MOTT MACDONALD

PennEast PIPELINE

HDD Design Report Wickecheoke Creek HDD Crossing

PennEast Pipeline Project

July 22, 2019

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1 Introduction

Mott MacDonald has prepared this HDD design report at the request of PennEast Pipeline Company, LLC (PennEast), for their proposed HDD crossing of the Wickecheoke Creek, part of the larger PennEast Pipeline Project. The proposed Project consists of 115 miles of 36-inch diameter (NPS 36) high pressure, natural gas pipeline from Luzerne County, Pennsylvania to Mercer County, New Jersey.

Specifically, this report summarizes Mott MacDonald's evaluation of the design elements and risk discussions (as determined in the information provided) and presents recommendations for enhancing the success of the Wickecheoke Creek HDD crossing.

The drawings and design elements have been prepared and evaluated with the aid of a geotechnical subsurface investigation performed by Mott MacDonald, laboratory assessment and testing analysis completed by Craig Test Boring Co., Inc (CTB). Brief discussions on the geotechnical conditions summarized in this design report have been extracted from the information presented in the site-specific Geotechnical Data Report (GDR). Greater detail on these conditions can be found in the site-specific GDR.

1.1 Crossing Description

The proposed plan and profile drawing is provided in Appendix A. The horizontal length of the proposed HDD is approximately 3,309 feet (with a true length of approximately 3,363 feet). An elevation difference of approximately 39 feet exists between the HDD entry and exit locations, with the HDD entry location at the lower elevation. The HDD entry location is located on the south side of the crossing.

The pipe staging area for the drag section is located on the north side of the crossing. It is envisioned that, due to limited workspace, the pipe string will be fabricated into two sections prior to pullback operations. The HDD Contractor must follow good HDD construction practices and limit the stoppage time for intermediate welding during pullback operations.

2 Anticipated Geotechnical Conditions

The following discussions on the anticipated geotechnical conditions are based on the information provided by the site-specific geotechnical investigation program. Borehole logs for completed borings to support the design of the crossings by HDD methods are provided in Appendix B. The objective of these discussions is to provide an explanation of the various construction risks identified in subsequent sections related to the geotechnical conditions.

2.1 Subsurface Investigations

A total of five (5) borings, designated as B-54, B-55, B-56, B-57 and B-WICK-1 were completed as part of the geotechnical investigation program to support the evaluation and design of the Wickecheoke Creek crossing. Borehole B-54 was drilled south of Rosemont Ringoes Road, approximately 199 feet south of the north HDD exit location to a depth of 100 feet (Elev. 203 feet) below ground surface. Borehole B-55 was drilled approximately 711 feet north of the edge of Wickecheoke Creek to a depth of 220 feet (Elev. 41) below ground surface. Borehole B-56 was drilled between Wickecheoke Creek and Lower Creek Road, approximately 43 feet south of the edge of Wickecheoke Creek to a depth of 160 feet (Elev. 6 feet) below ground surface. Borehole B-57 was drilled approximately 1,104 feet north of the HDD entry location to a depth of 150 feet (Elev. 54 feet) below ground surface. Borehole B-WICK-1 was drilled approximately 434 feet north of the HDD entry location to a depth of 100 feet (Elev. 147 feet) below ground surface.

A summary of the known subsurface materials encountered at the site is provided below.

2.2 Geotechnical Observations

2.2.1 Geotechnical Observations North of Wickecheoke Creek

The HDD installation on the north side of Wickecheoke Creek is anticipated to encounter soils overlying bedrock materials. Based on Boring B-54, the site soils are anticipated to include the following:

- Medium stiff silt with trace clay from the ground surface to a depth of 3.5 feet (from Elev. 303 to 299.5 feet).
- Medium dense to dense silty sand with trace fine gravel to a depth of 13.5 feet (to Elev. 289.5 feet).
- Dense to very dense decomposed rock with silt to a depth of 30 feet (to Elev. 273 feet).
- Highly weathered to slightly weathered, very weak to medium strong siltstone to a depth of 100 feet (to Elev. 203 feet). Rock quality designation (RQD) values ranged between 0 and 70 percent (avg. 35 percent). Recovery values ranged between 25 and 100 percent (avg. 92 percent).

Based on Boring B-55, the geotechnical materials are anticipated to include the following:

- Very stiff silt with coarse to fine sand from the ground surface to a depth of 13.5 feet (from Elev. 261 to 247.5 feet).
- Very dense decomposed rack fragments to a depth of 16 feet (to Elev. 245 feet).
- Highly weathered to slightly weathered, weak to medium strong siltstone to a depth of 65 feet (to Elev. 196 feet). RQD values ranged between 0 and 88 percent (avg. 44 percent). Recovery values ranged between 83 to 100 percent (avg. 96 percent).
- Slightly weathered to fresh, medium strong shale to a depth of 75 feet (to Elev. 186 feet). RQD values ranged between 53 and 77 percent (avg. 65 percent). Recovery values ranged between 90 and 100 percent (avg. 95 percent).
- Slightly weathered, medium strong sandstone to a depth of 80 feet (to Elev. 181 feet). RQD value of 77 percent and recovery value of 100 percent.

- Slightly weathered, medium strong to strong siltstone to a depth of 105 feet (to Elev. 156 feet). RQD values ranged between 53 and 88 percent (avg. 70 percent). Recovery values ranged between 90 and 100 percent (avg. 98 percent).
- Slightly weathered to fresh, strong to very strong argillite to a depth of 120 feet (to Elev. 141 feet). RQD values ranged between 82 to 88 percent (avg. 86 percent). Recovery values ranged between 97 to 100 percent (avg. 98 percent).
- Moderately weathered to fresh, medium strong to strong siltstone to a depth of 220 feet (to Elev. 41 feet). RQD values ranged between 42 and 97 percent (avg. 77 percent). Recovery values ranged between 87 to 100 percent (avg. 98 percent).

2.2.2 Geotechnical Observations at Wickecheoke Creek

The HDD installation beneath Wickecheoke Creek is anticipated to encounter soils overlying bedrock materials. Based on Boring B-56, the geotechnical materials are anticipated to include the following:

- Stiff to very stiff silt with decomposed rock fragments from the ground surface to a depth of 13.5 feet (from Elev. 166 to 152.5 feet).
- Very dense decomposed rock fragments to a depth of 17 feet (to Elev. 149 feet).
- Highly weathered to moderately weathered, very weak to medium strong siltstone to a depth of 22.5 feet (to Elev. 143.5 feet). RQD values ranged between 34 to 37 percent (avg. 36 percent). Recovery values ranged between 93 to 100 percent (avg. 97 percent).
- Moderately weathered, weak to medium strong sandstone to a depth of 33.2 (to Elev. 132.8 feet) RQD values ranged between 7 to 37 percent (avg. 21 percent). Recovery values ranged between 93 to 98 percent (avg. 96 percent).
- Moderately weathered, weak to medium strong siltstone to a depth of 45 feet (to Elev. 121 feet). RQD values ranged between 53 to 63 percent (avg. 58 percent) with recovery values of 100 percent. A layer of moderately weathered, weak to medium strong sandstone exists within the siltstone rock mass between a depth of 42.7 to 44.1 feet (from Elev. 123.3 to 121.9 feet).
- Moderately weathered, weak to medium strong sandstone to a depth of 52 feet (to Elev. 114 feet). RQD value of 75 percent and recovery value of 100 percent.
- Highly weathered to slightly weathered, weak to medium strong mudstone to a depth of 63 feet (to Elev. 103 feet). RQD values ranged between 40 and 80 percent (avg. 63 percent). Recovery values ranged between 60 and 97 percent (avg. 84 percent).
- Moderately weathered, weak to medium strong siltstone to a depth of 70 feet (to Elev. 96 feet). RQD value of 43 percent and recovery value of 100 percent. A layer of moderately weathered, medium strong sandstone exists within the siltstone rock mass between a depth of 67.1 to 68.7 feet (from Elev. 98.9 to 96 feet).
- Moderately weathered, weak to medium strong mudstone to a depth of 80 feet (to Elev. 86 feet). RQD values ranged between 62 and 65 percent (avg. 64 percent) with recovery values of 100 percent.
- Moderately weathered, weak to medium strong siltstone to a depth of 90 feet (to Elev. 76 feet). RQD values ranged between 51 and 52 percent (avg. 51.5 percent) with recovery values of 100 percent.
- Slightly weathered, medium strong mudstone to a depth of 96.5 feet (to Elev. 69.5 feet). RQD value of 89 percent and recovery value of 100 percent.
- Small layer of slightly weathered, medium strong siltstone to a depth of 97.9 feet (to Elev. 68.1 feet).
- Slightly weathered to fresh, medium strong to very strong sandstone to a depth of 126 feet (to Elev. 40 feet). RQD values ranged between 74 and 100 percent (avg. 93 percent). Recovery values ranged between 98 and 100 percent (avg. 99.7 percent).
- Moderately weathered to fresh, medium strong to strong mudstone to a depth of 131.7 feet (to Elev. 34.3 feet). RQD value of 58 percent and recovery value of 95 percent.

- Fresh, strong sandstone to a depth of 140 feet (to Elev. 26 feet). RQD values ranged between 57 and 93 percent (avg. 75 percent) with recovery values of 100 percent.
- Fresh, strong siltstone to a depth of 160 feet (to Elev. 6 feet). RQD values ranged between 50 and 100 percent (avg. 81 percent). Recovery values ranged between 98 and 100 percent (avg. 99.5 percent).

2.2.3 Geotechnical Observations South of Wickecheoke Creek and Lower Creek Road

The HDD installation beneath Wickecheoke Creek is anticipated to encounter soils overlying bedrock materials. Based on Boring B-57, the geotechnical materials are anticipated to include the following:

- Soft silty clay with trace fine sand from the ground surface to a depth of 3.5 feet (from Elev. 204 to 200.5 feet).
- Very stiff clayey silt with gravel and sand to a depth of 8.5 feet (to Elev. 195.5 feet).
- Medium dense gravel with clay and silt to a depth of 13.5 feet (to Elev. 190.5 feet).
- Very dense decomposed rock fragments with clay and silt to a depth of 20 feet (to Elev. 184 feet).
- Slightly weathered to fresh, weak to strong siltstone to a depth of 50 feet (to Elev. 154 feet). RQD values ranged between 17 to 83 percent (avg. 49 percent). Recovery values ranged between 50 and 100 percent (avg. 91 percent).
- Moderately weathered to fresh, strong sandstone to a depth of 56.8 feet (to Elev. 147.2 feet). RQD value of 85 percent and recovery value of 50 percent.
- Slightly weathered to fresh, medium strong to strong siltstone to a depth of 80 feet (to Elev. 124 feet). RQD values ranged between 50 and 95 percent (avg. 75 percent). Recovery values ranged between 90 and 100 percent (avg. 97 percent).
- Slightly weathered to fresh, medium strong to very strong sandstone to a depth of 150 feet (to Elev. 54 feet). RQD values ranged between 28 and 100 percent (avg. 79 percent). Recovery values ranged between 87 and 100 percent (avg. 97 percent).

Based on Boring B-WICK-1, the geotechnical materials are anticipated to include the following:

- Soft silty clay with trace fine sand from the ground surface to a depth of 3.5 feet (from Elev. 247 to 243.5 feet).
- Very dense decomposed rock fragments with gravel and sand to a depth of 12 feet (to Elev. 235 feet).
- Slightly weathered to fresh, strong to very strong sandstone to a depth of 27.4 feet (to Elev. 219.6 feet). RQD values ranged between 40 and 93 percent (avg. 69 percent). Recovery values ranged between 80 and 100 percent (avg. 94 percent).
- Slightly weathered to fresh, medium strong to strong siltstone to a depth of 40 feet (to Elev. 207 feet). RQD values ranged between 65 to 90 percent (avg. 76 percent). Recovery values ranged between 95 and 98 percent (avg. 97 percent).
- Fresh, very strong argillite to a depth of 50 feet (to Elev. 197 feet). RQD values ranged between 85 and 88 percent (avg. 87 percent) with recovery values of 100 percent.
- Moderately weathered to slightly weathered, medium strong to strong siltstone to a depth of 65 feet (to Elev. 182 feet). RQD values ranged between 47 and 73 percent (avg. 56 percent). Recovery values ranged between 93 and 98 percent (avg. 96 percent).
- Fresh, very strong argillite to a depth of 70 feet (to Elev. 177 feet). RQD value of 80 percent and recovery value of 100 percent.
- Fresh, strong to very strong sandstone to a depth of 91 feet (to Elev. 156 feet). RQD values ranged between 95 and 98 percent (avg. 97 percent). Recovery values ranged between 98 and 100 percent (avg. 99 percent).

- Slightly weathered, medium strong to strong siltstone to a depth of 100 (to Elev. 147 feet). RQD values ranged between 18 and 72 percent (avg. 45 percent). Recovery values ranged between 45 and 95 percent (avg. 70 percent).

Along the proposed HDD alignment, the bedrock throughout the Wickecheoke Creek installation appears to be of very poor to excellent quality depending on the strata, with an overall fair quality of the rock mass. The core recovery values for all strata ranged from 25 to 100 percent with an average value of 96 percent.

3 Wickecheoke Creek Crossing

3.1 HDD Bore Geometry and Alignment Considerations

3.1.1 Entry and Exit Angles

HDD operations are typically designed with entry angles between 8° and 16°, although steeper entry angles have been used where insufficient setback distance or steeply sloping ground exists for a given alignment. Exit angles are typically lower than the entry angle, as consideration must be given to the pipe diameter, the equipment necessary to transition the pipe into the bore, and the stresses induced as the pipe is forced over the break-over location as it enters the HDD bore.

For the Wickecheoke Creek installation, the entry and exit angles have been set at 14° and 12°, respectively, relative to the horizontal.

3.1.2 Vertical and Horizontal Curvature

Vertical curvature is inherent to all HDD installations. The need for horizontal curvature is dependent on the restrictions specific to a single crossing. While horizontal curvature is feasible, it greatly increases the complexity of the scope of design and construction when required. It also increases the stress, and therefore the risk, to the pipe and the overall installation. Steering in both planes is not a standard industry practice and can lead to complex radii and a reduction in the overall bending radius that the pipe will be subjected to. A straight alignment has been selected for the crossing eliminating the risks associated with horizontal curvature.

The proposed vertical curve radius of 3,600 feet shown in Appendix A is consistent with the HDD industry standard of 1,200 times the 36-inch outer diameter of the pipe. This radius has been taken as the design radius for the crossing.

