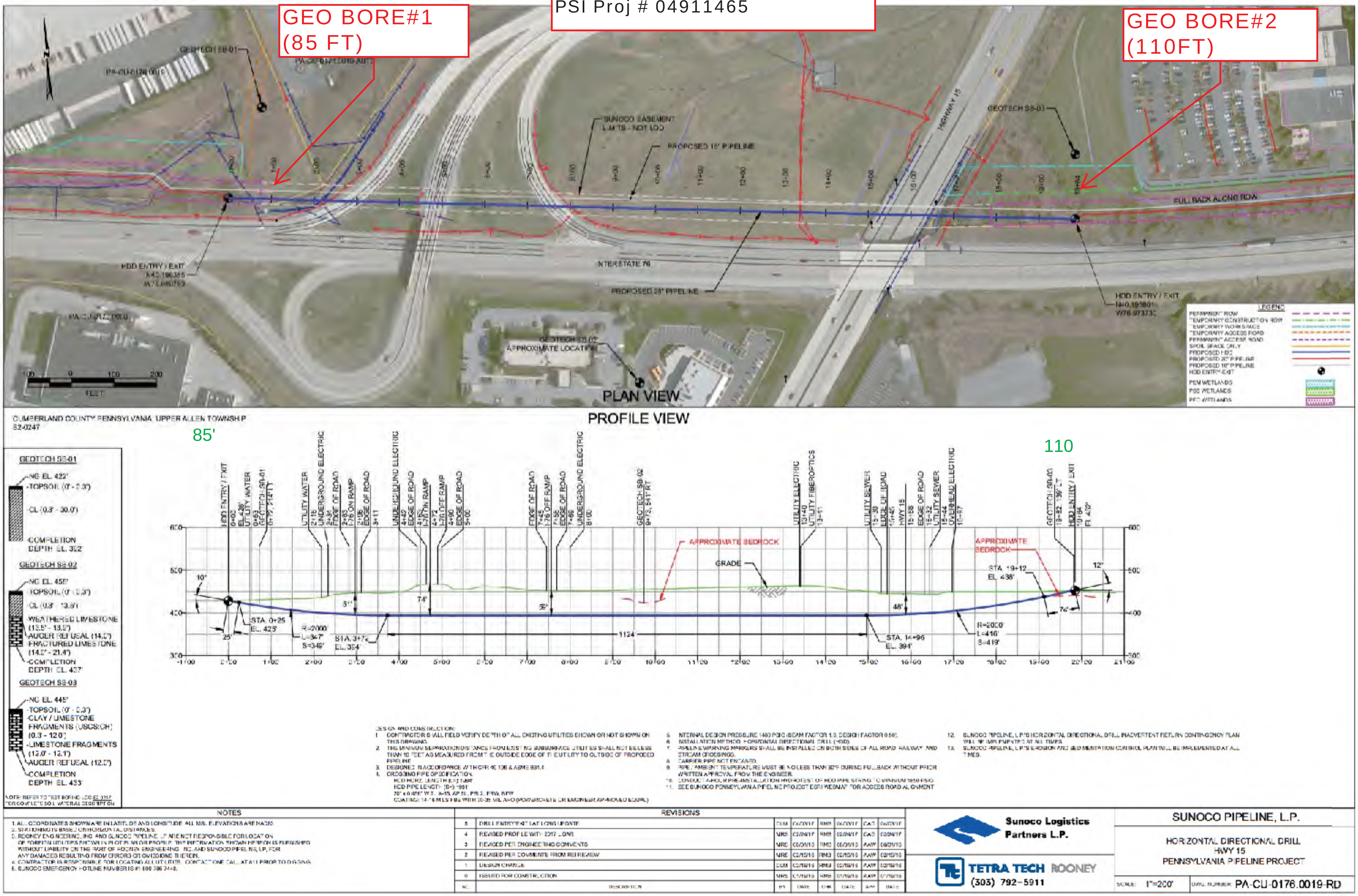


Created using PA DCNR Map Viewer

Map created on Fri Sep 22 2017

FIGURE 2: Boring Location Plan
HWY 15 - PPP4
DPS PO#20170824-1
PSI Proj # 04911465



pennsylvania
DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES

Visit us at http://www.dcnr.state.pa.us

Figure 3: Site Geology Plan

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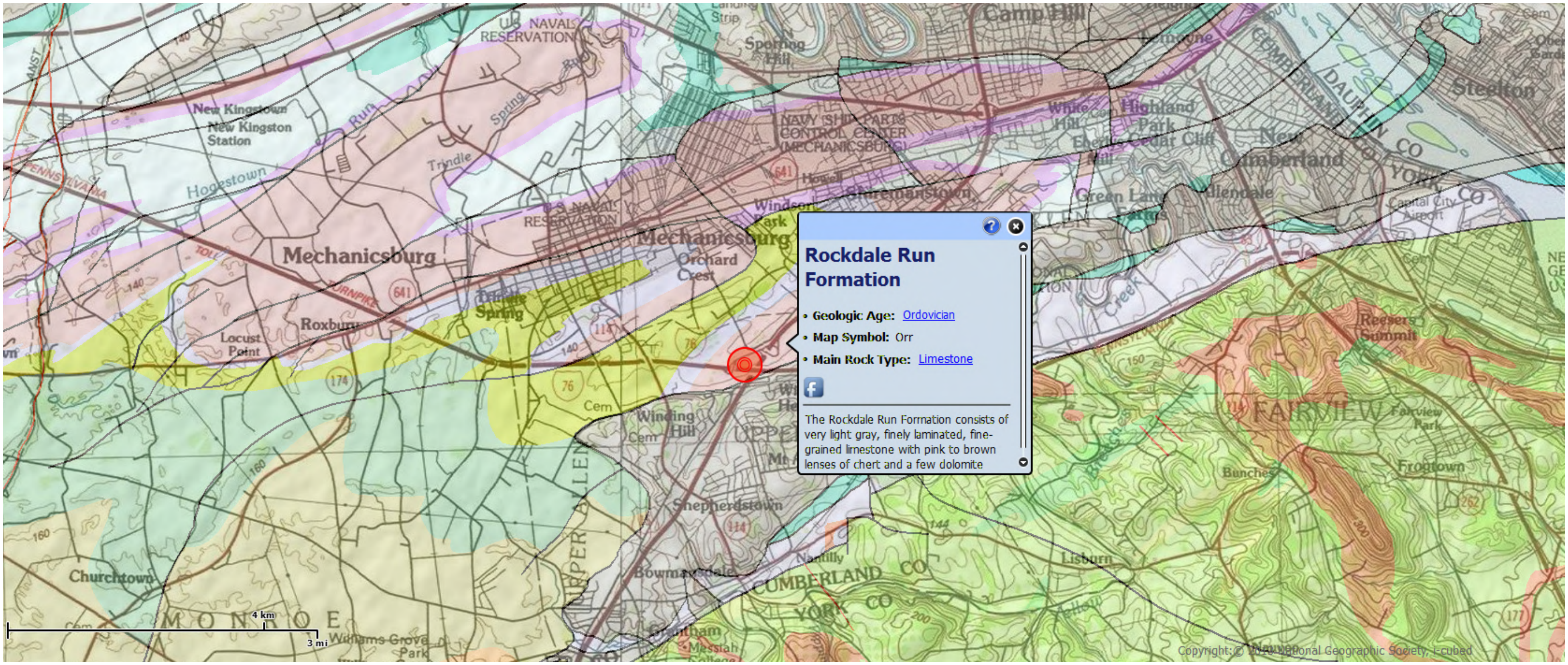


Created using PA DCNR Map Viewer

Map created on Fri Sep 22 2017

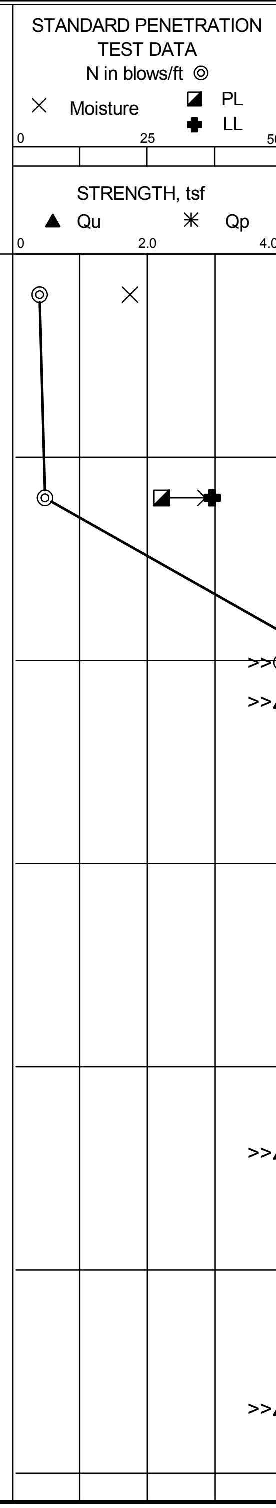
BORING B-01

DATE STARTED:	9/7/17	**DRILL COMPANY:**	AWK Drilling
DATE COMPLETED:	9/7/17	**DRILLER:**	T. Growden, Jr **LOGGED BY:** M. Wildman
COMPLETION DEPTH	85.0 ft	**DRILL RIG:**	CME 55 Track Mount
BENCHMARK:	N/A	**DRILLING METHOD:**	Casing/Rock Coring
ELEVATION:	N/A	**SAMPLING METHOD:**	2-in SSNQ2-in Core
LATITUDE:	n/a°	**HAMMER TYPE:**	Automatic
LONGITUDE:	n/a°	**EFFICIENCY**	N/A
STATION: N/A	**OFFSET:** N/A	**REVIEWED BY:**	F. Hoffman
REMARKS:			

