HORIZONTAL DIRECTIONAL DRILL ANALYSIS
LOYALHANNA LAKE CROSSING
PADEP SECTION 105 PERMIT NO.: E65-973
PA-WM2-0064.0000-WX-16
(SPLP HDD No. S2-0010)

HORIZONTAL DIRECTIONAL DRILL ANALYSIS
LOYALHANNA LAKE CROSSING
PADEP SECTION 105 PERMIT NO.: E65-973
PA-WM2-0064.0000-WX-16
(SPLP HDD No. S2-0010)

ATTACHMENT 2

COAL MINE SUBSIDENCE AND STRESS ANALYSIS

SUBSIDENCE POTENTIAL REVIEW

LOYALHANNA LAKE

16-INCH HORIZONTAL DIRECTIONAL DRILLED PIPELINE PROJECT

LOYALHANNA TOWNSHIP, WESTMORELAND COUNTY, PA

July 2018

PRESENTED FOR

Sunoco Logistics, L.P.
525 Fritztown Road
Sinking Spring, PA

PRESENTED BY

Tetra Tech
661 Anderson Drive
Foster Plaza 7
Pittsburgh, PA 15220

TETRA TECH

TABLE OF CONTENTS

INTRODUCTION ... 1

BACKGROUND ... 1

TYPES OF MINE SUBSIDENCE ... 3

CATEGORIES OF MINE SUBSIDENCE POTENTIAL ... 4

FINDINGS ... 7

RECOMMENDATIONS ... 12

CLOSURE ... 12

REFERENCES ... 14

FIGURES

1 Project Location with Angle of Draw

2 Project Location with Subsidence Categories

3 Plan and Profile

4 Subsidence Above the Seam

5 Change in Subsidence Above the Seam

6 Borehole and Pipeline Cross Section

TABLES

1 Summary of Categories of Subsidence Potential within Angle-of-Draw

2 Zones of Strata Fracturing During Subsidence

APPENDICES

A Dr. Heasley Subsidence Report

INTRODUCTION

Tetra Tech, Inc. (Tetra Tech) was retained by Sunoco Logistics L.P. (Sunoco) to review the mining activity and subsidence potential of the abandoned coal mines below the planned Loyalhanna Lake horizontal directional drilled pipeline (HDDP) located in Loyalhanna Township, Westmoreland County, Pennsylvania. Our report follows.

BACKGROUND

Mine subsidence is defined by Pennsylvania Department of Environmental Protection (PA DEP) as "movement of the ground surface as a result of readjustments of the overburden due to collapse or failure of underground mine workings." Overburden is the soil and rock lying between the coal and the surface. When subsidence occurs at or near the location of an overlying structure, damage to the structure may occur. The potential impacts to surface structures are "generally classified as cosmetic, functional, or structural. Cosmetic damage refers to slight problems where only the physical appearance of the structure is affected, such as cracking in plaster or drywall. Functional damage refers to situations where the structure's use has been impacted, such as jammed doors or windows. A more significant impact on structural integrity is classified as structural damage. This includes situations where entire foundations require replacement due to severe cracking of supporting walls and footings." (PADEP, 2017). When a new structure is designed over areas where potential mine subsidence could result in structural damage, structural engineers can mitigate the damage concerns by improving the structural integrity of the structure or by isolating the structure from the subsidence. When structural improvement or isolation is not possible or is cost prohibitive, the hazards posed by mine subsidence can be mitigated by grouting the remnant mined entries (filling voids with concrete like material to prevent settling) to reduce the potential for subsidence.

The most effective mitigation method is to relocate the structure over areas where the coal has not been mined; however, in Pennsylvania mining regions, this is not always a possibility. When a structure is located over abandoned mine workings, predicting the probability and timing of future subsidence is not a clearly defined science. The probability of future subsidence depends on the remaining stability of the mine pillars, the columns of coal left in place to support the overlying overburden. The timing of any future failure of the pillars would depend on knowing the exact failure strength, the geometry of the mine pillars and the reduction in the strength of the mine pillars over time. There is no specific way to know when pillar failure and subsequently subsidence will occur. Mining maps are prepared by active mining companies when the mine was operating to indicate where mining occurred and the type of mining conducted. Maps of abandoned mines are used by mining engineers to verify the mine layout and to estimate the size of remaining voids and pillars. These maps often lack complete details of the mining and are sometimes inaccurate. Incomplete or inaccurate knowledge of mine configuration can introduce additional errors into any future subsidence prediction.

Most abandoned mine subsidence impacts to structures that result in structural damage have occurred in areas of limited overburden, such as where the mine depth is less than 100 feet. Although the subsidence damage classifications above refer to surface impacts, similar classifications might be applicable for impacts to underground pipelines located below the ground surface. As an example, areas of minor ground movement after a pipeline has been installed within a horizontal drilled borehole may cause movement of the pipeline (similar to cosmetic or functional damage to a surface structure) but may not cause structural damage such as a break in the pipeline resulting in a loss of fluids or gas. Areas of potential structural damage should be avoided or mitigated.

The Seanor Mining Corporation operated the Loyal underground mine in Loyalhanna Township, Westmoreland County in the 1950's. Their primary mining method was room and pillar mining. No mining was conducted directly under the eastern portion of the HDDP, under the Loyalhanna Lake or on the eastern side of the lake. However, mining was conducted below the western portion of the HDDP. The Upper Freeport seam was mined from Station 27+00 to the western extent of the HDDP at Station 40+65 (1365 feet). The depth of the coal from surface is about 300 to 340 feet above the western portion of the HDDP.

The mining method employed at Loyal mine appears to have been room and pillar mining utilizing mechanized mining machines. The drum head continuous mining machines were introduced in the late 1960's. It is our opinion that this mine used a mechanized loading machine after the coal was broken by blasting. The mine plan was designed to complete five entry development main entries. Mine entries in the main entries appear (from the mine maps) to be about 22 feet wide with pillars averaging about 60 feet by 90 feet. Three entry submain development entries were driven to the right and left of each main and were spaced about 780 feet apart. The submains appear to use 22 feet wide entries and pillars of about 60 feet by 100 feet. Higher production rooms were driven to the right and left of each submain. They extended about 200 to 300 feet and used 35 feet wide entries and small pillars about 15 feet by 40 to 50 feet. The rooms closest to the HDDP were configured to maximize coal recovery and were only configured for short term stability. However, some of the main and submain entries were shown on the mine maps as being removed or split when the mines were withdrawing from these areas. It is our opinion that the locations were the pillars were removed or spilt the roof would fail and surface subsidence would occur. Most subsidence would occur almost immediately. The areas where the pillars remained after mining have the highest risk of future subsidence because the pillars in these areas were not designed to provide long-term support. As previously discussed, due to potential inaccuracies in the mine map, this cannot be guaranteed.

TYPES OF MINE SUBSIDENCE

Mine subsidence occurs in one of two physical forms; a trough or a sinkhole. A trough is a shallow, often broad, dish-shaped depression that develops when the overburden sags downward into a mine opening in response to roof collapse, the crushing of mine pillars, or the punching (pushing) of pillars into the mine floor. There can also be areas of surface heave around the edges of the subsidence troughs. Trough subsidence typically occurs in areas of deeper overburden, typically in areas of more than 100 feet of overburden. The depth and extent of the trough are closely related to the dimensions and thickness of the extracted coal.

A sinkhole is a depression in the ground surface that occurs due to localized collapse of the overburden directly into a mine opening (a room or entry). This is often called “chimney” type subsidence. Boundaries between the ground surface and the vertical walls of the sinkhole are often abrupt, and because sinkhole diameter generally increases with depth, the sinkhole in profile may initially resemble an open bottle with the top at the ground surface. Erosion of soil at the sinkhole’s periphery may increase the diameter near the ground surface to create an hourglass profile. Sinkhole subsidence typically occurs in areas of shallow overburden, primarily 100 feet or less. Sinkhole-prone areas are the primary locations where subsidence causes severe structural damage to buildings on the surface. Sinkhole subsidence in an area of single-seam mining is usually limited to areas where the total thickness of the rock layers above the coal is no more than 6 to 10 times the thickness of the coal mined in the area. The soil thickness overlying the rock is not included in this estimate. (Kendorski, 2006).

CATEGORIES OF MINE SUBSIDENCE POTENTIAL

Mining-induced subsidence is caused when a seam of coal is extracted and overlying rock layers cave into the voids left by mining such that there is movement on the ground surface. The probability of subsidence is greater in areas where a high percentage of coal is removed. In an analysis of underground mines, subsidence potential can be classified into the following three general categories:

Category 1 – Subsidence probably occurred during or soon after mining.

Category 2 – Support area where subsidence is unlikely.

Category 3 – Area where subsidence may occur in the future if it has not already occurred.

Room and pillar mining, the method of mining commonly used in the project area, is a method of mining where mine entries were excavated through the coal seam. The unmined coal, or coal pillars, remained in place to support the roof. As the mine workings reach the extent of the mine boundaries, some areas are “retreat mined.” In areas where retreat mining is employed, coal pillars are extracted for nearly full recovery (generally 80 to 90 percent recovery) of the coal seam. To accomplish full recovery in a safe manner, the roof of the mine is allowed to cave in a predictable controlled manner immediately following coal extraction. This controlled caving process systematically relieves built-up stresses caused by the cantilever action of the mine roof thereby reducing the risk of catastrophic strata failure where men are working. The limits and extents of the subsidence are relatively predictable where retreat mining is employed because subsidence normally occurs soon after mining. Category 1 refers to areas where nearly full extraction of the coal occurred as a result of retreat mining and there is very low probability of extensive future subsidence, although subsidence can occur at the edges of these areas due to failure of adjacent, highly stressed, supporting pillars.

Category 2 refers to areas where the mine configuration and pillars are adequately designed to provide permanent support to the ground surface. The amount of coal removed in these areas is generally low to moderate. These areas, although mined, generally remain stable over the long term and typically include main entries and haulage routes as well as low-extraction-ratio room and pillar areas of the mines where retreat mining did not occur. Areas of mines delineated as Category 2 would have a relatively low probability of future subsidence.

Category 3 refers to areas underlain by room and pillar mines with a high percentage of coal removed and where retreat mining was not performed. In Category 3 areas, it is uncertain whether subsidence occurred and whether there remains a likelihood of subsidence in the future. In these areas, entries were driven through the coal, and the pillar sizes were smaller than what would generally be required to provide permanent support. In other words, the pillars were designed with a low factor of safety (caused by the high extraction ratio), and there would be an elevated risk of pillar, roof, or floor failure. If subsidence already occurred, the possibility of future subsidence is very unlikely. However, if subsidence has not previously occurred, the possibility of future subsidence remains high. Of the three categories, Category 3 would have the highest probability for future subsidence.

In mining subsidence terms, the extent of the potential area impacted by subsidence can be defined using a specific angle from the coal seam to the ground surface that could be affected if roof or pillar failure occurred at the mine level. The potential subsidence affected area can be directly overhead but could also be offset a certain horizontal distance from the roof failure location. The angle, termed the "angle-of-draw," can vary depending on the overburden rock type (Peng, 1978). PA DEP accepts 20 degrees as the angle-of-draw for the flat-lying coal seams in the bituminous coal region; however, up to 35-degree angle-of-draws have been found in numerous subsidence publications. Because the Loyal mine is a flat lying coal seam, a 20- degree angle-of-draw would be expected. In an effort to provide conservative analysis to protect the HDDP, both angle-of-draws will be used in this report. The angle-of-draw can also be projected downward from a surface structure or a pipeline in the ground to determine what area within a mine could, if pillar or roof failure occurred, cause subsidence that may impact the surface or pipeline.

Tetra Tech reviewed the mine maps and the location and elevation of the planned HDDP. Figure 1 depicts the areas where potential roof failure at mine level could impact the strata at the level of both planned HDDP. Both angle-of-draws (20° and 35°) were shown on Figure 1. The area shown was created by using an angle-of-draw from the pipeline's bottom elevation to the top of the coal seam. A mining height of four and a half feet (4.5) was assumed based on information from the mine map. A 15' horizontal zone on each side of the HDDP (30' total) was also included. Figure 2 depicts each category of potential mine subsidence. A total of 5.8 acres lies within the 20° angle-of-draw influence area, while 11.1 acres lie within a 35° angle-of-draw influence area. A summary of subsidence category areas is shown on Table 1.

Table 1: Summary of Categories of Subsidence Potential within Angle-of-Draw

Subsidence Category	Subsidence Potential	20° Angle-of-Draw (Acres)	35° Angle-of-Draw (Acres)
1	Subsidence probably occurred during or soon after mining	0.7	1.2
2	Support area where subsidence is unlikely	0.4	0.7
3	Area where subsidence may occur in the future if it has not already occurred	4.7	9.2
Total		**5.8**	**11.1**

When roof or pillar failure occurs, strata above the mined area will collapse and/or sag downward to fill the voids left in the mine. Mining research has classified these areas as different zones based on the degree of fracturing expected. These zones depend on the width and height of the extraction, the overburden rock types, and the vertical height above the mine. A caved zone occurs from the roof of the mined coal and typically extends upwards for 6 to 10 times the mining thickness (Kendorski, 2006), and outward laterally within the angle-of-draw. In the case of Loyal Mine where the mined thickness is assumed to be a maximum of 4.5 feet, this zone would be from 27 to 45 feet above the top of coal. Rock in this zone would have extensive fracturing and sizable voids.

Above the cave zone a fracture zone occurs and extends for 24 to 30 times the mining thickness. In this zone, a lot of fractures would be present but the rock strata would remain as a single unit without extensive dislocated rock or voids present. At the Loyal Mine, this zone would extend from 27 to 45 feet to 108 to 135 feet above the top of mining.

The next zone would extend from the top of the fractured zone to about 60 times the mining thickness. This zone is termed the dilated zone. This zone would have small temporary fractures that would heal over time. The rock again would remain as a single unit. At the Loyal Mine, this dilation zone would extend from 108 to 135 feet up to 270 feet above the top of the coal. The zone above that is termed the constrained or bending zone where no fracturing would occur. In this case, the minimum distance between the HDDP's and the coal seam is 100 feet vertically. Both HDDP's would be mostly in the dilation zone. The zones are show on Table 2.

Table 2: Zones of Strata Fracturing During Subsidence

Zone	Extent Above Coal Seam (ft.) (x mining height)	Impact to Strata	Voids Created
Constrained	>60	No Fractures	None
Dilation	Up to 60	Small Fractures	Micro
Fracture	Up to 30	Fractured	Minimal
Caved	Up to 10	Fractured	Sizable
Mined Coal Seam			

Determining induced strains from subsidence during active mining has become a relatively accurate prediction, especially for longwall mines. There are numerous computer program models that were developed by mining agencies and universities that use variations in the rock type within the overlying strata, mining thickness, and mine geometry at coal seam level to predict ground movements at the surface during active full-recovery mining. These models not only predict the extent and amount of subsidence but can predict tilts and strains occurring at ground level. They can also be used to predict maximum strains when subsidence occurs. Abandoned mines are less predictable as to the time when subsidence would occur as well as the extent of subsidence. Mine subsidence from abandoned mine is less uniform or predictable than that of active mines. However, the use of models for active mining can be adapted to estimate subsidence and stress if subsidence would occur at abandoned mine sites.

FINDINGS

The mine maps were reviewed by experienced mining engineers. Even though the mining in the maps covering the area under the planned pipeline occurred nearly 60 years ago, the maps were found to be very detailed regarding the mining type and location of mining. The maps were georeferenced by PA DEP. In our opinion, the mine maps are a reliable indication of what was mined. We have reviewed several of the different maps available on the Pennsylvania Mine Map Atlas website. They all indicated the same depiction of the mine workings under the planned pipeline area.

The HDDP starts at the eastern side of Loyalhanna Lake where there is no mining. The HDDP goes under Loyalhanna Lake, with the overlying lake extending from Stations 7+61 to 23+65. The HDDP lies about 110 feet above the coal seam at Station 27+00. From Station 27+00 the boring ascends upward for 1,365 feet until it reaches the surface 4,065 feet from its start. At the surface exit location, the boring would be about 300 feet above the coal seam. Most of the area that the HDDP crosses over the mining is Subsidence Category 3 (area where subsidence may have occurred or may occur in the future). Small portions of the HDDP crosses over Subsidence Category 1 (subsidence probably occurred during or soon after mining) and Subsidence Category 2 (support area where subsidence is unlikely).

Figure 3 depicts the planned HDDP profile. To be conservative, the top of each fracture zone was selected as the maximum value based on the Kendorski's research (Kendorski, 2006). The HDDP crosses a small portion of the fracture zone and lies mostly in the dilated zone.

The PA DEP is responsible for maintaining an inventory of all subsidence related incidents in Pennsylvania. This includes mine subsidence incidents above abandoned mines such as Loyal Mine. It is our understanding that their recording of these incidents began shortly after 1977. To our knowledge there have been no subsidence incidents reported to PA DEP since 1977 anywhere near the planned HDDP.

When the earth subsides, the curvature of the strata can produce a horizontal strain within the strata. Some of this strain can be transferred to a rigid pipeline that is placed within the strata. Strain is defined as the amount of deformation in the direction of applied force divided by the initial length of the material. This results in a unitless number such as inches per inch. Strain can be induced by compression, tension, pipe bending, pipe placed in torsion or shear. Using historical subsidence data from primarily known conditions during longwall mining, models have been developed to predict the strains at ground surface. These models, although not a perfect translation, can be adapted to estimate strains within the relatively undisturbed rock strata at the elevations where the HDDP would be placed. Since the caved zone would be heavily fractured during subsidence, local strains within the caved zone cannot be accurately estimated. To estimate the strains that may be seen at the pipeline level in the zones about the caved zone, Tetra Tech engaged Dr. Keith Heasley, a mining engineer with experience using subsidence models to predict the possible strains. Dr. Heasley is a professor emeritus of mining engineering at West Virginia University. His full report can be found in Appendix A.

Modeling of the Loyal Mine was conducted using a base coal strength of 900 pounds per square inch (psi) to simulate the strength of the coal at the time of mining. Subsequently, a coal strength of 750 psi was modeled to simulate the coal strength after the mine pillars degrade over time. The predicted subsidence with both coal strengths along the pipeline alignment is shown on Figure 4. The 900-psi coal subsidence plot indicates anticipated ground subsidence directly after mining. The 750-psi plot predicts the subsidence that may occur along the pipeline as the mine conditions degrade over time. It is unknown when or if the 750-psi conditions will ever occur. Mine subsidence at this site may have already occurred, may occur at some time in the future, or may never occur. Predicting the exact condition of the mine at this time, or at any precise time in the future, is not possible. Subsidence may also occur in different areas at different times so that the estimated subsidence in the model may not occur at the same time.

Tetra Tech employed 3D seismic technology to gain a better understanding of the strata fracturing and anomalies at mine level. The subsidence model was run to reflect this information.

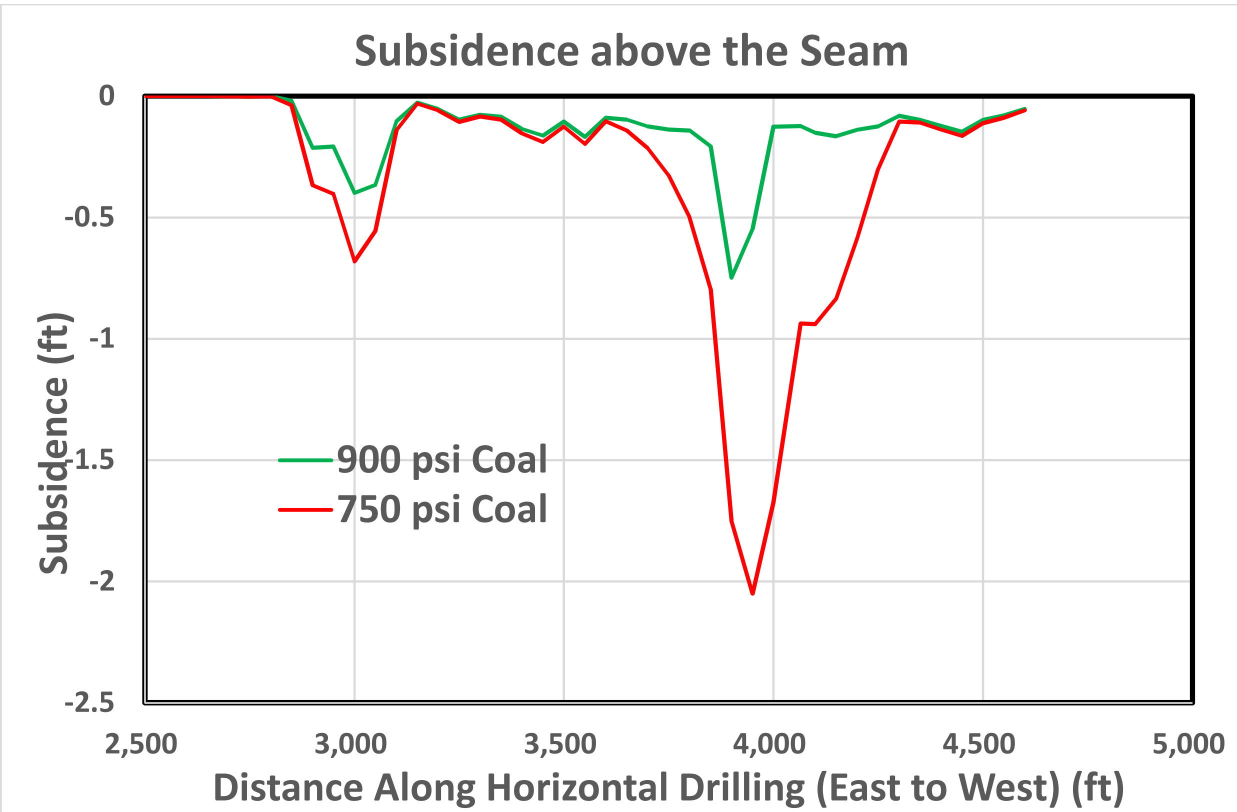


Figure 4 – Estimated Subsidence

LaModel was chosen as the mining-induced stress analysis program to estimate strain on the strata at the location of the pipeline within the strata. This program is primarily designed to calculate the seam stress and displacement within an underground mine. The software uses boundary elements for calculating the stresses and displacements in coal mines or other thin tabular seams or veins. During active mining, it can be used to optimize pillar sizes and mine layout by minimizing pillar stress. Multi-seam mining stress can also be reviewed. This program can also reasonably calculate surface subsidence. A medium distance of 150 feet above the Loyal Mine was chosen for detailed analysis of mine subsidence. In the LaModel program, the overburden is modeled as a continuum. Therefore, the program shows the subsidence directly over the mined areas and within the angle of draw. The magnitude of subsidence decreases as the distance from the mine increases and the subsidence spreads. The program does not model any dilation of the overburden.

The estimated maximum subsidence that the pipeline may experience in the future is the difference between the subsidence estimated using the original strength (900 psi) of coal and the subsidence estimated using degraded strength (750 psi) of coal. This differential subsidence is shown on Figure 4. There are two primary areas of potential future subsidence. One area is centered at Station 30+00 and occurs within an area of high production room mining area that was not completely retreat mined based on our interpretation of the 3D seismic data. The increased subsidence at this location was estimated to be about 0.25 foot (3.0 inches). The second area of increased subsidence occurs near where the HDDP exits to the surface at around Station 40+00. This area was also interpreted from the 3D seismic data as to not have been completely caved. This area was also in a high production room area but also extended into a portion of an area where the mine maps showed as a pillar removal area. The estimated additional subsidence at this area is estimated to be about 1.55 feet (18.6 inches).

The strains within the strata associated with the estimated future subsidence should the pillars fail are shown on Figure 5. The maximum strain values range from -4,245 microstrains to +4,222 microstrains and fluctuate continuously along the pipeline length. The level of strain that the pipeline may experience is a function of the ground movement and a function of how tightly the pipeline is coupled to the ground movement. If the pipeline can slide within the HDDP, then areas of tensile or compressive strain can be reasonably canceled by adjacent areas of the opposite strain.

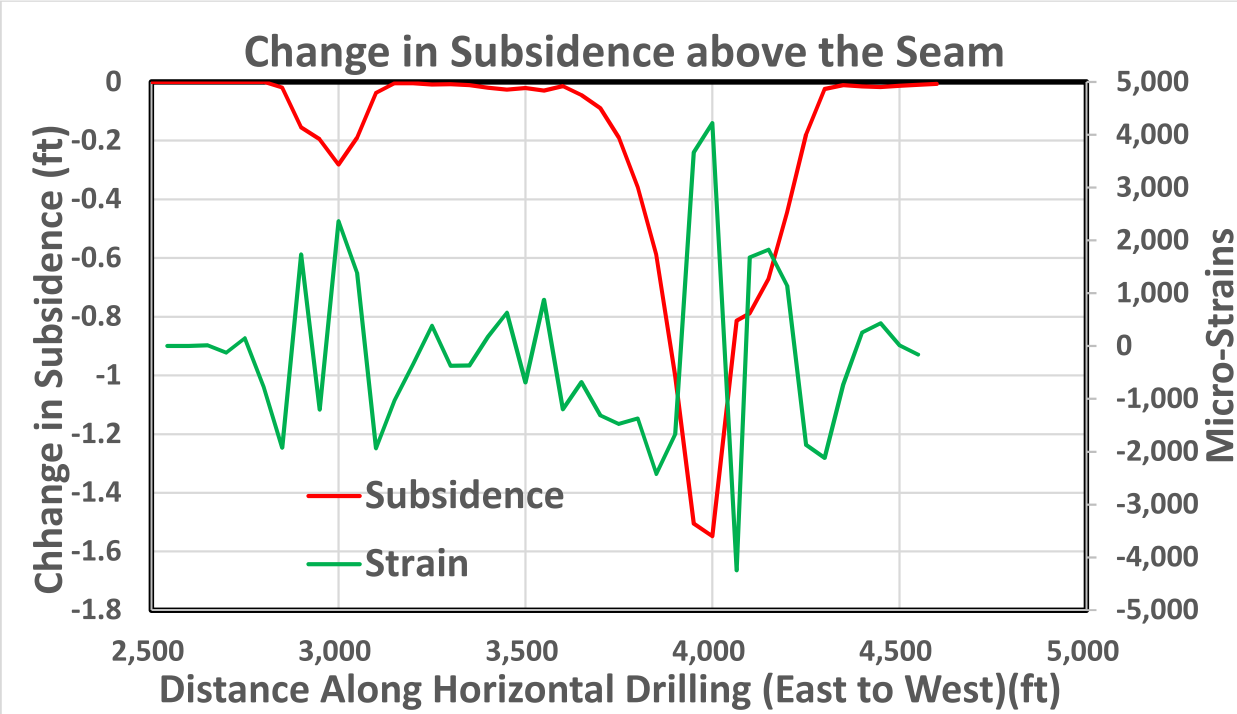
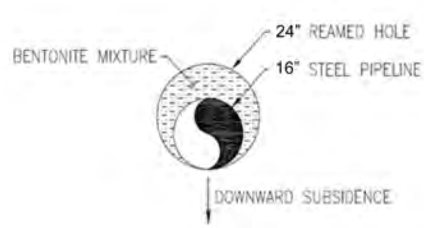


Figure 5 - Change in Subsidence

The modeled strains are in the strata at the location of the HDDP in the earth. The bored excavation of the HDDP will be larger than the pipe to be installed. As illustrated on Figure 6, the strain in the strata encompassing the hole, is not directly correlated to the strain imparted to the pipeline. The overbore (larger diameter of the hole compared to the pipe) leaves room for potential movement of the pipe within the strata. Transmission of the strain from the strata to the pipe associated with this project is reviewed by pipeline engineers.



HDDP 16”

Figure 6 – Borehole and Pipeline Cross Section

RECOMMENDATIONS

Based on the findings presented above, Tetra Tech recommends the following actions:

- Provide the estimated maximum subsidence and strain within the strata to pipeline engineers for their use to assure that the pipeline stresses are within appropriate pipeline design standards, including adequate factor of safety.
- Consider mitigating the subsidence strain by grouting the underlying abandoned coal mine if the pipeline stresses exceed appropriate pipeline design standards.

CLOSURE

The subsidence modeling calculates the stress and ground movement throughout the strata, from the coal seam to the surface. Numerical subsidence models have been calibrated both at the mine level (for optimizing pillar design) and at the surface (for subsidence prediction). Obviously, these are the locations where there is relatively simple access for performing the broad area measurements needed for the calibration of the model. Obtaining calibration measurements from within the solid rock mass between the mine and the surface is not very effective, since only limited locations can be practically measured versus wide area measurements in the mine or on the surface. In addition, underground subsidence has been observed in multi-seam mines and every indication is that the strain field is continuous throughout the overburden. Further, the numerical method used for simulating the rock strata is consistent with the physical laws of superposition and interpolation. Therefore, it is entirely reasonable and standard engineering practice to calculate/interpolate the subsidence at the location of the pipeline which is between the calibrated mine and surface locations. The model calculations are based on average subsidence parameters which may certainly have some variable for each individual site. Also, predicting subsidence from pillar failure and incomplete caving is different than the complete caving subsidence used to develop the subsidence parameters.

In areas where the pipeline is to be located greater than 50 feet below the ground surface, the drill will be over-bored to a diameter larger than the pipeline. This will decrease the frictional drag between the earth and the pipeline and maintaining this low-friction environment over the life of the pipeline would help decouple the pipeline from any ground movements and subsidence-induced strains.

This report was prepared to assist Sunoco in the evaluation of the subject project. The scope of this report is limited to the specific project, location, and time described herein. The report presents Tetra Tech's understanding of site conditions as discernible from information provided by others and obtained by Tetra Tech. Maps in this report are included only to aid the reader and should not be considered surveys. If additional data concerning this site become available, Tetra Tech should be informed so that we may examine the information and, if necessary, modify this report accordingly.

Respectfully submitted,

Thomas A. Gray, P.E.

Mining Engineer

Farley Wood, P.E.

Mining Engineer

Keith Heasley, PhD, P.E.

Mining Engineer

REFERENCES

Kendorski, F. S. (2006) Effect of Full-Extraction Underground Mining on Ground and Surface Waters a 25-Year Retrospective, 25th International Conference on Ground Control Mining, Morgantown WV 2006

PADEP (2017) Technical Guide to Mine Subsidence, Pennsylvania Department of the Environment Website http://www.dep.state.pa.us/msi/technicalguidetoms.html

The Pennsylvania State University (2014) Pennsylvania Mine Map Atlas, http://www.minemaps.psu.edu/

Peng, Syd S. (1978) Coal Mine Ground Control, John Wiley and Sons, Inc.

Peng, Syd S. (1992) Surface Subsidence Engineering, Society for Mining, Metallurgy, and Exploration, Inc.

National Coal Board, Mining Department (1975). Subsidence Engineers' Handbook. National Coal Board, London.

CERTIFICATION

SUBSIDENCE POTENTIAL REVIEW
LOYALHANNA LAKE
HORIZONTAL DIRECTIONAL DRILLED PIPELINE PROJECT

By affixing my seal to this document, I am confirming that the project conditions were reviewed and that accepted engineering practices were used to arrive at the reported results. Subsidence engineering is not an exact science and professional judgement was used to assess the many variables that exist, and is subject to those limitations that may be included in the Subsidence Report and information provided by third parties.

Thomas Gray, P.E.

License No. 26978-E

7/23/2018

Date

The term certify as used herein is defined as follows: An engineer's certification of condition is a declaration of professional judgement. It does not constitute a warranty or guarantee, either expressed or implied.

TETRA TECH ROONEY

Date: 7/19/2018

To: Mathew Gordon
Project Manager
Sunoco Logistics, L.P.
525 Fritztown Road
Sinking Spring, PA

Subject: **Subsidence Potential Review 16-inch Horizontal Drilled Pipeline Project Loyalhanna Lake– Loyalhanna Township, Westmoreland County, PA Mariner East II TTR Project: 204-3110 1.2 PPP2**

Mr. Gordon,

Tetra Tech Rooney has reviewed the above referenced subsidence report in addition to a Finite Element Analysis (FEA) model and we have confirmed that if the predicted subsidence does in fact occur in the future, the resulting stresses within the pipeline will still be in compliance with ASME B31.4.

COMMONWEALTH OF PENNSYLVANIA
REGISTERED PROFESSIONAL
JEFFREY A. LOWY
ENGINEER
PE082759
7/19/2018

Sincerely,

Jeff Lowy, P.E.
Civil Engineer
Tetra Tech Rooney

Attachments:

Geotechnical Report: Subsidence Potential Review 16-inch Loyalhanna Lake | Horizontal Directional Drilled Pipeline Project – Loyalhanna Township, Westmoreland County, PA

CC: Larry Gremminger, CWB, Environmental Project Consultant
Dean Shauers, P.E., President, Tetra Tech Rooney
Thomas A. Gray, P.E., Energy and Natural Resources Manager, Tetra Tech, Inc.

Tetra Tech Rooney
115 Inverness Drive East, Suite 300, Englewood, CO 80112
Tel 303.792.5911 Fax 303.792.0227 rooney-eng.com tetratech.com

LEGEND

LIMIT OF POTENTIAL INFLUENCE AREA ON PIPELINE

LIMIT OF NON AFFECTED AREAS

REFERENCE: SEANOR MINING CORP., LOYAL MINE – OBTAINED FROM PA DEP –UNDATED

TETRA TECH

www.tetratech.com

661 ANDERSEN DRIVE – FOSTER PLAZA 7
PITTSBURGH, PA 15220
T: (412) 921–7090 | F: (412) 921–4040

REVISIONS

NO.	BY	DATE	REMARKS

SUNOCO PIPELINE L.P.
SINKING SPRING, PENNSYLVANIA

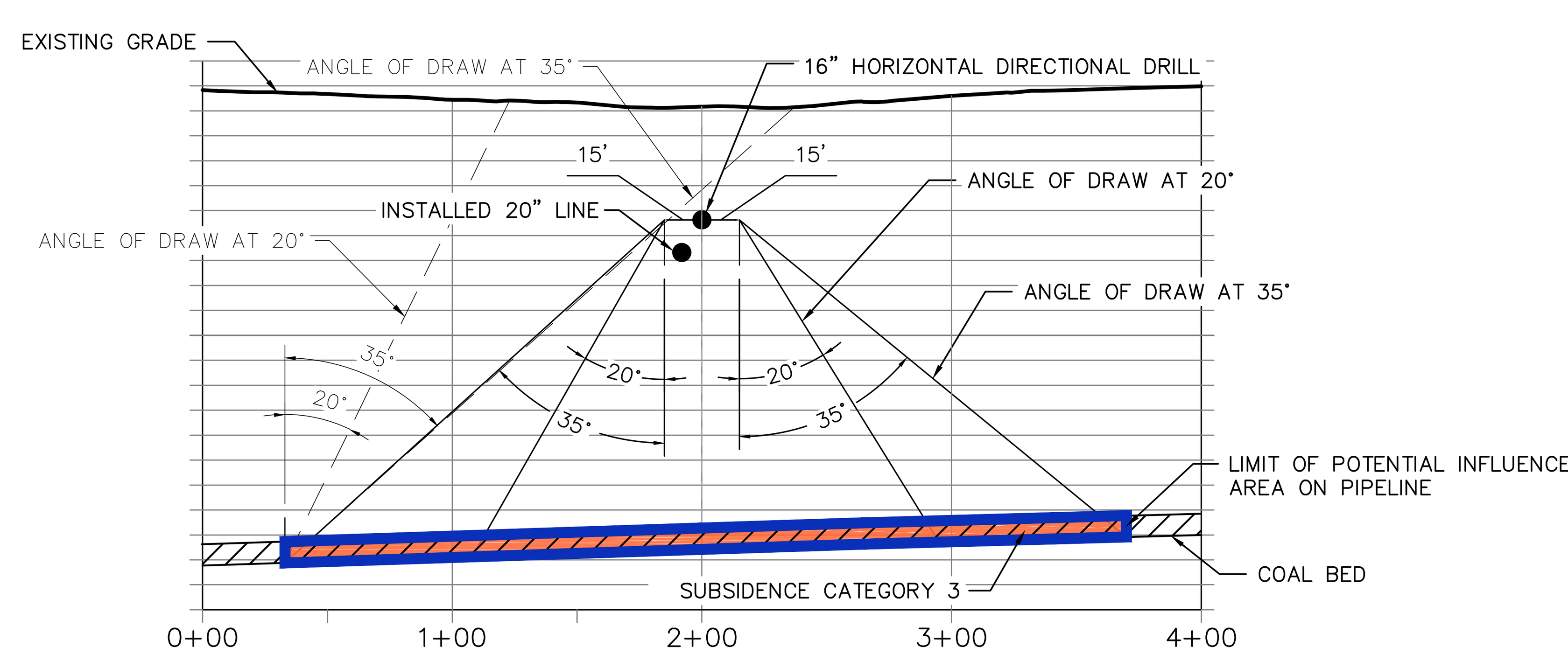
PENNSYLVANIA PIPELINE PROJECT

PROJECT LOCATION WITH ANGLE OF DRAW

WESTMORELAND COUNTY
LOYALHANNA LAKE
MINE AREA

DATE:	2/20/18
PROJECT NO.:	
DESIGNED BY:	TG
DRAWN BY:	JSM
CHECKED BY:	TG

FIGURE 1



A–A'
NOT TO SCALE

0 100 200
SCALE IN FEET

LEGEND

- LIMIT OF POTENTIAL INFLUENCE AREA ON PIPELINE (blue line)
- LIMIT OF NON AFFECTED AREAS (red line)
- SUBSIDENCE CATEGORY 1 (green)
- SUBSIDENCE CATEGORY 2 (yellow)
- SUBSIDENCE CATEGORY 3 (orange)

CATEGORIES OF MINE SUBSIDENCE POTENTIAL

CATEGORY 1: SUBSIDENCE PROBABLY OCCURRED DURING OR SOON AFTER MINING.
CATEGORY 2: SUPPORT AREA WHERE SUBSIDENCE UNLIKELY.
CATEGORY 3: AREAS WHERE SUBSIDENCE MAY HAVE OCCURRED OR MAY OCCUR IN THE FUTURE.

