SUNOCO PIPELINE
An ENERGY TRANSFER Company

535 Fritztown Road
Sinking Spring, PA 19608

June 7, 2018

Via Electronic Mail
Mr. Scott R. Williamson
Program Manager
Waterways and Wetlands Program
Department of Environmental Protectionl
South-central Regional Office
909 Elmerton Avenue
Harrisburg, PA 17110

Re: Hydrogeological Re-evaluation Report
Piney Creek Crossing Horizontal Directional Drill Location (S2-0142)
Permit No. E07-459
Woodbury Township, Blair County; Pennsylvania

Dear Mr. Williamson:

In compliance with the Corrected Stipulated Order dated August 10, 2017 (Order) a Reevaluation Report on the above-referenced horizontal directional drill ("HDD") was submitted to the Department on December 28, 2017. The Department requested more information and a revised Reevaluation Report by letter dated February 1, 2018, which Sunoco Pipeline, L.P. (SPLP) provided on March 8, 2018. In a letter dated April 19, 2018, the Department requested further information. Please accept this letter as a response. Your requests are bolded below followed by the response.

1. **Sunoco has proposed to use Drilplex as a component of this HDD. Drilplex is not an approved horizontal directional drilling fluid additive listed on the Department's web site. If Sunoco intends to use a drilling fluid additive for this HDD, it must use an approved drilling fluid additive listed on the Department's web site. Please revise the re-evaluation to address this issue.**

In the March 8, 2018 response, SPLP proposed the use of DrilPlex™, a horizontal directional drilling (HDD) additive certified for conformance with NSF/ANSI Standard 60, to mitigate the potential for HDD activities to impact private water supplies during the pilot phase of HDD S2-0142 Piney Creek Crossing. In subsequent conversations, the Department indicated that it would not approve use of DrilPlex™ as an HDD additive. Accordingly, SPLP informed the Department that it no longer intends to use DrilPlex™ at HDD S2-0142. The Department has indicated in separate discussions that it is not necessary to revise the Reevaluation Report to reflect this decision.

2. **With respect to the annular pressure and formation pressure capacity curves (APC/FPC) and narrative discussion used to produce the curves that was requested in the DEP's February 1, 2018 letter for this HDD Re-evaluation, DEP offers the following summary and requests the following information:**

- **There are many discrepancies between the stationing and elevations on the revised plan/profile maps and the APC/FPC curves and soil profiles, and even among the various tables used to create each curve.**

  To assist in understanding, the new APC curves attached to this response have additional labeling such that the data being presented can be readily correlated to the HDD profile.

- **It appears that DPS underestimated the soil thickness, thereby overestimating the bedrock thickness, as shown by differences between the soil thickness used in the FPC curve calculations and what was determined from the geophysical surveys.**

  This data has been checked and clarified.

- **It appears that DPS calculated a drill path where the annular pressure clearly exceeds the total stress of the overburden at places along the drill path.**

  The APC calculations are not used to calculate or establish an HDD profile in advance, rather the data to perform this analysis is obtained from the design profile and geotechnical data, and then adjustments are made post analysis, as SPLP has done, and as is reflected on the new HDD profiles attached to this response.

- **DEP requests that SPLP re-examine the above, revise the re-evaluation accordingly, including the new APC/FPC curves and as appropriate, new drill paths/profile.**

  This has been done. Newly revised profiles and the APC analysis for these profiles are provided as attachments to this letter.

SPLP submits that we have been, and are, in complete compliance with the terms and requirements of analysis of the Order, as agreed to by the Department, and that no further analysis is required for the Department to consent to the start of this HDD. We therefore request that the Department approve the Reevaluation Report for the Piney Creek Horizontal Directional Drills (S2-0142) as soon as possible.

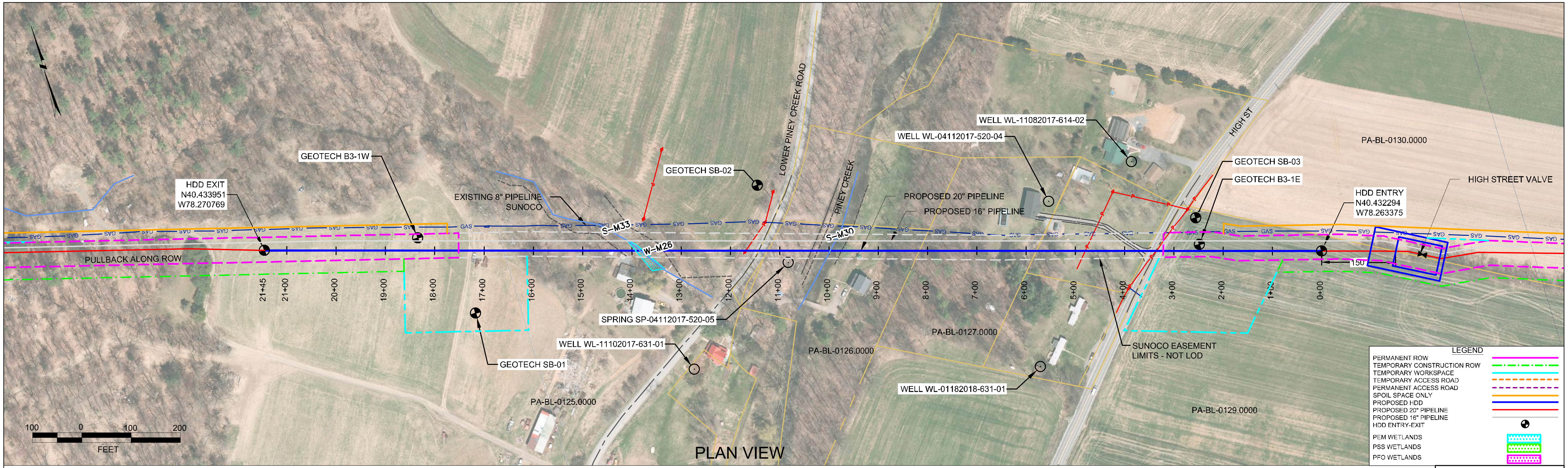
Sincerely,

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

Attachments:
1-HDD Plan and Profiles
2-Annular Pressure Calculations

ATTACHMENT 1

HORIZONTAL DIRECTION DRILL PLAN AND PROFILES (REVISED)



BLAIR COUNTY, PENNSYLVANIA - WOODBURY TOWNSHIP
S2-0142

PROFILE VIEW

GEOTECH B3-1E

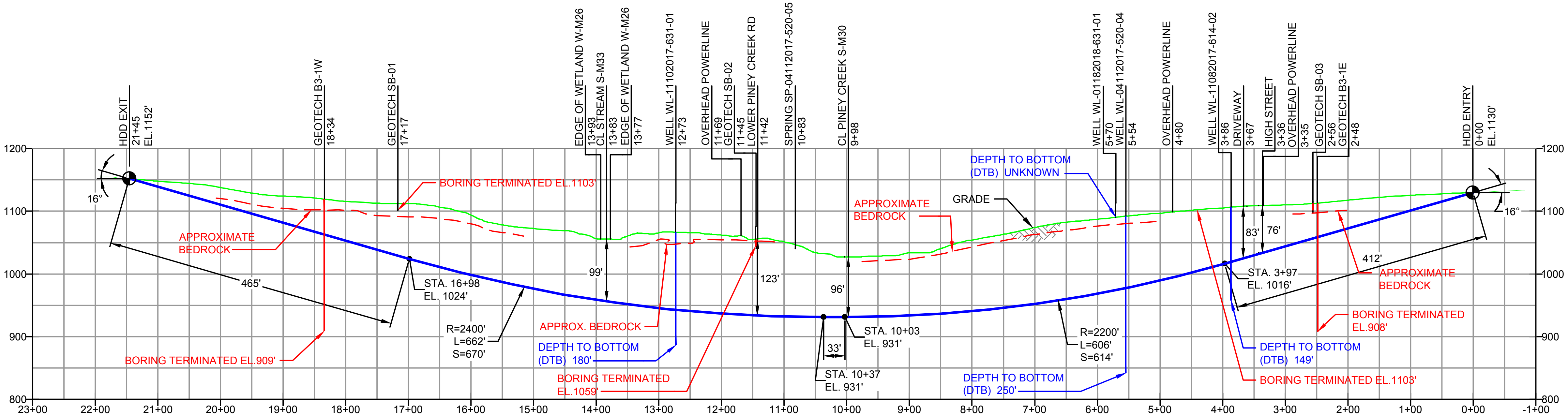
-NG EL. 1098'
-LEAN CLAY W/ GRAVEL CL (0.0' - 1.5')
-WEATHERED ROCK (1.5' - 15.0')
-GROUNDWATER (89.0')
-MUDSTONE/CALCEROUS LIMESTONE (15.0' - 190.0')
-BORING TERMINATED EL.908'

NOTE: REFER TO TEST BORING LOG B3-1E TERRACON PROJECT #J217P078 FOR COMPLETE SOIL MATERIAL DESCRIPTION

GEOTECH B3-1W

-NG EL. 1104'
-LEAN CLAY W/ WEATHERED ROCK CL (0.0' - 10.0')
-GROUNDWATER (27.5')
-CALCEROUS SHALE (10.0' - 195.0')
-BORING TERMINATED EL.909'

NOTE: REFER TO TEST BORING LOG B3-1W TERRACON PROJECT #J217P078 FOR COMPLETE SOIL MATERIAL DESCRIPTION



GEOTECH SB-01

-NG EL. 1113'
-TOPSOIL (0' - 0.1')
-ML (0.1' - 4.0')
-SM/GM (4.0' - 10.0')
-COMPLETION DEPTH EL. 1103'

GEOTECH SB-02

-NG EL. 1076'
-CL/ML (0.0' - 9.4')
-FRACTURED LIMESTONE (9.4' - 17.0')
-COMPLETION DEPTH EL. 1059'

GEOTECH SB-03

-NG EL. 1115'
-TOPSOIL (0' - 0.1')
-SM (0.1' - 3.6')
-CL/ML (3.6' - 4.8')
-SM/GM (4.8' - 11.8')
-COMPLETION DEPTH EL. 1103'

NOTE: REFER TO TEST BORING LOG S2-0142 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=): 2145'
   HDD PIPE LENGTH (S=): 2194'
   20" x 0.456" W.T., X-65, API5L, PSL2, ERW, BFW
   COATING: 14-16 MILS FBE WITH 40 MILS MIN. ARO (POWERCRETE R95)
5. INTERNAL DESIGN PRESSURE 1480 PSIG (SEAM FACTOR 1.0, DESIGN FACTOR 0.50 (HOOP STRESS)).
6. INSTALLATION METHOD: HORIZONTAL DIRECTIONAL DRILL (HDD).
7. PIPELINE WARNING MARKERS SHALL BE INSTALLED ON BOTH SIDES OF ALL ROAD, RAILWAY, AND STREAM CROSSINGS.
8. CARRIER PIPE NOT ENCASED.
9. PIPE / AMBIENT TEMPERATURE MUST BE NO LESS THAN 30°F DURING PULLBACK WITHOUT PRIOR WRITTEN APPROVAL FROM THE ENGINEER.
10. CONDUCT 4-HOUR PRE-INSTALLATION HYDROTEST OF HDD PIPE STRING TO MINIMUM 1850 PSIG.
11. SEE SUNOCO PENNSYLVANIA PIPELINE PROJECT ESRI WEBMAP FOR ACCESS ROAD ALIGNMENT.
12. SUNOCO PIPELINE, L.P.'S HORIZONTAL DIRECTIONAL DRILL INADVERTENT RETURN CONTINGENCY PLAN WILL BE IMPLEMENTED AT ALL TIMES.
13. SUNOCO PIPELINE, L.P.'S EROSION AND SEDIMENTATION CONTROL PLAN WILL BE IMPLEMENTED AT ALL TIMES.

NOTES

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

REF. DRAWING

DWG NO		DWG NO	DESCRIPTION
ES-3.57	TO	ES-3.58	EROSION & SEDIMENT PLAN
SHEET 41	TO	SHEET 41	AERIAL SITE PLAN

REVISIONS

NO.	DESCRIPTION	BY	DATE	CHK	DATE	APP	DATE
EP7	MOVED EAST SIDE DRILL ENTRY/EXIT LOCATION PER CLIENT REQUEST	MRS	05/31/18	RMB	05/31/18	CAG	05/31/18
EP6	MOVED EAST SIDE DRILL ENTRY/EXIT LOCATION PER CLIENT REQUEST	MRS	05/14/18	RMB	05/14/18	CAG	05/14/18
EP5	ADDED ADDITIONAL INFORMATION PER CLIENT REQUEST	MRS	02/28/18	RMB	02/28/18	CAG	02/28/18
EP4	UPDATED GEOTECH INFO PROVIDED BY DPS	MRS	11/15/17	RMB	11/15/17	CAG	11/15/17
EP3	MOVED DRILL ENTRY/EXIT LOCATION - DESIGN PER MICHELS	MRS	09/22/17	RMB	09/22/17	CAG	09/22/17
EP2	REVISED PER PADEP COMMENTS RECEIVED 09-06-16	DLM	09/30/16	RMB	09/30/16	AAW	09/30/16

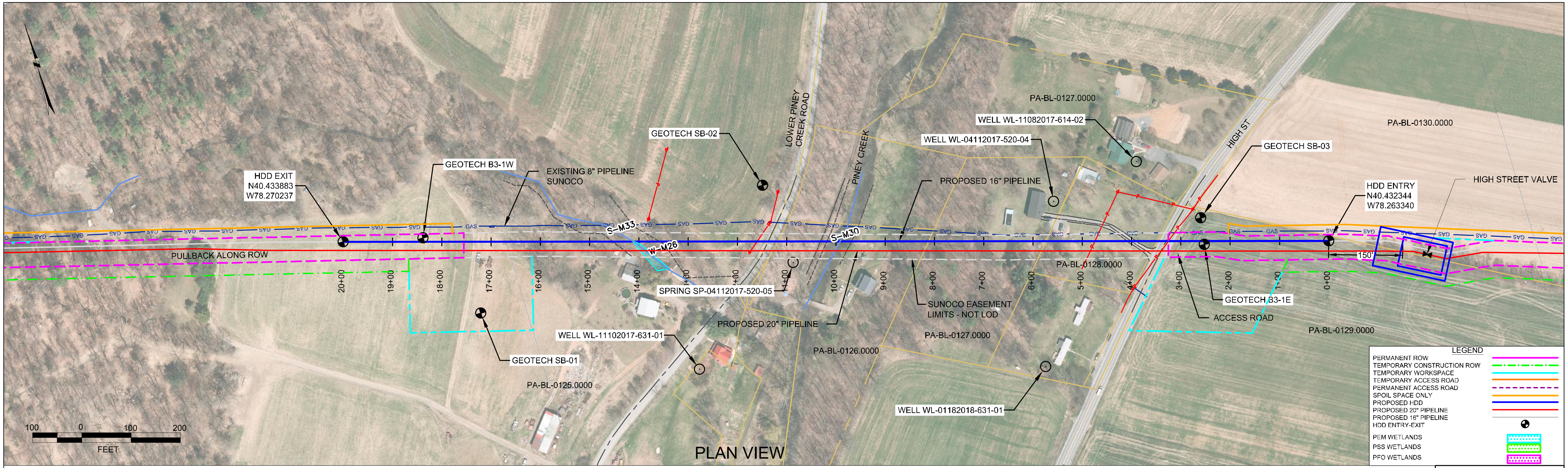
Sunoco Logistics Partners L.P.