Water		
▽ Pre-Core		7.8 feet
▼ 9/9/2017 @ 5:13 p.m.		11.7 feet
▼ 9/10/2017 @ 8:17 a.m.		17.3 feet

BORING LOCATION:
See Boring Location Plan

Elevation (feet)	Depth, (feet)	Sample Type	Sample No.	Recovery (inches)	MATERIAL DESCRIPTION	USCS Classification	SPT Blows per 6-inch (SS) RQD & Recovery % (NX)	Moisture, %	Additional Remarks
	0		S-1	14	**RESIDUUM**-Medium Stiff, Brown, SILT with Sand, moist to moist/wet	ML	2-2-3-3 N=5	22	
	5		S-2	24	Moist/wet from 5 to 7 feet.		2-2-4-3 N=6	36	LL = 37 PL = 28
					Highly Weathered LIMESTONE-No split-spoon sample recovery.				
	10		S-3	0	**LIMESTONE**-Light gray to black, Very fine grained, Slightly Weathered, very broken to massive, hard to very hard		50/1"		
			R-1	35			RQD=97 Rec=100%		Q_u = 495.0 tsf 168.0 pcf 1 min. 1 min. 1 min. 1 min.
	15		R-2	60			RQD=100 Rec=100%		1 min. 1 min. 1 min. 1 min. 1 min.
	20		R-3	60			RQD=98 Rec=100%		1 min. Q_u = 552.8 tsf 1 min. 168.3 pcf 1 min. 1 min.
	25		R-4	71	**DOLOMITE**-Gray to dark gray, Very fine grained, Slightly Weathered, massive, very hard		RQD=98 Rec=98%		1 min. 1 min. 2 min. 3 min. Q_u = 1319.2 tsf 172.6 pcf 2 min.
	30								



Continued Next Page

Professional Service Industries, Inc.
1707 S. Cameron Street, Suite B
Harrisburg, PA 17104
Telephone: (717) 230-8622

PROJECT NO.: 04911465
PROJECT: Energy Transfer HDD (DPS)
LOCATION: HWY 15 (PPP4)
Cumberland Co., PA
PA-CU-0176.0019-RD/PO#20170824-1

The stratification lines represent approximate boundaries. The transition may be gradual.

DATE STARTED:	9/7/17	**DRILL COMPANY:**	AWK Drilling		
DATE COMPLETED:	9/7/17	**DRILLER:**	T. Growden, Jr	**LOGGED BY:**	M. Wildman
COMPLETION DEPTH	85.0 ft	**DRILL RIG:**	CME 55 Track Mount		
BENCHMARK:	N/A	**DRILLING METHOD:**	Casing/Rock Coring		
ELEVATION:	N/A	**SAMPLING METHOD:**	2-in SSNQ2-in Core		
LATITUDE:	n/a°	**HAMMER TYPE:**	Automatic		
LONGITUDE:	n/a°	**EFFICIENCY**	N/A		
STATION: N/A	**OFFSET:** N/A	**REVIEWED BY:**	F. Hoffman		
REMARKS:					

BORING B-01

Water

▽ Pre-Core		7.8 feet
▼ 9/9/2017 @ 5:13 p.m.		11.7 feet
▼ 9/10/2017 @ 8:17 a.m.		17.3 feet

BORING LOCATION:
See Boring Location Plan

Elevation (feet)	Depth, (feet)	Graphic Log	Sample Type	Sample No.	Recovery (inches)	MATERIAL DESCRIPTION	USCS Classification	SPT Blows per 6-inch (SS) RQD & Recovery % (NX)	Moisture, %	STANDARD PENETRATION TEST DATA N in blows/ft ◎; × Moisture; PL; LL (0 25 50); STRENGTH, tsf ▲ Qu ✳ Qp (0 2.0 4.0)	Additional Remarks
	30			R-5	48	**LIMESTONE**-Light gray to black, Very fine grained, Slightly Weathered, very broken to massive, hard to very hard		RQD=100 Rec=100%			2 min. 2 min. 2 min. 2 min. 3 min.
	35			R-6	60			RQD=100 Rec=100%		>>▲	Q_u = 301.4 tsf 167.9 pcf 2 min. 2 min. 2 min. 2 min. 1 min.
	40			R-7	60			RQD=100 Rec=100%		>>▲	2 min. Q_u = 695.3 tsf 167.7 pcf 1 min. 1 min. 1 min. 1 min.
	45			R-8	60			RQD=100 Rec=100%			1 min. 1 min. 1 min. 2 min. 2 min.
	50			R-9	60			RQD=100 Rec=100%			2 min. 2 min. 2 min. 2 min. 2 min.
	55			R-10	60	Broken seam @ 54.2 feet (~ 1-1/2 inches thick)		RQD=100 Rec=100%		>>▲	1 min. 1 min. Q_u = 503.5 tsf 167.1 pcf 1 min. 1 min. 1 min.
	60										

Continued Next Page

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PROJECT NO.: 04911465
PROJECT: Energy Transfer HDD (DPS)
LOCATION: HWY 15 (PPP4)
Cumberland Co., PA
PA-CU-0176.0019-RD/PO#20170824-1

The stratification lines represent approximate boundaries. The transition may be gradual.

DATE STARTED: 9/7/17
DATE COMPLETED: 9/7/17
COMPLETION DEPTH 85.0 ft
BENCHMARK: N/A
ELEVATION: N/A
LATITUDE: n/a°
LONGITUDE: n/a°
STATION: N/A OFFSET: N/A
REMARKS:

DRILL COMPANY: AWK Drilling
DRILLER: T. Growden, Jr LOGGED BY: M. Wildman
DRILL RIG: CME 55 Track Mount
DRILLING METHOD: Casing/Rock Coring
SAMPLING METHOD: 2-in SS NQ2-in Core
HAMMER TYPE: Automatic
EFFICIENCY: N/A
REVIEWED BY: F. Hoffman

BORING B-01

Water		
▽ Pre-Core		7.8 feet
▼ 9/9/2017 @ 5:13 p.m.		11.7 feet
▽ 9/10/2017 @ 8:17 a.m.		17.3 feet

BORING LOCATION:
See Boring Location Plan

Elevation (feet)	Depth, (feet)	Graphic Log	Sample Type	Sample No.	Recovery (inches)	MATERIAL DESCRIPTION	USCS Classification	SPT Blows per 6-inch (SS) RQD & Recovery % (NX)	Moisture, %	STANDARD PENETRATION TEST DATA N in blows/ft ◎; × Moisture; PL; LL (0–25–50); STRENGTH, tsf ▲ Qu ✳ Qp (0–2.0–4.0)	Additional Remarks
	60			R-11	60	**LIMESTONE**-Light gray to black, Very fine grained, Slightly Weathered, very broken to massive, hard to very hard Weathered seam @ 62.5 feet (~ 2-1/2 inches thick)		RQD=90 Rec=100%			1 min. 1 min. 1 min. 1 min. 2 min.
	65			R-12	60			RQD=100 Rec=100%		>>▲	2 min. 2 min. 2 min. Q_u = 564.5 tsf 166.9 pcf 2 min. 2 min.
	70			R-13	60	Nearly vertical fracture @ 70.2 feet		RQD=88 Rec=100%			1 min. 2 min. 2 min. 2 min. 2 min.
	75			R-14	60			RQD=82 Rec=100%		>>▲	2 min. 2 min. 2 min. 2 min. Q_u = 290.4 tsf 169.8 pcf 2 min.
	80			R-15	60			RQD=94 Rec=100%			1 min. 2 min. 2 min. 1 min.
				R-16	24			RQD=100 Rec=100%			1 min. 2 min.
	85					Test boring terminated @ 85 feet					

