HORIZONTAL DIRECTIONAL DRILL ANALYSIS
PARK ROAD CROSSING
PADEP SECTION 105 PERMIT NO.: E15-862
PA-CH-0111.0000-RD-20
(SPLP HDD# S3-0300-20)

HORIZONTAL DIRECTIONAL DRILL ANALYSIS
PARK ROAD CROSSING
PADEP SECTION 105 PERMIT NO.: E15-862
PA-CH-0111.0000-RD-16
(SPLP HDD# S3-0300-20)

This reanalysis of the horizontal directional drill (HDD) installation of a 20-inch diameter pipeline that traverses Park Road and Wetland C43, in Upper Uwchlan Township, Chester 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 18 on the list of HDDs included on Exhibit 3 of the Order.

The 16-inch HDD was initiated before the temporary injunction issued by the Pennsylvania Department of Environmental Protection (PADEP) Environmental Hearing Board on July 25, 2017. This HDD had inadvertent returns (IRs) on the installation of the first pipe (16-inch), and therefore, the installation of the second pipe (20-inch) requires reanalysis. The IRs associated with the HDD of the 16-inch pipe were remediated and the installation of the 16-inch pipeline was completed.

The 20-inch pipe HDD is referred to herein as HDD S3-0300-20.

PIPE INFORMATION

20-Inch: 0.456 wall thickness; X-65

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

For steel pipe the "pipe stress allowance" is the amount of curvature that a piece or length of pipeline can bend without resulting in damages such as a "kink" or "crimp" in the wall of the pipe. The innate curvature ability of pipe is termed the "free stress radius". The stress allowances of the pipe are determined by the ductility of the steel, wall thickness, and the diameter of the pipe. An HDD design is limited by the horizontal distance between the points of entry and exit and the free stress radius of the pipe.

Ductility of the steel used for pipelines is determined by the percentage of carbon within the steel. Generally steel pipe is categorized as "low carbon" having less than 0.3% carbon content within the steel, and "high carbon" having greater than 3% carbon within the steel. As the carbon content within the steel used to make the pipe increases, the flexibility of the pipe is decreased. The X65 20-inch pipe utilized on the Mariner project is a low carbon steel pipe.

The design of an HDD profile accounts for the free stress radius of the pipeline segment to be pulled into the drilled entry, through the entry radius of curvature at maximum horizontal depth, out the exit radius leaving maximum depth, and out the drilled exit; therefore, each HDD has a minimum of four (4) points of pipeline curvature to assess for pipeline stress. Additionally, a horizontally drilled profile is not a "perfect" pathway, especially when drilled through rock formations. The pilot tool cutting into the rock face has a larger cutting face than the drill stem pushing the tool forward, which results in flexibility of the tooling within the pilot hole, and as a result the pilot tool will drift in orientation as proceeding forward because the cutting tool will proceed easier into softer material while cutting due to natural variances in hardness of the materials being cut, whether they are soils or rock. Steering of the pilot tool is used to correct drifting as it occurs. As a result of this natural drifting during completion of the pilot hole, the entire length of the drilled pilot hole is assessed for stress allowances on three (3) joint intervals before reaming of the annulus is permitted. If errors during pilot drilling or reaming occur and a mid-point is identified that would breach the pipe stress allowance, then the use of an over-reamed annulus is assessed for breach of the stress allowance. In cases where an over-reamed annulus will not correct the stress problem, then the HDD must be re-drilled.

All the information and the stress assessment procedures discussed above are incorporated into the profile design and implemented in analysis of the drilling profile to ensure the integrity of the pipeline as installed.

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Specifics for the original permitted 20-inch HDD plan and profile are discussed in the original permitted HDD design summary below. Specifics for the revised 20-Inch HDD plan and profile are discussed in the Redesigned Horizontal Directional Drill Design Summary at the end of this report.

ORIGINAL HORIZONTAL DIRECTIONAL DRILL DESIGN SUMMARY: 20-INCH

- Horizontal length: 2,030 feet (ft)
- Entry/Exit angle: 10 degrees
- Maximum depth of cover: 87 ft
- Depth of cover under wetlands and streams: 15 – 80 ft
- Pipe design radius: 2,000 ft

The original profile design factors are below the pipeline stress allowances for all points of analysis.

ROOT CAUSE ANALYSIS FOR THE 16-INCH PIPE INSTALLATION INADVERTENT RETURNS

Two IRs occurred during installation of the 16-inch pipeline. One during the pilot phase, approximately 5 gallons in volume, and one during the reaming phase, less than 1 gallon in volume. Both IRs occurred at 250 to 279 ft before the HDD exit point, while drilling tools were between 34 and 40 ft below the ground surface.

Drilling fluid pressures were reduced to minimum levels, which allowed for completion of the pilot hole without an additional incident. When the IR occurred in the reaming phase, the reamer was retreated and then installed at the exit point and pulled to the previously reamed section of the profile, and no additional incidents occurred during completion of the ream.

In both IR instances, the drilling tools were past the exit radius and proceeding to the exit point with decreasing depth below ground while proceeding through weathered bedrock with poor qualities. Due to the distance from entry, it is obvious that the drilling fluid pressures required to maintain return flows to the entry pit exceeded the retention strength of the bedrock and overburden; therefore, the root cause of the IRs is poor rock/overburden strength while operating at normal drilling fluid pressure to maintain return flows.

GEOLOGIC ANALYSIS

HDD S3-0300-20 is located within the Piedmont Uplands Section of the Piedmont Physiographic Province in Southeast Pennsylvania. At this location, gneiss bedrock is overlain by relatively thick, highly weathered and fractured bedrock or saprolite containing variegated micaceous sands and silts with weathered rock fragments. The majority of the bedrock at the redesigned 20-inch HDD profile is mapped as crystalline, Precambrian-aged graphitic felsic gneiss, historically referred to as the Pickering Gneiss. The northwest third of the HDD skirts the contact between the Pickering Gneiss and a banded mafic gneiss (PaGEODE).

The Pickering Gneiss is a medium-gained crystalline aggregate of quartz, feldspar, hornblende, and mica. The diagnostic secondary constituent of the Pickering Gneiss is graphite, which is more or less abundantly present parallel to the gneissic structures. The distinctive graphite-bearing beds of the Pickering Gneiss are often yellowish or reddish due to the oxidation of iron-bearing secondary minerals. The rock can very spatially in the primary mineral constituents so that quartz schist, quartz-feldspar gneiss, mica schist and hornblende schist also account for graphite-bearing rock (Bascom and Stose, 1938).

The banded mafic gneiss is a dark, medium-to fine grained rock consisting of calcic plagioclase, hypersthene or augite, and quartz and can be felsic locally. Banding is poorly developed and massive (PaGEODE).

These gneiss units are generally buried under a thick mantle of soil comprised of decomposed bedrock. Where exposed over geologic time, the rock decomposes into a softer material that maintains its original texture (saprolite). Soil borings advanced in the area of HDD S3-0300-20 confirm the presence of saprolite up to 30 feet thick and fractured, low RQD (25 percent or less) bedrock to as much as 116 feet below ground surface.

No karst features are anticipated within the overall vicinity of HDD S3-0300-20 because limestone and marble units are absent or insignificant and there are no known or mapped sinkholes in the area of the drill path (Kochanov 1993; Kochanov and Reese 2003).

A multi-method geophysical survey at the S3-0300 HDD was performed in January 2019. The purpose of the survey was to detect and delineate subsurface fracture zones that could contribute to potential IRs and/or losses of circulation (LOCs), and to determine the rock profile and rock rippability/strength for comparison to drilling hardness. Seismic refraction with seismic multi-spectral analysis of surface waves (MASW) and refraction methods were used to identify potential fracture zones and approximate the depth of competent bedrock along the profile. The combined methods identified potential fracture zones crossing the alignment at a frequency of approximately one zone every 60 feet. The seismic refraction profiles indicate the depth to competent bedrock ranges from approximately 10 to 27 feet.

The HDD of Park Road and Wetland C43 will be within metamorphic rock that contains variable amounts of weathering and rock strength. Based upon the deep vertical geotechnical cores performed in 2017, at the west end of the HDD, soil overburden occurs to 6 ft of depth, then transitions to highly weathered rock with poor recovery values and no RQD value from 6 – 66 ft of depth. From 66 ft of depth to profile depth core recovery varied from 0 – 41%, and RQD values ranged from 0 – 27. Data from the eastern core shows soil to 16 ft of depth; from 16 – 49 ft of depth core data indicates weathered bedrock having recovery values of 0 – 72%, and RQD values of 7 – 35. From 49 ft of depth to profile depth recovery values ranged from 26 – 100, and RQD values range from 41 – 93.

Based upon the drilling data from the 16-inch installation it appears the eastern geotech data is representative of the majority of the HDD profile.

Attachment 1 provides a discussion on the geology and results of the geotechnical and geophysical investigation performed at this location.

HYDROGEOLOGY, GROUND WATER, AND WELL PRODUCTION ZONES

Most groundwater in the gneissic units of Chester County is stored in the unconsolidated weathered rock near the land surface with lesser amount stored in the underlying bedrock fractures. Based on soil borings and borings advanced into bedrock, groundwater has been encountered in both the soil/weathered bedrock zone and more competent bedrock, under water-table conditions.

Wetland W-C43 as well as stream S-C87 and its tributaries represent a local groundwater discharge point. Stream S-C87 flows to the west towards Marsh Creek and Marsh Creek Lake.

Depth to the water table in the fractured gneiss is generally less than 50 ft-bgs (Low et al. 2002). In the geo-technical borings advanced in 2015, groundwater was encountered at a depth of 16 feet in SB-01 and 18 feet in SB-02. In the geo-technical borings advanced in 2017, groundwater was encountered at a depth of 9.5 feet in B6-20W and 9.0 feet in B6-20E. Based upon water level data reported to Pennsylvania Groundwater Information System (PAGWIS) for wells in gneissic bedrock in Uwchlan and Upper Uwchlan Townships of Chester County, groundwater levels ranged from 4 to 170 ft-bgs with an average depth of 36 ft-bgs. Per PAGWIS, the range in well yields were from 1 to 200 gallons per minute with an average of 21 gallons per minutes.

As a condition of the corrected Stipulated Order, other Sunoco subcontractors have researched private water supplies within a 450-foot radius of the HDD. Six private supply wells are located within 450-feet of the HDD and two domestic wells are located just outside of the 450-foot search area. One of the eight well owners reported a depth to water of 35 ft-bgs. Information regarding depth to water in the remaining seven wells and well yield for any of the wells was not known.

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

ADJACENT FEATURES ANALYSIS

The crossing of Park Road is located in Upper Uwchlan Township, Chester County, approximately 0.6 miles southeast of the community of Eagle, in a suburban area with residential home sites along public roadways, farmland, and unmanaged woodlands. The Pennsylvania Turnpike is approximately 900 ft north of this HDD.

The pipeline route follows parallel to an existing SPLP pipeline easement from approximately the intersection of Park Road with Moore Road to approximately 360 ft south of the most southern baseball field at Hickory Park. This HDD is set under Park Road, various utilities (overhead electric line and underground utilities, including gas pipelines and a fiber optic line) situated immediately adjacent and parallel to or crossing perpendicular to the easement, residences, a recreational park, Wetland C43, and five streams (Streams S-C92, S-C91, S-C90, S-C89, and S-C87). Streams S-C92, S-C91, S-C90, and S-C89 drain to Marsh Creek, a Chapter 93 designated high quality trout fishery. Stream S-C87 is a Chapter 93 designated high quality trout stocked fishery. Wetland C43 is comprised of emergent and forested vegetation cover types. The presence of the aforementioned features necessitated the HDD to avoid effects on: public infrastructure; a recreational park; utilities; two high quality streams and their floodways; three streams that drain to a high quality stream and their floodways; forested wetland conversion; and habitat for the threatened bog turtle.

SPLP identified all landowners within a 450-foot radius of the HDD profile and 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, six private water supply wells were identified within 450 ft of the original permitted HDD profile. Two private water supply wells were identified just outside of the 450-foot search area. A map of these well locations is provided within the Hydrogeologic Report in Attachment 1. No well complaints were received during drilling and installation of the 16-inch pipeline.

With landowner permission, eight wells within and adjacent to 450 ft of the original permitted HDD profile were sampled. This sampling effort will be repeated after installation of the 20-inch pipeline is completed.

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To further avoid and mitigate any adverse effects from the HDD to private water wells, and 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 this HDD location.

ALTERNATIVES ANALYSIS

As required by the Order, the reanalysis of HDD S3-0300-20 includes an evaluation of open cut alternatives and a re-route analysis. As part of the Pennsylvania Department of Environmental Protection (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 HDD as originally permitted was designed to avoid direct impacts to Park Road; three residential home sites; five streams and their associated floodways and forested wetland riparian areas; habitat for the threatened bog turtle; parallel and crossing utilities; a recreational park, and public infrastructure.

Open-cut Analysis

SPLP specifications require a minimum of 48 inches of cover over the installed pipelines below ground and below the bottom of watercourses. To meet this cover requirement, open cut construction through Wetland C43 and five streams (Streams S-C92, S-C91, S-C90, S-C89, and S-C87) would require a minimum authorized open cut work space 50 ft in width to accommodate the 20-inch diameter pipeline, allowing for the pipeline to be installed with sufficient separation for integrity management and in consideration of the effects of trenching in open water on construction workspace. The assessed area of impact by this open cut plan would directly affect: 3,770 square feet of state water bottoms; 1.1 acres of floodway; 1.5 acres of wetlands, including conversion of 0.4 acre of forested wetlands; and 1.9 acres of conversion of forested uplands. As a result, the alteration of the current permitted route from HDD to open cut would require major modifications of the state Chapter 102 and Chapter 105 permits, and associated authorizations issued by the United States Army Corps of Engineers.

440 linear ft of the HDD profile passes under three residential home sites, one of which is 36 ft from the 20-inch centerline, and a second is 56 ft from the 20-inch centerline.

Although technically feasible, comparing the direct effects of open cut construction to the occurrence of two IRs totaling less than 6 gallons in volume, which were readily contained and cleaned up, results in SPLP's opinion that an HDD crossing of this area is still the preferred methodology.

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 ft at a time, or less, varying by the underlying substrate. Conventional auger bores for the 16-inch pipeline, attempted at longer distances, have at times had alignment drift and elevation deflections occur which have complicated installation.

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The horizontal length of this crossing (greater than 2,028 ft) is beyond the technically practicable limits of a conventional auger bore to complete regardless of substrate or topographic conditions. Subset within this length, a conventional auger bore of Park Road and the residential home sites southeast of Park Road would need to be at least 530 ft in length. This length of crossing is beyond the technically practicable limits of a conventional auger bore. If it were possible, it would also result in aboveground disturbance to public recreational fields in Hickory Park due to access and workspace requirements. Similarly, a conventional auger bore of Wetland C43 and five streams (Streams S-C92, S-C91, S-C90, S-C89, and S-C87) would need to be at least 1,100 ft in length, which is beyond the technically feasible limits of such an installation method.

FlexBor Analysis

SPLP contractors attempted three (3) FlexBors and partially completed two of these to replace HDDs on the Mariner Project. One FlexBor failed in the pilot phase and was replaced with a conventional bore under a highway and open cut construction. The two partially successful FlexBors completed the pilot phases, but both had difficulties completing the reaming phase. SPLP's analysis is that this technology is not perfected for larger diameter bore attempts.

Direct Pipe Bore Analysis

The direct pipe bore method is also known as "microtunneling". This method of pipeline installation is a remote-controlled, continuously supported pipe jacking method. During the direct pipe installation, operations are managed by an operator in an above-ground control room alongside of the installation pit. Rock and soil cutting and removal occurs by drilling fluid injection through the cutting tool during rotation at the face of the bore, and the cuttings are forced into inlet holes in the crushing cone at the tool face for circulation to a recycling plant through a closed system. The entire operating system for this method of pipeline installation, including the cutting tool drive hydraulics, fluid injection, fluid return, and operating controls are enclosed inside the outside diameter bore pipe (or casing pipe) being installed. At the launching point/entry pit, the bore pipe is attached to a "jacking block" that hammers the bore pipe while the tool is cutting through the substrate or geology. The cutting tool face is marginally larger in diameter than the pipe it is attached to. As a result, there is minimal annulus space, which minimizes the potential for drilling fluid returns or the production of groundwater returning back to the point of entry. Unlike an HDD, this technology has no steering capability. Changes in direction are made by adjusting the cutting angle of the tool face which results in a maximum of 4 degrees radius between the point of entry and exit.

SPLP's construction contractors have successfully completed one (1) Direct Pipe Bore approximately 925 ft on the Pennsylvania Pipeline Project at the crossing of the Frankston Branch of the Juniata River in Blair County. This Direct Pipe Bore was setup within a relatively flat area immediately outside the river floodplain and bored under the floodplain, wetlands, and river, exiting at the toe of a mountain slope.

A Direct Pipe bore of Park Road and the residential home sites southeast of Park Road of 530 ft in length is feasible; however, it would require acquiring additional workspace on the northwest side of Park Road to accommodate the bore setup. A bore setup on the southeast end is not possible due to space limits imposed by a crossing pipeline owned by another company. Proceeding southeast, the recreational area can be crossed by open cut construction, leaving the 1,100 ft crossing of Wetland C43 and five streams (Streams S-C92, S-C91, S-C90, S-C89, and S-C87) remaining. This extent is technically possible by a Direct Pipe bore given the distance and ground elevations; however, a review of this crossing was performed by the contractor who employs this technology and it was their determination that a Direct Bore of this crossing is high risk, and likely to fail due to distance while crossing through and under weak saturated subsurface conditions. This conclusion then results in this extent requiring open cut construction as discussed above, or implementation of a shorter and shallower HDD, which elevates the risk of IRs to Water of the Commonwealth, when compared to the revised 20-inch HDD profile.

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Re-Route Analysis

The SPLP pipeline route as currently permitted is parallel to an existing SPLP pipeline and has been routed to minimize impacts to 105 resources while avoiding impacts to Park Road, residential home sites, and Hickory Park. No practicable re-route option lies to the north or south of the proposed route that would not transect the same infrastructure and natural resources transected by the proposed route. Shifting the pipeline route north would still result in crossings of Park Road, possibly the Pennsylvania Turnpike, and commercial areas, requiring a new utility corridor while also increasing the number of residential structures in proximity to the pipeline. A new utility corridor would require consent of newly-affected landowners or the use of eminent domain/condemnation, and would create a new land encumbrance on every private property crossed. Shifting the route south would not avoid crossing Park Road and would require significantly more clearing of forested habitat, thereby creating a new "greenfield" corridor. Given site conditions and features north and south of the proposed pipeline alignment, no practicable re-route exists that would result in less impacts to existing infrastructure, residential home sites, and environmental resources.

In summary, due to shifts of the route to the north or south requiring crossing of Park Road, residential home sites to the north, and creation of a new "greenfield" corridor to the south, there is no identifiable alternative route that would result in less impacts to aquatic and forested woodland resources and existing residences and associated infrastructure in the vicinity of HDD S3-0300-20.

This re-route analysis conducted for the Park Road HDD is consistent with the conclusions reached in the alternatives analysis previously submitted to PADEP.

HORIZONTAL DIRECTIONAL DRILL REDESIGN

SPLP has considered all geologic data and the events during installation of the 16-inch pipeline and has redesigned the 20-inch HDD profile. A summary of the redesign factors is provided below. The original and redesigned HDD plan and profile for the 20-inch pipeline are provided in Attachment 2.

Revised Horizontal Directional Drill Design Summary: 20-inch

- Horizontal length: 2,028 feet (ft)
- Entry/Exit angles: 16 degrees
- Maximum depth of cover: 114 ft
- Depth of cover under wetland W-C43: 34 - 101 ft
- Maximum depth of cover under streams: 90 - 100 ft
- Pipe design radius: 2,400 ft

The redesigned HDD profile has maximized the angle of entry and exit to reduce the potential for IRs as occurred during installation of the 16-inch pipeline. The remaining design factors are below the pipeline stress allowances for all points of analysis.

CONCLUSION

Based on the original and revised profile for the 20-inch HDD, the revised HDD profile increases the depth in bedrock for a majority of the HDD profile; therefore, adjustments to the plan of construction for the 20-inch pipeline represent a reduced risk of IRs that would impact Waters of the Commonwealth. Upland and punch out 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:

- SPLP will provide the drilling crew and company inspectors the location(s) data on potential zones of higher risk for fluid loss and IRs, including the area related to previous IRs, and potential zones of fracture concentration identified by the fracture trace analysis, so that monitoring can be enhanced when drilling through these locations.

- 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;

- The drilling manager and SPLP drilling inspectors will monitor the tool face pressure while advancing towards exit to determine when mud pressures can be reduced to lower IR potential while completing the final footage for exiting of the pilot tool. During the reaming phase, the driller can implement both push and pull reaming to minimize IR potential at this HDDs southeast end to lower IR potential;

- During all drilling phases, the use of Loss Control Materials (LCMs) will be implemented upon detection of a LOC or indications of a potential IR are noted or an IR is observed. The use of LCMs, however, is less effective 70 ft-bgs. 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 result in a material having the competency of a friable sandstone or mortar, after setup. 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.

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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-evaluation 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

6/19/2019
Date:

Pertaining to the practice of geology

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6/20/19
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Pertaining to the pipeline stress and HDD geometry

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ATTACHMENT 1

GEOLOGY AND HYDROGEOLOGICAL EVALUATION REPORT

HDD HYDROGEOLOGIC REEVALUATION REPORT

Mariner East II
Spread 6
HDD S3-0300
Park Road/Wetland C-43
Upper Uwchlan Township, Chester County, Pennsylvania

Prepared for:

Sunoco Pipeline, LP

Prepared by:

Groundwater & Environmental Services, Inc.
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Exton, Pennsylvania 19341

June 2019

HDD HYDROGEOLOGIC REEVALUATION REPORT

Mariner East II
Spread 6
HDD S3-0300
Park Road/Wetland C-43
Upper Uwchlan Township, Chester County, Pennsylvania

June 2019

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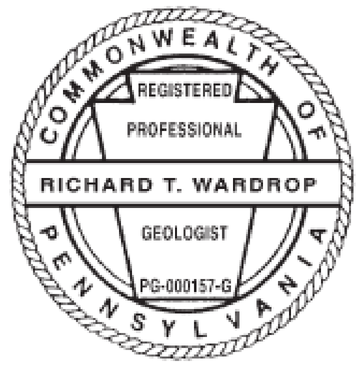
By affixing my seal to this document, I am certifying that the geologic and hydrogeologic information is true and correct. I further certify I am licensed to practice in the Commonwealth of Pennsylvania and that it is within my professional expertise to verify the correctness of the information.



June 20, 2019

Richard T. Wardrop, P. G. Date
Lic. No. PG000157G

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FIGURES

ATTACHMENTS

1.0 INTRODUCTION

Sunoco Pipeline, L.P. (SPLP), retained Groundwater & Environmental Services, Inc. (GES) to prepare a horizontal directional drill (HDD) Hydrogeologic Reevaluation Reports (HRRs) for the Mariner East II pipeline project. The project involves installation of a 20-inch and a 16-inch natural gas liquids pipeline parallel to one another. This HRR is for the alignment referred to as HDD S3-0300 Park Road/Wetland C-43, which will be used for installation of the 20-inch line. Installation of the 16-inch line has been completed; however, during that installation an Inadvertent Return (IR) occurred. As such, HDD S3-0300 appears on Exhibit 3 of the Stipulated Order EHB Docket No. 2017-009-L signed August 10, 2017, which lists HDDs requiring HRRs because an IR occurred during installation of the first of the two pipelines.

The discussion presented in this report is based on the original permitted plan and profile (P & P) for HDD S3-0300 developed by Tetra Tech/Rooney, revised 9/30/2016 (permitted profile) and a proposed redesign of the 20-imch profile (proposed P & P), revised 3/14/2019, both of which are included in **Attachment A**. The as-built 16-inch profile is also shown on the 20-inch proposed profile. The profiles are similar in terms of length and location of the entry/exits. The proposed profile runs approximately 31 feet deeper along the deepest portions of the profile, which is intended to reduce the risk of losses of circulation (LOCs) and IRs.

HDD S3-0300 is in Upper Uwchlan Township, Chester County, approximately 0.6 miles south of where Rout I-76 passes over SR Route 100, and approximately 2.0 miles east of Marsh Creek Lake. A map depicting the location of the HDD within the local topography is presented as **Figure 1**.