3.1.3 HDD Installation Depth

The depth of cover for a given HDD installation is dependent on several factors, including but not limited to:

- The anticipated geotechnical materials
- The presence of preferential flow pathways
- The design bending radius
- The presence of existing utilities and/or structures
- Installation length

Of these, the most important factors are the properties of the overlying geotechnical material, and the resistance these materials provide against the required installation-induced bore fluid pressures necessary to remove the cuttings.

Another important factor in establishing the proper installation depth is the ability to maintain bore stability over the course of the installation. This is accomplished by placing the HDD bore through geotechnical materials that are favorable to HDD operations. For this installation, the HDD is anticipated to be within the siltstone and sandstone bedrock for the majority of the installation.

The proposed HDD installation crosses beneath several surface features including waterbodies and roads. From a south to north orientation, the following minimum depths of cover are noted:

- Lower Creek Road: Approximately 131 feet.
- Wickecheoke Creek: Approximately 110 feet.
- Waterbody 031219_LD_1002_P_MI: Approximately 103 feet.

- Waterbody 031219_LD_1003_I_MI: Approximately 86 feet.

3.1.4 Bore Diameter

The diameter of the HDD bore must be greater than the outer diameter of the pipe. This larger bore is required to facilitate the flow of drilling fluids around the pipe, reduce the frictional force acting on the pipe as it is installed, and to help the pipe negotiate curves in the alignment.

The acceptable industry standard for the final bore diameter is generally 1.5 times larger than the pipe outer diameter for small diameter pipe (less than 24 inches), and 12 inches larger than the outer diameter for larger diameter installations. However, the actual diameter of the bore is typically dependent upon the geotechnical conditions and the required bore geometry. Hence, it may be necessary to increase the diameter beyond the typical industry standard to facilitate the installation process. To increase the likelihood of success, it is highly recommended that the final bore diameter be selected by the HDD Contractor, based on their experiences with similar geotechnical materials, pipe diameters, and installation lengths, and to suit their means and methods.

Based on typical HDD industry standards, the anticipated bore diameter for the NPS 36 pipe is 48 inches.

3.2 Line and Grade Accuracy

The horizontal and vertical position of the bottom hole assembly is tracked using a downhole survey tool, consisting of a probe that utilizes Earth's gravitational and magnetic fields. These tools have a nominal accuracy of approximately:

- Inclination: ± 0.1°
- Azimuth: ± 0.3° to 0.5°
- Tool-face: ± 0.1°

The accuracy of these tools can be enhanced by using a surface wire/coil loop established over the alignment. Inducing an electrical current through the wire creates a localized magnetic field from which the downhole probe can determine its location relative to the surveyed coil and magnetic field.

These enhanced guidance systems include TruTracker and ParaTrack systems. The TruTracker guidance system relies on a closed loop surveyed wire layout that is at least as wide as the depth of the HDD installation. For highways and water body crossings, individual coils are often established on each side of the crossing feature. A ParaTrack system relies on a single wire placed directly over the HDD alignment centerline, with a return wire offset several hundred feet from the alignment to form a closed loop system. When augmented with a surface coil, the lateral and vertical position of the survey probe is plus or minus two (2) percent of the depth separating the location of the probe and the surface coil. Greater inaccuracies may occur if site constraints prevent the use of an energized wire grid on the ground surface.

Fiber-optic gyroscopic guidance systems have also been used to track downhole tooling. This type of system relies on an inertial measurement unit to calculate the position of the bottom hole assembly and is not affected by magnetic interference. This tool is very effective in accurately locating the surface tool position during pilot bore drilling.

With these methods, survey readings can be taken at the end of each drilled joint or every half of a joint. Stand-alone surveys can be completed where the surface coils are established. Here the inaccuracy is a function of the specific depth of cover at the location in question. Where the surface coils cannot be established, such as across a highway or beneath a river, the position of the bottom hole assembly is determined based on the calculated position of the previous measurement. In this manner, any inaccuracy built into the measured position is additive as the drill length increases. However, as the bottom hole assembly re-encounters the surface coil on the opposite side of the highway or river, the inaccuracy is once again a function of a stand-alone measurement based on the specific depth of cover at the location in question.

Mott MacDonald recommends the use of a ParaTrack system. The HDD Contractor must assure adequate coverage of surveying with no gaps in coverage while using a surface coil and/or beacon.

3.3 Required Workspace and Staging Areas

For the proposed HDD installation, the staging area for the HDD entry location on the south side of the crossing has been established at 250 feet by 250 feet, and the staging area for the HDD exit location on the north side of the crossing has been established at 250 feet by 255 feet. This area is required to stage equipment necessary for the installation, which includes the drill rig, stacks of drill pipe, operator control cabin, tooling trailers, crane or excavator, separation plant, mud tanks, mud pumps, Baker storage tanks, office trailer, and support trailers.

In addition to the entry and exit staging areas, a staging area of 75 feet wide by the length of the pipe string (greater width is required where multiple drag sections are required as is the case for this installation) is also required for welding sections of the pipe string, and preferably the entire pipe string when possible, prior to installation. The proposed staging area for the drag section is located on the north side of the crossing, as insufficient workspace area was able to be attained on the south side of the crossing for pipe stringing and pullback activities. The available length of the staging area is approximately 2,600 feet north of Rosemont Ringoes Road, resulting in the need for fabricating the pipe string into a two (2) drag sections and the need for one (1) intermediate weld during pullback operations. The HDD Contractor will need to minimize delays during intermediate welding operations. During pullback operations, Rosemont Ringoes Road will need to be shutdown to pull the fabricated pipe to the HDD exit location.

The temporary work space established for the Wickecheoke Creek installation is sufficient for HDD operations.

3.4 Drilling Fluid Make-Up Water and Source

HDD operations require a continuous source of water to support construction activities. It is typical for contractors to make use of an onsite source, or have water delivered from a nearby source. In each case, the contractor should verify that the water source is suitable for HDD operations, or treat it (filtration, pH, etc.) so that it is suitable for use.

For the proposed crossing, the contractor will be required to haul and store water on site for construction activities. Estimates of fresh water requirements is a function of maintaining drilling fluid flow within the bore during the HDD installation, and water requirements to adjust for hole volume, minor losses to processed spoils and surrounding geotechnical materials, wash water, etc. Daily fresh water usage typically ranges from 2,650 to 5,300 ft^3, depending on the process and storage capabilities of the Contractor.

Total fresh water requirements can be estimated as a function of the final reamed diameter. Factors of between two (2) and seven (7) times the final reamed diameter have been used to estimate the fresh water requirements necessary to support HDD operations. Based on a factor of four (4), the estimated total water usage (assuming no loss in circulation) is approximately 1,523,095 gallons (203,608 ft^3). This volume estimate assumes good HDD industry practices and procedures are followed, and that no significant fluid losses occur during the installation. This volume also includes fresh water required for buoyancy control during the HDD installation (estimated at approximately 151,125 gallons).

3.5 Disposal of Excess Drilling Fluid and Processed Spoils

Excess drilling fluids and processed spoils will need to be disposed of during the installation. The direct area around the HDD is not expected to be suitable for permanent disposal of drilling fluid or processed solids (based on local, state, and federal regulations). Local, temporary storage will be required, either in above ground tanks or a lined borrow pit. A suitable offsite disposal site should be located for disposal of drilling fluid and processed spoil per the local, state, and federal guidelines.