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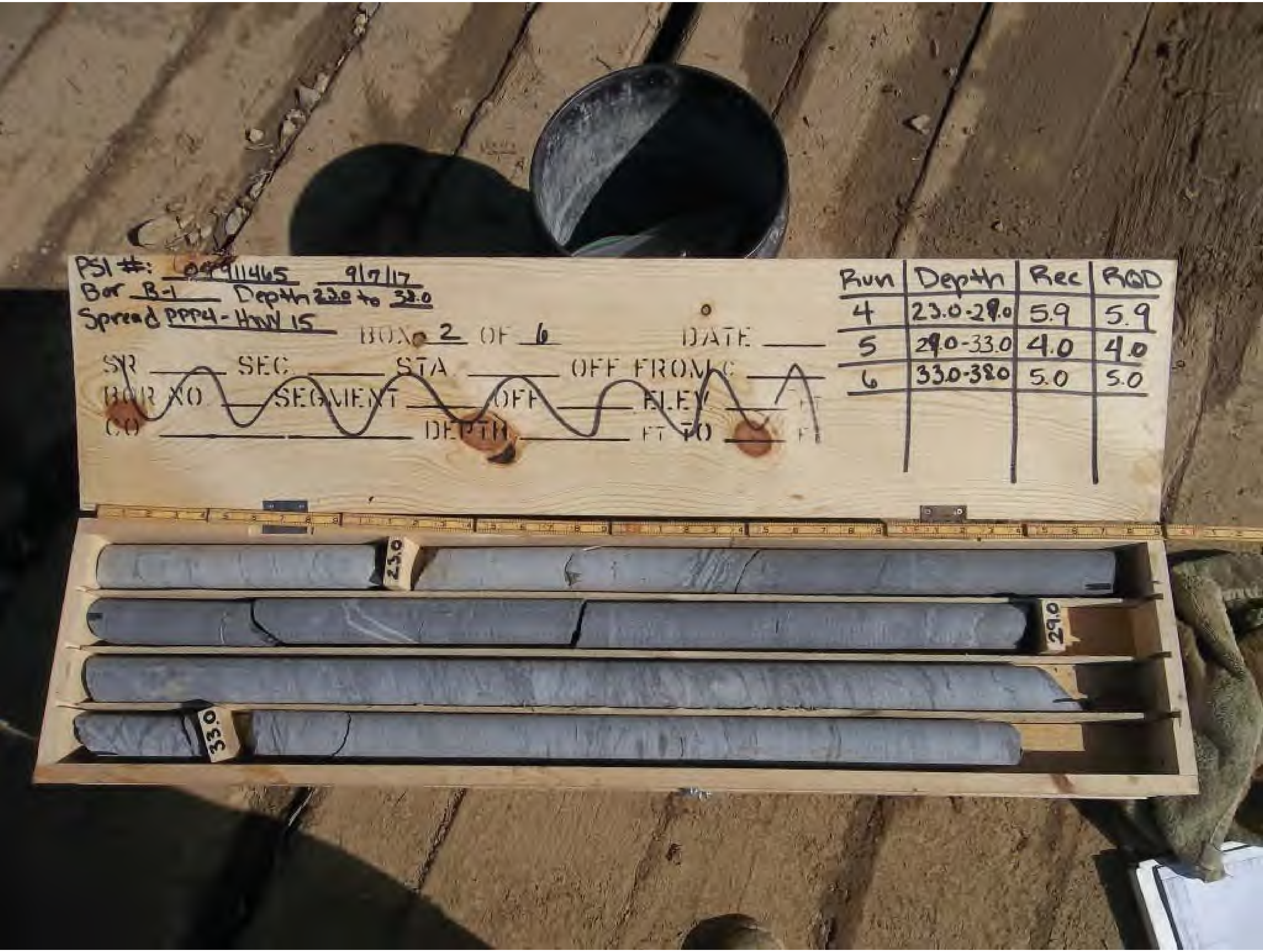
LOCATION: HWY 15 (PPP4)
Cumberland Co., PA
PA-CU-0176.0019-RD/PO#20170824-1

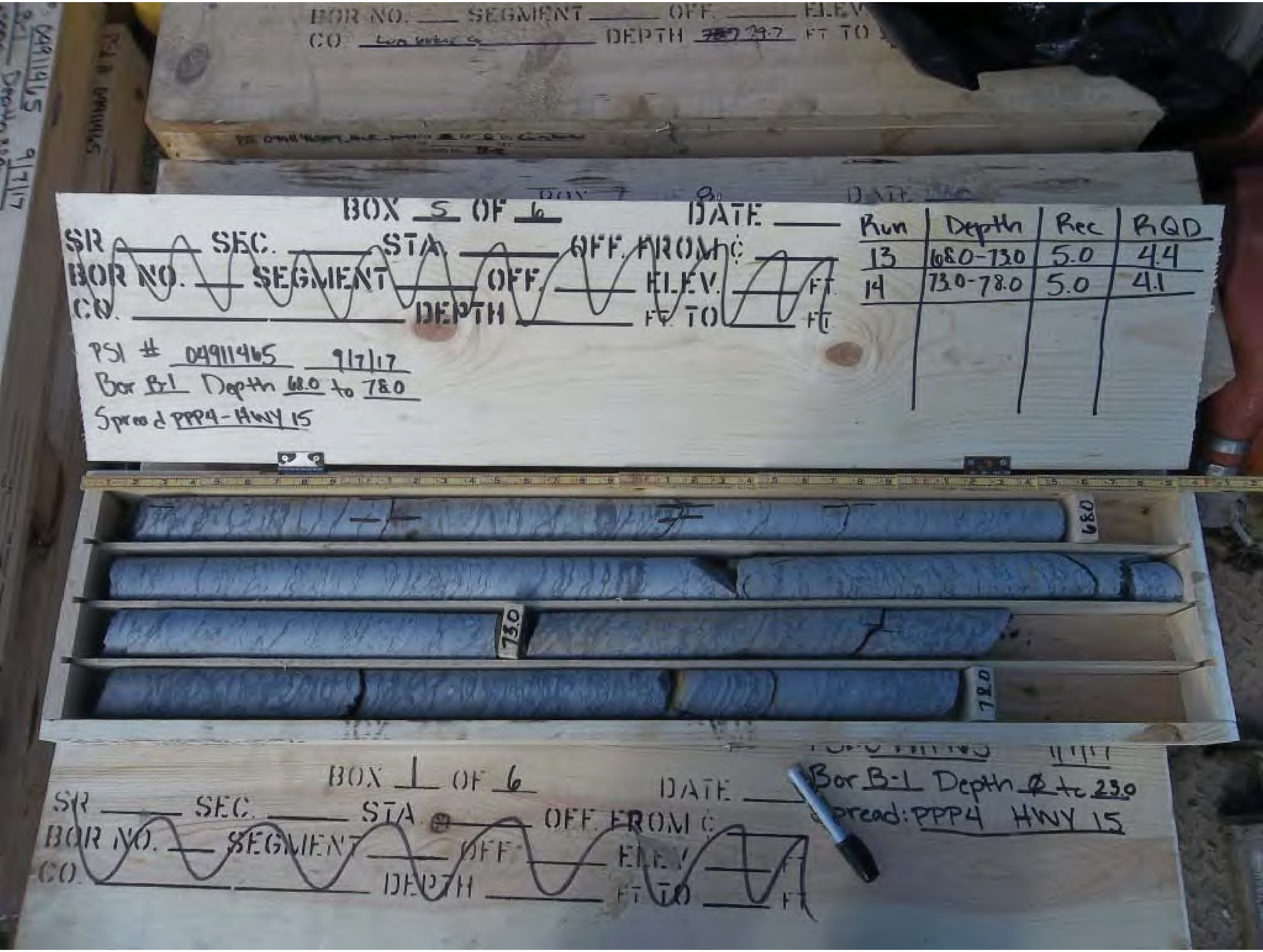
The stratification lines represent approximate boundaries. The transition may be gradual.


PSI#: 04911465 9/7/17
Bor B-1 Depth Ø to 23.0
Spread: PPP4-HWY15
BOX 1 OF 6
Run Depth Rec RQD
1 10.8-13.0 2.8 2.8
2 13.0-18.0 5.0 5.0
3 18.0-23.0 5.0 4.9
0.0
10.1
13.0
18.0


PSI #: 04911465 9/7/17
Bor B-1 Depth 23.0 to 38.0
Spread PPP4-HWY 15
BOX 2 OF 6
DATE
SR SEC STA OFF FROM C
BOR NO. SEGMENT OFF ELEV FT
CO DEPTH FT TO FT
Run | Depth | Rec | RQD
4 | 23.0-29.0 | 5.9 | 5.9
5 | 29.0-33.0 | 4.0 | 4.0
6 | 33.0-38.0 | 5.0 | 5.0
25.0
29.0
33.0


BOX 3 OF 6
DATE
SR
SEC.
STA.
OFF. FROM ¢
BOR NO.
SEGMENT
OFF.
ELEV.
FT
CO.
DEPTH
FT. TO
FT
PSI #: 04911465
9/7/17
Bor B-1
Depth 38.0 to 53.0
Spread PPP4- HWY 15
Run
Depth
Rec.
RQD
7
38.0-43.0
5.0
5.0
8
43.0-48.0
5.0
5.0
9
48.0-53.0
5.0
5.0
38.0
43.0
45.0
48.0


BOX 4 OF 6 DATE
SR SEC. STA. OFF. FROM ¢
BOR NO. SEGMENT OFF. ELEV. FT.
CO DEPTH FT TO FT.
Run | Depth | Rec | RQD
10 | 53.0-58.0 | 5.0 | 5.0
11 | 58.0-63.0 | 5.0 | 4.5
12 | 63.0-68.0 | 5.0 | 5.0
PSI #: 04911465 9/7/17
Bor B-1 Depth 53.0 to 68.0
Spread PPP4 - HWY 15
53.0
58.0
63.0


BOX 5 OF 6
DATE
SR
SEC.
STA.
OFF. FROM ¢
BOR NO.
SEGMENT
OFF.
ELEV.
CO.
DEPTH
FT. TO
FT.
PSI # 04911465 9/7/17
Bor B-1 Depth 68.0 to 78.0
Spread PPP4-HWY 15
Run | Depth | Rec | RQD
13 | 68.0-73.0 | 5.0 | 4.4
14 | 73.0-78.0 | 5.0 | 4.1
68.0
73.0
78.0
BOX 1 OF 6
Bor B-1 Depth 0 to 23.0
Spread: PPP4 HWY 15


PSI #: 04911465 9/7/17
Bor B1 Depth 78.0 to 85.0
Spread
BOX 6 OF 6
DATE
SR SEC STA OFF FRONT
BOR NO SEGMENT OFF ELEV FT
CO DEPTH FT TO FT
Run Depth Rec RQD
15 78.0-83.0 5.0 4.7
16 83.0-85.0 2.0 2.0
78.0
83.0
85.0

