August 26, 2019

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Subject: HDD Design and Constructability Review Report
Tilgham Lateral HDD #1

INTRODUCTION

Laney Group Inc. (Laney) is pleased to present this Horizontal Directional Drill (HDD) design review report for HDD #1 of the Tilgham Lateral project. We understand that the Tilgham Lateral Project will consist of a new 16-inch diameter natural gas pipeline to be installed near Lower Chichester Township, Pennsylvania. During the review process, Laney reviewed the plan and profile drawings of the nine HDD crossings provided by Hunt, Guillot, and Associates (HGA). The nine HDD crossings as listed below in Table 1. This report presents our design review of HDD #1 including a detailed assessment of pipe stresses, inadvertent return analysis, and constructability.

Table 1. Proposed HDD Crossings of the Tilgham Lateral Project

Crossing Name	Crossing Length (feet)	Drawing Reviewed	Revision Date
HDD #1	**1,254**	**8.A17022-TLGHMN-HDD-1**	**10/02/18**
HDD #2	2,028	8.A17022-TLGHMN-HDD-2	10/3/18
HDD #3	2,060	8.A17022-TLGHMN-HDD-3	10/15/18
HDD #4	2,851	8.A17022-TLGHMN-HDD-4	10/15/18
HDD #5	2,704	8.A17022-TLGHMN-HDD-5	05/22/18
HDD #6	991	8.A17022-TLGHMN-HDD-6	10/18/18
HDD #7	2,875	8.A17022-TLGHMN-HDD-7	10/22/18
HDD #8	1,575	8.A17022-TLGHMN-HDD-8	10/24/18
HDD #9	1,828	8.A17022-TLGHMN-HDD-9	10/25/18

Basis of Design Review

Our review of proposed HDD #1 was completed based on the parameters presented in Table 2. Our review of the proposed HDD design was completed in general accordance with the latest versions of the Code of Federal Regulations (CFR) Title 49, Part 195 (CFR, 2014), American Society of Mechanical Engineers (ASME) 31.4 (ASME, 2012) and 31.8 (ASME, 2014) and generally accepted practices within the pipeline industry.

Table 2. Basis of Design Review

Carrier Pipe Data	Design Parameter
16-inch Carrier Pipe Specifications:	16” OD[1] x 0.500”w.t.[2] API 5L X-52 steel pipe
Maximum Allowable Operating Pressure:	1440 psig[3]
Maximum Operating Temperature:	70 degrees Fahrenheit
Tie-In Temperature:	70 degrees Fahrenheit
Design Factor[4]	0.5

Notes:
[1] OD – outside diameter
[2] w.t. – wall thickness
[3] psig – pounds per square inch gauge
[4] As defined in Title 49 CFR Sections 192.5 and 192.111

Installation Stresses

The installation stress analyses are based upon the methods developed by the Pipeline Research Committee International (PRCI) of the American Gas Association (Installation of Pipelines by Horizontal Directional Drilling - An Engineering Design Guide, Contract No. PR-227-9424, November 2008).

The allowable tensile stress used for the analyses is derived from Sections 2.4.1, 3.1.2 and 3.2 of the American Petroleum Institute (API) Recommended Practice 2A – WSD (Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms – Working Stress Design, API Recommended Practice 2A-WSD, July 1, 1993).

Pulling loads for the HDD crossing for an un-ballasted carrier pipe pulled through a drilled hole with drilling fluid unit weights of 9.5 pounds per gallon (ppg) and 12.0 ppg were estimated. The estimated pull loads for the proposed HDD are presented in Table 3.

Table 3. Estimated Installation Loads[1]

Carrier Pipe	Drilling Fluid Density (lbs./gal)	Ballast Condition	Pull Load[2]
16-inch HDD #1	9.5	Empty	58,000
16-inch HDD #1	12	Empty	76,000

Notes:
[1] See attachments for detailed calculations.
[2] Assumes a fully open drilled hole.

OPERATING STRESSES

The analysis of operating stresses takes into consideration the stresses imposed on the carrier pipe during operation to compare estimated and allowable limits. The operating stresses on a pipeline installed by HDD include hoop stress from the maximum allowable operating pressure (MAOP), hoop stress from external pressure applied by the external hydrostatic and soil pressure acting on the outside of the carrier pipe, elastic bending as the carrier pipe conforms to the shape of the drilled hole, and thermal expansion and contraction stresses resulting from the difference between the constructed temperature and the operating temperature. For the current analyses, both installation and operating temperatures were assumed to be equal. Laney can evaluate different installation and operating temperatures if requested by HGA. A MAOP of 1,440 pounds per square inch (psi) was used in our analysis for the 16 inch diameter pipe.

Longitudinal stresses from bending were calculated assuming a minimum radius of curvature of 800 feet for the 16 inch diameter pipe. Our recommended minimum 3-joint radius of curvature of 800 feet meets applicable pipeline codes and standards while reducing the risk of construction delays while completing the pilot hole by providing a sufficient buffer between the design radius and minimum allowable pilot hole installation radius. Estimated calculations of operating stresses of the crossing are attached. Table 4 presents typical operating stress calculations using above values and no ground water head.

Table 4. Estimated Operating Stresses for Minimum Bending Radius

Stress Component	Stress (psi)*	Percent SMYS[1]	Maximum Allowable Percent SMYS[1]
Longitudinal Stress from Bending	24,200	47	-
Hoop Stress (S_H)	23,000	44	50[(2)]
Longitudinal Stress from Hoop Stress	6,900	13	-
Longitudinal Stress from Thermal Expansion	-	-	-
Net Longitudinal Stress (Compression Side) (S_L)	-17,300	33	90[(3)]
Combined Longitudinal and Hoop Stress			
$(S_H - S_L)$	40,300	78	90[(4)]
$(S_H^2 - S_H S_L + S_L^2)^{1/2}$	35,000	67	90[(4)]

Notes:
[*] Tensile positive and compressive negative
[1] Specified Minimum Yield Stress
[2] Limited by design factor from DOT regulations, CFR (2014).
[3] Limited by Section 833.3 of ASME B31.8 (2014).
[4] Limited by Section 833.4 of ASME B31.8 (2014).

DESIGN REVIEW AND CONSTRUCTABILITY FINDINGS

Table 5 below lists the particular aspects of site layout/design that Laney reviewed and provides comments and recommendations for each.