REFERENCE: SEANOR MINING CORP., LOYAL MINE – OBTAINED FROM PA DEP –UNDATED

TETRA TECH
www.tetratech.com
661 ANDERSEN DRIVE – FOSTER PLAZA 7
PITTSBURGH, PA 15220
T: (412) 921-7090 | F: (412) 921-4040

REVISIONS

NO.	BY	DATE	REMARKS

SUNOCO PIPELINE L.P.
SINKING SPRING, PENNSYLVANIA

PENNSYLVANIA PIPELINE PROJECT

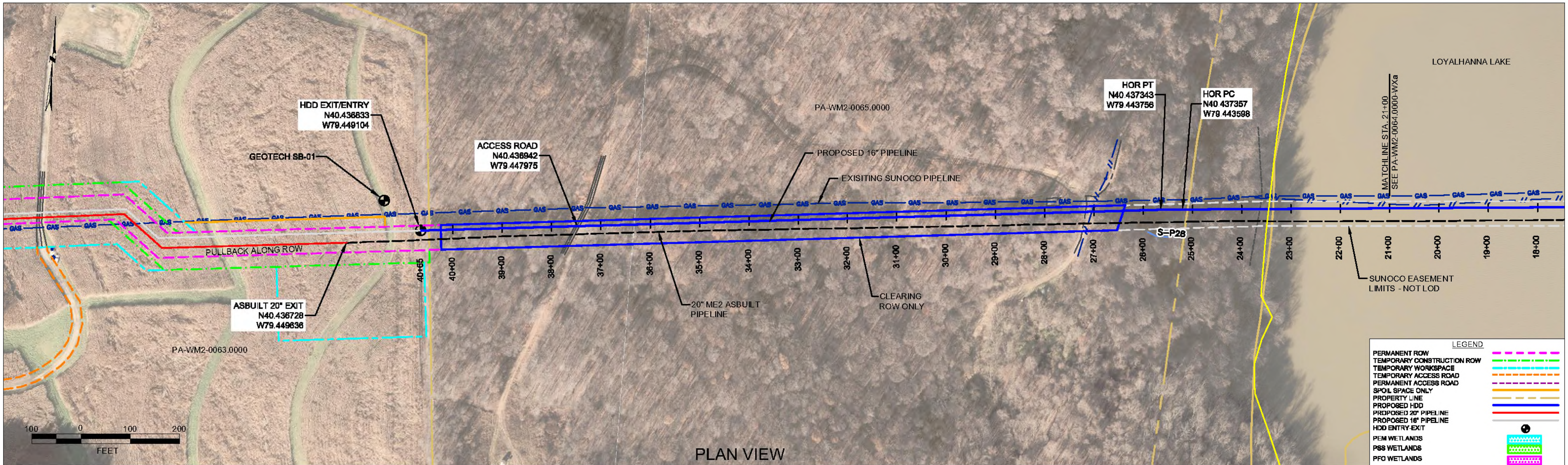
PROJECT LOCATION WITH SUBSIDENCE CATEGORIES

WESTMORELAND COUNTY
LOYALHANNA LAKE
MINE AREA

DATE:	2/20/18
PROJECT NO.:	
DESIGNED BY:	TG
DRAWN BY:	JSM
CHECKED BY:	TG

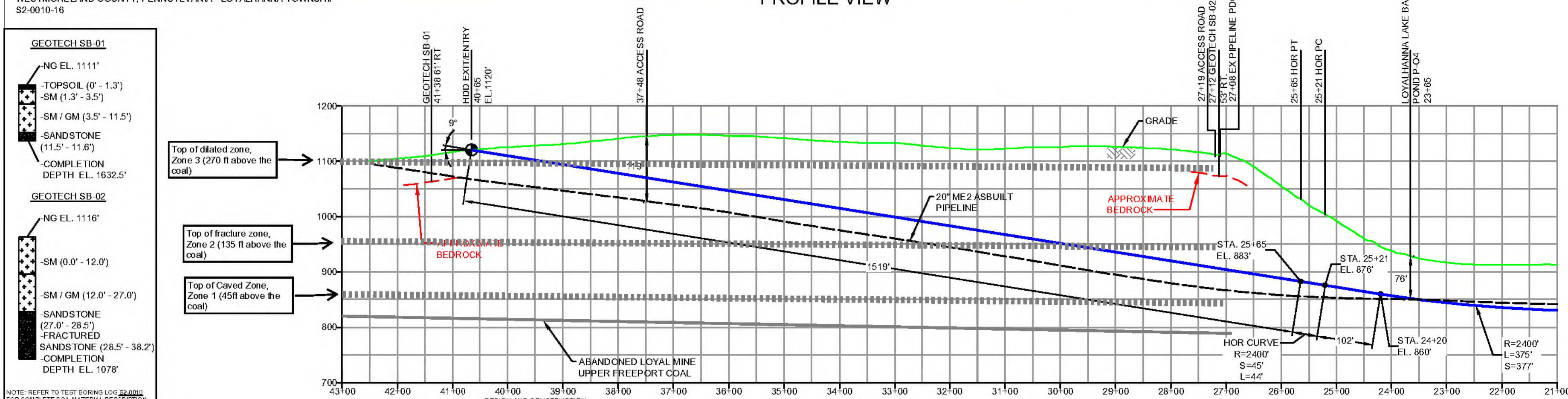
FIGURE 2

R:_Marcellus Shale Projects\Sunoco\5958 – Penn Pipeline Project\3 – Westmoreland\Spread 2\HDD Mining Review\Figures\PA-WM-HDD-FG021.dwg PIT JOY.SCABILLONI 5/31/2018 9:27:28 AM



WESTMORELAND COUNTY, PENNSYLVANIA - LOYALHANNA TOWNSHIP
S2-0010-16

PROFILE VIEW



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=): 4065'
   HDD PIPE LENGTH (S=): 4107'
   16" x 0.438" W.T., X-70, API5L, PSL2, ERW, BFW
   COATING: 14-16 MILS FBE WITH 30-35 MIL ARO (POWERCRETE OR ENGINEER APPROVED EQUAL)
5. INTERNAL DESIGN PRESSURE 1480 PSIG (SEAM FACTOR 1.0, DESIGH FACTOR 0.50).
6. INSTALLATION METHOD: HORIZONTAL DIRECTIONAL DRILL (HDD).
7. PIPELINE WARNING MARKERS SHALL BE INSTALLED ON BOTH SIDES OF ALL ROAD, RAILWAY, AND STREAM CROSSINGS.
8. CARRIER PIPE NOT ENCASED.
9. PIPE / AMBIENT TEMPERATURE MUST BE NO LESS THAN 30°F DURING PULLBACK WITHOUT PRIOR WRITTEN APPROVAL FROM THE ENGINEER.
10. CONDUCT 4-HOUR PRE-INSTALLATION HYDROTEST OF HDD PIPE STRING TO MINIMUM 1850 PSIG.
11. SEE SUNOCO PENNSYLVANIA PIPELINE PROJECT ESRI WEBMAP FOR ACCESS ROAD ALIGNMENT.

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-2.22	TO	ES-2.24	EROSION & SEDIMENT PLAN
SHEET 66	TO	SHEET 67	AERIAL SITE PLAN

REVISIONS

NO.	DESCRIPTION	BY	DATE	CHK	DATE	APP	DATE
EP4	DESIGN CHANGE - CHANGED DRILL ENTRY/EXIT ANGLE PER CLIENT REQUEST	MRS	02/07/18	RMB	02/07/18	CAG	02/07/18
EP3	DESIGN CHANGE - RELOCATED DRILL ENTRY/EXIT PER CLIENT REQUEST	MRS	12/04/17	RMB	12/04/17	CAG	12/04/17
EP2	REVISED PER PADEP COMMENTS RECEIVED 09-06-16	DLM	10/07/16	RMB	10/07/16	AAW	10/07/16
EP1	REVISED PER PADEP COMMENTS	MRS	05/17/16	RMB	05/17/16	AAW	05/17/16
EP		DLM	03/15/16	RMB	03/15/16	AAW	03/15/16
B	ADDED GEOTECH INFO	MRS	09/06/15	RMB	09/06/15	AAW	09/06/15

Sunoco Logistics Partners L.P.

TETRA TECH ROONEY
(303) 792-5911

SUNOCO PIPELINE, L.P.

HORIZONTAL DIRECTIONAL DRILL
LOYALHANNA LAKE
PENNSYLVANIA PIPELINE PROJECT

SCALE: 1"=200' | DWG NO. PA-WM2-0064.0000-WXb-16

REference: Tetra Tech Rooney Drawing PA_WM2_0064.000-Wxb-16

Figure 3 - Plan and Profile

LAMODEL ANALYSIS OF SUBSIDENCE POTENTIAL
AT LOYAL MINE
HORIZONTAL DIRECTIONAL DRILLED PIPELINE PROJECT
LOYALHANNA TOWNSHIP, WESTMORELAND COUNTY, PA
July, 2018

PRESENTED FOR

Sunoco Logistics, L.P.
525 Fritztown Road
Sinking Spring, PA

PRESENTED BY

Dr. Keith Heasley, Ph.D., P.E.
Mining Engineering Consulting
2988 Compressor Station Road
Bruceton Mills, WV 26525

TABLE OF CONTENTS

INTRODUCTION 2
MINING BACKGROUND 2
THE LAMODEL PROGRAM 2
  LAMODEL MATERIAL PROPERTY INPUT 2
POST-MINING MODEL RESULTS 3
DEGRADED MINE MODEL RESULTS 5
REFERENCES 7

FIGURES

1 Map of mine and overlying pipeline.
2 Overburden stress on the seam
3 Seam convergence with 900 psi coal strength
4 Pillar safety factors with 900 psi coal strength
5 Subsidence above the mine for 900 psi coal strength
6 Subsidence prediction along the pipeline alignment at different coal strengths
7 Pillar safety factor with 750 psi coal strength
8 Increase in subsidence going from 900 psi coal to 750 psi coal
9 Predicted worst case subsidence and associated strains (tension is negative)

INTRODUCTION

The Sunoco Logistic L.P. is planning to horizontally directional drill (HDD) a pipeline under Loyalhanna Lake and in the strata over the abandoned Loyal Mine in Loyalhanna Township, Westmoreland County, PA. The entire HDD section required to go under the lake will be about 4,065 feet long. The section above the Loyal Mine runs from Station 27+00 in the east to the western extent of the HDD at Station 40+65 and it is about 150 to 300 feet above the mine level. The objective of this investigation is to utilize the LaModel boundary-element program to analyze the future subsidence potential over the abandoned Loyal Mine, and in particular, to determine any potential subsidence and associated geologic strains that may occur along the proposed pipeline alignment.

MINING BACKGROUND

The Seanor Mining Corporation operated the underground Loyal Mine in Loyalhanna Township, Westmoreland County in the 1950's. The Upper Freeport seam was mined using the room and pillar mining method with some pillar retreat directly below the HDDP. No mining was conducted directly under the eastern portion of the HDDP which is under the Loyalhanna Lake. However, mining was conducted below the western portion of the HDDP which is above the Loyal Mine. The Upper Freeport seam was mined from Station 27+00 in the east to the western extent of the HDDP at Station 40+65. The depth of the coal from surface is about 300 to 340 feet above the western portion of the HDDP.

The mining method employed at Loyal mine appears to have been room and pillar mining utilizing mechanized mining machines. The drum head continuous mining machines were not introduced until the late 1960's; therefore, it is our opinion that this mine used a mechanized loading machine after the coal was broken by blasting. The mine plan was designed to complete five entry development mains. Mine entries in the main development appear (from the mine maps) to be about 22 feet wide with pillars on 60 feet by 95 feet centers. Three entry submain development entries were driven to the right and left of each main and were spaced about 780 feet apart. The submains appear to use 22 feet wide entries and pillars on 60 feet by 100 feet centers. Higher production rooms were driven to the right and left of each submain. They extended about 200 to 300 feet and used 35 feet wide entries and small pillars about 15 feet wide by 40 to 50 feet long. The rooms closest to the HDDP were utilized exclusively for coal recovery and were only configured for short term stability. Unlike in the Pittsburgh coal seam mining, the pillars in the production rooms were not retreat mined. However, some of the main and submain pillars were removed or split in very irregular patterns when withdrawing from these areas. It is our opinion that in the locations where the pillars were removed over larger areas, the roof would fail and surface subsidence would occur fairly quickly. However, the production rooms, or areas in the mains and submains where the pillars were split, or not removed over large areas have the highest risk of future subsidence because the pillars in these areas were not designed to provide long-term support.

THE LAMODEL PROGRAM

The LaModel program is used to model the stresses and displacements on thin tabular deposits such as coal seams. It uses the displacement-discontinuity (DD) variation of the boundary-element method, and because of this formulation, it is able to analyze large areas of single or multiple-seam coal mines (Heasley, 1998). LaModel is unique among boundary element codes because the overburden material includes laminations which give the model a very realistic flexibility for stratified sedimentary geologies and multiple-seam mines. Using LaModel, the total vertical stresses and displacements in the coal seam are calculated, and optionally, the surface subsidence, or subsidence anywhere in the overburden, can be calculated. Amongst subsidence prediction programs, LaModel has the unique ability of be able to model the highly variable subsidence associated with time-dependent, pillar failure.

Since LaModel's original introduction in 1996, it has continually been upgraded and modernized as operating systems and programming languages have changed. It can be used to calculate convergence, vertical stress, overburden stress, element safety factors, pillar safety factors, intra-seam subsidence, etc. on single and multiple seams with complex geometries and variable topography. Presently, the program can analyze a 2000 x 2000 grid with 6 different material models and 52 different individual in-seam materials. It uses a forms-based system for inputting model parameters and a graphical interface for creating the mine grid. Also, it includes a utility referred to as a "Wizard" for automatically calculating coal pillars with a Mark-Bieniawski pillar strength and another utility to assist with the development of "standard" gob properties. Recently, the LaModel program was interfaced with AutoCAD to allow mine plans and overburden contours to be automatically imported into the corresponding seam and overburden grids. Also, the output from LaModel can be downloaded into AutoCAD and overlain on the mine map for enhanced analysis and graphical display. Within the last couple of years, new algorithms have been added to the program to help optimize subsidence calculations (Yang, 2016).

LAMODEL MATERIAL PROPERTY INPUT

Mine Grid: The LaModel simulation of the Loyal Mine encompassed a fairly large area of the abandoned mine (see the "Mine Grid" area in Figure 1) in order to keep any edge effects from the boundary conditions from affecting the area of interest around the pipeline alignment. This model area was 2,500 feet wide and 2,000 feet high. A relatively small element size of 2 feet was used to best model the given entries and pillars. This smaller element size also facilitates using a thin lamination thickness for the overburden to optimize the subsidence angle-or-draw. With the 2 feet element width, the final grid size was 1250 X 1000 elements. Based on the mine map, the boundaries of the model were simulated with rigid boundary conditions on all four sides.

Subsequent seismic interpretation required adjustment to the original mine model that was digitized from the original mine map. In order to simulate the mine voids detected by the seismic survey under the survey stations 40+00 to 39+00, pillars in this area which were originally assumed to be fully extracted were changed to partially extracted. Seismic interpretation did not require adjustment to the other areas of the mine model that was digitized from the mine map.

The updated mine grid was automatically generated from an updated version of the digitized Loyal Mine.

Overburden Grid: For inputting the overburden information in order to accurately simulate the overburden stress on the seam, an overburden grid was developed that was 300 feet wider than the mine grid on all four sides. Therefore, the final overburden grid was 3100 feet wide by 2600 feet high and used 10 feet wide elements on a 310 X 260 element grid. The values for the overburden grid were then automatically generated from the AutoCAD topographic lines as shown in Figure 1. The result of the overburden grid generation process is the calculated overburden stress on the coal seam as plotted in Figure 2. In the plotted overburden stress, the lower stress areas on the west and east sides of the mine grid and higher stress area under the north-south oriented ridge in the center of the mine grid are clearly visible.

Overburden, Gob and Coal Properties: The material properties for the Loyal Mine model were generated using the LaModel subsidence optimization routines (Yang, 2016) to provide a subsidence factor (65%) and angle-of-draw consistent with the western Pennsylvania overburden and consistent with the 200 feet wide by 300 feet deep production panels that underlie the pipeline alignment. This resulted in an average rock modulus of 3,000,000 psi and lamination thickness of 1.25 feet for the overburden, and a final gob modulus of 16,800 psi for the strain-hardening gob model. For the initial model, intended to simulate the coal strength at the time of mining, a NIOSH recommended coal strength of 900 psi as implemented in the Mark-Bieniawski pillar strength formula by the LaModel coal wizard was used. To simulate the maximum potential subsidence that might occur over time after initial mining (assumedly due to coal, roof or floor degradation by oxidation, spalling, moisture, etc.), a 750 psi (17%) reduced coal strength was implemented into a separate “degraded mine” model. (This 750 psi coal strength has been determined to be a reasonable degraded coal strength for mines deeper than a couple of hundred feet.)

POST-MINING MODEL RESULTS

Seam Convergence: Initially, the model with the 900 psi coal strength intended to simulate the mine conditions immediately after mining was run and analyzed in order to gain an understanding of the post-mining conditions. The first model output to be examined was the seam convergence as shown in Figure 3. In this output, the overburden convergence over the fully extracted panel gobs is clearly visible. In particular, the full extraction areas adjacent to the pipeline show 2.0 to 2.5 feet of convergence.

Pillar Safety Factors: Next, the safety factors of the remaining coal pillars were examined, as shown in Figure 4. (Note: the scale of this safety factor plot was set to give details on the pillars with safety factors less than 2.5). This Figure shows that the pillars located under survey stations 40+65 to 40+00 and 34+00 to 32+00 are stable and this correlates with the seismic analysis.

Subsidence: The next output from the post-mining model to be examined was the subsidence at the pipeline location (see Figure 5). This subsidence is directly correlated to the seam convergence shown in Figure 3. Similar to the convergence, the increase in surface subsidence due to fully extracted pillars is evident in Figure 5. Here the original predicted subsidence under the pipeline location can be seen. Generally, the HDD starts (40+65) in the small subsidence trough (to the west) then crosses over partially extracted pillars (40+00 to 38+00), failed small pillars (30+00 to 29+00) and ends on the solid coal to the east (25+00).

The pipeline in the HDD sections ranges from approximately 300-350 feet above the seam, at the entry and exit hillside locations (40+65), to 150 feet above the seam under the survey station 28+00. In LaModel, an average distance above the seam of 150 feet was used to calculate the subsidence values which are applied to the HDD pipeline. In the LaModel program, the overburden is modeled as a continuum. Therefore, the program does show the subsidence horizontally expand, within the angle-of-draw, and the magnitude decrease as the distance from the mine increases, but the program does not model any vertical dilation of the overburden, which minimizes the change in subsidence with depth.

To examine the details of the previous subsidence along the pipeline alignment, the subsidence above the seam has been interpolated from the output shown in Figure 5 directly to the pipeline coordinates, as shown in Figure 6. In this plot, the subsidence under the pipeline as it crosses over the various gob and supporting gateroad pillar areas is clearly visible.

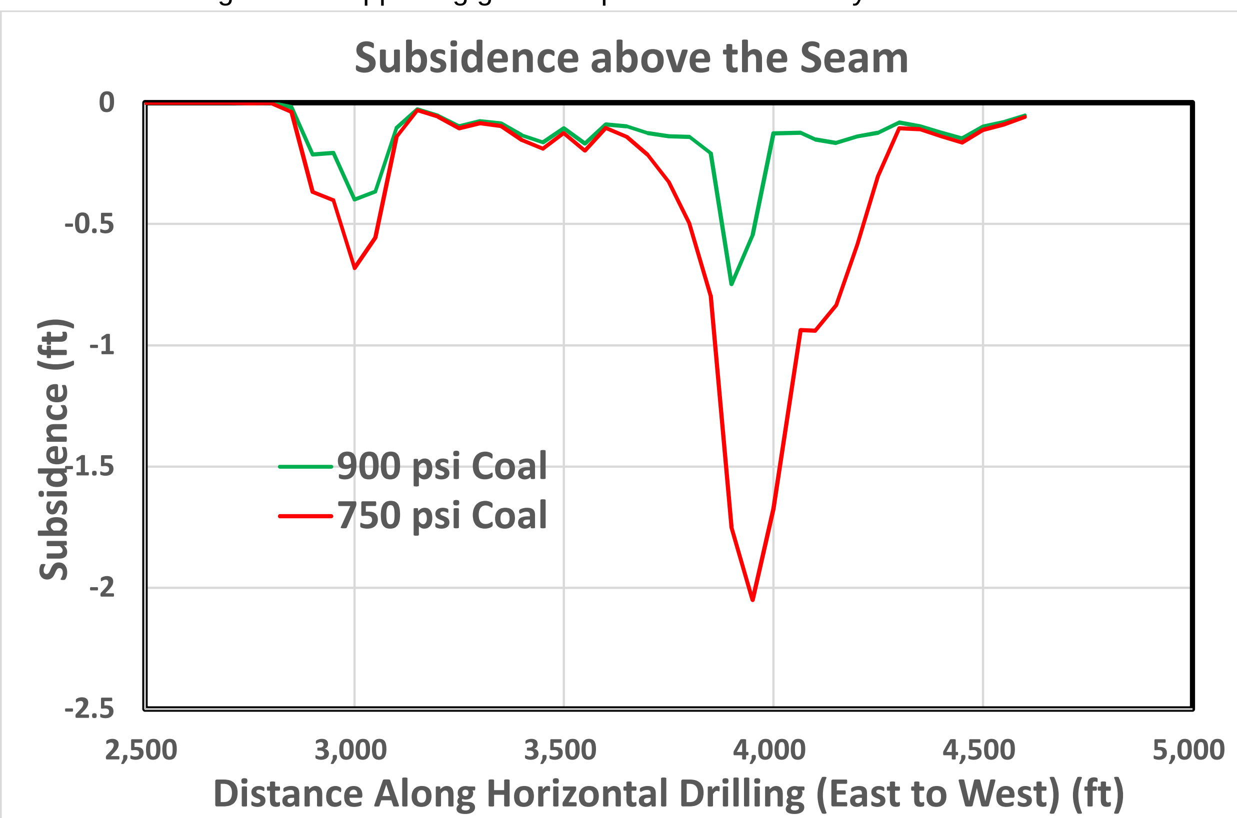


Figure 6. Subsidence prediction along the pipeline alignment at different coal strengths.

DEGRADED MINE MODEL RESULTS

As previously stated, the model with 900 psi coal strength (as shown in Figures 3, 4, and 5) was intended to simulate the mine conditions immediately after mining. The subsidence shown in Figure 5 and the 900 psi coal line in Figure 6 has assumedly already occurred immediately after mining. To simulate the maximum potential subsidence that might occur over time due to degradation of the coal, roof and/or floor by oxidation, spalling, moisture, etc., a model with a coal strength of 750 psi (a reasonable degraded coal strength for mines deeper than a couple of hundred feet) was run, analyzed and compared with the post-mining 900 psi model.

Pillar Safety Factors: The first output to be closely examined from the degraded mine model was pillar safety factors as shown in Figure 7. This Figure shows that the smaller pillars located under the survey stations 40+65 to 37+00 have now all failed. Also, the pillars under the survey stations 31+00 to 29+00 have failed.

Additional Subsidence: As the small sized pillars in some areas of the mine fail, they cause convergence directly over the pillar. Also, the pillar failure puts additional loading and associate convergence on the adjacent gob areas. The ground reaction to the pillar failures then results in additional overburden subsidence as shown in Figures 8 and 9. With a reduction in coal strength to 750 psi, the areas of greatest increased subsidence are the areas under the survey stations 40+65 to 37+00 and 31+00 to 29+00 where the pillar safety factors have changed from above 1.0 to below 1.0. Under survey stations 40+65 to 37+00, the additional subsidence is in the range of 0.2 to 1.5 feet (see Figures 8 and 9).

The degraded mine subsidence predicted in this model may have already occurred, may occur at some time in the future, or may never reach this level. Predicting the actual condition of the mine at this time, and at any given time in the future, is difficult.

Strains: The strains associated with the predicted post-mining subsidence are also shown in Figure 9. The maximum strain value at the HDD location is approximately 0.004, or 0.4%, and fluctuates continuously along the pipeline length.

The level of strain that the pipeline may experience is both a function of the ground movement and also a function of how tightly the pipeline is coupled to the ground movement. The pipeline is installed by the horizontal directional drill method which provides for an over-reamed bore hole. If the pipeline can easily slide, then areas of tension or compression in the ground can be reasonably canceled by sliding of the pipe between adjacent areas of the opposite strain. The exact response of the pipeline in the ground is to be analyzed in a separate report.

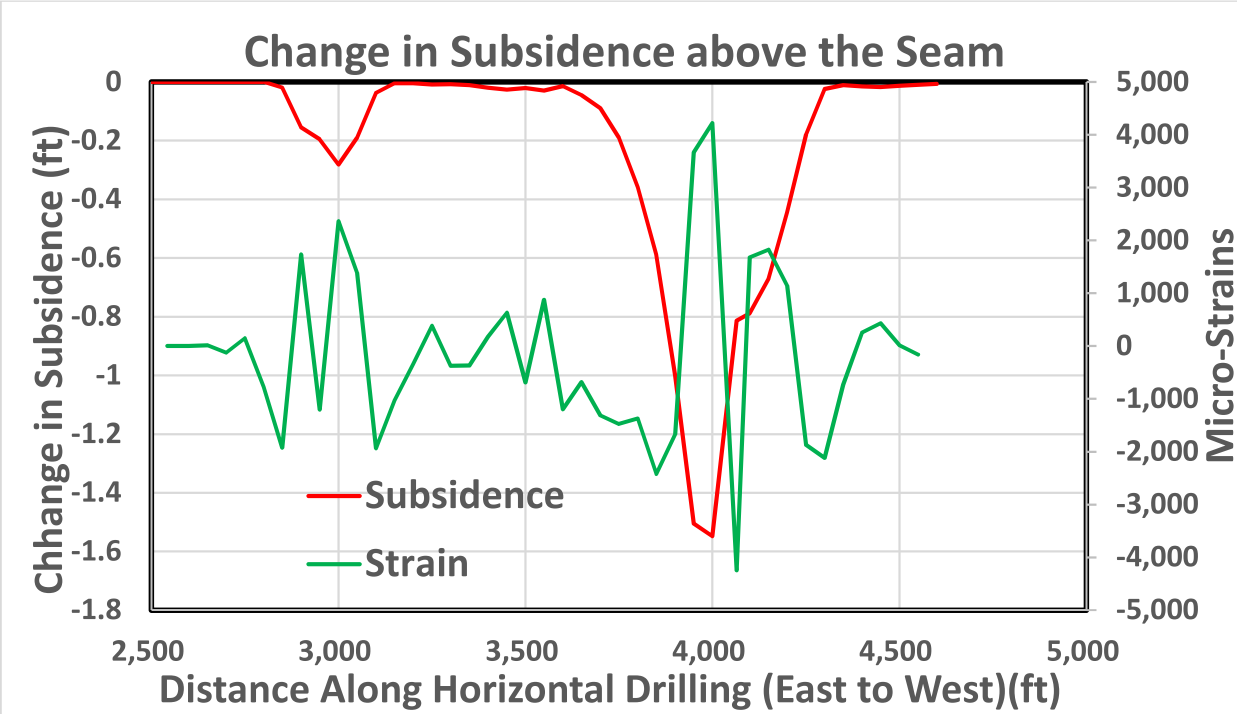


Figure 9. Predicted worst case subsidence and associated strains (tension is negative).

REFERENCES

Heasley, K. A. (1998) Numerical Modeling of Coal Mines with a Laminated Displacement-Discontinuity Code, Ph.D. dissertation, Colorado School of Mines, 187 pp.

Kendorski, F. S. (2006) Effect of Full-Extraction Underground Mining on Ground and Surface Waters a 25-Year Retrospective, 25th International Conference on Ground Control Mining, Morgantown WV 2006

The Pennsylvania State University (2014) Pennsylvania Mine Map Atlas, http://www.minemaps.psu.edu/

Yang, J. (2016) Calibrating LaModel for Subsidence, M.S. thesis, West Virginia University, 93 pp.

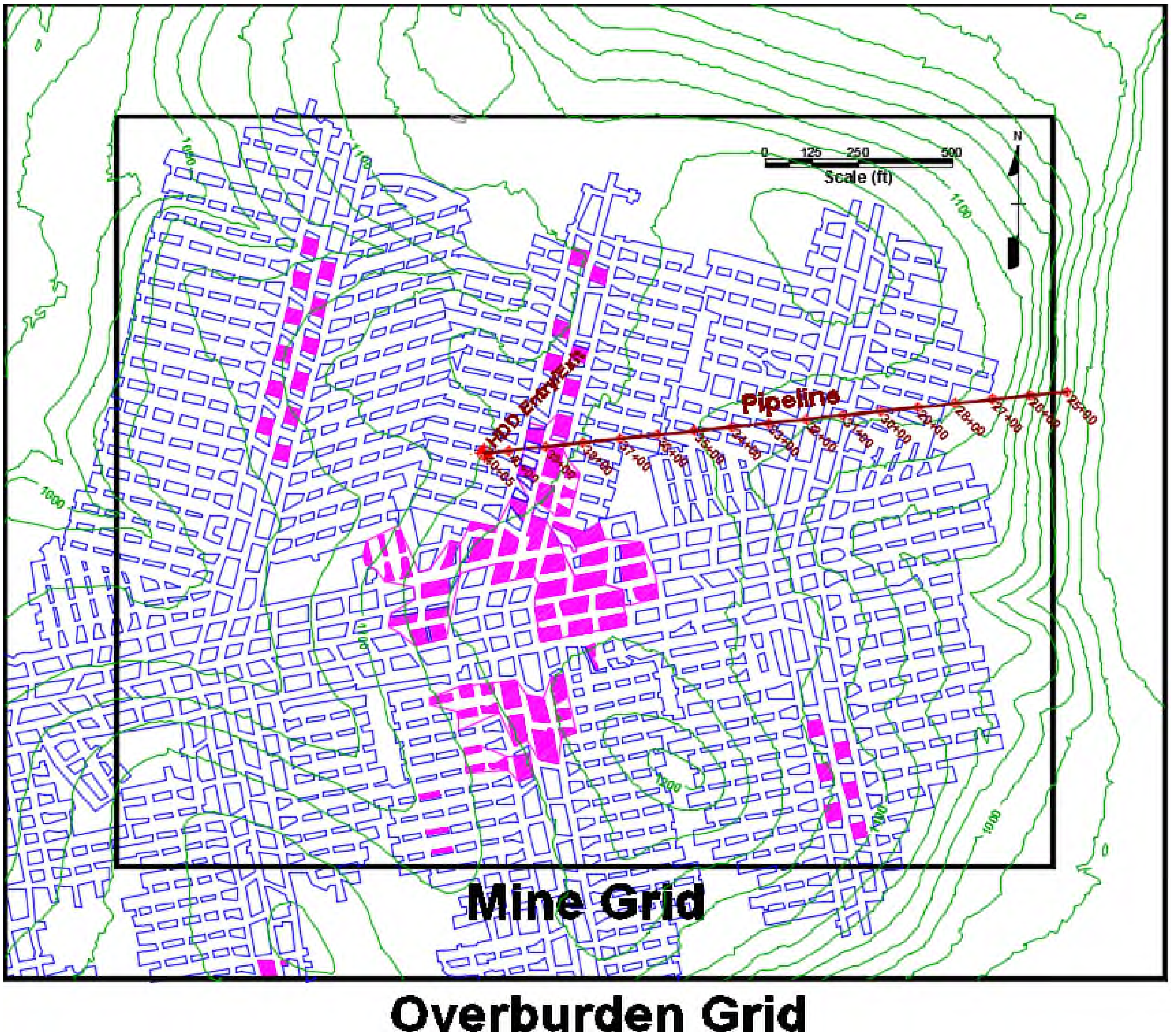


Figure 1. Map of mine and overlying pipeline

.

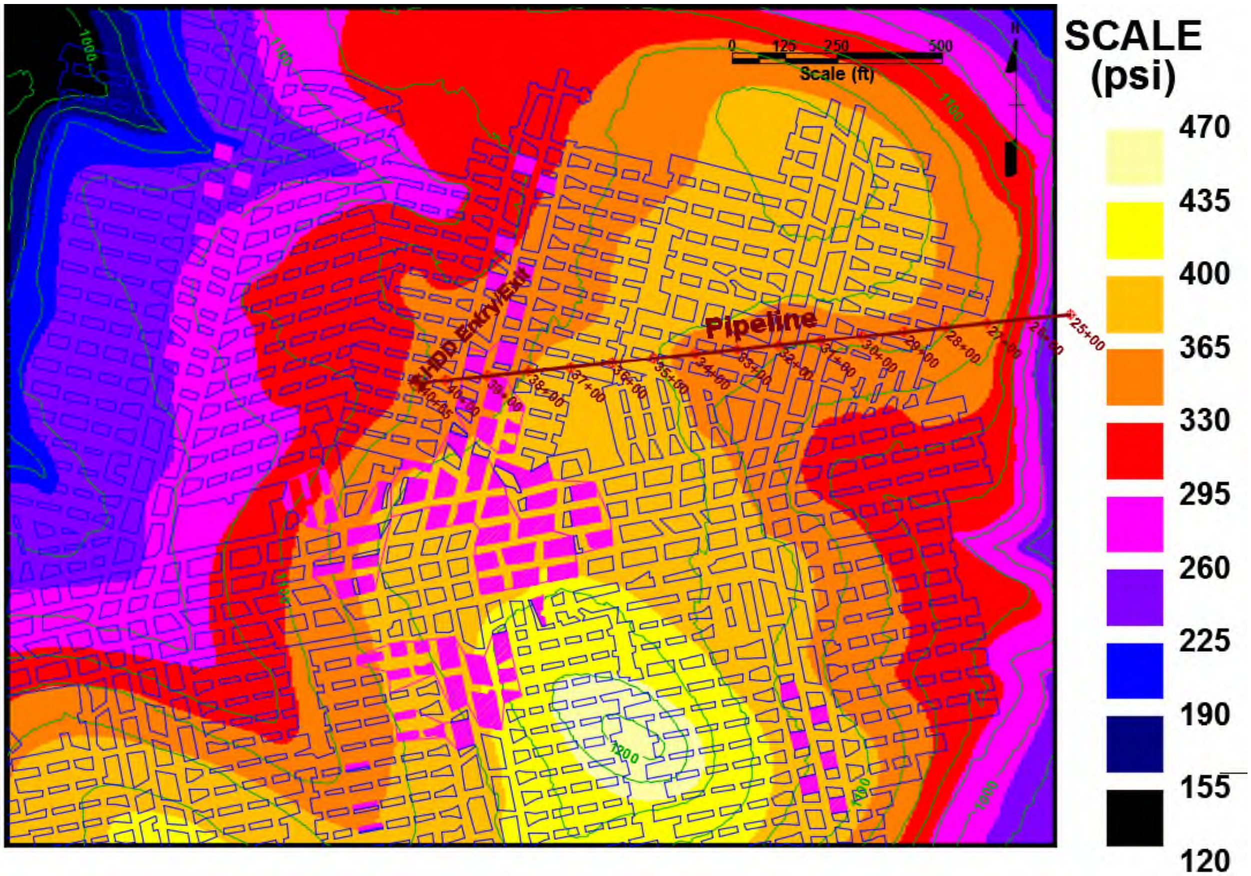


Figure 2. Overburden stress on the seam.

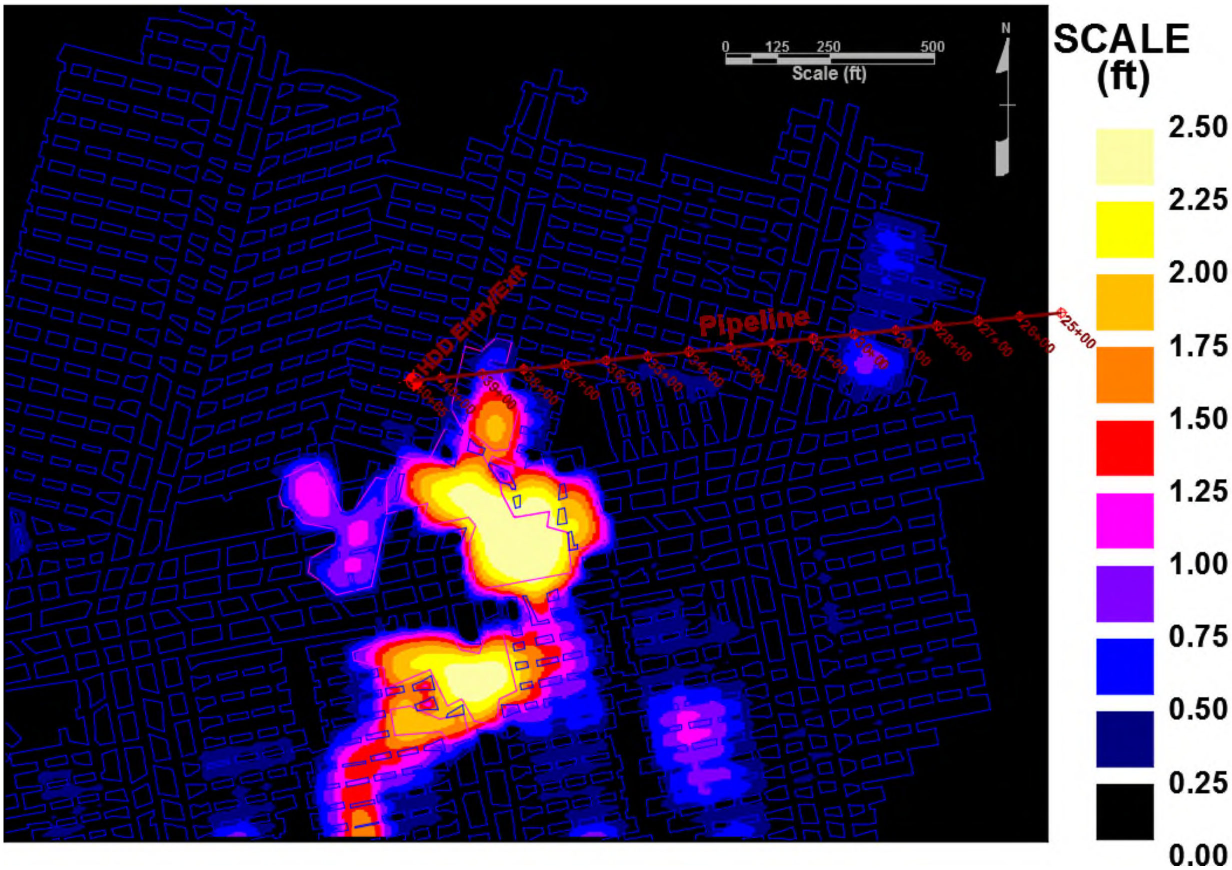


Figure 3. Seam convergence with 900 psi coal strength.

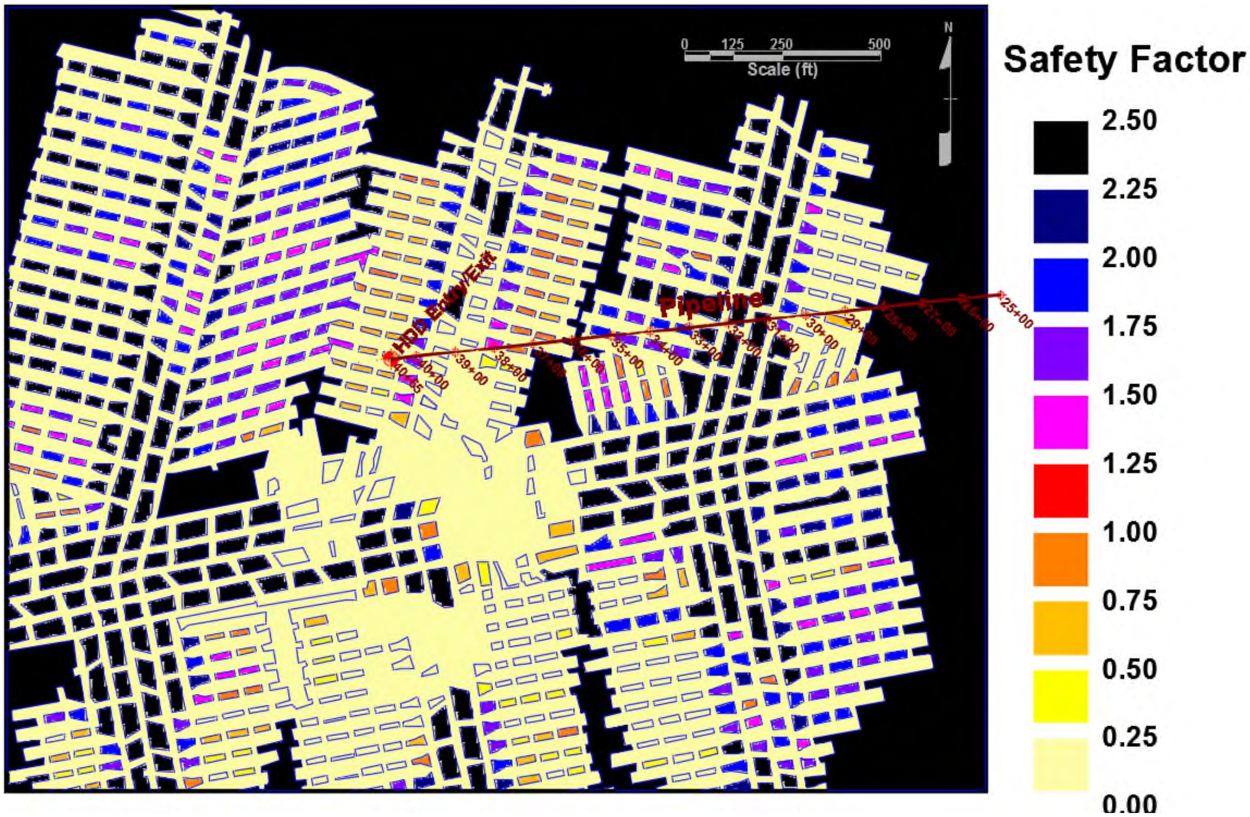


Figure 4. Pillar safety factors with 900 psi coal strength.