Disposal volumes of excess drilling fluid and spoil are estimated at approximately 1,188,560 gallons (5,885 yd^3) and 60,365 ft^3 (2,236 yd^3) respectively. During pullback operations, the estimated displaced fluid volume is approximately 167,975 gallons (832 yd^3).

3.6 Schedule

The duration of the HDD installation is conservatively estimated to take a total of 110 shifts, regardless of whether 24-hour operations are conducted to complete the crossing, as shown in Table 1 below. This estimate is based on 12-hour shifts. No provisions have been included for pad construction and erection and tear-down of a shelter (if used) in these durations. In addition, no contingency has been provided for adverse weather or more difficult drilling conditions.

Table 1: Estimated schedule duration for the HDD crossing

Activity	Duration (Shifts)
Mobilization	3
Rig Up / Equipment Setup	5
Pilot Bore Drilling	20
Reaming	74
Swab Pass	1
Product Pipe Pullback	2
Rig Down and Demobilization	5
Total Number of Shifts	**110**

4 HDD Engineering Evaluation

4.1 Pipeline Properties

The pipeline properties used for the evaluation of the Wickecheoke Creek HDD Crossing have been provided by PennEast, and are summarized in Table 2 below:

Table 2: Pipeline properties and input parameters for the HDD evaluation

Evaluation Parameter	Value
Pipe Size	NPS 36
Outer Diameter	36 in
Wall Thickness	0.762 in
Pipe Grade	X-70
Maximum Allowable Operating Pressure	1,480 psig
Minimum Operating Temperature	45°F
Maximum Operating Temperature	120°F
Poisson's Ratio	0.30
Elastic Modulus	29,200,000 psi
Coefficient of Thermal Expansion	6.5×10^{-6} in/in/°F
Design Factor	0.5

4.2 Design and Minimum Allowable Bend Radii

The minimum ultimate bend radius is a function of the maximum allowable operating pressure, pipe diameter, wall thickness, design factor, location factor, and specified minimum yield strength of the pipe material. Determination of the ultimate minimum bend radius is based on determining the hoop and longitudinal stresses under operating pressure, and then determining the available magnitude of stress that the product pipe can accommodate in an alignment bend/curve.

The minimum ultimate bending radius evaluation is completed in accordance with:

- ASCE Manual of Practice No. 108 Pipeline Design for Installation by Horizontal Directional Drilling
- 49 CFR 192 Transportation of Natural and Other Gas by Pipeline- Minimum Federal Safety Standards
- ASME B31.8 Gas Transmission Distribution and Piping Systems
- ASME B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids

Using the pipe properties presented in Table 2, the ultimate minimum bending radius is calculated for the pipe and pressure conditions. This radius represents the lowest radius that could be drilled without overstressing the pipe for the identified pipe properties and in-service loading. Based on the pipe properties provided in Table 2 and a design factor of 0.5, the ultimate minimum bending radius is approximately 2,500 feet.

The minimum allowable bending radius is the minimum radius that the HDD contractor is permitted to drill during their pilot bore to maintain the design alignment and profile. This radius is established above the calculated ultimate minimum bending radius to ensure that the pipe is not overstressed during the HDD

installation process, and sufficiently below the design radius provided on the Contract drawings. Based on an ultimate minimum bending radius of 2,500 feet, the minimum allowable bending radius has been established at 2,600 feet.

The design radius is the radius selected to develop the HDD plan and profile. This radius is greater than the minimum allowable bending radius given to the HDD contractor to complete the construction of the crossing. The design bending radius for developing the Wickecheoke Creek profile has been established at 3,600 feet, which is consistent with the HDD industry standard of 1,200 times the outer diameter of the NPS 36 pipe.

4.3 Operating Stress Evaluation

Evaluation of operating loads for pipelines installed by HDD methods is generally similar to the evaluation for pipelines installed by open-cut construction methods. The main difference between the two scenarios is that elastic bending (as a result of the curved HDD alignment profile) must be considered for the HDD installation. Elastic bending stresses occur as the pipe takes on the final shape of the HDD bore. As a rule, the bending stresses induced are not a critical stress condition on their own but must be considered in a combined loading condition with other stress conditions such as hoop stress and longitudinal stress.

An operating stress evaluation has been completed in compliance with the ASME B31.4 and B31.8. The input parameters for this analysis are provided in Table 2. The results of the evaluation are provided in Table 3 below and are based on the minimum allowable bending radius of 2,600 feet (based on the allowable bend radius provided to the HDD contractor). As observed in Table 3, the operating stresses are below the maximum allowable limits. Hence, the pipe properties (wall thickness and grade) are sufficient to meet the operating stresses within the HDD alignment.

Table 3: Summary of operating stress evaluation

Stress Condition	Estimated Stress (psi)	Percent of SMYS[1] (%)	Maximum Allowable Percent of SMYS[1] (%)
Longitudinal Bending Stress	16,846	24.1	--
Hoop Stress	34,961	49.9	50[2]
Longitudinal Tensile Stress from Hoop Stress	10,488	15.0	--
Longitudinal Stress from Thermal Expansion	-14,235	20.3	90[3]
Net Longitudinal Stress (Compression Side of the Curve)	-20,593	29.4	90[4]
Net Longitudinal Stress (Tension Side of the Curve)	13,099	18.7	90[4]
Maximum Shear Stress	27,777	39.7	45
Combined Biaxial Stress	55,554	79.4	90[4]

Notes: [1] Specified Minimum Yield Stress
[2] Limited by design factor
[3] Limited by ASME B31.4
[4] Limited by ASME B31.8

4.4 HDD Installation Load and Stress Evaluation

A total of six (6) pull load evaluations were completed for the HDD bore profile. These calculations are based on the installation load calculation method provided in American Society of Civil Engineer MREP 108 (2015), and the Pipeline Research Committee at the American Gas Association publication, entitled "Installation of Pipelines by Horizontal Directional Drilling, an Engineering Guide."

The pull load evaluation includes assumptions for final bore diameter, soil, pipe roller friction coefficients, drilling fluid yield point, plastic viscosity, drilling fluid pumping rate, and other installation parameters such as buoyancy control measures (i.e. whether or not the pipe will be filled with water during pullback operations). In addition, the evaluation accounts for the capstan effect induced by curves in the alignment, fluidic drag, buoyancy of the pipe string within the bore, and the weight of the tail string at start-up and throughout the installation process.

Six (6) installation evaluations were completed to investigate the effects of varying mud weights and buoyancy control measures during the installation of the pipe. The six (6) scenarios were:

- Case 1: Drilling Fluid Weight 10 ppg (Specific Gravity of 1.20)
  Pipe No buoyancy control (pipe empty of water)
- Case 2: Drilling Fluid Weight 10 ppg (Specific Gravity of 1.20)
  Pipe Full buoyancy control (pipe full of water)
- Case 3: Drilling Fluid Weight 11 ppg (Specific Gravity of 1.32)
  Pipe No buoyancy control (pipe empty of water)
- Case 4: Drilling Fluid Weight 11 ppg (Specific Gravity of 1.32)
  Pipe Full buoyancy control (pipe full of water)
- Case 5: Drilling Fluid Weight 12 ppg (Specific Gravity of 1.44)
  Pipe No buoyancy control (pipe empty of water)
- Case 6: Drilling Fluid Weight 12 ppg (Specific Gravity of 1.44)
  Pipe Full buoyancy control (pipe full of water)

A summary of the maximum anticipated pull load for each case scenario is provided in Table 4 below. Detailed calculations are provided in Appendix C. The anticipated installation loads shown in Table 4 are well below the ultimate allowable load of the pipe of approximately 3,542,953 lbs, based on a tensile stress equivalent to 60 percent of the yield stress for the given wall thickness and pipe grade provided in Table 2. It is important to note the difference in pull loads when buoyancy control measures are implemented, and water is added to the pipe during pullback, as the estimated installation loads are typically lower when buoyancy control measures are used. Mott MacDonald recommends the use of buoyancy control measures to lower the overall installation loads and stresses for this installation.