BORING B-02

DATE STARTED:	9/5/17	**DRILL COMPANY:**	AWK Drilling
DATE COMPLETED:	9/6/17	**DRILLER:**	T. Growden, Jr **LOGGED BY:** D. Calvert
COMPLETION DEPTH	110.0 ft	**DRILL RIG:**	CME 55 Track Mount
BENCHMARK:	N/A	**DRILLING METHOD:**	Casing/Rock Coring
ELEVATION:	N/A	**SAMPLING METHOD:**	2-in SSNQ2-in Core
LATITUDE:	n/a°	**HAMMER TYPE:**	Automatic
LONGITUDE:	n/a°	**EFFICIENCY**	N/A
STATION: N/A	**OFFSET:** N/A	**REVIEWED BY:**	F. Hoffman
REMARKS:			

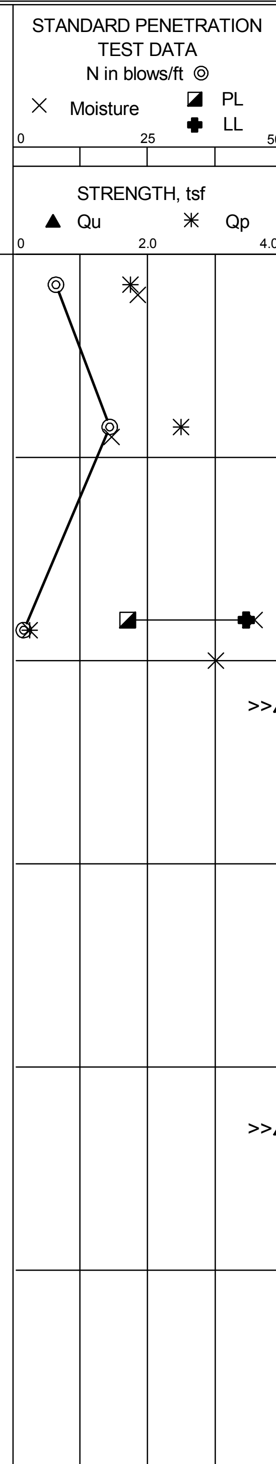
Water

▽	9/5/2017 @ 3:55 p.m.	26.1 feet
▼	9/6/2017 @ 8:17 a.m.	27.4 feet
▽	9/6/2017 @ 11:34 a.m.	27.8 feet

BORING LOCATION:
See Boring Location Plan

Elevation (feet)	Depth, (feet)	Sample No.	Recovery (inches)	MATERIAL DESCRIPTION	USCS Classification	SPT Blows per 6-inch (SS) RQD & Recovery % (NX)	Moisture, %	Additional Remarks
	0	S-1	9	**Probable FILL**-Brown to gray-brown, Lean CLAY with Sand, trace Gravel, moist	CL	3-3-5 N=8	23	
	5	S-2	10	**RESIDUUM**-Medium Dense, Brown to red-brown, Clayey SAND with Gravel, moist/wet	SC	7-9-9 N=18	18	Fines=26.9%
		S-3	7	**RESIDUUM**-Very Soft, Lean CLAY, trace Sand, moist/wet	CL	1-1-1 N=2	45	LL = 43 PL = 21
	10			**RESIDUUM**-Very Loose, Gray-brown, Clayey GRAVEL with Sand, moist/wet Casing refusal @ 10.3 feet	GC		38	
		R-1	29	**LIMESTONE**-Dark gray-brown, Highly Weathered, gravel-sized rock fragments		RQD=81 Rec=81%		>> Q_u = 546.3 tsf 170.3 pcf 2 min. 2 min. 3 min.
	15	R-2	60	**LIMESTONE**-Light gray to black, Very fine grained, Slightly Weathered, broken to massive, moderately hard to very hard, trace calcite stringers Weathered fracture @ 11.9 feet		RQD=95 Rec=100%		2 min. 2 min. 2 min. 2 min. 2 min.
	20	R-3	60			RQD=97 Rec=100%		2 min. 2 min. >> Q_u = 666.2 tsf 169.1 pcf 2 min. 2 min. 2 min.
	25	R-4	60			RQD=100 Rec=100%		2 min. 2 min. 2 min. 2 min. 2 min.
	30			*Continued Next Page*				

STANDARD PENETRATION TEST DATA



Professional Service Industries, Inc.
1707 S. Cameron Street, Suite B
Harrisburg, PA 17104
Telephone: (717) 230-8622

PROJECT NO.: 04911465
PROJECT: Energy Transfer HDD (DPS)
LOCATION: HWY 15 (PPP4)
Cumberland Co., PA
PA-CU-0176.0019-RD/PO#20170824-1

The stratification lines represent approximate boundaries. The transition may be gradual.

DATE STARTED:	9/5/17	**DRILL COMPANY:**	AWK Drilling
DATE COMPLETED:	9/6/17	**DRILLER:** T. Growden, Jr **LOGGED BY:**	D. Calvert
COMPLETION DEPTH	110.0 ft	**DRILL RIG:**	CME 55 Track Mount
BENCHMARK:	N/A	**DRILLING METHOD:**	Casing/Rock Coring
ELEVATION:	N/A	**SAMPLING METHOD:**	2-in SSNQ2-in Core
LATITUDE:	n/a°	**HAMMER TYPE:**	Automatic
LONGITUDE:	n/a°	**EFFICIENCY**	N/A
STATION: N/A	**OFFSET:** N/A	**REVIEWED BY:**	F. Hoffman
REMARKS:			

BORING B-02

Water

▽	9/5/2017 @ 3:55 p.m.	26.1 feet
▼	9/6/2017 @ 8:17 a.m.	27.4 feet
▽	9/6/2017 @ 11:34 a.m.	27.8 feet

BORING LOCATION:
See Boring Location Plan

Elevation (feet)	Depth, (feet)	Graphic Log	Sample Type	Sample No.	Recovery (inches)	MATERIAL DESCRIPTION	USCS Classification	SPT Blows per 6-inch (SS) RQD & Recovery % (NX)	Moisture, %	STANDARD PENETRATION TEST DATA N in blows/ft ◎; × Moisture; PL; LL (0–25–50); STRENGTH, tsf ▲ Qu ✳ Qp (0–2.0–4.0)	Additional Remarks
	30			R-5	60	**DOLOMITE**-Light gray to black, Very fine grained, Slightly Weathered, very broken to massive, hard to very hard, trace calcite stringers		RQD=100 Rec=100%		>>▲	2 min. 2 min. Q_u = 853.5 tsf 175.6 pcf 2 min. 2 min. 2 min.
	35			R-6	60	**LIMESTONE**-Light gray to black, Very fine grained, Slightly Weathered, broken to massive, moderately hard to very hard, trace calcite stringers		RQD=87 Rec=100%			2 min. 2 min. 2 min. 2 min. 2 min.
	40			R-7	60	Broken seam @ 42.7 feet (~ 2-1/4 inches thick)		RQD=97 Rec=100%		>>▲	2 min. Q_u = 229.9 tsf 167.8 pcf 2 min. 2 min. 2 min. 1 min.
	45			R-8	60	Weathered seam @ 47.8 feet (~ 2 inches thick)		RQD=100 Rec=100%		>>▲	2 min. 2 min. 1 min. Q_u = 1336.6 tsf 170.6 pcf
	50			R-9	59			RQD=83 Rec=98%			2 min. 2 min. 2 min.
	55			R-10	60	**DOLOMITE**-Light gray to dark gray, Very fine grained, Slightly Weathered, very broken to massive, very hard, trace calcite stringers Broken layer @ 59.5 feet (~ 4 inches thick)		RQD=88 Rec=100%		>>▲	2 min. 2 min. 2 min. 2 min. Q_u = 992.6 tsf 173.7 pcf
	60										

Continued Next Page

Professional Service Industries, Inc.
1707 S. Cameron Street, Suite B
Harrisburg, PA 17104
Telephone: (717) 230-8622

PROJECT NO.: 04911465
PROJECT: Energy Transfer HDD (DPS)
LOCATION: HWY 15 (PPP4)
Cumberland Co., PA
PA-CU-0176.0019-RD/PO#20170824-1

The stratification lines represent approximate boundaries. The transition may be gradual.

BORING B-02

DATE STARTED:	9/5/17	**DRILL COMPANY:**	AWK Drilling
DATE COMPLETED:	9/6/17	**DRILLER:** T. Growden, Jr **LOGGED BY:**	D. Calvert
COMPLETION DEPTH	110.0 ft	**DRILL RIG:**	CME 55 Track Mount
BENCHMARK:	N/A	**DRILLING METHOD:**	Casing/Rock Coring
ELEVATION:	N/A	**SAMPLING METHOD:**	2-in SSNQ2-in Core
LATITUDE:	n/a°	**HAMMER TYPE:**	Automatic
LONGITUDE:	n/a°	**EFFICIENCY**	N/A
STATION: N/A **OFFSET:** N/A		**REVIEWED BY:**	F. Hoffman
REMARKS:			

Water

▽	9/5/2017 @ 3:55 p.m.	26.1 feet
▼	9/6/2017 @ 8:17 a.m.	27.4 feet
▽	9/6/2017 @ 11:34 a.m.	27.8 feet