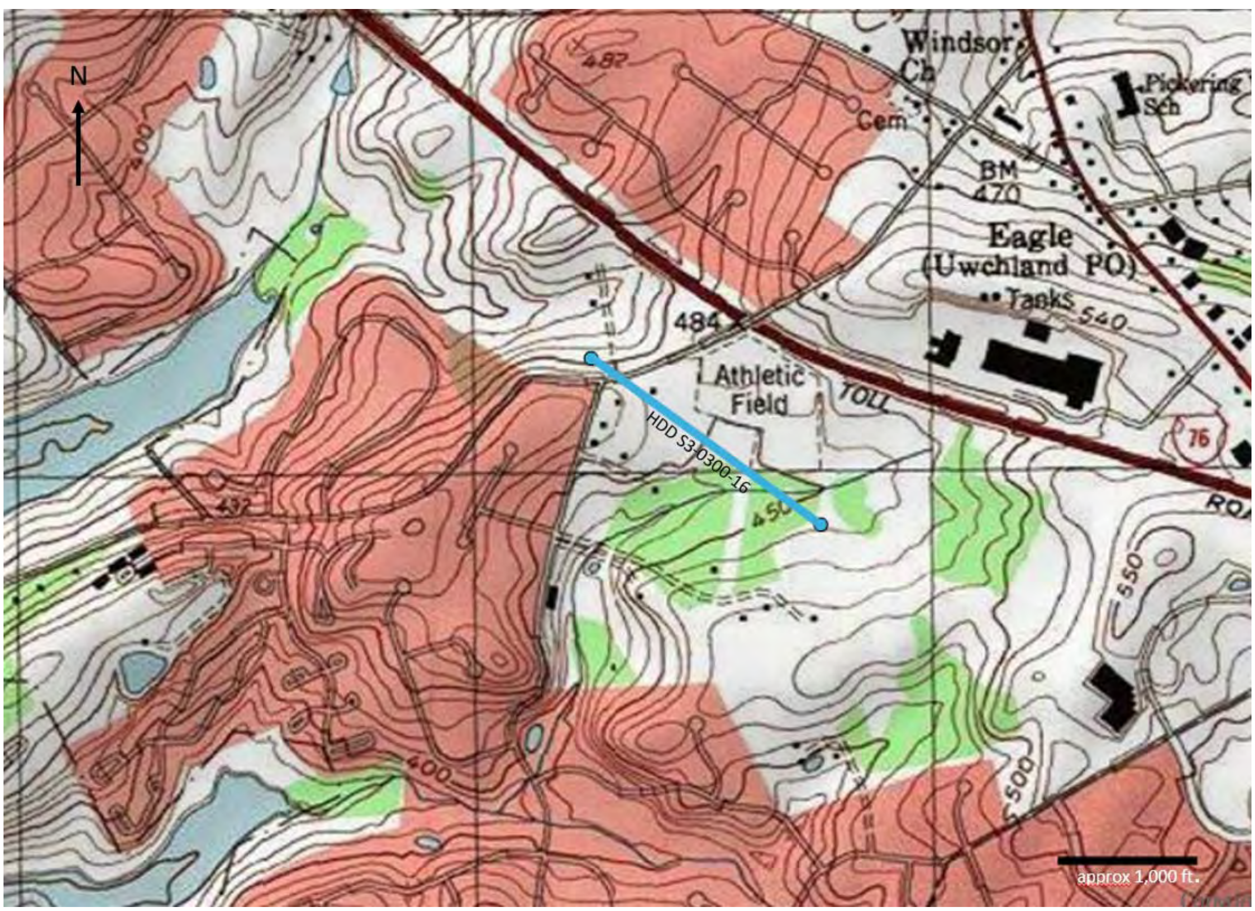

Figure 1. Site Location Map (modified from PaGEODE).

The contents of this report were developed from the interpretation of published information, field studies and observations made during drilling and installation of the 16-inch line. Site geotechnical boring programs were conducted by Tetra Tech on May 27, 2015 and July 28, 2015, and later by Terracon Consultants, Inc. (Terracon), from September 25 to September 28, 2017 in support of the HDD S3-0300 construction. Please note that GES did not oversee or direct the geotechnical drilling programs, including, but not limited to, the selection of number and location of borings; determination of surface elevations; target depths; observations of soil, rock cores and water levels during drilling operations; or preparation of boring logs. The geotechnical reports, boring logs, and any core photographs that resulted from these programs were generated by the two SPLP contractors. GES relied on these reports and incorporated their data into the general geologic and hydrogeologic framework for this HRR.

2.0 HDD GEOLOGY / HYDROGEOLOGY

2.1 Physiography

HDD S3-0300 is located within the Piedmont Uplands Section of the Piedmont Physiographic Province in Southeast Pennsylvania. The Piedmont Uplands Section is characterized by broad, rounded to flat-topped hills and shallow valleys with low to moderate topographic relief and is within the Delaware River basin.

2.1.1 Topography

The horizontal distance between the entry/exit points on the permitted profile is 2,030 feet and is two feet shorter on the proposed profile. The surface elevations along the permitted alignment show little topographic relief with a ground surface elevation at the northwestern entry/exit point of 458 feet above mean sea level (ft amsl), at stream C91 of approximately 440 ft amsl, and at the southeastern entry/exit point of 459 ft amsl. The entry/exit elevations on the proposed profile are six feet lower at the northwest entry/exit and one foot higher at the southeast entry/exit, therefore the southeast entry/exit is eight feet higher than northwest entry/exit point. (see **Attachment A**).

The HDD is located at the headwater of a tributary to Marsh Creek in a lowland surrounded by hills on all sides with top of hill elevations ranging from 490 to 550 ft amsl.

2.1.2 Hydrology

The HDD S3-0300 drill path passes underneath wetland W-C43 and the unnamed tributary to Marsh Creek Lake (S-C87), and several lower order tributaries of S-C87 (S-C89, S-C90, S-C91 and S-C92), which drain wetland W-C43. S-C87 flows away from the drill path to the southwest approximately 4,000 feet into Marsh Creek Lake.

2.2 Geology

2.2.1 Soils

Based on information obtained from the National Resource Conservation Service Web Soil Survey database (NRCS WSS) for Chester County, soils underlying HDD S3-0300 include the Gladstone Series (gravelly loam derived from granite and gneiss) at the southeast entry/exit point and the Cokesbury Series (silt loam derived from colluvium derived from granite and gneiss) at the northwest entry/exit point. The Cokesbury Series is poorly drained and found in depressions, and underlies wetland W-C43.

Unlithified materials along the drill path in the area of HDD S3-0300 were characterized by the two geotechnical borings installed by Tetra Tech (SB-01, SB-02) and the two borings installed by Terracon (B6-20W and B6-20E). The logs for these borings describe decomposed and severely weathered bedrock present below the soil to a depth of approximately 30 feet. The weathered bedrock or saprolite is described as variegated and micaceous sands and silts with weathered rock fragments overlaying competent bedrock. Saprolites reflect stratigraphic and structural properties of the parent bedrock, including fractures that may act as preferential flow paths for drilling fluids. Details found on the logs for these borings are provided in Section 2.2.8.

2.2.2 Bedrock Lithology

Bedrock underlying the region of HDD S3-0300 is generally comprised of meta-sedimentary rocks of Proterozoic age that have been severely folded and fractured since original deposition. Much of the S3-0300 profile passes through crystalline, Precambrian-aged graphitic felsic gneiss, historically referred to as the Pickering Gneiss. The northwest third of the HDD skirts the contact between the Pickering Gneiss and a banded mafic gneiss and the drill may come in contact with the latter along that portion of the profile (see **Figure 2**).

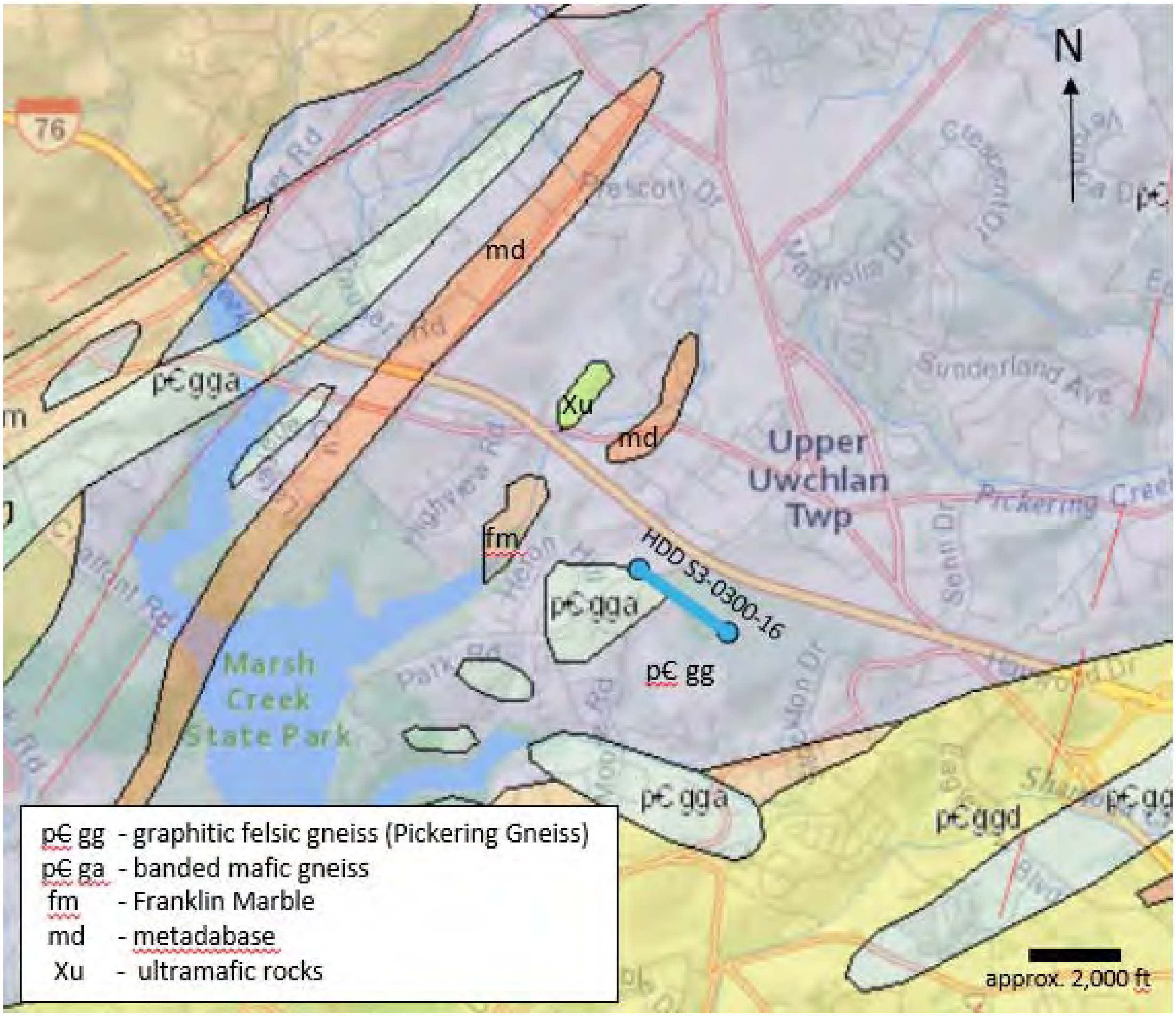

Figure 2. Site Geology (modified from PaGEODE).

The Pickering Gneiss is generally a massive sedimentary gneiss. It is a medium-gained crystalline aggregate of quartz, feldspar, hornblende and mica. The diagnostic secondary constituent of the Pickering Gneiss is graphite, which is more or less abundantly present parallel to the gneissic structures. The distinctive graphite-bearing beds of the Pickering Gneiss are often yellowish or reddish due to the oxidation of iron-bearing secondary minerals. The rock can vary spatially in the primary mineral constituents so that quartz schist, quartz-feldspar gneiss, mica schist and hornblende schist also account for graphite-bearing rock (Bascom and Stose, 1938). There is a history of graphite mining within the Pickering Gneiss proximal to HDD S3-0300. The Pickering Gneiss is generally buried under a thick mantle of soil comprised of decomposed gneiss. On fresh exposures, the gneiss is solid rock with only microscopic openings. However, where exposed over geologic time, the rock decomposes into a softer material that maintains its original texture (saprolite). The soil borings advanced in the area of HDD S3-0300 confirm the presence of saprolite up to 30 feet thick.

The banded mafic gneiss is a dark, medium-to fine grained rock consisting of calcic plagioclase, hypersthene or augite, and quartz and can be felsic locally. Banding is poorly developed and massive (PaGEODE).

2.2.3 Structure

No major structural features have been mapped close to the HDD S3-0300 alignment. The regional structural fabric trends NE. Cross-Section A-A' in Berg, et. al. (1980) shows the local gneiss bodies dipping steeply to the south.

Discontinuities in the form of joints, fractures and faults are imprinted in the bedrock units across the region. These features can act as conduits for groundwater movement and/or represent areas of weakness in the rock. The rocks at the HDD S3-0300 have been closely folded by the same forces that metamorphosed the rock from its original sedimentary character. Because of the close folds, the rocks can be faulted and jointed. Subsequent to the folding, the rocks have been intruded by igneous bodies of subsilicic and silicic dikes. Many of the dikes are small, irregular dikes whose small areal extent prevent them from being mapped beyond local features.

2.2.4 Fracture Trace Analysis

Fracture trace analysis using high altitude aerial photography was performed for the area of interest to identify potential zones of bedrock weakness along drill paths. Fracture traces (one mile in length or less) and lineaments (greater than one mile in length) can be the surficial expression on natural landscapes of vertical to near vertical zones of bedrock fracture concentration. Fracture trace analysis is partly subjective; therefore, every mapped fracture trace does not necessarily represent a zone of bedrock fracture concentration.

Figure 3 show the fracture trace mapping conducted for this reevaluation. The mapping was performed using aerial stereographic pairs flown in the fall of 1937. As such, much of the land surface appears undeveloped and fracture traces are more easily seen. The analysis yielded evidence of local fracture traces generally trending north and east-northeast. Two of the mapped fracture traces cross the drill path, one east-northeast trending trace at approximately Station 3+40 and a north-northwest trending trace that terminates along the alignment at approximately Station 9+05 on the proposed profile (see **Attachment A**).

2.2.5 Karst

Based on published geologic data, no karst features are anticipated within the region of HDD S3-0300 as limestone and marble units are absent or insignificant and there are no known or mapped sinkholes in the area of the drill path (Kochanov, 1993; Kochanov and Reese, 2003).

2.2.6 Mining

Many commercial attempts were made historically to mine the graphite from the Pickering Gneiss. The HDD S3-0300 drill path falls along the western terminus of a line of graphite mines that extends from just east of the drill path to Chester Springs in West Pikeland Township. Bascom and Stose (1938) mapped over a dozen graphite mines along this line that are no longer operating. The westernmost mine was located ½ mile west of Byers (Uwchlan P.O.), approximately 1,500 feet northeast of the drill path. In addition, a historic marble quarry was mapped approximately 2,300 feet northwest of the northwest entry/exit within an inclusion of the Franklin Marble. Given these locations, it is not anticipated that any historic mining quarry operations will affect installation of the 20-inch pipe.

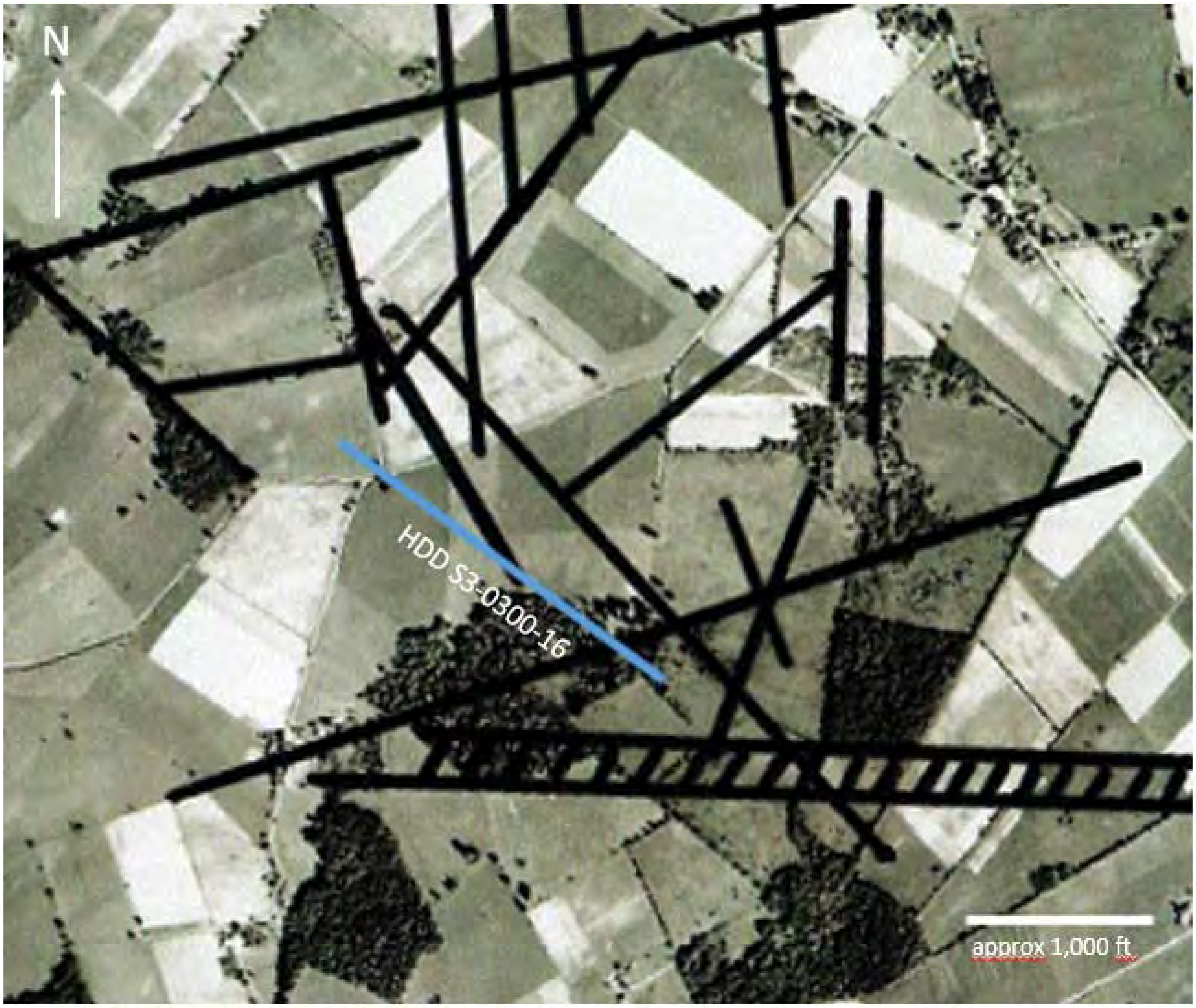

Figure 3. Fracture Trace Map.

2.2.7 Rock Engineering Properties

The properties of the bedrock units as described in Geyer and Wilshusen (1982) are as follows:

Felsic & intermediate gneiss (ggd) [granodiorite and granodioritic gneiss]:

- No bedding.
- Joints / fractures occur in a blocky pattern, moderately developed, moderately abundant, irregular; widely spaced; open and moderately dipping.

Banded mafic gneiss (gga) [gabbroic gneiss and gabbro]:

- Banding is poorly developed, massive in thickness.
- Joints / fractures are of an irregular pattern, moderately to poorly formed, of moderate abundance, widely to moderately spaced, irregular, steeply dipping and open.
- Difficult to excavate, slow drilling rates.
- Difficult to excavate, expect large surface and near-surface boulders, slow drilling rates.

2.2.8 Results of Geotechnical Borings

Original Geotechnical Borings – Tetra Tech
Two (2) geotechnical borings (SB-01 and SB-02) were installed and logged by Tetra Tech in 2015. The locations for these borings are shown on the proposed plan and profile in **Attachment A** and the logs are provided in **Attachment B**. The borings logs report an upper layer of silty clay to silt and sand grading to decomposed bedrock. The decomposed bedrock occurred from 6.5 to 30 feet below ground surface (ft bgs) in SB-01 and from 9 to 30 feet in SB-02. Both borings were terminated at 30 ft bgs. Groundwater was encountered at a depth of 16 feet in SB-01 and 18 feet in SB-02.

Recent Geotechnical Borings-Terracon
Two geotechnical borings were drilled by Terracon in September 2017 with the objective of collecting rock core from the approximate maximum planned depth of the HDD. B6-20W is located near the northwest entry/exit point and B6-20E is located near the southeast entry/exit point. Both borings were advanced to a total depth of 136 feet and the maximum depth of the redesigned HDD profile is approximately 85 feet.

Boring B6-20W reported weathered to highly weathered rock from 5.5 to 116 ft bgs. Split-spoon sample refusal occurred at approximately 60 ft bgs and the augers were advanced to 66 ft bgs where coring began. Highly weathered bedrock with RQDs of 25 and below was logged from 66 to 116 ft bgs. More competent bedrock was logged from 116 ft bgs to the total depth of 136 feet with RQDs from 39 to 63. A water level of 9.5 ft bgs was recorded for B6-20W.

Coring at B6-20E began at approximately 16 ft bgs. Low RQDs were reported in highly weathered bedrock to a depth of 49 feet. RQDs for the remainder of the boring ranged from 41 to 93 with zones of higher strength rock from 61 to 96 ft bgs and from 121 to 136 ft bgs. A water level measurement of 9.0 ft bgs was recorded for B6-20E.

The RQD values for the core samples taken at borings B6-20 W and B6-20E are congruent with other lines of evidence that suggest that the metamorphic rock along portions of the HDD S3-0300 profile show variable amounts of weathering and rock strength. Highly weathered bedrock was observed to as much as 116 ft bgs. The maximum depth of overburden along the profile is approximately 85 ft bgs therefore the drilling plan should account for zones of weaker bedrock and associated preferred pathways of fluid migration.

2.3 Hydrogeology

2.3.1 Occurrence of Groundwater
Most groundwater in the gneissic units of Chester County is stored in the unconsolidated weathered rock near the land surface with lesser amount stored in the underlying bedrock fractures. Based on soil borings and borings advanced into bedrock, groundwater has been encountered in both the soil/weathered bedrock zone and bedrock, under water-table conditions. Groundwater aquifer recharge occurs vertically through the unconsolidated overburden materials and downward into the more competent bedrock horizon. The storage of groundwater and direction of groundwater flow in the more competent fractured bedrock is expected to occur in discontinuities (fractures) sometimes in zones of fracture concentration as indicated by mapped fracture traces.

Wetland W-C43 as well as stream S-C87 and its tributaries represent a local groundwater discharge point. Stream S-C87 flows to the west towards Marsh Creek and Marsh Creek Lake.

2.3.2 Ground Elevation Between HDD Entry/Exits and Groundwater Discharge

There is only eight feet of elevation change between the northwestern and southeastern entry/exit points on the proposed profile. The profile shows an elevation of 452 ft amsl at the northwestern entry/exit point and 460 ft amsl at the southeastern entry/exit point. The highest topographic point along the alignment is approximately 465 ft amsl, just over 300 linear feet from the northwestern entry/exit point (**Attachment A**).

The depth to water measured in geotechnical boring B6-20W near the northwest entry/exit was 9.5 feet. A similar measurement was recorded for B6-20E, at 9.0 feet. Assuming a depth to water of 9.0 feet at the highest surface elevation location along the profile, the resultant water level measurement would have an elevation of 456 ft amsl. This is four feet above the proposed elevation of the northwest entry/exit indicating a risk of groundwater discharge created by completion of the pilot boring. This risk is affirmed by the groundwater discharge that continuously flowed at the northwest entry/exit mud pit for the 16-inch line, until tie-in was completed with the open trench section of pipe to the northwest. Similar conditions should be expected when drilling the 20-inch line at HDD S3-0300.

2.3.3 Water Level

Depth to the water table in fractured gneiss is generally less than 50 feet below surface (Low et al., 2002). In the geo-technical borings advanced in 2015, groundwater was encountered at a depth of 16 feet in SB-01 and 18 feet in SB-02. In the geo-technical borings advanced in 2017, groundwater was encountered at a depth of 9.5 feet in B6-20W and 9.0 feet in B6-20E. A PAGWIS search of wells completed in gneissic bedrock in Uwchlan and Upper Uwchlan Townships in Chester County. The wells listed with recorded static water levels had water levels ranging from 4 to 170 ft bgs with an average of 36 ft bgs.