TETRA TECH ROONEY
(303) 792-5911

SUNOCO PIPELINE, L.P.

HORIZONTAL DIRECTIONAL DRILL
LOWER PINEY CREEK RD
PENNSYLVANIA PIPELINE PROJECT

SCALE: 1"=200'
DWG. NUMBER: PA-BL-0126.0000-RD



PLAN VIEW

BLAIR COUNTY, PENNSYLVANIA - WOODBURY TOWNSHIP
S2-0142-16

PROFILE VIEW

GEOTECH B3-1E

-NG EL. 1098'
-LEAN CLAY W/ GRAVEL CL (0.0' - 1.5')
-WEATHERED ROCK (1.5' - 15.0')
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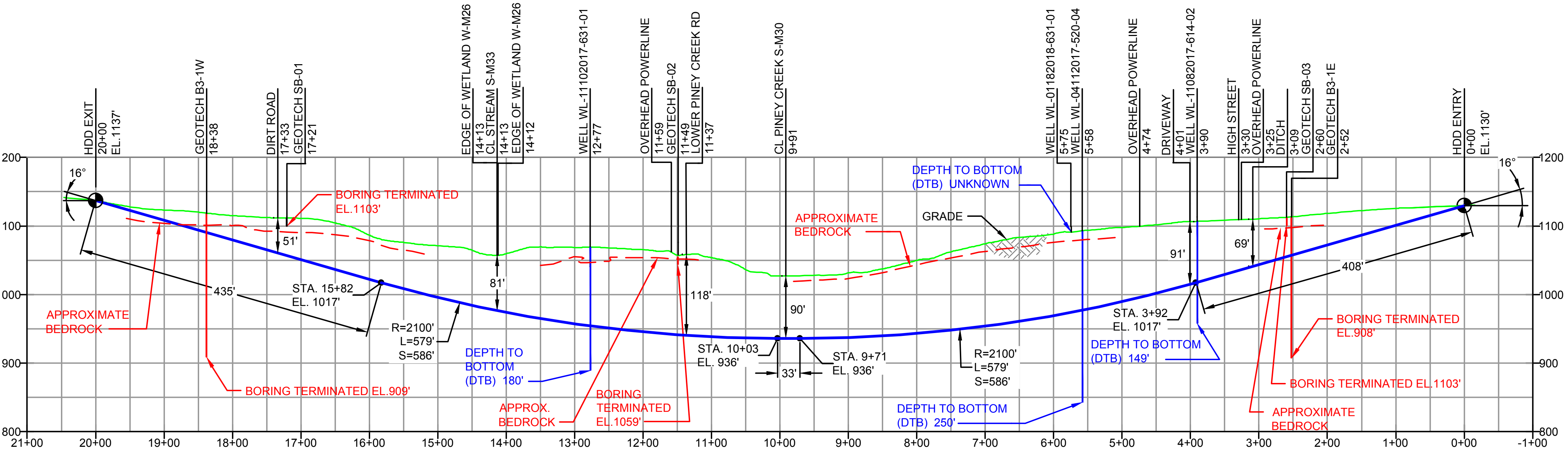

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3. DESIGNED IN ACCORDANCE WITH CFR 49 195 & ASME B31.4
4. CROSSING PIPE SPECIFICATION:
   HDD HORZ. LENGTH (L=): 2000'
   HDD PIPE LENGTH (S=): 2048'
   16" x 0.438" W.T., X-70, API5L, PSL2, ERW, BFW
   COATING: 14-16 MILS FBE WITH 40 MILS MIN. ARO (POWERCRETE R95)
5. INTERNAL DESIGN PRESSURE 2100 PSIG (SEAM FACTOR 1.0, DESIGN FACTOR 0.50 (HOOP STRESS)).
6. INSTALLATION METHOD: HORIZONTAL DIRECTIONAL DRILL (HDD).
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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.
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REVISIONS

NO.	DESCRIPTION	BY	DATE	CHK	DATE	APP	DATE
EP8	MOVED EAST SIDE DRILL ENTRY/EXIT LOCATION PER CLIENT REQUEST	MRS	05/31/18	RMB	05/31/18	CAG	05/31/18
EP7	MOVED EAST SIDE DRILL ENTRY/EXIT LOCATION PER CLIENT REQUEST	MRS	05/14/18	RMB	05/14/18	CAG	05/14/18
EP6	UPDATED NOTE 5 AND 10 PER INCREASED 16" MOP	MRS	04/10/18	RMB	04/10/18	CAG	04/10/18
EP5	ADDED ADDITIONAL INFORMATION PER CLIENT REQUEST	MRS	02/28/18	RMB	02/28/18	CAG	02/28/18
EP4	UPDATED GEOTECH INFO PROVIDED BY DPS	MRS	11/15/17	RMB	11/15/17	CAG	11/15/17
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Sunoco Logistics Partners L.P.

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(303) 792-5911

SUNOCO PIPELINE, L.P.

HORIZONTAL DIRECTIONAL DRILL
LOWER PINEY CREEK RD
PENNSYLVANIA PIPELINE PROJECT

SCALE: 1"=200'
DWG. NO: PA-BL-0126.0000-RD-16

ATTACHMENT 2

ANNULAR PRESSURE CALCULATIONS (REVISED)

HORIZONTAL DIRECTIONAL CONCEPTUAL DRILL DESIGN

PROJECT:
Sunoco Pipeline, L.P.
Mariner East Pipeline
Blair County, Pennsylvania

CROSSING:
LOWER PINEY CREEK HDD #S2-0142
20-INCH STEEL PIPE

ISSUE: **APC/FPC DESIGN**

Contents:

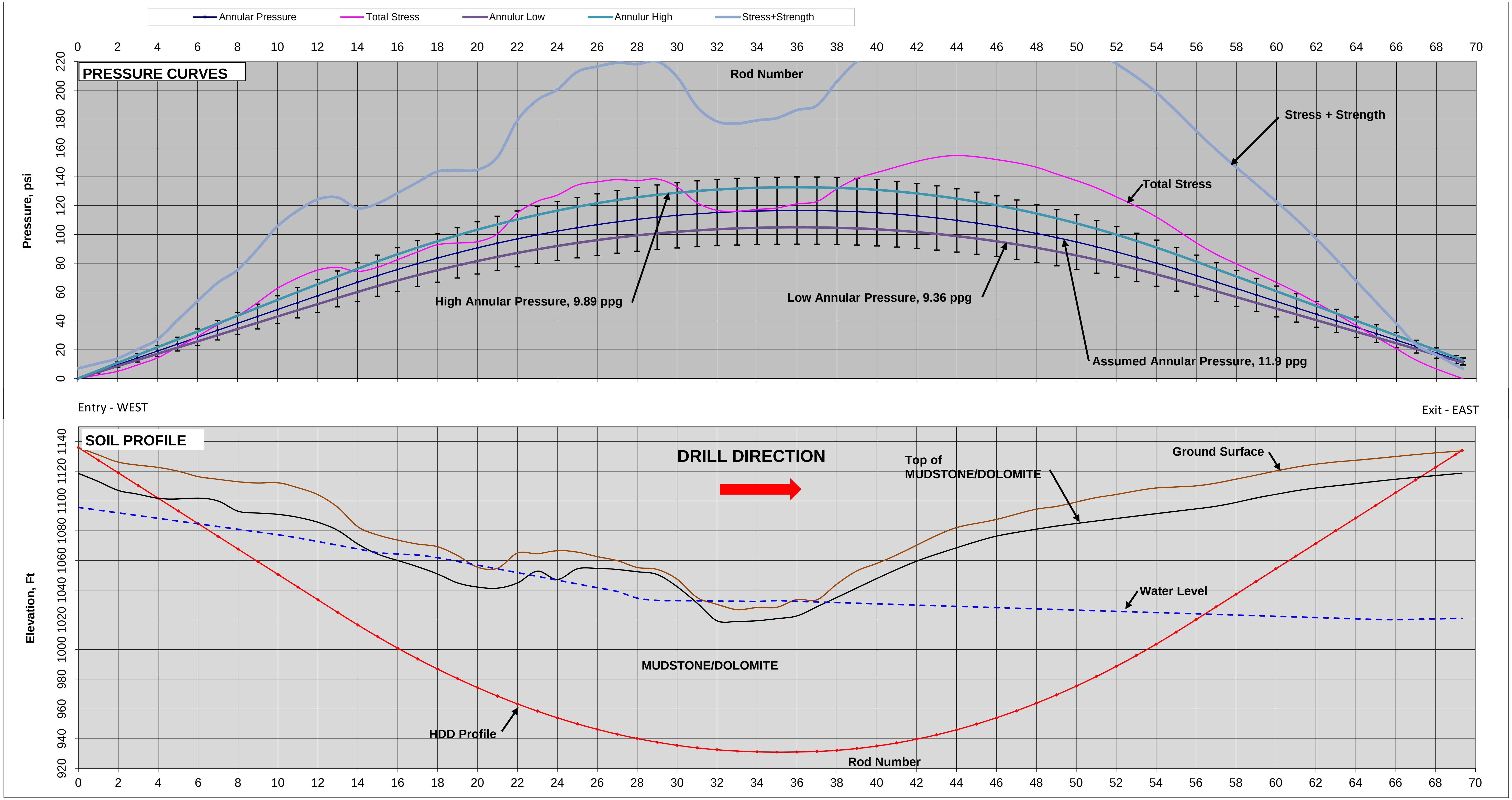
Figure 1 - Annular Pressure and Formation Pressure Capacity Curves
Table 1 - Design Summary, Assumptions, Conditions
Table 2 - Design Drill Path Calculation
Table 3 - Estimated Annular Pressure Curve Example Calculation
Table 4 - Estimated Formation Pressure Curve Example Calculation
DWG. NO: PA-BL-0126.0000-RD Latest Revision Dated 5/14/18

Prepared For:
Sunoco Logistics Partners L.P.
525 Fritztown Road
Sinking Spring, PA 19608
855-430-4491

Prepared By:
Directional Project Support
33311 Lois Lane, Suite A
Magnolia, Texas 77354
281.259.7819 (O) 617.510.8090 (C)
B. Dorwart

Project No: 0
Print Date: 4-Jun-2018

Revision	ID	DESCRIPTION	BY
6/4/2018	0	APC/FPC Design	BCD



Notes:

1. Geology is interpreted from project data
2. Rod length: 31 feet
3. The error bars are at 20 %
4. Ground surface data obtained from project survey data
5. Subsurface data from Geotechnical Report, Properties are interpreted from field and laboratory data as presented in Table 3.

Basis of annulur pressure calculations

12.25 in	Pilot Hole Diameter
78.0 pcf	Unit Weight Drill Fluid
252 gal/min	Pump Rate
5.50 in	Drill Rod Diameter
31	Ft per rod
20%	for APC curve

Print Date ; 6/4/2018 18:03

ISSUED: APC/FPC DESIGN

33311 Lois Lane, Suite A
Magnolia, Texas 77354
281.259.7819 (O) 617.510.8090 (C)

Sunoco Pipeline, L.P.
Mariner East Pipeline
Blair County, Pennsylvania

ANNULAR PRESSURE AND
FORMATION PRESSURE CURVES
LOWER PINEY CREEK HDD #S2-0142
20-INCH STEEL PIPE

Revision 0

FIGURE 1

C:\Users\bdorwart\Documents\DPS\Pennsylvania Pipeline\APC Designs\Spread 3\S2-0142 Lower Piney Ck\Revised design 5-30-18\20 inch\[Design_20in_ 6-4-18.xlsx]T4 Formation Pressure

TABLE 1
DESIGN SUMMARY, ASSUMPTIONS, CONDITIONS

Sunoco Pipeline, L.P.
Mariner East Pipeline
Blair County, Pennsylvania

LOWER PINEY CREEK HDD #S2-0142
20-INCH STEEL PIPE

Item	Comment/Exception/Assumption
1	PROJECT DATA AND SUMMARY: Project data provided as a technical basis for this submittal included four test borings, a seismic survey, and a resistivity survey. No laboratory data regarding moisture content, unit weight, or strength of the soil or rock has been provided. This information has been assumed for these calculations. Soil property assumptions are shown in the sample calculations on Table 4.
2	DRILL FLUID LOSS DURING CONSTRUCTION: Drill fluid loss during construction typically occurs as a result of one or a combination of the following: LEAKAGE, HYDRAULIC JACKING, HYDRAULIC FRACTURING. In all cases, the drill fluid finds an alternative path different than the design drill path that requires a lower pressure to move the drill fluid. Leakage occurs when an unplanned continuous pathway intersects the drill path. Unplanned pathways can develop as a result of drilling operations or may occur around a manmade feature such as piles or may be a naturally occurring feature such as a solution features or joints in the rock. Hydraulic jacking occurs when there are discontinuous cracks in the formation, such as along rock joints or along a confined relatively high permeability zone, into which the drill fluid can flow and exert hydraulic pressure because of the confinement. When the drill fluid pressure exceeds the restraining pressure, the sides of the confinement are hydraulically jacked apart. The enlarged opening allows more fluid volume capacity and continues to develop as long as the pressure remains. Hydraulic fracturing occurs when the drill fluid pressure exceeds the static stress state in the formation plus the strength of the formation material. The result is a fracturing of the formation parallel to the primary stress field which can provide a new path for the drill fluid. Once the formation is fractured that will continue to grow by hydraulic jacking until the drill fluid pressure is reduced or the formation strength increases. Note that hydraulic jacking and fracturing often build pressure in the formation such that during drill rod changes, the drill fluid discharges from the decoupled down hole drill rods until the built up pressure in the formation is reduced. Drill fluid 'loss' during the drilling advance is the source of this return fluid. Continuation of this situation can result in fluid release to the surface, into structures, or movement of adjacent structures such as buildings, highways, and bridges.