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Table 5. Summary of Design Review

Condition	Summary
Pipe Stresses	Laney performed pipe stress analyses on the HDD design completed by HGA. We estimate the pull load required to install the carrier pipe to be between 58,000 pounds and 76,000 pounds, assuming the pipe is pulled through an open and clean hole. We recommend a 3-joint minimum installation radius of 800 feet. As noted in Table 3 above, the proposed design meets applicable pipeline codes and standards. Please see attachments for detailed calculations.
Surface Conditions	The topography of the general area of the crossing is flat and well graded near the entry point towards Ridge Road and stays relatively flat toward the exit point with roughly a 6-foot difference in elevation between entry and exit points. This is a generally favorable condition for HDD installation.
Subsurface Conditions	Laney reviewed Borings B-1.1, B-1.2, and B-1.3 that were identified on the HDD drawing to assess the subsurface conditions at the HDD location. The three borings were completed near the entry point, midpoint, and exit point of the HDD. The borings show the drill profile predominantly passes through a silty sand layer into granitic pegmatite. Note, traces of gravel are present throughout the borings. Lab results show the unconfined compressive strength of the rock is between approximately 2,000 and 10,000 psi and RQD values averaging between 59 and 67 percent. Additional borings were performed to better detail the subsurface conditions. Boring B1.1A was performed along the HDD alignment. Boring B1.1A was performed to a depth of 70’. The boring encounters bedrock at approximately 25’ of depth until boring termination. The RQD of the rock is between 0% and 55%, this is considered very poor to fair quality. Sample C-4 was tested for unconfined compressive strength. At 48.5’ of depth the UCS of the rock in the borings is 16,401 psi, at approximately 55’ the UCS is 17,952, and at approximately 68’ the UCS is 7,025. Based on this boring, the assumption can be made that the majority of the bottom tangent is located in bedrock. The bedrock is low quality and fractures. This increases the chance of drilling fluid propagating through the fractures.
Profile Depth	As designed, the HDD profile is approximately 41 feet below Ridge Road. It is our opinion that this depth is adequate. If the subsurface material is consistent with the borings data at depth, soil conditions are adequate based on the boring logs provided on the drawing.
Profile Geometry	There is approximately 677 feet of bottom tangent based on the provided design drawing. There is a single horizontal curve in the current profile that adds to the complexity of the construction phase. Laney believes this will not pose an issue if the HDD contractor has an experienced steering technician during pilot hole operations. We recommend adding a note to the drawing stating a minimum allowable radius (3-joint average) of 800-feet is required.

Existing Utilities	Based on the provided information, there are some existing utilities in the area near the HDD profile. The nearest one shown on the drawing is approximately 18-feet from the drill path. We recommend confirming the locations of these utilities by performing all necessary one-calls and due diligences before commencing drilling operations.
Entry Staging	The workspace at entry is limited based on its proximity to the existing road. There is a nearby paved area where some equipment can be staged. This area is part of the pipeline right-of-way. It is recommended to plan around the difficulties of staging an HDD spread in the limited space available.
Exit Staging	Based on the provided HDD drawing, sufficient area for stringing the carrier pipe has been indicated. The workspace provides adequate space for the staging of the pipe side support equipment and pullback pipe string required for an HDD crossing of this magnitude.
Permitting Requirements	Laney did not review any permitting requirement and/or permit conditions set by any permitting agency applicable for this crossing. Therefore, we do not guarantee that the design satisfies any/all such requirements/conditions as they vary with different agencies.

HYDRAULIC FRACTURE ANALYSIS AND INADVERTENT DRILLING FLUID RETURNS

Hydraulic Fracture Analysis

Analysis of hydraulic fracture potential (fracture of the soil formation being drilled because of the annular pressure during drilling operation) consists of two steps: (i) estimation of annular drilling fluid pressure, and (ii) estimation of pressure at which shear failure of soil occurs (formation limit pressure). Typically, the maximum drilling fluid pressure occurs during pilot hole process. This is because frictional head loss is larger when the annular space between the drill pipe and drilled hole is small. As a result, the hydraulic fracture potential analysis is carried out for pilot hole process only. The factor of safety against hydraulic fracture is defined as the ratio between the estimated formation limit pressure and the estimated annular drilling fluid pressure. Analysis of inadvertent drilling fluid returns (returns of drilling fluid to the surface through fractured formation) potential is performed by comparing the shear strength of the strongest soil layer at or above the depth of the proposed HDD profile with the annular drilling fluid pressure.

Laney has made assumptions of anticipated downhole tooling and drilling fluid properties to estimate annular pressure along the proposed HDD geometry. If the selected HDD contractors intend to use tooling or drilling fluid properties significantly different from our assumptions, Laney can revise the annular pressure estimates.

The methodology used to estimate the formation limit pressure, as discussed in Appendix B of the USACE Report CPAR-GL-98 (Staheli, et. al., 1998, “Installation of Pipelines Beneath Levees Using Horizontal Directional Drilling,” U.S. Army Corps of Engineers, Waterways Experiment Station, CPAR-

98-1) is well suited to evaluating the hydraulic fracture potential for HDD installations in soil. In rock formations, the downhole drilling fluid pressures are relatively low such that fracturing of the intact rock mass is unlikely to be attributed to drilling fluid pressures. However, drilling fluid may flow through existing fractures within the rock mass. Because the model is unable to model flow through existing rock fractures, we have provided a limited analysis of estimated formation limit pressures, specifically where the proposed HDD profile is anticipated to be progressing through overburden soils.

Laney believes it is not possible to accurately model the risk of inadvertent drilling fluid returns because of drilling fluid loss to preexisting voids or fractures in the rock formation. As such, limit pressures are shown when the HDD profiles are located within the overburden soils only.

Drilling Fluid Loss to Pre-Existing Fractures and Voids

The quality of the rock mass in rock formations can affect the risk of drilling fluid loss attributed to pre-existing fractures and voids within the rock. The lower the RQD of the rock formation the higher risk of drilling fluid loss from the drilled hole which may potentially lead to inadvertent drilling fluid returns to the ground surface. Additionally, hole blockages which typically lead to an increase in downhole annular pressures may increase the risk of drilling fluid loss. Once inadvertent drilling fluid returns occur at the ground surface in rock formations it may be difficult to control and can occur a significant distance from the HDD alignment. Utilizing a downhole annular pressure tool can be an effective method to assist the HDD contractor in identifying the potential issues downhole such as blockages within the hole that may increase the risk of inadvertent drilling fluid returns. Based on the American Geotech Inc. Geotechnical Engineering Report, the average RQD values were 67 and 59 percent for the rock samples. Since the geotechnical bores terminated at a shallower depth than the HDD profile, the RQD of the rock encountered could be different than what the report shows. We anticipate that the potential for drilling fluid loss through these areas of good to fair RQD rock is moderate to high.

Inadvertent Drilling Fluid Returns

The drilling fluid lost through pre-existing fractures and voids may emerge at the ground surface or any other undesired location. This is referred to as inadvertent drilling fluid returns. Generally, inadvertent drilling fluid returns occurs near the entry and exit points, and other locations along the drill path where soil cover is thin. At these locations, hydraulic fracture potentials are high and seepage paths to return locations are short. In addition to this, inadvertent drilling fluid returns may occur at exploratory boring locations and along the interface of soil and existing structures like piles and utility poles.

The risk of inadvertent drilling fluid returns along the majority of the HDD alignment when the HDD profile is in good to excellent RQD bedrock is anticipated to be fair. It is currently not possible to accurately model the risk of inadvertent drilling fluid returns due to losses in preexisting voids or fractures in the rock formation. The highest risk of inadvertent drilling fluid returns is generally near the entry and exit points where the soil cover is thin and traces of gravel are present. Based on the currently available geotechnical data the HDD profile is planned to be in bedrock where the pressures are anticipated to be the highest and the risk of inadvertent drilling fluid returns is generally low. However, the risk of inadvertent return near the entry and exit points is high due to the presence of gravel and silts. Mitigation measures, such as conductor casing and a detailed drilling fluids plan, should be considered by the drilling contractor.