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2.3.4 Well Yields

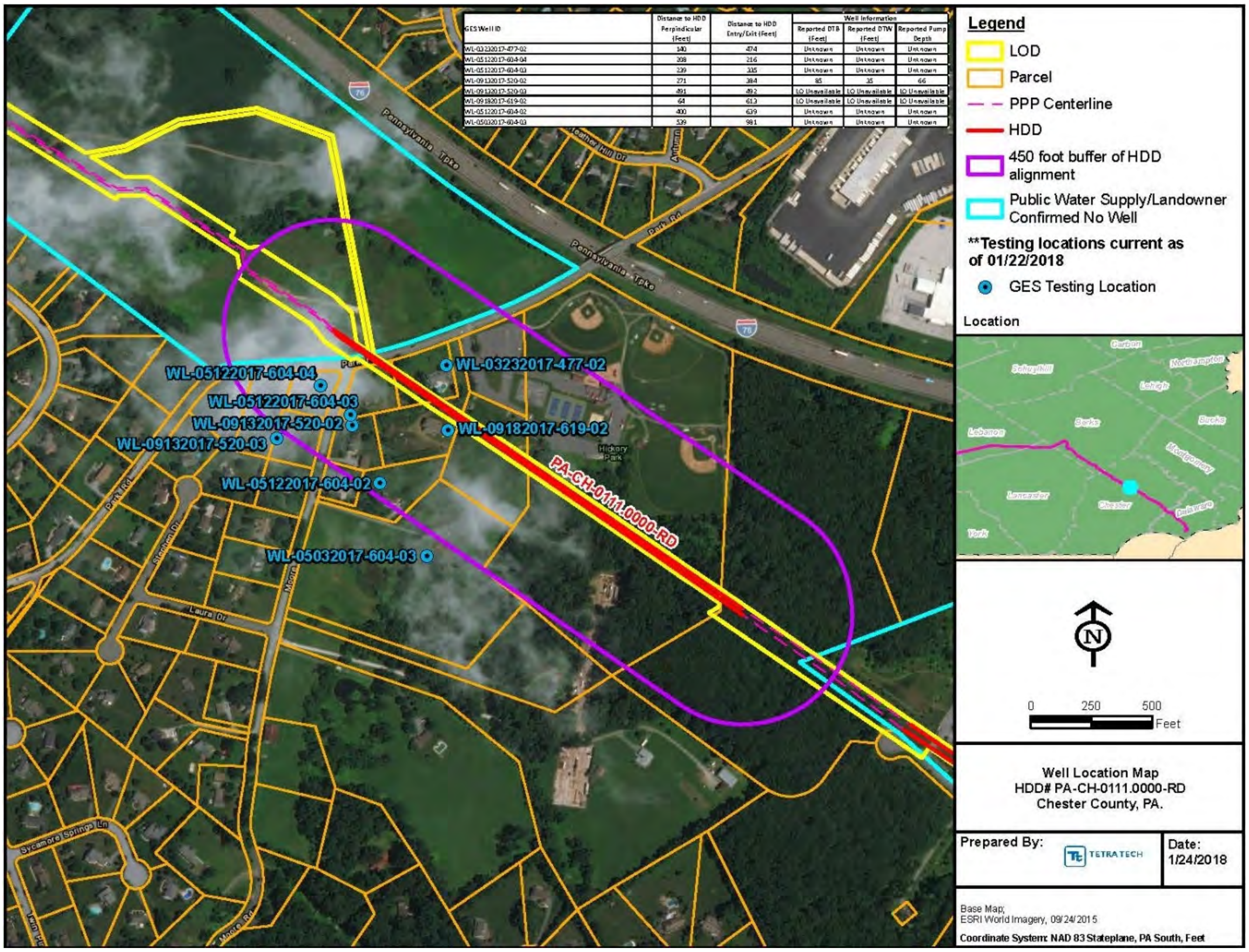
The above referenced PAGWIS search indicated a range in well yields from 1 to 200 gallons per minute (gpm) with an average of 21 gpm.

2.3.5 Water Supply Wells within 450 feet of ROW

SPLP conducted a water supply survey of landowners with parcels intersecting a perimeter drawn 450-feet from the HDD alignments (see **Figure 4**). Based on that survey, eight landowners with private water supplies accepted SPLP's offer to participate in a water supply sampling program. Six of the wells were actually located within 450-feet of the HDD and two additional wells fell just outside of 450-foot survey area. Sampling program technicians collected information about the water supplies during sampling events if the well owner has knowledge of the water supply characteristics. The owner of well WL-09132017-520-02 provided a well depth of 85 feet, pump depth of 66 feet and depth to water of 35 feet. Well characteristics were not available for the seven other wells. The above referenced PAGWIS search of local wells drilled in gneissic bedrock indicated well depths ranged from 18 to 560 ft bgs with an average depth of 167 ft bgs.

2.4 Summary of Geophysical Study

RETTEW / Enviroscan (Rettew) completed a geophysical survey at the HDD S3-0300 site in January 2019. The purpose of the survey was to detect and delineate subsurface fracture zones that could contribute to potential IRs and/or losses of circulation (LOCs), and to determine the rock profile and rock strength for ease-of-excavation along the HDD path. The results of the survey are provided in **Attachment C**. Seismic refraction with seismic multi-spectral analysis of surface waves (MASW) and refraction methods were used to identify potential fracture zones and approximate the depth of competent bedrock along the profile. As shown on the figures in **Attachment C**, the combined methods identified a potential fracture zones crossing the alignment at a frequency of approximately one zone every 60 feet. The seismic refraction profiles



GES Well ID	Distance to HDD Perpindicular (Feet)	Distance to HDD Entry/Exit (Feet)	Well Information: Reported DTB (Feet)	Well Information: Reported DTW (Feet)	Well Information: Reported Pump Depth
WL-03232017-477-02	140	474	Unknown	Unknown	Unknown
WL-05122017-604-04	208	216	Unknown	Unknown	Unknown
WL-05122017-604-03	239	335	Unknown	Unknown	Unknown
WL-09132017-520-02	271	384	85	35	66
WL-09132017-520-03	491	492	LO Unavailable	LO Unavailable	LO Unavailable
WL-09182017-619-02	64	613	LO Unavailable	LO Unavailable	LO Unavailable
WL-05122017-604-02	400	639	Unknown	Unknown	Unknown
WL-05032017-604-03	539	981	Unknown	Unknown	Unknown

Figure 4. 450-foot Water Supply Survey Map.

indicate the depth to competent bedrock ranges from approximately 10 to 27 feet. Rettew correlated thicker zones of weathered bedrock with potential fractures. One of the deeper zones of weathered bedrock is plotted approximately 50 feet northwest of where GES mapped an east-northeast trending fracture trace crossing the proposed profile at approximately Station 3+40. Based on these observations, the section along the proposed profile from approximately Station 2+90 to 4+40 (50 feet on either side of the two features), in particular, could represent a zone of bedrock weakness, susceptible to LOCs and potentially IRs.

3.0 OBSERVATIONS TO DATE

3.1 On This HDD Alignment

Two punch out IR locations were identified during installation of the 16-inch pipe at HDD S3-0300. The locations of the IRs are plotted on the proposed plan and profile in **Attachment A.** Each occurred along the ascending part of the southeast end of the profile where overburden was thinning, approaching the southeast entry/exit.

On 06/17/2017, the pilot bit was traveling northwest to southeast and ascending towards exit when an upland, punch out IR occurred at approximately Station 2+79. Drilling fluids from the IR migrated along the land surface into wetland C43 and flowed approximately 100 feet southeast through wetland W-C43 to the bank of stream S-C87. Approximately five gallons of drilling fluid, cuttings and groundwater appeared at the stream bank and were removed using a temporary diversion dam. A containment structure was installed at the location of the upland discharge point to manage additional IR fluids for the remainder of drilling activity. Vac trucks were used to contain the discharges and direct all recovered fluids back to the mud pit. The IR containment was adjusted while the pilot bore was being completed in response to migration of the IR discharge point to the southeast. No other IRs occurred during advance of the pilot boring

On 09/09/2017, a 20-inch reamer was proceeding from northwest to southeast when an IR occurred near the IR of 6/17/17, approximately 50 feet east of Station 2+50. At the time of the IR, the reamer was being pushed to the southeast entry/exit and was 1,385 feet into the bore. A very small volume (<0.5 gallons) entered stream S-C87. The IR immediately ceased flowing when drilling stopped. To mitigate future IR activity, the remainder of the 20-inch reaming pass was conducted by altering the ream to pulling the reamer from the southeast entry/exit to the location of the IR. This mitigation measure prevented any additional IR activity.

3.2 On Other HDD Alignments in Similar Hydrogeologic Settings

ME II HDDs in northern Chester County in the same basic geologic setting of S3-0300 include S3-0280 and HDD S3-290 (to the northwest) and S3-0310, S3-320, S3-330, S3-331 and S3-350 (to the southeast). IRs have occurred during installation of the 16-inch line at HDD S3-290, S3-320, and S3-331. These IRs have typically occurred where bedrock is densely fractured (sometimes indicated by a fracture trace or fracture trace intersection) or where the profile approaches an entry/exit point, closer to the surface, where unconsolidated overburden material thins and there is less overburden strength to contain drilling fluid pressures. IRs at entry and exit are hard to prevent and therefore common. In some cases, overburden thickness is reduced where the deepest part of the profile passes under a stream occupying a section of the alignment with the lowest surface elevation along the profile. At the exit end of pilot bores for HDDs, especially relatively long HDDs, an increase in annular pressure is often required to maintain circulation back to the drilling fluid pit at the entry, and this type of pressure increase has contributed some of the IRs that have occurred to date.

4.0 SUMMARY AND CONCLUSIONS OF HDD HYDROGEOLOGIC EVALUATION

4.1 HDD Site Conceptual Model

HDD S3-0300 is located along a headwater drainage area surrounded by uplands within gneissic bedrock with a relatively thick covering of saprolite and heavily weathered bedrock. Examination of geotechnical boring data and results of a geophysical study indicate the thickness of the saprolite and weathered bedrock is up to 116 ft bgs in the area of the HDD.

The Retttew geophysical study report identifies a saprolite / weathered bedrock zone from 10 to 27 feet deep and potential fracture zones along the profile at a frequency of approximately one zone every 60 feet. The PAGWIS data search of gneissic rock in northwest Chester County showed average depth to bedrock at 48 feet. Two fracture traces intersect the alignment for HDD S3-0300 along the proposed profile at Stations 9+05 and at Station 3+40. One of the deeper zones of weathered bedrock mapped by Rettew plots approximately 50 feet northwest of the fracture trace at Station 3+40. As such, the section along the proposed profile from approximately Station 2+90 to 4+40, in particular, could represent a zone of bedrock weakness, susceptible to LOCs and potentially IRs.

The as-built drawing for installation of the 16-inch line indicates the profile ranged from approximately 0 to 90 ft bgs. The permitted profile for the 20-inch pipe installation is very similar; however, the redesigned profile for the 20-inch line shows the pipe at depths ranging from 0 to 114 ft bgs. The deepest portion of the proposed profile is at elevation 342 ft amsl as opposed to 373 ft amsl for the permitted profile or 366 ft amsl for the as-built 16-inch line. By going deeper, the proposed profile reduces the risk of LOCs and IRs by increasing the likelihood that drilling will be in more competent bedrock at depth. Regardless, deepening the profile does not change the risk of punch in / punch out IRs like the two that occurred near the southeast entry/exit during the 16-inch pipe HDD at S3-0300 and at a few of the other ME II HDDs in similar hydrogeologic settings where overburden thins and is comprised entirely of saprolite and weathered bedrock. During installation of the 16-inch pipe at S3-0300, standard ME II HDD construction and best management practices were able to control drilling fluids with minimal adverse effects. Construction of the 16-inch line did result in two low volume IRs (5 and <0.5 gallons) in wetland W-C43 and tributary stream S-C87 which were easily contained and cleaned up.

This HRR identified a risk of groundwater discharge at the northwest entry/exit on the proposed profile based on a potential head differential between the local water table elevation and the elevation of the entry/exit. This risk is affirmed by the groundwater discharge that occurred at the northwest entry/exit associated with installation of the 16-inch pipeline.

Six private water supply wells within 450-feet of the S3-0300 alignment were sampled before and during construction of the 16-inch line. One well had a reported depth of 85 feet. Although well depth information was not available for the five other wells, published information concerning local wells indicates well depths average 167 ft bgs in the local geologic setting. As such, the profile for the 20-inch line passes through the zone of groundwater that is the source of water to these local private water wells. Regardless, there were no private well owner complaints regarding water quality or quantity issues during the installation of the 16-inch line.

4.2 Conclusions and Recommendations

The synthesis of regional and local geologic data together with past drilling performance during drilling for the 16-inch pipeline indicate there is a moderate to high risk of drilling fluid loss and IRs as the profiles gain in elevation towards the entry/exit locations. This is based on the depth of the proposed profile, strength of overburden materials within zones of saprolite and highly weathered bedrock, and low RQD bedrock with a relatively high frequency of potential bedrock fracture zones. In addition, local groundwater levels and experience during installation of the 16-inch line indicate a risk of groundwater discharge at the northwest entry/exit. Drilling plans and Best Management Practices should account for these conditions. Practices similar to that used for installation of the 16-inch line should be incorporated into the drilling plan because regardless of these conditions, IRs were minimal and easily contained during installation of that line.

Six local private water wells are present within 450 feet of the alignment. These wells are currently included in SPLP's groundwater monitoring program and will be part of pre-and post-construction sampling events associated with installation of the 20-inch line. SPLP's standard procedures include an offer to each of these well owners to provide a temporary water supply during construction of the 20-inch line. This offer should be reaffirmed prior to the start of construction to give the well owners the opportunity to assure no water supply impacts during construction of the 20-inch line.

Based on information provided by, and the expertise of, the HDD team, as well as our experience with the relevant hydrogeology and geology, GES believes that implementation of proposed profile for HDD S3-0300 and best management practices that are part of the current ME II construction project will minimize the risk of IRs and LOCs and minimize the likelihood of an impact to the environment. Furthermore, based on such information, expertise and experience, GES believes that implementation of the proposed profile in conjunction with the SPLP's temporary water supply offer to private well owners within 450 feet of the HDD alignment will minimize the risk of any impact to a private water supply. In the event of an impact to a private water supply, SPLP will implement the procedures of the IR PPC Plan.

5.0 REFERENCES

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Kochanov, W. E. 1993. Sinkholes and Karst-Related Features of Chester County, Pennsylvania. Pennsylvania Bureau of Topographic and Geologic Survey, Open File Report: 93-01, scale 1:24,000, 10 maps plus 9 page text.

Kochanov, W.E. and S. O. Reese. 2003. Density of Mapped Karst Features in South-Central and Southeastern Pennsylvania. Pennsylvania Bureau of Topographic and Geologic Survey, Map 68.

Low, D. J., D. J. Hippe, and D. Yannacci. 2002. Geohydrology of Southeastern Pennsylvania. United States Geological Survey, Water-Resources Investigations Report 00-4166, 346 p.

PAGWIS, Pennsylvania groundwater information system, Pennsylvania Geological Survey http://dcnr.state.pa.us/topogeo/groundwater/pagwis/records/index.htm

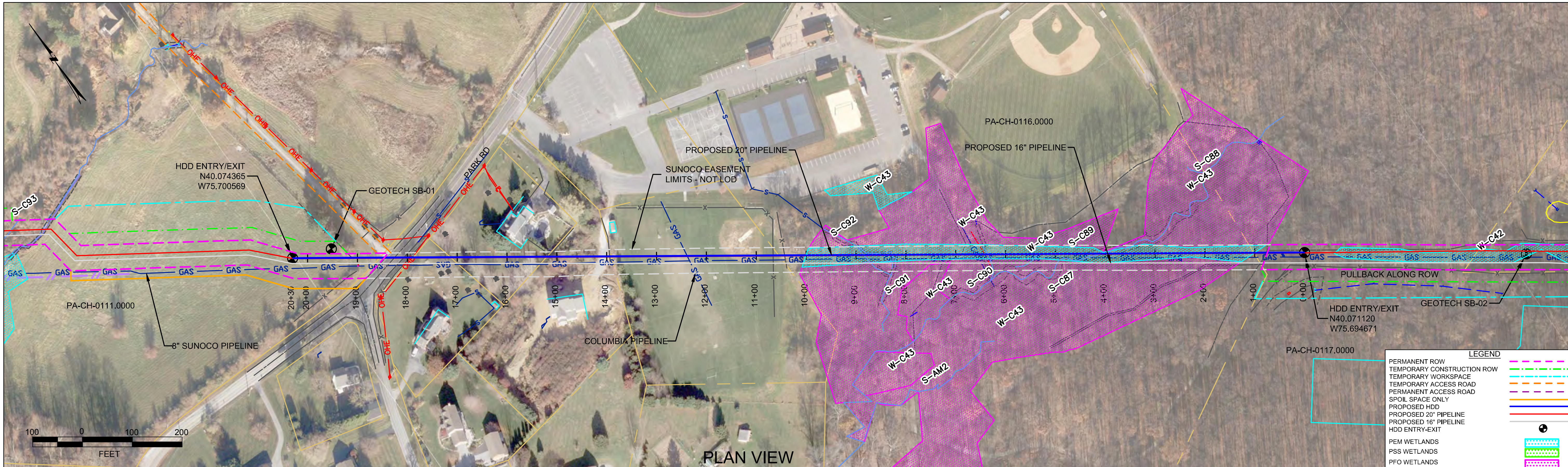
NRCS WSS, United State Department of Agriculture National Resource Conservation Service Web Soil Survey database (NRCS WSS) for Chester County, Accessed January 2018. https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

Attachment A

Plan and Profiles

Permitted Plan and Profile, rev. 9/30/16

Proposed Plan and Profile, rev. 3/14/19, showing IRs and geology



PLAN VIEW

CHESTER COUNTY, PENNSYLVANIA - UPPER UWCHLAN TOWNSHIP
S3-0300

PROFILE VIEW

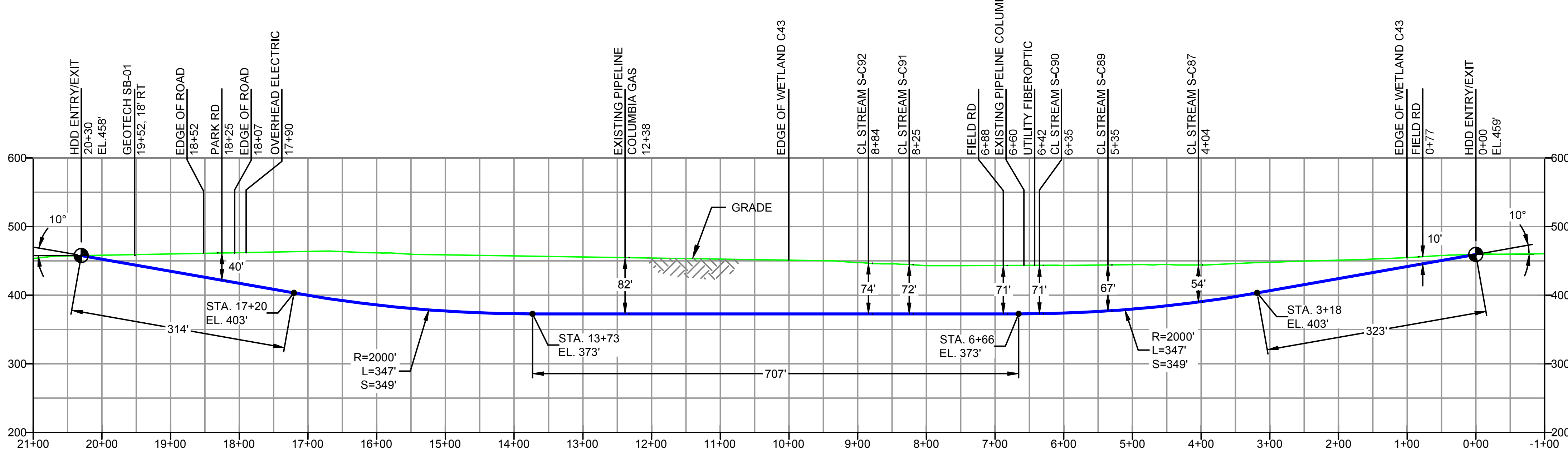
GEOTECH SB-01

- NG EL. 458'
- TOPSOIL (0' - 0.5')
- SM (0.5' - 6.5')
- GROUNDWATER (16.0')
- ML/SM (6.5' - 29.0')
- SM (29.0' - 30.0')
- COMPLETION DEPTH EL. 469'

GEOTECH SB-02

- NG EL. 469'
- TOPSOIL (0' - 0.5')
- CL (0.5' - 9.0')
- SM (9.0' - 30.0')
- GROUNDWATER (18.0')

NOTE:
1. REFER TO TEST BORING LOG S3-0210 FOR COMPLETE SOIL MATERIAL DESCRIPTION
2. PDOT RECORD INDICATED GRAPHITIC FELSIC GNEISS AT 25'-35' DEPTH, REFER TO PaGWIS PENNSYLVANIA DEPARTMENT OF TRANSPORTATION



DESIGN AND CONSTRUCTION:

1. CONTRACTOR SHALL FIELD VERIFY DEPTH OF ALL EXITING 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=):2030'
   HDD PIPE LENGTH (S=):2043'
   20" x 0.456" W.T., X-65, 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.

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-6.31	TO	ES-6.32	EROSION & SEDIMENT PLAN
SHEET 18	TO	SHEET 19	AERIAL SITE PLAN

REVISIONS

NO.	DESCRIPTION	BY	DATE	CHK	DATE	APP	DATE
EP2	REVISED PER PADEP COMMENTS RECEIVED 09-06-16	MRS	09/30/16	RMB	09/30/16	AAW	09/30/16
EP1	REVISED PER PADEP COMMENTS	MRS	05/05/16	RMB	05/05/16	AAW	05/05/16
EP		MRS	02/26/16	RMB	02/26/16	AAW	02/26/16
0	ISSUED FOR CONSTRUCTION	MRS	02/19/16	RMB	02/19/16	AAW	02/19/16

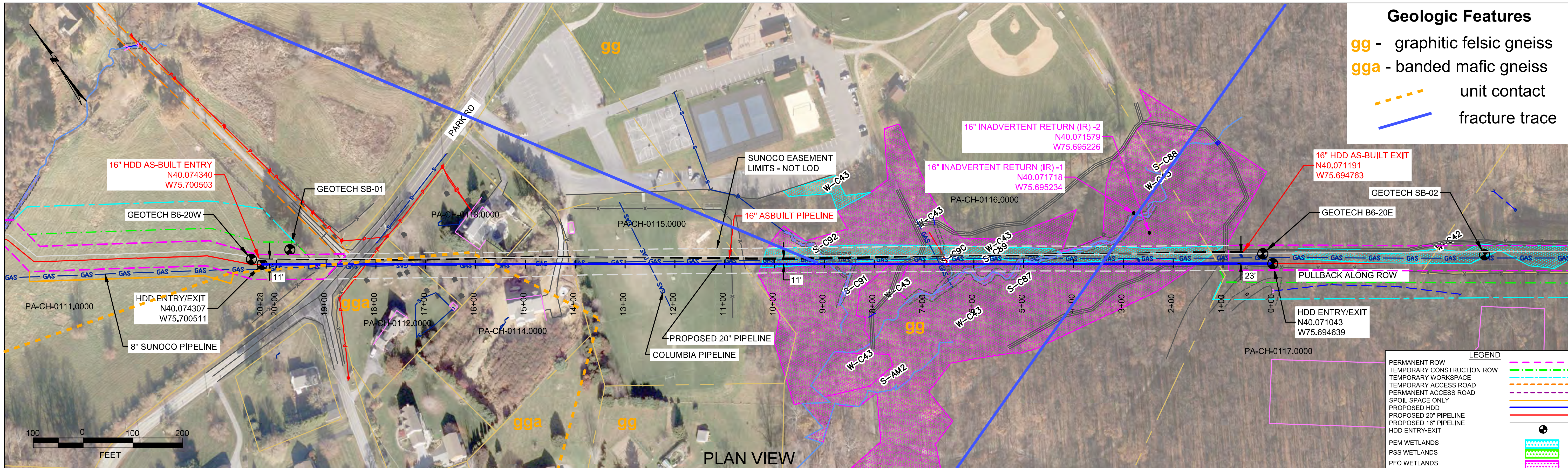
Sunoco Logistics Partners L.P.

TETRA TECH ROONEY
(303) 792-5911

SUNOCO PIPELINE, L.P.