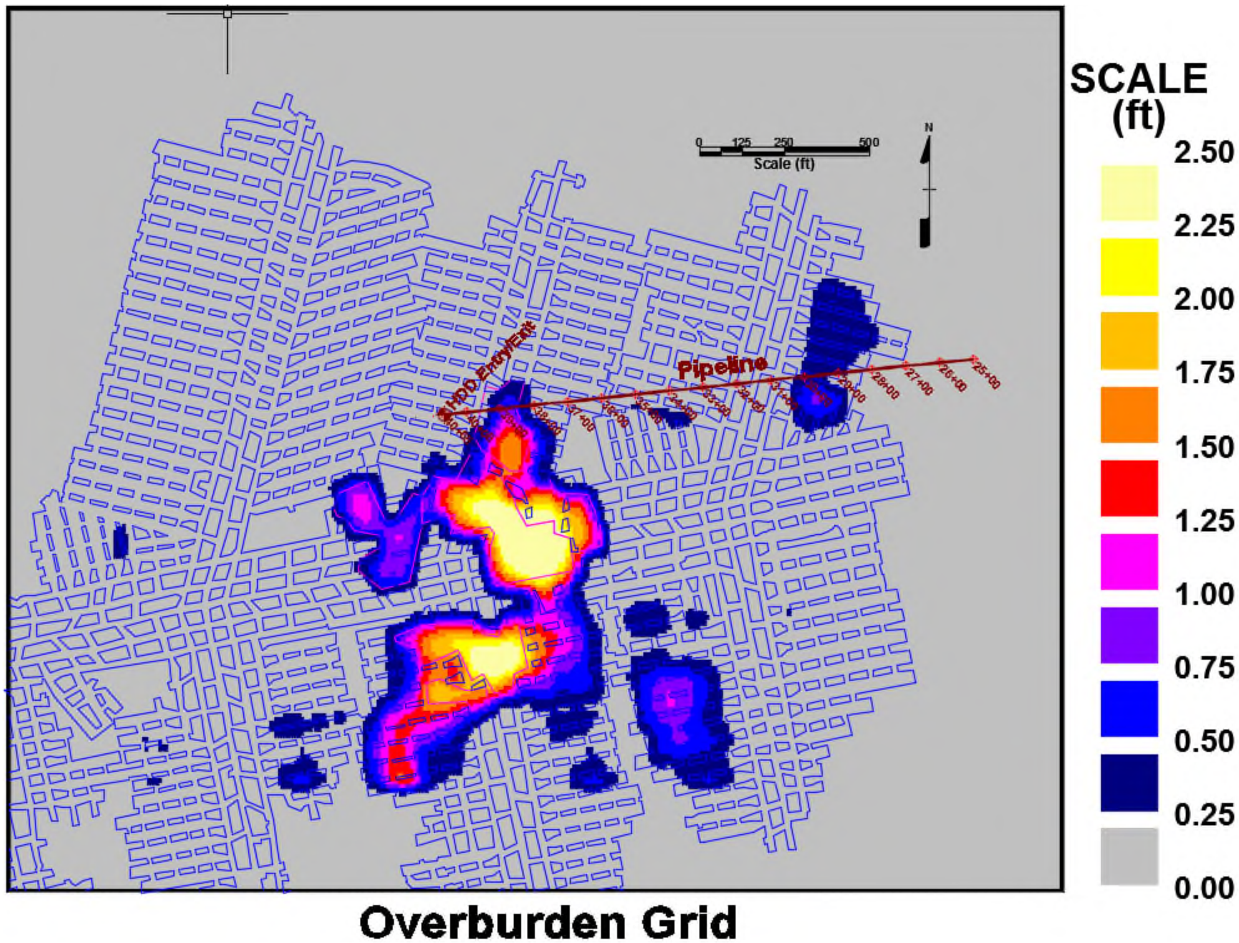


Figure 5. Subsidence above the mine for 900 psi coal strength.

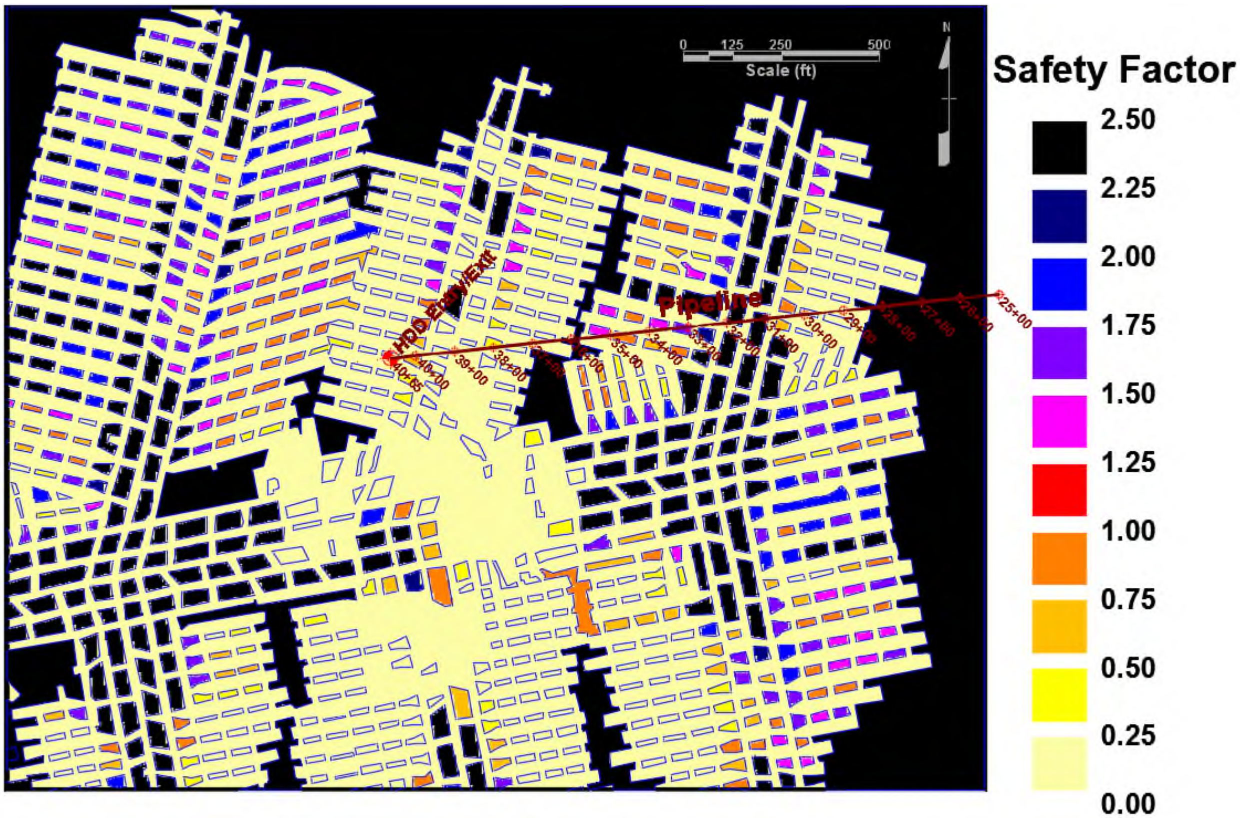


Figure 7. Pillar safety factor with 750 psi coal strength.

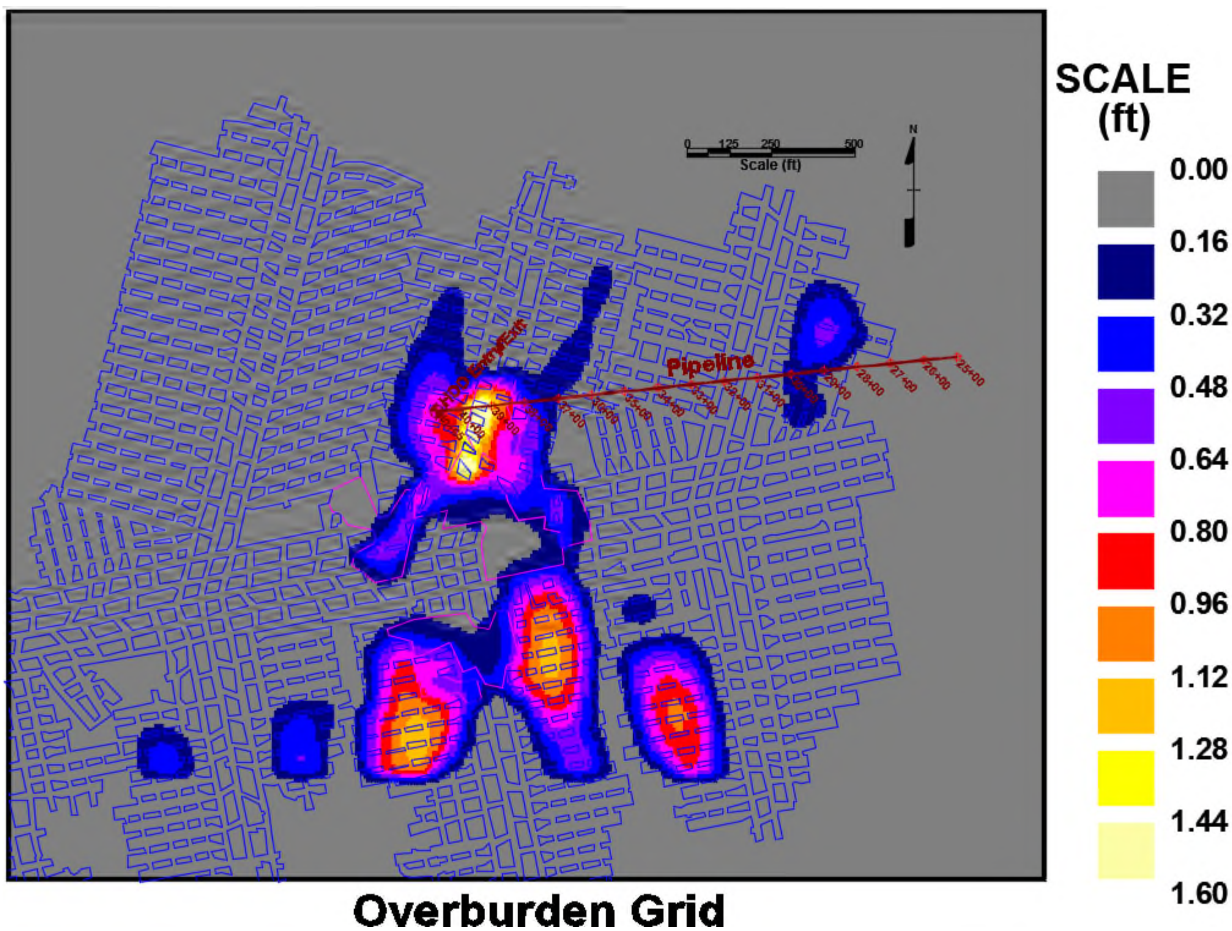


Figure 8. Increase in subsidence going from 900 psi coal to 750 psi coal.

Kiefner and Associates
4480 Bridgeway Avenue, Suite D
Columbus, Ohio 43219
T +1 614 888 8220
F +1 614 888 7323
www.kiefner.com

Kiefner
an Applus+ Company

July 26, 2018

Dean Shauers
President
Tetra Tech Rooney
115 Inverness Drive East, Suite 300
Englewood, CO 80112
dean.shauers@tetratech.com

Project Number: 0461-1807 Final
Re: Stress Analysis for the 16-inch Loyalhanna Lake Horizontal Directionally Drilled Pipeline Subjected to Ground Subsidence

Dear Mr. Shauers:

Sunoco Logistics Partners L.P. (Sunoco) has proposed the 16-inch Mariner East 2 (ME-2) pipeline as an expansion of the existing Mariner East pipeline system which transports natural gas liquids from Ohio to the Pittsburgh area in Pennsylvania. The 16-inch ME-2 pipeline crosses the Loyalhanna Lake to the east of Pittsburgh. This portion of the pipeline will be installed using horizontal directional drilling (HDD). The majority of the pipeline will consist of 16-inch outer diameter (OD), 0.375-inch wall thickness (WT), API 5L [1] Grade X70 line pipe. The HDD segment of the pipeline is approximately 4,065 feet long and consists of 16-inch OD, 0.438-inch WT, API 5L Grade X70 line pipe. The maximum operating pressure (MOP) of the pipeline is 2,100 psig. A portion of the pipeline which includes the HDD segment may experience future ground subsidence. Kiefner and Associates, Inc. (Kiefner) was retained to perform a stress analysis of the pipeline to determine the stresses in the HDD segment from a potential ground subsidence. Projected ground displacements and pipeline alignment coordinates have been provided to Kiefner by Tetra Tech Rooney. Listed in Table 1 are the pipeline characteristics.

Table 1. ME-2 Pipeline Characteristics

Parameter	Value / Description
OD (outer diameter)	16 inches
Normal WT (wall thickness)	0.375 inch
WT of the HDD segment	0.438 inch
Grade	X70
Specified minimum yield stress (SMYS)	70 ksi
Flange rating MOP (maximum operating pressure)	2,100 psig
HDD design radius	2,400 ft
HDD radius used in the analysis	1,200 ft

Soil-Pipe Interaction Analysis

The magnitude of the stresses that a pipeline may experience in a subsidence basin depends on subsidence displacement gradients and curvatures as well as properties of the soil supporting the pipeline, and the operating temperatures. These stresses were calculated in an ANSYS finite element analysis (FEA) model, incorporating the soil spring model outlined in the Guidelines for the Design of Buried Steel Pipe [2]. The FEA model used ANSYS quadratic three-node pipe elements (PIPE289) for modeling the pipeline and nonlinear springs to represent the soil-pipe interaction. The pipe elements are well-suited for large deflection and large strain applications, and include effects of shear deformation on the stresses. Furthermore, the pipe quadratic elements have internal pressure capabilities and can account for the effect of the internal pressure on the pipe curvature at the bend locations (Bourdon effect). Input parameters for the soil spring model include the soil density, cohesion, friction angle, and pipe coating friction parameter. The FEA parameters and assumptions are listed in Table 2.

The gap between the pipeline and the drilled hole along the HDD segment which will be filled with bentonite is on average about 4 inches. Thus, if the ground subsidence exceeds 4 inches (0.33 feet) the pipe can potentially come into contact with the bedrock. For this reason stiffer spring constants representative of a typical sandstone bedrock [3] were assigned to the HDD segments with a projected ground subsidence exceeding 4 inches.

Table 2. Soil-Pipe Interaction Parameters

Parameter	Value
Pipe elastic modulus	29600 ksi
Pipe Poisson's ratio	0.3
Pipe coefficient of thermal expansion	6.5×10^{-6} in/in/F
Soil-pipe interface friction factor	0.6 for in-ditch installation 0.1 for HDD installation
Soil density	120 pcf
Soil friction angle	30 deg for in-ditch installation 20 deg for HDD drilling mud (bentonite)
Bedrock spring constant (secant modulus)	1.29×10^{7} lbs/ft

Ground Subsidence

Ground subsidence displacements at about 1-foot intervals were provided to Kiefner in an Excel spreadsheet named '16in Loyalhanna HDD - Kiefner (JSB).xlsx'. These displacements were applied to the soil spring ends in the FEA model to simulate ground subsidence. Figure 1 shows the displacements as provided to Kiefner and the displacements applied to the FEA model versus pipe stationing. The location of the HDD segment and the region where direct pipe-to-rock contact is anticipated are also marked on the figure. Pipe stations used in the model are shifted by 1,000 feet to allow the FEA mesh to extend beyond the ends of the HDD segment. Therefore the model stationing in the figure is different than the HDD stationing in the Appendix. The second x-axis in the figure shows the HDD stations for comparison. In the rest of the report only the shifted stations are used.

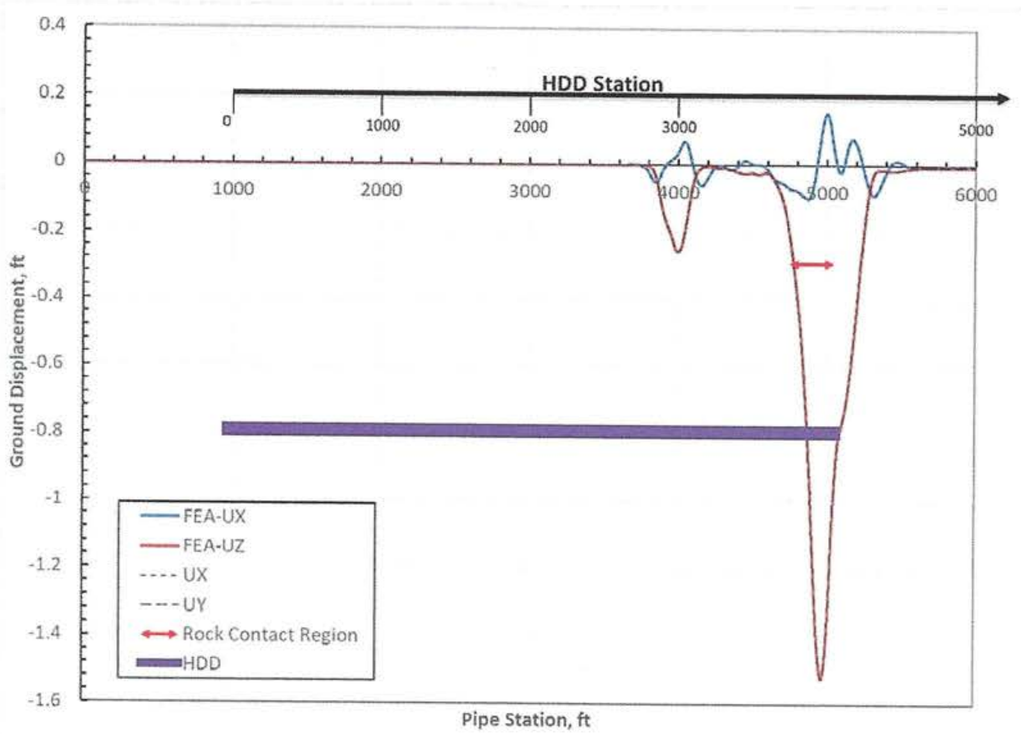


Figure 1. Ground Displacements and Applied FEA Displacements (The Second x-Axis in the Graph Hows HDD Stationing)

Operational and Installation Loads

Operational loads consist of the internal pressure and differential temperature (difference in pipe body temperature during installation and operation). The FEA pipe elements employed in this analysis had internal pressure capability. Thus internal pressures of zero and MOP were included in the FEA by direct application to the internal surfaces of the FEA element.

Differential temperatures were calculated based on climate data and expected operating temperatures. The climate information was extracted from the Southern Regional Climate Center [3] website for Salina 3W Station near Loyalhanna Lake. The climate normal for this station indicated a normal high temperature of 83.3 F in July and a normal low temperature of 19.6 F in January. The average annual temperature at this location is 50.6 F. The HDD installation is expected to occur in the summer of 2018. Therefore, the pipe body temperature at installation can be assumed as the average temperatures during August and September that is 67.3 F. Liquid pipelines usually operate at higher temperatures than the surrounding environment because of frictional loss. Based on our experience we assumed that the operating temperature of the pipeline in summer could be as high as 95 F. Therefore a positive differential temperature of 28 F was considered in the analysis. The highest negative differential temperature was calculated as the average annual temperature (50.6 F) minus the high temperature in August (82.6 F). This resulted in a temperature differential of -32 F. Table 3 shows the loading combinations used in the analysis.

In addition to the above loads, the HDD segment possesses locked-in stresses due to pipe curvature from the installation. The specified minimum radius of curvature for this HDD installation is 2,400 ft. However, since the actual radius can deviate from the minimum specified values, a minimum radius of 1,200 ft was assumed in the calculations. This amount of curvature induces a longitudinal stress of 16.4 ksi (23.4% SMYS).

Table 3. Loading Scenarios

Loading Case No.	Subsidence	HDD Curvature	Internal Pressure, psi	Differential Temperature, F
1	Included	Included	0	0
2	Included	Included	2,100	0
3	Included	Included	0	-28
4	Included	Included	2,100	-28
5	Included	Included	0	32
6	Included	Included	2,100	32

Result Summary

Six different loading scenarios listed in Table 3 were examined. Figure 2 shows the FEA results for loading Case 1 (subsidence and HDD curvature). The figure contains plots of the maximum (SL max) and the minimum longitudinal (SL min) stresses as well as the equivalent (von Mises) stresses in the pipeline. The horizontal axis is the pipe station (ft) while the vertical axis shows the FEA stresses in ksi. The horizontal dashed lines represent the allowable stress limits of ASME B31.4 [5], which is 90% SMYS for the longitudinal and equivalent stresses. The location of the HDD segment is also marked on the figure in a thick purple line. The plotted stresses include the HDD bending stress due to the installation curvature. Under loading Case 1 the maximum and minimum calculated stresses are about 16.4 ksi (23.5% SMYS) and −20.7 ksi (29.5% SMYS compression), while the maximum equivalent stress is 20.7 ksi (29.5% SMYS). These stresses are all within the allowable limit of 90% SMYS set forth in ASME B31.4.

Figure 3 through Figure 7 show similar results for loading Cases 2 through 6, respectively. The maximum longitudinal stress is associated with loading Case 6 and it is 74.4% SMYS. The maximum equivalent stress, also associated with loading Case 6, is 80.1% SMYS. Figure 7 shows that the location of the highest stress is at the induction bends outside of the HDD segment.

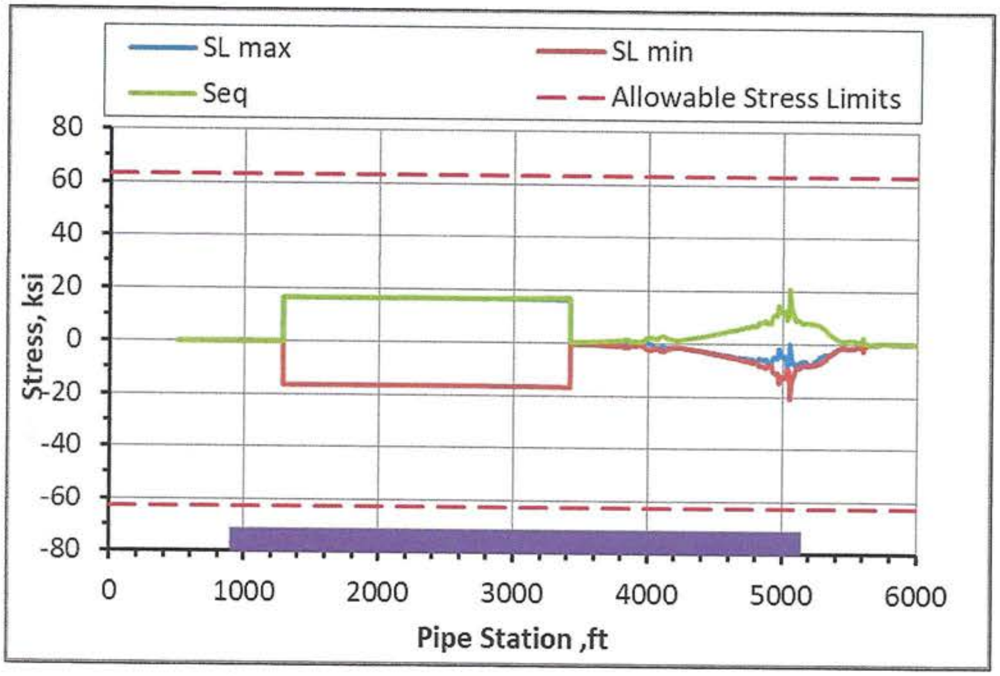


Figure 2. FEA Results for Loading Case 1

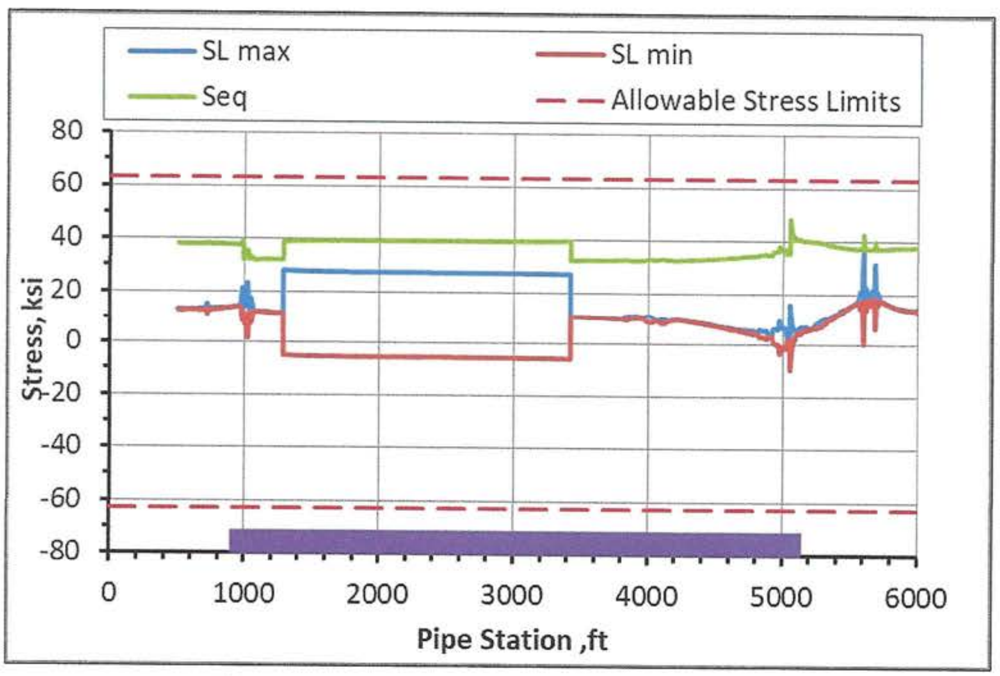


Figure 3. FEA Results for Loading Case 2

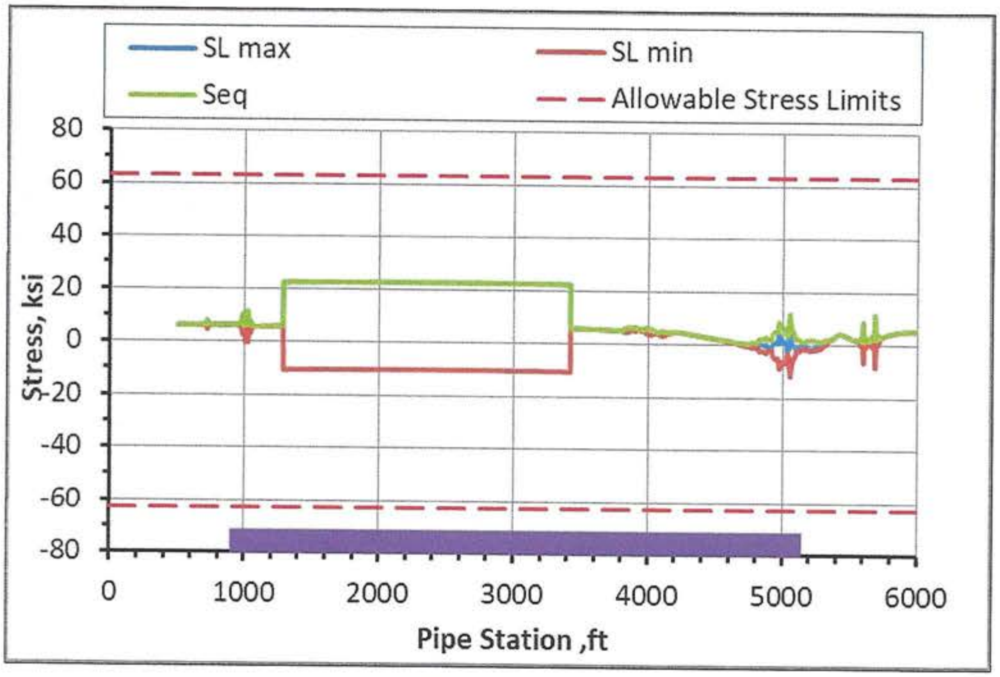


Figure 4. FEA Results for Loading Case 3

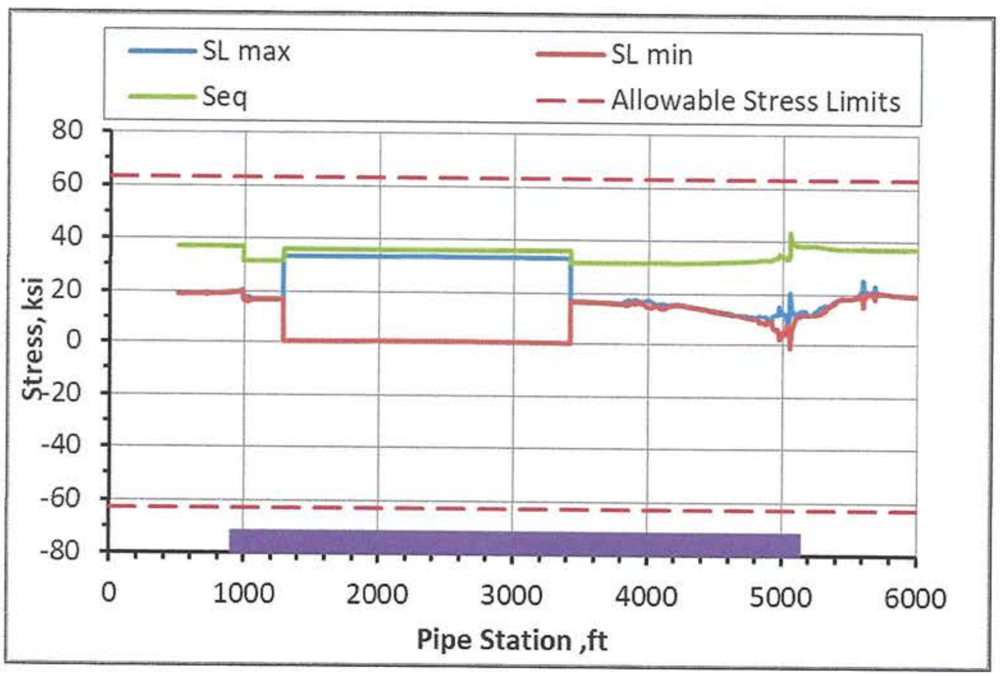


Figure 5. FEA Results for Loading Case 4

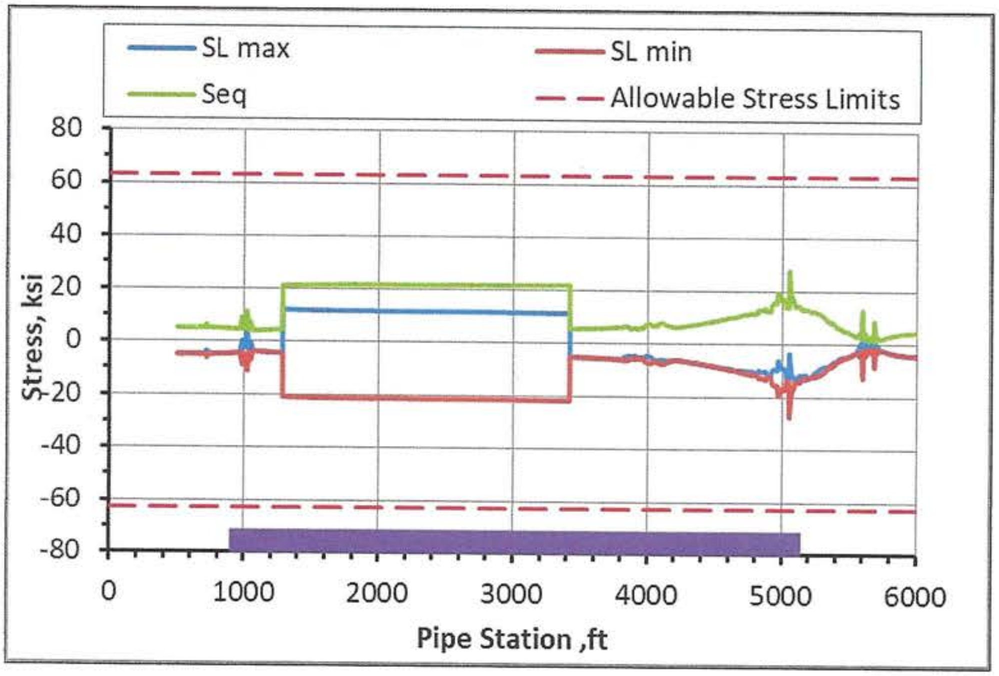


Figure 6. FEA Results for Loading Case 5

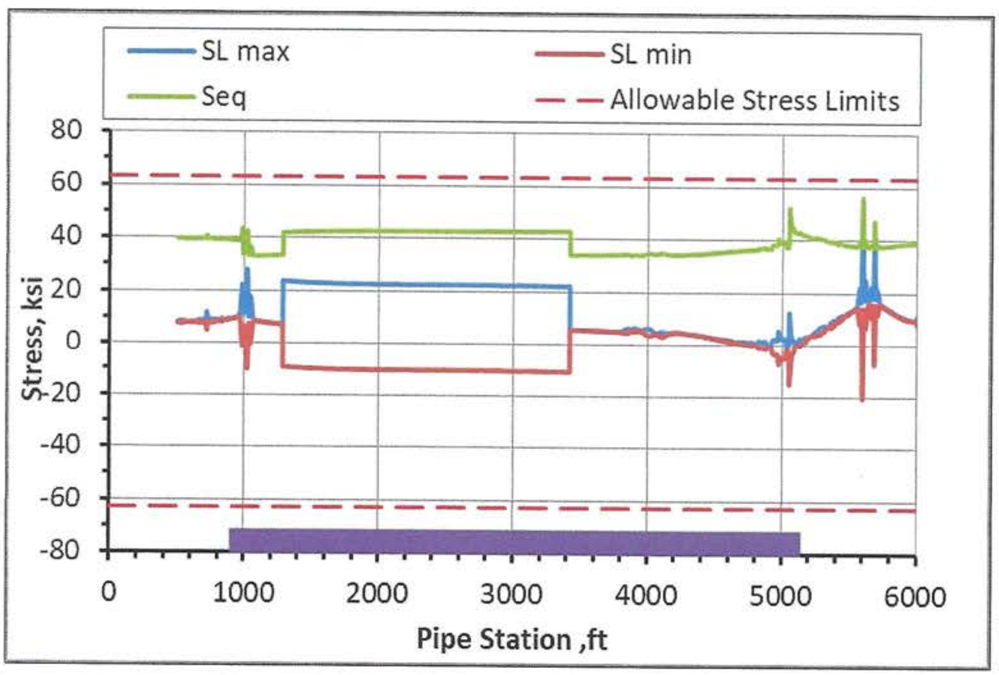


Figure 7. FEA Results for Loading Case 6

The maximum and minimum stresses are listed in Table 4. Table 5 shows the same results in percent SMYS. The results show that all the stresses are within the allowable limit of 90% SMYS.

Table 4. Summary of FEA Results

Loading Case No.	Maximum Longitudinal Stress, ksi	Minimum Longitudinal Stress, ksi	Maximum Equivalent Stress, ksi
1	16.4	-20.7	20.7
2	36.3	-9.7	48.4
3	22.6	-11.8	22.6
4	33.5	-1.2	43.4
5	12.0	-27.6	27.6
6	52.1	-20.6	56.0

Table 5. Summary of FEA Results as Percent SMYS

Loading Case No.	Maximum Longitudinal Stress	Minimum Longitudinal Stress	Maximum Equivalent Stress
1	23.5%	-29.5%	29.5%
2	51.9%	-13.9%	69.1%
3	32.3%	-16.8%	32.3%
4	47.8%	-1.7%	62.0%
5	17.2%	-39.5%	39.5%
6	74.4%	-29.4%	80.1%

If you have any further questions, please contact me.

Regards,

Benjamin Zand, PhD
Principal Engineer, Manager, Stress Analysis

Approved by

W. Greg Morris, PE
Senior Principal Engineer

BZ:tb

Bibliography

[1] API 5L-2004, "Specification for line pipe," American Petroleum Institute, Washington D.C., 43rd Edition, March 2004.

[2] AmericanLifelinesAlliance, "Guidelines for the Design of Buried Steel Pipe," AmericanLifelinesAlliance, American Society of Civil Engineers, July 2001 (with addenda through February 2005).

[3] Southern Regional Climate Center, "E328 Howe-Russell Complex, Louisiana State University, Baton Rouge, LA 70803," [Online]. Available: http://www.srcc.lsu.edu/climate_normals.html .

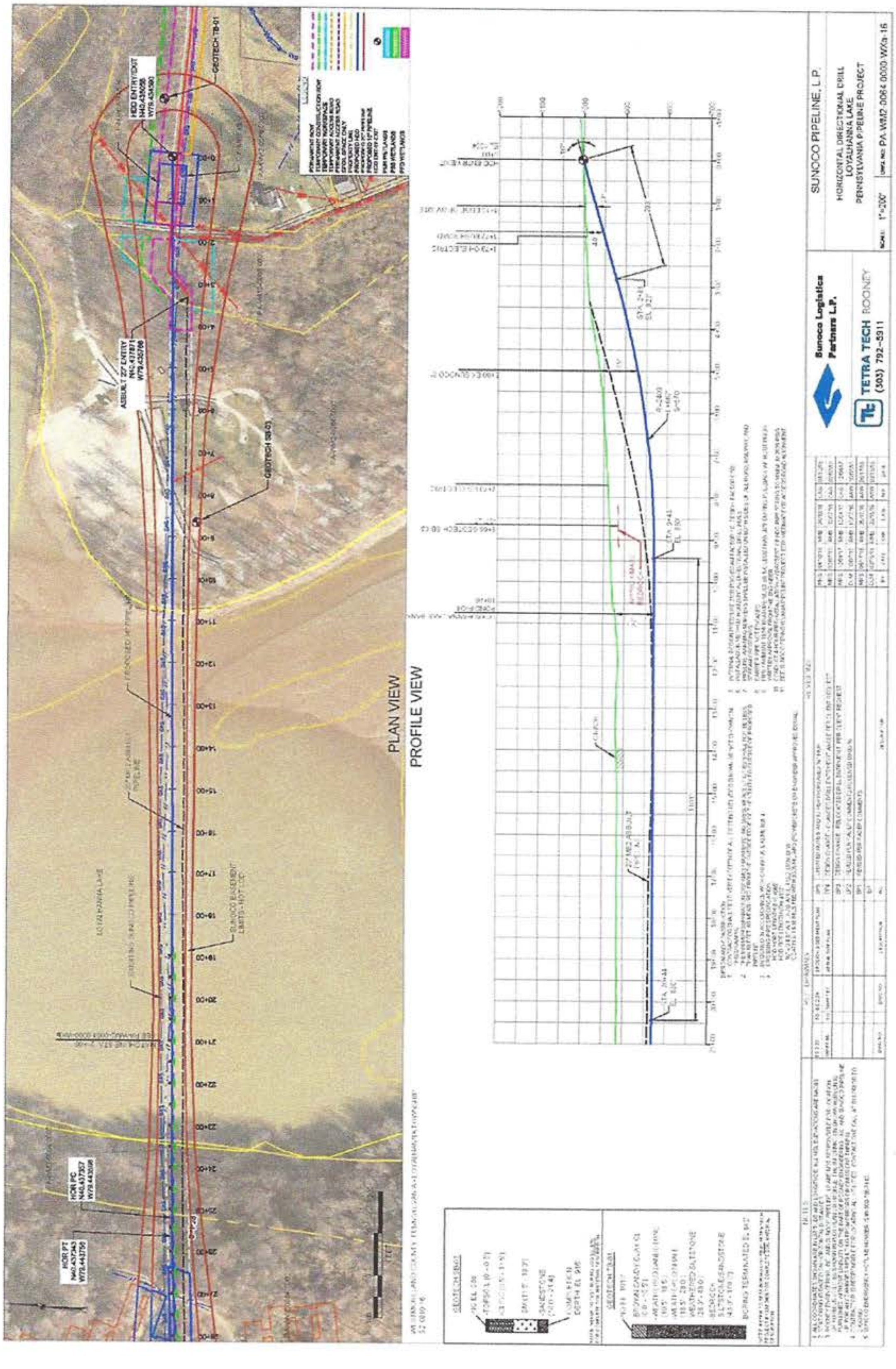
[4] ASME B31.4-2012, "Pipeline Transportation Systems for Liquids and Slurries," The American Society of Mechanical Engineers, New York, 2012.