BORING LOCATION:
See Boring Location Plan

Elevation (feet)	Depth, (feet)	Graphic Log	Sample Type	Sample No.	Recovery (inches)	MATERIAL DESCRIPTION	USCS Classification	SPT Blows per 6-inch (SS) RQD & Recovery % (NX)	Moisture, %	STANDARD PENETRATION TEST DATA N in blows/ft ◎ (× Moisture, PL, LL; 0–25–50) STRENGTH, tsf (▲ Qu, ✳ Qp; 0–2.0–4.0)	Additional Remarks
	60			R-11	60	**LIMESTONE**-Light gray to black, Very fine grained, Slightly Weathered, slightly broken to massive, hard to very hard, trace calcite stringers		RQD=90 Rec=100%			2 min. 2 min. 3 min. 2 min.
						DOLOMITE-Gray to dark gray, Very fine grained, Slightly Weathered, slightly broken to massive, very hard, trace calcite stringers					2 min.
	65			R-12	60	**LIMESTONE**-Light gray to dark gray, Very fine grained, Slightly Weathered, broken to massive, moderately hard		RQD=97 Rec=100%		>>▲	2 min. 3 min. 2 min. Q_u = 578.5 tsf 169.3 pcf 2 min. 3 min.
						LIMESTONE-Light gray-brown to dark gray-brown, Very fine grained, Weathered, very broken to broken, moderately hard					
	70			R-13	60	**LIMESTONE**-Light gray to black, Very fine grained, Slightly Weathered, massive, moderately hard to hard Broken seam @ 71.7 feet (~ 2-1/4 inches thick)		RQD=97 Rec=100%			2 min. 2 min. 2 min. 2 min.
						DOLOMITE-Gray to dark gray, Very fine grained, Slightly Weathered, slightly broken to massive, very hard, trace calcite stringers					2 min.
	75			R-14	60	**LIMESTONE**-Light gray-white to black, Very fine grained, Slightly Weathered, broken to massive, moderately hard to very hard		RQD=97 Rec=100%			2 min. 2 min. 2 min. 3 min. 2 min.
	80			R-15	60			RQD=97 Rec=100%		>>▲	Q_u = 513.5 tsf 168.9 pcf 2 min. 3 min. 2 min. 2 min. 2 min.
	85			R-16	60			RQD=73 Rec=100%			2 min. 3 min.
						DOLOMITE-Light gray to dark gray, Very fine grained, Slightly Weathered, broken to massive, hard, trace calcite stringers Vertical fracture from 87.1 to 87.8 feet.				>>▲	3 min. 3 min. Q_u = 668.5 tsf 175.1 pcf 2 min.
	90										

Continued Next Page

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PROJECT NO.: 04911465
PROJECT: Energy Transfer HDD (DPS)
LOCATION: HWY 15 (PPP4)
Cumberland Co., PA
PA-CU-0176.0019-RD/PO#20170824-1

The stratification lines represent approximate boundaries. The transition may be gradual.

DATE STARTED: 9/5/17	**DRILL COMPANY:** AWK Drilling	**BORING B-02**	
DATE COMPLETED: 9/6/17	**DRILLER:** T. Growden, Jr **LOGGED BY:** D. Calvert	**Water**	9/5/2017 @ 3:55 p.m. 26.1 feet
COMPLETION DEPTH 110.0 ft	**DRILL RIG:** CME 55 Track Mount		9/6/2017 @ 8:17 a.m. 27.4 feet
BENCHMARK: N/A	**DRILLING METHOD:** Casing/Rock Coring		9/6/2017 @ 11:34 a.m. 27.8 feet
ELEVATION: N/A	**SAMPLING METHOD:** 2-in SSNQ2-in Core	**BORING LOCATION:**	
LATITUDE: n/a°	**HAMMER TYPE:** Automatic	See Boring Location Plan	
LONGITUDE: n/a°	**EFFICIENCY** N/A		
STATION: N/A **OFFSET:** N/A	**REVIEWED BY:** F. Hoffman		
REMARKS:			

Elevation (feet)	Depth, (feet)	Graphic Log	Sample Type	Sample No.	Recovery (inches)	MATERIAL DESCRIPTION	USCS Classification	SPT Blows per 6-inch (SS) RQD & Recovery % (NX)	Moisture, %	STANDARD PENETRATION TEST DATA N in blows/ft ◎ (× Moisture, PL, LL; 0 25 50) STRENGTH, tsf ▲ Qu ✳ Qp (0 2.0 4.0)	Additional Remarks
	90			R-17	60	**LIMESTONE**-Light gray to black, Very fine grained, Slightly Weathered, broken to massive, hard to very hard, trace calcite stringers Broken layer @ 92.2 feet (~ 4-1/2 inches thick)		RQD=90 Rec=100%			2 min. 2 min. 2 min. 2 min. 2 min.
	95			R-18	60	Lost water return @ 9 feet		RQD=100 Rec=100%			3 min. 2 min. 2 min. 3 min. 2 min.
	100			R-19	60	Broken layer @ 103.3 feet (~ 4-1/2 inches thick) Broken seam @ 104.5 feet (~ 2-1/4 inches thick)		RQD=94 Rec=100%		>>▲	2 min. 2 min. 2 min. Q_u = 791.5 tsf 170.6 pcf 3 min.
	105			R-20	60			RQD=95 Rec=100%			3 min. 4 min. 3 min. 3 min. 3 min.
				R-21							
	110					Test boring terminated @ 111 feet					

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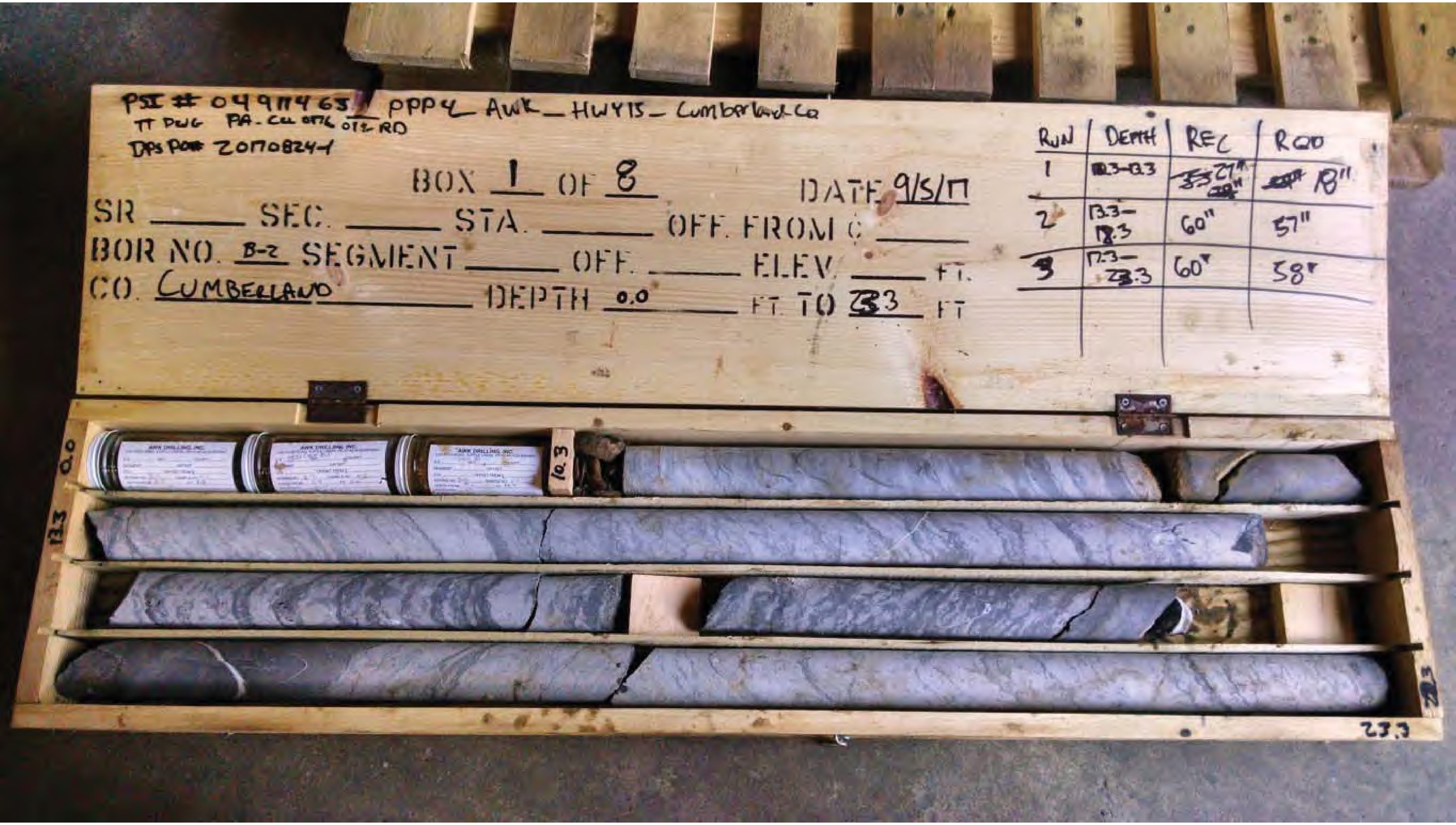
PROJECT NO.: 04911465
PROJECT: Energy Transfer HDD (DPS)
LOCATION: HWY 15 (PPP4)
Cumberland Co., PA
PA-CU-0176.0019-RD/PO#20170824-1

The stratification lines represent approximate boundaries. The transition may be gradual.