CONSTRUCTION RECOMMENDATIONS

We recommend the drilling contractor be prepared for difficulties with staging equipment for the HDD crossing due to the constrained workspace. Traffic control will also be required for the safety of work crews and the public.

We also recommend completing the pilot hole using a wireline steering system. Based on the ground surface, we believe there will be few issues placing the coil of wire across the length of the HDD. Contractors should also be aware of any restrictions the state has regarding acquisition of water and the disposal of drilling fluids.

In summary, the provided Tilgham Lateral HDD #1 design meets the majority of requirements of standard HDD design practices. It is our opinion the provided design of the proposed HDD is constructible, but does have some risk based on subsurface conditions.

We look forward to continuing to support you on this project. In the event you have any questions or comments, please let us know.

Laney Directional Drilling Company

Cole Byington
Staff Engineer

Andrew Sparks P.E.
Principal Geotechnical Engineer

Attachments:

1. Pipe Stress Analysis
2. Inadvertent Drilling Fluid Return Analysis
3. Preliminary Construction Schedule

PIPE STRESS ANALYSIS

Comments									
HGA - Adelphia - HDD #1 - 9.5ppg									
Description	**Section A**			**Section B**			**Section C**		
Line Pipe Properties									
Pipe Outside Diameter =	16.000	in		16.000	in		16.000	in	
Wall Thickness =	0.500	in			in			in	
Specified Minimum Yield Strength =	52,000	psi			psi			psi	
Young's Modulus =	2.9E+07	psi		2.9E+07	psi		2.9E+07	psi	
Moment of Inertia =	731.18	in^4		0.00	in^4		0.00	in^4	
Pipe Face Surface Area =	24.35	in^2		0.00	in^2		0.00	in^2	
Diameter to Wall Thickness Ratio, D/t =	32								
Poisson's Ratio =	0.3			0.3			0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F		6.5E-06	in/in/°F		6.5E-06	in/in/°F	
Pipe Weight in Air =	82.77	lb/ft		0.00	lb/ft		0.00	lb/ft	
Pipe Interior Volume =	1.23	ft^3/ft		1.40	ft^3/ft		1.40	ft^3/ft	
Pipe Exterior Volume =	1.40	ft^3/ft		1.40	ft^3/ft		1.40	ft^3/ft	
HDD Installation Properties									
Drilling Mud Density =	9.5	ppg		9.5	ppg		9.5	ppg	
=	71.1	lb/ft^3		71.1	lb/ft^3		71.1	lb/ft^3	
Ballast Density =	62.4	lb/ft^3		62.4	lb/ft^3		62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30								
Fluid Drag Coefficient =	0.050	psi			psi			psi	
Ballast Weight =	76.58	lb/ft		87.13	lb/ft		87.13	lb/ft	
Displaced Mud Weight =	99.22	lb/ft		99.22	lb/ft		99.22	lb/ft	
Installation Stress Limits									
Tensile Stress Limit, 90% of SMYS, F_t =	46,800	psi		0	psi		0	psi	
For D/t <= 1,500,000/SMYS, F_b =	39,000	psi	No	0	psi		0	psi	
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	38,488	psi	Yes	0	psi		0	psi	
For D/t > 3,000,000/SMYS and <= 300, F_b =	35,709	psi	No	0	psi		0	psi	
Allowable Bending Stress, F_b =	38,488	psi			psi			psi	
Elastic Hoop Buckling Stress, F_{he} =	24,922	psi		0	psi		0	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	24,922	psi	Yes	0	psi	Yes	0	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	27,886	psi	No	0	psi	No	0	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	21,047	psi	No	0	psi	No	0	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	52,000	psi	No	0	psi	No	0	psi	No
Critical Hoop Buckling Stress, F_{hc} =	24,922	psi		0	psi		0	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	16,615	psi		0	psi		0	psi	
Operating Stress Check									
Maximum Allowable Operating Pressure =	1,440	psig			psig			psig	
Radius of Curvature =	800	ft			ft			ft	
Installation Temperature =	70	°F			°F			°F	
Maximum Operating Temperature =	70	°F			°F			°F	
Groundwater Table Head =	0	ft			ft			ft	
Longitudinal Stress from Bending =	24,167	psi			psi			psi	
% SMYS =	46%								
Hoop Stress =	23,040	psi			psi			psi	
% SMYS =	44%								
Longitudinal Compressive Stress from Hoop Stress =	6,912	psi			psi			psi	
% SMYS =	13%								
Longitudinal Stress from Thermal Expansion =	0	psi			psi			psi	
% SMYS =	0%								
Net Longitudinal Compressive Stress =	-17,255	psi			psi			psi	
% SMYS =	33%								
Maximum Shear Stress =	20,147	psi			psi			psi	
Limited to 45% of SMYS by 402.3.1 of ASME/ANSI B 31.4 =	39%	ok							

Step 1, Property Input

Point	Station	Offset	Elevation	Length	Heading	Inclination	Azimuth	Properties	Submerged	Ballasted	Assumed Tension	Average Tension	Total Pull	Vertical Radius	Horizontal Radius
Entry Point	4+66.00	0.0	48.0		0.0	78.0	0.0						57,966		
				14.6				a	yes	no	1,000	Straight		0.0	0.0
PC1	4+80.28	0.0	45.0		0.0	78.0	0.0						57,505		
				335.1				a	yes	no	49,460	49,460		1600	0
PHC	8+12.94	0.0	10.0		0.0	90.0	0.0					0	41,415		
				116.1				a	yes	no	1,000	Straight		0	0
PT1	9+29.00	0.0	10.0		0.0	90.0	0.0						37,342		
				676.5				a	yes	no	23,532	23,532		0	1600
PHC	16+05.46	140.9	10.0		0.0	90.0	24.2					0	9,721		
				-275.0				a	yes	no	1,000	Straight		0	0
PC2	13+30.48	28.1	10.0		0.0	90.0	24.2						16,658		
				279.3				a	yes	no	10,476	10,476		1600	0
PT2	16+08.31	142.1	34.3		0.0	100.0	24.2					0	4,295		
				113.4				a	yes	no	1,000	Straight		0	0
Exit Point	17+19.99	187.9	54.0		0.0	100.0	24.2						0		
											1,000			0	0
						100.0	24.2								
											1,000			0	0
						100.0	24.2								
											1,000			0	0
						100.0	24.2								
											1,000			0	0
						100.0	24.2								
											1,000			0	0
						100.0	24.2								
											1,000			0	0
						100.0	24.2								
											1,000			0	0
						100.0	24.2								
											1,000			0	0
						100.0	24.2				Above Ground Load		0		
True Length				1,259.9											
Drilling Mud			48.0												
Ballast															