Table 4: Summary of anticipated pullback loads

Drilling Fluid Weight (ppg)	Product Pipe Buoyancy Condition	Estimated Pullback Force (lbs)
10 (Case 1)	Empty	806,132
10 (Case 2)	Full	449,368
11 (Case 3)	Empty	931,946
11 (Case 4)	Full	369,090
12 (Case 5)	Empty	1,054,075
12 (Case 6)	Full	284,642

The HDD Contractor may elect to use buoyancy control measure where a neutrally buoyant conditions is developed to lower the estimated pullback loads. Using a neutrally buoyant pipe during pullback operations lowers the estimated pull force to 369,090 lbs. with a drilling fluid weight of 11 ppg.

Results of the corresponding installation stresses (based on the design bending radius of 3,600 feet) are summarized below in Table 5.

Table 5: Summary of installation stress evaluation

Stress Condition	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Maximum Tensile Stress (Percent of Allowable)	9,556 psi (13.7%)	5,327 psi (7.6%)	11,048 psi (15.8%)	4,375 psi (6.3%)	12,496 psi (17.9%)	3,374 psi (4.8%)
Maximum Bending Stress (Percent of Allowable)	12,167 psi (17.4%)	12,167 psi (17.4%)	12,167 psi (17.4%)	12,167 psi (17.4%)	12,167 psi (17.4%)	12,167 psi (17.4%)
Maximum Hoop Stress (Percent of Allowable)	3,056 psi (4.4%)	507 psi (0.7%)	3,362 psi (4.8%)	812 psi (1.2%)	3,667 psi (5.2%)	1,118 psi (1.6%)
Maximum Unity Check – Tensile and Bending	0.43	0.35	0.45	0.34	0.48	0.32
Maximum Unity Check – Tensile, Bending, and Hoop	0.39	0.09	0.45	0.10	0.53	0.12

As observed in this Table, the results of the HDD installation stress evaluation are within the allowable limits for all cases.

4.5 Hydraulic Fracture Evaluation

The hydraulic fracture evaluation for this crossing has been completed in general accordance with the Delft Geotechnics Method outlined in Appendix B of the Army Corps of Engineers 1998 Report CPAR-GL-98 and 2002 Report ERDC/GSL TR-02-9 (Guidelines for Installation of Utilities Beneath Corp of Engineers Levees Using Horizontal Directional Drilling). This method is used to estimate the maximum effective pressure (i.e. drilling fluid pressure) that can be induced during an HDD operation within an individual soil horizon. This pressure is then compared with the fluid pressure required to induce slurry flow within the HDD bore to determine the potential for a hydraulic fracture for a given HDD alignment. The required fluid pressure for an HDD installation is governed by the drilling fluid weight (commonly referred to as the mud weight), installation length and depth, and drilling fluid flow properties (plastic viscosity, yield point, etc.).

The hydraulic fracture evaluation method described above and used in the HDD industry was developed for soil installations. Currently, no accepted method is available to model/predict the maximum allowable drilling fluid pressure within bedrock materials.

While bedrock tensile strength and unconfined compressive strength evaluations have been used to estimate the allowable drilling fluid pressure within bedrock materials, these methods tend to provide results that are not considered suitably conservative and greatly over-predict the true maximum allowable drilling fluid pressures. These over-predictions are a result of laboratory testing on sound or high-quality bedrock samples that are not representative of the strengths of the weaker bedrock materials that contain natural fractures/joints that are washed out or impacted by the geotechnical coring process. Hence, for bedrock hydraulic fracture evaluation, Mott MacDonald has elected to model the siltstone/shale bedrock materials as a strong soil. Mott MacDonald have used this conservative approach to successfully complete several HDD installations in similar bedrock materials.

The Delft Geotechnics Method assumes a uniform column of soil above any point of interest along the alignment. Where an increased risk of hydraulic fracture is identified, it does not necessarily mean that a hydraulic fracture will occur. A proper HDD execution plan, based on HDD industry standard construction practices, can reduce the risk of a hydraulic fracture from occurring.

To complete the hydraulic fracture evaluation, it is necessary to make several assumptions relative to the bore diameter, drilling fluid pumping rate, and drilling fluid properties. Parameters used in Mott MacDonald's evaluation are provided in Table 6 below. These parameters have been selected based on Mott MacDonald's experience in drilling within similar anticipated geotechnical materials.

Table 6: Assumptions used for hydraulic fracture evaluation

Evaluation Parameter	Value
Pilot Bore Diameter	12-¼ in
Drill Pipe Diameter	6-⅝ in
Drilling Fluid Pumping Rate	600 gal/min
Drilling Fluid Weight (Specific Gravity)	10.5 ppg (1.26)
Yield Point	19.5 lb./100 ft^2
Plastic Viscosity	13 cP

In addition to the assumptions provided in Table 6, assumptions are also required for the anticipated soil formation(s) and their properties including, but not limited to, geotechnical material strength, unit weight, cohesion, friction angle, and shear modulus. These assumptions are provided in Tables 7, Table 8, and Table 9 for the varied subsurface materials that are anticipated for this crossing. For this evaluation, Mott MacDonald assumes that the encountered subsurface material will be similar to that described in Section 2.0, namely, clay and decomposed bedrock overlying siltstone/sandstone bedrock.

Table 7: Material property assumptions for the medium stiff clay soils

Evaluation Parameter	Value
Soil Unit Weight Above / Below Water Table	120 lb./ft^3 / 115 lb./ft^3
Effective Cohesion	1,000 psf
Internal Friction Angle	0°
Young's Modulus	240,182 psf
Poisson's Ratio	0.30

Table 8: Material property assumptions for the decomposed bedrock

Evaluation Parameter	Value
Soil Unit Weight Above / Below Water Table	130 lb./ft^3 / 135 lb./ft^3
Effective Cohesion	0 psf
Internal Friction Angle	22°
Young's Modulus	449,037 psf
Poisson's Ratio	0.30

Table 9: Material property assumptions for the siltstone/sandstone bedrock

Evaluation Parameter	Value
Soil Unit Weight Above / Below Water Table	140 lb./ft^3 / 145 lb./ft^3
Effective Cohesion	4,500 psf
Internal Friction Angle	6°
Young's Modulus	751,875 psf
Poisson's Ratio	0.30

The results of the preliminary hydraulic fracture evaluation for the proposed crossing are provided in Figure 1 below for the pilot bore phase of the installation process. More detailed results are provided in Appendix D. A safety factor has been incorporated into the hydraulic fracture evaluation for the allowable bore pressure within the bedrock, to account for assumptions incorporated into the design and heterogeneity of the geotechnical materials. The graph also displays the total soil/bedrock overburden stress representing the equivalent unit weight of the overlying soil without consideration of any soil strength. Mott MacDonald recommends holding discussions with the HDD contactor if the actual bore pressures trend higher than those values estimated in Appendix D during actual construction, especially if the observed bore pressures spike during the installation.