Item	Comment/Exception/Assumption
3	ANNULAR PRESSURE CALCULATION: Annular Pressure at any point along a drill path is calculated as the sum of the elevation and dynamic heads. Pressure from elevation head is the difference in feet between elevation of the entry pit drill fluid and the measurement elevation times the drill fluid density in pcf divided by 144 to convert to psi. Dynamic head is the pressure required to make the drill fluid flow along the drill path from the measurement location to the drill entry location. Drill fluids are Non-Newtonian fluids thus pressure must be modeled with specific fluid properties based on assumptions for drill fluid rheological properties. Field rheological properties for these calculations need to be assumed by the design engineer based on experience. Assumptions should be verified by field values that may occur during operations, not on minimum or maximum capacity of a drill fluid. Field data can change from many field influences. Properties of various bentonitic products vary significantly. Additionally, subsurface conditions and cleaning system efficiency will have significant impacts on drill fluid properties. The design Annular Pressure Curve is a planning and design tool for the engineer thus the design curves are not a tool to be applied in the field without correction to account for actual field properties. Field values of drill fluid properties should be expected to change dynamically during even short drilling lengths as different subsurface materials may require different drill fluid properties and both subsurface conditions and the contractor ability to clean the drill fluid can change rapidly. Two methods are used in these calculations to calculate Annular pressure. METHOD B uses a hydraulic model for viscous flow in an annulus and is described in the HDD Good Practices Guidelines; a book available through the NASTT. Both methods are accepted in the industry. The annular pressure curves shown in Figure 1 plot the API-13D data by drill rod along the drill path. Three annular pressure curves are shown on Figure 1 representing three different drill fluid densities that range the possible field conditions that may occur: Assumed estimate of reasonable drill fluid properties, Highest reasonable drill fluid properties, Lowest reasonable drill fluid properties. The "Assumed estimate" data include a 20% error bar on each point representing the accuracy and range between low and high of the data with regard to the ability to predict the actual pressures. The 20% error bar is based on experience with field measurements of annular pressure vs predictions.
4	CALCULATION OF FORMATION PRESSURE: The Formation Pressure capacity is calculated by models. A model used to approximate the complexities of pressure in the subsurface caused by materials that are not uniform thus contain wide variation in both geometry and properties., A model necessary to simplify the conditions yet still provide some science to subsurface complexity. There are presently four models that may be applied to approximate subsurface conditions. Each model provides reasonable values only within the range of the model assumptions and field conditions. Engineering judgement and understanding of the model must be applied during selection of the most appropriate model for a specific set of subsurface conditions. The four models provide four alternative calculation methods: Total Stress, Cavity Expansion (Delft Equation), Total Stress plus Strength, and the Queens Equation. Input data assumptions and range of available properties have been shown to be significant to the results from all four models. Significant experience is required in determination of these input values and in the interpretation of the results. Additionally significant experience is necessary to determine if drained or undrained properties should be used in the analyses. In general, most fine grained materials, when exposed to HDD excavation rates, are best represented by undrained properties. Only highly permeable formations should be considered for drained properties as the undrained assumption means no change on water pressure during the drilling excavation process. Of note is that drained conditions typically provide higher formation pressure capacity than when using undrained properties. Thus these methods may not be conservative and can lead to overly optimistic expectations of Formation Pressure Capacity.

Item	Comment/Exception/Assumption
4a	**Total Stress Method** is based strictly on the dead weight of the overlying material above the drill path thus excludes any potential formation material strength. This method is a traditional approach to establish pressure limits to prevent hydraulic jacking along rock joints and other partings while grouting rock. The rule of thumb is apply no more than 1 psi per foot of rock during grout injection to prevent hydraulic jacking. This method is considered a reasonable approximation for limiting formation pressure in rock or very dense soils or weathered rock. Note that total stress and in particular the orientation of principal stress in the ground rotates with surface geometry. Fracturing of the ground always is orientated parallel to the principal stress at that point in the ground. Therefore, in areas of high topographic relief and where the drill path approaches a topographic surface within about 5 times the depth below the entry, then the total stress must be adjusted for both magnitude and direction as the principal stress will be rotated in either soil or rock.
4b	**Total Stress plus strength method** is a traditional Mohr-Coulomb material failure approach to include insitu formation strength. Experience from the tunneling industry indicates that the strength of the materials needs to include various factors to account for an underground excavation geometry, soil/rock properties, and excavation to ground interaction such as results from trenchless constructions. An acceptable approach has been developed by Terzaghi and later refined by Stein and others. However, these modifications apply only to underbalanced drilling where external pressure exceeds internal pressure. For most HDD constructions, the pressure is applied outward by the annular pressure thus applying extension tension and shear properties for strength calculations. Calculations in this analyses only apply simple sample shear strength as defined by the Mohr-Coulomb relation.
4c	**Cavity Expansion** is modeled either by the Delft or Queens equations. These equations add the material strength assuming failure is by cavity expansion stresses and geometry. The cavity expansion model does not provide assessment of fluid loss by leakage or hydraulic jacking. Experience with the Delft model indicates unconservative predictions and a correction factor should be applied to determine a realistic Pmax prior to application of a safety factor. This correction factor is in addition to the correction factors of 1.5 and 2.0 for sand and clay materials already included in the equation. The Queens equation addresses the shortcomings of the Delft equation by introducing the Ko factor which does vary in soil and rock as opposed to the Delft equation holding Ko as a constant. The result is expected to improve predictions for soils such that correction factors do not need to be applied to determine Pmax before application of safety factors. The cavity expansion relations are not generally appropriate for rock as fluid loss is typically by other processes such as leakage and/or hydraulic jacking.
5	TECHNICAL APPROACH DRILL FLUID MANAGEMENT: Table 2 provides the proposed drill path for the interpreted geologic profile assumed for the crossing. Table 3 provides the calculated Annular Pressure and Table 4 the calculated Formation Pressure Capacity. Calculations are provided for each drill rod along the design drill path. The results are summarized on Figure 1. Assessment is based on comparison of the Formation Pressure Capacity to the Annular Pressure. This relation provides a tool to assess the risk of hydraulic fracturing of a formation or hydraulic jacking along pathways within a formation caused by Annular Pressure exceeding the Formation Capacity Pressure. When the Annular Pressure is higher than the Formation Pressure Capacity, then the risk of drill fluid loss by jacking or hydrofracturing is considered high for the design drill path and drill direction. Mitigation considerations may include: reversing the drill direction, adjusting the depth of the drill path in problem areas, or reduction of drill fluid pressure by methods such as reduction of drill fluid weight, use of drill foam, reduction in the elevation head pressure which may be accomplished by pumping the drill fluid elevation in the hole down to a lower elevation.

Item	Comment/Exception/Assumption
6	**Limitations:** These calculations are for HDD planning purposes only. It should be expected that the drill process will generate new data that may require adjustments to the assumed conditions used for the basis of these calculations. Adjustments to the assumed subsurface conditions may require corresponding adjustments to the various HDD drill parameters or tools to optimize production. Typical parameters that are adjusted include: drill fluid pump rate, penetration rate, drill fluid properties, along with bit dimensions and types or other tooling.

C:\Users\bdowart\Documents\DPS\Pennsylvania Pipeline\APC Designs\Spread 3\S2-0142 Lower Piney Ck\Revised design 5-30-18\20 inch\[Design_20in_ 6-4-18.xlsx]T4 Formation Pressure

PATH DESIGN CALCULATIONS

Entry Station	21+00.00	FT
Exit Station	0+00.00	FT

Entry and Exit Design Coordinates & Elevations (Ft) (Note 2)

	East	North	Elevation
Entry	1823681.8220	401324.2570	1,136.00 ft
Horizontal Curve PI	1824687.6510	401022.9215	
Exit	1825693.4800	400721.5860	1,134.00 ft
Depth to Mudline	108.40 ft	Clearance Depth =	96.60 ft

Measured Plan Length at ties = 2099.9953 ft

Coordinate Length = 2099.9953 ft

OK-HORIZONTAL CURVE

Water Surface Elev.	1030.00 ft
Mudline Elev.	1027.60 ft
Lowest centerline Elev.	931.00 ft

SUMMARY HORIZONTAL CURVE CALCULATIONS

	Start			End						
	Station	Easting	Northing	Station	Easting	Northing	Azimuth	Length	Radius	Angle
Tangent	21+00.00	1823681.8220	401324.2570	10+50.00	1824687.6510	401022.9215	E 343.32235 N	1050.00		
Curve	10+50.00	1824687.6510	401022.9215	10+50.00	1824687.6510	401022.9215	E 343.32235 N	0.00	0.00	0.000 deg.
Tangent	10+50.00	1824687.6510	401022.9215	+.00	1825693.4800	400721.5860	E 343.32235 N	1050.00		

HORIZONTAL PLAN CALCULATIONS (FT)

Entry Tangent Segment		*Horizontal Curve Segment*		*Exit Tangent Segment*		
Plan Length, ft.	1050.00	Input Radius, ft.	0.00	Plan Length, ft.	1050.00	
Entry Azimuth, deg.[5]	E 343.32235 N	Curve, deg	0.000 deg.	Exit Azimuth, deg.[5]	E 343.32235 N	
Entry Azimuth, rad.[5]	5.99211	Curve, rad	0.00000	Exit Azimuth, rad.[5]	5.99211	
		Calculate PTH		**Calculate Exit**		
Calculate PCH		Chord Length, ft.	0.00	Easting	1825693.4800	*Check*
PCH Easting	1824687.6510	Arc Length, ft.	0.00	Northing	400721.5860	*Delta*
PCH Northing	401022.9215	Chord Azimuth, deg	343.3224			0.0000
		PI Easting =	1825143.4940			0.0000
		PI Northing =	400886.3559			OK CALC
		PTH Easting =	1824687.6510			
		PTH Northing =	401022.9215			Exit Station
						+.00
Cum Plan Length	1050.00	Cum Plan Length	1050.00	Cum Plan Length	2099.995296	OK STA

Pull Geometry

Pipe Entry EXIT Enter the pipe entry location into the hole: Entry/Exit

	Elevations		Vertical Angle, (-) = Clockwise			Path	Curve
Segment	Start	End	Start	End	Δ Angle	Length	Radius
Entry Tangent	1134.00 ft	1016.22 ft	16.00 deg	16.00 deg	0.00 deg	427.29 ft	0.00 ft
Entry Curve	1016.22 ft	931.00 ft	16.00 deg	0.00 deg	-16.00 deg	614.36 ft	2200.00 ft
Bottom Tangent	931.00 ft	931.00 ft	0.00 deg	0.00 deg	0.00 deg	30.64 ft	0.00 ft
Exit Curve	931.00 ft	1023.97 ft	0.00 deg	-16.00 deg	-16.00 deg	670.21 ft	2400.00 ft
Exit Tangent	1023.97 ft	1136.00 ft	-16.00 deg	-16.00 deg	0.00 deg	406.43 ft	0.00 ft
					Total Check =	2148.92 ft	OK

Compound Curve Assessment

	Vert. Plan	Horiz. Plan	
Entry	1052.22	1050.00	Yes, Horiz < Exit V(Tan+Curve
Exit	1017.13	1050.00	No, Horiz > Entry V(Tan+Curve)

VERTICLE PATH DESIGN CALCULATIONS (FT)

Entry Tangent Segment 1		*Entry Vert. Curve Segment 2*		*Middle Tangent Segment 3*		*Exit Vert. Curve Segment 4*		*Exit Tangent Segment 5*	
Entry Angle	-16.000 deg.	Vertical Radius	2400.00	Rod Length	30.64236	Radius	2200.00	Exit Elevation	1134.00
Entry Angle, rad.	-0.2793 rad	Vert. Curve, deg.	16.000 deg.	Inclined Bottom Tan	NO	Design Exit Angle	16.000 deg.		
Rod/Path Length	406.43	Vert. Curve, rad.	0.2793 rad			Vert. Curve, rad.	0.2793 rad		
Calculate Vertical PCV		**Calculate Vertical PTV**		**Calculate Vertical PCV**		**Calculate Vertical PTV**		**Calculate Exit**	
Plan Length	390.69	Plan Length	661.53	Plan Length	30.64236328	Vert. Curve, deg	16.000 deg.	Plan Length	410.73
Path Length	406.43	Arc Path Length	670.21	Path Length	30.64	Vert. Curve, rad.	0.27925268	Path Length	427.29
Tangent Depth	-112.03	Curve Vert Depth	-92.97	End Elevation	931.00	Plan Length	606.40	Elevation	1134.00
End Elevation	1023.97	End Elevation	931.00	Rise/drop	0.00	Path Arc Length	614.36	Rise/drop	117.78
		Lowest Elevation	931.00			Lowest Elevation	931.00		
		End Vert Angle	0.000 deg.	End Vert Angle	0.000 deg.	Elevation	1016.22		
		End Vert Angle, rad	0.0000 rad	End Vert Angle, rad	0.0000 rad	Curve Vert Depth	85.22	*Prop. Plan Length*	*2099.995296*