Step 2, Drilled Path Input

Point	Fluidic Drag	Weight & Weight Friction	Bending Friction	Total Pull	Tensile Stress		Bending Stress		External Hoop Stress		Tensile & Bending Stress		Tensile, Bending & Ext. Hoop Stress	
Entry Point	37,997	5,987	13,981	57,966	2,381	ok	0	ok	0	ok	0.05	ok	0.00	ok
					2,362	ok	0	ok	24	ok	0.05	ok	0.00	ok
PC1	37,557	5,967	13,981	57,505										
					2,362	ok	12,083	ok	24	ok	0.36	ok	0.12	ok
					1,701	ok	12,083	ok	300	ok	0.35	ok	0.11	ok
PHC	27,451	6,543	7,421	41,415										
					1,701	ok	0	ok	300	ok	0.04	ok	0.00	ok
					1,534	ok	0	ok	300	ok	0.03	ok	0.00	ok
PT1	23,950	5,970	7,421	37,342										
					1,534	ok	12,083	ok	300	ok	0.35	ok	0.11	ok
					399	ok	12,083	ok	300	ok	0.32	ok	0.09	ok
PHC	3,549	2,632	3,540	9,721										
					399	ok	0	ok	300	ok	0.01	ok	0.00	ok
					684	ok	0	ok	300	ok	0.01	ok	0.00	ok
PC2	11,842	1,275	3,540	16,658										
					684	ok	12,083	ok	300	ok	0.33	ok	0.10	ok
					176	ok	12,083	ok	108	ok	0.32	ok	0.09	ok
PT2	3,420	875	0	4,295										
					176	ok	0	ok	108	ok	0.00	ok	0.00	ok
Exit Point		0		0										

Step 3, Results Output

Point	Wall Thickness	Specified Minimum Yield Strength	Moment of Inertia	Pipe Face Surface Area	Soil Friction	Fluidic Drag	Pipe Weight	Ballast Weight	Displaced Mud Weight	Tensile Stress Limit, F_t	Allowable Bending Stress, F_b	Allowable Hoop Buckling Stress, $F_{hc}/1.5$
Entry Point												
	0.500	52,000	731.18	24.35	0.30	0.050	82.77	76.58	99.22	46,800	38,488	16,615
PC1												
	0.500	52,000	731.18	24.35	0.30	0.050	82.77	76.58	99.22	46,800	38,488	16,615
PHC												
	0.500	52,000	731.18	24.35	0.30	0.050	82.77	76.58	99.22	46,800	38,488	16,615
PT1												
	0.500	52,000	731.18	24.35	0.30	0.050	82.77	76.58	99.22	46,800	38,488	16,615
PHC												
	0.500	52,000	731.18	24.35	0.30	0.050	82.77	76.58	99.22	46,800	38,488	16,615
PC2												
	0.500	52,000	731.18	24.35	0.30	0.050	82.77	76.58	99.22	46,800	38,488	16,615
PT2												
	0.500	52,000	731.18	24.35	0.30	0.050	82.77	76.58	99.22	46,800	38,488	16,615
Exit Point												

Property Table

Point	Inclination, radians	Azimuth for Calculation	Azimuth, radians	cos(DL)	DL, radians	DL, degrees	Radius of Curvature	Ratio Factor	Delta Station	Delta Offset	Delta Elevation	Station, X	Offset, Z	Elevation, Y
Entry Point	1.3614	0.00	0.0000									466.0	0.0	48.0
				1.0000	0.0000	0.00	Straight	1.0000	14.3	0.0	3.0			
PC1	1.3614	0.00	0.0000									480.3	0.0	45.0
				0.9781	0.2094	12.00	1,600	1.0037	332.7	0.0	35.0			
PHC	1.5708	0.00	0.0000									812.9	0.0	10.0
				1.0000	0.0000	0.00	Straight	1.0000	116.1	0.0	0.0			
PT1	1.5708	0.00	0.0000									929.0	0.0	10.0
				0.9119	0.4228	24.22	1,600	1.0152	656.5	140.9	0.0			
PHC	1.5708	24.22	0.4228									1,585.5	140.9	10.0
				1.0000	0.0000	0.00	Straight	1.0000	-250.8	-112.8	0.0			
PC2	1.5708	24.22	0.4228									1,334.7	28.1	10.0
				0.9848	0.1745	10.00	1,600	1.0025	253.4	114.0	-24.3			
PT2	1.7453	24.22	0.4228									1,588.1	142.1	34.3
				1.0000	0.0000	0.00	Straight	1.0000	101.8	45.8	-19.7			
Exit Point	1.7453	24.22	0.4228									1,689.9	187.9	54.0

Geometry Table

Point	Segment Fluidic Drag	Total Fluidic Drag	Segment Angle, degrees	Displaced Mud Unit Weight	Ballast Unit Weight	Unit Weight	Segment Weight	Segment Weight, Radial	Segment Pull from Friction	Total Pull, Friction	Segment Weight, Axial	Total Pull, Axial Weight	Segment Pull, Fricton & Weight	Total Pull, Fricton & Weight	External Pressure	Internal Pressure	Net Pressure	Beam Center Displ.	j	U/2	X	Y	Bending Weight	Normal Force	Joint Pull, Bending	Total Pull, Bending
Entry Point		37,997								5,889		98		5,987												13,981
	440		12.0	99.2	0.00	-16.4	-240	-235	70		-50		21					0.000	4,605	0.02	0.01	5.78E-01	0	0	0	
PC1		37,557								5,819		148		5,967	1	0	1									13,981
	10,106		6.0	99.2	0.00	-16.4	-5,512	0	0		-576		-576					8.765	655	3.07	679.32	1.63E+06	-16	10,933	6,560	
PHC		27,451								5,819		724		6,543	19	0	19									7,421
	3,500		0.0	99.2	0.00	-16.4	-1,909	-1,909	573		0		573					0.000	4,605	0.15	2.63	2.29E+03	0	0	0	
PT1		23,950								5,246		724		5,970	19	0	19									7,421
	20,402		0.0	99.2	0.00	-16.4	-11,127	-11,127	3,338		0		3,338					35.617	949	4.28	1554.93	7.36E+06	0	6,468	3,881	
PHC		3,549								1,908		724		2,632	19	0	19									3,540
	-8,293		0.0	99.2	0.00	-16.4	4,523	4,523	1,357		0		1,357					0.000	4,605	-0.36	-33.58	6.92E+04	0	0	0	
PC2		11,842								551		724		1,275	19	0	19									3,540
	8,422		-5.0	99.2	0.00	-16.4	-4,593	0	0		400		400					6.088	1,423	1.18	249.67	5.18E+05	-16	5,901	3,540	
PT2		3,420								551		324		875	7	0	7									0
	3,420		-10.0	99.2	0.00	-16.4	-1,865	-1,837	551		324		875					0.000	4,605	0.15	2.45	2.09E+03	0	0	0	
Exit Point														0	-3	0	-3									
														0												
														0												
														0												
														0												
														0												
														0												
														0												
											Above Ground Load =			0												