As shown in the graph, the required bore pressure to facilitate the installation process is below the allowable bore pressure for the installation for the majority of the installation. Overall, the risk of a hydraulic fracture or inadvertent return is relatively low for this crossing. Only in the vicinity of the exit location does the required drilling fluid pressure exceed the allowable drilling fluid pressure. This area of increased inadvertent return risk is considered normal within the HDD industry as the pilot bore is steered upwards towards the exit location. In addition, there is an increased risk of an inadvertent return in the vicinity of STA 5107+00 where the depth of cover is lowest.

Once the pilot bore is completed, the hydraulic fracture risk associated with the reaming, swab, and pullback phase of the installation typically decreases, assuming the bore is reamed to its full extent and a subsequent swab pass is completed through the bore prior to installing the pipe. However, it is important to note that although the hydraulic fracture potential is significantly reduced, a hydraulic fracture event may still occur during the reaming pass if the bore becomes plugged or blocked such that the required drilling fluid pressure increases in magnitude to the point where it exceeds the estimated allowable mud pressure for the overlying soils. Use of HDD industry-standard construction practices, such as pumping sufficient drilling fluids, maintaining drilling fluid returns, monitoring and maintaining drilling fluid, and returning slurry properties, etc., should reduce any potential loss of drilling fluids.

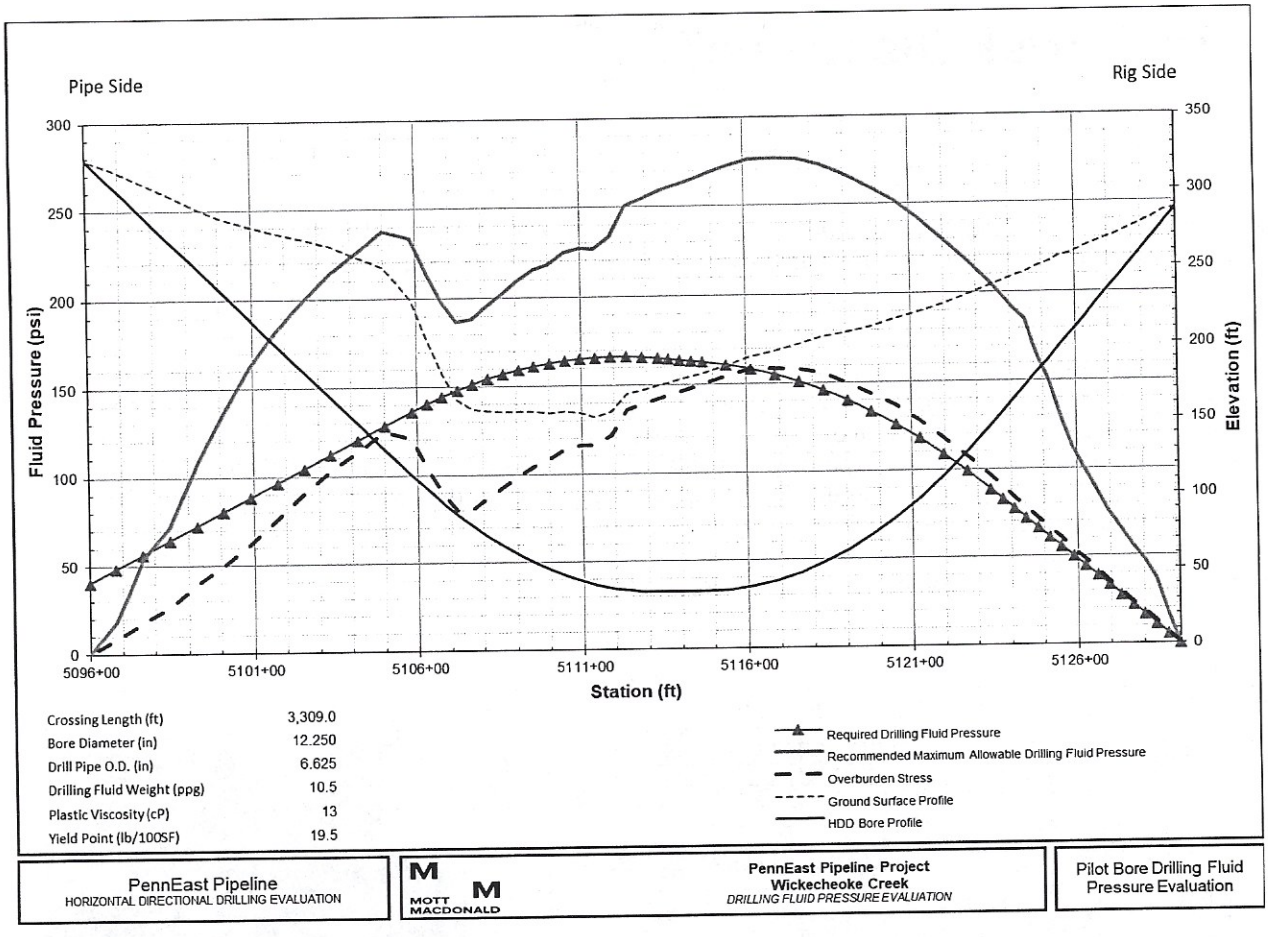

Figure 1: Calculated, recommended, and allowable drilling fluid pressures

5 HDD Risk Discussions

5.1 HDD Risk Characterization

Risk identification and mitigation is paramount to successfully completing the Wickecheoke Creek Installation. Discussions of the general risks associated with these crossings are presented below.

5.2 HDD Industry – State of Practice

Mott MacDonald maintains an up-to-date database of successfully completed HDD installations based on pipeline diameter and installation length, as shown in Table 10 below. This database is used to assess the achievable installation length for a given pipeline diameter. The green shaded cells indicate the common range of HDD industry experience/capability and was established with the requirement that several contractors have successfully completed similar installation lengths at the required pipe diameter. The yellow shaded cells identify the installation lengths and diameters that are considered feasible with an experienced contractor in favorable ground conditions. The red shaded cells are considered to be at the limits of, or beyond, the current state-of-practice for the HDD industry.

Table 10: State of the HDD Industry

Product Pipe Diameter	Installation Length												
	1,000 m	1,200 m	1,400 m	1,600 m	1,800 m	2,000 m	2,200 m	2,400 m	2,600 m	2,800 m	3,000 m	3,500 m	3,750 m
	3,281 ft	3,937 ft	4,593 ft	5,249 ft	5,905 ft	6,562 ft	7,218 ft	7,874 ft	8,530 ft	9,186 ft	9,842 ft	11,483 ft	12,303 ft
200 mm (8 inch)	16	9	14	4	5	10	5	0	0	0	1	0	1
250 mm (10 inch)	9	9	4	11	1	0	3	1	0	0	0	0	0
300 mm (12 inch)	14	10	9	4	3	1	0	1	1	0	0	1	0
350 mm (14 inch)	3	5	3	0	1	0	0	0	0	0	0	0	0
400 mm (16 inch)	9	4	4	6	4	1	3	0	0	0	2	0	0
450 mm (18 inch)	0	0	0	2	0	0	0	0	0	0	0	0	1
500 mm (20 inch)	8	10	9	1	0	1	2	1	0	0	0	0	0
600 mm (24 inch)	29	30	9	12	9	4	1	2	0	0	1	0	0
750 mm (30 inch)	23	10	10	11	8	3	1	3	0	0	1	0	0
900 mm (36 inch)	23	21	21	6	2	1	2	0	1	0	0	0	0
1050 mm (42 inch)	29	21	11	5	1	1	0	0	0	0	0	0	0
1200 mm (48 inch)	1	2	1	0	0	0	0	0	0	0	0	0	0

Colour Coding:

Within typical capabilities of industry. Multiple experienced contractors.