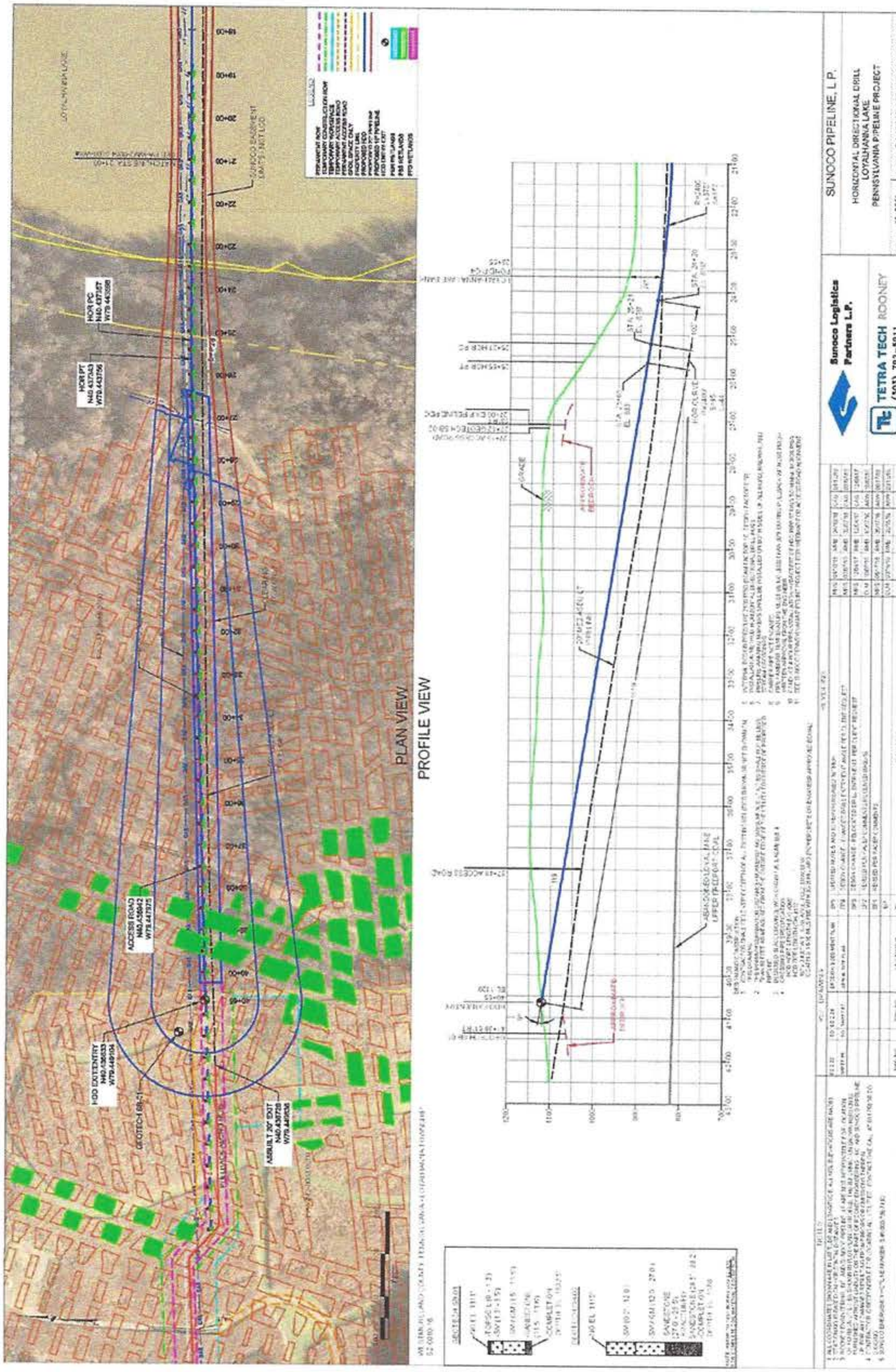
DISCLAIMER

This document presents findings and/or recommendations based on engineering services performed by employees of Kiefner and Associates, Inc. The work addressed herein has been performed according to the authors' knowledge, information, and belief in accordance with commonly accepted procedures consistent with applicable standards of practice, and is not a guaranty or warranty, either expressed or implied.

The analysis and conclusions provided in this report are for the sole use and benefit of the Client. No information or representations contained herein are for the use or benefit of any party other than the party contracting with Kiefner. The scope of use of the information presented herein is limited to the facts as presented and examined, as outlined within the body of this document. No additional representations are made as to matters not specifically addressed within this report. Any additional facts or circumstances in existence but not described or considered within this report may change the analysis, outcomes and representations made in this report.

Appendix
HDD Profile and Plan View

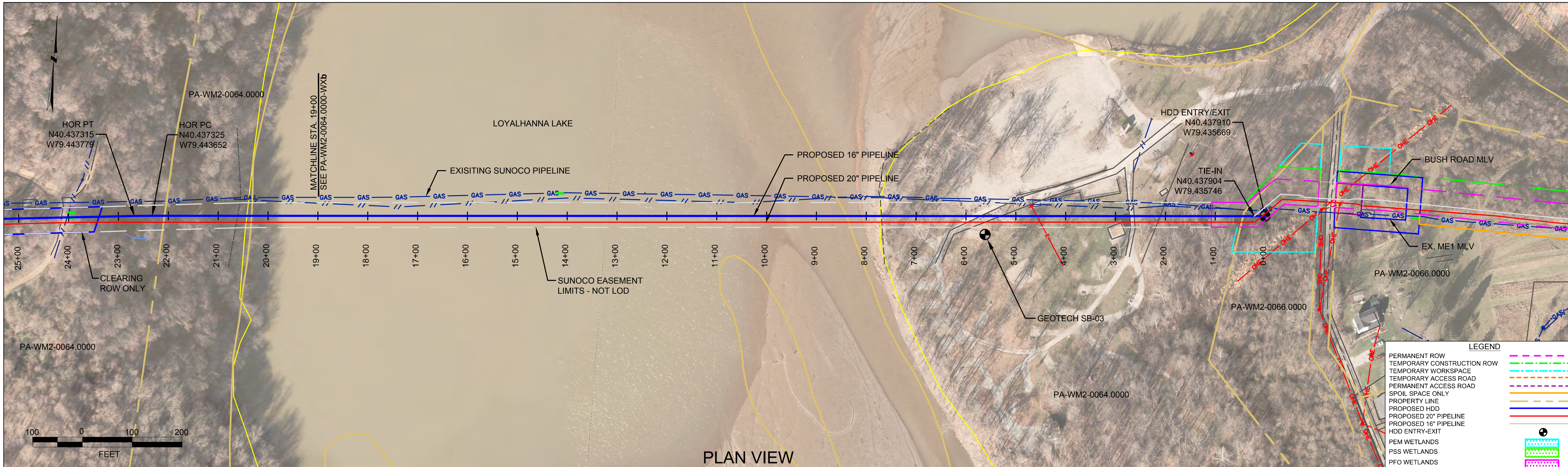

PLAN VIEW
PROFILE VIEW
SUNOCO PIPELINE, L.P.
HORIZONTAL DIRECTIONAL DRILL
LOYALHANNA LAKE
PENNSYLVANIA PIPELINE PROJECT
Sunoco Logistics Partners L.P.
TETRA TECH ROONEY
(303) 792-5911
1"=200'
PA-WM2-0064.0000-WX-16


PLAN VIEW
PROFILE VIEW
SUNOCO PIPELINE, L.P.
HORIZONTAL DIRECTIONAL DRILL
LOYALHANNA LAKE
PENNSYLVANIA PIPELINE PROJECT
Sunoco Logistics Partners L.P.
TETRA TECH ROONEY
(303) 792-5911
1"=200'
PA WMD 0064 0000 WXb-16

HORIZONTAL DIRECTIONAL DRILL ANALYSIS
LOYALHANNA LAKE CROSSING
PADEP SECTION 105 PERMIT NO.: E65-973
PA-WM2-0064.0000-WX-16
(SPLP HDD# S2-0010)

ATTACHMENT 3

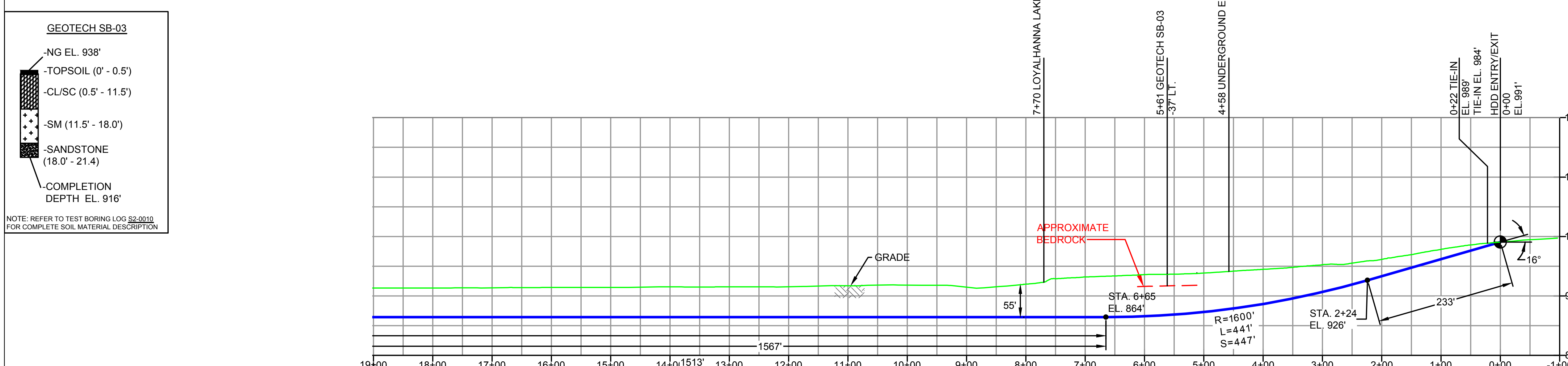
HORIZONTAL DIRECTIONAL DRILL PLAN AND PROFILES



PLAN VIEW

WESTMORELAND COUNTY, PENNSYLVANIA - LOYALHANNA TOWNSHIP
S2-0010-16

PROFILE VIEW



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=):3761'
   HDD PIPE LENGTH (S=):3799'
   16" x 0.438" W.T., X-70, API5L, PSL2, ERW, BFW
   COATING: 14-16 MILS FBE WITH 30-35 MIL ARO (POWERCRETE OR ENGINEER APPROVED EQUAL)
5. INTERNAL DESIGN PRESSURE 1480 PSIG (SEAM FACTOR 1.0, DESIGN FACTOR 0.50).
6. INSTALLATION METHOD: HORIZONTAL DIRECTIONAL DRILL (HDD).
7. PIPELINE WARNING MARKERS SHALL BE INSTALLED ON BOTH SIDES OF ALL ROAD, RAILWAY, AND STREAM CROSSINGS.
8. CARRIER PIPE NOT ENCASED.
9. PIPE / AMBIENT TEMPERATURE MUST BE NO LESS THAN 30°F DURING PULLBACK WITHOUT PRIOR WRITTEN APPROVAL FROM THE ENGINEER.
10. CONDUCT 4-HOUR PRE-INSTALLATION HYDROTEST OF HDD PIPE STRING TO MINIMUM 1850 PSIG.
11. SEE SUNOCO PENNSYLVANIA PIPELINE PROJECT ESRI WEBMAP FOR ACCESS ROAD ALIGNMENT.

Figure 1. Original 16-Inch HDD Plan and Profile

NOTES

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

REVISIONS

NO.	DESCRIPTION	BY	DATE	CHK	DATE	APP	DATE
5	DESIGN CHANGE (RELOCATED DRILL TO THE SOUTH RFI-0147)	DLM	04/18/17	RMB	04/18/17	CAG	04/18/17
4	REVISED PROFILE WITH 2017 LIDAR	MRS	03/20/17	RMB	03/20/17	CAG	03/20/17
3	REVISED PER ENGINEERING COMMENTS	MRS	08/26/16	RMB	08/26/16	AAW	08/26/16
2	MLV NAME UPDATE	DLM	04/07/16	RMB	04/07/16	AAW	04/07/16
1	ADDED "CLEARING ROW ONLY" ANNOTATION	MRS	03/24/16	RMB	03/24/16	AAW	03/24/16
0	ISSUED FOR CONSTRUCTION	MRS	12/21/15	RMB	12/21/15	AAW	12/21/15

Sunoco Logistics Partners L.P.

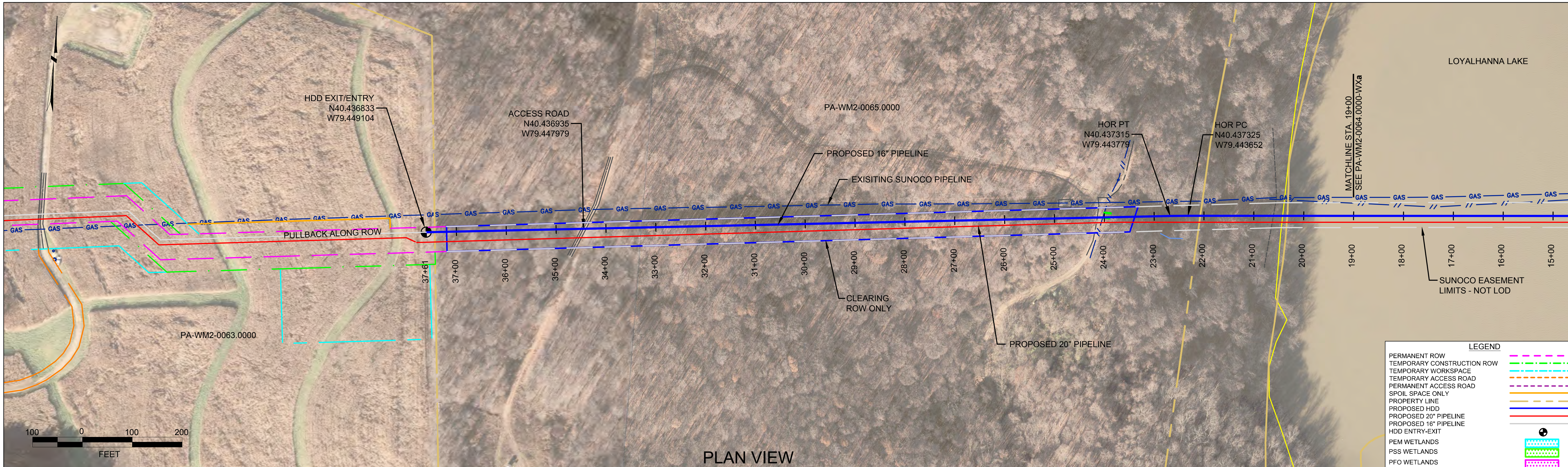
TETRA TECH ROONEY
(303) 792-5911

SUNOCO PIPELINE, L.P.

HORIZONTAL DIRECTIONAL DRILL
LOYALHANNA LAKE
PENNSYLVANIA PIPELINE PROJECT

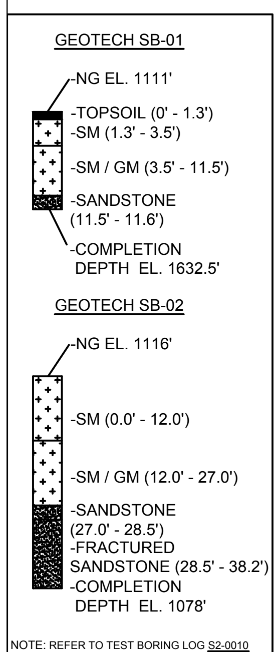
SCALE: 1"=200'
DWG. NO: PA-WM2-0064.0000-WXa-16

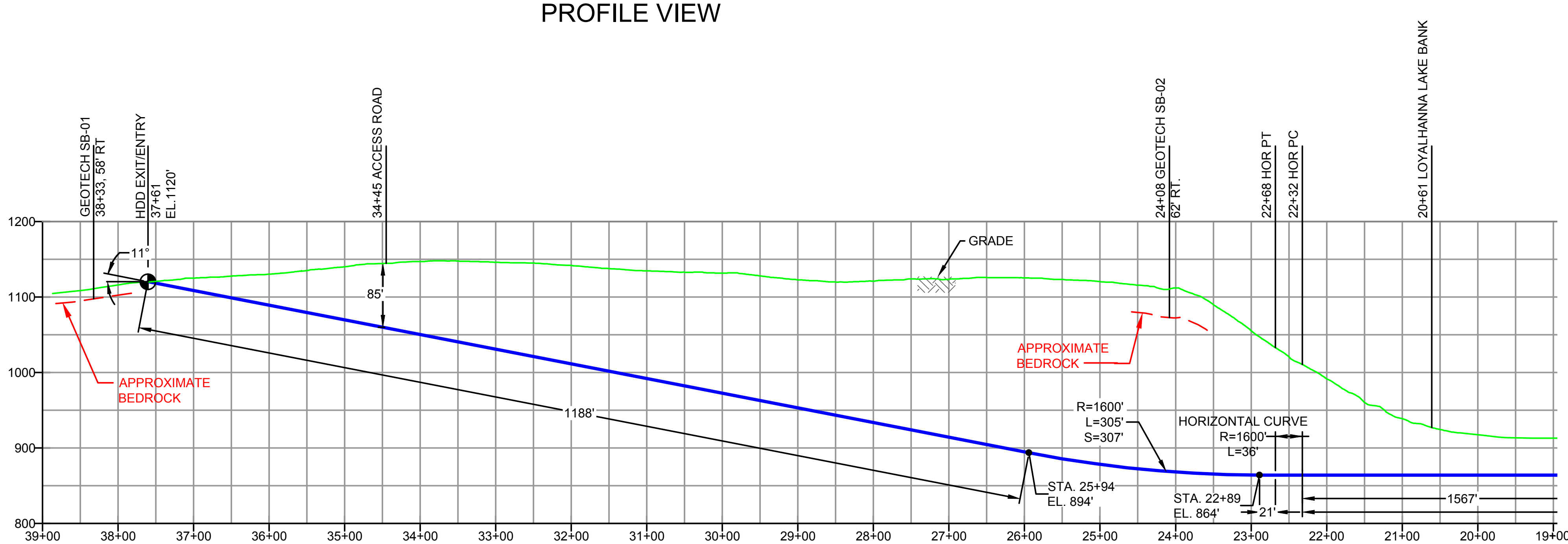
PLAN VIEW



PROFILE VIEW

WESTMORELAND COUNTY, PENNSYLVANIA - LOYALHANNA TOWNSHIP
S2-0010-16





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=):3761'
   HDD PIPE LENGTH (S=):3799'
   16" x 0.438" W.T., X-70, API5L, PSL2, ERW, BFW
   COATING: 14-16 MILS FBE WITH 30-35 MIL ARO (POWERCRETE OR ENGINEER APPROVED EQUAL)
5. INTERNAL DESIGN PRESSURE 1480 PSIG (SEAM FACTOR 1.0, DESIGH FACTOR 0.50).
6. INSTALLATION METHOD: HORIZONTAL DIRECTIONAL DRILL (HDD).
7. PIPELINE WARNING MARKERS SHALL BE INSTALLED ON BOTH SIDES OF ALL ROAD, RAILWAY, AND STREAM CROSSINGS.
8. CARRIER PIPE NOT ENCASED.
9. PIPE / AMBIENT TEMPERATURE MUST BE NO LESS THAN 30°F DURING PULLBACK WITHOUT PRIOR WRITTEN APPROVAL FROM THE ENGINEER.
10. CONDUCT 4-HOUR PRE-INSTALLATION HYDROTEST OF HDD PIPE STRING TO MINIMUM 1850 PSIG.
11. SEE SUNOCO PENNSYLVANIA PIPELINE PROJECT ESRI WEBMAP FOR ACCESS ROAD ALIGNMENT.

Figure 2. Original 16-Inch HDD Plan and Profile

NOTES

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

REVISIONS

NO.	DESCRIPTION	BY	DATE	CHK	DATE	APP	DATE
4	DESIGN CHANGE (RELOCATED DRILL TO THE SOUTH RFI-0147)	DLM	04/18/17	RMB	04/18/17	CAG	04/18/17
3	REVISED PROFILE WITH 2017 LIDAR	MRS	03/20/17	RMB	03/20/17	CAG	03/20/17
2	REVISED PER ENGINEERING COMMENTS	MRS	08/26/16	RMB	08/26/16	AAW	08/26/16
1	ADDED "CLEARING ROW ONLY" ANNOTATION	MRS	03/24/16	RMB	03/24/16	AAW	03/24/16
0	ISSUED FOR CONSTRUCTION	MRS	12/21/15	RMB	12/21/15	AAW	12/21/15

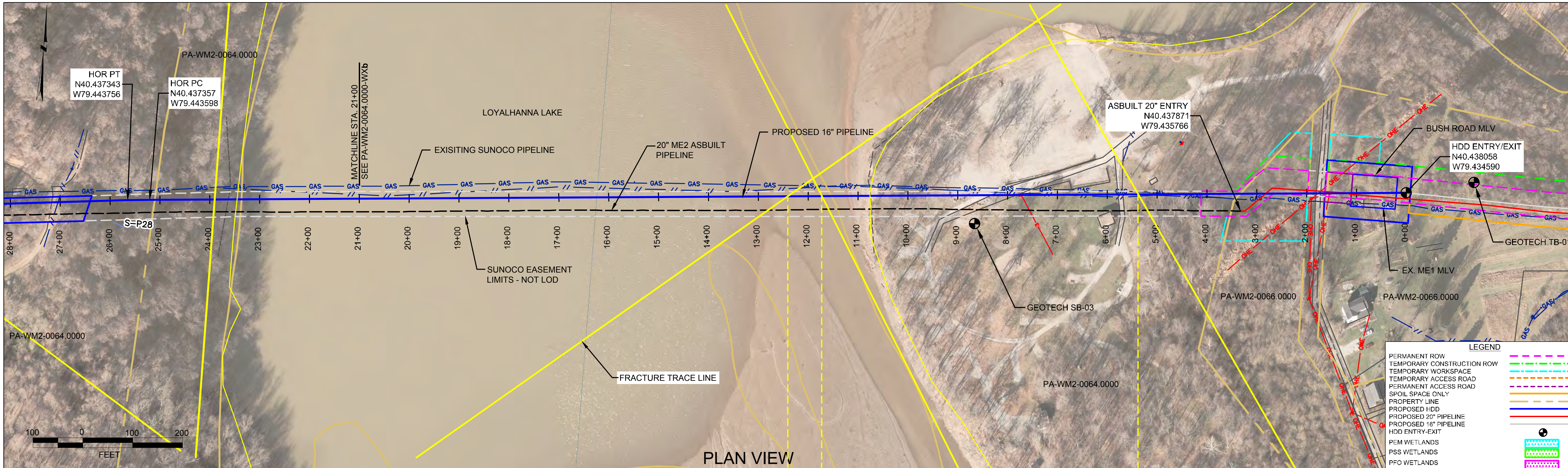
Sunoco Logistics Partners L.P.

TETRA TECH ROONEY
(303) 792-5911

SUNOCO PIPELINE, L.P.

HORIZONTAL DIRECTIONAL DRILL
LOYALHANNA LAKE
PENNSYLVANIA PIPELINE PROJECT

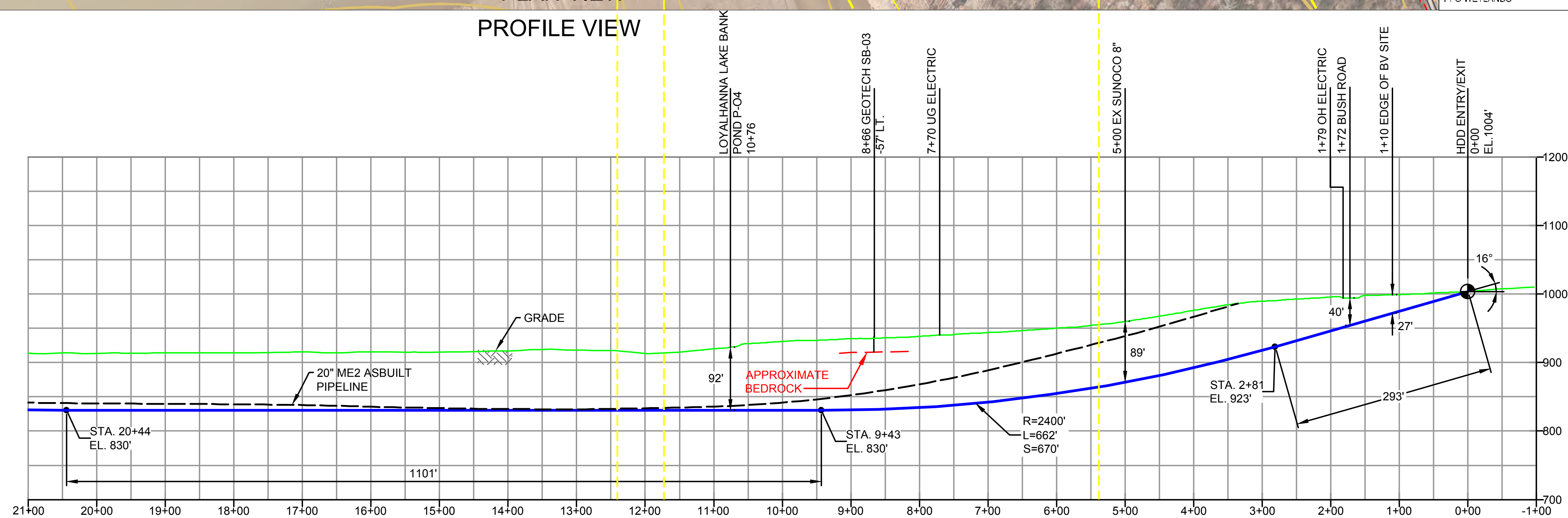
SCALE: 1"=200'   DWG. NO: PA-WM2-0064.0000-WXb-16



PLAN VIEW

WESTMORELAND COUNTY, PENNSYLVANIA - LOYALHANNA TOWNSHIP
S2-0010-16

PROFILE VIEW



GEOTECH SB-03

- NG EL. 938'
- TOPSOIL (0' - 0.5')
- CL/SC (0.5' - 11.5')
- SM (11.5' - 18.0')
- SANDSTONE (18.0' - 21.4)
- COMPLETION DEPTH EL. 916'

NOTE: REFER TO TEST BORING LOG S2-0010 FOR COMPLETE SOIL MATERIAL DESCRIPTION

GEOTECH TB-01

- NG EL. 1010'
- BROWN SANDY CLAY CL (0.0' - 10.5')
- WEATHERED SANDSTONE (10.5' - 18.5')
- WEATHERED SHALE (18.5' - 28.0')
- WEATHERED SILTSTONE (28.0' - 43.0')
- BEDROCK SILTSTONE/SANDSTONE (43.0' - 170.0')
- BORING TERMINATED EL.840'

NOTE: REFER TO TEST BORING LOG TB-01 TETRA TECH PROJECT # 103IP3406 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=):4065'
   HDD PIPE LENGTH (S=):4107'
   16" x 0.438" W.T., X-70, API5L, PSL2, ERW, BFW
   COATING: 14-16 MILS FBE WITH 30-35 MIL ARO (POWERCRETE OR ENGINEER APPROVED EQUAL)
5. INTERNAL DESIGN PRESSURE 2100 PSIG (SEAM FACTOR 1.0, DESIGH FACTOR 0.50).
6. INSTALLATION METHOD: HORIZONTAL DIRECTIONAL DRILL (HDD).
7. PIPELINE WARNING MARKERS SHALL BE INSTALLED ON BOTH SIDES OF ALL ROAD, RAILWAY, AND STREAM CROSSINGS.
8. CARRIER PIPE NOT ENCASED.
9. PIPE / AMBIENT TEMPERATURE MUST BE NO LESS THAN 30°F DURING PULLBACK WITHOUT PRIOR WRITTEN APPROVAL FROM THE ENGINEER.
10. CONDUCT 4-HOUR PRE-INSTALLATION HYDROTEST OF HDD PIPE STRING TO MINIMUM 2625 PSIG.
11. SEE SUNOCO PENNSYLVANIA PIPELINE PROJECT ESRI WEBMAP FOR ACCESS ROAD ALIGNMENT.

Figure 3. Revised 16-Inch HDD Plan and Profile

NOTES

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

REF. DRAWING

DWG NO		DWG NO	DESCRIPTION
ES-2.22	TO	ES-2.24	EROSION & SEDIMENT PLAN
SHEET 66	TO	SHEET 67	AERIAL SITE PLAN

REVISIONS

NO.	DESCRIPTION	BY	DATE	CHK	DATE	APP	DATE
EP6	ADDED FRACTURE TRACE LINES PER CLIENT REQUEST	MRS	07/24/18	RMB	07/24/18	CAG	07/24/18
EP5	UPDATED NOTE 5 AND 10 PER INCREASED 16" MOP	MRS	04/10/18	RMB	04/10/18	CAG	04/10/18
EP4	DESIGN CHANGE - CHANGED DRILL ENTRY/EXIT ANGLE PER CLIENT REQUEST	MRS	02/07/18	RMB	02/07/18	CAG	02/07/18
EP3	DESIGN CHANGE - RELOCATED DRILL ENTRY/EXIT PER CLIENT REQUEST	MRS	12/04/17	RMB	12/04/17	CAG	12/04/17
EP2	REVISED PER PADEP COMMENTS RECEIVED 09-06-16	DLM	10/07/16	RMB	10/07/16	AAW	10/07/16
EP1	REVISED PER PADEP COMMENTS	MRS	05/17/16	RMB	05/17/16	AAW	05/17/16

Sunoco Logistics Partners L.P.

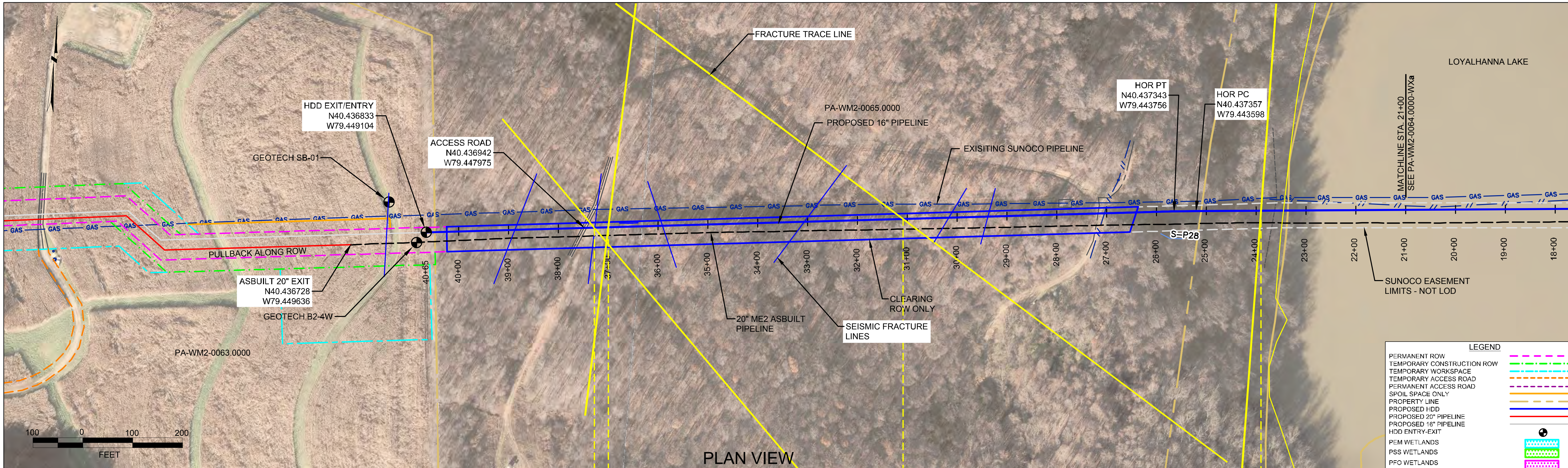
TETRA TECH ROONEY
(303) 792-5911

SUNOCO PIPELINE, L.P.

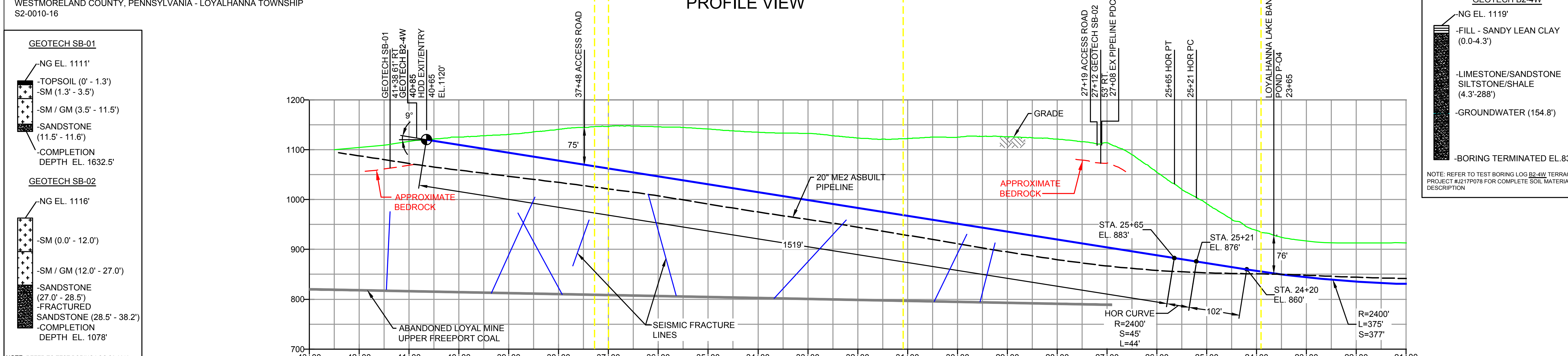
HORIZONTAL DIRECTIONAL DRILL
LOYALHANNA LAKE
PENNSYLVANIA PIPELINE PROJECT

SCALE: 1"=200'

DWG. NO. PA-WM2-0064.0000-WXa-16



WESTMORELAND COUNTY, PENNSYLVANIA - LOYALHANNA TOWNSHIP
S2-0010-16



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=):4065'
   HDD PIPE LENGTH (S=):4107'
   16" x 0.438" W.T., X-70, API5L, PSL2, ERW, BFW
   COATING: 14-16 MILS FBE WITH 30-35 MIL ARO (POWERCRETE OR ENGINEER APPROVED EQUAL)
5. INTERNAL DESIGN PRESSURE 2100 PSIG (SEAM FACTOR 1.0, DESIGH FACTOR 0.50).
6. INSTALLATION METHOD: HORIZONTAL DIRECTIONAL DRILL (HDD).
7. PIPELINE WARNING MARKERS SHALL BE INSTALLED ON BOTH SIDES OF ALL ROAD, RAILWAY, AND STREAM CROSSINGS.
8. CARRIER PIPE NOT ENCASED.
9. PIPE / AMBIENT TEMPERATURE MUST BE NO LESS THAN 30°F DURING PULLBACK WITHOUT PRIOR WRITTEN APPROVAL FROM THE ENGINEER.
10. CONDUCT 4-HOUR PRE-INSTALLATION HYDROTEST OF HDD PIPE STRING TO MINIMUM 2625 PSIG.
11. SEE SUNOCO PENNSYLVANIA PIPELINE PROJECT ESRI WEBMAP FOR ACCESS ROAD ALIGNMENT.

Figure 4. Revised 16-Inch HDD Plan and Profile

NOTES

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

REF. DRAWING

DWG NO		DWG NO	DESCRIPTION
ES-2.22	TO	ES-2.24	EROSION & SEDIMENT PLAN
SHEET 66	TO	SHEET 67	AERIAL SITE PLAN

REVISIONS

NO.	DESCRIPTION	BY	DATE	CHK	DATE	APP	DATE
EP6	ADDED FRACTURE TRACE LINES PER CLIENT REQUEST	MRS	07/24/18	RMB	07/24/18	CAG	07/24/18
EP5	UPDATED NOTE 5 AND 10 PER INCREASED 16" MOP	MRS	04/10/18	RMB	04/10/18	CAG	04/10/18
EP4	DESIGN CHANGE - CHANGED DRILL ENTRY/EXIT ANGLE PER CLIENT REQUEST	MRS	02/07/18	RMB	02/07/18	CAG	02/07/18
EP3	DESIGN CHANGE - RELOCATED DRILL ENTRY/EXIT PER CLIENT REQUEST	MRS	12/04/17	RMB	12/04/17	CAG	12/04/17
EP2	REVISED PER PADEP COMMENTS RECEIVED 09-06-16	DLM	10/07/16	RMB	10/07/16	AAW	10/07/16
EP1	REVISED PER PADEP COMMENTS	MRS	05/17/16	RMB	05/17/16	AAW	05/17/16

Sunoco Logistics Partners L.P.

TETRA TECH ROONEY
(303) 792-5911

SUNOCO PIPELINE, L.P.

HORIZONTAL DIRECTIONAL DRILL
LOYALHANNA LAKE
PENNSYLVANIA PIPELINE PROJECT

SCALE: 1"=200'
DWG. NO. PA-WM2-0064.0000-WXb-16

HORIZONTAL DIRECTIONAL DRILL ANALYSIS
LOYALHANNA LAKE CROSSING
PADEP SECTION 105 PERMIT NO.: E65-973
PA-WM2-0064.0000-WX-16
(SPLP HDD No. S2-0010)

This reanalysis of the horizontal directional drill (HDD) installation of a 16-inch diameter pipeline under Loyalhanna Lake in Loyalhanna Township, Westmoreland 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 1 on the list of HDDs included on Exhibit 3 of the Order.

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

The 16-inch pipeline HDD is referred to herein as HDD S2-0010.

PIPE INFORMATION

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

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

ORIGINAL HORIZONTAL DIRECTIONAL DRILL DESIGN SUMMARY: 16-INCH

- Horizontal length: 3,761 feet (ft)
- Entry/Exit angle: 11-16 degrees
- Maximum depth of cover (east side): 75 ft
- Maximum depth of cover under Loyalhanna Lake: 55 ft
- Pipe design radius: 1,600 ft

GEOLOGIC AND HYDROGEOLOGIC ANALYSIS

HDD S2-0010 is located within the Pittsburgh Low Plateau Section of the Appalachian Plateaus Physiographic Province. The Pittsburgh Low Plateau Section consists of smooth to irregular, undulating surfaces; narrow, relatively shallow valleys with strip mines and reclaimed mine lands. Bedrock in the area of HDD S2-0010 belongs to the Pennsylvanian age Glenshaw Formation, part of the Conemaugh Group. The Glenshaw Formation consists of repeated sequences of sandstone, siltstone, shale, claystone (including red beds), limestone, and coal. The coal beds in the Glenshaw Formation are sporadically mined. The base of the Upper Freeport coal occurs from approximate elevation 790 to 820 ft amsl beneath the western portion of the profile and historically has been economically significant coal bed in the area (Skema, 1988). Shale is the primary rock type. Bedrock dip at HDD S2-0010 is gently to the southeast. Discontinuities in the form of joints, fractures, and faults are imprinted in the broadly folded bedrock in the region. These fractures and bedding plane partings can act as conduits for groundwater movement and/or represent areas of weakness in the rock.

Fracture trace analysis using high altitude aerial photography was performed in the vicinity of HDD S2-0010 to identify potential zones of bedrock weakness along drill paths. Seven fracture traces intersect the HDD alignment. 3D Seismic data provided further information on potential fractures present in the west half of this HDD. This information has been incorporated into the new drilling profile data and will be utilized by the driller and monitoring Professional Geologists (PG) during implementation of this HDD to assess for the implementation of corrective actions if Loss of Circulation (LOC) is documented when drilling activities intersect these zones.

Karst geology is not present at this HDD location; although limestone was observed in recent geotechnical borings, karst conditions are not anticipated because limestones within the Glenshaw Formation are thinly interbedded and the development of karst features is not characteristic for these limestones.

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

Coal Mining and Subsidence

An abandoned Upper Freeport coal mine exits below the HDD alignment west of Loyalhanna Lake. The Seanor Mining Corporation operated the Loyal underground mine in the 1950's. Their primary mining method was room and pillar mining. A mining height of four and a half feet (4.5) was assumed based on information from the mine maps. No mining was conducted directly under the eastern portion of the HDD, under Loyalhanna Lake, or under the lake's western shoreline. From east to west on the HDD Plan and Profile, the Upper Freeport seam was mined from Station 27+00 to the western extent of the HDD at Station 40+65, an approximate distance of 1,365 feet under the HDD. The depth of the coal from land surface is about 330 feet at Station 27+00 and about 300 feet at Station 40+65. The redesigned HDD profile lies about 110 feet above the coal seam at Station 27+00. From Station 27+00 the boring ascends upward for 1,365 feet until it reaches the surface at the western entry/exit point. At the surface exit location, the boring would be about 300 feet above the coal seam.

Mine Pools

The roof of the abandoned Loyal Mine under the bluff west of Loyalhanna Lake varies in elevation from a low at the east edge of the mine of approximately 790 ft amsl to a high of approximately 820 ft amsl under the western entry/exit of the HDD. The mine does not continue under Loyalhanna Lake or east of Loyalhanna Lake along the HDD. The proposed profile for the 16-inch line is at approximately 900 ft amsl, 110 feet above the eastern edge of the mine and rises moving west to exit at the surface at approximately 1,120 ft amsl, approximately 300 feet above the mine.

The area that is mined and over which the HDD is proposed, is a bluff surrounded by the lake on the north, east and south, and by Serviceberry Run to the west. The USACE controls the lake level and USGS lake stage records for the Loyalhanna Lake dam from 2007 to July 2018 show lake stage varied from a minimum level of approximately 917 to a maximum level of about 954 ft amsl, with a mean of 924 ft amsl, and a mode of 923 ft amsl. When the lake stage is at its maximum, surface water surrounds the bluff on nearly all sides. As lake stage is managed, local groundwater flow gradient will vary from radially outward from the bluff, to relatively flat, to radially inward. Steep water table gradients, both inward and outward, may occur proximal to shorelines as lake stage goes up and down. Geotechnical boring B2-4W was drilled from a location near the west entry/exit for the HDD. This boring was drilled 288 feet deep and is thought to have entered the caved zone above the mine. A water level measured in the boring after the drilling was completed was approximately 854 ft amsl (33 feet above the estimated elevation of the mine roof). If this measurement is representative of the water table elevation under the interior of the bluff, it is lower than the stage of Loyalhanna Lake, predicting inward radial groundwater flow, above the mine.

It is not known whether the groundwater quality in the water table aquifer over the mine within the bluff has been affected by contact with the open mine. Based on the water level measurement from boring B2-4W and range of possible lake stage elevations, the water table surface appears to be maintained above the mine without an upward vertical flow gradient moving groundwater through the mine into higher portions of the bedrock aquifer. Bedrock in the area is on the southeast limb of an anticline and the local bedrock is not subject to the type of mine pool development that sometimes occurs from upward flow through a mine within a synclinal basin.