20-INCH HORIZONTAL DIRECTIONAL DRILL
PARK RD
PENNSYLVANIA PIPELINE PROJECT

SCALE: 1"=200' DWG. NO: PA-CH-0111.0000-RD



CHESTER COUNTY, PENNSYLVANIA - UPPER UWCHLAN TOWNSHIP
S3-0300

PROFILE VIEW

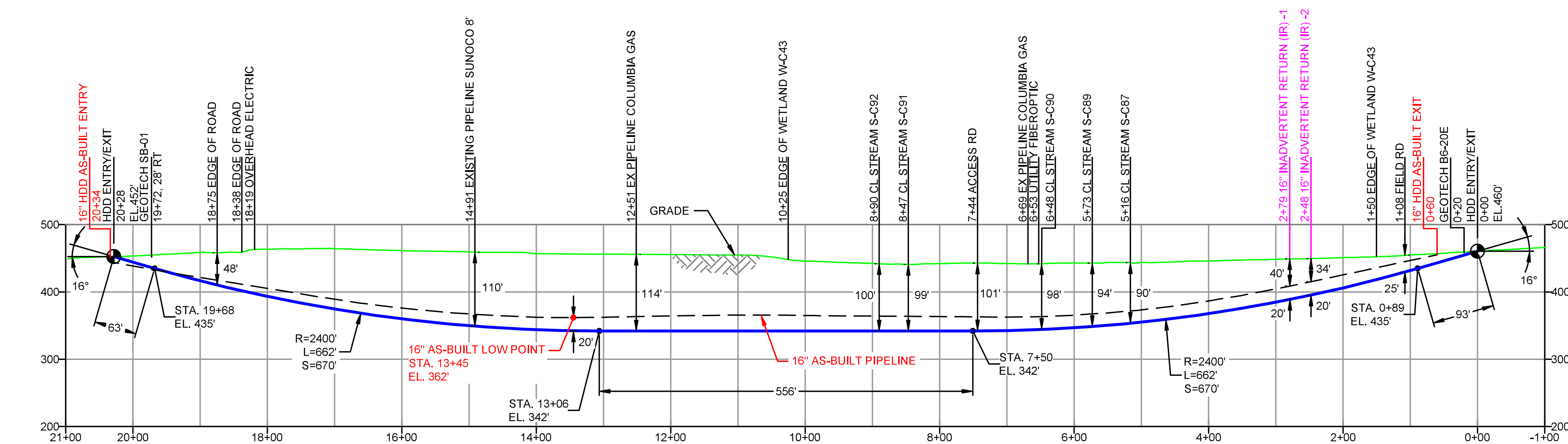
GEOTECH SB-01

- NG EL. 458'
- TOPSOIL (0' - 0.5')
- SM (0.5' - 6.5')
- GROUNDWATER (16.0')
- ML/SM (6.5' - 29.0')
- SM (29.0' - 30.0')
- COMPLETION DEPTH EL. 469'

GEOTECH SB-02

- NG EL. 469'
- TOPSOIL (0' - 0.5')
- CL (0.5' - 9.0')
- SM (9.0' - 30.0')
- GROUNDWATER (18.0')

NOTE:
1. REFER TO TEST BORING LOG S3-0300 FOR COMPLETE SOIL MATERIAL DESCRIPTION
2. PDOT RECORD INDICATED GRAPHITIC FELSIC GNEISS AT 25'-35' DEPTH, REFER TO PaGWIS PENNSYLVANIA DEPARTMENT OF TRANSPORTATION



GEOTECH B6-20W

- NG EL. 458'
- SANDY SILT ML (0.0' - 6.4')
- GROUNDWATER (9.5')
- WEATHERED ROCK (6.4' - 66.0')
- GNEISS (66.0' - 136.0')
- BORING TERMINATED EL.322'

NOTE: REFER TO TEST BORING LOG B6-20W TERRACON PROJECT #J217P078 FOR COMPLETE SOIL MATERIAL DESCRIPTION

GEOTECH B6-20E

- NG EL. 459'
- FILL - LEAN CLAY (0.0' - 5.0')
- GROUNDWATER (9.0')
- SANDY LEAN CLAY CL (5.0' - 16.0')
- QUARTZITE (16.0' - 46.0')
- GNEISS (46.0' - 136.0')
- BORING TERMINATED EL.323'

NOTE: REFER TO TEST BORING LOG B6-20E TERRACON PROJECT #J217P078 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=):2028'
   HDD PIPE LENGTH (S=):2052'
   20" x 0.456" W.T., X-65, API5L, PSL2, ERW, BFW
   COATING: 14-16 MILS FBE WITH 40 MILS MIN. ARO (POWERCRETE R95)
5. INTERNAL DESIGN PRESSURE 1480 PSIG (SEAM FACTOR 1.0, DESIGN FACTOR 0.50 (HOOP STRESS)).
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.

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-6.31	TO	ES-6.32	EROSION & SEDIMENT PLAN
SHEET 18	TO	SHEET 19	AERIAL SITE PLAN

REVISIONS

NO.	DESCRIPTION	BY	DATE	CHK	DATE	APP	DATE
EP3	SWITCHED 20" CENTERLINE LOCATION, INCREASED DEPTH OF DRILL AND ADDED GEOTECH INFORMATION	MRS	03/14/19	RMB	03/14/19	AMC	03/14/19
EP2	REVISED PER PADEP COMMENTS RECEIVED 09-06-16	MRS	09/30/16	RMB	09/30/16	AAW	09/30/16
EP1	REVISED PER PADEP COMMENTS	MRS	05/05/16	RMB	05/05/16	AAW	05/05/16
EP		MRS	02/26/16	RMB	02/26/16	AAW	02/26/16
0	ISSUED FOR CONSTRUCTION	MRS	02/19/16	RMB	02/19/16	AAW	02/19/16

Sunoco Logistics Partners L.P.

TETRA TECH ROONEY
(303) 792-5911

SUNOCO PIPELINE, L.P.

HORIZONTAL DIRECTIONAL DRILL
PARK RD
PENNSYLVANIA PIPELINE PROJECT

SCALE: 1"=200'
DWG. NO. PA-CH-0111.0000-RD

Attachment B

Geotechnical Boring Reports

Tetra Tech, May and July 2015

Terracon, September 2017

LEGEND:

Geotechnical Soil Boring (SB) Locations

TETRA TECH

GEOTECHNICAL BORING LOCATIONS
HDD S3-0300
CHESTER COUNTY, UPPER UWCHLAN TOWNSHIP, PA
SUNOCO PENNSYLVANIA PIPELINE PROJECT

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:	CH-0111, EXTON, PA	Page 1 of 1	
HDD No.:	S3-0300	Dates(s) Drilled: 05-27-15	Inspector: J. COSTELLO
Boring No.:	SB-01	Drilling Method: SPT - ASTM D1586	Driller: GREG
Drilling Contractor:	HAD DRILLING	Groundwater Depth (ft): 16.0	Total Depth (ft): 30.0
Boring Location Coordinates:		40° 4' 27.416" N	75° 42' 1.033" 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	0.5			TOPSOIL (6)					
1	3.0	5.0	0.5		9	SM	BROWN FINE TO MEDIUM SAND WITH SOME SILT, TRACE FINE	8	11	7	6	**18**
				6.5			GRAVEL.					
2	8.0	10.0	6.5		16	ML/SM	DR WEATHERED TO A YELLOWISH BROWN AND WHITE SILT AND	2	5	15	14	**20**
							FINE TO COARSE SAND, WITH A LITTLE UNWEATH. F-GRAVEL.					
3	13.0	15.0			24		DR WEATHERED TO A REDDISH BROWN WITH WHITE VEINS, SILT AND	3	5	10	19	**15**
							FINE TO COARSE SAND, WITH TRACE UNWEATH. F-GRAVEL.					
4	18.0	20.0			19		DR WEATHERED TO A BRWN AND REDDISH BROWN SILT AND FINE	1	2	4	5	**6**
							SAND. (USCS: ML/SM).					
5	23.0	25.0			24		DR WEATHERED TO A BRWN AND REDDISH BROWN SILT AND FINE	1	1	2	6	**3**
				29.0			SAND.					
6	28.0	30.0	29.0		24	SM	DR WEATHERED TO A WHITE, TAN, GRAY FINE TO COARSE SAND WITH	1	13	26	28	**39**
				30.0			SOME SILT, TRACE FINE UNWEATHERED GRAVEL.					
							WET ON SPOON AT 16'.					
							WATER LEVEL THROUGH AUGERS AT 16'.					
							CAVED AT 26'.					

Notes/Comments:
Pocket Pentrometer Testing

DR: DECOMPOSED ROCK

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:	730 STOCKTON DRIVE, DOWNINGTOWN, PA		Page 1 of 1
HDD No.:	S3-0300	Dates(s) Drilled: 07-28-15	Inspector: J. COSTELLO
Boring No.:	SB-02	Drilling Method: SPT - ASTM D1586	Driller: E. OGDEN
Drilling Contractor:	HAD DRILLING	Groundwater Depth (ft): 18.0	Total Depth (ft): 30.0
Boring Location Coordinates:		40° 4' 13.433" N	75° 41' 36.139" 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	0.5			TOPSOIL (6)					
1	3.0	5.0	0.5		24	CL	MOTTLED REDDISH BROWN AND GRAY SILTY CLAY WITH A LITTLE	1	4	6	10	**10**
				9.0			FINE SAND.					
2	8.0	10.0	9.0		24	SM	DR, VARIEGATED (GRAY, WHITE, BROWN, RED) FINE TO MEDIUM SAND	2	2	5	6	**7**
							WITH SOME SILT.					
3	13.0	15.0			22		DR, VARIEGATED (GRAY, WHITE, BROWN, RED) FINE TO MEDIUM SAND	1	1	2	4	**3**
							WITH SOME SILT. (USCS: SM)					
4	18.0	20.0			15		DR, VARIEGATED (GRAY, WHITE, BROWN, RED) FINE TO MEDIUM SAND	1	2	3	6	**5**
							WITH SOME SILT.					
5	23.0	25.0			14		DR, VARIEGATED (GRAY, WHITE, BROWN, RED) FINE TO MEDIUM SAND	1	4	6	9	**10**
							WITH SOME SILT, TRACE FINE GNEISS FRAGMENTS.					
6	28.0	30.0			14		DR, VARIEGATED (GRAY, WHITE, BROWN, RED) FINE TO MEDIUM SAND	5	7	21	31	**28**
				30.0			WITH SOME SILT, TRACE FINE GNEISS FRAGMENTS.					
							WET ON SPOON AT 18'.					
							WATER LEVEL THROUGH AUGERS AT 18'.					
							CAVED AT 17.3'.					

Notes/Comments:

Pocket Pentrometer Testing
S1: 2.75 TSF

DR: DECOMPOSED ROCK

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 S3-0300

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, %	
S3-0300	SB-01	2	8.0	10.0	12.9	21.6	-	-	-	-
		3	13.0	15.0	25.0	50.8	-	-	-	-
		4	18.0	20.0	34.7	51.9	43	33	10	ML/SM
		5	23.0	25.0	38.7	50.0	-	-	-	-
		6	28.0	30.0	13.5	24.6	NV	NP	NP	SM
	SB-02	2	8.0	10.0	23.5	20.5	-	-	-	-
		3	13.0	15.0	31.7	22.6	-	-	-	-
		4	18.0	20.0	41.7	33.1	30	25	5	SM
		5	23.0	25.0	32.2	28.7	-	-	-	-
		6	28.0	30.0	23.4	24.2	-	-	-	-

Notes:

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

REGIONAL GEOLOGY SUMMARY
SUNOCO PENNSYLVANIA PIPELINE PROJECT
HDD S3-0300

HDD No.	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
S3-0300	SB-01			(PreCambrian)			notes	
	SB-02							

Note : 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.

October 17, 2017

Directional Project Support, Inc.
33311 Lois Lane, Suite A
Magnolia, TX 77354

Attn: Mr. Robert Sessions
P: (318) 542 6657
E: fielduspl@Hotmail.com

Re: Geotechnical Site Characterization
Mariner East 2 Pipeline Project
Spread 6 – Park Road
Commonwealth of Pennsylvania
Drawing # PA-CH-0111.0000-RD
PO # 20170911
Terracon Project No. J217P078

Dear Mr. Sessions:

This letter provides a summary of the bedrock characterization for the Mariner East 2 Pipeline Project crossing to be located at Park Road (Drawing #PA-CH-0111.0000-RD) in the Commonwealth of Pennsylvania. Our services were performed in general accordance with our proposal number PJ2175108 dated July 28, 2017. Our scope of services included advancing two borings, designated as B6-20W and B6-20E, visual classification and photography of the rock core samples, and laboratory testing of representative rock samples.

Test borings, B6-20W and B6-20E were drilled between September 25 and 28, 2017 to a depth of 136.0 feet, as shown on the attached **Test Boring Location Plan**. Bedrock typically consisted of metamorphic rock comprised of gneiss at B6-20W, and gneiss and quartzite at B6-20E. Final test boring logs documenting overburden soil and bedrock conditions as well as photographs of the rock core samples are attached.

Rock compressive strength testing was performed on samples from approximately 20-foot intervals within the bedrock strata at B6-20E. As an exception to the planned 20-foot intervals, rock samples from B6-20W were not tested due to highly fractured or weathered conditions. Unconfined compressive strength test results are shown on the attached reports.

When laboratory soil testing results are available, we will submit a complete data report for the subject crossing. In the meantime, if you have questions, or if we may be of further service, please contact us.

Sincerely,
Terracon Consultants, Inc.

Marc A. Gullison, E.I.T.
Staff Geotechnical Engineer

Lawrence J. Dwyer, P.E. (CT 15120)
Principal

Attch:

TEST BORING LOCATION PLAN
EXPLORATION RESULTS (Boring Logs, Laboratory Data, Rock Core Photographs)
SUPPORTING INFORMATION (Unified Soil Classification System, Description of Rock Properties)

TEST BORING LOCATION PLAN

N

APPROXIMATE BORING LOCATION

DIAGRAM IS FOR GENERAL LOCATION ONLY, AND IS NOT INTENDED FOR CONSTRUCTION PURPOSES

Project Manager: JGS	Project No. J217P078		
Drawn by: SBL	Scale: N.T.S.		
Checked by: LJD	File Name: J217P078 BLP		
Approved by: LJD	Date: September. 2017		

Terracon
Consulting Engineers & Scientists
201 Hammer Mill Road Rocky Hill, Ct 06067
PH. (860) 721-1900 FAX. (860) 721-1939

TEST BORING LOCATION PLAN

Park Road HDD Core B6-20W and B6-20E
PA-CH-0111.0000-RD
Chester County, Pennsylvania

Exhibit
A-2

EXPLORATION RESULTS

BORING LOG NO. B6-20W Park Road West

PROJECT: Mariner East Pipeline Borings

SITE: Spread 6

CLIENT: Directional Project Support Incorporated
Magnolia, TX 77354

LOCATION PA-CH-0111.0000-RD
20170911
Latitude: 40.074364° Longitude: -75.700552°

Approximate Surface Elev: 458 (Ft.) +/-

DEPTH	DESCRIPTION	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	RQD (%)	Core rate (min/ft)	Penetrometer Test (tsf)
	SANDY SILT (ML), trace clay, orange-brown, very loose to loose				X	14	2-2-1 N=3			
			5		X	12	2-2-3 N=5			
6.4	Weathered rock, orange-brown, medium dense to very dense	451.5+/-								
			10	▽ (9.5')	X	13	6-9-10 N=19			
	Weathered rock, gray to brown		15		X	12	11-15-18 N=33			
			20		X	12	6-9-14 N=23			
			25		X	12	53-33-34 N=67			
			30							

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Mud rotary with wireline

Abandonment Method:
Grouted to surface

Notes:

WATER LEVEL OBSERVATIONS

▽ *9.5' WD*

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-27-2017	Boring Completed: 09-28-2017
Drill Rig: CME-850	Driller: Terracon/Peter M.
Project No.: J217P078	Exhibit: A-1

BORING LOG NO. B6-20W Park Road West

PROJECT: Mariner East Pipeline Borings

CLIENT: Directional Project Support Incorporated Magnolia, TX 77354

SITE: Spread 6

LOCATION PA-CH-0111.0000-RD 20170911
Latitude: 40.074364° Longitude: -75.700552°

Approximate Surface Elev: 458 (Ft.) +/-

DEPTH / Description	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	RQD (%)	Core rate (min/ft)	Penetrometer Test (tsf)
Weathered rock, orange-brown, medium dense to very dense *(continued)*				X	5	100/6"			
		35		X	4	100/4"			
		40		X	12	11-45-57 N=102			
		45		X	6	69-50/1"			
Similar, quartz layer at 45.6 feet									
		50		X	10	68-100/6"			
		55		X	5	100/5"			
		60							

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Mud rotary with wireline

Abandonment Method:
Grouted to surface

Notes:

WATER LEVEL OBSERVATIONS

9.5' WD

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-27-2017	Boring Completed: 09-28-2017
Drill Rig: CME-850	Driller: Terracon/Peter M.
Project No.: J217P078	Exhibit: A-1

BORING LOG NO. B6-20W Park Road West

PROJECT: Mariner East Pipeline Borings

SITE: Spread 6

CLIENT: Directional Project Support Incorporated Magnolia, TX 77354

LOCATION PA-CH-0111.0000-RD 20170911
Latitude: 40.074364° Longitude: -75.700552°

Approximate Surface Elev: 458 (Ft.) +/-

DEPTH	Material Description	ELEVATION (Ft.)	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	RQD (%)	Core rate (min/ft)	Penetrometer Test (tsf)
	Weathered rock, orange-brown, medium dense to very dense *(continued)*		X	7	60-50/1"			
66.0	Roller bit from 60.6 to 66 feet, begin core at 66 feet	392+/-						
71.0	Run 1, Soft, highly weathered, brownish-gray, fine-grained, GNEISS, foliation, primary joint set, moderately dipping, close spacing, rough, open	387+/-	Core	12		7	1 1 3 3 2.5	
76.0	Run 2, Similar	382+/-	Core	8		0	2 2 1.5 1 1.5	
78.0	Run 3, Similar	380+/-	Core	7		0	2.5 2.5	
81.0	Run 4, Similar, moderately weathered, light gray	377+/-	Core	4		0	2.25 3 2.5	
86.0	Run 5, Similar, with quartz bands	372+/-	Core	25		11	2 2 2 2.5 2	
	Run 6, Similar, brown		Core	15		9	2 2.5 2.5 2 1.75	

Depth scale (Ft.): 65, 70, 75, 80, 85, 90

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Mud rotary with wireline

Abandonment Method:
Grouted to surface

Notes:

WATER LEVEL OBSERVATIONS

9.5' WD

201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-27-2017	Boring Completed: 09-28-2017
Drill Rig: CME-850	Driller: Terracon/Peter M.
Project No.: J217P078	Exhibit: A-1

BORING LOG NO. B6-20W Park Road West

PROJECT: Mariner East Pipeline Borings

CLIENT: Directional Project Support Incorporated
Magnolia, TX 77354

SITE: Spread 6

LOCATION PA-CH-0111.0000-RD
20170911
Latitude: 40.074364° Longitude: -75.700552°

Approximate Surface Elev: 458 (Ft.) +/-

GRAPHIC LOG	DEPTH	DESCRIPTION	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	RQD (%)	Core rate (min/ft)	Penetrometer Test (tsf)
	91.0	Run 6, Similar, brown *(continued)*	367+/-				15				
	96.0	Run 7, Soft, highly weathered, brownish-gray, fine-grained, GNEISS, foliation, primary joint set, moderately dipping, close spacing, rough, open; secondary joint set, high angle From 94 to 95 feet: Similar, moderately weathered, light gray, with quartz bands, no secondary joint set From 95 to 96 feet: Similar, highly weathered, dark brown	362+/-	95			24		18	1.75 2 2 2.25 2	
	101.0	Run 8, Similar, moderately weathered, light gray, with quartz bands	357+/-	100			15		0	1.75 1.75 1.75 1.75 1.75	
	106.0	Run 9, Similar, highly weathered, clay layer from 101.5 to 102 feet	352+/-	105			20		0	1 0.75 1 1 1	
	111.0	Run 10, Similar, brown	347+/-	110			10		0	1 0.75 1 0.75 1	
	116.0	Run 11, Similar to 112 feet At 112 feet: Soft, highly weathered, gray and white, aphanitic to fine-grained, GNEISS, foliation, primary joint set, high angle to moderately dipping, moderately close spacing Slight green discoloration at 115.8 feet	342+/-	115			22		27	1.25 1.5 1.5 1.5 1.5	
		Run 12, Similar, moderately weathered, slightly open to moderately open		120			48.5		63	2.25 2 2 2 2.25	

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Mud rotary with wireline

Abandonment Method:
Grouted to surface

Notes:

WATER LEVEL OBSERVATIONS

▽ *9.5' WD*

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-27-2017	Boring Completed: 09-28-2017
Drill Rig: CME-850	Driller: Terracon/Peter M.
Project No.: J217P078	Exhibit: A-1

BORING LOG NO. B6-20W Park Road West

PROJECT: Mariner East Pipeline Borings

CLIENT: Directional Project Support Incorporated
Magnolia, TX 77354

SITE: Spread 6

LOCATION PA-CH-0111.0000-RD
20170911
Latitude: 40.074364° Longitude: -75.700552°

Approximate Surface Elev: 458 (Ft.) +/-

DEPTH	Description	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	RQD (%)	Core rate (min/ft)	Penetrometer Test (tsf)
121.0		337+/-				48.5				
	Run 13, Similar, moderately close spacing, highly weathered from 121.5 to 122.5 feet, clay in joints		125			49.5		56	2 2 2 2 2	
126.0		332+/-								
	Run 14, Similar, highly weathered from 127 to 128 feet		130			51		48	2 1.75 2 2 2.25	
131.0		327+/-								
	Run 15, Similar, graphite from 132 to 133 feet		135			39		39	2 2 2 1.75 2	
136.0		322+/-								
	Boring Terminated at 136 Feet									

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Mud rotary with wireline

Abandonment Method:
Grouted to surface

Notes:

WATER LEVEL OBSERVATIONS

9.5' WD

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-27-2017	Boring Completed: 09-28-2017
Drill Rig: CME-850	Driller: Terracon/Peter M.
Project No.: J217P078	Exhibit: A-1

BORING LOG NO. B6-20E Park Road East

PROJECT: Mariner East Pipeline Borings

SITE: Spread 6

CLIENT: Directional Project Support Incorporated
Magnolia, TX 77354

LOCATION PA-CH-0111.0000-RD 20170911
Latitude: 40.071119° Longitude: -75.694655°

Approximate Surface Elev: 459 (Ft.) +/-

DEPTH	Description	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	RQD (%)	Core rate (min/ft)	Penetrometer Test (tsf)
	FILL - LEAN CLAY, with rock fragments, trace organic matter, dark brown				X	4	2-2-2 N=4			0.25
5.0	**SANDY LEAN CLAY (CL)**, brown to gray, stiff to hard, (Residual soil)	454+/-	5		X	13	8-7-7 N=14			0
				∇ (9')						
			10		X	14	9-19-16 N=35			
16.0	Run 1, Very hard, severely weathered, white with gray and red, QUARTZITE, primary joint set, low angle, close spacing, moderately open; secondary joint set, vertical, close spacing, moderately open to open	443+/-	15		Core	37		36	2.5 2.25 2 2 1.5	
21.0	Run 2, Very hard, severely weathered, white with gray and black, QUARTZITE, primary joint set, moderately dipping, close spacing, moderately open	438+/-	20		Core	15		15	1 1 1.25 1 1.5	
26.0	Run 3, Completely weathered rock, missing recovery washed out in drill water	433+/-	25		Core	4		7	1.5 0.75 1 1 1.5	
			30							

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Mud rotary with wireline

Abandonment Method:
Grouted to surface

Notes:

WATER LEVEL OBSERVATIONS
∇ *9' on 9/26/17*

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-25-2017	Boring Completed: 09-26-2017
Drill Rig: CME-850	Driller: Terracon/Peter M.
Project No.: J217P078	Exhibit: A-2