PSI # 04911463 PPP4_AWK_HWY15_Cumberland Co
BOX 1 OF 8
DATE 9/5/17
SR SEC. STA. OFF. FROM ℄
BOR NO. B-2 SEGMENT OFF. ELEV. FT.
CO. CUMBERLAND DEPTH 0.0 FT. TO 23.3 FT
RUN DEPTH REC RQD
1
2 13.3-18.3 60" 57"
3 60" 58"
AWK DRILLING INC.
0.0
10.3
13.3
23.3

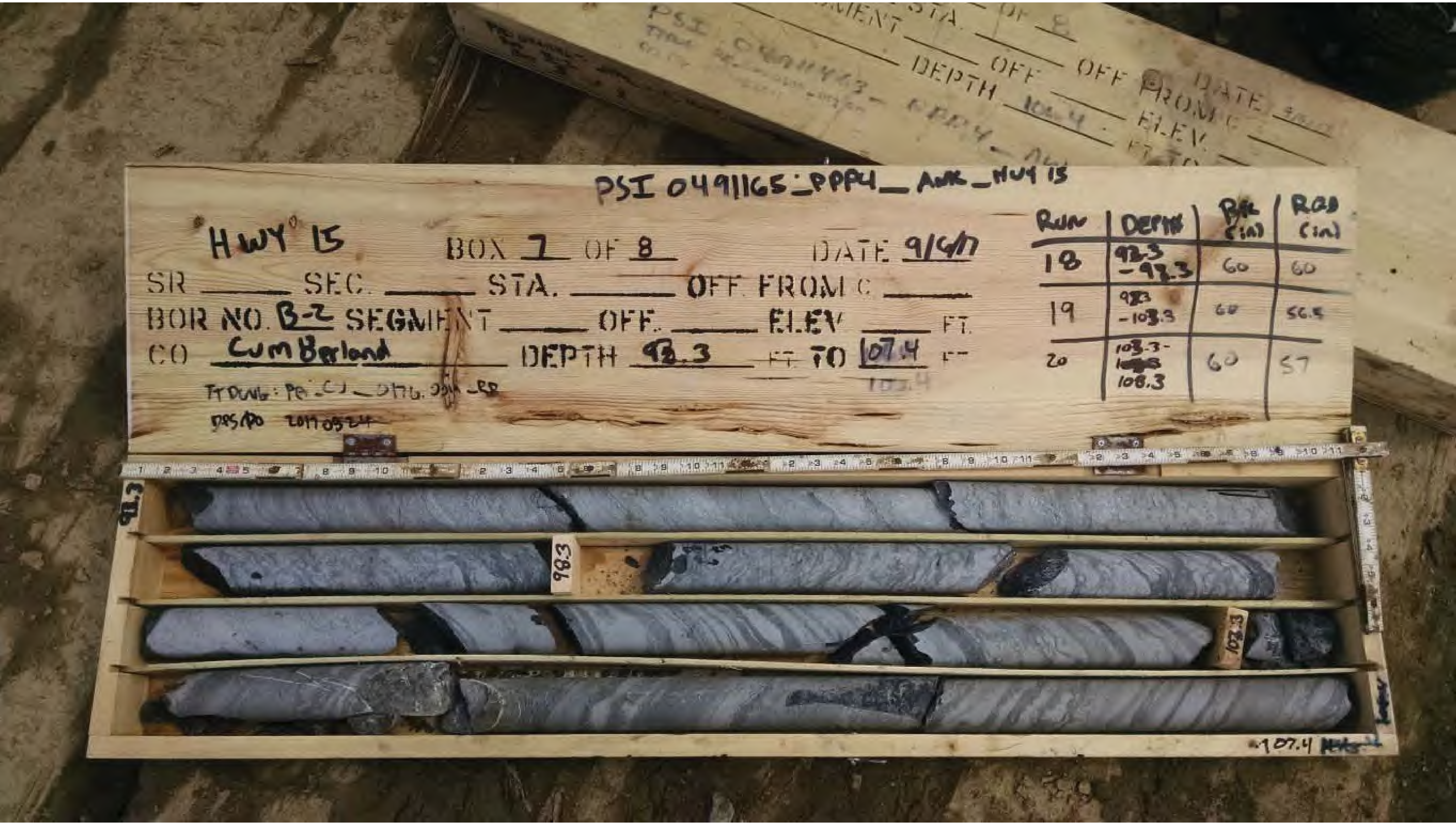
BOX 2 OF 8 DATE 9/5/17
SR SEC. STA. OFF. FROM ¢
BOR NO. B-2 SEGMENT OFF. ELEV. FT.
CO. Cumberland DEPTH 23.3 FT. TO 37.0 FT.
PSI #04911465_PPB4_AWL_HWY 15_Cumberland Co.
RUN
REC
4
60"
60"
5
60"
60"
6
60"
52"
23.3
28.3
33.3
37.0


BOX 3 OF 8
DATE 9/5/17
SR ___ SEC. ___ STA. ___ OFF. FROM ¢ ___
BOR NO. B-2 SEGMENT ___ OFF. ___ ELEV. ___ FT.
CO. Cumberland DEPTH 37.0 FT. TO 51.4 FT.
PSI# 04911465_ PPP4_ AWK_ Hwy 15_ Cumberland Co
RUN
DEPTH
REC
RQD
7
38.3 - 43.3
60"
58"
8
43.3 - 48.3
60
60
9
48.3 53.3
59"
50"
51.4


PSI # 04911465_PPP4LAWK_HWY15_CUMBERLAND Co
TT DOG: PA_CU_0176 0019-PO
D/S PO# 20170824-1
BOX 4 OF 8
DATE 9/5/17
SR SEC. STA. OFF. FROM ¢
BOR NO. B-2 SEGMENT OFF. ELEV. FT
CO CUMBERLAND DEPTH 51.4 FT. TO 65.4 FT.
RUN DEPTH REC RQD
10 53.3-58.3 60 53
11 57.3-63.3 60 54
12 63.3-68.3 60 58
59.3
63.3


BOX 5 OF 8
DATE 9/5/17
SR
SEC.
STA.
OFF. FROM ¢
BOR NO. B-2 SEGMENT
OFF.
ELEV.
FT.
CO. CUMBERLAND
DEPTH 65.4 FT TO 79.7 FT.
PSI: 04911463_PPPY_AWK_HWIS-CUMBERLAND CO.
PA_CU_0176001_RD
DPS POD 20170829-1
RUN
DEPTH
REC
RQD
13
68.3 - 73.3
60
58
14
73.3 - 78.3
60
58
15
78.3 - 83.3
60
58
65.4
68.3
73.3
78.3
79.7

BOX 6 OF 8
DATE
SR SEC STA. OFF. FROM ¢
BOR NO. B-2 SEGMENT OFF. ELEV. FT.
CO. CUMBERLAND DEPTH 79.7 FT. TO FT.
PSI: 04911463_ PPP4_ AWK _ HW15_ CUMBERLANDCO
TTDWG: PA_CU_
DPS
RUN
DEPTH (ft)
REC (in)
RQD (in)
16
60
44
17
60
54
88.3
93.3


PSI 0491165_PPPU_ AWK_HWY 15
HWY 15
BOX 7 OF 8
DATE 9/6/17
SR
SEC.
STA.
OFF. FROM ℄
BOR NO. B-2
SEGMENT
OFF.
ELEV
FT.
CO Cum Berland
DEPTH 98.3
FT. TO 107.4
FT.
RUN
DEPTH
REC (in)
RQD (in)
18
98.3 -98.3
60
60
19
98.3 -103.3
60
56.5
20
103.3- 108.3
60
57
98.3
103.3
107.4


PSI: [redacted] 04911463_PPP4 - ...
BOX 8 OF 8
DATE 9/6/17
SR SEC OFF. FROM ℄
BOR. NO. B-2 SEGMENT OFF. ELEV. FT
CO Cumberland DEPTH 107.4 FT TO 111.0 FT
Run
DEPTH
Rec
21
108.3
111.0
32.4
25.0
108.3
111.0

GENERAL NOTES

SAMPLE IDENTIFICATION

The Unified Soil Classification System (USCS), AASHTO 1988 and ASTM designations D2487 and D-2488 are used to identify the encountered materials unless otherwise noted. Coarse-grained soils are defined as having more than 50% of their dry weight retained on a #200 sieve (0.075mm); they are described as: boulders, cobbles, gravel or sand. Fine-grained soils have less than 50% of their dry weight retained on a #200 sieve; they are defined as silts or clay depending on their Atterberg Limit attributes. Major constituents may be added as modifiers and minor constituents may be added according to the relative proportions based on grain size.

DRILLING AND SAMPLING SYMBOLS

SFA: Solid Flight Auger - typically 4" diameter flights, except where noted.
HSA: Hollow Stem Auger - typically 3¼" or 4¼ I.D. openings, except where noted.
M.R.: Mud Rotary - Uses a rotary head with Bentonite or Polymer Slurry
R.C.: Diamond Bit Core Sampler
H.A.: Hand Auger
P.A.: Power Auger - Handheld motorized auger

SS: Split-Spoon - 1 3/8" I.D., 2" O.D., except where noted.
ST: Shelby Tube - 3" O.D., except where noted.
RC: Rock Core
TC: Texas Cone
BS: Bulk Sample
PM: Pressuremeter
CPT-U: Cone Penetrometer Testing with Pore-Pressure Readings

SOIL PROPERTY SYMBOLS

N: Standard "N" penetration: Blows per foot of a 140 pound hammer falling 30 inches on a 2-inch O.D. Split-Spoon.
N_{60}: A "N" penetration value corrected to an equivalent 60% hammer energy transfer efficiency (ETR)
Q_u: Unconfined compressive strength, TSF
Q_p: Pocket penetrometer value, unconfined compressive strength, TSF
w%: Moisture/water content, %
LL: Liquid Limit, %
PL: Plastic Limit, %
PI: Plasticity Index = (LL-PL),%
DD: Dry unit weight, pcf
▼,▽,▼: Apparent groundwater level at time noted

RELATIVE DENSITY OF COARSE-GRAINED SOILS

Relative Density	N - Blows/foot
Very Loose	0 - 4
Loose	4 - 10
Medium Dense	10 - 30
Dense	30 - 50
Very Dense	50 - 80
Extremely Dense	80+