If the lake stage is representative of the mine pool elevation, the geometry of the revised profile would not create a new mine pool discharge. The limits for the bottom and top of the pool would be from the lowest elevation of the mine (790 feet amsl) to the highest lake stage (955 ft amsl). The revised profile passes through this zone from Station 26+90 to 30+40; however, entry/exit points are at elevation 1,120 ft and 1,004 feet for the west and east entry/exit point, respectively.

If a Loss of Circulation (LOC) from the HDD loses drilling fluid to the water table aquifer that overlies the mine it is not likely that the additional recharge will affect the local water table elevation as the control of that elevation would be largely influenced by the head boundary established by the stage of the lake, surrounding the bluff. During low lake elevation stages, local water table gradients may be steep towards the lake and a heightened level of inspection is recommended to prevent a large volume LOC and/or an IR from entering a surface water.

Subsidence Potential

TetraTech mine engineers have completed a study of the current conditions of the Loyal Mine and overlying geology in this section of the proposed pipeline installation. As presented and discussed in the TetraTech report provided as Attachment 2 of the Reevaluation Report, the mine maps are generally a reliable indication of the extent of what was mined. Tetra Tech employed 3D seismic technology combined with existing profile depth geotechnical cores to gain a better understanding of the strata fracturing and anomalies at mine level.

Subsidence modeling of the Loyal Mine was conducted using a base coal strength of 900 pounds per square inch (psi) to simulate the strength of the coal at the time of mining. Subsequently, a coal strength of 750 psi was modeled to simulate the coal strength after the mine pillars degrade over time.

There are two primary areas of potential future subsidence. One area is centered at Station 30+00 and occurs within an area of high production room mining that was not completely retreat mined based on the interpretation of the 3D seismic data. The increased subsidence at this location was estimated to be about 0.25 foot (3.0 inches). The second area of increased subsidence occurs near where the HDD exits to the surface at around Station 40+00. This area was also interpreted from the 3D seismic data as to not have been completely collapsed. This area is also in a high production room area and extends into a portion of an area where the mine maps showed pillar removal. The estimated additional subsidence at this area is estimated to be about 1.55 feet (18.6 inches).

Based upon the data obtained from the subsidence analysis, SPLP contracted Keifner and Associates, Inc. to perform a Finite Elements Analysis (FEA, or pipe stress analysis) of the potential future stress on the pipeline installation. Based upon the results of the FEA analysis, the pipeline engineers have concluded that the potential stress on the pipeline from further subsidence will not exceed allowable limits as established by ASME B31.4-2012, *(Pipeline Transportation Systems for Liquids and Slurries, The American Society of Mechanical Engineers, New York, 2012).* The findings by the pipeline engineers is included within the TetraTech report provided in Attachment 2.

HYDROGEOLOGY, GROUNDWATER, AND WELL PRODUCTION ZONES

Most groundwater in the HDD S2-0010 area occurs and moves within a fractured bedrock aquifer. Groundwater occurs within the secondary porosity created by fractures and bedding plan partings. Given that the area surrounding Loyalhanna Lake is a groundwater discharge zone, the water table is shallow at some locations near the lake and occupies unconsolidated alluvium associated with Loyalhanna Lake and the former Loyalhanna Creek stream channel.

Although groundwater was not encountered or measured in geotechnical borings, the Pennsylvania Groundwater Information System (PaGWIS) reported one well, 5,460 ft north of the HDD S2-0010 western entry/exit. This domestic well (PaWellID 648252) is completed to 180 ft below ground surface (bgs) within bedrock. Static water was reported at 45 ft bgs and the well yield was reported at 4 gallons per minute (gpm). Based on the results of a PaGWIS database search, yields from wells drilled into the Glenshaw Formation and within two miles of HDD S2-0010 range from 1.5 to 10 gpm.

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

INADVERTENT RETURN (IR) DISCUSSION

No IRs were reported along the alignment of the HDD S2-0010 drill on the list of IRs for the Mariner East 1 (ME I) Project, as documented in the IR PPC Plan for Westmoreland County. In general, the HDD S2-0010 IRs and other IRs on the ME II Project located in the Glenshaw Formation have been related to shallow overburden, coarse grained unconsolidated materials near the surface (such as alluvium and mine spoil), large elevation changes between entry/exits and the lowest elevation points along the profiles (sometimes creating soil plugs, elevated annular pressures, and loss of fluids), and the interconnectivity of open bedrock structural features that is difficult to predict.

On May 14, 2017, the second day of drilling for the pilot hole drilling of the ME II HDD for the 20-inch diameter pipeline at HDD S2-0010, returns were lost when the pilot bit was 228 ft west of the eastern exit/entry point. The loss of returns appeared as IRs at multiple locations along the eastern shore of the lake. Minor volumes of drilling fluid appeared in the tributary north of the alignment and in Loyalhanna Lake along the eastern shoreline, and were rapidly managed and cleaned up. On June 8, 2017, a vertical relief bore (relief well) was installed and began to capture the drilling fluids and lost returns and the IRs ceased**.** IRs occurring after June 9, 2017, were due to fluid pressures built up in the HDD borehole between the relief well 250 ft down slope of the east entry. On occasion, short-term high flow events occurred at the relief well after periods of very low flow during reamer passes. At these times, cuttings were not being efficiently removed from the borehole due to the vertical movement of the return fluids and effect of gravity on the cuttings, causing the borehole to plug from cuttings build up within the borehole annulus below the location of the relief well. Operation of the relief well resulted in nearly continuous loss of returns at the HDD entry/exit pits until the pipe was pulled into place on July 20, 2017. Fluids and cuttings recovered at the relief well were captured and either cycled to the mud pit at the east entry/exit or managed as residual waste.

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

The occurrence of the IR events during the installation of the 20-inch diameter pipeline under Loyalhanna Lake resulted from the proximity of the entry point to a falling away slope that paralleled the land surface, and resulting shallow depth of cover on the HDD entry radius, while proceeding through fractured sandstone bedrock in the upper 50 ft of the profile.

HORIZONTAL DIRECTIONAL DRILL ANALYSIS
LOYALHANNA LAKE CROSSING
PADEP SECTION 105 PERMIT NO.: E65-973
PA-WM2-0064.0000-WX-16
(SPLP HDD No. S2-0010)

ADJACENT FEATURES ANALYSIS

The crossing of Loyalhanna Lake is located in Westmoreland County, approximately 6.8 miles east of the community of Delmont, and approximately 2.8 miles north/northwest of New Alexandria, Pennsylvania.

The pipeline alignment for HDD S2-0010 spans Loyalhanna Lake from east of Bush Road to a bluff approximately 1,700 ft west of the western shoreline, in Loyalhanna Township, Westmoreland County, Pennsylvania

This HDD location is set under Loyalhanna Lake for one-third of its length, with forested woodlands adjacent to its western entry/exit point and the United States Army Corps of Engineer (USACE) Bush Recreation Area and forested woodlands at its eastern exit/entry point. This HDD avoids surficial impacts to stream S-P28 and Loyalhanna Lake, neither of which are designated as high quality or exceptional value, and surficial impacts to the floodways of stream S-P28 and Loyalhanna Lake, a Federal Emergency Management Agency (FEMA) 100-year floodplain (Chapter 106 area), and underground utilities (gas line and electric line), parallel to and crossing perpendicular to the easement.

SPLP performed a preconstruction survey of landowners within 450 ft and greater from the HDD S2-0010 alignment. Four landowners responded positively to an offer to have their wells tested. Well depth information was provided by the property owner for well WL-10242016-520-01 located approximately 321 ft from the HDD S2-0010 alignment (95 ft below ground surface [bgs]) and for well WL-04272017-499-02 located approximately 396 ft from the alignment (400 ft bgs). Comparing these estimated production zone depth intervals to the elevation of the revised 16-inch diameter HDD S2-0010 profile indicates the upper portions of the production intervals could intersect the elevation of the profile, keeping in mind these wells are located approximately 321 ft and 396 ft horizontally from the HDD profile.

All four wells are plotted on Figure 4 of the GES report in Attachment 1 and were previously sampled in association with the IRs that occurred on the eastern shore during the installation of the 20-inch diameter pipeline. The owner of well WL-08172017-499-01 has been provided a temporary water supply since this water supply was affected by drilling fluid during the installation of the 20-inch diameter pipeline. This temporary supply will be maintained throughout completion of the HDD S2-0010 16-inch diameter pipeline. No other property owners within the 450-ft area have accepted SPLP’s offer to provide temporary water during installation of the 16-inch diameter pipeline.

ALTERNATIVES ANALYSIS

The HDD as permitted is an alternative plan of installation to a conventional open trench construction plan. During the PADEP Chapter 105 permit process for the Pennsylvania Pipeline Project, SPLP created and submitted for review a project-wide alternatives analysis. The baseline route provided for the pipeline construction to cross every wetland and stream on the project by open trench construction procedures. The alternatives analysis submitted to PADEP conceptually analyzed the feasibility of any alternative to trenched resource crossings (e.g., reroute, bore, HDD). The decision making processes for changing from an open cut to HDD is discussed thoroughly in the submitted alternatives analysis and was an important part of the overall PADEP approval of HDD plans as currently permitted. Where HDDs are planned and received PADEP Chapter 105 and 102 authorizations, they have already been evaluated to be the preferred alternative based on several variables that led SPLP and PADEP to believe there would be less impacts on the environment in general, and aquatic and upland natural resources specifically, if these resources were drilled rather than trenched.

Using the HDD method for this crossing avoids direct impacts to two streams/waterbodies, Loyalhanna Lake and stream S-P28, their associated floodways, associated forested woodlands and riparian habitats, a public recreation area, infrastructure associated with the public recreation area, and existing underground utility lines. Therefore, alteration of the current permitted route and plans for installation would result in additional direct impacts to aquatic resources and require major modifications of the state Chapter 102 and Chapter 105 permits, and Section 404, Section 408, and easement authorizations, and associated National Environmental Policy Act (NEPA) Environmental Assessment and Finding of No Significant Impact (FONSI) issued by the USACE.

Open-cut and Conventional Bore Analysis

The pipeline route follows parallel to an existing SPLP pipeline easement. 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, construction through stream S-P28 and Loyalhanna Lake would require a minimum authorized open cut work space 75 ft in width in Stream S-P28 and 150-ft of width across Loyalhanna Lake to accommodate the 16-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 4.19 acres of state water bottoms, 0.015 acre of associated floodways, approximately 1.25 acres of a FEMA 100-year floodplain (Chapter 106 area), and 3.75 acres of a public recreation area.

An open cut crossing method in Loyalhanna Lake would not be able to avoid creating temporary water quality impacts due to the size and perennial nature of Loyalhanna Lake. Trench excavation at this depth would most likely involve the use of a clam shell dragline excavator, in open/flowing water, surrounded by silt curtain to minimize the area affected by temporary suspension of sediment. A significant volume of surface water (and produced groundwater) would be expected to fill all excavations during the open trench process. These water volumes would be too large to isolate and/or pump to a discharge filtration structure. Therefore, the resulting suspended lake substrates and cloudy water would be generated for the entire duration of this crossing until completion. This would represent a temporary impact on water quality and would also impact the recreational use of the Bush Recreation Area as a result of land and water disturbance, construction noise, reduced aesthetic quality (presence of construction equipment/activities and turbid water), and restricted public access during construction activities.

Conventional auger bore is technically limited to less than 200 linear ft at a time varying by the underlying substrate. The Loyalhanna Lake S2-0010 HDD profile spans more than 4,000 ft at this location. Due to the width and depth of Loyalhanna Lake at the location of this HDD, and adjacent topography there are no subset locations within this length of area to feasibly employ this type of installation method.

At a crossing distance of 1,289 ft the extent of the lake crossing is also beyond the technical limits of FlexBor technology given site limitations. Although theoretically a FlexBor pilot could complete the crossing distance, the location topography necessitates an entry pit inside the Bush Recreation Area, which results in the receiving side and pipe pull side being into the face of a steep topographic bluff, which prevents pull back of the product pipeline.

Re-Route Analysis

The pipeline route as currently permitted follows an existing SPLP easement and this HDD avoids impacts to forested woodlands that provide a buffer along the western and eastern shoreline of Loyalhanna Lake. This alignment bypasses or avoids direct impacts to forested woodlands, Loyalhanna Lake, one stream, floodways, a FEMA 100-year floodplain (Chapter 106 area), and a public recreation area.

No practicable re-route option lies to the north or south of the proposed route that would not transect Loyalhanna Lake and the same forested woodlands, floodways, and FEMA 100-year floodplain (Chapter 106 area) transected by the proposed route. If the pipeline route were shifted to the north to follow an existing utility corridor that also crosses Loyalhanna Lake, it would have additional direct effects on several existing residences and associated residential infrastructure, including underground utilities. Any considered reroute to the south in the vicinity of this HDD would be a new utility corridor requiring consent of newly-affected landowners or the use of eminent domain/condemnation, and would create a new land encumbrance on every private property crossed. Additionally, a reroute to the south would result in new “greenfield” corridor through existing forested woodlands along the western and eastern shorelines of Loyalhanna Lake. 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 environmental resources.

In summary, due to the woodlands along the western and eastern shorelines of Loyalhanna Lake to the north and south of the proposed HDD, additional direct effects to several residences and infrastructure for a shift to the north, and creation of a new “greenfield” corridor for any shift 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 S2-0010.

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

HORIZONTAL DIRECTIONAL DRILL REDESIGN

Additional geologic investigations have been completed and observations of the 20-inch pipeline installation have been utilized in the redesign of the planned HDD. This information and observations have been used to adjust the HDD S2-0010 profile. A summary of the redesign factors is provided below.

Revised Horizontal Directional Drill Design Summary: 16-inch

- Horizontal length: 4,065 ft
- Entry/Exit angle: 9-16 degrees
- Maximum Depth of cover (east side): 100 ft
- Maximum depth of cover under Loyalhanna Lake: 90 ft
- Pipe design radius: 2,400 ft

It is SPLP’s intent to modify the original permitted profile design and to pursue a deeper and longer HDD profile. As shown on the HDD Plan and Profiles in Attachment 3, the revised profile eastern entry/exit location is moved approximately 304 ft to the east. At the IR risk portion of the profile (as discussed in the IR section) the HDD has been deepened by approximately 59 to 73 feet. The depth below the lake has been increased by 35 ft. The location of the western entry/exit was not changed; however the entry adjustment extends the overall length of this HDD to 4,065 ft.

Figures 1 and 2 in Attachment 3 presents the original HDD plan and profile. Figures 3 and 4 present the revised HDD plan and profiles.

CONCLUSION

Based on the original and revised profiles for HDD S2-0010, the revised profile for HDD S2-0010 is longer, goes deeper into bedrock, and is deeper beneath Loyalhanna Lake and the eastern shoreline than the original profile. As such, the revised profile represents a greatly reduced risk of creating one or more IRs, similar to those that occurred during installation of the 20-inch diameter pipeline. Procedures established and documented in SPLP’s revised IR Assessment, Preparedness, Prevention, and Contingency (PPC) Plan (rev. February 7, 2018) across all ME II spreads have proven to be very effective in eliminating IRs or minimizing the extent of IRs.

HORIZONTAL DIRECTIONAL DRILL ANALYSIS
LOYALHANNA LAKE CROSSING
PADEP SECTION 105 PERMIT NO.: E65-973
PA-WM2-0064.0000-WX-16
(SPLP HDD# S2-0010)

Given the geotechnical boring information, fracture trace mapping, and mine subsidence fracturing derived from 3-D seismic data, the drilling best management practices for HDD S2-0010 addresses the appropriate measures required for drilling through zones of variable bedrock strength, especially through the zones indicated by the fracture traces.

The redesign of the HDD will not prevent all IRs. IR's 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, Sunoco will employ the following HDD best management practices:

- SPLP will provide the drilling crew and company inspectors (UI, EI, PGs) 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 and 3D seismic along the drill path, so that monitoring can be enhanced when drilling through these locations.

- Based upon the behavior of the soil overburden and near subsurface geology during the entry of the pilot phase, the initial pilot will be injected with an LCM pill to close off fracturing within the known depth of weak sandstone bedrock. If the LCM fails to provide adequate control, then casing of the pilot hole will be implemented to control IRs.

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

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

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

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

- During all drilling phases, the use of Loss Control Materials (LCMs) can be implemented if indications of a potential IR are noted or an IR is observed; and

- If LCMs prove ineffective to mitigate loss of returns or IRs, then grouting of the pilot hole may be implemented.

FEASIBILITY DETERMINATION

Based on the information reviewed by the HDD Reevaluation Team, consisting of the Geotechnical Evaluation Leader, Professional Geologists, Professional Engineers, and HDD Specialists, it is the HDD Reevaluation Team's professional opinion that the proposed HDD design and implementation of the management measures contained within this re-revaluation report will minimize the risk of IRs and impacts to public and private water supplies during the construction phases of the HDD.

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

Larry J. Gremminger, CWB
Geotechnical Evaluation Leader
Mariner East II Pipeline Project

8-17-2018
Date

Pertaining to the practice of geology as set forth in the attached Hydrogeologic Reevaluation Report

Richard T. Wardrop, P.G.
License No. PG-000157-G
Groundwater & Environmental Services, Inc.
Lead Hydrogeologist

8/17/2018
Date

COMMONWEALTH OF PENNSYLVANIA
REGISTERED PROFESSIONAL
RICHARD T. WARDROP
GEOLOGIST
PG-000157-G

Pertaining to Pipe Stress and HDD Geometry

Jeffrey A. Lowy, P.E
License No. PE 082759
Rooney Engineering, Inc.
Civil Engineer

8/17/2018
Date

COMMONWEALTH OF PENNSYLVANIA
REGISTERED PROFESSIONAL
JEFFREY A. LOWY
ENGINEER
PE082759
8/17/18

Pertaining to Horizontal Directional Drilling Practices

Douglas R. Steen
Directional Project Support, Inc.
HDD Specialist

8/17/2018
Date

HORIZONTAL DIRECTIONAL DRILL ANALYSIS
LOYALHANNA LAKE CROSSING
PADEP SECTION 105 PERMIT NO.: E65-973
PA-WM2-0064.0000-WX-16
(SPLP HDD# S2-0010)

ATTACHMENT 1

GEOLOGY AND HYDROGEOLOGICAL EVALUATION REPORT

HDD HYDROGEOLOGIC REEVALUATION REPORT

Mariner East II
Spread 2
HDD S2-0010-16
Loyalhanna Lake
Loyalhanna Township, Westmoreland County, Pennsylvania

Prepared for:

Sunoco Pipeline L.P.

Prepared by:

Groundwater & Environmental Services, Inc.
440 Creamery Way, Suite 500
Exton, Pennsylvania 19341

August 2018

HDD HYDROGEOLOGIC REEVALUTION REPORT

Mariner East II
Spread 2
HDD S2-0010-16
Loyalhanna Lake
Loyalhanna Township, Westmoreland County, Pennsylvania

August 2018

Prepared for:

Sunoco Pipeline L.P.
525 Fritztown Road
Sinking Spring, Pennsylvania 19608

Prepared by:

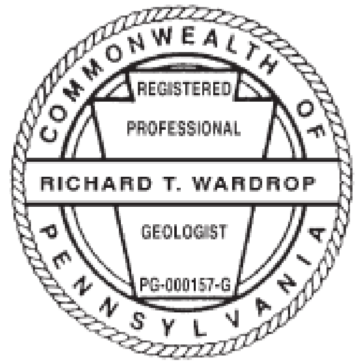
Joseph A. Maule, P.G.
Principal Hydrogeologist

Reviewed by:

Richard T. Wardrop, P.G.
Lead Hydrogeologist

Groundwater & Environmental Services, Inc.
440 Creamery Way, Suite 500
Exton, Pennsylvania 19341
(610) 458-1077

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.



August 16, 2018

Richard T. Wardrop, P. G. — Date

Lic. No. PG000157G

TABLE OF CONTENTS

1.0 INTRODUCTION 1
2.0 HDD GEOLOGY / HYDROGEOLOGY 3
2.1 Physiography 3
2.1.1 Topography 3
2.1.2 Hydrology 3
2.2 Geology 3
2.2.1 Soils 3
2.2.2 Bedrock Lithology 4
2.2.3 Structure 4
2.2.4 Fracture Trace Analysis 4
2.2.5 Karst Terrain 4
2.2.6 Mining 5
2.2.7 Rock Engineering Properties 6
2.2.8 Results of Geotechnical Borings 6
2.3 Hydrogeology 8
2.3.1 Occurrence of Groundwater 8
2.3.2 Ground Elevation Between HDD Entry/Exits 8
2.3.3 Water Level 8
2.3.4 Well Yields 9
2.3.5 450-foot Water Source Survey 9
2.3.6 Mine Pool 10
2.4 Summary of Geophysical Studies 11
3.0 OBSERVATIONS TO DATE 12
3.1 On This HDD Alignment 12
3.1.1 ME I 12
3.1.2 ME II 12
3.2 On Other HDD Alignments in Similar Hydrogeologic Settings 14
3.2.1 ME I 14
3.2.2 ME II 14
4.0 SUMMARY AND CONCLUSIONS 15
4.1 HDD Site Conceptual Model 15
4.2 Conclusions and Recommendations 16
5.0 REFERENCES 17

FIGURES

Figure 1. Site Location Map
Figure 2. Site Geology Map and Structure Contour Map of the Pittsburgh Coal
Figure 3. Location of Abandoned Upper Freeport Coal Mine and HDD S2-0010-16 Alignment
Figure 4. Preconstruction Groundwater Supply Sampling Locations
Figure 5. IR Location Map – HDD S2-0010 20-inch Line

ATTACHMENTS

Attachment A. Geotechnical Boring Reports

1.0 INTRODUCTION

Sunoco Pipeline, L.P., (SPLP) retained Groundwater & Environmental Services, Inc. (GES) to prepare HDD Hydrogeologic Reevaluation Reports (HRRs) for horizontal directional drills (HDDs) listed on Exhibit 3 of Stipulated Order EHB Docket No. 2017-009-L signed August 10, 2017. This report discusses the hydrogeologic reevaluation for HDD S2-0010-16 (the 16-inch HDD for this location). The planned alignment for HDD S2-0010-16 spans Loyalhanna Lake from east of Bush Road to a bluff approximately 1,700 feet west of the western shoreline, in Loyalhanna Township, Westmoreland County, Pennsylvania. The discussion presented in this report is based on a plan and profile developed by Tetra Tech/Rooney, revised on July 24, 2018, (revised profile) in comparison to an original plan and profile dated April 18, 2017 (see Figures 1 through 4 of Horizontal Directional Drill Analysis (HDDA)). The revised plan and profile was developed to increase the depth of the borehole by extending the east entry/exit point east and making the profile longer. The purpose is to minimize the risk of inadvertent returns (IRs) by advancing the pilot hole from the eastern entry/exit such that the drill enters bedrock a shorter distance from the entry/exit and continues in bedrock below a wedge of unconsolidated material that contributed to the IRs associated with the 20-inch line installed there.

As described in the Stipulated Order (pages 3 and 4), the HRRs will provide information to eliminate, reduce, or control the release or IR of HDD drilling fluids to the surface of the ground or impact to water supplies at the location during HDD operations. The HRRs are not intended to evaluate potential adverse effects to nearby man-made structures from HDD operations.

A map depicting the location of the HDD with topographic information for the surrounding area is presented as **Figure 1**.

This report presents the following information:

- Geologic and hydrogeologic characteristics in the area of HDD S2-0010-16;
- Summaries of studies performed pertinent to reevaluation, including fracture trace analysis, geotechnical borings and geophysical studies.
- A site conceptual model; and
- A reevaluation summary with conclusions.

The contents of this report were developed from interpretation of published information, field observations, and related field studies. Site geotechnical boring programs were conducted by Tetra Tech in September 2014 and, more recently by Tetra Tech in August 2017 and by Terracon Consultants, Inc. (Terracon) in October 2017, in support of the HDD S2-0010-16 reevaluation (**see Attachment A**). Please note that GES did not oversee or direct any of these geotechnical drilling programs, including, but not limited to, the selection of number and location of borings, determination of surface elevations, target depths, observations of rock cores 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.

Figure 1. Site Location Map (modified from USGS Saltsburg, PA 1:24,000 Topo. Quad., rev. 2016)

2.0 HDD GEOLOGY / HYDROGEOLOGY

2.1 Physiography

HDD S2-0010-16 is located within the Pittsburgh Low Plateau Section of the Appalachian Plateaus Physiographic Province, which consists of smooth to irregular, undulating surfaces; narrow, relatively shallow valleys; strip mines and reclaimed mine lands (Sevon, 2000). Local relief between valley floors and the ridges typically range from 300 to 1,200 feet. Loyalhanna Lake is the reservoir created by the construction of a US Army Corp of Engineers' (USACE's) flood control dam on Loyalhanna Creek, completed north of the site in 1951 and the HDD S2-0010-16 drill path crosses under the lake. The surrounding area is comprised of rural residential and agricultural properties and recreational facilities associated with the USACE Brush Creek Recreational Area (camping, boating, fishing, etc….), located on the east shore of the lake (see **Figure 1**).

2.1.1 Topography

The topography along HDD S2-0010-16 consists of bluffs standing above the lake on either end with a relatively flat flood plain on the east shoreline and a steep (200-foot elevation change) slope rising from the western shore of Loyalhanna Lake.

The original profile for the 16-inch line is a concave bore on the eastern and western ends with a straight run at the base of the bore (see Figures 1 and 2 of HDDA). The surface elevation of the western entry/exit of HDD S2-0010-16 is 1,120 feet above mean sea level (ft amsl) and the eastern entry/exit of the original HDD S2-0010-16-16 is 989 ft amsl. The overall length of HDD S2-0010-16 for the original profile is 3,761 feet. The revised profile is longer and runs deeper than the original profile. The eastern entry/exit location is moved approximately 304 feet to the east and the location of the western entry/exit was not changed, extending the overall length to 4,065 feet. The surface elevation of the eastern entry/exit in the revised profile is 1,004 ft amsl and the elevation of the western entry/exit on the revised profile is unchanged at 1,120 ft amsl.

2.1.2 Hydrology

The nearest surface water bodies to the HDD S2-0010-16 location include Loyalhanna Lake (Pond-04) that crosses the drill path at Stations 8+09 and 20+56 of the original profile. Stream S-P28 was identified just south of the right-of-way at Station 22+75 of the original profile but does not cross the drill path. Loyalhanna Lake is fed by Loyalhanna Creek from the south-southeast and discharges at the Loyalhanna Dam approximately 1.4 miles north of HDD S2-0010-16 before Loyalhanna Creek flows north to the Conemaugh River, 3.3 miles to the north of HDD S2-0010-16. No wetlands were identified within the right-of-way of HDD S2-0010-16. The original profile showed the 16-inch pipeline crossing approximately 50 to 52 feet below the lake bottom; whereas the revised profile shows the pipeline crossing 76 to 92 feet below the lake bottom.

2.2 Geology

2.2.1 Soils

Based on information obtained from the National Resource Conservation Service Web Soil Survey (USDA NRCS WSS), soils at the entry/exits for HDD S2-0010-16 can range from 1.5 to greater than 7 feet thick. Overburden is primarily composed of moderately well- to well-drained fine-loamy colluvium and residuum from weathered siltstone, sandstone, and shale. These soils are moderately well- to well-drained and groundwater levels are at 1.3 to greater than 7 feet below ground surface (ft bgs). Similarly, Geyer and Wilshusen (1982) describe the soil overburden over the Glenshaw Formation (see Section 2.2.2) as a channery silt loam and silt loam from weathered limestone, sandstone and shale ranging from three to greater than six feet thick. The profile passes beneath alluvium derived from the former Loyalhanna Creek stream channel and current lake action.

2.2.2 Bedrock Lithology

Figure 2 is a map depicting site bedrock geology for the area surrounding HDD S2-0010-16 (Newport, 1973). Bedrock underlying the area of HDD S2-0010-16 belongs to the Pennsylvanian age Glenshaw Formation, part of the Conemaugh Group. The Glenshaw Formation consists of repeated sequences of sandstone, siltstone, shale, claystone (including red beds), limestone, and coal. Shale is the primary rock type. It contains four major marine zones that are, from highest to lowest in stratigraphic position: the Ames, Woods Run, Pine Creek, and Brush Creek. The coal beds in the Glenshaw Formation are sporadically mined. The base of the Upper Freeport coal occurs from approximate elevation 750 to 820 ft amsl beneath the profile and historically has been economically significant coal bed in the area (Skema, 1988).

2.2.3 Structure

Newport (1973) provided a structure contour map for the Pittsburgh coal in Westmoreland County. Structurally, the HDD S2-0010-16 drill path is located on the eastern flank of the Grapeville-Jacksonville anticline (**see Figure 2**). The axial plane trace of the Grapeville-Jacksonville anticline is located west of the western end of HDD S2-0010-16 and plunges to the southwest. Bedrock dip at HDD S2-0010-16 is gently to the southeast.

Discontinuities in the form of joints, fractures and faults are imprinted in the broadly folded bedrock in the region. These fractures and bedding plane partings can act as conduits for groundwater movement and/or represent areas of weakness in the rock. Nickelsen and Hough (1967) conducted regional mapping of joints in shale, coal, and sandstone in the Appalachian Plateau. In the vicinity of HDD S2-0010-16, two systematic joint sets in shale were mapped with approximate trends of WNW and NW and a third, non-systematic joint set, oriented perpendicular to systematic joint sets.

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) are the surficial expression on natural landscapes of vertical zones of bedrock fracture concentration and can be zones of weaker bedrock and preferential pathways for fluid migration. Fracture trace analysis is partly subjective; therefore, every mapped fracture trace does not necessarily represent a zone of bedrock fracture concentration.

Figures 3 and 4 of the HDDA show fracture traces plotted on the revised plan and profile. This mapping was performed using aerial stereographic pairs flown in the spring of 1939, topographic maps and LIDAR maps. Seven fracture traces intersect the HDD alignment. Four intersect the western portion of the alignment and are oriented, two NNE and two NW parallel to joint mapping of Nickelsen and Hough (1967). Three fracture traces cross the eastern portion of the alignment, two oriented NNW and on oriented NE. The NE trending fracture trace parallels one of the non-systematic joint sets of Nickelsen and Hough (1967).

2.2.5 Karst Terrain

Based on published geologic data, no karst features are anticipated within the region of HDD S2-0010-16. Although limestone was observed in geotechnical borings TB-01 and B2-4W, karst conditions are not anticipated because limestones within the Glenshaw Formation are thinly interbedded and the development of karst is not characteristic for these limestones.

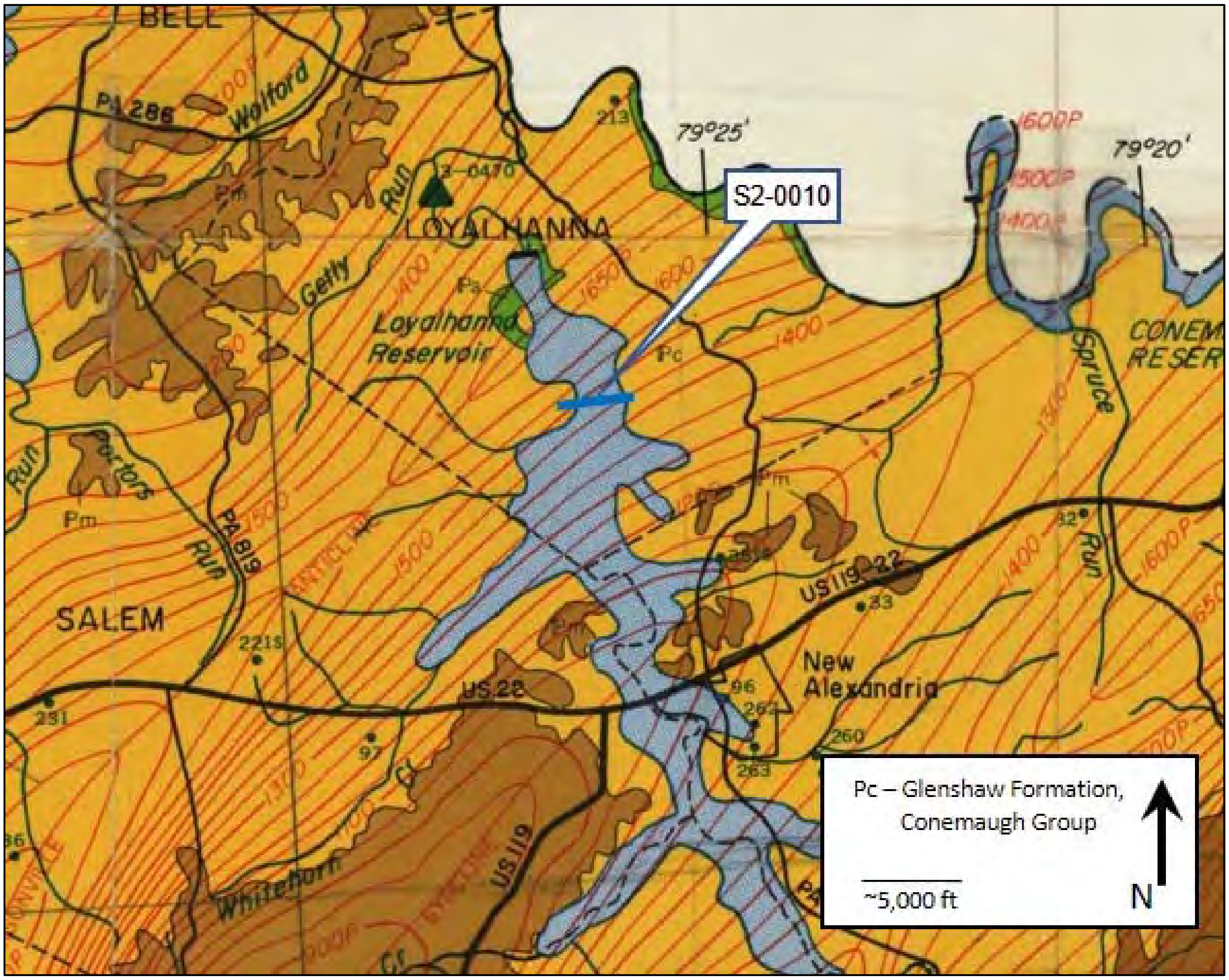


Figure 2. Site Geology Map and Structure Contour Map of the Pittsburgh Coal (modified from Newport, 1973)

2.2.6 Mining

A review of published mining data indicates that an abandoned deep Upper Freeport coal mine exits below the alignment west of the west shoreline of Loyalhanna Lake (**see Figure 3**). Skema (1998) shows the base of the coal seam ranging from 790 to 820 ft amsl moving west from the western shoreline to the western entry/exit. The seam ranges from 3 to 4 feet thick therefore a 4.5 foot thick mine void can be anticipated. The Pennsylvania Mine Map Atlas web site lists this as the abandoned Loyal Mine developed by the Seanor Coal Company (record 0817_UMM_500_002, 1/1/1992). Notations on the Seanor Mining Corp, Loyal Mine, Upper Freeport seam, 1"-200' scale map indicate room and pillar mining occurred from October to December 1959 and secondary extractions occurred between February and March 1960. The original profile for the 16-inch line was closest to the mine at the eastern extent of the mapped workings with an approximate vertical separation of 80 feet. The vertical separation increases moving west along the profile from this point as the coal seam dips gently to the southeast and the profile is rapidly gaining elevation towards the western entry/exit. The separation at the closest point was increased to approximately 115 feet on the revised profile with a similar ever increasing separation moving west and the separation is about 305 feet at the western entry/exit.

Figure 3. Location of abandoned Upper Freeport Coal Mine and HDD S2-0010-16 Alignment (modified from PA Mine Map Atlas)

2.2.7 Rock Engineering Properties

The Glenshaw Formation rock properties are as follows (Geyer and Wilshusen 1982):

- Well bedded; thick to massive sandstone, well bedded to nodular limestone, thin and fissile shale, and very poor bedded claystone.
- Joints are poorly to moderately well formed; open and vertical; closely to moderately spaced; and moderate distribution.
- Sandstone, siltstone, and limestone are moderately resistant weathering, whereas, claystone, shale, and coal weather extensively and deeply.
- Fast to moderate drilling rate.

2.2.8 Results of Geotechnical Borings

The locations of the five geotechnical boring discussed in this section are shown on the plans and profiles on Figures 1 through 4 of the HDDA and the boring logs are provided in **Attachment A**.

Original Borings

Three geotechnical borings, SB-01, SB-02, and SB-03, were installed by Tetra Tech in September 2014 in support of the original HDD design. These borings were advanced to depths of 11.6 ft bgs, 38.2 ft bgs, and 21.4 ft bgs, respectively. All three borings were augered to refusal, except for SB-02, which was cored to depth after auger refusal at 28.5 ft bgs. Boring SB-01 is located at Station 38+33 (72 feet west of the western entry/exit) of the original profile plan with a surface elevation of approximately 1,111 ft amsl. Boring SB-02 is located at Station 24+08 of the original profile with a surface elevation of approximately 1,116 ft amsl. Boring SB-03 is located at Station 5+62 of the original profile plan with a surface elevation of approximately 938 ft amsl.

Unconsolidated materials in SB-01 are comprised of 11.5-feet of silty sand and gravel. A 12-foot layer of silty sand is above 16.5 feet of silty sand and gravel in SB-02. Overburden in SB-03 consists of 11.5-feet of sand and clay above silty sand to 18 ft bgs.

The top of bedrock was logged as sandstone in all three borings, SB-01, SB-02, and SB-03, at depths of 11.5 ft bgs, 27.0 ft bgs, and 18.0 ft bgs; respectively. Groundwater was not encountered in any of these borings.

For SB-02, bedrock cores were obtained from 28.5 ft bgs to 38.2 ft bgs. The core was described as brown and gray micaceous sandstone with weathering, oxidation, and fracturing. Over the three core runs, core recovery was 88 to 98% and RQDs ranged from 48 to 69%.

Recent Borings
TB-01
Boring TB-01 was advanced on August 16, 2017, approximately 130 feet ENE of the eastern entry/exit location on the revised profile. The boring was installed to a depth of 170 ft bgs. Unconsolidated overburden observed at TB-01 was comprised of sandy clay to 10.5 ft bgs, followed by weathered sandstone to 18.5 ft bgs, weathered shale to 28.0 ft bgs, and weathered siltstone to 43.0 ft bgs, where bedrock coring began.

Bedrock cores contained shale, claystone, and sandstone characteristic of the Glenshaw Formation. Zones of high angle fracturing were noted at 43 ft bgs, at 54 ft bgs, from 57 to 76.5 ft bgs, and from 87 to 98 ft bgs. Recoveries throughout the core were high ranging from 93 to 100 percent except for recovery of 75 percent in the first run of two feet. Regarding RQD values, core quality was variable and ranged from 25 to 100 percent, and did not show a trend with depth. Two zones of poor to fair RQD at 85 to 87 ft bgs and at 115 ft bgs are the likely due to thin bedded shale with horizontal fractures, and thin coal seams observed in the deeper interval. At 95 and 142 ft bgs, broken rock was observed and correlated to poor and fair RQD in limestone and coal, respectively. The deepest zone with fair RQD was at 150 ft bgs due to sub-horizontal fracturing. No static groundwater level was measured in TB-01.

B2-4W
Boring B2-4W, was advanced approximately 100 feet NW of the western entry/exit on the revised profile for HDD S2-0010-16. This boring was located at an elevation of approximately 1,119 ft amsl and overburden was logged as 4.3 feet of sandy clay above 14.3 feet of weathered limestone above weathered sandstone to 18.6 ft bgs where coring began. The cored rock at B2-4W showed similar high recoveries to those seen in TB-01, with the exception of 30 percent recovery in the run from 138 to 143 ft bgs. RQDs were variable ranging from 50 to 100 percent, with the exception of zero RQD in the run from 138 to 143 ft bgs. Moderately weathered carbonaceous shale was observed within this interval. In addition, drilling water was lost at 128.4 ft bgs (just above this zone). High-angled fractures, weathering, and clay-filled fractures were observed within fair RQD zones at 188, 228, and 238 ft bgs, and a 0.6 foot thick coal seam was logged at 215 ft bgs resulting in low RQD. Water level readings were occasionally recorded as the borehole advanced over the nine day period from 9/7/17 to 9/15/17, and the water level dropped from 85.4 ft bgs on 9/11/17 to 265.3 ft bgs when the boring was completed. Drilling was terminated at 288 ft bgs where the core barrel sheared off, at the estimated elevation of the Loyal Mine.