BORING LOG NO. B6-20E Park Road East

PROJECT: Mariner East Pipeline Borings

CLIENT: Directional Project Support Incorporated Magnolia, TX 77354

SITE: Spread 6

LOCATION PA-CH-0111.0000-RD 20170911

Latitude: 40.071119° Longitude: -75.694655°

Approximate Surface Elev: 459 (Ft.) +/-

DEPTH	DESCRIPTION	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	RQD (%)	Core rate (min/ft)	Penetrometer Test (tsf)
31.0		428+/-				4				
36.0	Run 4, Hard, severely weathered, blue-gray with black, fine-grained, GNEISS, primary joint set, moderately dipping, close spacing, moderately open; secondary joint set, high angle, close spacing, open	423+/-	35			27		25	0.5 4 2 1.5 2.25	
41.0	Run 5, Hard to medium hard, severely weathered, blue-gray with black and red-brown, fine-grained, GNEISS, very thin foliation; primary joint set, moderately dipping, very close to close spacing, planar, open	418+/-	40			28		7	2 1.5 2 2.5 2	
46.0	Run 6, Similar to 42.2 feet At 42.2 feet: Very hard, moderately to highly weathered, white and black, coarse-grained QUARTZITE, primary joint set, low angle, close spacing, slightly open to open; secondary joint set, vertical, close spacing, moderately open to open; secondary joint set, vertical, close spacing, open	413+/-	45			44		35	1.5 2.25 3.25 4.5 4.5	
49.0	From 46 to 49 feet: Completely weathered GNEISS	410+/-								
51.0	Run 7, Very hard, moderately weathered, white and black, coarse-grained GNEISS, very thin foliation; primary joint set, vertical, close spacing, slightly open to open	408+/-	50			16		58	2 2	
56.0	Run 8, Soft to very hard, moderately weathered to residual soil, blue with gray, brown and white, fine-grained GNEISS, primary joint set, low angle, close to very close spacing, moderately open to open From 55 to 56 feet: Medium to very hard, moderately to completely weathered, blue with white and brown, coarse-grained, healed BRECCIA, planar horizontal foliation; primary joint set, low angle, close, open	403+/-	55			54		43	2.75 2.25 2.75 1.5 1.5	
	Run 9, Similar to Run 8, with QUARTZITE from 56.8 to 57.3 feet and healed BRECCIA from 59.3 to 60.3 feet, with occasional seams of pyrite from 59.5 to 60 feet		60			53		41	3 2.25 3 4 2.5	

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Mud rotary with wireline

Abandonment Method:
Grouted to surface

Notes:

WATER LEVEL OBSERVATIONS

▽ *9' on 9/26/17*

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-25-2017	Boring Completed: 09-26-2017
Drill Rig: CME-850	Driller: Terracon/Peter M.
Project No.: J217P078	Exhibit: A-2

BORING LOG NO. B6-20E Park Road East

PROJECT: Mariner East Pipeline Borings

CLIENT: Directional Project Support Incorporated
Magnolia, TX 77354

SITE: Spread 6

LOCATION PA-CH-0111.0000-RD 20170911
Latitude: 40.071119° Longitude: -75.694655°

Approximate Surface Elev: 459 (Ft.) +/-

DEPTH	Description	ELEVATION (Ft.)	DEPTH (Ft.)	RECOVERY (In.)	FIELD TEST RESULTS	RQD (%)	Core rate (min/ft)	Penetrometer Test (tsf)
				53				
61.0	Run 10, Very hard, slightly weathered, blue-gray with white and brown, GNEISS, horizontal, planar, very thin foliation; primary joint set, low angle, close spacing, moderately open; secondary joint set, high angle, close spacing, moderately open Soft, completely weathered zone from 61 to 61.6 feet	398+/-	65	58		81	2.25 2.75 3.5 4 5	
66.0	Run 11, Similar, low angled, planar, thin foliation; primary joint set, moderately dipping, very close to close, open; secondary joint set, high angle, close to moderately close, moderately open, occasional seams of pyrite from 68.5 to 70 feet	393+/-	70	58		73	3 3 2 2.75 2	
71.0	Run 12, Similar	388+/-	75	60		93	4 2.75 2.5 2.75 3	
76.0	Run 13, Similar From 76 to 76.8 feet: Coarse-grained GNEISS, undulated, very thin foliation; low angle joints	383+/-	80	59		76	3.5 2.25 1.75 2.25 3	
81.0	Run 14, Similar From 85.8 to 86 feet: Completely weathered	378+/-	85	60		86	3 2 3.25 3 1.5	
86.0	Run 15, Similar	373+/-	90	57		83	3 2 2.25 2 1.75	

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Mud rotary with wireline

Abandonment Method:
Grouted to surface

Notes:

WATER LEVEL OBSERVATIONS

9' on 9/26/17

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-25-2017	Boring Completed: 09-26-2017
Drill Rig: CME-850	Driller: Terracon/Peter M.
Project No.: J217P078	Exhibit: A-2

BORING LOG NO. B6-20E Park Road East

PROJECT: Mariner East Pipeline Borings

CLIENT: Directional Project Support Incorporated Magnolia, TX 77354

SITE: Spread 6

LOCATION PA-CH-0111.0000-RD 20170911
Latitude: 40.071119° Longitude: -75.694655°
Approximate Surface Elev: 459 (Ft.) +/-

DEPTH	Description	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	RQD (%)	Core rate (min/ft)	Penetrometer Test (tsf)
91.0	Run 15, Similar *(continued)*	368+/-				57				
96.0	Run 16, Similar, primary joint set, moderate angle, slightly open, close, no secondary joints From 94.5 to 95.3 feet: Highly fractured zone From 95.3 to 95.8 feet: Vertical joints	363+/-	95			60		80	2.75 2 2 2.5 3	
101.0	Run 17, Very hard, severely to slightly weathered, gray with black and white, fine-grained, FELSIC GNEISS, low angle, undulated, thin foliation; primary joint set, low angle, close spacing, slightly open to open; secondary joint set, vertical, close spacing, moderately open	358+/-	100			60		52	3 3 2.75 3.5 3.5	
106.0	Run 18, Similar, tertiary joint set, vertical, close spacing, moderately open From 103.3 to 104.3 feet: Highly fractured zone From 104.8 to 105.6 feet: Vertical joint	353+/-	105			60		43	3.25 2.25 3.25 3.5 3.25	
111.0	Run 19, Similar, secondary joint set, high angle, close spacing, moderately open From 109 to 109.4 feet and 110 to 110.5 feet: very coarse grained PEGMATITE seams	348+/-	110			60		65	3 2 3.25 2.75 2.75	
116.0	Run 20, Similar, primary joint set, moderately dipping, close spacing, moderately open; secondary joint set, high angle, close, moderately open to open From 112.3 to 112.7 feet and 114.8 to 115.7 feet: Very coarse grained PEGMATITE	343+/-	115			60		48	3.5 2 2.75 3 3	
	Run 21, Similar From 116.8 to 118.1 feet: Highly fractured zone At 117.8 feet: Coarse-grained seam of PEGMATITE		120			53		63	3.75 3 4.5 4.5 3.25	

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Mud rotary with wireline

Abandonment Method:
Grouted to surface

Notes:

WATER LEVEL OBSERVATIONS
9' on 9/26/17

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-25-2017	Boring Completed: 09-26-2017
Drill Rig: CME-850	Driller: Terracon/Peter M.
Project No.: J217P078	Exhibit: A-2

BORING LOG NO. B6-20E Park Road East

PROJECT: Mariner East Pipeline Borings

SITE: Spread 6

CLIENT: Directional Project Support Incorporated Magnolia, TX 77354

LOCATION PA-CH-0111.0000-RD 20170911

Latitude: 40.071119° Longitude: -75.694655°

Approximate Surface Elev: 459 (Ft.) +/-

GRAPHIC LOG	DEPTH	Description	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	RQD (%)	Core rate (min/ft)	Penetrometer Test (tsf)
	121.0		338+/-				53				
	126.0	Run 22, Hard, slightly weathered, gray with white, coarse-grained PEGMATITE, horizontal, planar, thin foliation	333+/-	125			56		93	5.5 5 5 3.25 4	
	131.0	Run 23, From 126 to 129 feet: Similar to Run 22, PEGMATITE, sharp contact at 129 feet From 129 to 131 feet: Similar to Run 20, FELSIC GNEISS From 130.5 to 130.8 feet: Coarse grained	328+/-	130			58		73	4 3.5 4.5 5 4	
	136.0	Run 24, Similar to Run 20, FELSIC GNEISS, primary joint set, moderately dipping, close spacing, moderately open to open; secondary joint set, vertical, close spacing, slightly open to open From 133 to 134.8 feet: Vertical fracture	323+/-	135			55		70	5 4.5 4.75 5 5	

Boring Terminated at 136 Feet

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Mud rotary with wireline

Abandonment Method:
Grouted to surface

Notes:

WATER LEVEL OBSERVATIONS

▽ *9' on 9/26/17*

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

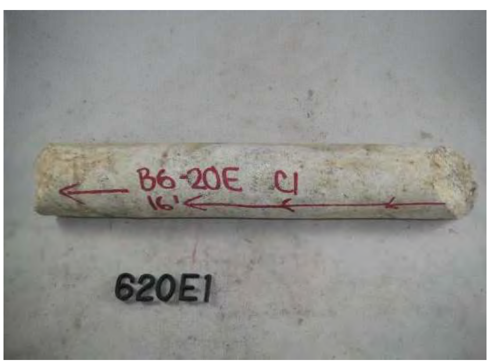
Boring Started: 09-25-2017	Boring Completed: 09-26-2017
Drill Rig: CME-850	Driller: Terracon/Peter M.
Project No.: J217P078	Exhibit: A-2

ASTM D7012 (Method C) Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens

Boring No.:	B6-20E	Lithology :	Quartzite
Sample No.:	1	Moisture Content :	As received
Sample Depth:	16 feet	Lab Temperature :	70° F
Sampling Date:	9/25/17	Loading Rate:	55 psi/s
		Time to Failure:	8 min

Diameter:	1.96 in	**Maximum Axial Load at Failure:**	**26,680 lb**
Length:	4.50 in	**Compressive Strength:**	**8,843 psi**
L/D:	2.30	**Compressive Strength:**	**60.97 Mpa**
End Area:	3.02 in^2	**Unit Weight**	**161 pcf**

Before the Test



After the Test

Drawing # : PA-CH-0111.0000-RD
PO # : 20170911
Crossing : Park Road
Spread : Spread 6

Project:	Mariner East Pipeline	Terracon	Performed by:	D. Savage
Project No.	J217P078	77 Sundial Ave., Suite 401 W	Test Date:	10/16/2017
Location:	Spread 6	Manchester, New Hampshire	Reviewed By :	L. Dwyer
Client :	Directional Project Support Inc.		Review Date :	10/16/2017

ASTM D7012 (Method C) Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens

Boring No.:	B6-20E	Lithology :	Quartzite
Sample No.:	2	Moisture Content :	As received
Sample Depth:	27 feet	Lab Temperature :	70° F
Sampling Date:	9/25/17	Loading Rate:	55 psi/s
		Time to Failure:	13 min

Diameter:	1.96 in	**Maximum Axial Load at Failure:**	**43,820 lb**
Length:	4.61 in	**Compressive Strength:**	**14,523 psi**
L/D:	2.35	**Compressive Strength:**	**100.14 Mpa**
End Area:	3.02 in^2	**Unit Weight**	**176 pcf**

Before the Test

After the Test

Drawing # : PA-CH-0111.0000-RD
PO # : 20170911
Crossing : Park Road
Spread : Spread 6

Project:	Mariner East Pipeline	Terracon	Performed by:	D. Savage
Project No.	J217P078	77 Sundial Ave., Suite 401 W	Test Date:	10/16/2017
Location:	Spread 6	Manchester, New Hampshire	Reviewed By :	L. Dwyer
Client :	Directional Project Support Inc.		Review Date :	10/16/2017

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ASTM D7012 (Method C) Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens

Boring No.:	B6-20E	Lithology :	Gneiss
Sample No.:	3	Moisture Content :	As received
Sample Depth:	54 feet	Lab Temperature :	70° F
Sampling Date:	9/25/17	Loading Rate:	55 psi/s
		Time to Failure:	16 min

Diameter:	1.99 in	**Maximum Axial Load at Failure:**	**52,160 lb**
Length:	4.55 in	**Compressive Strength:**	**16,770 psi**
L/D:	2.29	**Compressive Strength:**	**115.63 Mpa**
End Area:	3.11 in^2	**Unit Weight**	**177 pcf**

Before the Test

Photographs are mislabeled as 6-20E-1

After the Test

Drawing # : PA-CH-0111.0000-RD
PO # : 20170911
Crossing : Park Road
Spread : Spread 6

Project:	Mariner East Pipeline	Terracon	Performed by:	D. Savage
Project No.	J217P078	77 Sundial Ave., Suite 401 W	Test Date:	10/16/2017
Location:	Spread 6	Manchester, New Hampshire	Reviewed By :	L. Dwyer
Client :	Directional Project Support Inc.		Review Date :	10/16/2017

ASTM D7012 (Method C) Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens

Boring No.:	B6-20E	Lithology :	Gneiss
Sample No.:	4	Moisture Content :	As received
Sample Depth:	76 feet	Lab Temperature :	70° F
Sampling Date:	9/25/17	Loading Rate:	55 psi/s
		Time to Failure:	8 min

Diameter:	1.98 in	**Maximum Axial Load at Failure:**	**26,320 lb**
Length:	4.25 in	**Compressive Strength:**	**8,548 psi**
L/D:	2.15	**Compressive Strength:**	**58.94 Mpa**
End Area:	3.08 in^2	**Unit Weight**	**178 pcf**

Before the Test

Photographs are mislabeled as 6-20E-2

After the Test

Drawing # : PA-CH-0111.0000-RD
PO # : 20170911
Crossing : Park Road
Spread : Spread 6

Project:	Mariner East Pipeline	Terracon 77 Sundial Ave., Suite 401 W Manchester, New Hampshire	Performed by:	D. Savage
Project No.	J217P078		Test Date:	10/16/2017
Location:	Spread 6		Reviewed By :	L. Dwyer
Client :	Directional Project Support Inc.		Review Date :	10/16/2017

ASTM D7012 (Method C) Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens

Boring No.:	B6-20E	Lithology :	Gneiss
Sample No.:	5	Moisture Content :	As received
Sample Depth:	87 feet	Lab Temperature :	70° F
Sampling Date:	9/25/17	Loading Rate:	55 psi/s
		Time to Failure:	5 min

Diameter:	1.98 in	**Maximum Axial Load at Failure:**	**15,210 lb**
Length:	4.56 in	**Compressive Strength:**	**4,940 psi**
L/D:	2.30	**Compressive Strength:**	**34.06 Mpa**
End Area:	3.08 in^2	**Unit Weight**	**168 pcf**

Before the Test

Photographs are mislabeled as 6-20E-3

After the Test

Drawing # : PA-CH-0111.0000-RD
PO # : 20170911
Crossing : Park Road
Spread : Spread 6

Project:	Mariner East Pipeline	Terracon	Performed by:	D. Savage
Project No.	J217P078	77 Sundial Ave., Suite 401 W	Test Date:	10/16/2017
Location:	Spread 6	Manchester, New Hampshire	Reviewed By :	L. Dwyer
Client :	Directional Project Support Inc.		Review Date :	10/16/2017

ASTM D7012 (Method C) Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens

Boring No.:	B6-20E	Lithology :	Gneiss
Sample No.:	6	Moisture Content :	As received
Sample Depth:	96 feet	Lab Temperature :	70° F
Sampling Date:	9/25/17	Loading Rate:	55 psi/s
		Time to Failure:	11 min

Diameter:	1.99 in	**Maximum Axial Load at Failure:**	**35,110 lb**
Length:	4.52 in	**Compressive Strength:**	**11,288 psi**
L/D:	2.27	**Compressive Strength:**	**77.83 Mpa**
End Area:	3.11 in^2	**Unit Weight**	**172 pcf**

Before the Test

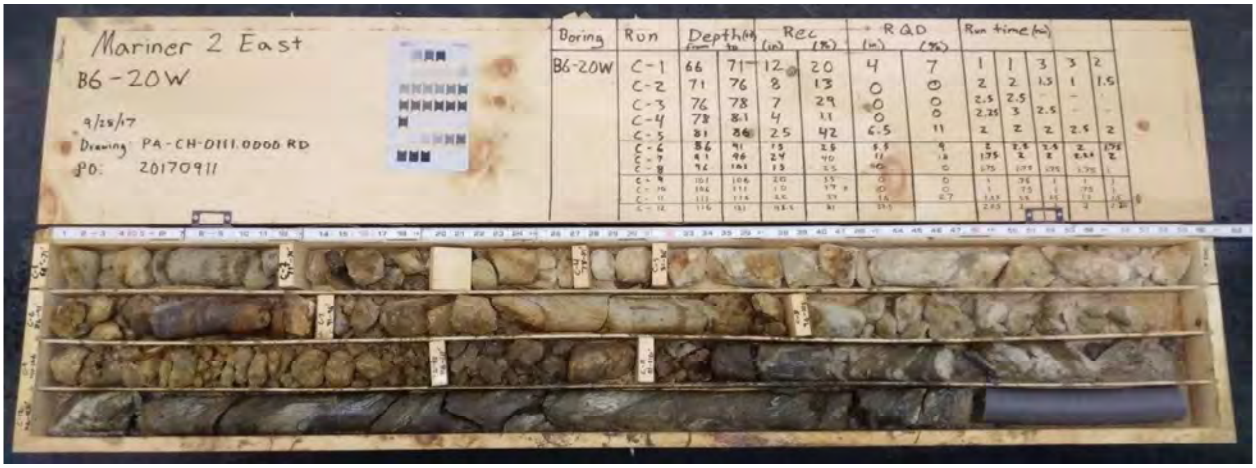
Photographs are mislabeled as 6-20E-4

After the Test

Drawing # : PA-CH-0111.0000-RD
PO # : 20170911
Crossing : Park Road
Spread : Spread 6

Project:	Mariner East Pipeline	Terracon	Performed by:	D. Savage
Project No.	J217P078	77 Sundial Ave., Suite 401 W	Test Date:	10/16/2017
Location:	Spread 6	Manchester, New Hampshire	Reviewed By :	L. Dwyer
Client :	Directional Project Support Inc.		Review Date :	10/16/2017

Terracon

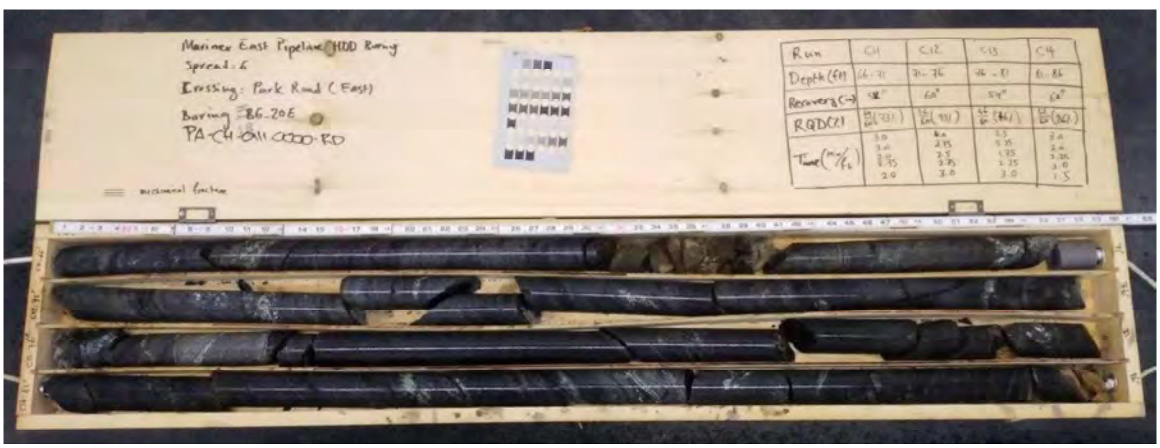


Photograph 1: B6-20W, Samples C-1 to C-12 (66 to 121 feet)

Photograph 2: B6-20W, Samples C-13 to C-15 (121 to 136 feet)

Photograph 1: B6-20E, Samples C-1 to C-5 (16 to 41 feet)

Photograph 2: B6-20E, Samples C-6 to C-10 (41 to 66 feet)



Photograph 3: B6-20E, Samples C-11 to C-14 (66 to 86 feet)

Photograph 4: B6-20E, Samples C-15 to C-18 (86 to 106 feet)

Photograph 5: B6-20E, Samples C-19 to C-22 (106 to 126 feet)

Photograph 6: B6-20E, Samples C-23 to C-24 (126 to 136 feet)

Attachment C

Geophysical Study Report

Rettew / Enviroscan, May 10, 2019

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

Engineers
Environmental Consultants
Surveyors
Landscape Architects
Safety Consultants
Geophysicists

May 10, 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 S3-0300 Park Road
PA-CH-0111.0000-RD
Upper Uwchlan Township, Chester County, Pennsylvania
RETTEW Project No. 096302015

Dear Mr. Gremminger:

RETTEW Associates, Inc. completed a multi-technique geophysical survey at the S3-0300 Park Road horizontal directional drill (HDD) site. The purpose of the survey was to detect and delineate subsurface fracture zones that could contribute to potential inadvertent returns (IRs) and/or a loss of circulation, and to determine the rock profile and rock rippability for ease-of-excavation along the HDD path. The following report, figures, and attachments describe the methods and results of the investigation.

EXECUTIVE SUMMARY

The multi-technique geophysical survey was completed on January 10, 2019. Two different geophysical techniques were utilized to detect and delineate subsurface features and provide a bedrock profile. These methods, and their general results, are as follows:

- Seismic refraction and MASW results confirmed the presence of low-velocity zones within the bedrock that could represent fracture zones
- Electrical resistivity imaging (ERI) identified a relatively conductive surface layer over a discontinuous mildly resistive layer, with the discontinuities possibly suggesting the presence of fracture zones.

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 is mildly fractured, with a few potential anomalous zones of concern including the locations that intersect the geologic contact crossing the survey area. The top-of-rock is expected to be slightly irregular with a weathered zone above competent rock and potential residual clay- or soil-filled fractures within the bedrock formation.

SITE DESCRIPTION

The Park Road HDD site is located east of Marsh Creek Reservoir in Upper Uwchlan Township, Chester County, Pennsylvania (see **Figure 1**). A geophysical survey was conducted over accessible areas of the path between the HDD exit/entry locations (**Figure 2**).

The site bedrock geology consists of Precambrian-aged banded mafic gneiss in the west and the graphitic felsic gneiss in the east (The Geologic Map of Pennsylvania, PA Department of Conservation and Natural Resources Geology Interactive Map, 2017 – see **Figure 2**). The banded mafic gneiss is described as dark, fine- to medium-grained, and highly metamorphosed from a probable sedimentary origin. The graphitic felsic gneiss includes the Pickering Gneiss and small areas of marble. Outside the marble, it is dominantly quartz and feldspar with varying amounts of graphite and various metamorphic minerals. It can also be medium-grained, light to dark gray and greenish-gray, and is also of probable sedimentary origin (Berg et al., 1980). The Geologic Map of Pennsylvania (PA Department of Conservation and Natural Resources Geology Interactive Map, 2017) shows several contacts and major fractures and faults within a mile of the survey area, as seen on the geologic inset on **Figure 2,** upper right (Ibid.).

SEISMIC MASW AND REFRACTION SURVEY

Seismic Multi-Spectral Analysis of Surface Waves (MASW) and refraction methods utilize the speed of seismic waves through various geologic layers and features to characterize the subsurface geologic conditions. The methods enable determination of the general material types, and the approximate depth to bedrock or rock profile. MASW can detect low velocities below the top of rock that might be associated with fracture zones. The principles of seismic refraction are summarized in **Appendix A**.

The seismic survey consisted of a single profile along the HDD center line between the exit/entry points (see blue triangles, **Figure 2**). Color-contour velocity models of the seismic profiles for the seismic refraction and MASW are presented on **Figures 3 and 4,** respectively. 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 or P-wave velocities for refraction, and shear or S-wave velocities for MASW), with increasing velocities from blue to yellow to orange to brown (upper profile), and purple to grey to tan to brown (lower profile). Please note that high- and low-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 into the ground using current 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 of the measured apparent resistivities along a profile (or profiles in the case of 3D resistivity).

The resistivity survey consisted of a single profile between the exit/entry points (see orange dots, **Figure 2**). The apparent resistivity data were mathematically inverted using EarthImager 2D by AGI to provide a cross-sectional image of the profile. This is shown as successive segments in **Figure 5**. Specific ERI survey parameters are listed in **Appendix B**.