ANGULARITY OF COARSE-GRAINED PARTICLES

Description	Criteria
Angular:	Particles have sharp edges and relatively plane sides with unpolished surfaces
Subangular:	Particles are similar to angular description, but have rounded edges
Subrounded:	Particles have nearly plane sides, but have well-rounded corners and edges
Rounded:	Particles have smoothly curved sides and no edges

GRAIN-SIZE TERMINOLOGY

Component	Size Range
Boulders:	Over 300 mm (>12 in.)
Cobbles:	75 mm to 300 mm (3 in. to 12 in.)
Coarse-Grained Gravel:	19 mm to 75 mm (¾ in. to 3 in.)
Fine-Grained Gravel:	4.75 mm to 19 mm (No.4 to ¾ in.)
Coarse-Grained Sand:	2 mm to 4.75 mm (No.10 to No.4)
Medium-Grained Sand:	0.42 mm to 2 mm (No.40 to No.10)
Fine-Grained Sand:	0.075 mm to 0.42 mm (No. 200 to No.40)
Silt:	0.005 mm to 0.075 mm
Clay:	<0.005 mm

PARTICLE SHAPE

Description	Criteria
Flat:	Particles with width/thickness ratio > 3
Elongated:	Particles with length/width ratio > 3
Flat & Elongated:	Particles meet criteria for both flat and elongated

RELATIVE PROPORTIONS OF FINES

Descriptive Term	% Dry Weight
Trace:	< 5%
With:	5% to 12%
Modifier:	>12%

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GENERAL NOTES

(Continued)

CONSISTENCY OF FINE-GRAINED SOILS

Q_U - TSF	N - Blows/foot	Consistency
0 - 0.25	0 - 2	Very Soft
0.25 - 0.50	2 - 4	Soft
0.50 - 1.00	4 - 8	Firm (Medium Stiff)
1.00 - 2.00	8 - 15	Stiff
2.00 - 4.00	15 - 30	Very Stiff
4.00 - 8.00	30 - 50	Hard
8.00+	50+	Very Hard

MOISTURE CONDITION DESCRIPTION

Description	Criteria
Dry:	Absence of moisture, dusty, dry to the touch
Moist:	Damp but no visible water
Wet:	Visible free water, usually soil is below water table

RELATIVE PROPORTIONS OF SAND AND GRAVEL

Descriptive Term	% Dry Weight
Trace:	< 15%
With:	15% to 30%
Modifier:	>30%

STRUCTURE DESCRIPTION

Description	Criteria
Stratified:	Alternating layers of varying material or color with layers at least ¼-inch (6 mm) thick
Laminated:	Alternating layers of varying material or color with layers less than ¼-inch (6 mm) thick
Fissured:	Breaks along definite planes of fracture with little resistance to fracturing
Slickensided:	Fracture planes appear polished or glossy, sometimes striated

Description	Criteria
Blocky:	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed:	Inclusion of small pockets of different soils
Layer:	Inclusion greater than 3 inches thick (75 mm)
Seam:	Inclusion 1/8-inch to 3 inches (3 to 75 mm) thick extending through the sample
Parting:	Inclusion less than 1/8-inch (3 mm) thick

SCALE OF RELATIVE ROCK HARDNESS

Q_U - TSF	Consistency
2.5 - 10	Extremely Soft
10 - 50	Very Soft
50 - 250	Soft
250 - 525	Medium Hard
525 - 1,050	Moderately Hard
1,050 - 2,600	Hard
>2,600	Very Hard

ROCK BEDDING THICKNESSES

Description	Criteria
Very Thick Bedded	Greater than 3-foot (>1.0 m)
Thick Bedded	1-foot to 3-foot (0.3 m to 1.0 m)
Medium Bedded	4-inch to 1-foot (0.1 m to 0.3 m)
Thin Bedded	1¼-inch to 4-inch (30 mm to 100 mm)
Very Thin Bedded	½-inch to 1¼-inch (10 mm to 30 mm)
Thickly Laminated	1/8-inch to ½-inch (3 mm to 10 mm)
Thinly Laminated	1/8-inch or less "paper thin" (<3 mm)

ROCK VOIDS

Voids	Void Diameter
Pit	<6 mm (<0.25 in)
Vug	6 mm to 50 mm (0.25 in to 2 in)
Cavity	50 mm to 600 mm (2 in to 24 in)
Cave	>600 mm (>24 in)

GRAIN-SIZED TERMINOLOGY

(Typically Sedimentary Rock)

Component	Size Range
Very Coarse Grained	>4.76 mm
Coarse Grained	2.0 mm - 4.76 mm
Medium Grained	0.42 mm - 2.0 mm
Fine Grained	0.075 mm - 0.42 mm
Very Fine Grained	<0.075 mm

ROCK QUALITY DESCRIPTION

Rock Mass Description	RQD Value
Excellent	90 -100
Good	75 - 90
Fair	50 - 75
Poor	25 -50
Very Poor	Less than 25

Degree of Brokeness

Characteristic	Description
Less than 1 inch	Very Broken
1 inch to 3 inches	Broken
3 inches to 6 inches	Slightly Broken
Greater than 6 inches	Massive

DEGREE OF WEATHERING

Slightly Weathered:	Rock generally fresh, joints stained and discoloration extends into rock up to 25 mm (1 in), open joints may contain clay, core rings under hammer impact.
Weathered:	Rock mass is decomposed 50% or less, significant portions of the rock show discoloration and weathering effects, cores cannot be broken by hand or scraped by knife.
Highly Weathered:	Rock mass is more than 50% decomposed, complete discoloration of rock fabric, core may be extremely broken and gives clunk sound when struck by hammer, may be shaved with a knife.

SOIL CLASSIFICATION CHART

NOTE: DUAL SYMBOLS ARE USED TO INDICATE BORDERLINE SOIL CLASSIFICATIONS

MAJOR DIVISIONS			SYMBOLS GRAPH	SYMBOLS LETTER	TYPICAL DESCRIPTIONS
COARSE GRAINED SOILS MORE THAN 50% OF MATERIAL IS LARGER THAN NO. 200 SIEVE SIZE	GRAVEL AND GRAVELLY SOILS MORE THAN 50% OF COARSE FRACTION RETAINED ON NO. 4 SIEVE	CLEAN GRAVELS (LITTLE OR NO FINES)		GW	WELL-GRADED GRAVELS, GRAVEL - SAND MIXTURES, LITTLE OR NO FINES
				GP	POORLY-GRADED GRAVELS, GRAVEL - SAND MIXTURES, LITTLE OR NO FINES
		GRAVELS WITH FINES (APPRECIABLE AMOUNT OF FINES)		GM	SILTY GRAVELS, GRAVEL - SAND - SILT MIXTURES
				GC	CLAYEY GRAVELS, GRAVEL - SAND - CLAY MIXTURES
	SAND AND SANDY SOILS MORE THAN 50% OF COARSE FRACTION PASSING ON NO. 4 SIEVE	CLEAN SANDS (LITTLE OR NO FINES)		SW	WELL-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES
				SP	POORLY-GRADED SANDS, GRAVELLY SAND, LITTLE OR NO FINES
		SANDS WITH FINES (APPRECIABLE AMOUNT OF FINES)		SM	SILTY SANDS, SAND - SILT MIXTURES
				SC	CLAYEY SANDS, SAND - CLAY MIXTURES
FINE GRAINED SOILS MORE THAN 50% OF MATERIAL IS SMALLER THAN NO. 200 SIEVE SIZE	SILTS AND CLAYS	LIQUID LIMIT LESS THAN 50		ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
				CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
				OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY
	SILTS AND CLAYS	LIQUID LIMIT GREATER THAN 50		MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SAND OR SILTY SOILS
				CH	INORGANIC CLAYS OF HIGH PLASTICITY
				OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
HIGHLY ORGANIC SOILS				PT	PEAT, HUMUS, SWAMP SOILS WITH HIGH ORGANIC CONTENTS