Load Calculation Table

PIPE STRESS ANALYSIS

Comments									
HGA - Adelphia - HDD #1 - 12ppg									
Description	**Section A**			**Section B**			**Section C**		
Line Pipe Properties									
Pipe Outside Diameter =	16.000	in		16.000	in		16.000	in	
Wall Thickness =	0.500	in			in			in	
Specified Minimum Yield Strength =	52,000	psi			psi			psi	
Young's Modulus =	2.9E+07	psi		2.9E+07	psi		2.9E+07	psi	
Moment of Inertia =	731.18	in^4		0.00	in^4		0.00	in^4	
Pipe Face Surface Area =	24.35	in^2		0.00	in^2		0.00	in^2	
Diameter to Wall Thickness Ratio, D/t =	32								
Poisson's Ratio =	0.3			0.3			0.3		
Coefficient of Thermal Expansion =	6.5E-06	in/in/°F		6.5E-06	in/in/°F		6.5E-06	in/in/°F	
Pipe Weight in Air =	82.77	lb/ft		0.00	lb/ft		0.00	lb/ft	
Pipe Interior Volume =	1.23	ft^3/ft		1.40	ft^3/ft		1.40	ft^3/ft	
Pipe Exterior Volume =	1.40	ft^3/ft		1.40	ft^3/ft		1.40	ft^3/ft	
HDD Installation Properties									
Drilling Mud Density =	12.0	ppg		12.0	ppg		12.0	ppg	
=	89.8	lb/ft^3		89.8	lb/ft^3		89.8	lb/ft^3	
Ballast Density =	62.4	lb/ft^3		62.4	lb/ft^3		62.4	lb/ft^3	
Coefficient of Soil Friction =	0.30								
Fluid Drag Coefficient =	0.050	psi			psi			psi	
Ballast Weight =	76.58	lb/ft		87.13	lb/ft		87.13	lb/ft	
Displaced Mud Weight =	125.33	lb/ft		125.33	lb/ft		125.33	lb/ft	
Installation Stress Limits									
Tensile Stress Limit, 90% of SMYS, F_t =	46,800	psi		0	psi		0	psi	
For D/t <= 1,500,000/SMYS, F_b =	39,000	psi	No	0	psi		0	psi	
For D/t > 1,500,000/SMYS and <= 3,000,000/SMYS, F_b =	38,488	psi	Yes	0	psi		0	psi	
For D/t > 3,000,000/SMYS and <= 300, F_b =	35,709	psi	No	0	psi		0	psi	
Allowable Bending Stress, F_b =	38,488	psi			psi			psi	
Elastic Hoop Buckling Stress, F_{he} =	24,922	psi		0	psi		0	psi	
For F_{he} <= 0.55*SMYS, Critical Hoop Buckling Stress, F_{hc} =	24,922	psi	Yes	0	psi	Yes	0	psi	Yes
For F_{he} > 0.55*SMYS and <= 1.6*SMYS, F_{hc} =	27,886	psi	No	0	psi	No	0	psi	No
For F_{he} > 1.6*SMYS and <= 6.2*SMYS, F_{hc} =	21,047	psi	No	0	psi	No	0	psi	No
For F_{he} > 6.2*SMYS, F_{hc} =	52,000	psi	No	0	psi	No	0	psi	No
Critical Hoop Buckling Stress, F_{hc} =	24,922	psi		0	psi		0	psi	
Allowable Hoop Buckling Stress, $F_{hc}/1.5$ =	16,615	psi		0	psi		0	psi	
Operating Stress Check									
Maximum Allowable Operating Pressure =	1,440	psig			psig			psig	
Radius of Curvature =	800	ft			ft			ft	
Installation Temperature =	70	°F			°F			°F	
Maximum Operating Temperature =	70	°F			°F			°F	
Groundwater Table Head =	0	ft			ft			ft	
Longitudinal Stress from Bending =	24,167	psi			psi			psi	
% SMYS =	46%								
Hoop Stress =	23,040	psi			psi			psi	
% SMYS =	44%								
Longitudinal Compressive Stress from Hoop Stress =	6,912	psi			psi			psi	
% SMYS =	13%								
Longitudinal Stress from Thermal Expansion =	0	psi			psi			psi	
% SMYS =	0%								
Net Longitudinal Compressive Stress =	-17,255	psi			psi			psi	
% SMYS =	33%								
Maximum Shear Stress =	20,147	psi			psi			psi	
Limited to 45% of SMYS by 402.3.1 of ASME/ANSI B 31.4 =	39%	ok							

Step 1, Property Input

Point	Station	Offset	Elevation	Length	Heading	Inclination	Azimuth	Properties	Submerged	Ballasted	Assumed Tension	Average Tension	Total Pull	Vertical Radius	Horizontal Radius
Entry Point	4+66.00	0.0	48.0		0.0	78.0	0.0						76,033		
				14.6				a	yes	no	1,000	Straight		0.0	0.0
PC1	4+80.28	0.0	45.0		0.0	78.0	0.0						75,539		
				335.1				a	yes	no	65,837	65,837		1600	0
PHC	8+12.94	0.0	10.0		0.0	90.0	0.0					0	56,134		
				116.1				a	yes	no	1,000	Straight		0	0
PT1	9+29.00	0.0	10.0		0.0	90.0	0.0						51,152		
				676.5				a	yes	no	33,968	33,968		0	1600
PHC	16+05.46	140.9	10.0		0.0	90.0	24.2					0	16,784		
				-275.0				a	yes	no	1,000	Straight		0	0
PC2	13+30.48	28.1	10.0		0.0	90.0	24.2						21,567		
				279.3				a	yes	no	13,625	13,625		1600	0
PT2	16+08.31	142.1	34.3		0.0	100.0	24.2					0	5,684		
				113.4				a	yes	no	1,000	Straight		0	0
Exit Point	17+19.99	187.9	54.0		0.0	100.0	24.2						0		
											1,000			0	0
						100.0	24.2								
											1,000			0	0
						100.0	24.2								
											1,000			0	0
						100.0	24.2								
											1,000			0	0
						100.0	24.2								
											1,000			0	0
						100.0	24.2								
											1,000			0	0
						100.0	24.2								
											1,000			0	0
						100.0	24.2								
											1,000			0	0
						100.0	24.2				Above Ground Load		0		
True Length				1,259.9											
Drilling Mud			48.0												
Ballast															

Step 2, Drilled Path Input

Point	Fluidic Drag	Weight & Weight Friction	Bending Friction	Total Pull	Tensile Stress		Bending Stress		External Hoop Stress		Tensile & Bending Stress		Tensile, Bending & Ext. Hoop Stress	
Entry Point	37,997	15,491	22,544	76,033	3,123	ok	0	ok	0	ok	0.07	ok	0.01	ok
					3,103	ok	0	ok	30	ok	0.07	ok	0.01	ok
PC1	37,557	15,438	22,544	75,539										
					3,103	ok	12,083	ok	30	ok	0.38	ok	0.13	ok
					2,306	ok	12,083	ok	379	ok	0.36	ok	0.12	ok
PHC	27,451	16,929	11,755	56,134										
					2,306	ok	0	ok	379	ok	0.05	ok	0.00	ok
					2,101	ok	0	ok	379	ok	0.04	ok	0.00	ok
PT1	23,950	15,447	11,755	51,152										
					2,101	ok	12,083	ok	379	ok	0.36	ok	0.12	ok
					689	ok	12,083	ok	379	ok	0.33	ok	0.10	ok
PHC	3,549	6,811	6,425	16,784										
					689	ok	0	ok	379	ok	0.01	ok	0.00	ok
					886	ok	0	ok	379	ok	0.02	ok	0.00	ok
PC2	11,842	3,300	6,425	21,567										
					886	ok	12,083	ok	379	ok	0.33	ok	0.10	ok
					233	ok	12,083	ok	137	ok	0.32	ok	0.09	ok
PT2	3,420	2,264	0	5,684										
					233	ok	0	ok	137	ok	0.00	ok	0.00	ok
Exit Point		0		0										