RESULTS

The seismic refraction data are presented as a cross-sectional profile on **Figure 3**. The data indicate a general three-layer stratigraphy consisting of a residual or sedimentary soil mantle, a weathered rock zone, 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 5-15 feet. This is consistent with a relatively compact soil mantle (shaded blue to yellow). The deepest layers have velocities over 10,000 fps (shaded orange to brown), consistent with competent bedrock (Carmichael, R. S., 1989). The seismic refraction results show multiple low-velocity zones indicative of fracture zones. The suspected fracture zones are highlighted on the seismic profiles in magenta.

The MASW seismic cross sections are presented on **Figure 4**. The MASW velocity models show lateral velocity changes within the bedrock layer across the profiles, and relatively consistent with the seismic refraction. Velocity lows below the bedrock surface could indicate fractures which might be potential pathways for IRs and/or locations for loss of circulation.

The seismic velocity models from the ray-tracing method (not shown) were compared to standard ripping charts (see **Appendix C**, Caterpillar, Inc., 1995) using the inferred/assumed layer compositions to determine the general rippability of each stratum. In general, the surficial layer (bounded at depth by the 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 contour (based on the average ray-trace velocity of over 10,930 fps and Caterpillar charts). The 5,000-fps contour represents the top of weathered rock. For trenching (as opposed to open field ripping), material below approximately the 3500-fps contour color (greenish blue) may become non-rippable (for a CAT-330 tracked excavator or equivalent). The selection of the contour 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 5.** The electrical profiles show a general two-layer model with a relatively conductive surface layer over a discontinuous mildly resistive layer. The upper layer is relatively discontinuous, with irregularities that could represent near-surface disturbances given the site development history. The deep conductive (blue) anomalies below the inferred top-of-rock may represent fractures or weathered seams within bedrock. Note that most of the western half of the bedrock along the HDD is relatively conductive (below 1000 Ohm-m) which is unusually low for metamorphic rock. These low resistivity values may indicate ubiquitous fracturing within the bedrock despite the low number of apparent unique features as seen on either end of the HDD.

CONCLUSIONS

In general, the geophysical survey results display anomalies indicative of fractures that are possible locations for IRs and/or loss of returns along most of the HDD alignment. **Figure 6** summarizes the anomalous areas with various colored double-arrows. Overlapping and/or adjacent arrows indicate the highest risk of IR, but any anomalous areas might have an enhanced risk.

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.

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: Seismic Refraction Survey Results
Figure 4: Seismic MASW Survey Results
Figure 5: Electrical Resistivity Survey Results
Figure 6: Geophysical Results Summary
Appendix A: Introduction to Seismic Refraction
Appendix B: Geophysical Survey Parameters
Appendix C: Caterpillar Ripping Charts

References

Berg, T.M., Edmunds, W.E., Geyer, A.R., and others, 1980, Geologic Map of Pennsylvania, PA Geological Survey, 4th series.

Carmichael, R. S. (1989), Physical Properties of Rocks and Minerals, CRC Press.

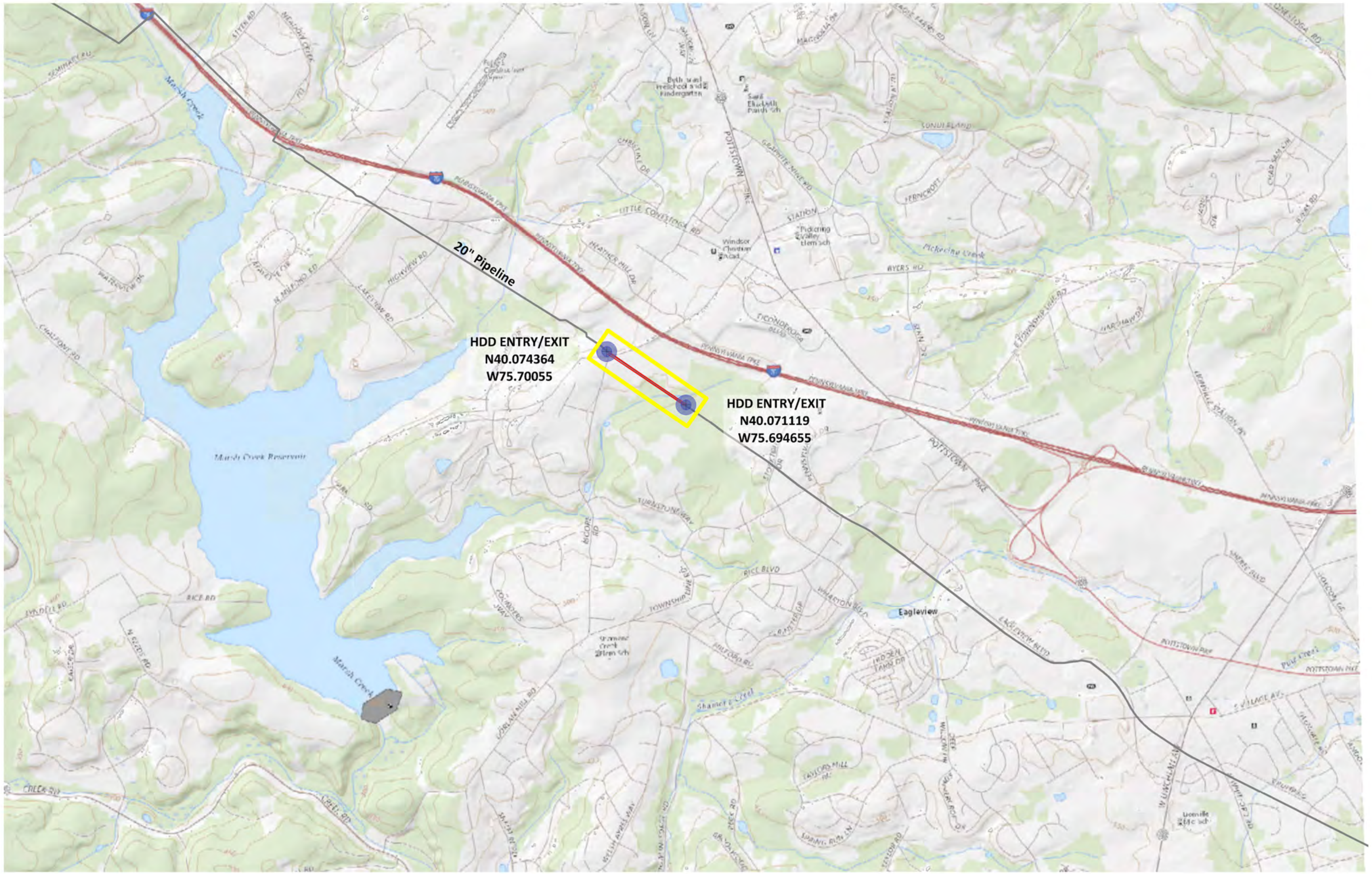
Caterpillar Tractor Company (1995), The Applicator, Caterpillar Tractor Company Marketing Division.

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

PA Department of Conservation and Natural Resources Geology Interactive Map, (http://www.gis.dcnr.state.pa.us.html), 2017.

Z:\Shared\Projects\09630\096302015 - Spread 6 Eight Sites\GP\S3-0300 Park Road\Report\Final\S3-0300 Park Road Geophysic Final Report 5-10-19.docx

ENCLOSURES



Geophysical Survey Legend

- Proposed 20" HDD Alignment
- Geophysical Survey Area
- HDD Entry/Exit Point

Scale (ft)

0 1000 2000 3000 4000

Notes:

Basemap extracted from USGS US Topgraphic WMS Server, extracted 01/2019.

SURVEY DATE:	12/27/2018
RETTEW No.:	096302015
REVIEWED BY:	FKB
DRAWN BY:	CHR
DATE:	02/27/2019
SCALE:	1" = 2000'
FIGURE NO.	1 of 6

RETTEW | ENVIROSCAN

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

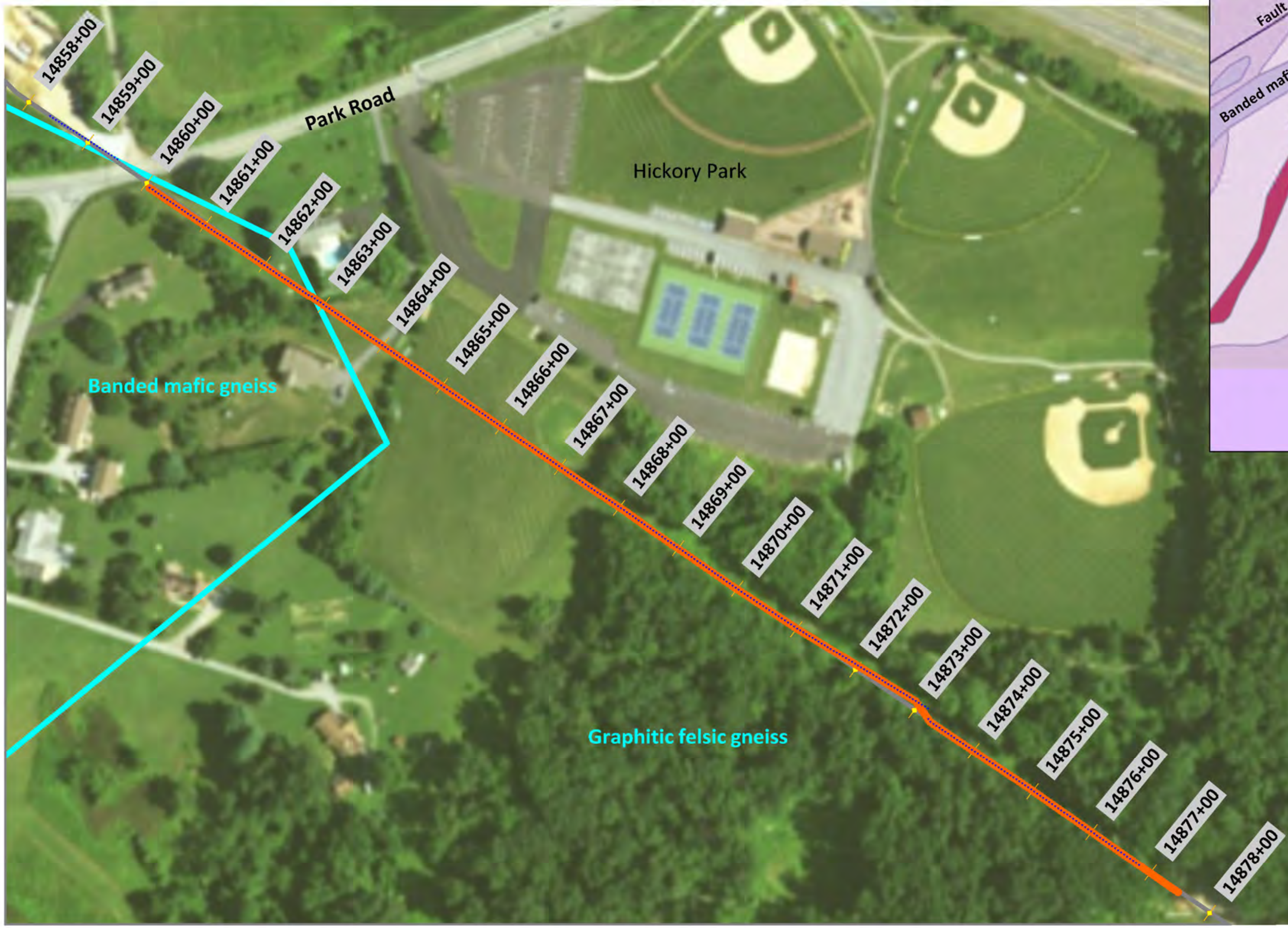
Figure 1: Topographic Basemap

Park Road
S3-0300
PA-CH-0111.0000-RD

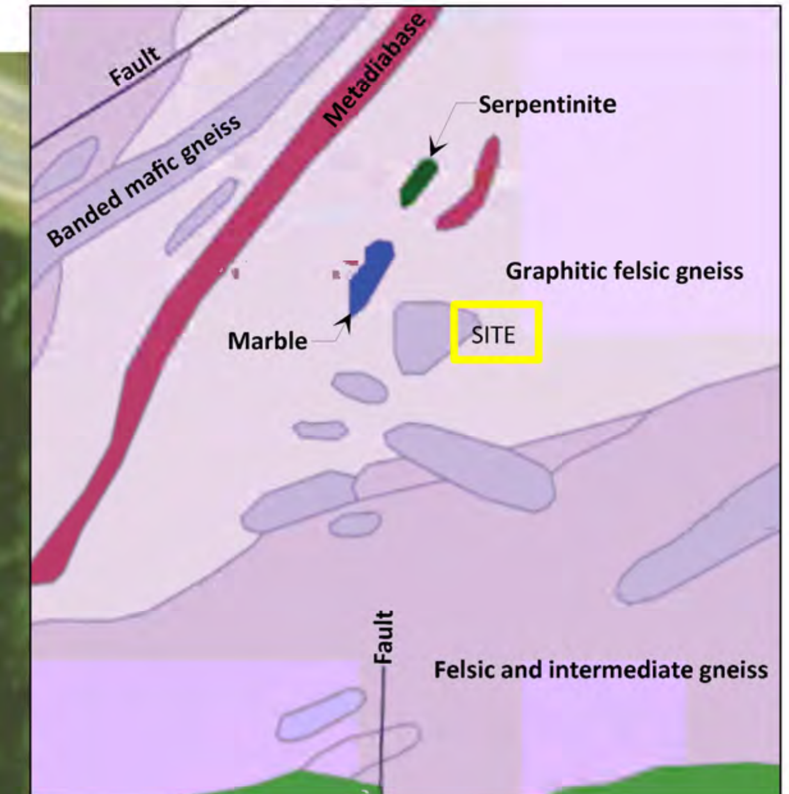
CHESTER COUNTY, PA

UPPER UWCHLAN TOWNSHIP

Site Coverage



Regional Geologic Map



Geophysical Survey Legend

- HDD Entry/Exit
- Electrical Resistivity Station
- Seismic Geophone Location
- Mapped Geologic Contact
- 11256+00 20" Product Line with Station Number

Scale (ft)

0 80 160 240 320

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, and Wood (1980).

SURVEY DATE: 12/27/2018
RETTEW No.: 096302015
REVIEWED BY: FKB
DRAWN BY: CHR
DATE: 02/21/2019
SCALE: 1" = 160'
FIGURE NO. **2 of 6**

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Figure 2: Data Coverage Map and Geologic Setting

Park Road
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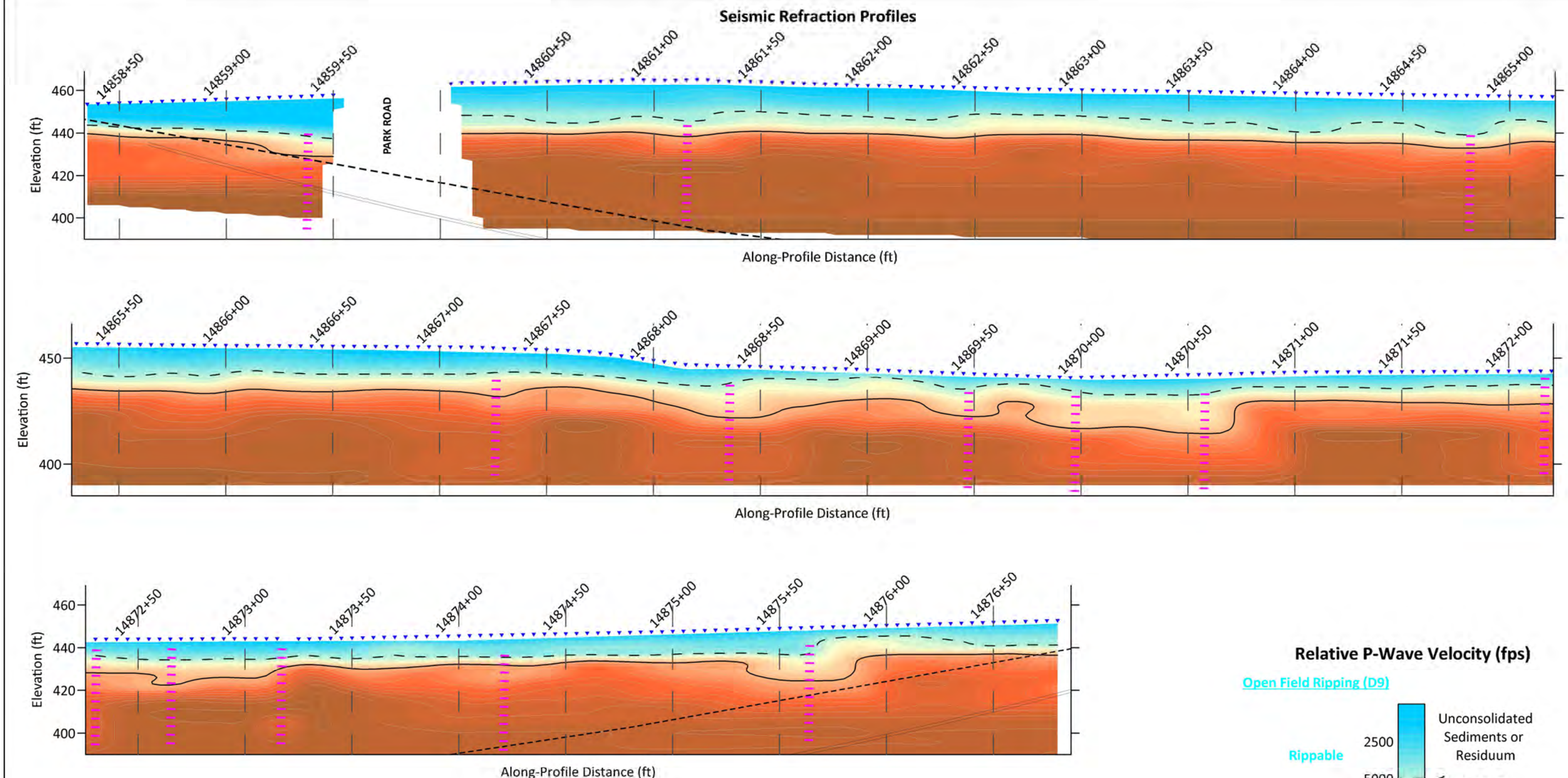
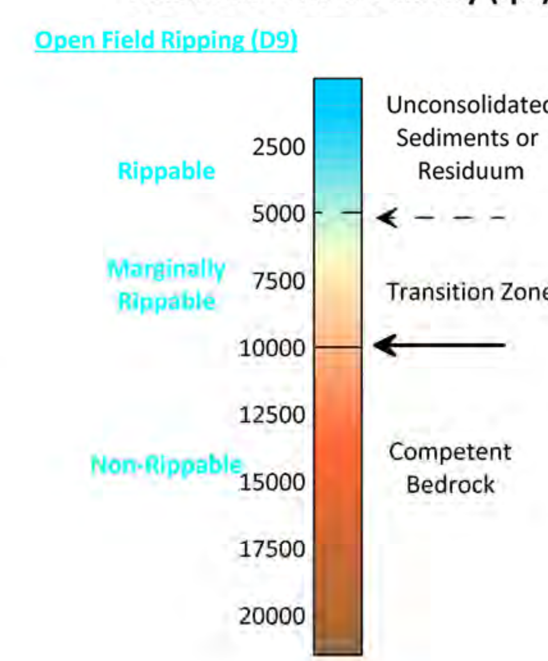
CHESTER COUNTY, PA

UPPER UWCHLAN TOWNSHIP

Seismic Refraction Profiles



Relative P-Wave Velocity (fps)



Geophysical Survey Legend

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

Weighted Average Velocity (Trg)

V_1 = 1,228 fps

V_2 = 10,930 fps

Notes:

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

Relative seismic velocity models from SeisImager (by Oyo Corporation) tomographic and ReMi inversions.

SURVEY DATE: 12/27/2018
RETTEW No.: 096302015
REVIEWED BY: FKB
DRAWN BY: CHR
DATE: 05/09/2019
SCALE: 1" = 50'
FIGURE NO.: 3 of 6

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CHESTER COUNTY, PA

Figure 3: Seismic Refraction Survey Results

Park Road
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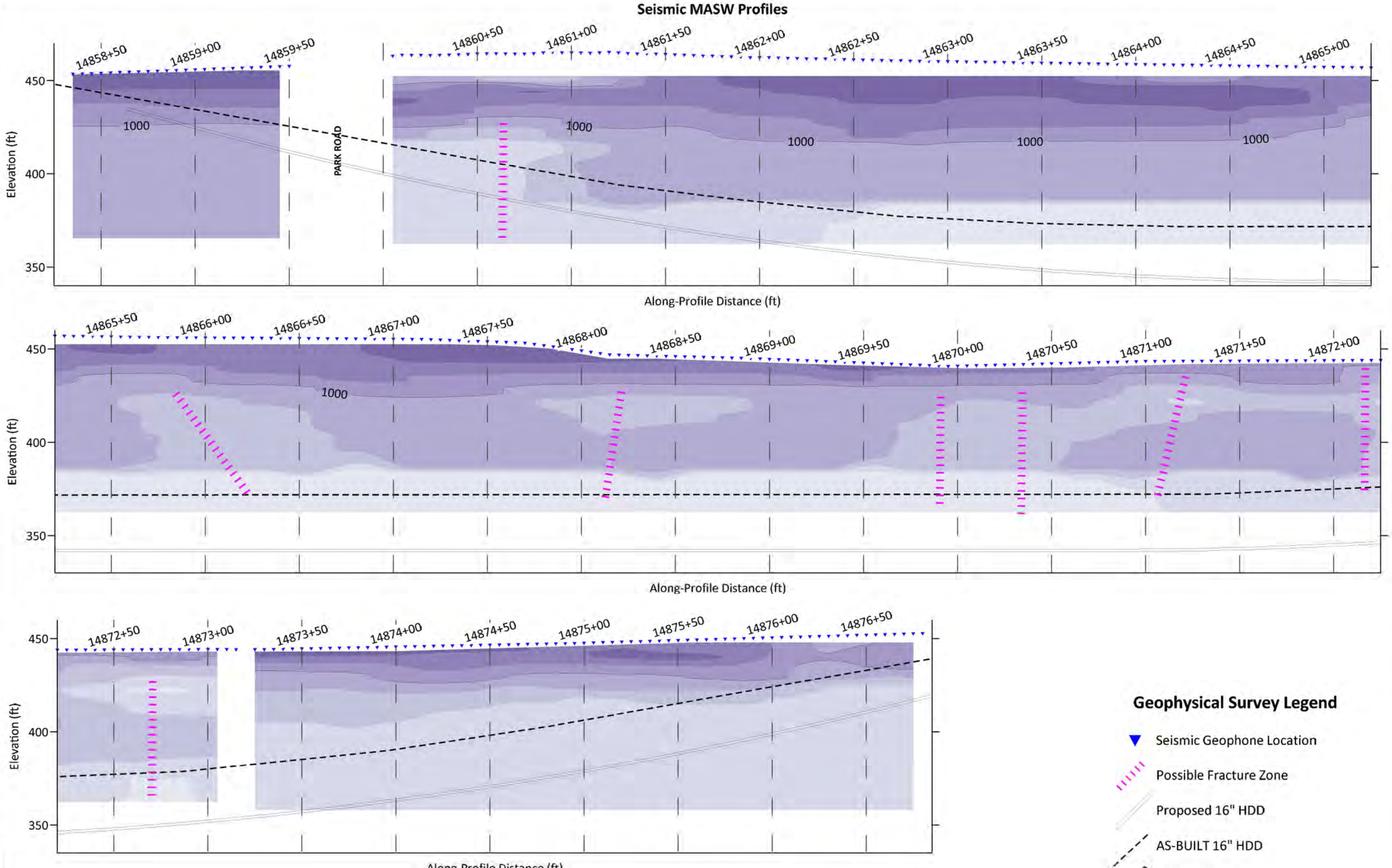
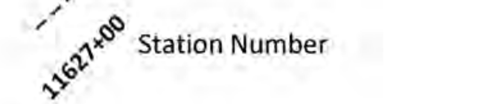
UPPER UWCHLAN TOWNSHIP

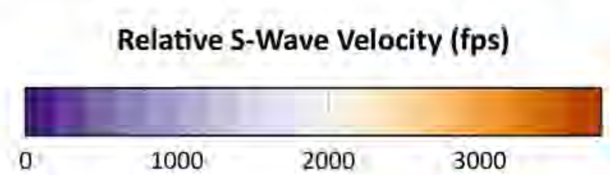




Notes:

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

Relative seismic velocity models from SeisImager (by Oyo Corporation) tomographic and ReMi inversions.