SUMMARY VERTICLE CURVE CALCULATIONS

Start Station	21+00.00	Start Station	17+09.31	Start Station	10+47.78	Start Station	10+17.13	Start Station	4+10.73
PVC Station	17+09.31	PTV Station	10+47.78	PCV Station	10+17.13	PTV Station	4+10.73	Exit Station	+.000
Cum Plan Length	390.69	Cum Plan Length	1052.22	Cum Plan Length	1082.86 ft	Cum Plan Length	1689.26	Cum Plan Length	2099.995296
Cum Path Length	406.43	Cum Path Length	1076.64	Cum Path Length	1107.28 ft	Cum Path Length	1721.64	Cum Path Length	2148.922607
Cum Depth	-112.03	Cum Depth	-205.00	Cum Depth	-205.00 ft	Cum Depth	-119.78	Cum Depth	-2.00

Stationing Check
OK STATIONING

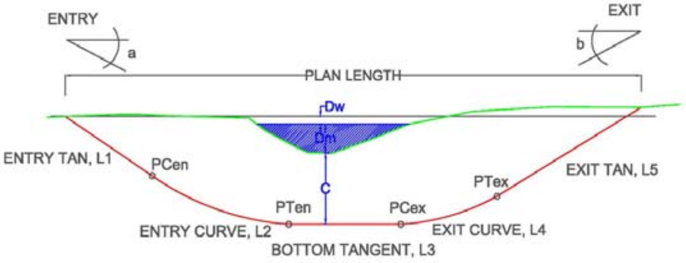
Plan Length Check
OK CALCULATION

Summary of Drill Calculations

Entry to Exit Elevation Change =	**-2.00 ft**
Minimum Design Elevation =	**931.00 ft**
Invert Depth below exit =	**203.00 ft**
Invert Depth below entry =	**205.00 ft**
Path Length =	**2,148.92 ft**
Plan Length =	**2,100.00 ft**
Minimum Plan Length (No Tangent) =	**2,069.35 ft**
Entry Angle =	**-16.00 deg**
Exit Angle =	**16.00 deg**
Compound Curve at Entry =	**0 ft**
Compound Curve at Exit =	**NO**

NOTES:

1. Sign convention for angles - positive (+) angles are counterclockwise. Due East is defined as 0 degrees.
2. Coordinates are in feet and reference NAD 83 Pennsylvania South State Plane
3. Elevations are in feet and reference NAVD 88.
4. All calculation locations represent the center of the drill hole.



🟨	Indicates inputs
🟧	Indicates status on internal design checks

ISSUE: **APC/FPC DESIGN**

Sunoco Pipeline, L.P.
Mariner East Pipeline
Blair County, Pennsylvania

TABLE 2
DESIGN DRILL PATH CALCULATION
LOWER PINEY CREEK HDD #S2-0142
20-INCH STEEL PIPE

Directional Project Support
33311 Lois Lane, Suite A
Magnolia, Texas 77354

Revision 0 10/22/2017

TABLE 3
ESTIMATED ANNULAR PRESSURE CURVE (APC) EXAMPLE CALCULATION

Sunoco Pipeline, L.P.
Mariner East Pipeline
Blair County, Pennsylvania

LOWER PINEY CREEK HDD #S2-0142
20-INCH STEEL PIPE
INPUT

1. Drill path data

	Measured Distance	Elevations	Angles	Lengths	Angle Change	
Drill Entry	0.000 ft	1136	-16	Entry to PC	406.433 ft	
PC	406.433 ft			PC to PT	670.206 ft	-0.024 deg/ft
PT	1076.639 ft			Invert Tangent	30.642 ft	
PC	1107.282 ft			PC to PT	614.356 ft	0.026 deg/ft
PT	1721.638 ft			PT to Exit	427.285 ft	
Drill Exit	**2148.923 ft**	1134.00 ft	16		**2148.923 ft**	
					Length Ck	**OK**

2. Drill Fluid Hydraulic Assumptions

	Assumed		Low		High	
Density, γ_f =	78	10.43 lb/gal	70	9.36 lb/gal	89	11.90 lb/gal
Dynamic annulus pressure P_d =	0.0050 psi/ft		0.0047 psi/ft		0.0054 psi/ft	
Drill fluid viscosity, μ_p =	15 cp		4 cp		13 cp	
Yield point of drill fluid, YP =	30		16		5	

3. Drill Data Assumptions

Assumed Drill Size:	**DD660**		
Avg Rod length =	31.0 feet	Max Rig Pump =	1200 gpm
Diameter of hole, D_h =	12.25	Number of drill rods =	69
Drill Rod Tube Diameter, D_r =	5.500 in	Estimated annular pilot uphole drill fluid velocity, V_{ha} =	51.55 ft/min
Drilling Pump rate, gpm =	252 gal/min		

4. Calculate Annular Pressure, P

Method A - (API RP) 13D

$$P_A = [\gamma_f\,(Y_{entry} - Y)/144] + (P_d)(MD)$$

Method B - HDD Good Practices Cavity Expansion Annular Pressure

$$P_B = [\gamma_f * (Y_{entry} - Y)/144] + MD*[\mu_p*(V_{ha}/60)/(1000*(D_h\text{-}D_r)^2) + YP/[200*(D_h\text{-}D_r)]$$

Start Station	0+00.00	-1

Drill Path			Assumed Return Density		Low Return Density		High Return Density	
			Density, γ_{fE} =	78	Density, γ_{fL} =	70	Density, γ_{fH} =	89
Rod Measured Distance MD	Station X	Elevation Y	Annular Fluid Pressure P_A	Annular Fluid Pressure P_B	Annular Fluid Pressure P_A	Annular Fluid Pressure P_B	Annular Fluid Pressure P_A	Annular Fluid Pressure P_B
ft	ft	ft	psi	psi	psi	psi	psi	psi
0.00	0+00.00	1,136.00	0.00	0.00	0.00	0.00	0.00	0.00
31.00	-0+29.80	1,127.46	4.78	5.33	4.30	4.53	5.45	5.40
62.00	-0+59.60	1,118.91	9.57	10.65	8.60	9.05	10.90	10.81
93.00	-0+89.40	1,110.37	14.35	15.98	12.90	13.58	16.35	16.21
124.00	-1+19.20	1,101.82	19.13	21.30	17.20	18.11	21.79	21.61
155.00	-1+49.00	1,093.28	23.91	26.63	21.50	22.63	27.24	27.02
186.00	-1+78.79	1,084.73	28.70	31.96	25.80	27.16	32.69	32.42
217.00	-2+08.59	1,076.19	33.48	37.28	30.10	31.69	38.14	37.82
248.00	-2+38.39	1,067.64	38.26	42.61	34.40	36.21	43.59	43.23
279.00	-2+68.19	1,059.10	43.04	47.93	38.70	40.74	49.04	48.63
310.00	-2+97.99	1,050.55	47.83	53.26	43.00	45.27	54.49	54.04
341.00	-3+27.79	1,042.01	52.61	58.59	47.30	49.79	59.94	59.44

Drill Path			Assumed Return Density		Low Return Density		High Return Density	
			Density, γ_{fE} =	78	Density, γ_{fL} =	70	Density, γ_{fH} =	89
Rod Measured Distance MD	Station X	Elevation Y	Annular Fluid Pressure P_A	Annular Fluid Pressure P_B	Annular Fluid Pressure P_A	Annular Fluid Pressure P_B	Annular Fluid Pressure P_A	Annular Fluid Pressure P_B
ft	ft	ft	psi	psi	psi	psi	psi	psi
372.00	-3+57.59	1,033.46	57.39	63.91	51.60	54.32	65.38	64.84
403.00	-3+87.39	1,024.92	62.17	69.24	55.90	58.85	70.83	70.25
434.00	-4+17.24	1,016.54	66.86	74.47	60.12	63.29	76.18	75.54
465.00	-4+47.18	1,008.54	71.35	79.51	64.16	67.56	81.29	80.62
496.00	-4+77.23	1,000.91	75.64	84.33	68.01	71.64	86.17	85.45
527.00	-5+07.38	993.68	79.71	88.95	71.67	75.52	90.81	90.04
558.00	-5+37.61	986.84	83.57	93.35	75.14	79.22	95.21	94.39
589.00	-5+67.93	980.39	87.22	97.55	78.43	82.73	99.36	98.50
620.00	-5+98.34	974.33	90.65	101.52	81.52	86.05	103.27	102.37
651.00	-6+28.81	968.66	93.88	105.29	84.42	89.18	106.94	105.99
682.00	-6+59.36	963.39	96.89	108.84	87.13	92.11	110.37	109.37
713.00	-6+89.98	958.51	99.68	112.18	89.65	94.86	113.55	112.51
744.00	-7+20.65	954.03	102.26	115.31	91.97	97.41	116.49	115.40
775.00	-7+51.38	949.95	104.63	118.22	94.10	99.77	119.18	118.05
806.00	-7+82.16	946.26	106.78	120.91	96.04	101.93	121.63	120.45
837.00	-8+12.98	942.97	108.72	123.39	97.79	103.91	123.83	122.61
868.00	-8+43.85	940.08	110.44	125.66	99.34	105.68	125.78	124.52
899.00	-8+74.75	937.59	111.94	127.70	100.70	107.27	127.49	126.18
930.00	-9+05.68	935.50	113.23	129.54	101.86	108.66	128.95	127.59
961.00	-9+36.63	933.80	114.30	131.15	102.83	109.86	130.16	128.76
992.00	-9+67.61	932.51	115.16	132.55	103.60	110.86	131.13	129.68
1023.00	-9+98.59	931.62	115.79	133.73	104.18	111.66	131.85	130.36
1054.00	-10+29.59	931.13	116.21	134.69	104.57	112.28	132.32	130.79
1085.00	-10+60.59	930.98	116.45	135.47	104.79	112.72	132.58	131.00
1116.00	-10+91.59	931.04	116.57	136.14	104.90	113.06	132.71	131.08
1147.00	-11+22.59	931.38	116.54	136.65	104.88	113.27	132.67	130.99
1178.00	-11+53.58	932.16	116.27	136.92	104.65	113.27	132.35	130.64
1209.00	-11+84.55	933.37	115.77	136.96	104.21	113.05	131.77	130.01
1240.00	-12+15.51	935.03	115.03	136.77	103.55	112.62	130.92	129.11
1271.00	-12+46.44	937.11	114.05	136.33	102.68	111.98	129.79	127.94
1302.00	-12+77.34	939.63	112.84	135.67	101.61	111.12	128.40	126.51
1333.00	-13+08.19	942.59	111.39	134.76	100.31	110.06	126.74	124.80
1364.00	-13+39.01	945.98	109.71	133.62	98.81	108.78	124.81	122.83
1395.00	-13+69.77	949.81	107.79	132.25	97.10	107.30	122.62	120.58
1426.00	-14+00.48	954.07	105.64	130.64	95.17	105.60	120.15	118.07
1457.00	-14+31.12	958.76	103.25	128.79	93.04	103.69	117.42	115.30
1488.00	-14+61.69	963.88	100.63	126.72	90.70	101.58	114.42	112.25
1519.00	-14+92.19	969.44	97.77	124.41	88.14	99.25	111.16	108.94
1550.00	-15+22.61	975.42	94.69	121.86	85.38	96.71	107.63	105.37
1581.00	-15+52.94	981.83	91.37	119.09	82.41	93.97	103.83	101.53
1612.00	-15+83.18	988.67	87.82	116.08	79.23	91.02	99.77	97.43
1643.00	-16+13.31	995.93	84.04	112.85	75.85	87.86	95.45	93.06
1674.00	-16+43.35	1,003.61	80.03	109.38	72.26	84.50	90.87	88.43
1705.00	-16+73.27	1,011.72	75.79	105.69	68.47	80.93	86.03	83.54
1736.00	-17+03.10	1,020.15	71.38	101.82	64.51	77.21	80.98	78.45
1767.00	-17+32.90	1,028.70	66.91	97.89	60.51	73.43	75.87	73.30
1798.00	-17+62.70	1,037.24	62.43	93.96	56.50	69.64	70.76	68.14
1829.00	-17+92.50	1,045.79	57.96	90.03	52.49	65.86	65.64	62.98
1860.00	-18+22.29	1,054.33	53.48	86.10	48.48	62.08	60.53	57.82
1891.00	-18+52.09	1,062.88	49.01	82.16	44.48	58.30	55.41	52.66
1922.00	-18+81.89	1,071.42	44.53	78.23	40.47	54.52	50.30	47.50
1953.00	-19+11.69	1,079.97	40.06	74.30	36.46	50.74	45.19	42.34
1984.00	-19+41.49	1,088.51	35.59	70.37	32.45	46.96	40.07	37.18
2015.00	-19+71.29	1,097.06	31.11	66.44	28.45	43.18	34.96	32.03
2046.00	-20+01.09	1,105.60	26.64	62.51	24.44	39.40	29.85	26.87

Drill Path			**Assumed Return Density**		**Low Return Density**		**High Return Density**	
			Density, γ_{fE} =	**78**	**Density, γ_{fL} =**	**70**	**Density, γ_{fH} =**	**89**
Rod Measured Distance MD	**Station X**	**Elevation Y**	**Annular Fluid Pressure P_A**	**Annular Fluid Pressure P_B**	**Annular Fluid Pressure P_A**	**Annular Fluid Pressure P_B**	**Annular Fluid Pressure P_A**	**Annular Fluid Pressure P_B**
ft	**ft**	**ft**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**
2077.00	-20+30.89	1,114.15	22.16	58.58	20.43	35.62	24.73	21.71
2108.00	-20+60.69	1,122.69	17.69	54.65	16.43	31.84	19.62	16.55
2139.00	-20+90.49	1,131.24	13.21	50.72	12.42	28.06	14.51	11.39
2148.92	-21+00.02	1,133.97	11.78	49.46	11.14	26.85	12.87	9.74