2.3 Hydrogeology

In general, groundwater flow proximal to HDD S2-0010-16 moves along gradients established by a water table surface that is a subdued reflection of the local topography. The alignment of HDD S2-0010-16 passes west to east through a historically meandering stream valley prior to the damming of Loyalhanna Creek to create the current lake (Pond-04). The area formerly occupied by Loyalhanna Creek and now by Loyalhanna Lake is within a groundwater discharge zone. The topographic gradient is much steeper towards the lake from the west than from the east and water table gradients are assumed to have similar relative gradients. Groundwater seepage into the lake can be seen along bedding plane partings on rock cliffs surrounding the lake and from outcrops within stream valleys draining into the lake. See Section 2.3.6 for a discussion on the hydrogeology of the bluff west of the lake.

2.3.1 Occurrence of Groundwater

Most groundwater in area of the drill occurs and moves within a fractured bedrock aquifer. Groundwater occurs within the secondary porosity created by fractures, bedding plan partings, and faults. Given the area groundwater discharge zone, the water table is shallow at some locations near the lake and occupies unconsolidated alluvium associated with Loyalhanna Lake and the former Loyalhanna Creek stream channel.

Within the bluff west of Loyalhanna Lake, where the western portion of the HDD will be constructed, mine subsidence has increased the porosity of the bedrock. Kendorski (2006) describes three zones of increasing porosity with depth over a mine. These include the dilated zone, fractured zone and caved zone. Assuming a mine void thickness of 4.5 feet for the abandoned Loyal Mine, the cave zone is estimated to be as much as 45 feet thick, directly over the mine. Above that, the fracture zone could extend to as much as 135 feet above the mine, the dilated zone could extend above the fractured zone to as much as 270 feet above the mine.

2.3.2 Ground Elevation Between HDD Entry/Exits

The surface elevation of the eastern entry/exit in the original profile for HDD S2-0010-16 is 989 ft amsl and the elevation of the western exit/entry is 1,120 ft amsl. The original profile has a bottom elevation of 863 ft amsl.

The horizontal length of the 16-inch drill was increased approximately 304 feet by moving the eastern entry/exit point east. The surface elevation of the eastern entry/exit in the revised profile is 1,004 ft amsl and the elevation of the western exit/entry is unchanged at 1,120 ft amsl. The revised profile has an approximate bottom elevation of 830 ft amsl, 33 feet lower than the original profile.

2.3.3 Water Level

Groundwater was not encountered or measured in geotechnical borings SB-01, SB-02, SB-03 or TB-01. The groundwater level continuously dropped during the drilling of B2-4W from 85.4 feet to 265.3 feet bgs after completion of the boring.

The Pennsylvania Groundwater Information System (PaGWIS) reported one well, 5,460 feet north of the HDD S2-0010-16 western entry/exit. This domestic well (PaWellID 648252) is completed to 180 ft bgs within bedrock, but no information regarding the geologic formation was reported. During drilling, a void was encountered at 180 ft bgs and backfilled with Hole Plug™ to 160 ft bgs. Static water was reported at 45 ft bgs and the well yield was reported at 4 gallons per minute (gpm).

The USACE controls the lake level and United States Geological Survey (USGS) lake stage records for the Loyalhanna Lake dam from 2007 to July 2018 show lake stage varied from a minimum level of approximately 917 to a maximum level of about 954 ft amsl, with a mean of 924 ft amsl, and a mode of 923 ft amsl (USGS, 2018). When the lake stage is higher, groundwater flow gradients local to the shoreline may be inward from the lake, as long as the elevated lake stage is maintained.

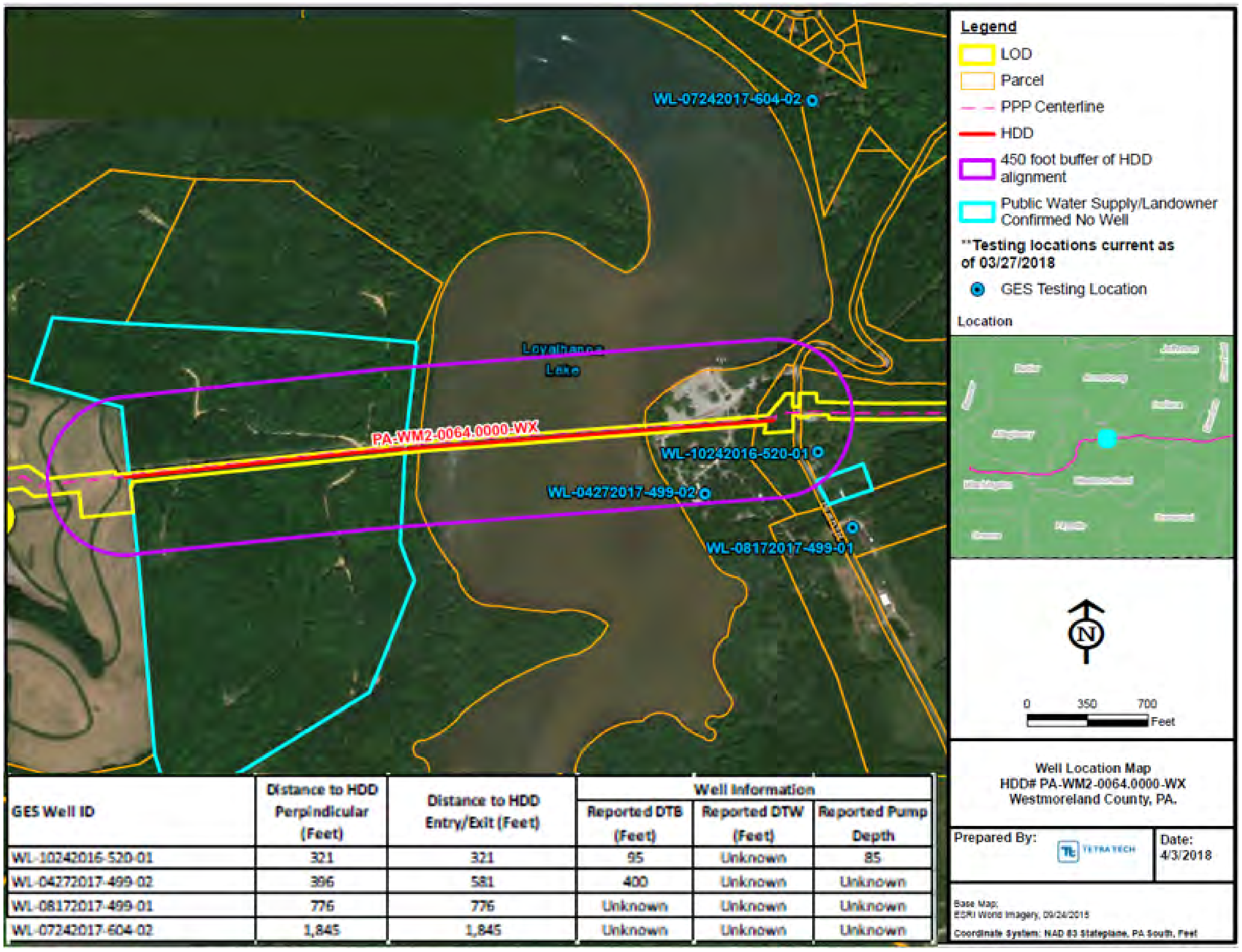
2.3.4 Well Yields

Published median well yields (Geyer and Wilshusen 1982) are highly variable in the Conemaugh Group and have ranged from 1 to 357 gpm. McElroy (1998) notes that median yield of wells drilled into the Glenshaw Formation in Cambria County is 12 gpm with a range from 0 to 30 gpm. Based on the results of a PaGWIS database search, yields from wells drilled into the Glenshaw Formation and within two miles of HDD S2-0010-16 range from 1.5 to 10 gpm.

2.3.5 450-foot Water Source Survey

SPLP performed a preconstruction survey of landowners within 450 feet and greater from the HDD S2-0010-16 alignment and four landowners responded positively to an offer to have their wells tested. **Figure 4** illustrates the sampling locations. Property owners for two wells within the 450-foot area responded positively to the offer from SPLP to have their wells sampled. No well specific water level or pump depth information was available or could be collected during the sampling of these wells. Well depth information was provided by the property owner for well WL-10242016-520-01 located approximately 321 feet from the S2-0010-16 alignment (95 ft bgs) and for well WL-04272017-499-02 located approximately 396 feet from the alignment (400 ft bgs). Assuming twenty feet of steel surface casing, a conservatively large estimate of the water production zone for WL-10242016-520-01is from 20 to 95 ft bgs. Similarly, the production zone for well WL-04272017-499-02 would be 20 to 400 ft bgs. Comparing these estimated production zone depth intervals to the elevation of the revised 16-inch HDD profile indicates the upper portions of the production intervals could intersect the elevation of the profile, keeping in mind these wells are approximately 321 feet and 396 feet horizontally from the profile.

All four wells plotted on **Figure 4** were previously sampled in association with the IRs that occurred on the eastern shore during the installation of the 20-inch line at HDD-S2-0010 (see Section 3.1.2). All property owners with wells within the 450-foot area were offered temporary water supplies during the pending installation of the 16-inch line and none accepted the offer. The owner of well WL-08172017-499-01 has been on a temporary water supply since this water supply was affected by drilling fluid during the installation of the 20-inch line. This temporary supply will be maintained until completion of HDD S2-0010-16. No other parcel owners within the 450-foot area have accepted SPLP's offer to provide temporary water during installation of the 16-inch line.



GES Well ID	Distance to HDD Perpindicular (Feet)	Distance to HDD Entry/Exit (Feet)	Well Information		
			Reported DTB (Feet)	Reported DTW (Feet)	Reported Pump Depth
WL-10242016-520-01	321	321	95	Unknown	85
WL-04272017-499-02	396	581	400	Unknown	Unknown
WL-08172017-499-01	776	776	Unknown	Unknown	Unknown
WL-07242017-604-02	1,845	1,845	Unknown	Unknown	Unknown

Figure 4. Preconstruction Groundwater Supply Sampling Locations

2.3.6 Mine Pool

In regions where there are abandoned deep mines, HDD assessments need to consider the potential to create a new mine pool discharge by producing a drain with the HDD boring or by raising the mine pool elevation from loss of circulation (LOC). Staff at the PADEP District Mining office in Cambria County, USACE at Loyalhanna Lake and USACE Geotechnical Branch office in Pittsburgh have suggested that a mine pool associated with the Loyal Mine could be in direct hydraulic communication with Loyalhanna Lake. The mine pool, if present, is not currently being regulated by PADEP. A Freedom of Information Act (FOIA) request was made to the USACE requesting any information associated with a potential hydraulic connection between Loyalhanna Lake and the abandoned Upper Freeport underground coal mine (Loyal Mine) operated by Seanor Mining Corporation in the 1950s. The only information provided through the FOIA request was historic lake stage data managed by the USGS from January 2015 to present. As described below, GES was able to obtain historic lake stage data from 2007 to July 2018 using publically available USGS web based tools.

The roof of the abandoned Loyal Mine under the bluff west of Loyalhanna Lake varies in elevation from a low at the east edge of the mine of approximately 790 ft amsl to a high of approximately 820 ft amsl under the western entry/exit of the HDD. The mine does not persist under Loyalhanna Lake or east of Loyalhanna Lake along the HDD. The proposed profile for the 16-inch line is at approximately 900 ft amsl, 110 feet above the eastern edge of the mine and rises moving west to exit at the surface at approximately 1,120 ft amsl, approximately 280 feet above the mine.

The area that is deep mined and over which the HDD is proposed, is a bluff surrounded by the lake on the north, east and south, and by Serviceberry Run to the west. The USACE controls the lake level and USGS lake stage records for the Loyalhanna Lake dam from 2007 to July 2018 were obtained and show lake stage varied from a minimum level of approximately 917 to a maximum level of about 954 ft amsl, with a mean of 924 ft amsl, and a mode of 923 ft amsl. When the lake stage is at its maximum, surface water surrounds the bluff on nearly all sides. During times of average and the lowest lake stage, surface water surrounds the bluff to the north, east and south. A source of local groundwater recharge is the precipitation falling onto the bluff. Given the area of the bluff, this recharge is limited predicting a relatively subdued (flatter) water table mound under the bluff whose elevation is more controlled by lake stage and less controlled by recharge from precipitation. As lake stage is managed, local groundwater flow gradient will vary from radially outward from the bluff to relatively flat, to radially inward. Steep water table gradients, both inward and outward, may occur proximal to shorelines as lake stage goes up and down. Geotechnical boring B2-4W was drilled from a location near the west entry/exit for the HDD. This boring was drilled 288 feet deep and is thought to have entered the caved zone described in Section 2.3.1. A water level measured in the boring after the drilling was completed was approximately 854 ft amsl (33 feet above the estimated elevation of the mine roof). If this measurement is representative of the water table elevation under the interior of the bluff, it is lower than the stage of Loyalhanna Lake, predicting inward radial groundwater flow, above the mine.

It is not known whether the groundwater quality in the water table aquifer over the mine within the bluff has been affected by contact with the open mine. Based on the water level measurement from boring B2-4W and range of possible lake stage elevations, the water table surface appears to be maintained above the mine without an upward vertical flow gradient moving groundwater through the mine into higher portions of the bedrock aquifer. Bedrock in the area is on the southeast limb of an anticline and the local bedrock is not subject to the type of mine pool development that sometimes occurs from upward flow through a mine within a synclinal basin.

If the lake stage is representative of the mine pool elevation, the geometry of the revised profile would not be such that the HDD boring could create a new mine pool discharge. The limits for the bottom and top of the pool would be from the lowest elevation of the mine (790 feet amsl) to the highest lake stage (955 ft amsl). The revised profile passes through this zone from Station 26+90 to 30+40; however, entry/exit points are at elevation 1,120 ft and 1,004 feet for the west and east entry/exit point, respectively.

If an LOC from the HDD loses drilling fluid to the water table aquifer that overlies the mine it is not likely that the additional recharge will affect the local water table elevation as the control of that elevation would be much greater from the head boundary established by the stage of the lake, surrounding the bluff. During low stages, local water table gradients may be steep towards the lake and a heightened level of inspection is indicated to prevent a large volume LOC and/or an IR from entering surface water.

2.4 Summary of Geophysical Studies

No geophysical studies were conducted for the purposes of this hydrogeologic reevaluation. A 3-D seismic survey was performed as part of a mine subsidence assessment performed by Tetra-Tech. Zones of fracturing from mine subsidence were delineated by analysis of the 3-D seismic survey data (see Figure 4 of HDDA).

3.0 OBSERVATIONS TO DATE

3.1 On This HDD Alignment

3.1.1 ME I

No IRs were reported along the alignment of the HDD S2-0010-16 drill on the list of IRs for ME I documented in the IR PPC Plan for Westmoreland County.

3.1.2 ME II

During the second day of drilling the pilot hole for the 20-inch line at HDD S2-0010 returns were lost when the pilot bit was 228 feet west of the eastern exit/entry point. Nearly continuous loss of returns continued until the pipe was pulled into place on July 20, 2017. Due to the loss of returns, IRs appeared at multiple locations along the eastern shore of the lake (**see Figure 5**). Minor volumes of drilling fluid appeared in the tributary north of the alignment and in Loyalhanna Lake along the eastern shoreline, and were rapidly managed and cleaned up. On June 8, 2017, a vertical relief boring was installed and began to capture the lost returns and the IRs ceased. Loss of returns was managed from this position by transporting drilling fluids from the relief well discharge back to the mud pit at the drill rig and to frac tanks for the remainder of the 20-inch pipe installation. All IRs were contained and managed using best management practices including the digging of sumps, use of sump pumps, silt fence, open water booms, and vacuum trucks.

In addition to the IRs, drilling fluid appeared in two water supply wells east of the eastern lake shoreline; at the USACE camp ground well and in a well on the bluff south of the eastern entry/exit point; wells WL-04272017-499-02 and WL-10242016-520-01, respectively (**see Figures 4 and 5**).

The cause of the IRs was assessed based on accounts of historic land use relayed by local residents to GES Professional Geologist (PG) staff members during the HDD S2-0010 20-inch line inspection work at Loyalhanna Lake. One account described a former quarry high wall just west of the eastern entry/exit, in which case, fill material would have been brought in to create a slope between Stations 0+00 and 2+50 (original profile) from the bluff to the shoreline. This fill could have contained coarse materials (sands and gravels and buried coarse quarry materials (gravel to boulder sized stones) that were not removed from the quarry floor before backfilling. Another account was of field drains being installed within the slope for agricultural purposes. Either account, or both in combination, would have created preferred pathways for fluid storage and migration beneath the slope. It is believed that the pilot hole went through this wedge of backfill as it was gaining depth advancing west. This zone of conductive backfill is likely floored by competent bedrock. The wedge of material formed by the quarry high wall, quarry floor, and slope extends north to south, running between the gravel parking lot and Bush Road. The drilling fluid lost to this zone, filled up all available subsurface pore space, and was eventually expressed as IRs.

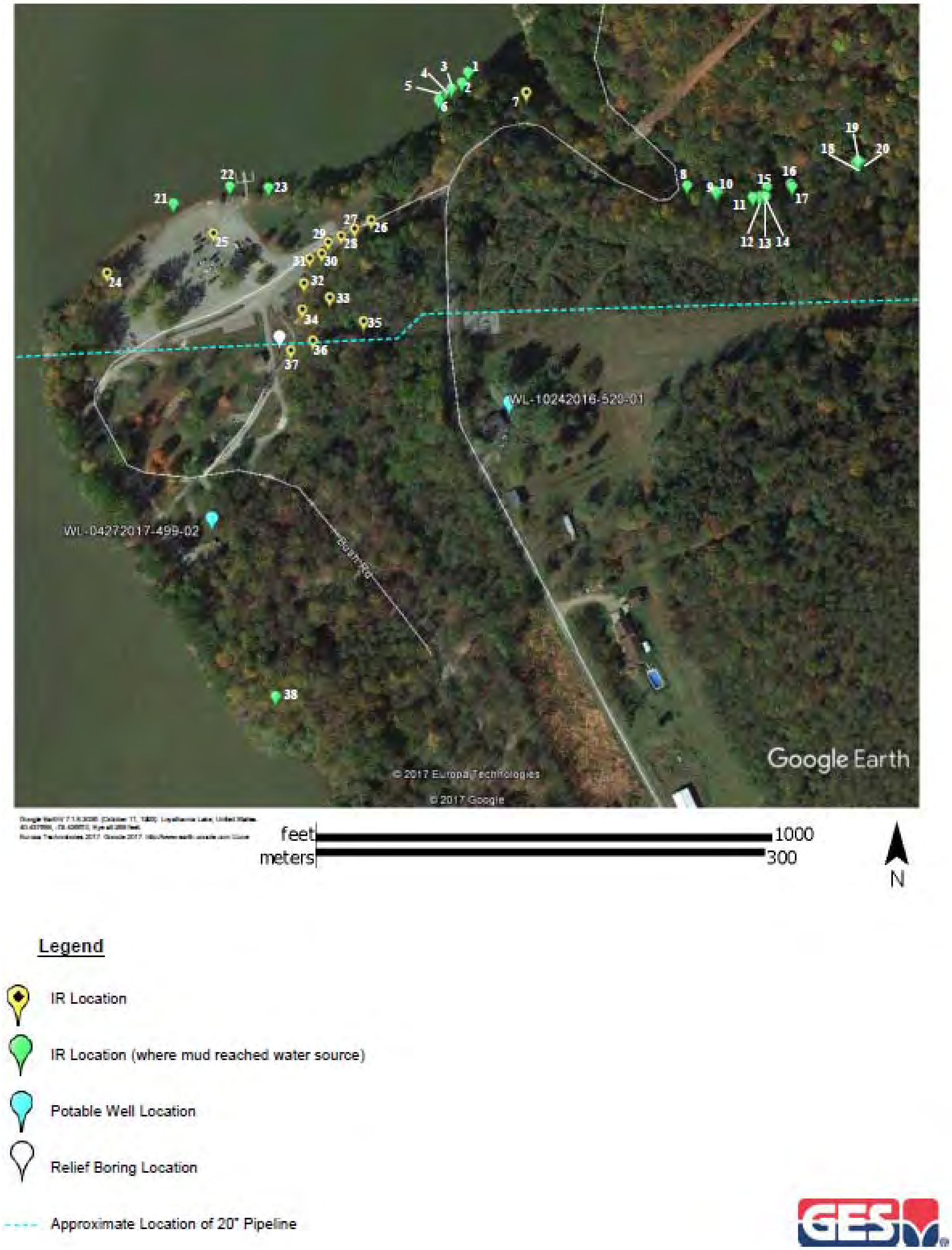


Figure 5. IR Location Map – HDD S2-0010 20-inch Line (modified from GoogleEarthTM, 2017)

A relief well was installed along the alignment at approximately Station 2+25 (original profile). This action was highly effective in stopping all of the IRs. Drilling fluid returns, intercepted by the relief well, were conveyed to a sump and managed by either transporting the fluid back to the mud pit at the drilling rig or containerizing the returns in frac tanks. The relief well system began to operate on June 9, 2017, at which time all of the IRs started to dissipate and eventually stopped flowing.

The only time IRs became active again, after June 9, 2017, was when fluid pressures built up in the HDD borehole between the relief well and the east entry, such as when reamers were being tripped out of the boring from west to east. Drilling fluids were released to the ground on a few occasions when IR or relief well containments were breached. Periods of high flows at the relief well and extremely heavy rainfall events contributed to these types of releases when containment systems could not manage unusually high volumes of fluids over a short period of time. On occasion short-term high flow events occurred at the relief well after periods of very low flow during reamer passes. At these times, cuttings were not being efficiently removed from the borehole causing the borehole to plug and causing drilling fluid and cuttings to build up behind the plug. This plugging was released by advancing the reamer in and out, or the pressure build up behind the plug would eventually push the plug out, causing a surge of cuttings laden drilling fluid to exit at the relief well.

Comparing the original to revised plan and profiles for HDD S2-0020-16 (see Figures 1 through 4 of the HDDA) the revised profile has been lengthened 304 feet east. The radius of entry at the eastern entry/exit is the same at 16 degrees. The revised profile for the 16-inch line is greater than 50 feet below the as-built profile for the 20-inch line beneath the area where returns were first lost on the 20-inch line and the 16-inch line will pass under the wedge of unconsolidated materials discussed above.

3.2 On Other HDD Alignments in Similar Hydrogeologic Settings

3.2.1 ME I

No IRs were reported on the list of IRs for ME I documented in the IR PPC Plan for site underlain by Glenshaw formation bedrock.

3.2.2 ME II

All of the IRs to date in Spreads 1 and 2 for the ME II pipeline have occurred while drilling through the cyclic sequences of sandstone, shale, limestone, clays seams and coal present within western Pennsylvania bedrock formations, including the Allegheny Group, Casselman Formation, Glenshaw Formation, Monongahela Group, and Waynesburg Formation. Entries and exits pass through alluvium, colluvium and soils developed on top weathered bedrock and mine spoils. In general, the IRs have been related to shallow overburden, coarse grained unconsolidated materials near the surface (such as alluvium and mine spoil), large elevation changes between entry/exits and the lowest elevation points along the profiles (sometimes creating soil plugs, elevated annular pressures and loss of fluids), and the interconnectivity of open bedrock structural features that is difficult to predict.

4.0 SUMMARY AND CONCLUSIONS

4.1 HDD Site Conceptual Model

The revised profile for HDD S2-0010-16 is relatively symmetric with entry/exits points located on elevated ground west and east of Loyalhanna Lake (see Figure 3 and 4 of HDDA). It is assumed a large percentage of the eastern part of the drill, east of the lake will be below the water table. The lake is present above the HDD profile in the central portion of the drill. A relatively deep water table is assumed west of the lake in the bluff therefore a large percentage of that portion of the drill is assumed to be above the water table. On the revised profile the western entry/exit for the 16-inch line is approximately 200 feet above the lake bottom and the eastern/entry point is approximately 80 feet above the lake bottom. The possibility of the pilot hole for HDD S2-0010-16 creating a drain causing excessive groundwater discharge at both entry/exit point, and an associated lowering of the local water table, is low because the entry/exit points are both at higher elevations than the water table along the entire path. However, given the length of the drill and the elevation difference between entry/exits and the lowest (horizontal portion) of the profile, the drilling plan should include procedures to prevent the condition where cuttings are not being removed from the borehole in an efficient manner, causing the borehole to plug behind a drill bit or reamer and elevated fluid pressure to build up behind the plug.

The planned borehole crosses beneath Loyalhanna Lake at a minimum depth of 76 feet along the western edge on the revised profile, whereas on the original profile this separation was slightly greater than 50 feet. Similarly, in the eastern part of the alignment, the depth from Loyalhanna Lake to the HDD profile is approximately 55 feet on the original profile but is shown at approximately 92 feet on the revised profile. The difference in depth of profile between the original and revised profiles in the central part of the HDD is an increase of approximately 33 feet. At both exit/entry locations on the revised profile the clay faction of soils near the surface will help to reduce the risk of IRs during entry and exit, however this layer is relatively thin near the western entry/exit (4.3 feet) as indicated on the log for boring B2-4W. The cored sections for both geotechnical borings showed good recovery, except for the run between 138 and 143 ft bgs in boring B2-4W which had only 30 percent recovery. RQDs for both borings were variable ranging from 50 to 100% and showed no trend with depth, except for a section of 0 percent RQD, again from 138 to 143 ft bgs in B2-4W. Seven fracture traces intersect the HDD alignment representing the potential presence of vertical zones of fracture concentration and weaker bedrock.

The abandoned Upper Freeport coal Loyal Mine underlies the western portion of the revised profile. The method of mining was room and pillar and it is estimated that an approximate 4.5 foot mine void was left between abandoned pillars. Mining activity was completed in the 1960s. The abandoned mine workings are closest to the profile at the eastern limit of the mine where the profile passes approximately 115 feet above the mine roof. Moving west from that point the vertical separation continuously increases as the mine is following the very gentle dip of local bedrock and the profile is rapidly increasing in elevation approaching the western entry/exit where the separation between the mine and pipe will be approximately 305 feet. Over this part of the profile bedrock fracturing will be greater than that encountered in other parts of the drill due to mine subsidence effects (see Figure 4 of HDDA).

As discussed in Section 2.3.6, the stage of Loyalhanna Lake is likely controlling the position of the water table under the HDD profile along the western part of the alignment. The water table gradient there can be outward to the lake, relatively flat or inward from the lake. Steep gradient could be present toward the lake and Serviceberry Run when lake stage is low and a heightened level of inspection is indicated to prevent a large volume LOC and/or an IR from entering surface water as drilling passes over the western shoreline of the lake.

SPLP performed a preconstruction survey of landowners within 450 feet and greater of the revised HDD S2-0010-16 alignment and four landowners responded positively to an offer to have their wells tested. All four wells were previously sampled in association with the IRs that occurred on the eastern shore during the installation of the 20-inch line at HDD-S2-0010 (see Section 3.1.2). One well, WL-08172017-499-01, located approximately 776 feet south of the 16-inch alignment was affected by drilling fluid during the installation of the 20-inch line. A temporary water supply was provided to the residence at that time and SPLP will continue the service through installation of the 16-inch line. The fact that this well was affected and that IRs during the 20-inch line installation occurred up to 1,000 feet from the 20-inch alignment demonstrates a large percentage of the local available secondary pore space in the bedrock aquifer east of Loyalhanna Lake was occupied by drilling fluid at the completion of that installation. It is believed that a large portion of the fluid in the pore space will have cured since that time; however, some portion may still be in a fluid state. Losses of circulation during the installation of the 16-inch line could add pressure on the interconnected network of drilling fluid filled fractures, causing IRs from the 20-inch line installation to reactivate and/or the quality of water produced from local supply wells to be affected. Procedures established and documented in the revised IR PPC Plan (rev. April 2018) across all ME II spreads have proven to be very effective in reducing the volume of drilling fluid lost to fractured bedrock aquifers. These measures will serve to reduce the potential for the 20-inch line IRs to reactivate.

4.2 Conclusions and Recommendations

Based on the original and revised profiles for HDD S2-0010-16, the revised profile for HDD S2-0010-16 is longer, goes deeper into bedrock, and is deeper beneath Loyalhanna Lake and the eastern shoreline than the original profile (see Figures 1 through 4 of HDDA). As such, the revised profile represents a reduced risk of creating one or more IRs, similar to those that occurred during installation of the 20-inch line there. Procedures established and documented in the revised IR PPC Plan (April, 2018) across all ME II spreads have proven to be effective in eliminating IRs and minimizing the extent of IRs. Contractors and inspectors should be especially observant during the 16-inch HDD as losses of circulation during the installation of the 16-inch line could add pressure to the interconnected network of bedrock fractures, causing IRs from the 20-inch line installation to reactivate and/or the quality of water produced from local supply wells to be affected.

Given the geotechnical boring information, fracture trace mapping and effect of mine subsidence, during the drilling of HDD S2-0010-16 the drilling manager and inspectors should be alert to the presence of potential vertical zones of fracture concentration (fracture traces), 2) mine subsidence fractures and 3) dilated bedding planes from mine subsidence, some of which have been delineated on the revised plan and profile (Figure 4 of the HDDA), and be prepared to stop and take corrective actions in accordance with the drilling best management practices (BMPs) and the April 2018 IR Plan.

5.0 REFERENCES

Geyer, A. R. and J. P. Wilshusen, (rev. 1982) *Engineering Characteristics of the Rocks of Pennsylvania,* PaDER, ORM, Pa Geol. Surv., 4th ser., EGR-1.

GoogleEarthTM (2017) (https://www.google.com/earth/)

Kendorski, F. S. (2006) *Effect of Full-Extraction Underground Mining on Ground and Surface Waters a 25-Year Retrospective*, 25th Int. Conf. on Ground Control Mining, Morgantown, WV 2006.

McElroy, T. A. (1998), *Groundwater Resources of Cambria County,* Pa Geol. Surv., 4th ser., W67.

Newport, T. G. (1973), *Summary Ground-Water Resources of Westmoreland County*, Pa Geol. Surv., 4th ser., W37.

Nickelsen, R. P. and Hough, V. D., (1967) *Jointing in the Appalachian Plateau of Pennsylvania*, GSA Bull. v. 78, p. 609-630.

Sevon, W. D, (2000), *Physiographic Provinces of Pennsylvania*, Pa Geol. Surv., 4th ser., Map 13.

Skema, V. W. (1988), *Coal Resources of Westmoreland County, Pennsylvania – Part 1, Coal Crop Lines, Mined-Out Areas, and Structure Contours*, Pa Geol. Surv., 4th ser., M 094.

PAGWIS, Pennsylvania Groundwater Information System (http://dcnr.state.pa.us/topogeo/groundwater/pagwis/records/index.htm).

Pennsylvania Mine Map Atlas (http://www.minemaps.psu.edu).

USDA NRCS WSS, United States Department of Agriculture, Natural Resources Conservation Service – Web Soil Survey for Westmoreland County (https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx).

USGS (United States Geological Survey), Saltsburg, Pennsylvania, 1:24,000 topographic quadrangle map, rev. 2016.

USGS (United States Geological Survey), National Water Information Interface System / 03046500 Loyalhanna Creek Lake, PA (https://waterdata.usgs.gov/nwis/uv?site_no=03046500), 2018.

Attachment A

Geotechnical Boring Reports

LEGEND:

Geotechnical Soil Boring (SB) Locations

TETRA TECH

GEOTECHNICAL BORING LOCATIONS

HDD S2-0010

WESTMORELAND COUNTY, LOYALHANNA 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:	LOYALHANNA LAKE (WEST SIDE), SALTZBURG, PA		Page 1 of 1	
HDD No.:	S2-0010	Dates(s) Drilled: 09-09-14	Inspector:	E. WATT
Boring No.:	SB-01	Drilling Method: SPT - ASTM D1586	Driller:	S. HOFFER
Drilling Contractor:	HAD DRILLING	Groundwater Depth (ft): NOT ENCOUNTERED	Total Depth (ft):	11.5

Sample No.	Sample Depth (ft)		Strata Depth (ft)		Recov. (in)	Strata (USCS)	Description of Materials	6" Increment Blows *				N
	From	To	From	To								
			0.0	1.3			TOPSOIL (15")					
			1.3	3.5		SM	BROWN SILTY SAND, TRACE MICA.					
1	3.0	3.7	3.5		5	SM/ GM	DR WEATHERED TO A LIGHT BROWN FINE SAND WITH SOME	2	50/2"			>50
							COARSE UNWEATERED SANDSTONE GRAVEL.					
2	8.0	8.5			3		DR WEATHERED TO A LIGHT BROWN FINE SAND, LITTLE SILT, WITH	50/6"				>50
				11.5			SOME COARSE UNWEATERED SANDSTONE GRAVEL.					
3	11.5	11.6	11.5	11.6	1		PARTIALLY WEATHERED SANDSTONE.	50/2"				>50
							AUGER REFUSAL AT 11.5'. SUBSEQUENTLY OFF-SET BORING					
							AND CONTINUOUSLY DRILLED TO AUGER REFUSAL AT 5'. OFF-SET					
							WAS 17' NORTH OF ORIGINAL BORING.					
							CAVED AT 10'.					

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:	LOYALHANNA LAKE (WEST SIDE), SALTZBURG, PA			Page 1 of 1	
HDD No.:	S2-0010	Dates(s) Drilled: 09-10-14		Inspector:	E. WATT
Boring No.:	SB-02	Drilling Method: SPT - ASTM D1586		Driller:	S. HOFFER
Drilling Contractor:	HAD DRILLING	Groundwater Depth (ft): NOT ENCOUNTERED		Total Depth (ft):	38.2

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
							NO TOPSOIL					
			0.0			SM	MOTTLED (VARYING SHADES OF BROWN) FINE SAND WITH TRACE					
				3.5			SILT.					
1	3.0	5.0	3.5		16		DR WEATHERED TO A LIGHT BROWN FINE SAND, WITH A LITTLE	7	14	17	17	**31**
							SILT.					
2	8.0	10.0			14		DR WEATHERED TO A LIGHT BROWN FINE SAND, WITH A LITTLE	2	19	25	40	**44**
				12.0			SILT.					
3	13.0	13.8	12.0		4	SM/GM	DR WEATHERED TO A LIGHT BROWN AND GRAY FINE SAND WITH	6	50/3"			**>50**
							SOME SILT, AND WITH SOME F-C UNWEATHERED GRAVEL.					
4	18.0	18.7			8		DR WEATHERED TO A FINE TO MEDIUM SAND, LITTLE SILT, WITH	10	50/2"			**>50**
							SOME F-C UNWEATHERED SANDSTONE GRAVEL.					
5	23.0	23.7			8		DR WEATHERED TO A FINE TO MEDIUM SAND, LITTLE SILT, WITH	20	50/2"			**>50**
				27.0			SOME F-C UNWEATHERED SANDSTONE GRAVEL.					
6	28.0	28.2	27.0	28.5	<1		PARTIALLY WEATHERED SANDSONE.	50/2"				**>50**
							AUGUR REFUSAL AT 28.5'.					
							ROCK CORING					
RUN 1	28.5	30.5	28.5		21	ROCK	HIGHLY FRACTURD BROWN AND GRAY MICACEOUS THINLY	TCR: 88%, SCR: 60%, RQD: 48%				
				29.0			BEDED SANDSTONE.					
			29.0				BROWN AND GRAY MICACEOUS SANDSTONE. FRACTURE AT 29.63',					
				30.5			29.9 TO 30.12'. ZONES OF WEATHERING/OXIDATION.					
RUN 2	30.5	35.5	30.5		59		SMILAR SANDSTONE, FRACTURES AT 31.2, 32.1, 33.03, 33.89,	TCR: 98%, SCR: 87%, RQD: 69%				
				35.5			AND 34.05 TO 34.2.					
RUN 3	35.5	38.2	35.5	38.2	30		SIMILAR SANDSTONE, FRACTURES AT 35.5 TO 37.5, 35.93, 36.81,	TCR: 94%, SCR: 70%, RQD: 48%				
							37.14, 37.25.					
							CAVED AT 28'.					
							CORE TESTING RESULTS (DEPTH 31.8'):					
							COMPRESSIVE STRENGTH: 10,820 PSI					
							UNIT WEIGHT: 157.4 PCF					

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:	LOYALHANNA LAKE (EAST SIDE, CAMP GROUND), SALTZBURG, PA		Page 1 of 1	
HDD No.:	S2-0010	Dates(s) Drilled: 09-09-14	Inspector:	E. WATT
Boring No.:	SB-03	Drilling Method: SPT - ASTM D1586	Driller:	S. HOFFER
Drilling Contractor:	HAD DRILLING	Groundwater Depth (ft): NOT ENCOUNTERED	Total Depth (ft):	21.4

Sample No.	Sample Depth (ft)		Strata Depth (ft)		Recov. (in)	Strata (USCS)	Description of Materials	6" Increment Blows *				N
	From	To	From	To								
			0.0	0.5			TOPSOIL (6")					
1	3.0	5.0	0.5			CL/SC	MOTTLED ORANGE BROWN AND LIGHT GRAY FINE SAND AND CLAY,	1	5	9	12	**14**
							WITH A LITTLE FINE GRAVEL.					
2	8.0	10.0					MOTTLED ORANGE BROWN AND LIGHT GRAY FINE SAND AND CLAY,	3	5	7	10	**12**
				11.5			WITH A LITTLE FINE GRAVEL (USCS: CL/SC)					
3	13.0	15.0	11.5			SM	BROWN FINE TO MEDIUM SAND WITH SOME SILT.	2	4	5	6	**9**
4	18.0	18.4					PARTIALLY WEATHERED BROWN SAND STONE	50/5"				**>50**
5	21.0	21.4					PARTIALLY WEATHERED GRAY SAND STONE	50/5"				**>50**
							AUGUR REFUSAL AT 21.4'. EVIDENCE OF SANDSTONE ROCK IN					
							AUGER CUTTINGS.					
							CAVED AT 16'					

Notes/Comments:

Pocket Pentrometer Testing
S2: 1.75 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.

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:	LOYALHANNA LAKE (EAST SIDE), SALTZBURG, PA	Page 1 of 1	
HDD No.:	S2-0010	Dates(s) Drilled: 09-08-14	Inspector: E. WATT
Boring No.:	SB-04	Drilling Method: SPT - ASTM D1586	Driller: S. HOFFER
Drilling Contractor:	HAD DRILLING	Groundwater Depth (ft): NOT ENCOUNTERED	Total Depth (ft): 16.0

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	0.4			TOPSOIL (4.5")					
1	3.0	5.0	0.4	4.5		SM	BROWN FINE SAND AND SILT, TRACE F-SANDSTONE GRAVEL.	3	9	9	21	**18**
2	8.0	8.4	4.5				WEATHERED TO PARTIALLY WEATHERED DARK BROWN	50/4"				**0**
				9.0			SANDSTONE.					
							AUGER REFUSAL AT 9'.					
							<u>ROCK CORING</u>					
RUN 1	9.0	11.0	9.0			PARTIALLY WEATHERED ROCK	GRAY TO DARK GRAY MICACEOUS SANDSTONE, WITH WEATHERING	TCR: 83%, SCR: 73%, RQD: 17%				
							AND OXIDATION THROUGHOUT. COAL SEAM AT 10.03'. FRACTURES					
				10.1			AT 9.33', 9.57', 9.75', 9.84', 9.95'.					
			10.1				MIX OF LIGHT BROWN TO DARK GRAY LIMESTONE/CALCARIOUS					
				10.3			SANDSTONE.					
			10.3	11.0			HIGHLY FRACTURED, VARIOUS SHADES OF BROWN SANDSTONE.					
RUN 2	11.0	16.0	11.0	16.0			HIGHLY FRACTURED DARK GRAY SILTSTONE/MUDSTONE. ZONES	TCR: 37%, SCR: 0%, RQD: 0%				
							OF WEATHERING/OXIDATION THROUGHOUT.					
							COULD NOT RE-ENTER CORE HOLE TO ADVANCE FURTHER DUE					
							TO CAVE.					
							CAVED AT 14'.					

Notes/Comments:
<u>Pocket Pentrometer Testing</u>   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.