Step 3, Results Output

Point	Wall Thickness	Specified Minimum Yield Strength	Moment of Inertia	Pipe Face Surface Area	Soil Friction	Fluidic Drag	Pipe Weight	Ballast Weight	Displaced Mud Weight	Tensile Stress Limit, F_t	Allowable Bending Stress, F_b	Allowable Hoop Buckling Stress, $F_{hc}/1.5$
Entry Point												
	0.500	52,000	731.18	24.35	0.30	0.050	82.77	76.58	125.33	46,800	38,488	16,615
PC1												
	0.500	52,000	731.18	24.35	0.30	0.050	82.77	76.58	125.33	46,800	38,488	16,615
PHC												
	0.500	52,000	731.18	24.35	0.30	0.050	82.77	76.58	125.33	46,800	38,488	16,615
PT1												
	0.500	52,000	731.18	24.35	0.30	0.050	82.77	76.58	125.33	46,800	38,488	16,615
PHC												
	0.500	52,000	731.18	24.35	0.30	0.050	82.77	76.58	125.33	46,800	38,488	16,615
PC2												
	0.500	52,000	731.18	24.35	0.30	0.050	82.77	76.58	125.33	46,800	38,488	16,615
PT2												
	0.500	52,000	731.18	24.35	0.30	0.050	82.77	76.58	125.33	46,800	38,488	16,615
Exit Point												

Property Table

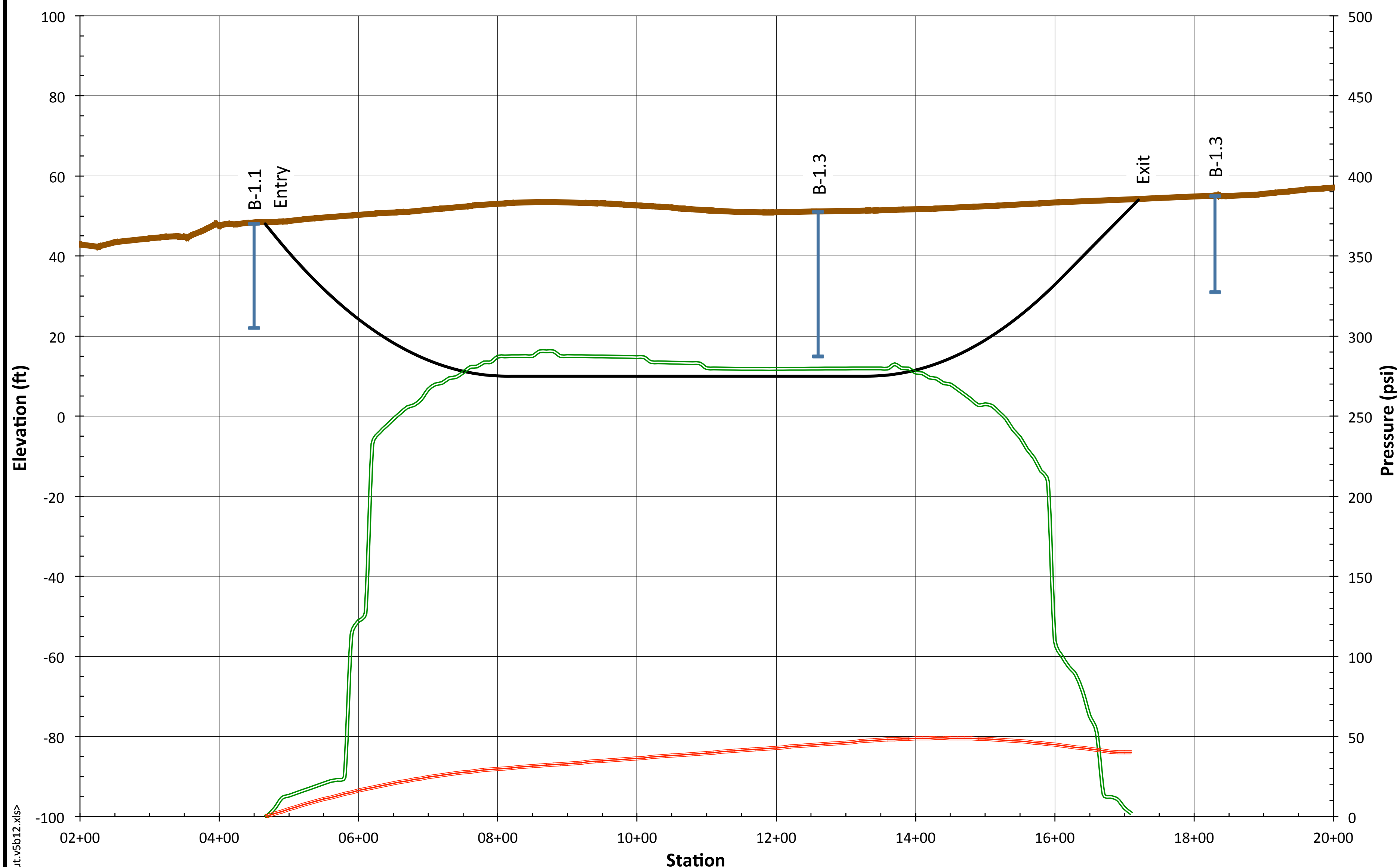
Point	Inclination, radians	Azimuth for Calculation	Azimuth, radians	cos(DL)	DL, radians	DL, degrees	Radius of Curvature	Ratio Factor	Delta Station	Delta Offset	Delta Elevation	Station, X	Offset, Z	Elevation, Y
Entry Point	1.3614	0.00	0.0000									466.0	0.0	48.0
				1.0000	0.0000	0.00	Straight	1.0000	14.3	0.0	3.0			
PC1	1.3614	0.00	0.0000									480.3	0.0	45.0
				0.9781	0.2094	12.00	1,600	1.0037	332.7	0.0	35.0			
PHC	1.5708	0.00	0.0000									812.9	0.0	10.0
				1.0000	0.0000	0.00	Straight	1.0000	116.1	0.0	0.0			
PT1	1.5708	0.00	0.0000									929.0	0.0	10.0
				0.9119	0.4228	24.22	1,600	1.0152	656.5	140.9	0.0			
PHC	1.5708	24.22	0.4228									1,585.5	140.9	10.0
				1.0000	0.0000	0.00	Straight	1.0000	-250.8	-112.8	0.0			
PC2	1.5708	24.22	0.4228									1,334.7	28.1	10.0
				0.9848	0.1745	10.00	1,600	1.0025	253.4	114.0	-24.3			
PT2	1.7453	24.22	0.4228									1,588.1	142.1	34.3
				1.0000	0.0000	0.00	Straight	1.0000	101.8	45.8	-19.7			
Exit Point	1.7453	24.22	0.4228									1,689.9	187.9	54.0