TABLE 4
ESTIMATED FORMATION PRESSURE CURVE (FPC) EXAMPLE CALCULATION
Sunoco Pipeline, L.P.
Mariner East Pipeline
Blair County, Pennsylvania

LOWER PINEY CREEK HDD #S2-0142
20-INCH STEEL PIPE
INPUT

1. Drill path data from vertical path calculations

	Measured Distance	Elevations	Angles	Lengths	Angle Change		
Entry	0.000 ft	1136	-16	Entry to PC	406.433 ft		
PC	406.433 ft			PC to PT	670.206 ft	-0.024 deg/ft	
PT	1076.639 ft		0	Invert Tangent	30.642 ft		
PC	1107.282 ft			PC to PT	614.356 ft	0.026 deg/ft	
PT	1721.638 ft			PT to Exit	427.285 ft		
Exit	**2148.923 ft**	1134.00 ft	16		**2148.923 ft**	**Length Ck**	**OK**

2. Drill Fluid Hydraulic Data for Estimated Drill Fluid

Dynamic annulus pressure = 0.00497 psi/LF

Uphole Drill Fluid Density = 78 10.4 lb/gal

Drill fluid viscosity, cp = 15 cp

Up hole drill fluid velocity, ft/sec = 51.55 ft/sec

Pump rate, gpm = 252 gal/min

Diameter of hole D_H, in = 12.25

Diameter of Drill Rod D_R, in = 5.5

Yield point of drill fluid, lb/100 ft^2 = 30.00 Lb/100FT^2

Radius

R_H = 6.125 in

R_R = 2.750 in

3. Soil Profile Data

Technical approach to generate data as no testing available

Undrained conditions use ν = 0.5

Material Layer	Dry Density γ (pcf)	Moisture Content %	Insitu Saturated Density (pcf)	Effective UW (pcf)	Phi, Φ	Undrained Cohesion c, psf	Poisson Ratio μ	Slow Shear Modulus, G psf	OCR Cohessive (Use 0 if non-cohessive)	Model Material Layer Description	Cohesive
1	100	25.0%	125	37.60 pcf	22	1000	0.5	260,000	1	Lean Clay/Clayey Silt	Y
2	160	10.0%	176	97.60 pcf	40	20	0.3	1,000,000	1	MUDSTONE/DOLOMITE	Y
3	160	10.0%	176	97.60 pcf	40	20	0.3	1,000,000	1	MUDSTONE/DOLOMITE	Y
4								0			
5								0			
6								0			
7								0			
8								0			
9								0			
10								0			
Water	62.4			62.40 pcf							

Dynamic Shear Velocity, $V_s = 61.4*N_{60}^{1/2}$ Based on Seed and Idris approximation

Dynamic Shear Modulus, $G_{max} = (\gamma/g)*Vs^2$

Extended Strain Shear Modulus G is typically between 5% and 20% of G_{max}

g = acceleration of gravity = 32.2 ft/s^2

Select Reduction Factor, RF = 100% Ref 1

4 Select Controlling Location and list properties (Based on inspection of Figure 1 plot

Joint = 30 Away Distance from Entry = 905.68 ft Depth of Cover = 111.80 ft

Layers	***Surface 1-2***	***Surface 2-3***	***Surface 3-4***	***Surface 4-5***	***Surface 5-6***	***Surface 6-7***	***Surface 7-8***	***Surface 8-9***	***Surface 9-10***	**TOTAL**	Total CK
Soil Type in Layer =	1	2	3								
Dry Density in Layer, γ_d =	100.00 pcf	160.00 pcf	160.00 pcf								
Insitu Density in Layer, γ_s =	125.00 pcf	176.00 pcf	176.00 pcf								
Effective Weight in Layer, γ'_e =	37.60 pcf	97.60 pcf	97.60 pcf								
Total Layer Thickness over drill, h_s =	5.04 ft	106.76 ft	0.00 ft							111.80 ft	111.80 ft
Saturated Thickness over drill, h_{sat} =	0.00 ft	97.42 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	97.42 ft	
Dry Thickness over drill, h_{dry} =	5.04 ft	9.34 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	14.38 ft	
Contribution Effective Stress, σ' =	503.92 psf	12,561.54 psf	0.00 psf								
Contribution Total Stress, $\sigma = h_s*\gamma_s$	503.92 psf	18,640.82 psf	0.00 psf								
Shear Modulus, G =	260,000 psf	1,000,000 psf	1,000,000 psf								

Height of Water above Soil Surface, h_w = 0.00 ft

Total soil and water height above drill path, H_T = 111.80 ft

Total water height above drill path, H_W = 97.42 ft

Properties At Drill Depth for Selected Joint

R_H =	0.51 ft	Radius of drill hole
$R_{max} = h_s/FS_D$ =	55.90 ft	Maximum allowable radius of plastic zone = Height of soil above Drill Path (h_s) divided by Delft & Queens Equation FS_D
	2	Soil Layer At Drill Depth
G_w =	1,000,000 psf	Large Strain Shear Modulus at drill depth
$S_u = c = q_u/2$	20 psf	Cohessive material: cohession c = unconfined compressive strength (q_u) divided by 2
ϕ =	40 deg	0.6981 rad
H_W =	97.42 ft	Total water height above drill path
FS_D =	2	Factor of Safety for Delft & Queens Equation soil type: Use 1.5 for Sand and 2 for Clay at Drill Depth - Apply to R_{max} and P_{max}
μ =	0.3	Poisson ration o Granular Soil: Angle of internal friction of layer at drill path depth
OCR =	1	Over Consolidation Ratio
K_o =	0.429	Coefficient of lateral earth pressure at rest. For OCR = 1 use relation $K_o = \mu/(1 - \mu)$; For OCR >1 use $K_o = (K_{onormally\ consolidated}) * OCR^{-1/2}$
σ_o =	19,145 psf	Total Stress at drill depth, $\sigma = \gamma_d$(above water)*hdry + γ_s(saturated)*h_{sat}
u =	6,079 psf	Water pressure at drill depth, $u = \gamma_W * H_W$
σ' =	13,065 psf	Effective Stress at drill depth, $\sigma' = \sigma - u$

5. Method A - Total Stress Method (Conservative)

Calculate Allowable Controlling Formation Pressure Capacity

$P_{max} = \sigma_o = \Sigma (h_s*\gamma_s) + h_w*\gamma_w$

P_{maxA} = 19,145 psf	132.95 psi	
	132.95 psi	Check Calculation

6. Method B - Total Stress Method + Local Formation Strength

Calculate Allowable Controlling Formation Pressure Capacity

$P_{max} = \Sigma (h_s*\gamma_s) + h_w*\gamma_w + S$

P_{maxB} 30,128 psf	209.22 psi	
	209.22 psi	Check Calculation

Based on Mohr-Coulomb

Strength = $c + \sigma' * \tan(\phi)$

10,983 psf	76.27 psi

7. Method C - Delft Equation for cavity expansion (Assumes undrained properties)

$$P_{max} = \mu + [p'_f + c * \cot \phi] * \{[R_o/R_{pmax}]^2 + [(\sigma_o' * \sin \phi + c * \cos \phi)/ G]\}^{-\sin \phi/(1+\sin \phi)} - c*\cot(\phi)$$

Sin(ϕ) =	0.64278761	
Cos(ϕ) =	0.76604444	
Cot(ϕ) =	1.19175359	
μ =	6,079 psf	Initial Pore Pressure, $\mu = \gamma_w * H_w$
σ' =	13,065 psf	Effective Stress, $\sigma_o' = \Sigma [\gamma_d*h_d + \gamma' * h_s]$
p'_f =	21,479 psf	p'_f = 149.16

A =	21502.94594	$A = p'_f + c * \cot \phi$
B =	8.33702E-05	$B = [R_o/R_{pmax}]^2$
C =	0.008413642	$C = (\sigma_o' * \sin \phi + c * \cos \phi)/G$
D =	-0.391278584	$D = -\sin \phi/(1+\sin \phi)$
E =	23.83507185	$E = c*\cot \phi$
σ' =	13,065.47	Check Calculation
	144,965 psf	Check Calculation

Checks
21502.94594
8.33702E-05
0.008413642
-0.391278584
23.83507185

P_{max} =	144,965 psf	1,006.70 psi	$P_{max} = \mu + A * (B + C)^D - E$
P_{allC} =	72,482 psf	503.35 psi	$P_{all} = P_{max}/FS$

8. Method D - Queens Equation (Cohessive Soils Only) better for softer clay soils (Assumes undrained properties)

$K_o < 1$ $P_i = S_u + (1/2)*(3K_o-1)*\sigma_o - S_u*\ln[(R_o/R_{pmax})^2 + (S_u/G)]$

$K_o > 1$ $P_i = S_u + (1/2)*(3-K_o)*\sigma_o - S_u*\ln[(R_o/R_{pmax})^2 + S_u/G]$

To Determine if hydraulic fracturing or blowout occurs **(<2Su) indicates hydraulic fracturing; (>2Su) indicates blowout**

$K_o < 1$ $F_1(K_o,\sigma_o,S_u) = (3*K_o - 1)*\sigma_o$

$K_o > 1$ $F_1(K_o,\sigma_o,S_u) = (3 - K_o)*\sigma_o$

K_o =	0.429	P_i =	2,939 psf	20.41 psi
		F_1 =	Expect Blowout	

20.41 psi	Check Calculation

9. SUMMARY and Assessment of Estimated Drilling Annular Pressure and Formation Capacity

(See Annular Pressure Calculations for joint by joint calculations)

Method A - (API RP) 13D

Method B - HDD Good Practices Cavity Expansion Annular Pressure

$P_{annularA}$ =	113.23 psi	$P_A = [\gamma_f (Y_{entry} - Y)/144] + (P_d)(MD)$
$P_{annularB}$ =	129.54 psi	$P_B = [\gamma_f * (Y_{entry} - Y)/144] + MD*[\mu_p*V_{ha}/(1000*(Dh-Dr)^2)] + YP/[200*(D_h-D_r)]$

Method A	132.95 psi	FS =	1	Total Stress
Method B	209.22 psi	FS =	1	Total Stress + Strength
Method C	503.35 psi	At FS_D =	2	Delft Equation
Method D	20.41 psi	At FS_D =	2	Queens Equation

Comparitive Factor of Safety against Drill Fluid Loss at Critical Joint

Critical Joint = 30 Depth of Cover = 111.8 ft

Confining Pressure Calculation Method	Method A	Method B	Method C	Method D
Method (X)/$P_{annularA}$	1.17	1.85	4.45	0.18
Method (X)/$P_{annularB}$	1.03	1.62	3.89	0.16

Acceptable if Factor of Safety >=1.0

HORIZONTAL DIRECTIONAL CONCEPTUAL DRILL DESIGN

PROJECT:
Sunoco Pipeline, L.P.
Mariner East Pipeline
Blair County, Pennsylvania

CROSSING:
LOWER PINEY CREEK HDD #S2-0142
16-INCH STEEL PIPE

ISSUE: **APC/FPC DESIGN**

Contents:

Figure 1 - Annular Pressure and Formation Pressure Capacity Curves
Table 1 - Design Summary, Assumptions, Conditions
Table 2 - Design Drill Path Calculation
Table 3 - Estimated Annular Pressure Curve Example Calculation
Table 4 - Estimated Formation Pressure Curve Example Calculation
DWG. NO: PA-BL-0126.0000-RD-16 Latest Revision Dated 5/14/18

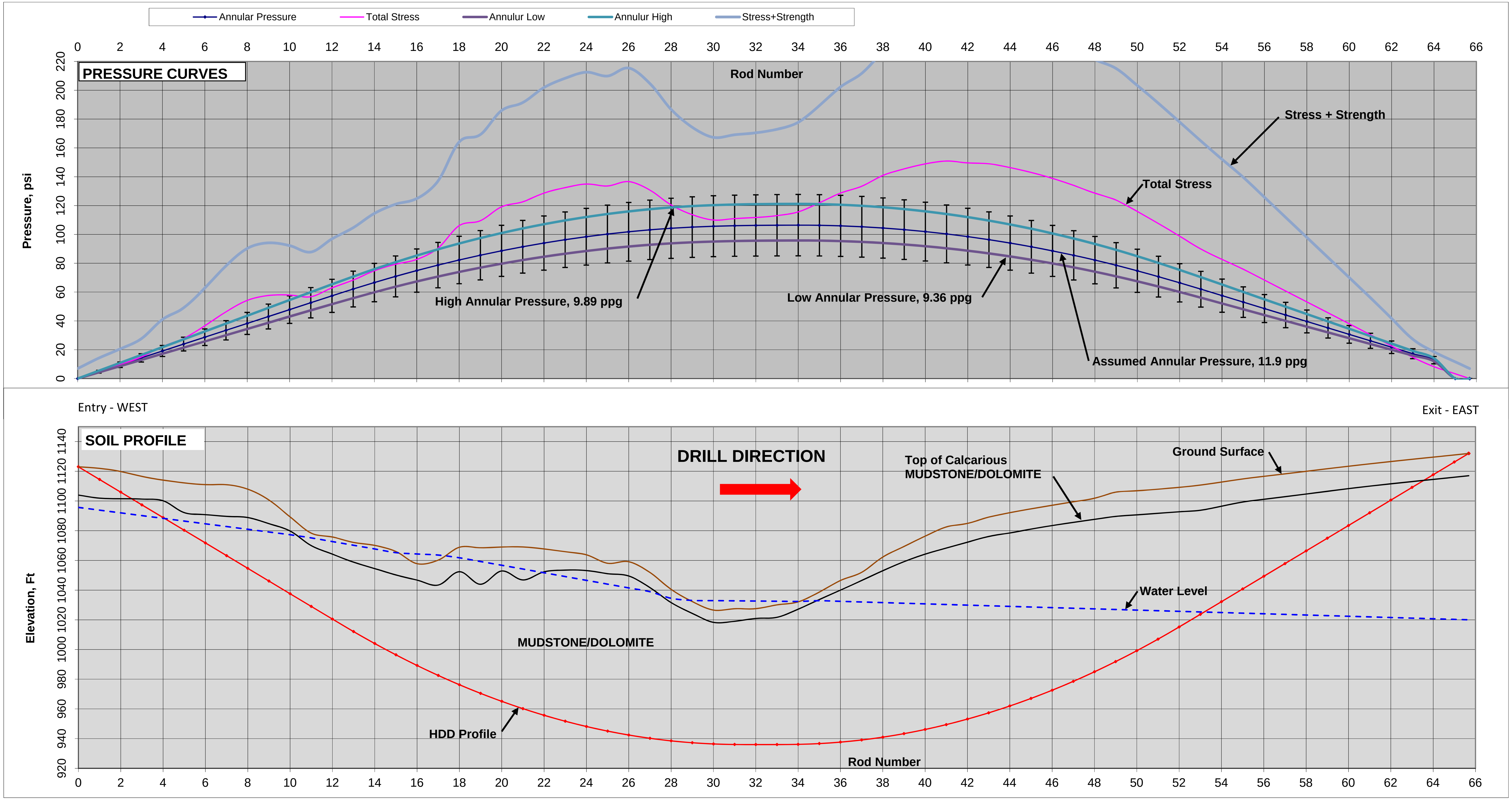
Prepared For:
Sunoco Logistics Partners L.P.
525 Fritztown Road
Sinking Spring, PA 19608
855-430-4491