LABORATORY TESTING SUMMARY
SUNOCO PENNSYLVANIA PIPELINE PROJECT
HDD S2-0010 LOYALHANNA LAKE SOIL BORINGS

HDD No.	Test Boring No.	Sample No.	Depth of Sample (ft.)		Water Content, % (ASTM D2216)	Percent Silts/Clays, % (ASTM D1140)	Atterburg Limits (ASTM D4318)			USCS Classif. (ASTM D2487)
			From	To			Liquid Limit, %	Plastic Limit, %	Plasticity Index, %	
S2-0010	SB-01	1	3.0	3.7	5.3	10.9	-	-	-	-
		2	8.0	8.5	4.6	13.2	-	-	-	-
	SB-02	1	3.0	5.0	8.0	21.0	-	-	-	-
		3	13.0	13.8	4.1	23.5	-	-	-	-
		4	18.0	18.7	3.6	10.4	-	-	-	-
		5	23.0	23.7	3.5	11.3	-	-	-	-
		6	28.0	28.2	3.5	16.5	-	-	-	-
	SB-03	1	3.0	5.0	11.8	48.5	-	-	-	-
		2	8.0	10.0	18.1	51.3	26	15	11	CL/SC
		3	13.0	15.0	19.0	29.7	-	-	-	-
		5	21.0	21.4	8.2	14.1	-	-	-	-
	SB-04	1	3.0	5.0	12.3	43.4	-	-	-	-

Notes:

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

Sunoco Pennsylvania Pipeline Project
Regional Geological Description
HDD S2-0010 Loyalhanna Lake

HDD No.	Name	Boring No.	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
S2-0010	Loyalhanna Lake	SB-01 SB-02 SB-03 SB-04	**Glenshaw Formation** - Cyclic sequences of shale, sandstone, red beds, and thin limestone and coal; includes four marine limestone or shale horizons; red beds are involved in landslides; base is at top of Upper Freeport coal.	Lake bottom	Glenshaw	Shale-sandstone with limestone-clastic-coal	280-375	10-30

SUNOCO PENNSYLVANIA PIPELINE
ROCK CORE DESCRIPTION SUMMARY TABLE

Location	Boring No.	Core Run	Core Depth (ft)		TCR (%)	SCR (%)	RQD (%)	Depth (ft)		Weathering	Classification	Bedding Thickness (ft)	Color	Discontinuity Data
			From	To				From	To					
S2-0010	SB-2	1	28.5	30.5	87.5	60	48	28.5	30.5	Slight	Sandstone	2	Gray	Moderatley fractured - Avg. Dip 19° (5° - 25°)
S2-0010	SB-2	2	30.5	35.5	98	82.5	69	30.5	35.5	Slight	Sandstone	5 (continuous from above)	Gray	Moderately to heavily fractured - Avg. Dip 3° (0° - 5°)
S2-0010	SB-2	3	35.5	38.2	94	70	48	35.5	38.2	Moderate	Sandstone	2.7 (continuous from above)	Gray	Heavily fractured - Avg. Dip 18° (2° - 46°)
S2-0010	SB-4	1	9	11	83	73	17	9	11	Moderate	Sandstone	2	Gray	Heavily fractured - Avg. Dip 4° (0° - 11°)
S2-0010	SB-4	2	11	16	94	70	48	11	16	Heavily	Siltstone	5	Gray	Heavily to extremely fractured - Rubble

FIELD DESCRIPTION AND LOGGING SYSTEM FOR SOIL EXPLORATION

GRANULAR SOILS

(Sand, Gravel & Combinations)

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

Relative Proportions

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

Particle Size Identification

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

COHESIVE SOILS

(Silt, Clay & Combinations)

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

Plasticity

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

ROCK

(Rock Cores)

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

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

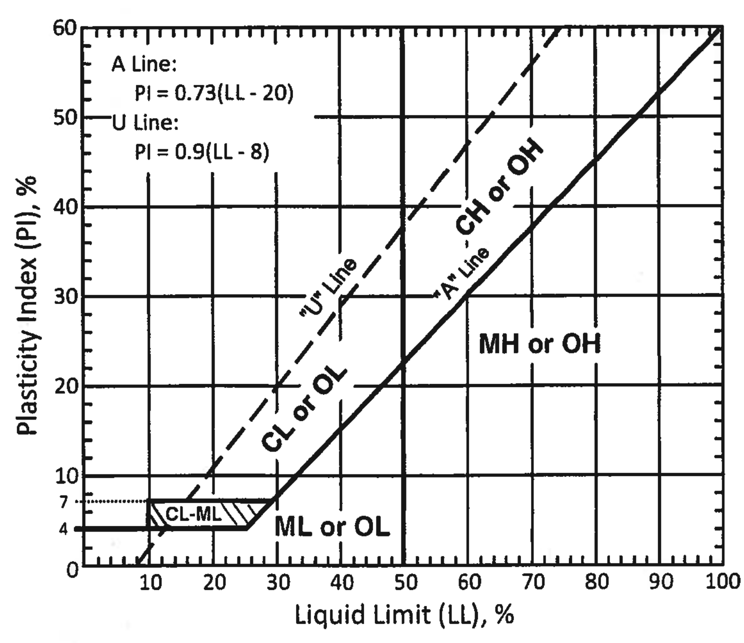
Groundwater observations were made at the times indicated. Groundwater elevations fluctuate throughout a given year, depending on actual field porosity and variations in seasonal and annual precipitation.

UNIFIED SOIL CLASSIFICATION SYSTEM [Casagrande (1948)]

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

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

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



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

LEGEND:

◎ Geotechnical Test Boring (TB) Location

TETRA TECH

GEOTECHNICAL BORING LOCATION
LOYALHANNA LAKE, COMMONWEALTH OF PENNSYLVANIA
SUNOCO PENNSYLVANIA PIPELINE PROJECT

FIELD DESCRIPTION AND LOGGING SYSTEM FOR SOIL EXPLORATION

GRANULAR SOILS
(Sand, Gravel & Combinations)

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

Relative Proportions

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

Particle Size Identification

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

COHESIVE SOILS
(Silt, Clay & Combinations)

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

Plasticity

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

ROCK
(Rock Cores)

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

RQD: Rock Quality Designation
TCR: Total Core Recovery
SCR: Solid Core Recovery

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

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

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:	OFF BUSH ROAD AT LOYALHANNA LAKE, COMMONWEALTH OF PA		
HDD No.:		Dates(s) Drilled: Aug 15 to 16, 2017	Inspector: M. ESPOSITO
Boring No.:	TB-01	Drilling Method: SPT - ASTM D1586	Driller: ROBERTS
Drilling Contractor: SHENANDOAH DRILLING		Groundwater Depth (ft): See Notes.	Total Depth (ft): 170
Boring Location Coordinates:		40°26'17.34"N	79°26'2.80"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
1	0	1.5	0.0		9	CL	BROWN SANDY CLAY, TRACE FINE TO COARSE	8	10	12		**22**
							GRAVEL.					
2	5.0	7.0			12		BROWN SANDY CLAY (USCS: CL).	3	3	3	6	**6**
				10.5								
3	10.0	11.0	10.5		10	WEATHERED SANDSTONE	GRAYISH BROWN PARTIALLY WEATHERED SANDSTONE.	5	50/6"			**>50**
4	15.0	17.0			20		DECOMPOSE ROCK WEATHERED TO A VARIABLE COLORED SILTY	6	10	12	14	**22**
				18.5			CLAY, A LITTLE FINE TO COARSE ROCK FRAGS. (USCS: CL).					
5	20.0	21.2	18.5		16	WEATHERED SHALE	GRAY PARTIALLY WEATHERED ROCK (SHALE)	9	37	50/3"		**>50**
6	25.0	26.2			16		GRAY PARTIALLY WEATHERED ROCK (SHALE)	19	47	50/2"		**>50**
				28.0								
7	30.0	30.1	28.0		1	WEATHERED SILTSTONE	GRAY PARTIALLY WEATHERED ROCK (SILTSTONE)	50/1"				**>50**
8	35.0	35.1			1		GRAY PARTIALLY WEATHERED ROCK (SILTSTONE)	50/1"				**>50**
9	40.0	40.1		43.0	2		GRAY PARTIALLY WEATHERED ROCK (SILTSTONE)	50/1"				**>50**
							AUGER REFUSAL AT 43.0'.					
							<u>ROCK CORING</u>					
RUN 1	43.0	45.0	43.0	45.5	18.0	BEDROCK	GRAY SILTSTONE. MODERATE WEATHERING.	TCR: 75%, SCR: 67%, RQD: 25%				
RUN 2	45.0	50.0	45.5	45.8	59.0		BROWNISH GRAY SHALE, SLIGHT WEATHERING.	TCR: 98%, SCR: 93%, RQD: 74%				
			45.8	46.5			GRAY SILTSONE, SLIGHT WEATHERING.					
			46.5	47.0			GRAY SHALE, SLIGHT WEATHERING.					
RUN 3	50.0	55.0	47.0	54.5	57.5		GRAY SANDSTONE, SLIGHT WEATHERING.	TCR: 96%, SCR: 93%, RQD: 83%				
			54.5	55.0			GRAY SILTSTONE, MODERATE WEATHERING.					
RUN 4	55.0	60.0	55.0	56.5	56.4		GRAY, WITH BROWN, SANDSTONE, STAINING, MODERATE WEATHER.	TCR: 94%, SCR: 85%, RQD: 80%				
			56.5	57.0			GRAY WITH BROWN SHALE, MODERATE STAINING.					
RUN 5	60.0	65.0	57.0		60.0		GRAY SANDSTONE.	TCR: 100%, SCR: 100%, RQD: 100%				
							(CONTINUED ON NEXT PAGE)					

Notes/Comments:

GROUNDWATER NOT ENCOUNTERED WITHIN OVERBURDEN SOILS AT AUGER REFUSAL DEPTH OF 43.0 FEET BELOW GROUND SURFACE.

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: OFF BUSH ROAD AT LOYALHANNA LAKE, COMMONWEALTH OF PA			Page 2 of 2
HDD No.:	Dates(s) Drilled: Aug 15 to 16, 2017	Inspector: M. ESPOSITO	
Boring No.: TB-01	Drilling Method: SPT - ASTM D1586	Driller: ROBERTS	
Drilling Contractor: SHENANDOAH DRILLING	Groundwater Depth (ft): See Notes.	Total Depth (ft): 170	
Boring Location Coordinates:	40°26'17.34"N	79°26'2.80"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
							(CONTINUE ROCK CORING DATA)		
RUN 6	65.0	70.0		70.0	57	BEDROCK	GRAY SANDSTONE. SLIGHT WEATHERING.	TCR: 95%, SCR: 95%, RQD: 95%	
RUN 7	70.0	75.0	70.0	76.5	60		DARK GRAY SILTSTONE, SLIGHT WEATHERING.	TCR: 100%, SCR: 92%, RQD: 82%	
RUN 8	75.0	80.0	76.5		58		GRAY SANDSTONE, SLIGHT WEATHERING.	TCR: 97%, SCR: 97%, RQD: 92%	
RUN 9	80.0	85.0		85.0	60		(SAME).	TCR: 100%, SCR: 98%, RQD: 88%	
RUN 10	85.0	90.0	85.0	87.0	60		DARK GRAY SHALE, SLIGHT WEATHERING.	TCR: 100%, SCR: 88%, RQD: 66%	
			87.0				GRAY AND DARK GRAY SANDSTONE, MODERATE WEATHERING.		
RUN 11	90.0	95.0		98.0	60		GRAY AND DARK GRAY SANDSTONE, SLIGHT WEATHERING.	TCR: 100%, SCR: 95%, RQD: 87%	
RUN 12	95.0	100.0	98.0		60		**DARK GRAY LIMESTONE, RUBBLE FROM 98 TO 100 FEET,**	TCR: 100%, SCR: 50%, RQD: 48%	
				102.0			SOLID ROCK FROM 100' TO 102'.		
RUN 13	100.0	105.0	102.0		58		DARK GRAY SHALE, SLIGHT TO MODERATE WEATHERING.	TCR: 97%, SCR: 93%, RQD: 83%	
RUN 14	105.0	110.0			56		(SAME)	TCR: 93%, SCR: 90%, RQD: 85%	
RUN 15	110.0	115.0		115.5	60		(SAME)	TCR: 100%, SCR: 90%, RQD: 66%	
RUN 16	115.0	120.0	115.5	116.0	60.0		DARK GRAY SHALE WITH COAL LENSES, MODERATE WEATHERING.	TCR: 100%, SCR: 90%, RQD: 50%	
			116.0	121.5			LIGHT TO DARK GRAY SILTSTONE, SLIGHT WEATHERING.		
RUN 17	120.0	125.0	121.5	125.0	59.0		LIGHT GRAY SHALE, SLIGHT WEATHERING.	TCR: 98%, SCR: 98%, RQD: 94%	
RUN 18	125.0	130.0	125.0	128.5	60.0		LIGHT GRAY SANDSTONE, SOLID.	TCR: 100%, SCR: 94%, RQD: 80%	
			128.5	129.0			LIGHT TO DARK GRAY BASAL CONGLOMERATE, SLIGHT WEATHERING.		
RUN 19	130.0	135.0	129.0	132.5	56.0		DARK GRAY MUDSTONE, SLIGHT WEATHERING.	TCR: 94%, SCR: 82%, RQD: 76%	
			132.5	135.5			DARK GRAY SILTSTONE, SLIGHT WEATHERING.		
RUN 20	135.0	140.0	135.5	142.0	60.0		DARK GRAY SHALE, SLIGHT WEATHERING.	TCR: 100%, SCR: 78%, RQD: 66%	
RUN 21	140.0	145.0	142.0	142.5	58		DARK GRAY HEAVILY WEATHERED COAL, RUBBLE.	TCR: 97%, SCR: 82%, RQD: 52%	
			142.5	143.0			DARK GRAYDARK GRAY SHALE, MODERATE WEATHERING.		
RUN 22	145.0	150.0	143.0		59		GRAY TO GREENISH GRAY SILTSTONE, SLIGHT WEATHERING.	TCR: 98%, SCR: 88%, RQD: 82%	
RUN 23	150.0	155.0			60		SAME	TCR: 100%, SCR: 80%, RQD: 58%	
RUN 24	155.0	160.0		159.5	58		SAME	TCR: 96%, SCR: 82%, RQD: 74%	
RUN 25	160.0	165.0	159.5	164.0	60		GRAY SHALE.	TCR: 100%, SCR: 100%, RQD: 92%	
RUN 26	165.0	170.0	164.0	170.0	60		DARK GRAY SILTSTONE.	TCR: 100%, SCR: 100%, RQD: 100%	

Notes/Comments:

GROUNDWATER NOT ENCOUNTERED WITHIN OVERBURDEN SOILS AT AUGER REFUSAL DEPTH OF 43.0 FEET BELOW GROUND SURFACE.

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.

ROCK CORE DESCRIPTION SUMMARY
SUNOCO PENNSYLVANIA PIPELINE PROJECT
LOYALHANNA LAKE, TB-01

Rock Core Run	Core Run Depth From	Core Run Depth To	TCR	SCR	RQD	Rock Strata From	Rock Strata To	Weathering	Classification	Bedding Thickness	Color	Discontinuity Data
1	43	45	75	67	25	43	45	Moderate	Siltstone	Massive	Gray	Fractures ranging from 0° to 80°, Avg. 24°
2	45	50	98	93	74	45	45.5	Slight	Siltstone	Thinly Bedded	Gray	Fractures nearly horizontal; Lamination nearly horizontal
						45.5	45.75	Slight	Shale	Thinly Bedded	Browning Gray	Nearly horizontal bedding, fracturing along bedding planes
						45.75	46.5	Slight	Siltstone	Thinly Bedded	Gray	Single fracture, 10°
						46.5	47	Slight	Shale	Thinly Bedded	Gray	Nearly horizontal bedding
3	50	55	96	93	83	47	54.5	Slight	Sandstone	Massive with thin laminations	Gray	Fractures ranging from 0° to 13°, Avg. 6°; Laminations ranging from 0° to 20°, Avg. 5°
						54.5	55	Moderate	Siltstone	Thinly Bedded	Gray	Fractures ranging from 0° to 20°, Avg. 10°
4	55	60	94	85	80	55	56.5	Moderate	Sandstone	Massive	Gray with brown staining	Fractures ranging from 10° to 60°, Avg. 26°
						56.5	57	Moderate	Shale	Thinly Bedded	Gray with brown staining	Thin shale bed
5	60	65	100	100	100	57	70	Slight	Sandstone	Massive with thin laminations	Gray	Predominantly intact with few fractures; Fractures ranging from 5° to 53°, Avg. 20°
6	65	70	95	95	95							
7	70	75	100	92	82	70	76.5	Slight	Siltstone	Massive	Dark Gray	Shale beds from 74' to 74.3' and 75.7' to 75.9'; Fractures ranging from 4° to 65°, Avg. 12°
8	75	80	97	97	92	76.5	85	Slight	Sandstone	Massive with thin laminations	Gray	Laminations 5°; Fractures 5°; All fractures along laminations; Clasts at 82' and 82.5'
9	80	85	100	98	88							
10	85	90	100	88	66	85	87	Slight	Shale	Thinly Bedded	Dark Gray	Fractures ranging from 9° to 17°, Avg. 12°; Bedding approx. 15°
11	90	95	100	95	88	87	98	Slight	Sandstone	Massive	Gray and Dark Gray	Sandstone with large clasts of shale; Fractures ranging from 5° to 80°, Avg. 37°
12	95	100	100	50	48	98	102	Slight	Limestone	Massive	Dark Gray	Rubble to 100', then one solid piece to 102 ft.
13	100	105	97	93	83	102	115.5	Slight	Shale	Thinly Bedded	Dark Gray	Nearly horizontal bedding; Fractures ranging from 0° to 12°, Avg. 8°
14	105	110	93	90	85							
15	110	115	100	90	66							
16	115	120	100	90	50	115.5	116	Moderate	Shale with Coal Lenses	Thinly Bedded	Dark Gray	Rubble
						116	121.5	Slight	Siltstone	Massive	Light to Dark Gray	Fractures ranging from 4° to 25°, Avg. 11°
17	120	125	98	98	94	121.5	125	Slight	Shale	Thinly Bedded	Light Gray	Nearly horizontal bedding; Fractures ranging from 3° to 13°, Avg. 7°

ROCK CORE DESCRIPTION SUMMARY
SUNOCO PENNSYLVANIA PIPELINE PROJECT
LOYALHANNA LAKE, TB-01

Rock Core Run	Core Run Depth		TCR	SCR	RQD	Rock Strata		Weathering	Classification	Bedding Thickness	Color	Discontinuity Data
	From	To				From	To					
18	125	130	100	94	80	125	128.5	Slight	Sandstone, grading coarser with depth	Thinly Bedded	Light Gray	No Fractures
						128.5	129	Slight	Basal Conglomerate	Massive	Light to Dark Gray	No Fractures
19	130	135	94	82	76	129	132.5	Slight	Mudstone	Massive	Dark Gray	Fractures ranging from 0° to 15°, Avg. 6°
						132.5	135.5	Slight	Siltstone	Massive	Dark Gray	Fractures nearly horizontal; Lamination nearly horizontal
20	135	140	100	78	66	135.5	142	Slight	Shale	Thinly Bedded	Dark Gray	Nearly horizontal bedding
21	140	145	97	82	52	142	142.5	Heavily	Coal	Massive	Black	Rubble
						142.5	143	Slight	Shale	Thinly Bedded	Dark Gray	Nearly horizontal bedding
22	145	150	98	88	82	143	159.5	Slight to Moderate	Siltstone	Massive	Gray to Greenish Gray	Fractures ranging from 0° to 35°, Avg. 15°
23	150	155	100	80	58							
24	155	160	96	82	74							
25	160	165	100	100	92	159.5	164	Slight	Shale	Thinly Bedded	Gray	Fractures nearly horizontal; Bedding nearly horizontal
26	165	170	100	100	100	164	170	Slight	Siltstone	Massive	Dark Gray	No Fractures

Sunoco Pennsylvania Pipeline Project
Regional Geological Description
Loyalhanna Lake

Name	Boring No.	Geology Description	GENERAL TOPOGRAPHIC SETTING	BEDROCK FORMATION	GENERAL ROCK TYPE	APPROX MAX FORMATION THICKNESS (FT)	DEPTH TO ROCK (Ft bgs) based on nearby well drilling logs
Loyalhanna Lake	TB-01	**Glenshaw Formation** - Cyclic sequences of shale, sandstone, red beds, and thin limestone and coal; includes four marine limestone or shale horizons; red beds are involved in landslides; base is at top of Upper Freeport coal.	Lake bottom	Glenshaw	Shale-sandstone with limestone-clastic-coal	280-375	10-30

LABORATORY TESTING SUMMARY
SUNOCO MARINER EAST
LOYALHANNA LAKE HDD INVESTIGATION (AUGUST 2017)

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, %	
TB-01	1	0.0	1.5	12.5	52.3	-	-	-	-
	2	5.0	7.0	18.9	64.0	35	21	14	CL
	4	15.0	17.0	21.0	88.2	38	21	17	CL
	5	20.0	21.2	5.9	84.7				
	6	25.0	26.2	6.2	33.3	-	-	-	-

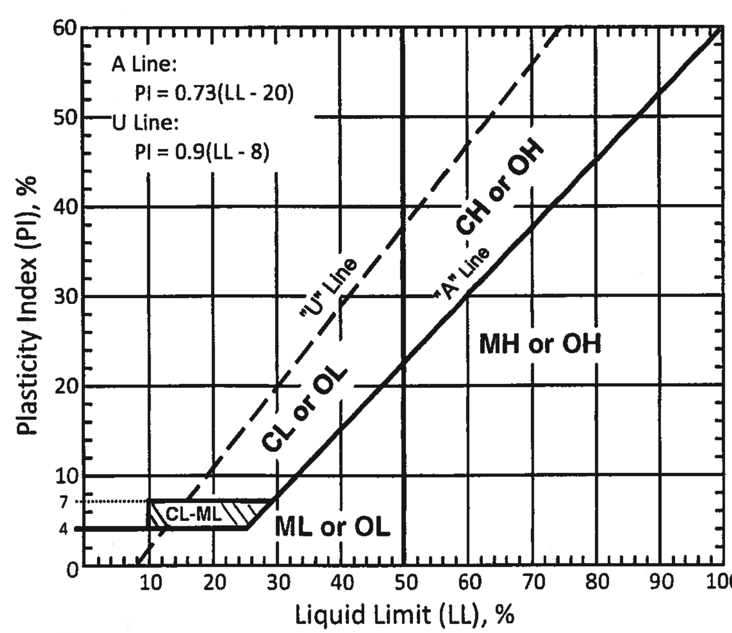
Notes:
1) Sample depths based on feet below grade at time of exploration.

UNIFIED SOIL CLASSIFICATION SYSTEM [Casagrande (1948)]

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

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

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



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

October 13, 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 2 – Loyalhanna Lake
Commonwealth of Pennsylvania
Drawing # PA-WM2-0064.0000-WXb
PO #20170912-3
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 Loyalhanna Lake (Drawing # PA-WM2-0064.0000-WXb) 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 one boring, designated as B2-4W, visual classification and photography of the rock core samples, and laboratory testing of representative rock samples.

Test boring, B2-4W was drilled between September 7 and 15, 2017 to a depth of 288.0 feet, as shown on the attached **Test Boring Location Plan**. Bedrock typically consisted of interlayered sedimentary rock comprised of sandstone, shale, siltstone, and limestone. The final test boring log 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 the boring location. 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 Log, 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

Loyalhanna Lake HDD Core B2-4W
PA-WM2-0064.0000-WXb
Westmoreland County, Pennsylvania

Exhibit
A-2

EXPLORATION RESULTS

BORING LOG NO. B2-4W Loyalhanna Lake West

PROJECT: Mariner East Pipeline Borings

SITE: Spread 2

CLIENT: Directional Project Support Incorporated
Magnolia, TX 77354

LOCATION PA-WM2-0064.0000-WXb
201700912-3
Latitude: 40.436772° Longitude: -79.449165°

Approximate Surface Elev: 1119 (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 - SANDY LEAN CLAY, trace gravel, brown to light brown, stiff									
4.3		1114.5+/-			X	17.5	6-7-12 N=19			
	Highly weathered, light brown and yellow brown LIMESTONE, trace clay and sand		5							
					X	4	35-50/0"			
			10							
	Soft to moderately hard, very severely weathered, brown SANDSTONE				X	1	50/1"			
			15							
18.6		1100.5+/-			X	1	50/1"			
	Run 1, Moderately hard, severely weathered, brown, fine to medium-grained, micaceous SANDSTONE, thin bedding, primary joint set, low angle, close to very close, rough, planar, slightly open, iron stained From 21.4 to 23 feet: High angle joint, rough, tight, clay-filled, iron-stained		20		Core	51		45	1.25 1.25 1 0.75	
23.0	Run 2, Similar to 24.9 feet At 24.9 feet: Moderately hard, moderately weathered, brown to gray, fine to medium-grained, micaceous SANDSTONE, thin bedding, primary joint set, low angle, close to moderately close, smooth, planar, slightly open, iron stained	1096+/-	25		Core	52		55	0.5 0.5 1.25 0.75 0.75	
28.0	Run 3, Similar to 31 feet, smooth to rough From 30.3 to 30.9 feet: high angle joint, rough, planar, slightly open,	1091+/-	30		Core	60			1.25	

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:

Additional water level observations:
156.3' on 9/14/17
165.3' on 9/15/17
265.3' after boring completion

WATER LEVEL OBSERVATIONS

- *85.4' on 8/11/17*
- *133' on 9/12/17*
- *154.8' on 9/13/17*

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-07-2017	Boring Completed: 09-15-2017
Drill Rig: Diedrich D-50	Driller: Terra Testing, Inc.
Project No.: J217P078	Exhibit: A-1

BORING LOG NO. B2-4W Loyalhanna Lake West

PROJECT: Mariner East Pipeline Borings

CLIENT: Directional Project Support Incorporated
Magnolia, TX 77354

SITE: Spread 2

LOCATION PA-WM2-0064.0000-WXb
201700912-3
Latitude: 40.436772° Longitude: -79.449165°

Approximate Surface Elev: 1119 (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)
	iron-stained At 31 feet: Moderately hard, slightly weathered, gray, fine to medium-grained, micaceous SANDSTONE, thin bedding, primary joint set, low angle, moderately close, rough, planar, slightly open, iron stained					60		70	1 0.5 0.5 0.5	
33.0	Run 4, Similar	1086+/-	35			60		93	0.5 0.5 0.5 0.5 0.5	
38.0	Run 5, Similar	1081+/-	40			60		97	0.5 0.5 0.5 0.5 0.75	
43.0	Run 6, Similar to 45.7 feet, interbedded coal seams from 45.2 to 45.6 feet At 45.7 feet: Moderately hard, slightly weathered, dark gray, carbonaceous SHALE, very thin bedding, primary joint set, low angle, close to moderately close, smooth, planar, fresh, slightly open; secondary joint set, high angle, moderately close to close, rough, planar, open, fresh	1076+/-	45			60		77	0.5 0.5 0.75 1 1.25	
48.0	Run 7, Similar	1071+/-	50			60		70	3.25 3.25 1.5 1.25 1.25	
53.0	Run 8, Moderately hard, fresh, dark gray, carbonaceous SHALE, very thin bedding, primary joint set, low angle, close to moderately close, smooth, planar, fresh, tight to slightly open	1066+/-	55			60		95	1.25 1.5 0.75 0.75 0.5	
58.0	Run 9, Similar to 58.8 feet At 58.8 feet: Moderately hard, slightly weathered, gray SHALE	1061+/-	60			54			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:

Additional water level observations:
156.3' on 9/14/17
165.3' on 9/15/17
265.3' after boring completion

WATER LEVEL OBSERVATIONS

- *85.4' on 8/11/17*
- *133' on 9/12/17*
- *154.8' on 9/13/17*

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-07-2017	Boring Completed: 09-15-2017
Drill Rig: Diedrich D-50	Driller: Terra Testing, Inc.
Project No.: J217P078	Exhibit: A-1

BORING LOG NO. B2-4W Loyalhanna Lake West

PROJECT: Mariner East Pipeline Borings

CLIENT: Directional Project Support Incorporated Magnolia, TX 77354

SITE: Spread 2

LOCATION PA-WM2-0064.0000-WXb 201700912-3
Latitude: 40.436772° Longitude: -79.449165°

Approximate Surface Elev: 1119 (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)
interbedded with siltstone, occasional calcareous nodules, very thin bedding, primary joint set, low angle, rough, planar, fresh, slightly open From 58.6 to 58.9 feet: Conglomeratic zone 63.0	1056+/-				54		57	2.5 2.25 1.25 1.75	
Run 10, Similar 68.0	1051+/-	65			53		75	2.25 1.5 1.25 1.75 1.5	
Run 11, Similar 73.0	1046+/-	70			60		80	1.25 1.25 0.75 0.75 0.5	
Run 12, Similar From 76.3 to 76.5, 76.7 to 77 feet: High angle joints, rough, planar, slightly open, fresh 78.0	1041+/-	75			60		88	0.5 0.75 0.75 0.75 1.25	
Run 13, Similar to 78.2 feet At 78.2 feet: Moderately hard, fresh, gray, fine to medium grained, micaceous SANDSTONE, thin bedding, primary joint set, low angle, close to moderately close, smooth, planar, fresh, slightly open 83.0	1036+/-	80			60		98	0.25 0.5 0.5 0.5 0.5	
Run 14, Similar, slightly open to open From 86.1 to 86.8 feet: Argillaceous zone Lost water circulation at 86 feet, regained during following run 88.0	1031+/-	85	▽		60		95	0.5 0.75 0.5 0.75 1	
Run 15, Similar		90			60			0.5	

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:

Additional water level observations:
156.3' on 9/14/17
165.3' on 9/15/17
265.3' after boring completion

WATER LEVEL OBSERVATIONS

- ▽ *85.4' on 8/11/17*
- ▽ *133' on 9/12/17*
- ▼ *154.8' on 9/13/17*

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-07-2017	Boring Completed: 09-15-2017
Drill Rig: Diedrich D-50	Driller: Terra Testing, Inc.
Project No.: J217P078	Exhibit: A-1

BORING LOG NO. B2-4W Loyalhanna Lake West

PROJECT: Mariner East Pipeline Borings

SITE: Spread 2

CLIENT: Directional Project Support Incorporated Magnolia, TX 77354

LOCATION PA-WM2-0064.0000-WXb 201700912-3
Latitude: 40.436772° Longitude: -79.449165°

Approximate Surface Elev: 1119 (Ft.) +/-

DEPTH	Description	ELEVATION (Ft.)	DEPTH (Ft.)	RECOVERY (In.)	RQD (%)	Core rate (min/ft)
93.0		1026+/-		60	86	0.5 0.5 0.5 0.25
98.0	Run 16, Similar	1021+/-	95	60	98	0.5 0.75 0.5 0.5 0.5
103.0	Run 17, Similar From 100.7 to 101.2 feet: Turbidite zone	1016+/-	100	60	100	0.5 0.5 0.25 0.75 0.5
108.0	Run 18, Similar to 107.6 feet From 106.2 to 107.3 feet: Calcareous zone At 107.6 feet: Moderately hard, fresh, gray SILTSTONE interbedded with shale, very thin bedding, primary joint set, low angle, close to moderately close, rough, planar, tight to slightly open	1011+/-	105	58	85	0.5 1 1.25 1 1.25
113.0	Run 19, Similar	1006+/-	110	60	88	2 2.25 1.5 1.25 1.25
118.0	Run 20, Similar From 116.9 to 117.1 feet: Arenaceous zone From 117.3 to 117.6 feet: High angle joint, tight, rough, planar, clay-filled	1001+/-	115	60	88	1.75 1.25 1.25 1.25 1.25
	Run 21, Similar to 118.6 feet At 118.6 feet: Moderately hard, fresh, gray, fine to medium-grained		120	60		1.25

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:
Additional water level observations:
156.3' on 9/14/17
165.3' on 9/15/17
265.3' after boring completion

WATER LEVEL OBSERVATIONS
- *85.4' on 8/11/17*
- *133' on 9/12/17*
- *154.8' on 9/13/17*

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-07-2017	Boring Completed: 09-15-2017
Drill Rig: Diedrich D-50	Driller: Terra Testing, Inc.
Project No.: J217P078	Exhibit: A-1

BORING LOG NO. B2-4W Loyalhanna Lake West

PROJECT: Mariner East Pipeline Borings

CLIENT: Directional Project Support Incorporated
Magnolia, TX 77354

SITE: Spread 2

LOCATION PA-WM2-0064.0000-WXb 201700912-3
Latitude: 40.436772° Longitude: -79.449165°

Approximate Surface Elev: 1119 (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)
123.0	SANDSTONE interbedded with siltstone and occasional calcareous nodules, thin bedding, primary joint set, low angle, close to moderately close, rough, planar, fresh, slightly open	996+/-				60		83	1.25 1.25 1 0.75	
128.0	Run 22, Similar to 126.5 feet From 123.6 to 123.4 feet: High angled, healed joint At 125.4 feet: low angle joint, tight, slightly rough, planar, clay-filled At 126.5 feet: Hard, slightly weathered, gray, argillaceous LIMESTONE, thin bedding, primary joint set, low angle, close to moderately close, rough, planar, open, fresh	991+/-	125			60		73	1 1 1 1.25 1.5	
133.0	Run 23, Similar From 128 to 128.4 feet: High angle joint, rough, stepped, tight, clay-filled Lost water circulation at 128.4 feet, no circulation for remainder of boring	986+/-	130	∇ (133')		60		85	1.75 1.5 1.75 1.5 1.25	
138.0	Run 24, Moderately hard, moderately weathered, dark gray, carbonaceous SHALE, very thin bedding, primary joint set, low angle, very close to close, slightly open, smooth, planar, fresh; secondary joint set, moderately dipping, slickensided, planar, tight, fresh	981+/-	135			56		38	1.75 1.25 1.5 1.5 2	
143.0	Run 25, Similar	976+/-	140			18		0	3.75 3.25 3.25 3.25 3.5	
148.0	Run 26, Similar From 143.1 to 143.5 feet: Clay-filled broken zone	971+/-	145			48		30	2 3.5 2.25 2 1.5	
	Run 27, Similar to 149.4 feet From 148.2 to 148.4 feet: Clay-filled zone		150			60			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:

Additional water level observations:
156.3' on 9/14/17
165.3' on 9/15/17
265.3' after boring completion

WATER LEVEL OBSERVATIONS

85.4' on 8/11/17
133' on 9/12/17
154.8' on 9/13/17

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-07-2017	Boring Completed: 09-15-2017
Drill Rig: Diedrich D-50	Driller: Terra Testing, Inc.
Project No.: J217P078	Exhibit: A-1

BORING LOG NO. B2-4W Loyalhanna Lake West

PROJECT: Mariner East Pipeline Borings

CLIENT: Directional Project Support Incorporated Magnolia, TX 77354

SITE: Spread 2

LOCATION PA-WM2-0064.0000-WXb 201700912-3
Latitude: 40.436772° Longitude: -79.449165°

Approximate Surface Elev: 1119 (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)
153.0	From 148.5 to 148.6 feet: Moderately dipping joint, rough, planar, tight, slightly weathered From 149.4 to 152.3 feet: Moderately hard, slightly weathered, gray SILTSTONE interbedded with shale, very thin bedding, primary joint set, low angle, very close to close, rough, planar, slightly open, fresh	966+/-				60		73	1.25 1.5 1.25 1.25	
158.0	At 152.3 feet: Moderately hard, slightly weathered, gray SHALE, very thin bedding, primary joint set, low angle, very close to close, smooth, planar, slightly open, fresh Run 28, Similar	961+/-	155	▼		60		57	1.25 1.25 1.5 1.25 1.25	
163.0	Run 29, Similar to 161.6 feet At 161.6 feet: Moderately hard, fresh, gray SHALE interbedded with siltstone, very thin bedding, primary joint set, low angle, close to moderately close, rough, planar, moderately open, fresh	956+/-	160			60		82	1.5 1.75 1.5 2.5 2	
168.0	Run 30, Similar to 166 feet At 166 feet: Hard, fresh, gray, argillaceous LIMESTONE, thin to medium bedding, intact	951+/-	165			60		100	1.5 1.25 0.75 0.75 0.75	
173.0	Run 31, Similar to 168.7 feet At 168.7 feet: Moderately hard, fresh, dark gray, carbonaceous SHALE interbedded with siltstone, primary joint set, moderately dipping, moderately close, rough, planar, fresh, open	946+/-	170			60		100	0.5 1.25 1 0.75 0.75	
178.0	Run 32, Similar to 175.8 feet At 175.8 feet: Moderately hard, slightly weathered, gray SILTSTONE interbedded with shale and occasional calcareous nodules, very thin bedding, primary joint set, low angle, close to very close, rough, planar, fresh, slightly open	941+/-	175			56		92	0.75 0.75 1 1.25 1.75	
	Run 33, Similar		180			57			1.25	

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:
Additional water level observations:
156.3' on 9/14/17
165.3' on 9/15/17
265.3' after boring completion

WATER LEVEL OBSERVATIONS
- *85.4' on 8/11/17*
- *133' on 9/12/17*
- *154.8' on 9/13/17*

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-07-2017	Boring Completed: 09-15-2017
Drill Rig: Diedrich D-50	Driller: Terra Testing, Inc.
Project No.: J217P078	Exhibit: A-1

BORING LOG NO. B2-4W Loyalhanna Lake West

PROJECT: Mariner East Pipeline Borings

CLIENT: Directional Project Support Incorporated
Magnolia, TX 77354

SITE: Spread 2

LOCATION PA-WM2-0064.0000-WXb
201700912-3
Latitude: 40.436772° Longitude: -79.449165°

Approximate Surface Elev: 1119 (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)
	183.0 — 936+/-				57		70	1.75 1.5 1.25 1.25	
	Run 34, Similar to 184.4 feet At 184.4 feet: Moderately hard, fresh, gray, carbonaceous SHALE interbedded with siltstone, very thin bedding, primary joint set, low angle, close to moderately close, smooth, planar, fresh From 186 to 186.3 feet: High angle joint, rough, stepped, fresh, open 188.0 — 931+/-	185			60		95	1.25 1.25 1.25 1.75 1.25	
	Run 35, Similar 193.0 — 926+/-	190			60		95	1 1.25 1.25 0.75 0.75	
	Run 36, Similar From 194.4 to 194.6 feet: Moderately dipping joint, smooth, planar, fresh, slightly open From 195.1 to 195.3 feet: Moderately dipping joint, rough, stepped, fresh, open 198.0 — 921+/-	195			60		78	1.25 1.5 1.75 1.25 1.75	
	Run 37, Similar 203.0 — 916+/-	200			60		100	2.5 2.25 2 2.75 2.5	
	Run 38, Similar From 203 to 203.5 feet: Calcareous zone From 206.2 to 206.3 feet: Moderately dipping joint, smooth, planar, tight, fresh 208.0 — 911+/-	205			60		80	1.5 1.5 1.25 1 1.25	
	Run 39, Similar to 210 feet, carbonaceous from 208.8 to 210 feet From 210 to 211.3 feet: Moderately hard, fresh, gray, fine to	210			60			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:

Additional water level observations:
156.3' on 9/14/17
165.3' on 9/15/17
265.3' after boring completion

WATER LEVEL OBSERVATIONS

85.4' on 8/11/17
133' on 9/12/17
154.8' on 9/13/17

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-07-2017	Boring Completed: 09-15-2017
Drill Rig: Diedrich D-50	Driller: Terra Testing, Inc.
Project No.: J217P078	Exhibit: A-1

BORING LOG NO. B2-4W Loyalhanna Lake West

PROJECT: Mariner East Pipeline Borings

CLIENT: Directional Project Support Incorporated Magnolia, TX 77354

SITE: Spread 2

LOCATION PA-WM2-0064.0000-WXb 201700912-3

Latitude: 40.436772° Longitude: -79.449165°

Approximate Surface Elev: 1119 (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)
213.0	medium-grained SANDSTONE interbedded with shale, thin bedding, intact At 211.3 feet: Moderately hard, slightly weathered, gray SILTSTONE interbedded with shale, very thin bedding, primary joint set, low angle, close to moderately close, rough, planar, fresh, slightly open	906+/-				60		87	1.5 1.75 1.25 2	
218.0	Run 40, Similar, coal seam from 215.4 to 216 feet	901+/-	215			56		65	2 2.25 2.5 2 1.75	
223.0	Run 41, Similar to 221.2 feet, clay-filled zone from 218.3 to 218.5 feet At 221.2 feet: Moderately hard, fresh, gray SILTSTONE interbedded with sandstone, very thin bedding, primary joint set, low angle, close to moderately close, smooth, planar, fresh, slightly open	896+/-	220			60		75	1.5 1.25 1.5 1.25 0.75	
228.0	Run 42, Similar	891+/-	225			60		100	0.75 1 1 1 1.25	
233.0	Run 43, Similar From 230.9 to 231.3 feet: High angle joint, rough, stepped, slightly open, fresh	886+/-	230			60		95	1 0.5 1.25 0.5 0.5	
238.0	Run 44, Similar to 233.5 feet At 233.5 feet: Moderately hard, slightly weathered, gray SHALE interbedded with siltstone, very thin bedding, primary joint set, low angle, close, rough, planar, tight to slightly open, slightly weathered From 234.3 to 234.5 and 234.9 to 235.2 feet: Clay-filled zones	881+/-	235			60		52	1.25 1.5 1.25 1.25 2	
	Run 45, Similar		240			57			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:

Additional water level observations:
156.3' on 9/14/17
165.3' on 9/15/17
265.3' after boring completion

WATER LEVEL OBSERVATIONS

- *85.4' on 8/11/17*
- *133' on 9/12/17*
- *154.8' on 9/13/17*

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-07-2017	Boring Completed: 09-15-2017
Drill Rig: Diedrich D-50	Driller: Terra Testing, Inc.
Project No.: J217P078	Exhibit: A-1