Zone of limited industry application. Considered feasible with an experienced contractor and favourable ground conditions.

Exceeds current capabilities of industry. Considered risky even with an experienced contractor and favourable ground conditions.

NOTE: Current State of the HDD Industry shown above is based solely on the reported installation lengths and diameters. Site-specific geotechnical and installation based risks have not been considered in developing this chart.

It is very important to note that the state of the HDD industry shown above includes crossings with similar elevations between HDD entry/exit locations and the crossing feature, good soils/bedrock materials, and adequate staging area for fabricating the pipe string. These completed projects mostly reflect those with low risk profiles (especially for larger and longer HDD installations). As such, when comparing a specific crossing to those completed projects within the HDD industry, the site-specific geotechnical and crossing risks need to be thoroughly considered and evaluated to ensure comparison to the completed project listings is deemed to be adequate. If the current proposed crossing carries a low risk profile, then the comparison can serve as a guide to what has been successfully completed within the HDD industry. However, if the current proposed crossing carries a high-risk profile, then the comparison to the completed projects may not be applicable.

As observed in Table 10 above, a few HDD installations have been successfully completed at or near a diameter of NPS 36 for lengths similar to or longer than the horizontal installation length of approximately 3,309 feet, with a true pipe length of approximately 3,363 feet, required for this crossing. Therefore, from a constructability standpoint, the Wickecheoke Creek Installation falls within the zone of limited experience

of what has been accomplished to date within the HDD industry and will require an experienced HDD contractor to undertake the work.

5.3 Geotechnical Risk Discussions

Sands, silts, and clays typically present no significant challenge to an HDD installation. These materials are often described as good to excellent materials in terms of feasibility. However, when these soils exist in a soft or loose state, they may not provide sufficient strength to resist the required fluid pressures necessary to complete an HDD installation. Within these materials, the required drilling fluid pressures can exceed their strength, resulting in the formation of a hydraulic fracture through the overlying soils and ponding of drilling fluids at the ground surface. This risk can only be mitigated by placing the HDD bore within more favorable geotechnical materials that provide greater resistance to induced drilling fluid pressures, or by using conductor casings to provide an open pathway for drilling fluid flow.

Soils containing gravels and larger size particles (cobbles) range from marginally acceptable to unacceptable in terms of feasibility, depending upon the percentage of gravels by weight and particle size. Only those particles that can be suspended within the drilling fluid can be removed from the bore. Generally speaking, gravel-sized particles less than approximately 0.5 to 0.75 inches can be removed from the bore, provided good HDD practices are followed. Particles greater in size typically cannot be suspended by the drilling fluid and tend to settle out and accumulate along the bottom of the bore. The risks associated with accumulation of larger particles within the bore increase with greater bore diameter, due to the greater exposed soil materials in the crown of a larger bore. Gravel deposits containing large particles were not observed during the geotechnical investigations.

Bedrock can be highly variable and can be classified as being excellent to unacceptable with respect to HDD feasibility. Competent bedrock is well suited for HDD as the bore tends to remain open for extended periods of time. However, heavily weathered, jointed, fractured or fissured bedrock can present challenges with respect to bore stability. In fact, poor quality bedrock can present the same challenges as coarse granular (gravel) deposits, where fracturing and jointing is extensive and present an unacceptable risk in terms of constructability to an HDD installation. The risk associated with these materials arises from the inability to support and maintain stability within the bore.

This risk increases with RQD ratings below 60 percent. For the Wickecheoke Creek installation, the rock quality is typically greater than 60 percent based on the borings. Isolated areas of poor-quality siltstone exist primarily at the soil/rock interface and improve in quality with an increase in depth. The poor-quality bedrock at the transition zone of the soil/rock interface can cause both steering problems and borehole instability, especially in a dry hole condition.

Preferential flow pathways may occur where heavily weathered, jointed, fractured or fissured bedrock exists. If interconnected, preferential flow pathways may exist for drilling fluid losses into the rock mass, horizontally to the face of a slope, or upwards towards the ground surface. Fortunately, the presence of the drilling fluid slurry within the bore is often capable of sealing fractures and/or joints as drilling fluids migrates into these features, resulting in low potential for inadvertent returns of drilling fluids at the ground surface.

Based on the geotechnical information available to date, the HDD installation has been designed within favorable geotechnical materials to the extent possible.

5.4 Crossing-Specific Risk Discussions

Controlling and maintaining fluid flow within the bore is critical to the success of an HDD installation. Installation risks significantly increase when slurry circulation is not maintained within the HDD bore. The flow of drilling fluid follows the path of least resistance. As long as the bore is located within favorable geotechnical materials at a sufficient installation depth and properly drilled by the HDD contractor, a stable flow pathway can be created between the drill bit and the HDD entry or exit locations, and maintaining drilling fluid flow within the bore should not be an issue. As observed in the hydraulic fracture evaluation, loss of drilling fluids through the overlying soil is not anticipated for this crossing.

The length of the pipe staging area is insufficient to fabricate the product pipe into a single string prior to pullback operations and an intermediate weld will be required. The intermediate weld will require stoppage of pullback operations for the new pipe segment is welded on. This stoppage represents a significant risk to the installation because the bore is required to remain open much longer than would be required for the installation of a single pipe string. In good quality bedrock that is anticipated for the Wickecheoke Creek HDD Crossing, maintaining stability is possible yet represents a moderate risk. Stoppages for the intermediate welds also provide downtime, while welding occurs, that allows the drilling fluids to "gel" and which can make it harder to resume pullback operations due to the increased friction between the gelled fluids and the product pipe. Start-up loads will increase when pullback operations are resumed. In some cases, the gel strength of the fluids is too great and the resulting loads lead to damage of the product pipe or the pipe may become stuck at its current position in the bore. Prior to pullback operations, a swab pass should be completed to gauge whether the bore has been conditioned to accept the product pipe. Areas of high torque and/or pull force should be re-reamed to lower the drill rig effort to pass tools through this portion of the bore. The product pipe should be installed with the shortest section of pipe first with the longest pipe section last to decrease the startup load on the pipe required to resume drilling operations. A hydraulic thruster may be required to help push the pipe into the bore as the drill rig pulls.

The exit location is approximately 39 feet higher than the elevation of the entry location which will result in approximately 186 feet of dry hole above the rig elevation. Once the bore is advanced above the elevation of the drilling rig it may be difficult to maintain a column of drilling fluid within the portion of the bore above the elevation of the HDD entry location. Lack of a full column of drilling fluid to help support the portion of the bore above the elevation of the lower drill rig can lead to instability and raveling of the bore within this section. Boring B-54 indicates a layer of dense silty sand overlying dense decomposed bedrock along the exit tangent. Risks of an unsupported bore in the site soils and poor-quality bedrock present a significant raveling or bore instability risk.The density of this soil layer and the presence of fine grained soil constituents (i.e. silt and clay) will help to reduce tendencies for raveling within this area. However, the HDD Contractor will need to be prepared to deal with any bore instability and raveling in the event it becomes a significant issue. The HDD contractor will need to pay attention to the swab pass to determine if any debris has accumulated within the bore. This risk is common to HDD installations and can be managed appropriately during construction.