Prepared By:
Directional Project Support
33311 Lois Lane, Suite A
Magnolia, Texas 77354
281.259.7819 (O)   617.510.8090 (C)
B. Dorwart

Project No: 0
Print Date: 3-Jun-2018

Revision	ID	DESCRIPTION	BY
10/22/2017	0	APC/FPC Design	BCD
6/3/2018	1	APC/FPC Design with revised drill path	BCD

C:\Users\bdorwart\Documents\DPS\Pennsylvania Pipeline\APC Designs\Spread 3\S2-0142 Lower Piney Ck\Revised design 5-30-18\16 inch\[Design_16in_ 6-3-18.xlsx]T4 Formation Pressure



Notes:

1. Geology is interpreted from project data
2. Rod length: 31 feet
3. The error bars are at 20 %
4. Ground surface data obtained from project survey data
5. Subsurface data from Geotechnical Report, Properties are interpreted from field and laboratory data as presented in Table 3.

Basis of annulur pressure calculations

12.25 in	Pilot Hole Diameter
78.0 pcf	Unit Weight Drill Fluid
252 gal/min	Pump Rate
5.50 in	Drill Rod Diameter
31	Ft per rod
20%	for APC curve

Print Date ; 6/4/2018 17:58

ISSUED: APC/FPC DESIGN

33311 Lois Lane, Suite A
Magnolia, Texas 77354
281.259.7819 (O) 617.510.8090 (C)

Sunoco Pipeline, L.P.
Mariner East Pipeline
Blair County, Pennsylvania

ANNULAR PRESSURE AND
FORMATION PRESSURE CURVES
LOWER PINEY CREEK HDD #S2-0142
16-INCH STEEL PIPE

Revision 1

FIGURE 1

TABLE 1
DESIGN SUMMARY, ASSUMPTIONS, CONDITIONS
Sunoco Pipeline, L.P.
Mariner East Pipeline
Blair County, Pennsylvania

LOWER PINEY CREEK HDD #S2-0142
16-INCH STEEL PIPE

Item	Comment/Exception/Assumption
1	PROJECT DATA AND SUMMARY: Project data provided as a technical basis for this submittal included four test borings, a seismic survey, and a resistivity survey. No laboratory data regarding moisture content, unit weight, or strength of the soil or rock has been provided. This information has been assumed for these calculations. Soil property assumptions are shown in the sample calculations on Table 4.
2	DRILL FLUID LOSS DURING CONSTRUCTION: Drill fluid loss during construction typically occurs as a result of one or a combination of the following: LEAKAGE, HYDRAULIC JACKING, HYDRAULIC FRACTURING. In all cases, the drill fluid finds an alternative path different than the design drill path that requires a lower pressure to move the drill fluid. Leakage occurs when an unplanned continous pathway intersects the drill path. Unplanned pathways can develop as a result of drilling operations or may occur around a manmade feature such as piles or may be a naturally occuring feature such as a solution features or joints in the rock. Hydraulic jacking occurs when there are discontinous cracks in the formation, such as along rock joints or along a confined relatively high permeability zone, into which the drill fluid can flow and exert hydraulic pressure because of the confinement. When the drill fluid pressure exceeds the restraining pressure, the sides of hte confinement are hydraulically jacked apart. The enlarged opening allows more fluid volume capacity and continues to develop as long as the pressure remains. Hydraulic fracturing occurs when the drill fluid pressure exceeds the static stress state in the formation plus the strength of the formation material. The result is a fracturing of the formation parrellel to the primary stress field which can provide a new path for the drill fluid. Once the formation is fractured that will continue to grow by hydraulic jacking until the drill fluid pressure is reduced or the formation strength increases. Note that hydraulic jacking and fracturing often build pressure in the formation such that during drill rod changes, the drill fluid discharges from the decoupled down hole drill rods until the built up pressure in the formation is reduced. Drill fluid 'loss' during the drilling advance is the source of this return fluid. Continuation of this situation can result in fluid release to the surface, into structures, or movement of adjacent structures such as buildings, highways, and bridges.

Item	Comment/Exception/Assumption
3	ANNULAR PRESSURE CALCULATION: Annular Pressure at any point along a drill path is calculated as the sum of the elevation and dynamic heads. Pressure from elevation head is the difference in feet between elevation of the entry pit drill fluid and the measurement elevation times the drill fluid density in pcf divided by 144 to convert to psi. Dynamic head is the pressure required to make the drill fluid flow along the drill path from the measurement location to the drill entry location. Drill fluids are Non-Newtonian fluids thus pressure must be modeled with specific fluid properties based on assumptions for drill fluid rheological properties. Field rheological properties for these calculations need to be assumed by the design engineer based on expereince. Assumptions should be verified by field values that may occur during operations, not on minimum or maximum capacity of a drill fluid. Field data can change from many field influences. Properties of various bentonitic products vary significantly. Additionally, subsurface conditions and cleaning system efficiiency will have significant impacts on drill lfuid porperties. The design Annular Pressure Curve is a planning and design tool for the engineer thus the design curves are not a tool to be applied in the field without correction to account for actual field properties. Field values of drill fluid properties should be expected to change dynamically during even short drilling lengths as different subsurface materials may require different drill fluid properties and both subsurface conditions and the contractor ability to clean the drill fluid can change rapidly. Two methods are used in these calculations to calculate Annular pressure. METHOD B uses a hydraulic model for viscous flow in an annulus and is described in the HDD Good Practices Guidelines; a book available through the NASTT. Both methods are accepted in the industry. The annular pressure curves shown in Figure 1 plot the API-13D data by drill rod along the drill path. Three annular pressure curves are shown on Figure 1 representing three different drill fluid densities that range the possible field conditions that may occur: Assumed estimate of reasonable drill fluid properties, Highest reasonable drill fluid properties, Lowest reasonable drill fluid properties. The "Assumed estimate" data include a 20% error bar on each point representing the accuracy and range between low and high of the data with regard to the ability to predict the actual pressures. The 20% error bar is based on experience with field measurements of annular pressure vs predictions.
4	CALCULATION OF FORMATION PRESSURE: The Formation Pressure capacity is calculated by models. A model used to approximate the complexities of pressure in the subsurface caused by materials that are not uniform thus contain wide variation in both geometry and properties., A model necessary to simplify the conditions yet still provide some science to subsurface complexity. There are presently four models that may be applied to approximate subsurface conditions. Each model provides reasonable values only within the range of the model assumptions and field conditions. Engineering judgement and understanding of the model must be applied during selection of the most appropriate model for a specific set of subsurface conditions. The four models provide four alternative calculation methods: Total Stress, Cavity Expansion (Delft Equation), Total Stress plus Strength, and the Queens Equation. Input data assumptions and range of available properties have been shown to be significant to the results from all four models. Significant experience is required in determination of these input values and in the interpretation of the results. Additionally significant expereince is necessary to determine if drained or undrained properties should be used in the analyses. In general, most fine grained materials, when exposed to HDD excavation rates, are best represented by undrained properites. Only highly permeable formations should be considered for drained properties as the undrained assumption means no change on water pressure during the drilling excavation process. Of note is that drained conditions typically provide higher formation pressure capacity than when using undrained properties. Thus these methods may not be conservative and can lead to overly optimistic expectations of Formation Pressure Capacity.

Item	Comment/Exception/Assumption
4a	**Total Stress Method** is based strictly on the dead weight of the overlying material above the drill path thus excludes any potential formation material strength. This method is a traditional approach to establish pressure limits to prevent hydraulic jacking along rock joints and other partings while grouting rock. The rule of thumb is apply no more than 1 psi per foot of rock during grout injection to prevent hydraulic jacking. This method is considered a reasonable approximation for limiting formation pressure in rock or very dense soils or weathered rock. Note that total stress and in particular the orientation of principal stress in the ground rotates with surface geometry. Fracturing of the ground always is orientated parrellel to the principal stress at that point in the ground. Therefore, in areas of high topographic relief and where the drill path approaches a topographic surface within about 5 times the depth below the entry, then the total stress must be adjusted for both magnitude and direction as the principal stress will be rotated in either soil or rock.
4b	**Total Stress plus strength method** is a traditional Mohr-Coulomb material failure approach to include insitu formation strength. Experience from the tunneling industry indicates that the strength of the materials needs to include various factors to account for an underground excavation geometry, soil/rock properties, and excavation to ground interaction such as results from trenchless constructions. An acceptible approach has been developed by Terzaghi and later refined by Stein and others. However, these modifications apply only to underbalanced drilling where external pressure exceeds internal pressure. For most HDD constructions, the pressure is applied outward by the annular pressure thus applying extension tension and shear properties for strength calculations. Calculations in this analyses only apply simple sample shear strength as defined by the Mohr-Coulomb relation.
4c	**Cavity Expansion** is modeled either by the Delft or Queens equations. These equations add the material strength assuming faulure is by cavity expansion stresses and geometry. The cavity expansion model does not provide assessment of fluid loss by leakage or hydraulic jacking. Expereince with the Delft model indicates unconservative predictions and a correction factor should be applied to determine a realistic Pmax prior to application of a safety factor. This correction factor is in addition to the correction factors of 1.5 and 2.0 for sand and clay materials already included in the equation. The Queens equation addresses the shortcomings of the Delft equation by intorducing the Ko factor which does vary in soil and rock as opposed to the Delft equation holding Ko as a constant. The result is expected to improve predictions for soils such that correction factors do not need to be applied to determine Pmax before application of safety factors. The cavity expansion relations are not generally appropriate for rock as fluid loss is typically by other processes such as leakage and/or hydraulic jacking.
5	TECHNICAL APPROACH DRILL FLUID MANAGEMENT: Table 2 provides the proposed drill path for the interpreted geologic profile assumed for the crossing. Table 3 provides the calculated Annular Pressure and Table 4 the calculated Formation Pressure Capacity. Calculations are provided for each drill rod along the design drill path. The results are summarized on Figure 1. Assessment is based on comparison of the Formation Pressure Capacity to the Annular Pressure. This relation provides a tool to assess the risk of hydraulic fracturing of a formation or hydraulic jacking along pathways within a formation caused by Annular Pressure exceeding the Formation Capacity Pressure. When the Annular Pressure is higher than the Formation Pressure Capacity, then the risk of drill fluid loss by jacking or hydrofracturing is considered high for the design drill path and drill direction. Mitigation considerations may include: reversing the drill direction, adjusting the depth of the drill path in problem areas, or reduction of drill fluid pressure by methods such as reduction of drill fluid weight, use of drill foam, reduction in the elevation head pressure which may be accomplished by pumping the drill fluid elevation in the hole down to a lower elevation.

Item	Comment/Exception/Assumption
6	**Limitations:** These calculations are for HDD planning purposes only. It should be expected that the drill process will generate new data that may require adjustments to the assumed conditions used for the basis of these calculations. Adjustments to the assumed subsurface conditions may require corresponding adjustments to the various HDD drill parameters or tools to optimize production. Typical parameters that are adjusted include: drill fluid pump rate, penetration rate, drill fluid properties, along with bit dimensions and types or other tooling.