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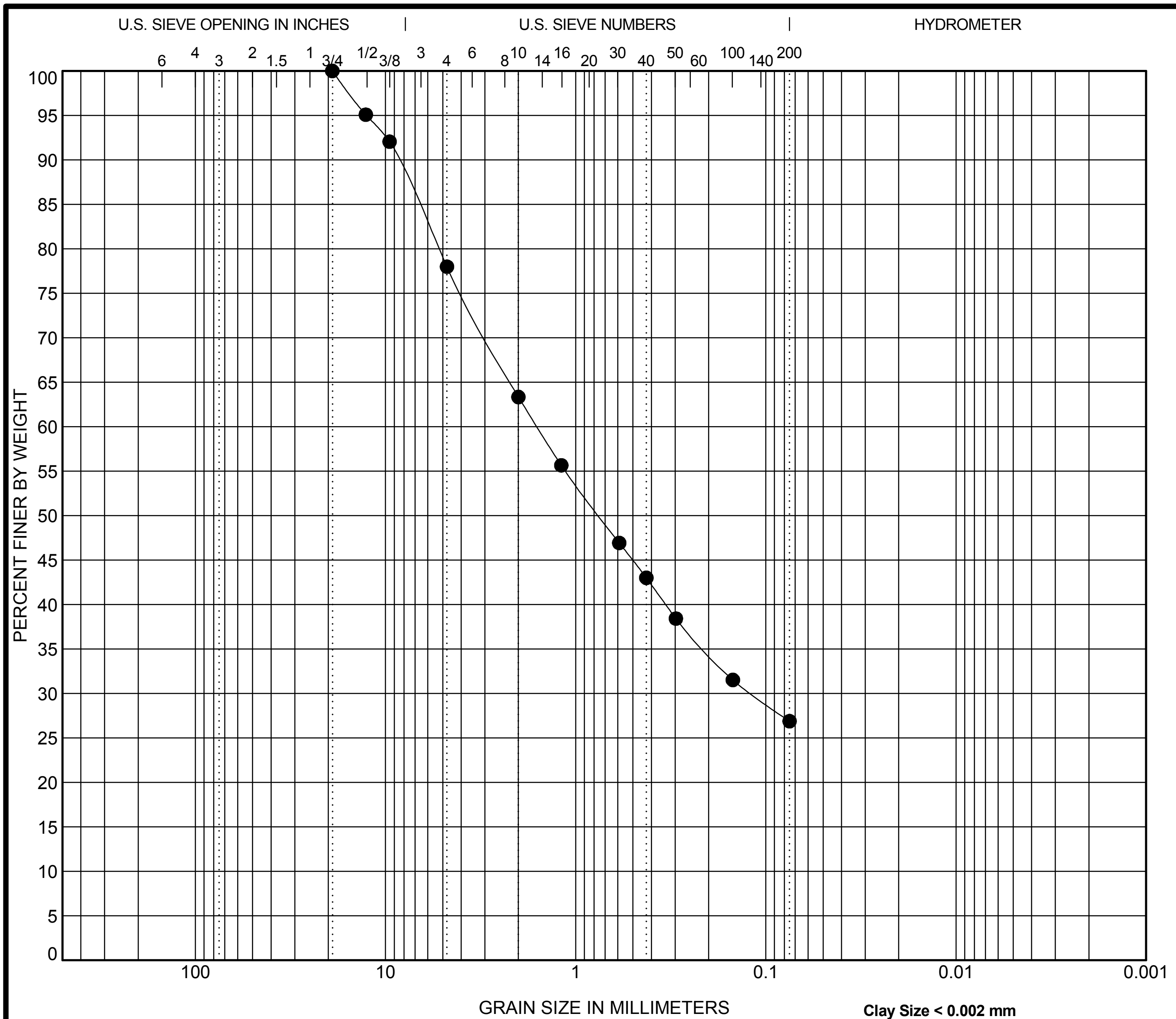
Table 4–3 Hardness and unconfined compressive strength of rock materials

Hardness category	Typical range in unconfined compressive strength (MPa)	Strength value selected (MPa)	Field test on sample	Field test on outcrop
Soil*	< 0.60		Use USCS classifications	
Very soft rock or hard, soil-like material	0.60–1.25		Scratched with fingernail. Slight indentation by light blow of point of geologic pick. Requires power tools for excavation. Peels with pocket knife.	
Soft rock	1.25–5.0		Permits denting by moderate pressure of the fingers. Handheld specimen crumbles under firm blows with point of geologic pick.	Easily deformable with finger pressure.
Moderately soft rock	5.0–12.5		Shallow indentations (1–3 mm) by firm blows with point of geologic pick. Peels with difficulty with pocket knife. Resists denting by the fingers, but can be abraded and pierced to a shallow depth by a pencil point. Crumbles by rubbing with fingers.	Crumbles by rubbing with fingers.
Moderately hard rock	12.5–50		Cannot be scraped or peeled with pocket knife. Intact handheld specimen breaks with single blow of geologic hammer. Can be distinctly scratched with 20d common steel nail. Resists a pencil point, but can be scratched and cut with a knife blade.	Unfractured outcrop crumbles under light hammer blows.
Hard rock	50–100		Handheld specimen requires more than one hammer blow to break it. Can be faintly scratched with 20d common steel nail. Resistant to abrasion or cutting by a knife blade, but can be easily dented or broken by light blows of a hammer.	Outcrop withstands a few firm blows before breaking.
Very hard rock	100–250		Specimen breaks only by repeated, heavy blows with geologic hammer. Cannot be scratched with 20d common steel nail.	Outcrop withstands a few heavy ringing hammer blows but will yield large fragments.
Extremely hard rock	> 250		Specimen can only be chipped, not broken by repeated, heavy blows of geologic hammer.	Outcrop resists heavy ringing hammer blows and yields, with difficulty, only dust and small fragments.

Method used to determine consistency or hardness (check one):
Field assessment: _____ Uniaxial lab test: _____ Other: __________ Rebound hammer (ASTM D5873): _____
* See NEH631.03 for consistency and density of soil materials. For very stiff soil, SPT N values = 15 to 30. For very soft rock or hard, soil-like material, SPT N values exceed 30 blows per foot.



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification		Classification	LL	PL	PI	Cc	Cu
● B-02	4.5	Clayey SAND with Gravel (SC)					

Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● B-02	4.5	19.05	1.597	0.119		22.0	51.1	26.9	

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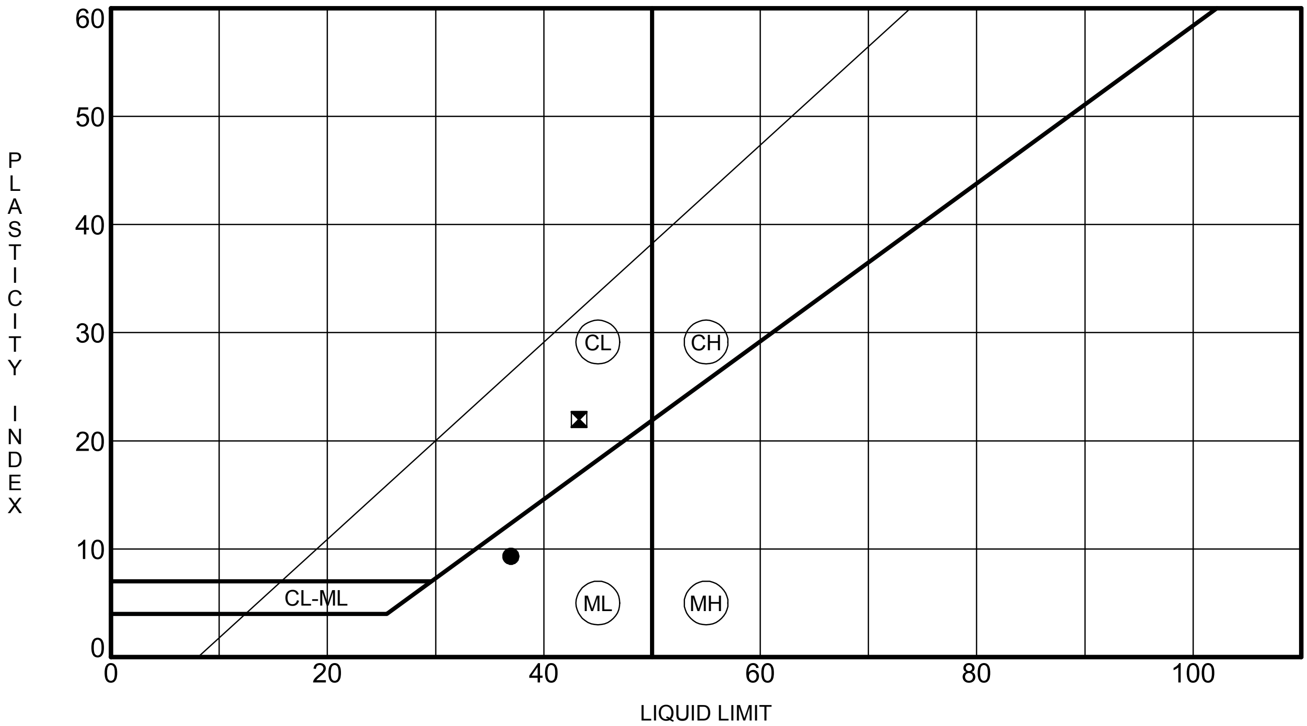
GRAIN SIZE DISTRIBUTION

Project: Energy Transfer HDD (DPS)
PSI Job No.: 04911465
Location: HWY 15 (PPP4)
Cumberland Co., PA



	Boring	Depth (ft)	LL	PL	PI	Fines	Classification (*Visual)
●	**B-01**	**6.0**	**37**	**28**	**9**		**SILT with Sand (ML)**
⧗	**B-02**	**9.0**	**43**	**21**	**22**		**Lean CLAY (CL)**

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ATTERBERG LIMIT RESULTS

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Cumberland Co., PA

Laboratory Summary Sheet

Borehole	Approx. Depth	Liquid Limit	Plastic Limit	Plasticity Index	Qu (tsf)	%<#200 Sieve	Est. Specific Gravity	Water Content (%)	Dry Density (pcf)	Satur-ation (%)	Void Ratio
B-01	1							22			
B-01	6	37	28	9				36			
B-01	11				495.04						
B-01	22.1				552.79						
B-01	28.4				1319.18						
B-01	34.9				301.38						
B-01	40.6				695.34						
B-01	57				503.52						
B-01	67.4				564.48						
B-01	78.2				290.38						
B-02	1							23			
B-02	4.5					26.9%		18			
B-02	9	43	21	22				45			
B-02	10							38			
B-02	11.1				546.32						
B-02	21.5				666.23						
B-02	31.7				853.51						
B-02	40.8				229.87						
B-02	47.5				1336.64						
B-02	58.7				992.64						
B-02	67.8				578.50						
B-02	79.9				513.45						
B-02	88.5				668.55						
B-02	102.6				791.47						

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Summary of Laboratory Results

PSI Job No.: 04911465
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Cumberland Co., PA
PA-CU-0176.0019-RD/PO#20170824-1