Geometry Table

Point	Segment Fluidic Drag	Total Fluidic Drag	Segment Angle, degrees	Displaced Mud Unit Weight	Ballast Unit Weight	Unit Weight	Segment Weight	Segment Weight, Radial	Segment Pull from Friction	Total Pull, Friction	Segment Weight, Axial	Total Pull, Axial Weight	Segment Pull, Fricton & Weight	Total Pull, Fricton & Weight	External Pressure	Internal Pressure	Net Pressure	Beam Center Displ.	j	U/2	X	Y	Bending Weight	Normal Force	Joint Pull, Bending	Total Pull, Bending
Entry Point		37,997								15,238		254		15,491												22,544
	440		12.0	125.3	0.00	-42.6	-621	-608	182		-129		53					0.000	4,605	0.02	0.01	5.78E-01	0	0	0	
PC1		37,557								15,055		383		15,438	2	0	2									22,544
	10,106		6.0	125.3	0.00	-42.6	-14,261	0	0		-1,491		-1,491					8.765	568	3.54	722.02	1.72E+06	-43	17,982	10,789	
PHC		27,451								15,055		1,874		16,929	24	0	24									11,755
	3,500		0.0	125.3	0.00	-42.6	-4,939	-4,939	1,482		0		1,482					0.000	4,605	0.15	2.63	2.29E+03	0	0	0	
PT1		23,950								13,573		1,874		15,447	24	0	24									11,755
	20,402		0.0	125.3	0.00	-42.6	-28,789	-28,789	8,637		0		8,637					35.617	790	5.14	1634.36	7.62E+06	0	8,883	5,330	
PHC		3,549								4,937		1,874		6,811	24	0	24									6,425
	-8,293		0.0	125.3	0.00	-42.6	11,703	11,703	3,511		0		3,511					0.000	4,605	-0.36	-33.58	6.92E+04	0	0	0	
PC2		11,842								1,426		1,874		3,300	24	0	24									6,425
	8,422		-5.0	125.3	0.00	-42.6	-11,884	0	0		1,036		1,036					6.088	1,247	1.34	293.58	6.08E+05	-43	10,708	6,425	
PT2		3,420								1,426		838		2,264	9	0	9									0
	3,420		-10.0	125.3	0.00	-42.6	-4,826	-4,753	1,426		838		2,264					0.000	4,605	0.15	2.45	2.09E+03	0	0	0	
Exit Point														0	-4	0	-4									
														0												
														0												
														0												
														0												
														0												
														0												
														0												
												Above Ground Load =		0												

Load Calculation Table

ADELPHIA GATEWAY, LLC - TILGHMAN LATERAL - HDD #1



Crossing Length (ft)	1254
Hole Diameter (in)	12.250
Drill Pipe O.D. (in)	6.625
Drilling Fluid Weight (ppg)	9.5
Plastic Viscosity (cP)	18
Yield Point (lb/100 sf)	36

Ground Surface Elevation (ft)
HDD Profile (ft)
Formation Limit Pressure (psi)
Estimated Annular Drilling Fluid Pressure (psi) for Pilot Hole

ADELPHIA GATEWAY, LLC - TILGHMAN LATERAL - HDD #1

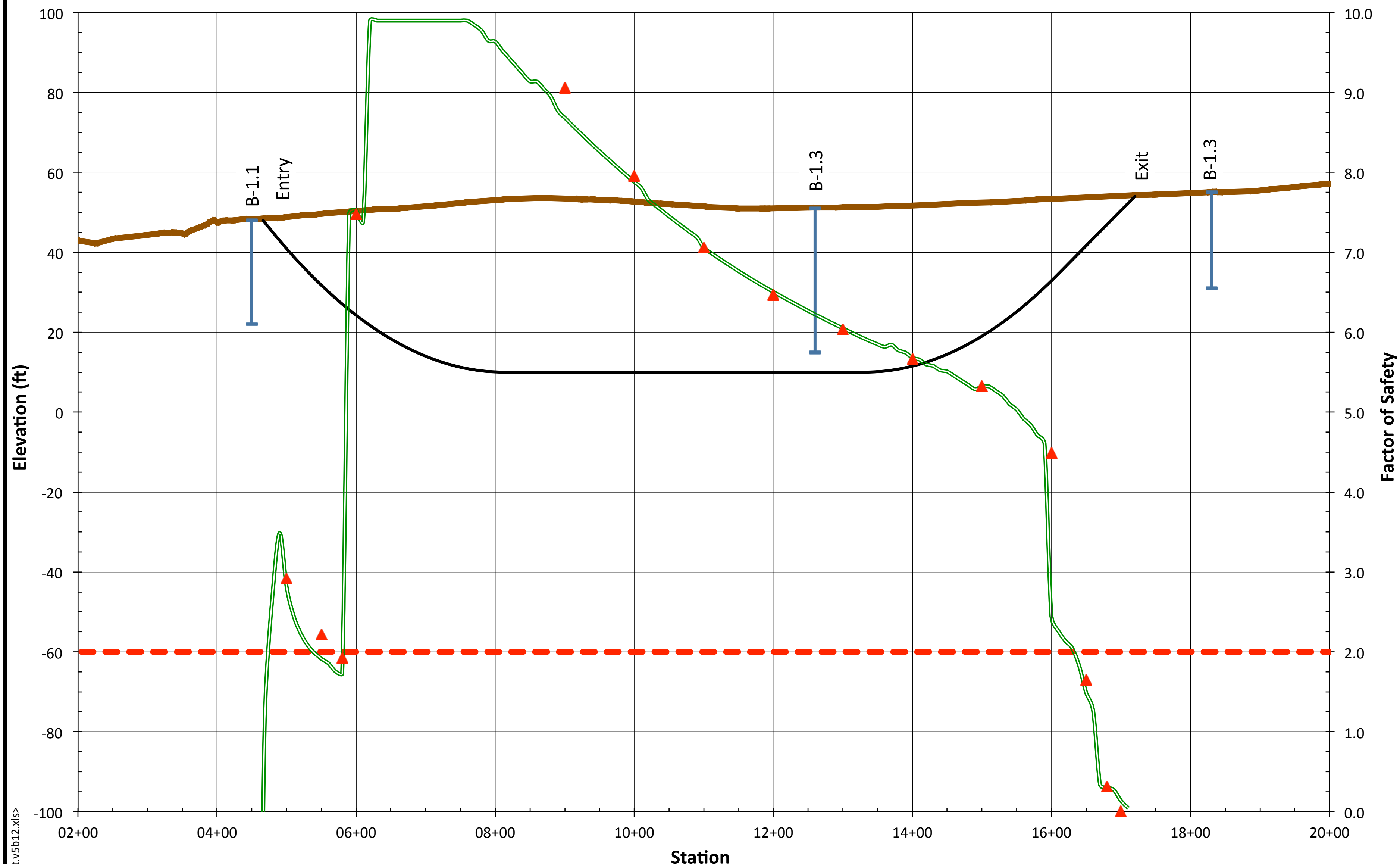
ESTIMATED ANNULAR DRILLING FLUID AND FORMATION LIMIT PRESSURES

Laney

FIGURE 1

10181 AES 190118 <FracOut.v5b12.xls>

ADELPHIA GATEWAY, LLC - TILGHMAN LATERAL - HDD #1



10181 AES 190118 <FracOut.v5b12.xls>

Crossing Length (ft)	1254
Hole Diameter (in)	12.250
Drill Pipe O.D. (in)	6.625
Drilling Fluid Weight (ppg)	9.5
Plastic Viscosity (cP)	18
Yield Point (lb/100 sf)	36