BORING LOG NO. B2-4W Loyalhanna Lake West

PROJECT: Mariner East Pipeline Borings

CLIENT: Directional Project Support Incorporated
Magnolia, TX 77354

SITE: Spread 2

LOCATION PA-WM2-0064.0000-WXb 201700912-3
Latitude: 40.436772° Longitude: -79.449165°

Approximate Surface Elev: 1119 (Ft.) +/-

DEPTH	Description	ELEVATION (Ft.)	DEPTH (Ft.)	RECOVERY (In.)	FIELD TEST RESULTS	RQD (%)	Core rate (min/ft)	Penetrometer Test (tsf)
243.0		876+/-		57		88	1.5 1.25 1.5 1.25	
248.0	Run 46, Similar to 247.2 feet From 243.9 to 244.1 feet: Clay-filled zone At 247.2 feet: Moderately hard, fresh, gray SILTSTONE interbedded with shale, very thin bedding, primary joint set, low angle, close to moderately close, smooth, planar, fresh, moderately open; secondary joint set, high angle, moderately close, smooth, planar, slightly open, fresh	871+/-	245	60		57	2 1.75 2.25 1.5 1.25	
253.0	Run 47, Similar	866+/-	250	58		97	1 0.5 0.75 1 1	
258.0	Run 48, Similar	861+/-	255	60		85	1.5 1.25 1 1 1	
263.0	Run 49, Similar to 261.3 feet At 261.3 feet: Moderately hard, fresh, gray SILTSTONE interbedded with sandstone and shale, very thin bedding, primary joint set, low angle, moderately close, smooth, planar, fresh, slightly open	856+/-	260	60		88	0.75 0.5 0.75 0.5 0.75	
268.0	Run 50, Similar	851+/-	265	60		95	1 0.5 0.75 0.75 1	
	Run 51, Similar From 276.6 to 277.7 feet: Carbonaceous zone		270	58			0.5	

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:

Additional water level observations:
156.3' on 9/14/17
165.3' on 9/15/17
265.3' after boring completion

WATER LEVEL OBSERVATIONS
- *85.4' on 8/11/17*
- *133' on 9/12/17*
- *154.8' on 9/13/17*

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-07-2017	Boring Completed: 09-15-2017
Drill Rig: Diedrich D-50	Driller: Terra Testing, Inc.
Project No.: J217P078	Exhibit: A-1

BORING LOG NO. B2-4W Loyalhanna Lake West

PROJECT: Mariner East Pipeline Borings

SITE: Spread 2

CLIENT: Directional Project Support Incorporated
Magnolia, TX 77354

LOCATION PA-WM2-0064.0000-WXb
201700912-3
Latitude: 40.436772° Longitude: -79.449165°

Approximate Surface Elev: 1119 (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)
273.0		846+/-				58		97	0.5 0.5 0.75 0.75	
278.0	Run 52, Similar	841+/-	275			57		95	0.5 0.5 0.5 1 1	
283.0	Run 53, Similar At 281 to 281.3 and 281.9 to 282.2 feet: Moderately dipping joints, rough, planar, open, fresh	836+/-	280			60		85	0.5 0.25 0.5 0.75 0.75	
288.0	Run 54, Moderately hard, moderately weathered, gray SHALE interbedded with siltstone, very thin bedding, primary joint set, low angle, close, smooth, planar, fresh, slightly open Core barrel sheared off at 288 feet, unable to continue	831+/-	285			41		50	0.5 0.75 0.5 1 0.5	

Boring Terminated at 288 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:

Additional water level observations:
156.3' on 9/14/17
165.3' on 9/15/17
265.3' after boring completion

WATER LEVEL OBSERVATIONS

- *85.4' on 8/11/17*
- *133' on 9/12/17*
- *154.8' on 9/13/17*

Terracon
201 Hammer Mill Rd
Rocky Hill, CT

Boring Started: 09-07-2017	Boring Completed: 09-15-2017
Drill Rig: Diedrich D-50	Driller: Terra Testing, Inc.
Project No.: J217P078	Exhibit: A-1

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

Boring No.:	B2-4W	Lithology :	Sandstone
Sample No.:	1	Moisture Content :	As received
Sample Depth:	25 feet	Lab Temperature :	70° F
Sampling Date:	9/5/17	Loading Rate:	55 psi/s
		Time to Failure:	11 min

Diameter:	1.99 in	Maximum Axial Load at Failure:	36,850 lb
Length:	4.67 in	Compressive Strength:	11,848 psi
L/D:	2.35	Compressive Strength:	81.69 Mpa
End Area:	3.11 in^2	Unit Weight	161 pcf

Before the Test

After the Test

Drawing # : PA-WM2-0064.0000-WXb
PO # : 20170912-3
Crossing : Loyalhanna Lake
Spread : Spread 2

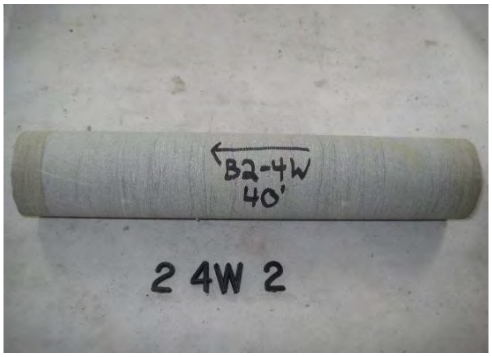
Project:	Mariner East Pipeline	Terracon	Performed by:	C. Santana
Project No	J217P078	77 Sundial Ave., Suite 401 W	Test Date:	10/13/2017
Location:	Spread 2	Manchester, New Hampshire	Reviewed By :	L.Dwyer
Client :	Directional Project Support Inc.		Review Date :	10/13/2017

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

Boring No.:	B2-4W	Lithology :	Sandstone
Sample No.:	2	Moisture Content :	As received
Sample Depth:	40 feet	Lab Temperature :	70° F
Sampling Date:	9/5/17	Loading Rate:	55 psi/s
		Time to Failure:	12 min

Diameter:	1.99 in	Maximum Axial Load at Failure:	38,900 lb
Length:	4.45 in	Compressive Strength:	12,507 psi
L/D:	2.24	Compressive Strength:	86.23 Mpa
End Area:	3.11 in^2	Unit Weight	157 pcf

Before the Test



After the Test

Drawing # : PA-WM2-0064.0000-WXb
PO # : 20170912-3
Crossing : Loyalhanna Lake
Spread : Spread 2

Project:	Mariner East Pipeline	Terracon	Performed by:	C. Santana
Project No.	J217P078		Test Date:	10/13/2017
Location:	Spread 2	77 Sundial Ave., Suite 401 W	Reviewed By :	L.Dwyer
Client :	Directional Project Support Inc.	Manchester, New Hampshire	Review Date :	10/13/2017

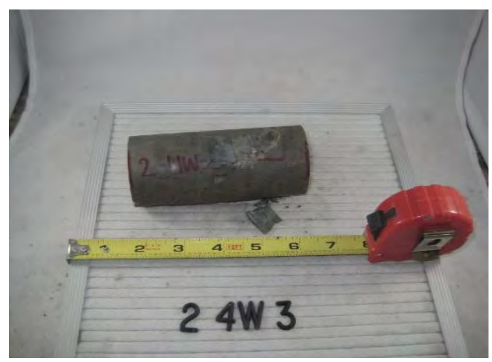
ASTM D7012 (Method C) Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens

Boring No.:	B2-4W	Lithology :	Shale
Sample No.:	3	Moisture Content :	As received
Sample Depth:	65 feet	Lab Temperature :	70° F
Sampling Date:	9/5/17	Loading Rate:	55 psi/s
		Time to Failure:	3 min

Diameter:	1.98 in	Maximum Axial Load at Failure:	8,340 lb
Length:	4.66 in	Compressive Strength:	2,709 psi
L/D:	2.35	Compressive Strength:	18.68 Mpa
End Area:	3.08 in^2	Unit Weight	167 pcf

Before the Test

After the Test



Drawing # : PA-WM2-0064.0000-WXb
PO # : 20170912-3
Crossing : Loyalhanna Lake
Spread : Spread 2

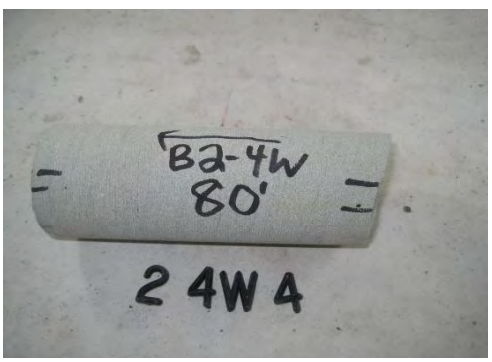
Project:	Mariner East Pipeline	Terracon	Performed by:	C. Santana
Project No.	J217P078	77 Sundial Ave., Suite 401 W	Test Date:	10/13/2017
Location:	Spread 2	Manchester, New Hampshire	Reviewed By :	L.Dwyer
Client :	Directional Project Support Inc.		Review Date :	10/13/2017

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

Boring No.:	B2-4W	Lithology :	Sandstone
Sample No.:	4	Moisture Content :	As received
Sample Depth:	80 feet	Lab Temperature :	70° F
Sampling Date:	9/5/17	Loading Rate:	55 psi/s
		Time to Failure:	16 min

Diameter:	1.98 in	Maximum Axial Load at Failure:	51,540 lb
Length:	4.66 in	Compressive Strength:	16,739 psi
L/D:	2.35	Compressive Strength:	115.41 Mpa
End Area:	3.08 in^2	Unit Weight	161 pcf

Before the Test



After the Test

Drawing # : PA-WM2-0064.0000-WXb
PO # : 20170912-3
Crossing : Loyalhanna Lake
Spread : Spread 2

Project:	Mariner East Pipeline	Terracon	Performed by:	C. Santana
Project No	J217P078		Test Date:	10/13/2017
Location:	Spread 2	77 Sundial Ave., Suite 401 W	Reviewed By :	L.Dwyer
Client :	Directional Project Support Inc.	Manchester, New Hampshire	Review Date :	10/13/2017

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

Boring No.:	B2-4W	Lithology :	Sandstone
Sample No.:	5	Moisture Content :	As received
Sample Depth:	100.5 feet	Lab Temperature :	70° F
Sampling Date:	9/5/17	Loading Rate:	55 psi/s
		Time to Failure:	9 min

Diameter:	1.97 in	Maximum Axial Load at Failure:	28,780 lb
Length:	4.54 in	Compressive Strength:	9,442 psi
L/D:	2.30	Compressive Strength:	65.10 Mpa
End Area:	3.05 in^2	Unit Weight	160 pcf

Before the Test

After the Test

Drawing # : PA-WM2-0064.0000-WXb
PO # : 20170912-3
Crossing : Loyalhanna Lake
Spread : Spread 2

Project:	Mariner East Pipeline	Terracon 77 Sundial Ave., Suite 401 W Manchester, New Hampshire	Performed by:	C. Santana
Project No.	J217P078		Test Date:	10/13/2017
Location:	Spread 2		Reviewed By :	L.Dwyer
Client :	Directional Project Support Inc.		Review Date :	10/13/2017

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

Boring No.:	B2-4W	Lithology :	Sandstone
Sample No.:	6	Moisture Content :	As received
Sample Depth:	119 feet	Lab Temperature :	70° F
Sampling Date:	9/5/17	Loading Rate:	55 psi/s
		Time to Failure:	8 min

Diameter:	1.98 in	Maximum Axial Load at Failure:	27,490 lb
Length:	4.64 in	Compressive Strength:	8,928 psi
L/D:	2.34	Compressive Strength:	61.56 Mpa
End Area:	3.08 in^2	Unit Weight	166 pcf

Before the Test

After the Test

Drawing # : PA-WM2-0064.0000-WXb
PO # : 20170912-3
Crossing : Loyalhanna Lake
Spread : Spread 2

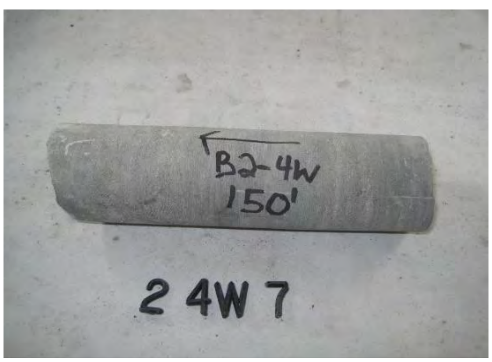
Project:	Mariner East Pipeline	Terracon 77 Sundial Ave., Suite 401 W Manchester, New Hampshire	Performed by:	C. Santana
Project No	J217P078		Test Date:	10/13/2017
Location:	Spread 2		Reviewed By :	L.Dwyer
Client :	Directional Project Support Inc.		Review Date :	10/13/2017

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

Boring No.:	B2-4W	Lithology :	Siltstone
Sample No.:	7	Moisture Content :	As received
Sample Depth:	150 feet	Lab Temperature :	70° F
Sampling Date:	9/5/17	Loading Rate:	55 psi/s
		Time to Failure:	10 min

Diameter:	1.99 in	Maximum Axial Load at Failure:	32,100 lb
Length:	4.52 in	Compressive Strength:	10,321 psi
L/D:	2.27	Compressive Strength:	71.16 Mpa
End Area:	3.11 in^2	Unit Weight	168 pcf

Before the Test



After the Test

Drawing # : PA-WM2-0064.0000-WXb
PO # : 20170912-3
Crossing : Loyalhanna Lake
Spread : Spread 2

Project:	Mariner East Pipeline	Terracon	Performed by:	C. Santana
Project No.	J217P078	77 Sundial Ave., Suite 401 W	Test Date:	10/13/2017
Location:	Spread 2	Manchester, New Hampshire	Reviewed By :	L.Dwyer
Client :	Directional Project Support Inc.		Review Date :	10/13/2017

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

Boring No.:	B2-4W	Lithology :	Shale
Sample No.:	8	Moisture Content :	As received
Sample Depth:	164 feet	Lab Temperature :	70° F
Sampling Date:	9/5/17	Loading Rate:	55 psi/s
		Time to Failure:	6 min

Diameter:	1.98 in	Maximum Axial Load at Failure:	19,100 lb
Length:	4.41 in	Compressive Strength:	6,203 psi
L/D:	2.23	Compressive Strength:	42.77 Mpa
End Area:	3.08 in^2	Unit Weight	173 pcf

Before the Test

After the Test

Drawing # : PA-WM2-0064.0000-WXb
PO # : 20170912-3
Crossing : Loyalhanna Lake
Spread : Spread 2

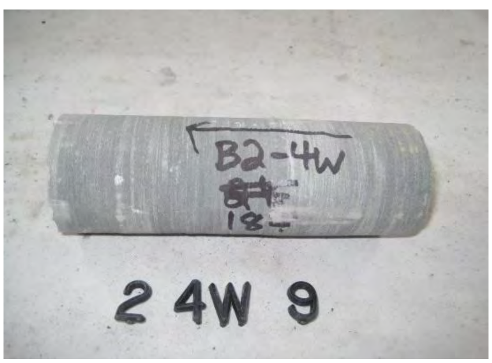
Project:	Mariner East Pipeline	Terracon	Performed by:	C. Santana
Project No	J217P078		Test Date:	10/13/2017
Location:	Spread 2	77 Sundial Ave., Suite 401 W	Reviewed By :	L.Dwyer
Client :	Directional Project Support Inc.	Manchester, New Hampshire	Review Date :	10/13/2017

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

Boring No.:	B2-4W	Lithology :	Siltstone
Sample No.:	9	Moisture Content :	As received
Sample Depth:	184 feet	Lab Temperature :	70° F
Sampling Date:	9/5/17	Loading Rate:	55 psi/s
		Time to Failure:	9 min

Diameter:	1.91 in	Maximum Axial Load at Failure:	30,100 lb
Length:	4.60 in	Compressive Strength:	10,505 psi
L/D:	2.41	Compressive Strength:	72.43 Mpa
End Area:	2.87 in^2	Unit Weight	168 pcf

Before the Test



After the Test

Drawing # : PA-WM2-0064.0000-WXb
PO # : 20170912-3
Crossing : Loyalhanna Lake
Spread : Spread 2

Project:	Mariner East Pipeline	Terracon	Performed by:	C. Santana
Project No	J217P078		Test Date:	10/13/2017
Location:	Spread 2		Reviewed By :	L.Dwyer
Client :	Directional Project Support Inc.	77 Sundial Ave., Suite 401 W Manchester, New Hampshire	Review Date :	10/13/2017

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

Boring No.:	B2-4W	Lithology :	Shale
Sample No.:	10	Moisture Content :	As received
Sample Depth:	200.5 feet	Lab Temperature :	70° F
Sampling Date:	9/5/17	Loading Rate:	55 psi/s
		Time to Failure:	5 min

Diameter:	1.99 in	Maximum Axial Load at Failure:	15,770 lb
Length:	4.73 in	Compressive Strength:	5,070 psi
L/D:	2.38	Compressive Strength:	34.96 Mpa
End Area:	3.11 in^2	Unit Weight	171 pcf

Before the Test

After the Test

Drawing # : PA-WM2-0064.0000-WXb
PO # : 20170912-3
Crossing : Loyalhanna Lake
Spread : Spread 2

Project:	Mariner East Pipeline	Terracon	Performed by:	C. Santana
Project No	J217P078		Test Date:	10/13/2017
Location:	Spread 2	77 Sundial Ave., Suite 401 W	Reviewed By :	L.Dwyer
Client :	Directional Project Support Inc.	Manchester, New Hampshire	Review Date :	10/13/2017

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

Boring No.:	B2-4W
Sample No.:	11
Sample Depth:	220 feet
Sampling Date:	9/5/17

Lithology :	Siltstone	
Moisture Content :	As received	
Lab Temperature :	70°	F
Loading Rate:	55	psi/s
Time to Failure:	0	min

Diameter:	N/A	in
Length:	N/A	in
L/D:	N/A	
End Area:	N/A	in^2

Maximum Axial Load at Failure:	N/A	lb
Compressive Strength:	N/A	psi
Compressive Strength:	N/A	Mpa
Unit Weight	N/A	pcf

Specimen broke during preparation

Before the Test

After the Test

Drawing # :	PA-WM2-0064.0000-WXb
PO # :	20170912-3
Crossing :	Loyalhanna Lake
Spread :	Spread 2

Project:	Mariner East Pipeline	Terracon	Performed by:	C. Santana
Project No.	J217P078	77 Sundial Ave., Suite 401 W	Test Date:	10/13/2017
Location:	Spread 2	Manchester, New Hampshire	Reviewed By :	L.Dwyer
Client :	Directional Project Support Inc.		Review Date :	10/13/2017

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

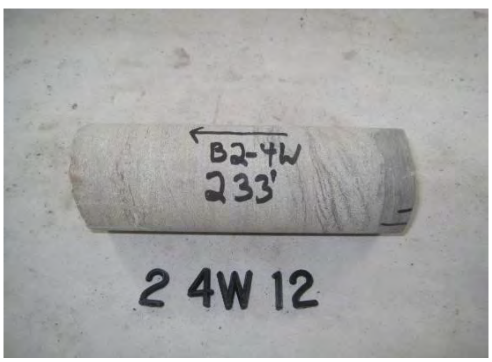
Boring No.:	B2-4W
Sample No.:	12
Sample Depth:	233 feet
Sampling Date:	9/5/17

Lithology :	Siltstone
Moisture Content :	As received
Lab Temperature :	70° F
Loading Rate:	55 psi/s
Time to Failure:	18 min

Diameter:	1.99 in
Length:	4.49 in
L/D:	2.26
End Area:	3.11 in^2

Maximum Axial Load at Failure:	57,850 lb
Compressive Strength:	18,600 psi
Compressive Strength:	128.24 Mpa
Unit Weight	164 pcf

Before the Test



After the Test

Drawing # :	PA-WM2-0064.0000-WXb
PO # :	20170912-3
Crossing :	Loyalhanna Lake
Spread :	Spread 2

Project:	Mariner East Pipeline	Terracon	Performed by:	C. Santana
Project No.	J217P078		Test Date:	10/13/2017
Location:	Spread 2		Reviewed By :	L.Dwyer
Client :	Directional Project Support Inc.	77 Sundial Ave., Suite 401 W Manchester, New Hampshire	Review Date :	10/13/2017

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

Boring No.:	B2-4W	Lithology :	Shale
Sample No.:	13	Moisture Content :	As received
Sample Depth:	246 feet	Lab Temperature :	70° F
Sampling Date:	9/5/17	Loading Rate:	55 psi/s
		Time to Failure:	2 min

Diameter:	1.99 in	Maximum Axial Load at Failure:	7,620 lb
Length:	4.46 in	Compressive Strength:	2,450 psi
L/D:	2.24	Compressive Strength:	16.89 Mpa
End Area:	3.11 in^2	Unit Weight	165 pcf

Before the Test

After the Test

Drawing # : PA-WM2-0064.0000-WXb
PO # : 20170912-3
Crossing : Loyalhanna Lake
Spread : Spread 2

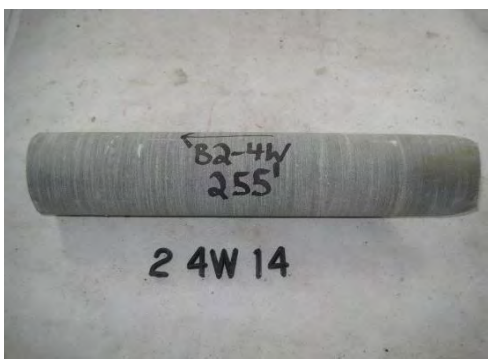
Project:	Mariner East Pipeline	Terracon 77 Sundial Ave., Suite 401 W Manchester, New Hampshire	Performed by:	C. Santana
Project No.	J217P078		Test Date:	10/13/2017
Location:	Spread 2		Reviewed By :	L.Dwyer
Client :	Directional Project Support Inc.		Review Date :	10/13/2017

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

Boring No.:	B2-4W	Lithology :	Siltstone
Sample No.:	14	Moisture Content :	As received
Sample Depth:	255 feet	Lab Temperature :	70° F
Sampling Date:	9/5/17	Loading Rate:	55 psi/s
		Time to Failure:	9 min

Diameter:	1.99 in	Maximum Axial Load at Failure:	28,610 lb
Length:	4.47 in	Compressive Strength:	9,199 psi
L/D:	2.25	Compressive Strength:	63.42 Mpa
End Area:	3.11 in^2	Unit Weight	162 pcf

Before the Test



After the Test

Drawing # : PA-WM2-0064.0000-WXb
PO # : 20170912-3
Crossing : Loyalhanna Lake
Spread : Spread 2

Project:	Mariner East Pipeline	Terracon	Performed by:	C. Santana
Project No.	J217P078	77 Sundial Ave., Suite 401 W	Test Date:	10/13/2017
Location:	Spread 2	Manchester, New Hampshire	Reviewed By :	L.Dwyer
Client :	Directional Project Support Inc.		Review Date :	10/13/2017

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

Boring No.:	B2-4W	Lithology :	Siltstone
Sample No.:	15	Moisture Content :	As received
Sample Depth:	265 feet	Lab Temperature :	70° F
Sampling Date:	9/5/17	Loading Rate:	55 psi/s
		Time to Failure:	0 min

Diameter:	N/A in	Maximum Axial Load at Failure:	N/A lb
Length:	N/A in	Compressive Strength:	N/A psi
L/D:	N/A	Compressive Strength:	N/A Mpa
End Area:	N/A in^2	Unit Weight	N/A pcf

Specimen broke during preparation

Before the Test

After the Test

Drawing # : PA-WM2-0064.0000-WXb
PO # : 20170912-3
Crossing : Loyalhanna Lake
Spread : Spread 2

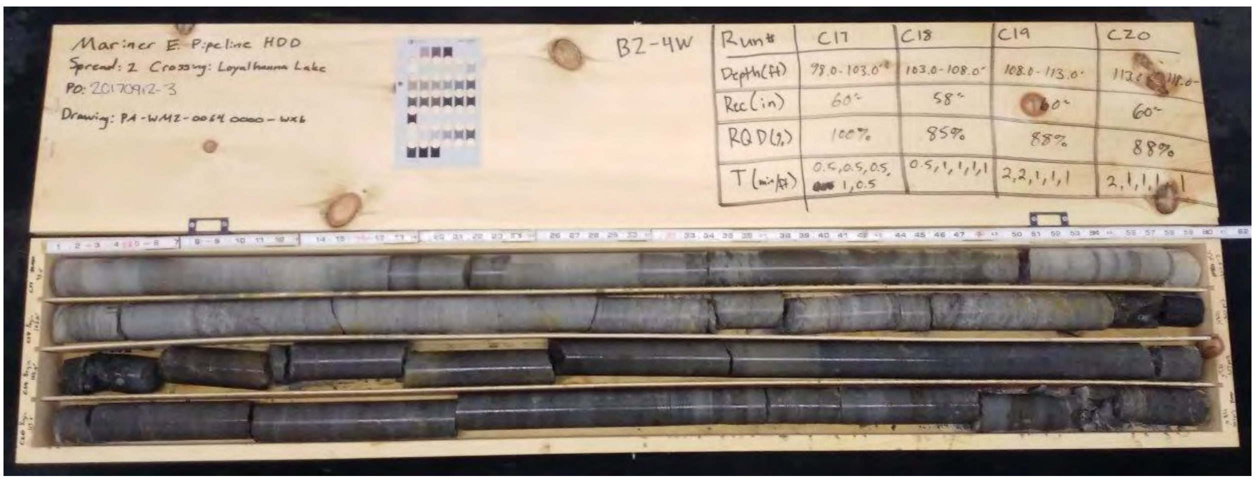
Project:	Mariner East Pipeline	Terracon 77 Sundial Ave., Suite 401 W Manchester, New Hampshire	Performed by:	C. Santana
Project No.	J217P078		Test Date:	10/13/2017
Location:	Spread 2		Reviewed By :	L.Dwyer
Client :	Directional Project Support Inc.		Review Date :	10/13/2017

Photograph 1: B2-4W, Samples C-1 to C-4 (18.6 to 38 feet)

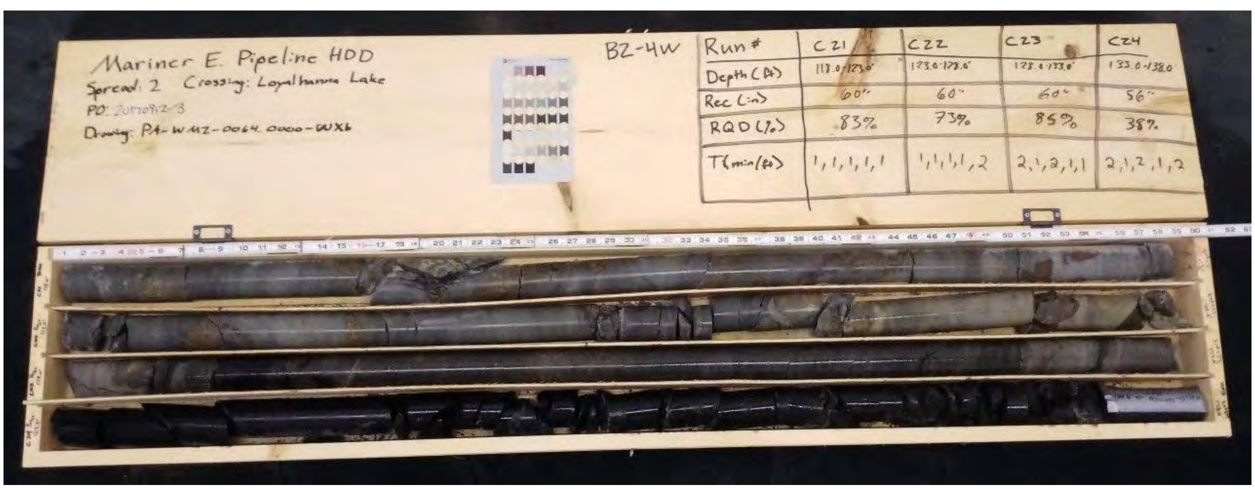
Photograph 2: B2-4W, Samples C-5 to C-8 (38 to 58 feet)

Photograph 3: B2-4W, Samples C-9 to C-12 (58 to 78 feet)

Photograph 4: B2-4W, Samples C-13 to C-16 (78 to 98 feet)

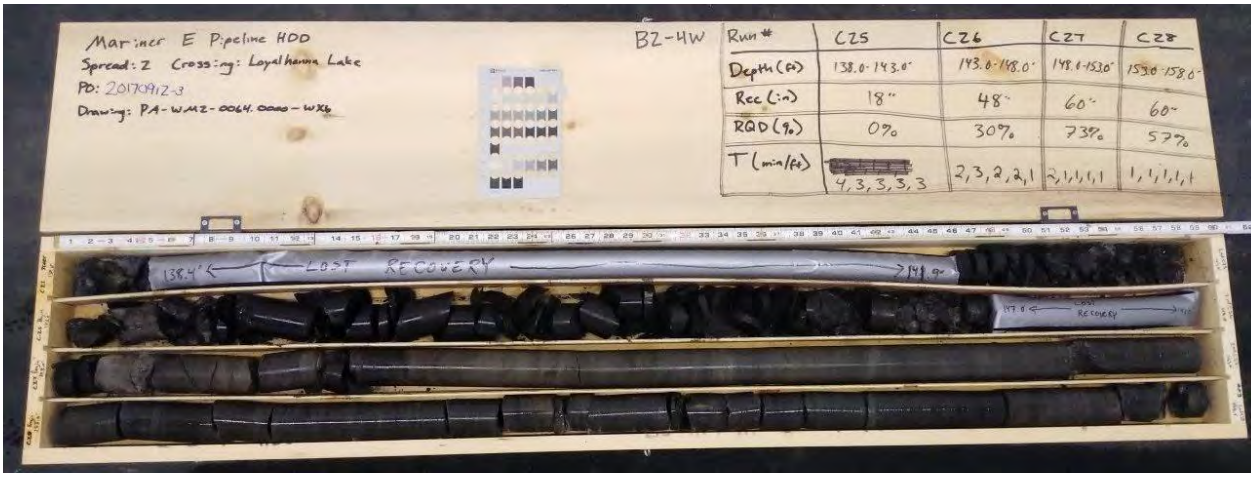


Photograph 5: B2-4W, Samples C-17 to C-20 (98 to 118 feet)



Photograph 6: B2-4W, Samples C-21 to C-24 (118 to 138 feet)

Terracon



Photograph 7: B2-4W, Samples C-25 to C-28 (138 to 158 feet)

Photograph 8: B2-4W, Samples C-29 to C-32 (158 to 178 feet)

Photograph 9: B2-4W, Samples C-33 to C-36 (178 to 198 feet)

Photograph 10: B2-4W, Samples C-37 to C-40 (198 to 218 feet)

Photograph 11: B2-4W, Samples C-41 to C-44 (218 to 238 feet)

Photograph 12: B2-4W, Samples C-45 to C-48 (238 to 258 feet)

Photograph 13: B2-4W, Samples C-49 to C-52 (258 to 278 feet)

Photograph 14: B2-4W, Samples C-53 to C-54 (278 to 288 feet)

SUPPORTING INFORMATION

UNIFIED SOIL CLASSIFICATION SYSTEM

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests [A]					Soil Classification: Group Symbol	Soil Classification: Group Name [B]
Coarse-Grained Soils: More than 50% retained on No. 200 sieve	**Gravels:** More than 50% of coarse fraction retained on No. 4 sieve	**Clean Gravels:** Less than 5% fines [C]	Cu ³ 4 and 1 £ Cc £ 3 [E]		GW	Well-graded gravel [F]
			Cu < 4 and/or 1 > Cc > 3 [E]		GP	Poorly graded gravel [F]
		Gravels with Fines: More than 12% fines [C]	Fines classify as ML or MH		GM	Silty gravel [F,G,H]
			Fines classify as CL or CH		GC	Clayey gravel [F,G,H]
	Sands: 50% or more of coarse fraction passes No. 4 sieve	**Clean Sands:** Less than 5% fines [D]	Cu ³ 6 and 1 £ Cc £ 3 [E]		SW	Well-graded sand [I]
			Cu < 6 and/or 1 > Cc > 3 [E]		SP	Poorly graded sand [I]
		Sands with Fines: More than 12% fines [D]	Fines classify as ML or MH		SM	Silty sand [G,H,I]
			Fines classify as CL or CH		SC	Clayey sand [G,H,I]
Fine-Grained Soils: 50% or more passes the No. 200 sieve	**Silts and Clays:** Liquid limit less than 50	**Inorganic:**	PI > 7 and plots on or above “A”		CL	Lean clay [K,L,M]
			PI < 4 or plots below “A” line [J]		ML	Silt [K,L,M]
		Organic:	Liquid limit - oven dried	< 0.75	OL	Organic clay [K,L,M,N]
			Liquid limit - not dried			Organic silt [K,L,M,O]
	Silts and Clays: Liquid limit 50 or more	**Inorganic:**	PI plots on or above “A” line		CH	Fat clay [K,L,M]
			PI plots below “A” line		MH	Elastic Silt [K,L,M]
		Organic:	Liquid limit - oven dried	< 0.75	OH	Organic clay [K,L,M,P]
			Liquid limit - not dried			Organic silt [K,L,M,Q]
Highly organic soils:	Primarily organic matter, dark in color, and organic odor				PT	Peat

[A] Based on the material passing the 3-inch (75-mm) sieve

[B] If field sample contained cobbles or boulders, or both, add “with cobbles or boulders, or both” to group name.

[C] Gravels with 5 to 12% fines require dual symbols: GW-GM well-graded gravel with silt, GW-GC well-graded gravel with clay, GP-GM poorly graded gravel with silt, GP-GC poorly graded gravel with clay.

[D] Sands with 5 to 12% fines require dual symbols: SW-SM well-graded sand with silt, SW-SC well-graded sand with clay, SP-SM poorly graded sand with silt, SP-SC poorly graded sand with clay

[E] $Cu = D_{60}/D_{10}$ $\quad Cc = \dfrac{(D_{30})^2}{D_{10} \times D_{60}}$

[F] If soil contains ³ 15% sand, add “with sand” to group name.

[G] If fines classify as CL-ML, use dual symbol GC-GM, or SC-SM.

[H] If fines are organic, add “with organic fines” to group name.

[I] If soil contains ³ 15% gravel, add “with gravel” to group name.

[J] If Atterberg limits plot in shaded area, soil is a CL-ML, silty clay.

[K] If soil contains 15 to 29% plus No. 200, add “with sand” or “with gravel,” whichever is predominant.

[L] If soil contains ³ 30% plus No. 200 predominantly sand, add “sandy” to group name.

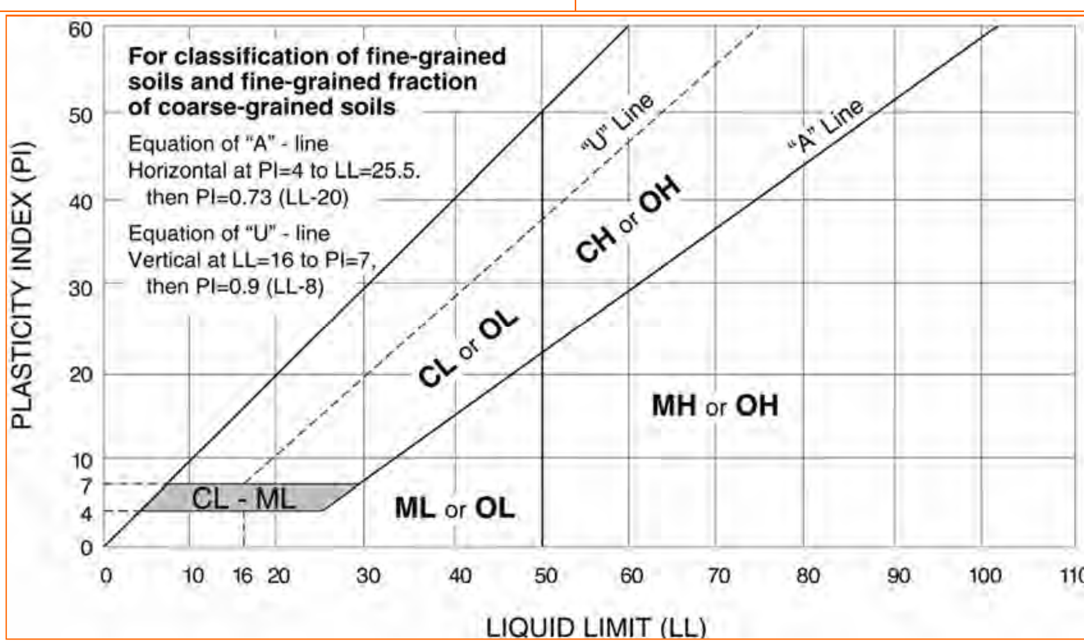
[M] If soil contains ³ 30% plus No. 200, predominantly gravel, add “gravelly” to group name.

[N] PI ³ 4 and plots on or above “A” line.

[O] PI < 4 or plots below “A” line.

[P] PI plots on or above “A” line.

[Q] PI plots below “A” line.



DESCRIPTION OF ROCK PROPERTIES

WEATHERING	
Fresh	Rock fresh, crystals bright, few joints may show slight staining. Rock rings under hammer if crystalline.
Very Slight	Rock generally fresh, joints stained, some joints may show thin clay coatings, crystals in broken face show bright. Rock rings under hammer if crystalline.
Slight	Rock generally fresh, joints stained, and discoloration extends into rock up to 1 in. Joints may contain clay. In granitoid rocks some occasional feldspar crystals are dull and discolored. Crystalline rocks ring under hammer.
Moderate	Significant portions of rock show discoloration and weathering effects. In granitoid rocks, most feldspars are dull and discolored; some show clayey. Rock has dull sound under hammer and shows significant loss of strength as compared with fresh rock.
Moderately Severe	All rock except quartz discolored or stained. In granitoid rocks, all feldspars dull and discolored and majority show kaolinization. Rock shows severe loss of strength and can be excavated with geologist's pick.
Severe	All rock except quartz discolored or stained. Rock "fabric" clear and evident, but reduced in strength to strong soil. In granitoid rocks, all feldspars kaolinized to some extent. Some fragments of strong rock usually left.
Very Severe	All rock except quartz discolored or stained. Rock "fabric" discernible, but mass effectively reduced to "soil" with only fragments of strong rock remaining.
Complete	Rock reduced to "soil". Rock "fabric" no discernible or discernible only in small, scattered locations. Quartz may be present as dikes or stringers.

HARDNESS (for engineering description of rock – not to be confused with Moh's scale for minerals)	
Very Hard	Cannot be scratched with knife or sharp pick. Breaking of hand specimens requires several hard blows of geologist's pick.
Hard	Can be scratched with knife or pick only with difficulty. Hard blow of hammer required to detach hand specimen.
Moderately Hard	Can be scratched with knife or pick. Gouges or grooves to ¼ in. deep can be excavated by hard blow of point of a geologist's pick. Hand specimens can be detached by moderate blow.
Medium	Can be grooved or gouged 1/16 in. deep by firm pressure on knife or pick point. Can be excavated in small chips to pieces about 1-in. maximum size by hard blows of the point of a geologist's pick.
Soft	Can be gouged or grooved readily with knife or pick point. Can be excavated in chips to pieces several inches in size by moderate blows of a pick point. Small thin pieces can be broken by finger pressure.
Very Soft	Can be carved with knife. Can be excavated readily with point of pick. Pieces 1-in. or more in thickness can be broken with finger pressure. Can be scratched readily by fingernail.

Joint, Bedding, and Foliation Spacing in Rock [1]

Spacing	Joints	Bedding/Foliation
Less than 2 in.	Very close	Very thin
2 in. – 1 ft.	Close	Thin
1 ft. – 3 ft.	Moderately close	Medium
3 ft. – 10 ft.	Wide	Thick
More than 10 ft.	Very wide	Very thick

1. Spacing refers to the distance normal to the planes, of the described feature, which are parallel to each other or nearly so.

Rock Quality Designator (RQD) [1]

RQD, as a percentage	Diagnostic description
Exceeding 90	Excellent
90 – 75	Good
75 – 50	Fair
50 – 25	Poor
Less than 25	Very poor

1. RQD (given as a percentage) = length of core in pieces 4 inches and longer / length of run

Joint Openness Descriptors

Openness	Descriptor
No Visible Separation	Tight
Less than 1/32 in.	Slightly Open
1/32 to 1/8 in.	Moderately Open
1/8 to 3/8 in.	Open
3/8 in. to 0.1 ft.	Moderately Wide
Greater than 0.1 ft.	Wide

References: American Society of Civil Engineers. Manuals and Reports on Engineering Practice - No. 56. Subsurface Investigation for Design and Construction of Foundations of Buildings. New York: American Society of Civil Engineers, 1976. U.S. Department of the Interior, Bureau of Reclamation, Engineering Geology Field Manual.