SURVEY DATE: 12/27/2018
RETTEW No.: 096302015
REVIEWED BY: FKB
DRAWN BY: CHR
DATE: 05/09/2019
SCALE: 1" = 50'
FIGURE NO. 4 of 6

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Figure 4: Seismic MASW Survey Results

Park Road
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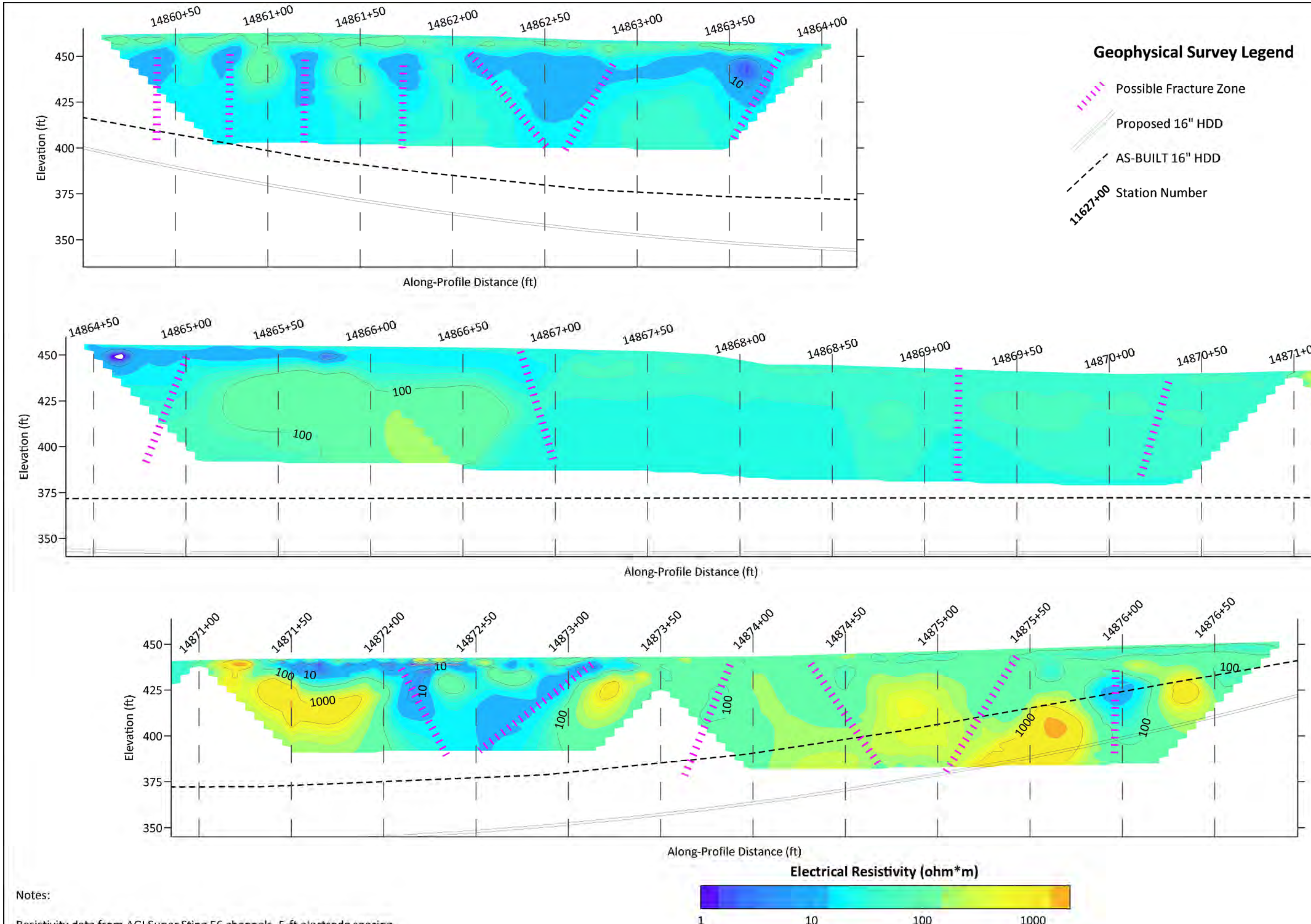
CHESTER COUNTY PA
UPPER UWCHLAN TOWNSHIP



Notes:

Resistivity data from AGI Super Sting 56 channels, 5-ft electrode spacing.

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

SURVEY DATE: 12/27/2018
RETTEW No.: 096302015
REVIEWED BY: FKB
DRAWN BY: CHR
DATE: 05/09/2019
SCALE: 1" = 50'
FIGURE NO. 5 of 6

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RETTEW Associates, Inc.
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Phone (717) 394-3721 Fax (717) 394-1063

Figure 5: Electrical Resistivity Survey Results

Park Road
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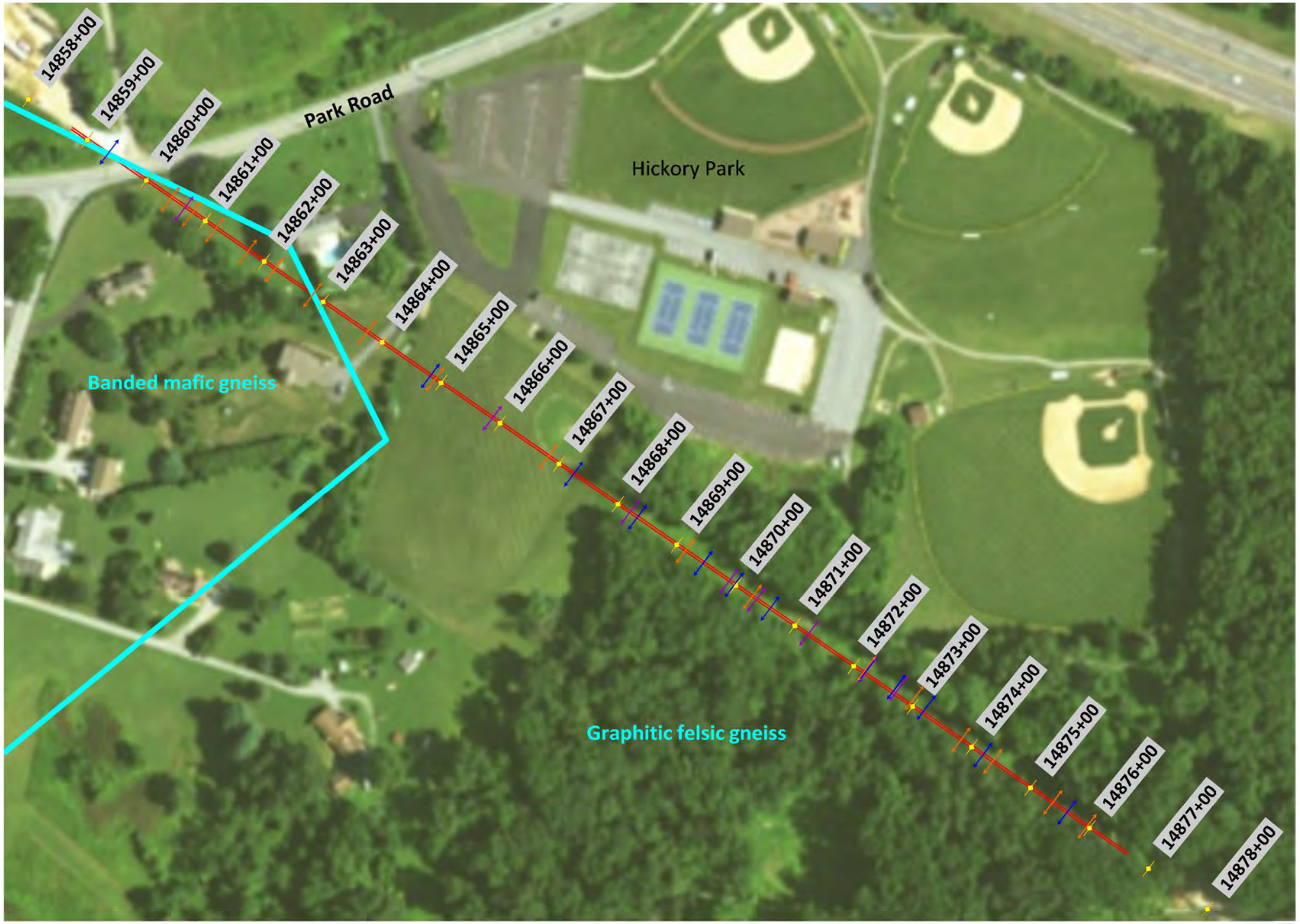
PA-CH-0111.0000-RD

CHESTER COUNTY, PA
UPPER UWCHLAN TOWNSHIP



Geophysical Survey Legend

Possible Fracture Zone Detected By:

- Electrical Resistivity
- Seismic MASW
- Seismic Refraction

Proposed 20" HDD

11627+00 Station Number

Scale (ft)

0 80 160 240 320

Notes:

Basemap from Google Earth Pro, extracted 01/2019.

Geophysical results from previous figures.

SURVEY DATE: 12/27/2018

RETTEW No.: 096302015

REVIEWED BY: FKB

DRAWN BY: CHR

DATE: 02/27/2019

SCALE: 1" = 160'

FIGURE NO. 6 of 6

ENVIROSCAN

RETTEW

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Figure 6: Geophysical Results Summary

Park Road

S3-0300

PA-CH-0111.0000-RD

CHESTER COUNTY, PA

UPPER UWCHLAN TOWNSHIP

APPENDIX A

Introduction to Seismic Refraction

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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).

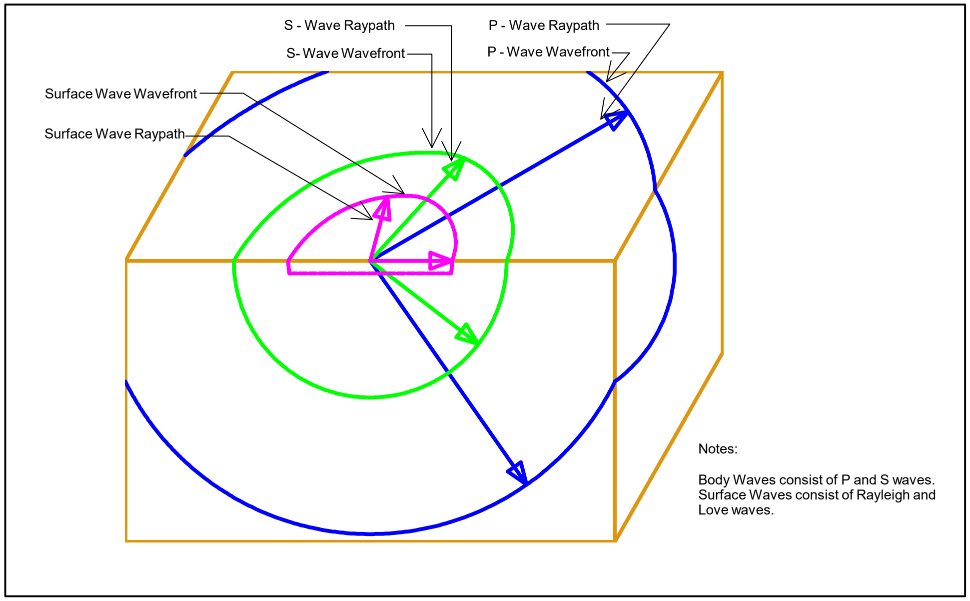


Figure SR-1 **Seismic Wave Types** Rev. 04/2018

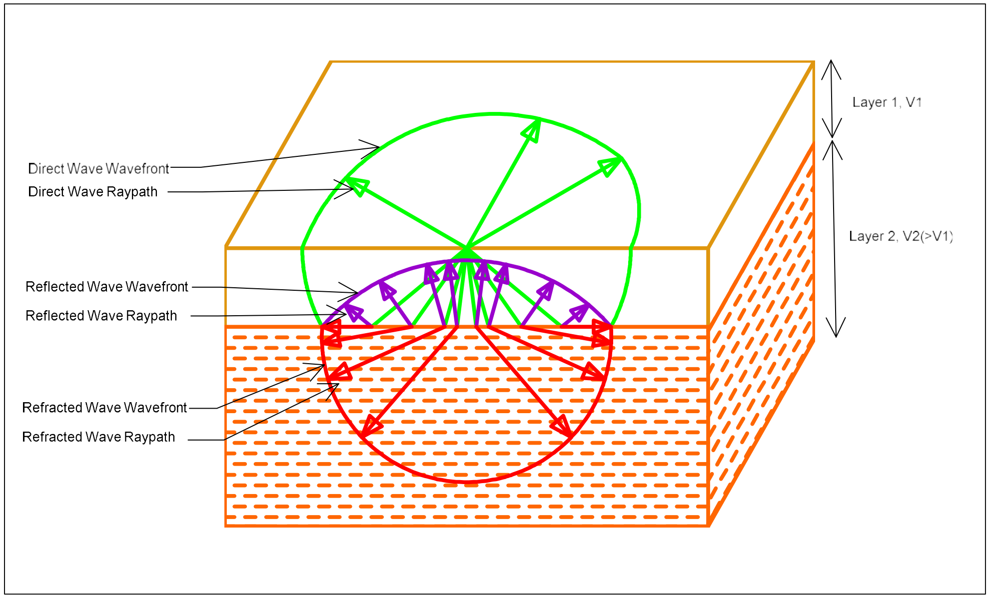


Figure SR-2 **Effect of Layering on Body Wave Raypath** Rev. 04/2018

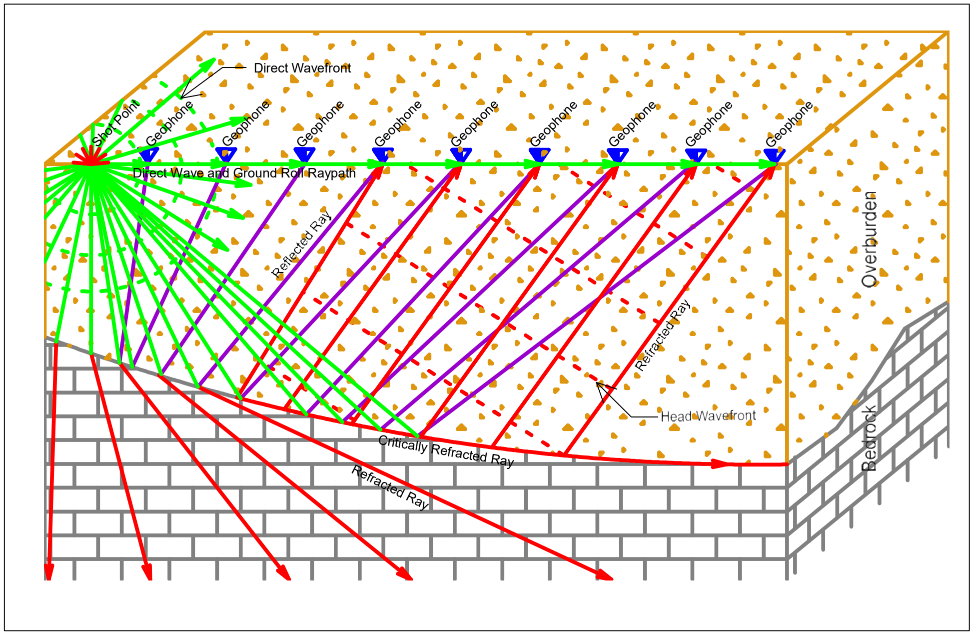


Figure SR-3 **Seismic Ray Path Geometry** Rev. 04/2018

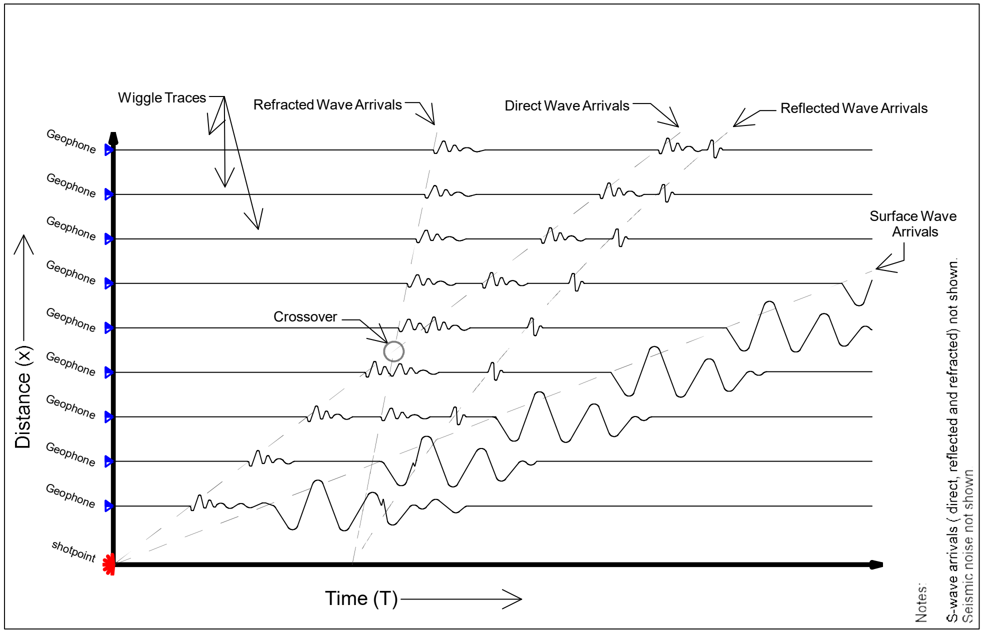


Figure SR-4 **Idealized Seismic Record and T- X Graph** Rev. 04/2018

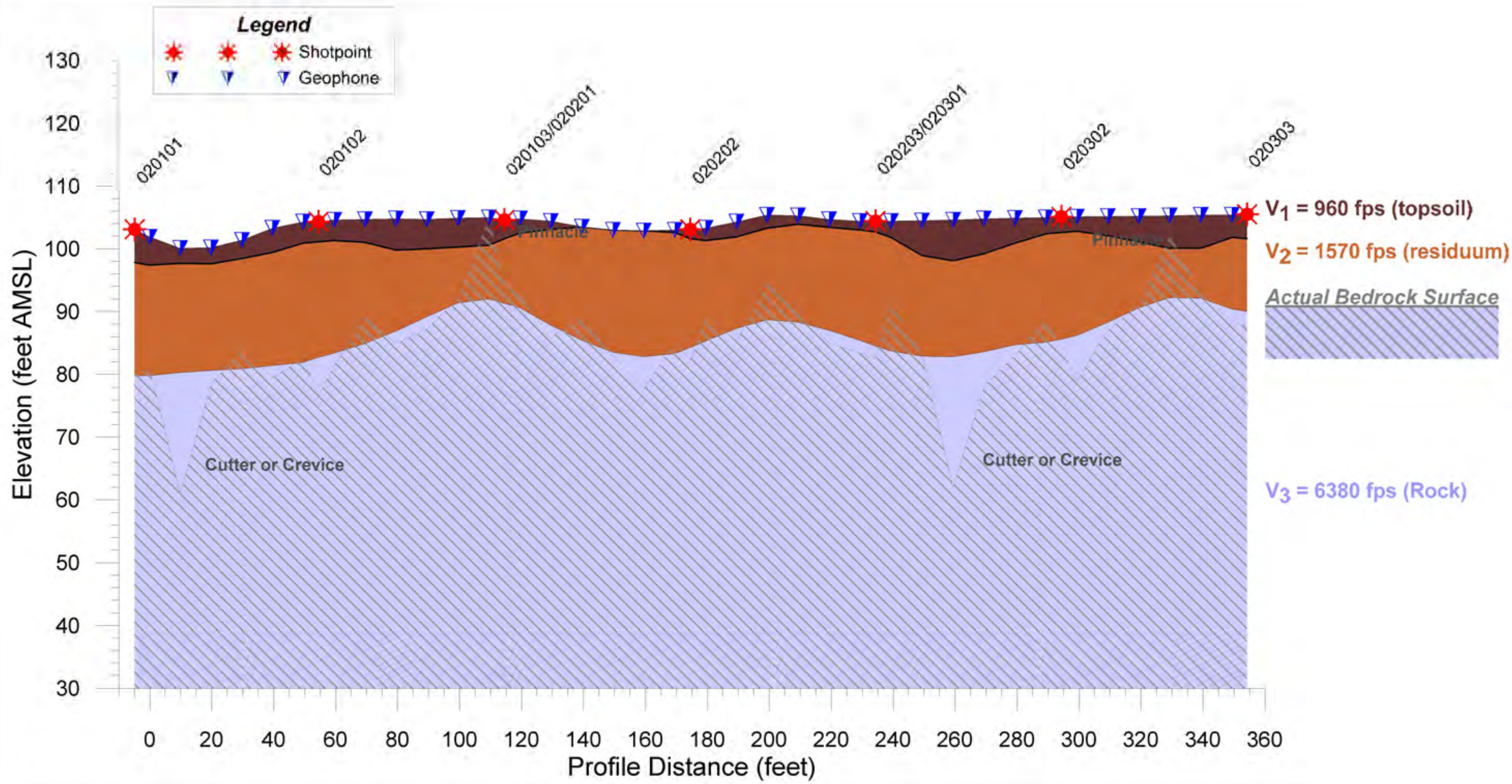


Figure SR-5 **Example Karst Terrane Seismic Profile** Revised 04/2018

APPENDIX B

Geophysical Survey Parameters

Geophysical Survey Parameters -- Park Road

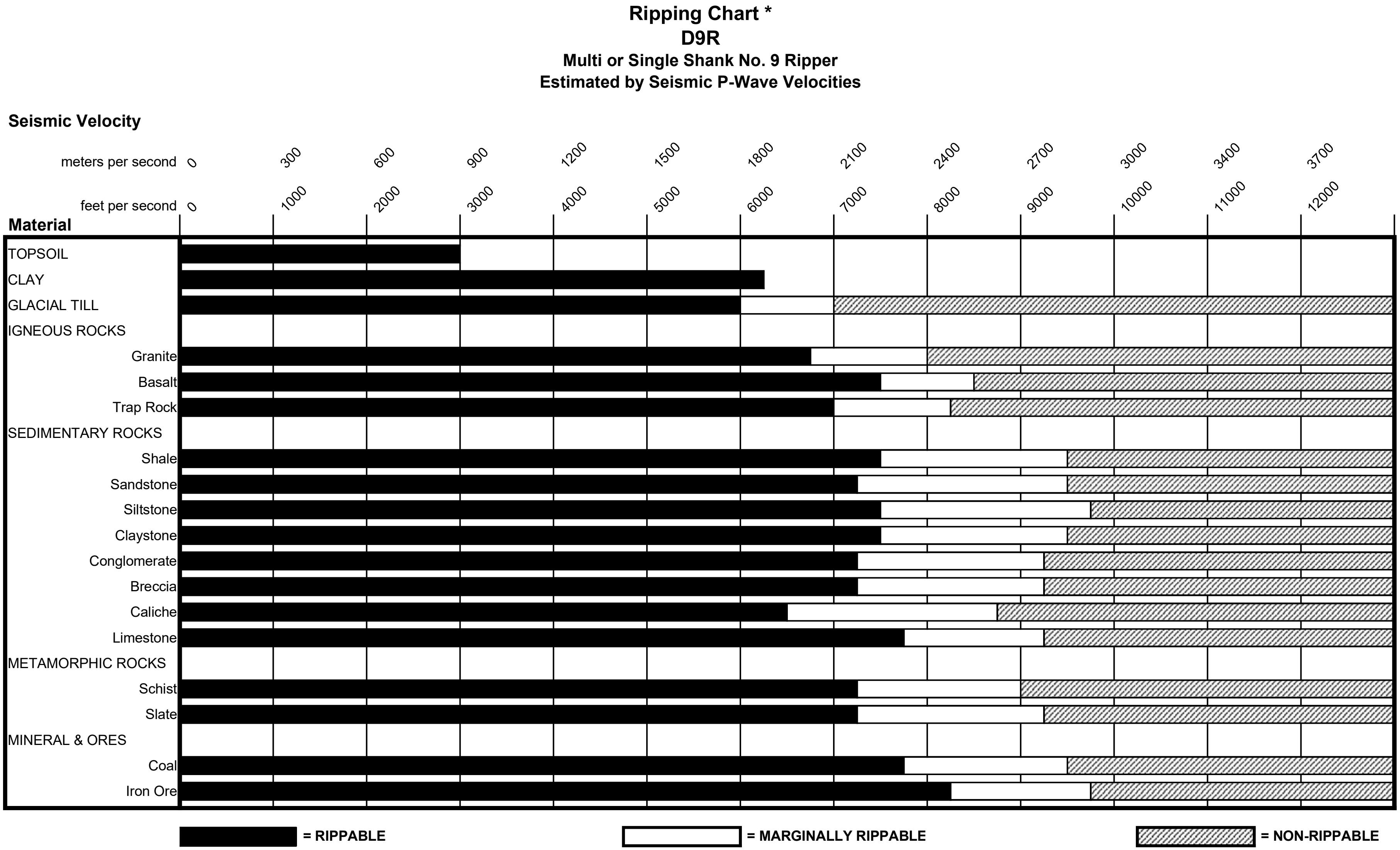
	Spacing[1] (feet)	Shot Interval[2] (feet)	Offset[3] (feet)	Spread Length[4] (feet)	Array Type[5]	Effective Depth[6] (feet)	Lateral Resolution[6] (feet)	Vertical Resolution[6] (percent)	System
Seismic Refraction	5	40	20	120		24	5	15	**Geometrics Geode**
Seismic MASW	5	5	20	120		40	5	25	**Geometrics Geode**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