- Ground Surface Elevation (ft)
- HDD Profile (ft)
- Factor of Safety = 2
- Hydraulic Fracture Factor of Safety for Pilot Hole
- Drilling Fluid Surface Release Factor of Safety for Pilot Hole

ADELPHIA GATEWAY, LLC - TILGHMAN LATERAL - HDD #1

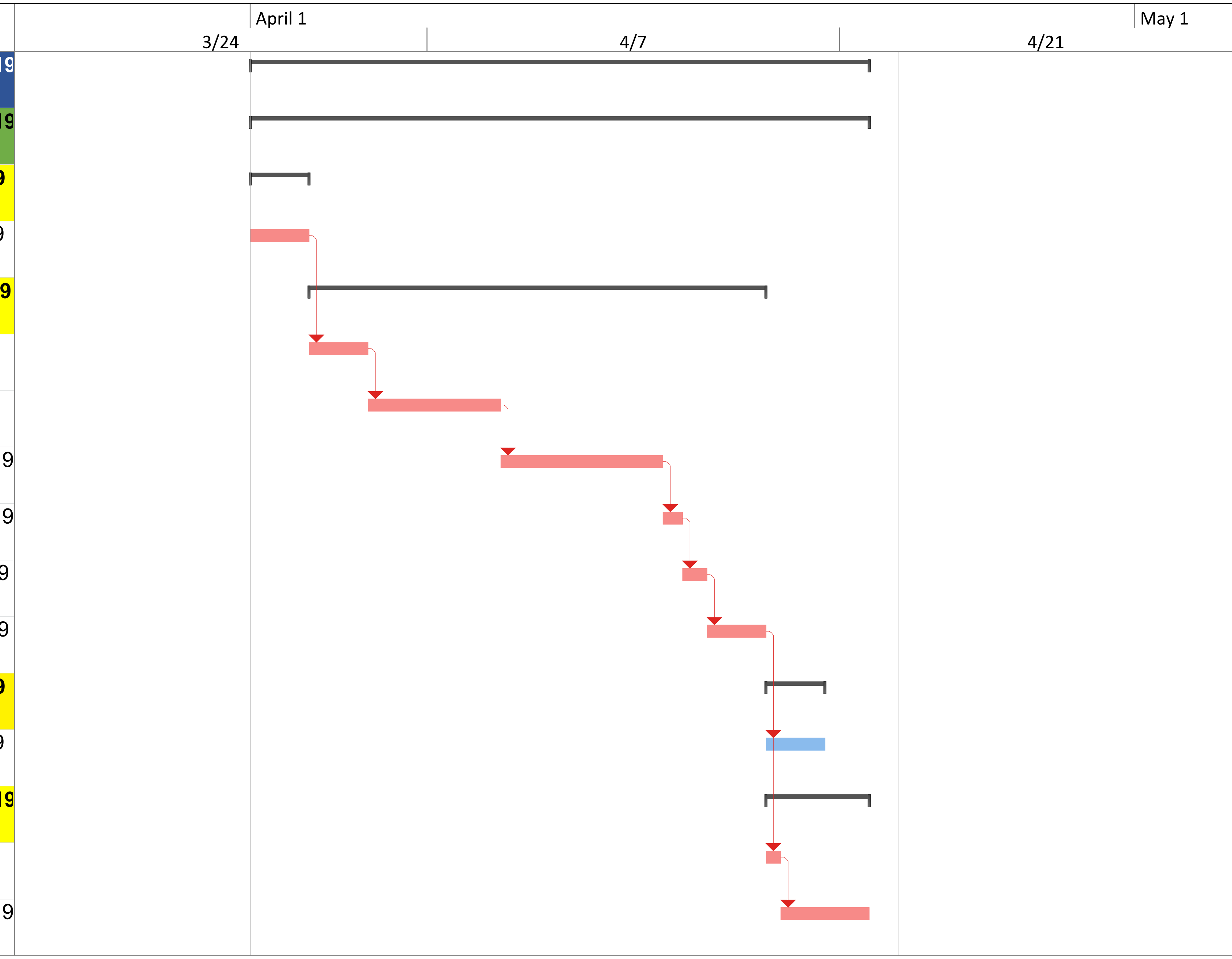
HYDRAULIC FRACTURE AND DRILLING FLUID SURFACE RELEASE FACTORS OF SAFETY

Laney

FIGURE 2

HDD 1

ID	WBS	Task Name	Duration	Start	Finish
1	**1**	**Tilgham Lateral HDD**	**27 days**	**Mon 4/1/19**	**Mon 4/22/19**
2	**1.1**	**HDD CONSTRUCTION**	**27 days**	**Mon 4/1/19**	**Mon 4/22/19**
3	**1.1.1**	**Mob/Demob**	**3 days**	**Mon 4/1/19**	**Wed 4/3/19**
4		Mobilize to HDD 1	3 days	Mon 4/1/19	Wed 4/3/19
5	**1.1.2**	**Drilling**	**20 days**	**Wed 4/3/19**	**Thu 4/18/19**
6		Rig up	3 days	Wed 4/3/19	Fri 4/5/19
7		Pilot Hole	5 days	Fri 4/5/19	Tue 4/9/19
8		24" Ream Pass	7 days	Tue 4/9/19	Mon 4/15/19
9		Swab Run	1 day	Mon 4/15/19	Mon 4/15/19
10		Pull Back	1 day	Mon 4/15/19	Tue 4/16/19
11		Rig Down	3 days	Tue 4/16/19	Thu 4/18/19
12	**1.1.3**	**Demobilization**	**3 days**	**Thu 4/18/19**	**Sat 4/20/19**
13		Demobilize from HDD 1	3 days	Thu 4/18/19	Sat 4/20/19
14	**1.1.4**	**Post Construction**	**4 days**	**Thu 4/18/19**	**Mon 4/22/19**
15		Perform Hydrostatic test	1 day	Thu 4/18/19	Fri 4/19/19
16		Site Restoration	3 days	Fri 4/19/19	Mon 4/22/19



Project: Eastern System Expansion
Date: 9-28-17

Task	External Tasks	Manual Task	Finish-only	Manual Progress
Split	External Milestone	Duration-only	Deadline	
Milestone	Inactive Task	Manual Summary Rollup	Critical	
Summary	Inactive Milestone	Manual Summary	Critical Split	
Project Summary	Inactive Summary	Start-only	Progress	