PATH DESIGN CALCULATIONS

Entry Station	0+00.00	FT
Exit Station	19+89.94	FT

Entry and Exit Design Coordinates & Elevations (Ft) (Note 2)

	East	North	Elevation
Entry	1823773.9250	401317.5210	1,123.00 ft
Horizontal Curve PI	1824727.0950	401032.1605	
Exit	1825680.2650	400746.8000	1,132.00 ft
Depth to Mudline	95.40 ft	Clearance Depth =	91.60 ft

Measured Plan Length at ties =	1989.9384 ft
Coordinate Length =	1989.9384 ft

OK - NO HORIZONTAL CURVE TANGENT

Water Surface Elev.	1030.00 ft
Mudline Elev.	1027.60 ft
Lowest centerline Elev.	936.00 ft

SUMMARY HORIZONTAL CURVE CALCULATIONS

	Start			End						
	Station	Easting	Northing	Station	Easting	Northing	Azimuth	Length	Radius	Angle
Tangent	0+00.00	1823773.9250	401317.5210	9+94.97	1824727.0950	401032.1605	E 343.33333 N	994.97		
Curve	9+94.97	1824727.0950	401032.1605	9+94.97	1824727.0950	401032.1605	E 343.33333 N	0.00	0.00	0.000 deg.
Tangent	9+94.97	1824727.0950	401032.1605	19+89.94	1825680.2650	400746.8000	E 343.33333 N	994.97		

HORIZONTAL PLAN CALCULATIONS (FT)

Entry Tangent Segment		*Horizontal Curve Segment*		*Exit Tangent Segment*		
Plan Length, ft.	994.97	Input Radius, ft.	0.00	Plan Length, ft.	994.97	
Entry Azimuth, deg.[5]	E 343.33333 N	Curve, deg	0.000 deg.	Exit Azimuth, deg.[5]	E 343.33333 N	
Entry Azimuth, rad.[5]	5.99230	Curve, rad	0.00000	Exit Azimuth, rad.[5]	5.99230	
		Calculate PTH		**Calculate Exit**		
Calculate PCH		Chord Length, ft.	0.00	Easting	1825680.2650	*Check*
PCH Easting	1824727.0950	Arc Length, ft.	0.00	Northing	400746.8000	*Delta*
PCH Northing	401032.1605	Chord Azimuth, deg	343.3333			0.0000
		PI Easting =	1824727.0950			0.0000
		PI Northing =	401032.1605			OK CALC
		PTH Easting =	1824727.0950			
		PTH Northing =	401032.1605			Exit Station
						19+89.94
Cum Plan Length	994.97	Cum Plan Length	994.97	Cum Plan Length	1989.938355	OK STA

Pull Geometry

Pipe Entry	EXIT	Enter the pipe entry location into the hole: Entry/Exit					
	Elevations		Vertical Angle, (-) = Clockwise			Path	Curve
Segment	Start	End	Start	End	Δ Angle	Length	Radius
Entry Tangent	1132.00 ft	1017.35 ft	16.00 deg	16.00 deg	0.00 deg	415.94 ft	0.00 ft
Entry Curve	1017.35 ft	936.00 ft	16.00 deg	0.00 deg	-16.00 deg	586.43 ft	2100.00 ft
Bottom Tangent	936.00 ft	936.00 ft	0.00 deg	0.00 deg	0.00 deg	63.99 ft	0.00 ft
Exit Curve	936.00 ft	1017.35 ft	0.00 deg	-16.00 deg	-16.00 deg	586.43 ft	2100.00 ft
Exit Tangent	1017.35 ft	1123.00 ft	-16.00 deg	-16.00 deg	0.00 deg	383.29 ft	0.00 ft
					Total Check =	2036.08 ft	OK

Compound Curve Assessment

	Vert. Plan	Horiz. Plan	
Entry	947.28	994.97	No, Horiz > Entry V(Tan+Curve)
Exit	978.67	994.97	No, Horiz > Entry V(Tan+Curve)

VERTICLE PATH DESIGN CALCULATIONS (FT)

Entry Tangent Segment 1		*Entry Vert. Curve Segment 2*		*Middle Tangent Segment 3*		*Exit Vert. Curve Segment 4*		*Exit Tangent Segment 5*	
Entry Angle	-16.000 deg.	Vertical Radius	2100.00	Rod Length	63.98712	Radius	2100.00	Exit Elevation	1132.00
Entry Angle, rad.	-0.2793 rad	Vert. Curve, deg.	16.000 deg.	Inclined Bottom Tan	NO	Design Exit Angle	16.000 deg.		
Rod/Path Length	383.29	Vert. Curve, rad.	0.2793 rad			Vert. Curve, rad.	0.2793 rad		
Calculate Vertical PCV		**Calculate Vertical PTV**		**Calculate Vertical PCV**		**Calculate Vertical PTV**		**Calculate Exit**	
Plan Length	368.44	Plan Length	578.84	Plan Length	63.98711694	Vert. Curve, deg	16.000 deg.	Plan Length	399.83
Path Length	383.29	Arc Path Length	586.43	Path Length	63.99	Vert. Curve, rad.	0.27925268	Path Length	415.94
Tangent Depth	-105.65	Curve Vert Depth	-81.35	End Elevation	936.00	Plan Length	578.84	Elevation	1132.00
End Elevation	1017.35	End Elevation	936.00	Rise/drop	0.00	Path Arc Length	586.43	Rise/drop	114.65
		Lowest Elevation	936.00			Lowest Elevation	936.00		
		End Vert Angle	0.000 deg.	End Vert Angle	0.000 deg.	Elevation	1017.35		
		End Vert Angle, rad	0.0000 rad	End Vert Angle, rad	0.0000 rad	Curve Vert Depth	81.35	*Prop. Plan Length*	*1989.938355*

SUMMARY VERTICLE CURVE CALCULATIONS

Start Station	0+00.00	Start Station	3+68.44	Start Station	9+47.28	Start Station	10+11.27	Start Station	15+90.11
PVC Station	3+68.44	PTV Station	9+47.28	PCV Station	10+11.27	PTV Station	15+90.11	Exit Station	19+89.938
Cum Plan Length	368.44	Cum Plan Length	947.28	Cum Plan Length	1011.27 ft	Cum Plan Length	1590.11	Cum Plan Length	1989.938355
Cum Path Length	383.29	Cum Path Length	969.72	Cum Path Length	1033.71 ft	Cum Path Length	1620.14	Cum Path Length	2036.08374
Cum Depth	-105.65	Cum Depth	-187.00	Cum Depth	-187.00 ft	Cum Depth	-105.65	Cum Depth	9.00

Summary of Drill Calculations

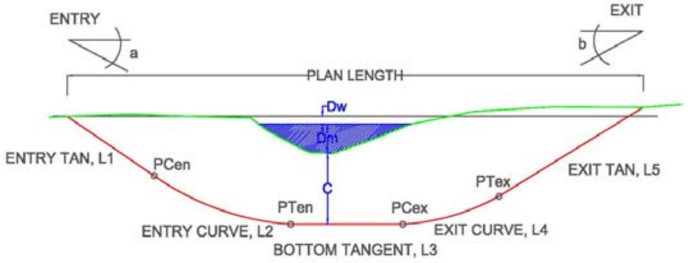
Entry to Exit Elevation Change =	**9.00 ft**
Minimum Design Elevation =	**936.00 ft**
Invert Depth below exit =	**196.00 ft**
Invert Depth below entry =	**187.00 ft**
Path Length =	**2,036.08 ft**
Plan Length =	**1,989.94 ft**
Minimum Plan Length (No Tangent) =	**1,925.95 ft**
Entry Angle =	**-16.00 deg**
Exit Angle =	**16.00 deg**
Compound Curve at Entry =	**NO**
Compound Curve at Exit =	**NO**

Stationing Check
OK STATIONING

Plan Length Check
OK CALCULATION

NOTES:

1. Sign convention for angles - positive (+) angles are counterclockwise.
   Due East is defined as 0 degrees.
2. Coordinates are in feet and reference NAD 83 Pennsylvania South State Plane
3. Elevations are in feet and reference NAVD 88.
4. All calculation locations represent the center of the drill hole.



🟨	Indicates inputs
🟧	Indicates status on internal design checks

ISSUE: **APC/FPC DESIGN**

Sunoco Pipeline, L.P.
Mariner East Pipeline
Blair County, Pennsylvania

TABLE 2
DESIGN DRILL PATH CALCULATION
LOWER PINEY CREEK HDD #S2-0142
16-INCH STEEL PIPE

Directional Project Support
33311 Lois Lane, Suite A
Magnolia, Texas 77354

Revision 1
10/22/2017

TABLE 3
ESTIMATED ANNULAR PRESSURE CURVE (APC) EXAMPLE CALCULATION
Sunoco Pipeline, L.P.
Mariner East Pipeline
Blair County, Pennsylvania

LOWER PINEY CREEK HDD #S2-0142
16-INCH STEEL PIPE
INPUT
1. Drill path data

	Measured Distance	Elevations	Angles	Lengths	Angle Change	
Drill Entry	0.000 ft	1123	-16	Entry to PC	383.292 ft	
PC	383.292 ft			PC to PT	586.431 ft	-0.027 deg/ft
PT	969.723 ft			Invert Tangent	63.987 ft	
PC	1033.710 ft			PC to PT	586.431 ft	0.027 deg/ft
PT	1620.140 ft			PT to Exit	415.943 ft	
Drill Exit	**2036.084 ft**	1132.00 ft	16		**2036.084 ft**	
					Length Ck	**OK**

2. Drill Fluid Hydraulic Assumptions

	Assumed		**Low**		**High**	
Density, γ_f =	78	10.43 lb/gal	70	9.36 lb/gal	89	11.90 lb/gal
Dynamic annulus pressure P_d =	0.0050 psi/ft		0.0047 psi/ft		0.0054 psi/ft	
Drill fluid viscosity, μ_p =	15 cp		4 cp		13 cp	
Yield point of drill fluid, YP =	30		16		5	

3. Drill Data Assumptions

Assumed Drill Size: **DD660**

Avg Rod length =	31.0 feet	Max Rig Pump =	1200 gpm
Diameter of hole, D_h =	12.25	Number of drill rods =	66
Drill Rod Tube Diameter, D_r =	5.500 in	Estimated annular pilot uphole drill fluid velocity, V_{ha} =	51.55 ft/min
Drilling Pump rate, gpm =	252 gal/min		

4. Calculate Annular Pressure, P

Method A - (API RP) 13D

$$P_A = [\gamma_f\,(Y_{entry} - Y)/144] + (P_d)(MD)$$

Method B - HDD Good Practices Cavity Expansion Annular Pressure

$$P_B = [\gamma_f * (Y_{entry} - Y)/144] + MD*[\mu_p*(V_{ha}/60)/(1000*(D_h-D_r)^2) + YP/[200*(D_h-D_r)]$$

Start Station 0+00.00 1

Drill Path			**Assumed Return Density**		**Low Return Density**		**High Return Density**	
			Density, γ_{fE} =	**78**	**Density, γ_{fL} =**	**70**	**Density, γ_{fH} =**	**89**
Rod Measured Distance MD	**Station X**	**Elevation Y**	**Annular Fluid Pressure P_A**	**Annular Fluid Pressure P_B**	**Annular Fluid Pressure P_A**	**Annular Fluid Pressure P_B**	**Annular Fluid Pressure P_A**	**Annular Fluid Pressure P_B**
ft	**ft**	**ft**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**
0.00	0+00.00	1,123.00	0.00	0.00	0.00	0.00	0.00	0.00
31.00	0+29.80	1,114.46	4.78	5.33	4.30	4.53	5.45	5.40
62.00	0+59.60	1,105.91	9.57	10.65	8.60	9.05	10.90	10.81
93.00	0+89.40	1,097.37	14.35	15.98	12.90	13.58	16.35	16.21
124.00	1+19.20	1,088.82	19.13	21.30	17.20	18.11	21.79	21.61
155.00	1+49.00	1,080.28	23.91	26.63	21.50	22.63	27.24	27.02
186.00	1+78.79	1,071.73	28.70	31.96	25.80	27.16	32.69	32.42
217.00	2+08.59	1,063.19	33.48	37.28	30.10	31.69	38.14	37.82
248.00	2+38.39	1,054.64	38.26	42.61	34.40	36.21	43.59	43.23
279.00	2+68.19	1,046.10	43.04	47.93	38.70	40.74	49.04	48.63
310.00	2+97.99	1,037.55	47.83	53.26	43.00	45.27	54.49	54.04
341.00	3+27.79	1,029.01	52.61	58.59	47.30	49.79	59.94	59.44