[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)***

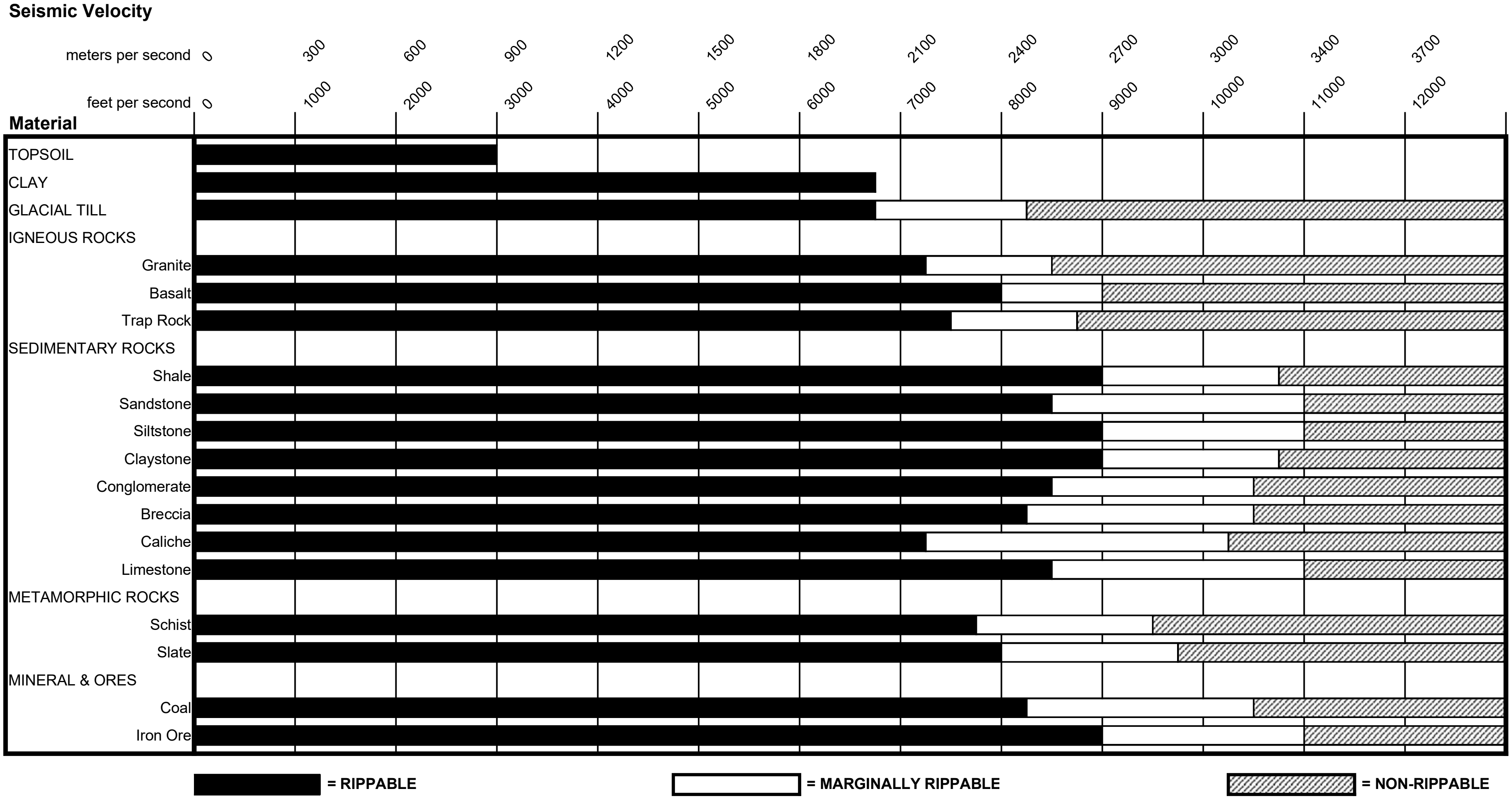
APPENDIX C

Caterpillar Ripping Charts



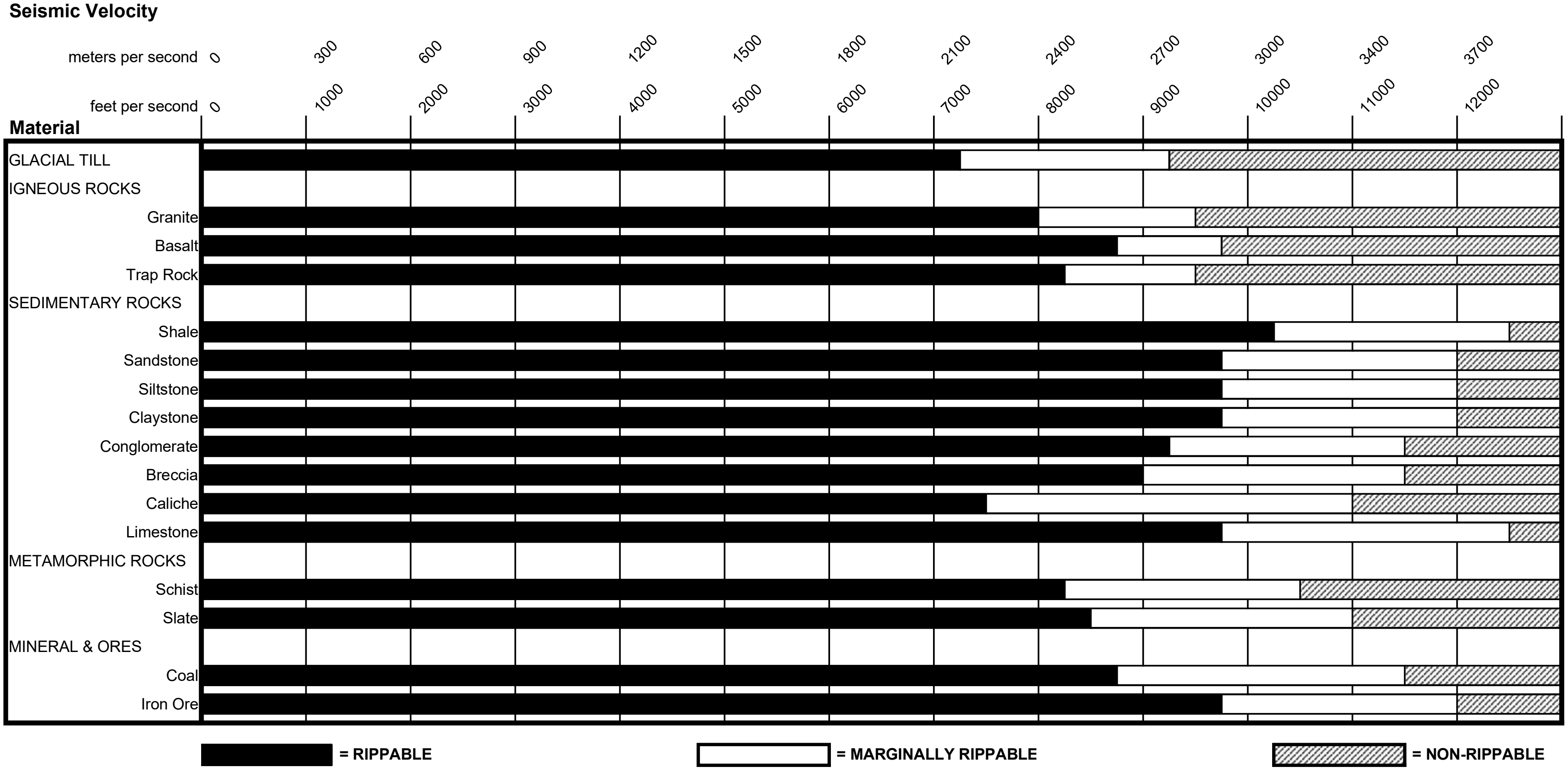
* Caterpillar Performance Handbook, Edition 26, Caterpillar, Inc., Peoria, Illinois

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

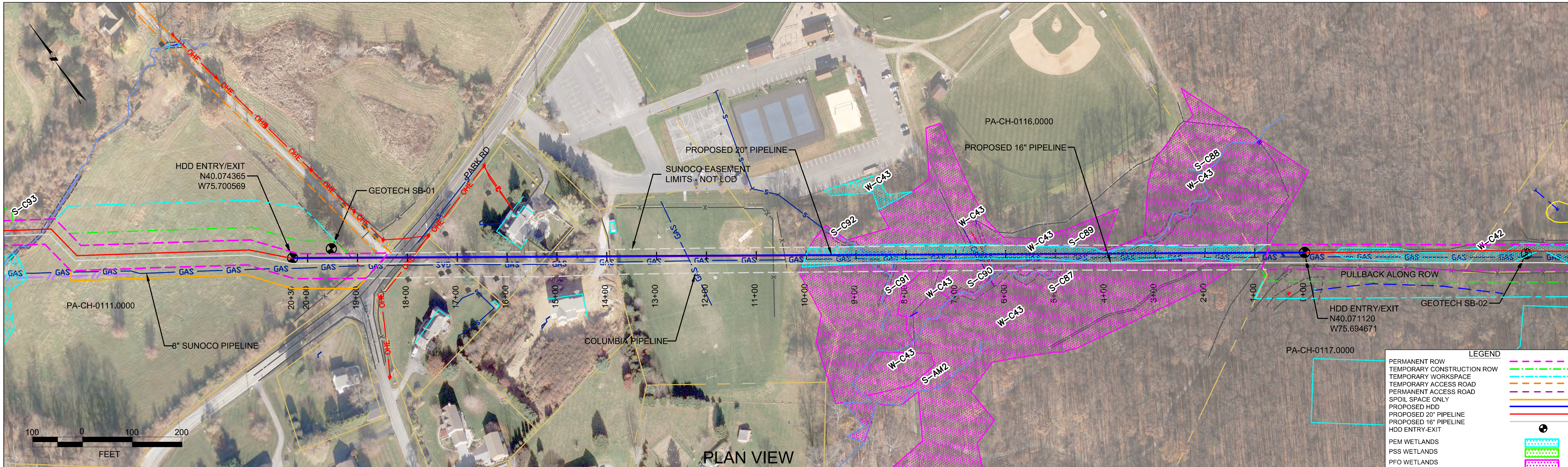


* Caterpillar Performance Handbook, Edition 26, Caterpillar, Inc., Peoria, Illinois

HORIZONTAL DIRECTIONAL DRILL ANALYSIS
PARK ROAD CROSSING
PADEP SECTION 105 PERMIT NO.: E15-862
PA-CH-0111.0000-RD-16
(SPLP HDD# S3-0300-20)

ATTACHMENT 2

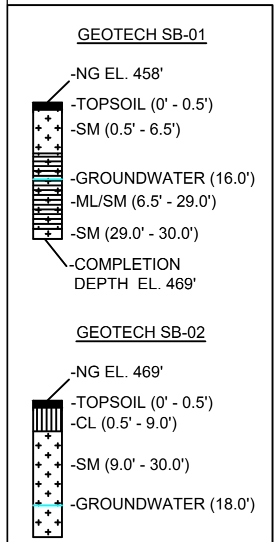
HORIZONTAL DIRECTIONAL DRILL PLAN AND PROFILES



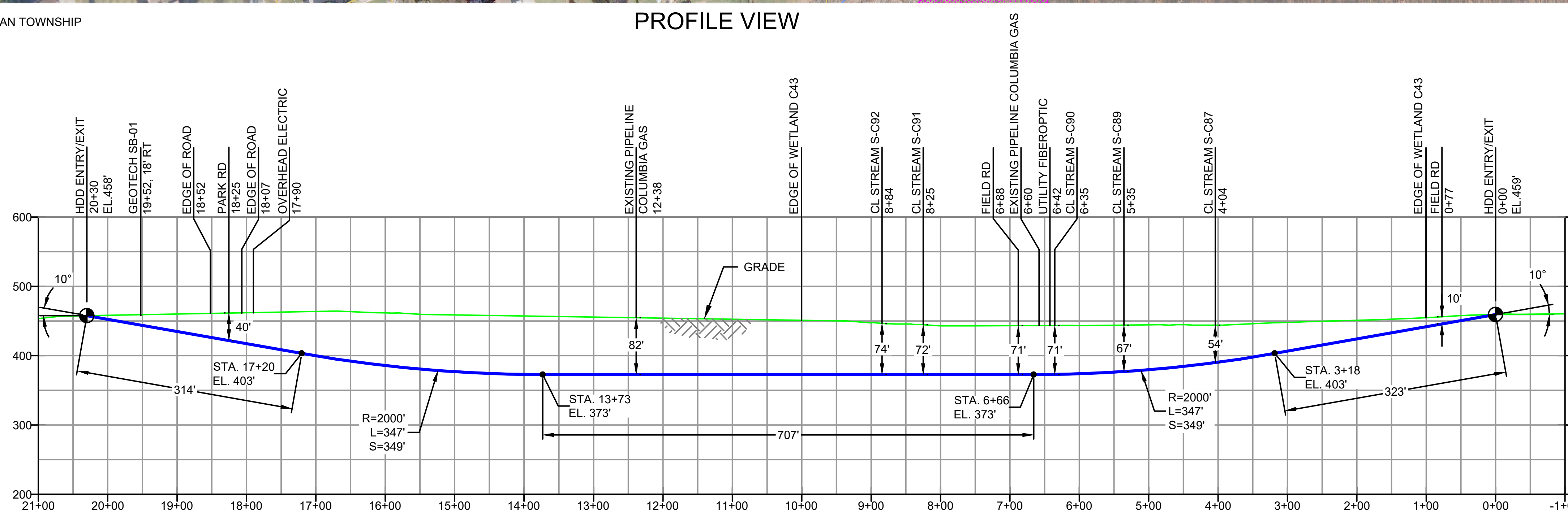
PLAN VIEW

CHESTER COUNTY, PENNSYLVANIA - UPPER UWCHLAN TOWNSHIP
S3-0300

PROFILE VIEW



NOTE:
1.REFER TO TEST BORING LOG S3-0210 FOR COMPLETE SOIL MATERIAL DESCRIPTION
2. PDOT RECORD INDICATED GRAPHITIC FELSIC GNEISS AT 25'-35' DEPTH, REFER TO PaGWIS PENNSYLVANIA DEPARTMENT OF TRANSPORTATION



DESIGN AND CONSTRUCTION:

1. CONTRACTOR SHALL FIELD VERIFY DEPTH OF ALL EXITING 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=):2030'
   HDD PIPE LENGTH (S=):2043'
   20" x 0.456" W.T., X-65, 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. Original 20-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-6.31	TO	ES-6.32	EROSION & SEDIMENT PLAN
SHEET 18	TO	SHEET 19	AERIAL SITE PLAN

REVISIONS

NO.	DESCRIPTION	BY	DATE	CHK	DATE	APP	DATE
EP2	REVISED PER PADEP COMMENTS RECEIVED 09-06-16	MRS	09/30/16	RMB	09/30/16	AAW	09/30/16
EP1	REVISED PER PADEP COMMENTS	MRS	05/05/16	RMB	05/05/16	AAW	05/05/16
EP		MRS	02/26/16	RMB	02/26/16	AAW	02/26/16
0	ISSUED FOR CONSTRUCTION	MRS	02/19/16	RMB	02/19/16	AAW	02/19/16

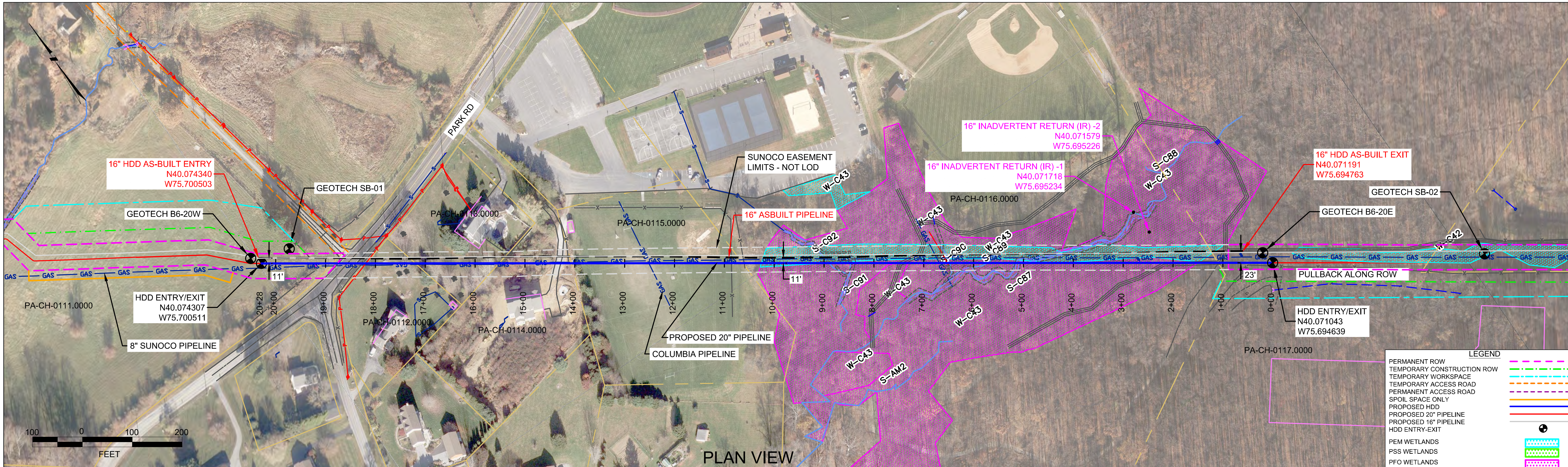
Sunoco Logistics Partners L.P.

TETRA TECH ROONEY
(303) 792-5911

SUNOCO PIPELINE, L.P.

20-INCH HORIZONTAL DIRECTIONAL DRILL
PARK RD
PENNSYLVANIA PIPELINE PROJECT

SCALE: 1"=200' DWG. NO: PA-CH-0111.0000-RD



CHESTER COUNTY, PENNSYLVANIA - UPPER UWCHLAN TOWNSHIP
S3-0300

PROFILE VIEW

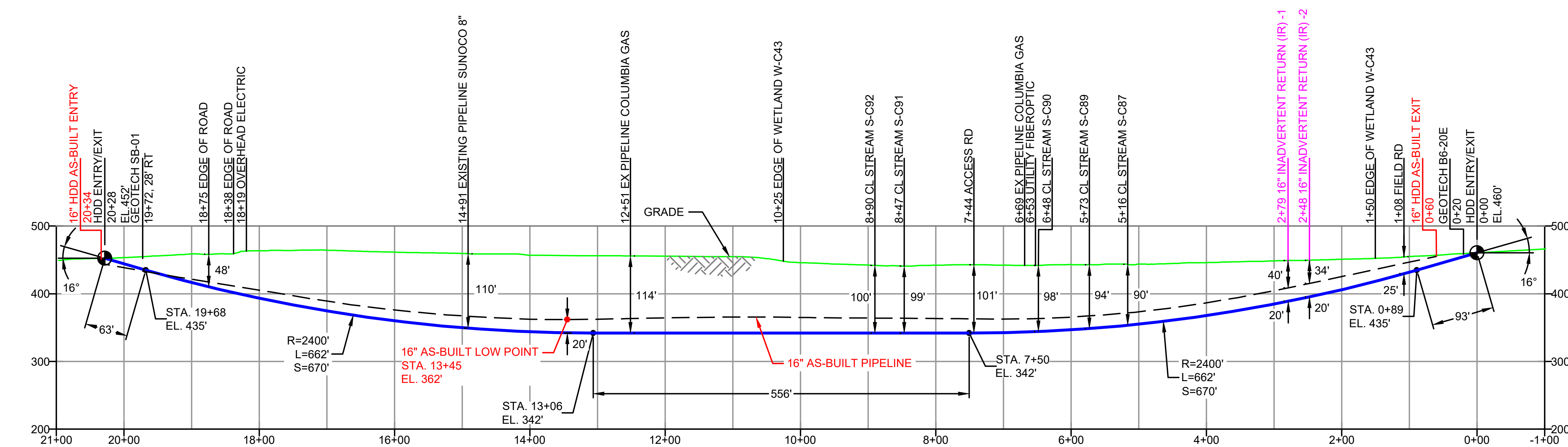
GEOTECH SB-01

- NG EL. 458'
- TOPSOIL (0' - 0.5')
- SM (0.5' - 6.5')
- GROUNDWATER (16.0')
- ML/SM (6.5' - 29.0')
- SM (29.0' - 30.0')
- COMPLETION DEPTH EL. 469'

GEOTECH SB-02

- NG EL. 469'
- TOPSOIL (0' - 0.5')
- CL (0.5' - 9.0')
- SM (9.0' - 30.0')
- GROUNDWATER (18.0')

NOTE:
1. REFER TO TEST BORING LOG S3-0300 FOR COMPLETE SOIL MATERIAL DESCRIPTION
2. PDOT RECORD INDICATED GRAPHITIC FELSIC GNEISS AT 25'-35' DEPTH, REFER TO PaGWIS PENNSYLVANIA DEPARTMENT OF TRANSPORTATION



GEOTECH B6-20W

- NG EL. 458'
- SANDY SILT ML (0.0' - 6.4')
- GROUNDWATER (9.5')
- WEATHERED ROCK (6.4' - 66.0')
- GNEISS (66.0' - 136.0')
- BORING TERMINATED EL.322'

NOTE: REFER TO TEST BORING LOG B6-20W TERRACON PROJECT #J217P078 FOR COMPLETE SOIL MATERIAL DESCRIPTION

GEOTECH B6-20E

- NG EL. 459'
- FILL - LEAN CLAY (0.0' - 5.0')
- GROUNDWATER (9.0')
- SANDY LEAN CLAY CL (5.0' - 16.0')
- QUARTZITE (16.0' - 46.0')
- GNEISS (46.0' - 136.0')
- BORING TERMINATED EL.323'

NOTE: REFER TO TEST BORING LOG B6-20E TERRACON PROJECT #J217P078 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=):2028'
   HDD PIPE LENGTH (S=):2052'
   20" x 0.456" W.T., X-65, API5L, PSL2, ERW, BFW
   COATING: 14-16 MILS FBE WITH 40 MILS MIN. ARO (POWERCRETE R95)
5. INTERNAL DESIGN PRESSURE 1480 PSIG (SEAM FACTOR 1.0, DESIGN FACTOR 0.50 (HOOP STRESS)).
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.

Figure 2. Redesigned 20-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-6.31	TO	ES-6.32	EROSION & SEDIMENT PLAN
SHEET 18	TO	SHEET 19	AERIAL SITE PLAN

REVISIONS

NO.	DESCRIPTION	BY	DATE	CHK	DATE	APP	DATE
EP3	SWITCHED 20" CENTERLINE LOCATION, INCREASED DEPTH OF DRILL AND ADDED GEOTECH INFORMATION	MRS	03/14/19	RMB	03/14/19	AMC	03/14/19
EP2	REVISED PER PADEP COMMENTS RECEIVED 09-06-16	MRS	09/30/16	RMB	09/30/16	AAW	09/30/16
EP1	REVISED PER PADEP COMMENTS	MRS	05/05/16	RMB	05/05/16	AAW	05/05/16
EP		MRS	02/26/16	RMB	02/26/16	AAW	02/26/16
0	ISSUED FOR CONSTRUCTION	MRS	02/19/16	RMB	02/19/16	AAW	02/19/16

Sunoco Logistics Partners L.P.

TETRA TECH ROONEY
(303) 792-5911

SUNOCO PIPELINE, L.P.

HORIZONTAL DIRECTIONAL DRILL
PARK RD
PENNSYLVANIA PIPELINE PROJECT

SCALE: 1"=200' DWG. NO: PA-CH-0111.0000-RD