Drill Path			Assumed Return Density		Low Return Density		High Return Density	
			Density, γ_{fE} =	78	Density, γ_{fL} =	70	Density, γ_{fH} =	89
Rod Measured Distance MD	Station X	Elevation Y	Annular Fluid Pressure P_A	Annular Fluid Pressure P_B	Annular Fluid Pressure P_A	Annular Fluid Pressure P_B	Annular Fluid Pressure P_A	Annular Fluid Pressure P_B
ft	ft	ft	psi	psi	psi	psi	psi	psi
372.00	3+57.59	1,020.46	57.39	63.91	51.60	54.32	65.38	64.84
403.00	3+87.43	1,012.06	62.10	69.16	55.83	58.78	70.75	70.16
434.00	4+17.37	1,004.01	66.61	74.22	59.89	63.06	75.89	75.25
465.00	4+47.42	996.41	70.88	79.03	63.73	67.13	80.75	80.07
496.00	4+77.58	989.26	74.91	83.61	67.36	70.98	85.34	84.62
527.00	5+07.85	982.55	78.70	87.94	70.77	74.62	89.66	88.89
558.00	5+38.21	976.28	82.25	92.03	73.96	78.04	93.70	92.88
589.00	5+68.66	970.47	85.55	95.88	76.93	81.24	97.46	96.60
620.00	5+99.19	965.10	88.61	99.48	79.68	84.22	100.94	100.04
651.00	6+29.80	960.19	91.42	102.84	82.22	86.98	104.14	103.20
682.00	6+60.48	955.73	94.00	105.95	84.53	89.52	107.07	106.08
713.00	6+91.22	951.72	96.32	108.82	86.63	91.84	109.71	108.67
744.00	7+22.01	948.17	98.40	111.44	88.50	93.94	112.08	110.99
775.00	7+52.86	945.07	100.23	113.82	90.15	95.82	114.16	113.03
806.00	7+83.74	942.43	101.82	115.95	91.58	97.48	115.96	114.79
837.00	8+14.67	940.24	103.15	117.83	92.79	98.91	117.48	116.26
868.00	8+45.62	938.51	104.25	119.46	93.78	100.13	118.71	117.45
899.00	8+76.59	937.24	105.09	120.85	94.55	101.12	119.67	118.36
930.00	9+07.58	936.43	105.68	121.99	95.09	101.89	120.34	118.99
961.00	9+38.58	936.07	106.03	122.88	95.41	102.43	120.73	119.33
992.00	9+69.58	936.00	106.22	123.61	95.59	102.84	120.94	119.49
1023.00	10+00.58	936.00	106.38	124.31	95.73	103.21	121.10	119.61
1054.00	10+31.58	936.15	106.45	124.93	95.81	103.51	121.18	119.64
1085.00	10+62.57	936.68	106.32	125.34	95.70	103.63	121.02	119.44
1116.00	10+93.56	937.67	105.94	125.50	95.36	103.52	120.58	118.95
1147.00	11+24.53	939.11	105.31	125.42	94.81	103.19	119.85	118.18
1178.00	11+55.47	941.01	104.43	125.09	94.03	102.64	118.85	117.13
1209.00	11+86.38	943.37	103.31	124.51	93.03	101.87	117.56	115.80
1240.00	12+17.25	946.18	101.94	123.68	91.81	100.88	115.99	114.18
1271.00	12+48.08	949.45	100.33	122.61	90.37	99.66	114.13	112.28
1302.00	12+78.85	953.17	98.46	121.29	88.71	98.23	112.00	110.11
1333.00	13+09.57	957.35	96.36	119.73	86.82	96.57	109.59	107.65
1364.00	13+40.22	961.98	94.00	117.92	84.72	94.69	106.89	104.91
1395.00	13+70.80	967.06	91.40	115.86	82.39	92.59	103.92	101.89
1426.00	14+01.30	972.59	88.56	113.56	79.85	90.28	100.67	98.59
1457.00	14+31.72	978.57	85.48	111.02	77.09	87.74	97.14	95.02
1488.00	14+62.05	985.00	82.15	108.24	74.11	84.99	93.33	91.17
1519.00	14+92.28	991.88	78.58	105.21	70.91	82.02	89.25	87.04
1550.00	15+22.40	999.20	74.76	101.94	67.50	78.83	84.89	82.63
1581.00	15+52.41	1,006.97	70.71	98.43	63.87	75.43	80.26	77.96
1612.00	15+82.30	1,015.18	66.42	94.68	60.03	71.81	75.35	73.01
1643.00	16+12.12	1,023.67	61.97	90.78	56.05	68.06	70.28	67.88
1674.00	16+41.92	1,032.21	57.50	86.85	52.04	64.28	65.16	62.72
1705.00	16+71.72	1,040.75	53.03	82.92	48.03	60.50	60.05	57.56
1736.00	17+01.52	1,049.30	48.55	78.99	44.03	56.72	54.93	52.41
1767.00	17+31.32	1,057.84	44.08	75.06	40.02	52.94	49.82	47.25
1798.00	17+61.11	1,066.39	39.60	71.13	36.01	49.16	44.71	42.09
1829.00	17+90.91	1,074.93	35.13	67.20	32.00	45.38	39.59	36.93
1860.00	18+20.71	1,083.48	30.65	63.27	28.00	41.60	34.48	31.77
1891.00	18+50.51	1,092.02	26.18	59.34	23.99	37.82	29.37	26.61
1922.00	18+80.31	1,100.57	21.71	55.41	19.98	34.03	24.25	21.45
1953.00	19+10.11	1,109.11	17.23	51.47	15.98	30.25	19.14	16.30
1984.00	19+39.91	1,117.66	12.76	47.54	11.97	26.47	14.03	11.14
2015.00	19+69.71	1,126.20	0.00	0.00	0.00	0.00	0.00	0.00
2036.08	19+89.98	1,132.01	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 4
ESTIMATED FORMATION PRESSURE CURVE (FPC) EXAMPLE CALCULATION
Sunoco Pipeline, L.P.
Mariner East Pipeline
Blair County, Pennsylvania

LOWER PINEY CREEK HDD #S2-0142
16-INCH STEEL PIPE
INPUT

1. Drill path data from vertical path calculations

	Measured Distance	Elevations	Angles	Lengths	Angle Change		
Entry	0.000 ft	1123	-16	Entry to PC	383.292 ft		
PC	383.292 ft			PC to PT	586.431 ft	-0.027 deg/ft	
PT	969.723 ft		0	Invert Tangent	63.987 ft		
PC	1033.710 ft			PC to PT	586.431 ft	0.027 deg/ft	
PT	1620.140 ft			PT to Exit	415.943 ft		
Exit	**2036.084 ft**	1132.00 ft	16		**2036.084 ft**	**Length Ck**	**OK**

2. Drill Fluid Hydraulic Data for Estimated Drill Fluid

Dynamic annulus pressure =	0.00497 psi/LF	
Uphole Drill Fluid Density =	78	10.4 lb/gal
Drill fluid viscosity, cp =	15 cp	
Up hole drill fluid velocity, ft/sec =	51.55 ft/sec	
Pump rate, gpm =	252 gal/min	
Diameter of hole D_H, in =	12.25	
Diameter of Drill Rod D_R, in =	5.5	
Yield point of drill fluid, lb/100 ft^2 =	30.00 Lb/100FT^2	

Radius

R_H = 6.125 in
R_R = 2.750 in

3. Soil Profile Data

Technical approach to generate data as no testing available

Undrained conditions use ν = 0.5

Material Layer	Dry Density γ (pcf)	Moisture Content %	Insitu Saturated Density (pcf)	Effective UW (pcf)	Phi, Φ	Undrained Cohesion c, psf	Poisson Ratio μ	Slow Shear Modulus, G psf	OCR Cohessive (Use 0 if non-cohessive)	Model Material Layer Description	Cohesive
1	100	25.0%	125	37.60 pcf	22	1000	0.5	260,000	1	Lean Clay/Clayey Silt	Y
2	160	10.0%	176	97.60 pcf	40	20	0.3	1,000,000	1	Mudstone/Dolomite	Y
3	160	10.0%	176	97.60 pcf	40	20	0.3	1,000,000	1	Mudstone/dolomite	Y
4								0			
5								0			
6								0			
7								0			
8								0			
9								0			
10								0			
Water	62.4			62.40 pcf							

Dynamic Shear Velocity, $V_s = 61.4*N_{60}^{1/2}$ Based on Seed and Idris approximation

Dynamic Shear Modulus, $G_{max} = (\gamma/g)*Vs^2$

Extended Strain Shear Modulus G is typically between 5% and 20% of G_{max}

g = acceleration of gravity = 32.2 ft/s^2

Select Reduction Factor, RF = 100% Ref 1

4 Select Controlling Location and list properties (Based on inspection of Figure 1 plot

Joint = 30   Away Distance from Entry = 907.58 ft   Depth of Cover = 90.11 ft

Layers	***Surface 1-2***	***Surface 2-3***	***Surface 3-4***	***Surface 4-5***	***Surface 5-6***	***Surface 6-7***	***Surface 7-8***	***Surface 8-9***	***Surface 9-10***	**TOTAL**	Total CK
Soil Type in Layer =	1	2	3								
Dry Density in Layer, γ_d =	100.00 pcf	160.00 pcf	160.00 pcf								
Insitu Density in Layer, γ_s =	125.00 pcf	176.00 pcf	176.00 pcf								
Effective Weight in Layer, γ'_e =	37.60 pcf	97.60 pcf	97.60 pcf								
Total Layer Thickness over drill, h_s =	8.25 ft	81.86 ft	0.00 ft							90.11 ft	90.11 ft
Saturated Thickness over drill, h_{sat} =	8.25 ft	81.86 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	90.11 ft	
Dry Thickness over drill, h_{dry} =	0.00 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	0.00 ft	
Contribution Effective Stress, σ' =	516.27 psf	9,299.71 psf	0.00 psf								
Contribution Total Stress, $\sigma = h_s*\gamma_s$	1,428.76 psf	14,407.99 psf	0.00 psf								
Shear Modulus, G =	260,000 psf	1,000,000 psf	1,000,000 psf								

Height of Water above Soil Surface, h_w = 6.38 ft

Total soil and water height above drill path, H_T = 96.49 ft

Total water height above drill path, H_W = 96.49 ft

Properties At Drill Depth for Selected Joint

R_H =	0.51 ft	Radius of drill hole
$R_{max} = h_s/FS_D$ =	45.06 ft	Maximum allowable radius of plastic zone = Height of soil above Drill Path (h_s) divided by Delft & Queens Equation FS_D
	2	Soil Layer At Drill Depth
G_w =	1,000,000 psf	Large Strain Shear Modulus at drill depth
$S_u = c = q_u/2$	20 psf	Cohessive material: cohession c = unconfined compressive strength (q_u) divided by 2
ϕ =	40 deg	0.6981 rad
H_W =	96.49 ft	Total water height above drill path
FS_D =	2	Factor of Safety for Delft & Queens Equation soil type: Use 1.5 for Sand and 2 for Clay at Drill Depth - Apply to R_{max} and P_{max}
μ =	0.3	Poisson ration o Granular Soil: Angle of internal friction of layer at drill path depth
OCR =	1	Over Consolidation Ratio
K_o =	0.429	Coefficient of lateral earth pressure at rest. For OCR = 1 use relation $K_o = \mu/(1 - \mu)$; For OCR >1 use $K_o = (K_{onormally\ consolidated}) * OCR^{-1/2}$
σ_o =	15,837 psf	Total Stress at drill depth, $\sigma = \gamma_d$(above water)*hdry + γ_s(saturated)*h_{sat}
u =	6,021 psf	Water pressure at drill depth, $u = \gamma_W * H_W$
σ' =	9,816 psf	Effective Stress at drill depth, $\sigma' = \sigma - u$

5. Method A - Total Stress Method (Conservative)

Calculate Allowable Controlling Formation Pressure Capacity

$P_{max} = \sigma_o = \Sigma (h_s*\gamma_s) + h_w*\gamma_w$

P_{maxA} = 15,837 psf   109.98 psi

109.98 psi   Check Calculation

6. Method B - Total Stress Method + Local Formation Strength

Calculate Allowable Controlling Formation Pressure Capacity

$P_{max} = \Sigma (h_s*\gamma_s) + h_w*\gamma_w + S$

P_{maxB} 24,093 psf   167.31 psi

167.31 psi   Check Calculation

Based on Mohr-Coulomb

Strength = $c + \sigma' * \tan(\phi)$

8,257 psf   57.34 psi

7. Method C - Delft Equation for cavity expansion (Assumes undrained properties)

$P_{max} = \mu + [p'_f + c * \cot \phi] * \{[R_o/R_{pmax}]^2 + [(\sigma_o' * \sin \phi + c * \cos \phi)/G]\}^{-\sin \phi/(1+\sin \phi)} - c*\cot(\phi)$

$\mathrm{Sin}(\phi)$ = 0.64278761

$\mathrm{Cos}(\phi)$ = 0.76604444

$\mathrm{Cot}(\phi)$ = 1.19175359

μ = 6,021 psf Initial Pore Pressure, $\mu = \gamma_w * H_w$

σ' = 9,816 psf Effective Stress, $\sigma_o' = \Sigma [\gamma_d * h_d + \gamma' * h_s]$

p'_f = 16,141 psf p'_f = 112.09

A = 16164.71691 $A = p'_f + c * \cot \phi$

B = 0.000128338 $B = [R_o/R_{pmax}]^2$

C = 0.006324908 $C = (\sigma_o' * \sin \phi + c * \cos \phi)/G$

D = -0.391278584 $D = -\sin \phi/(1+\sin \phi)$

E = 23.83507185 $E = c*\cot \phi$

σ' = 9,815.97 Check Calculation

Checks
16164.71691
0.000128338
0.006324908
-0.391278584
23.83507185

P_{max} = 122,290 psf 849.24 psi $P_{max} = \mu + A * (B + C)^D - E$

P_{allC} = 61,145 psf 424.62 psi $P_{all} = P_{max}/FS$

122,290 psf Check Calculation

8. Method D - Queens Equation (Cohesive Soils Only) better for softer clay soils (Assumes undrained properties)

$K_o < 1$ $P_i = S_u + (1/2)*(3K_o-1)*\sigma_o - S_u*\ln[(R_o/R_{pmax})^2 + (S_u/G)]$

$K_o > 1$ $P_i = S_u + (1/2)*(3-K_o)*\sigma_o - S_u*\ln[(R_o/R_{pmax})^2 + S_u/G]$

To Determine if hydraulic fracturing or blowout occurs **(<2Su) indicates hydraulic fracturing; (>2Su) indicates blowout**

$K_o < 1$ $F_1(K_o,\sigma_o,S_u) = (3*K_o - 1)*\sigma_o$

$K_o > 1$ $F_1(K_o,\sigma_o,S_u) = (3 - K_o)*\sigma_o$

K_o = 0.429

P_i = 2,459 psf 17.07 psi

F_1 = Expect Blowout

17.07 psi Check Calculation

9. SUMMARY and Assessment of Estimated Drilling Annular Pressure and Formation Capacity

(See Annular Pressure Calculations for joint by joint calculations)

Method A - (API RP) 13D

Method B - HDD Good Practices Cavity Expansion Annular Pressure

$P_{annularA}$ = 105.68 psi $P_A = [\gamma_f (Y_{entry} - Y)/144] + (P_d)(MD)$

$P_{annularB}$ = 121.99 psi $P_B = [\gamma_f * (Y_{entry} - Y)/144] + MD*[\mu_p * V_{ha}/(1000*(Dh-Dr)^2)] + YP/[200*(D_h-D_r)]$

Method A 109.98 psi FS = 1 Total Stress

Method B 167.31 psi FS = 1 Total Stress + Strength

Method C 424.62 psi At FS_D = 2 Delft Equation

Method D 17.07 psi At FS_D = 2 Queens Equation

Comparitive Factor of Safety against Drill Fluid Loss at Critical Joint

Critical Joint = 30 Depth of Cover = 90.1 ft

Confining Pressure Calculation Method	Method A	Method B	Method C	Method D
Method (X)/$P_{annularA}$	1.04	1.58	4.02	0.16
Method (X)/$P_{annularB}$	0.90	1.37	3.48	0.14

Acceptable if Factor of Safety >=1.0