With the elevation difference, the HDD Contractor will need to be prepared for flushing events that may occur during the drilling process where uncontrolled flow of fluids flow out of the bore towards the lower elevation HDD entry location. The HDD Contractor must be prepared to contain and capture these fluids at the entry location. This can easily be accomplished with mud pumps, mud lines, and several storage tanks on this side of the crossing.

During pullback operations, the HDD Contractor must provide injection of drilling fluids into the bore at the HDD exit location (pipe entry location) in addition to the drilling fluids injected through the pulling assembly. These fluids are necessary to reduce the potential damage to the pipe coating from being pulled through a dry hole.

6 Summary

For the Wickecheoke Creek installation, geotechnical risks have been acknowledged, but no fatal deterrents have been identified within the alignment. Based on the required installation length and diameter, the HDD contracting community in North America has successfully completed a limited number of HDD installations of similar lengths.

While not anticipated, if an attempted HDD installation is unsuccessful, the proposed HDD alignment could be modified using the same HDD entry/exit locations to accommodate an additional HDD attempt, depending on the condition that resulted in the HDD failure. Prior to attempting a second HDD crossing, a risk mitigation workshop should be held with all parties to determine the cause of the initial failure and any mitigation measures that could be adopted to reduce the risk(s) during the second HDD attempt.

7 Limitations

This report is intended to be used in its entirety. The data, interpretations, conclusions, and recommendations contained within this report are provided for informational purposes for PennEast, and pertain specifically to the Wickecheoke Creek HDD installation. The data and conclusions presented herein do not and should not be applied to any other project site or HDD installation. Interpretations of the subsurface conditions are based on the information obtained from the geotechnical borings. The subsurface conditions presented between the geotechnical borings are interpretations and may vary from the actual conditions encountered.

It is recommended that Mott MacDonald provide construction monitoring services to verify the subsurface conditions encountered during construction, provide field design services, and evaluate contractor performance in accordance with the contract and the approved contractor supplied work plan.

Appendix A

HDD Plan and Profile

Appendix B

Geotechnical Boring Logs

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SOIL/ROCK BORING LOG LEGEND

USCS Group Symbol

UNIFIED SOIL CLASSIFICATION SYSTEM AND SYMBOL CHART					
COARSE-GRAINED SOILS (more than 50% of material is larger than No. 200 sieve size.)			FINE-GRAINED SOILS (more than 50% of material is smaller than No. 200 sieve size.)		
Gravels More than 50% of coarse fraction larger than N.4 sieve size	Clean Gravels (Less than 5% fines)		**SILTS AND CLAYS** Liquid limit less than 50%	ML	Inorganic silts and very fine sands, rock flour, silty of clayey of clayey fine sands or clayey silts with slight plasticity
	GW	Well-graded gravels, gravel-sand mixtures, little or no fines		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
	GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines		OL	Organic silts and organic silty clays of low plasticity
	Gravels with fines (more than 12% fines)		**SILTS AND CLAYS** Liquid limit 50% or greater	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
	GM	Silty gravels, gravel-sand-silt mixtures		CH	Inorganic clays of high plasticity, fats clays
	GC	Clayey gravels, gravel-sand-clay mixtures		OH	Organic clays of medium to high plasticity, organic silts
Sands More than 50% of coarse fraction larger than N.4 sieve size	Clean Sands (Less than 5% fines)		**HIGHLY ORGANIC SOILS**	PT	Peat and other highly organic soils
	SW	Well-graded sands, gravelly sands, little or no fines	Determine percentages of sand and Gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows:		
	SP	Poorly-graded sands, gravelly sands, little or no fines			
	Sands with fines (More than 12% fines)		Less than 5 percent ..... GW, GP, SW, SP More than 12 percent ..... GM, GC, SM, SC 5 to 12 percent ..... Borderline cases requiring dual symbols		
	SM	Silty sands, sand-silt mixtures			
	SC	Clayey sands, sand-clay mixtures			

Minor Components

Description	Criteria
20 – 30%	some
10 – 20%	little
1 – 10%	trace

Infilling

Description	Symbol
Clay	CL
Silt	ML
Sand	SD
Calcite	CA
Carbonate	C
Dolomite	DO
Gypsum/Tale	GY
Hematite	HE
Limonite	L
Quartz	QZ
Chlorite	CH
Pyrite	PY
Iron Oxide Staining	FE
Stylolite	ST
Not Determined	X
None	N
Healed	H

Weathering of Rock Mass

Description	Symbol	Criteria	Grade
Fresh (Unweathered)	FR	No visible sign of rock material weathering, except slight discoloration on major discontinuity surfaces.	I
Slightly Weathered	SL	Discoloration indicates weathering of rock material and discontinuity surfaces. All rock material may be discolored by weathering and may be somewhat weaker than externally than in its fresh condition.	II
Moderately Weathered	M	Less than half of the rock material is decomposed and/or disintegrated to soil. Fresh or discolored rock is present either as a continuous framework or as corestones.	III
Highly Weathered	H	More than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a discontinuous framework or as corestones.	IV
Completely Weathered	C	All rock material is decomposed and/or disintegrated to soil. The original mass structure remains largely intact.	V
Residual Soil	RS	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.	VI

Discontinuity Spacing

Description	Symbol	Spacing (in.)
Extremely Close	EC	< 0.75
Very Close	VC	0.75 – 2.5
Close	C	2.5 – 8.0
Moderate	M	8 – 24
Wide	W	24 – 80
Very Wide	VW	80 – 24
Extremely Wide	EW	> 240

Spacing Type

Description	Symbol	Spacing (in.)
Joint	J	A natural fracture along which no displacement has occurred. May occur in parallel groups called sets.
Shear	S	A natural fracture along which differential movement has occurred. May be slickensided or striated.
Fault	F	A natural fracture along which displacement has occurred. Usually lined with gouge and slickensides.
Vein	V	A thin, sheet-like igneous intrusion into a fissure.
Bedding Joint	B	Joints that occur along bedding planes.
Foliation Joint	FJ	Joints that occur parallel to the foliation of a rock mass.
Shear Zone	SZ	Zone of fractured rock and gouge bordering the displacement plane.

Field Strength*

Description	Criteria	Grade	Approx. Range of Uniaxial Compressive Strength (psi)
Extremely Weak	Indented by thumbnail.	R0	40 – 150
Very Weak	Crumbles under firm blows with point of geological hammer, can be peeled by a pocket knife.	R1	150 – 700
Weak	Can be peeled by a pocket knife with difficulty, shallow indentations made by firm blow with point of geological hammer.	R2	700 – 4,000
Medium Strong	Cannot be scraped or peeled with a pocket knife, specimen can be fractured with single firm blow of geological hammer.	R3	4,000 – 7,000
Strong	Specimen requires more than one blow of geological hammer to fracture it.	R4	7,000 – 15,000
Very Strong	Specimen requires many blows of geological hammer to fracture it.	R5	15,000 – 36,000
Extremely Strong	Specimen can only be chipped with geological hammer.	R6	>36,000

Roughness

Intermediate Scale	Symbol	Small Scale	Symbol
Stepped	S	Rough	R
Undulating	U	Smooth	Sm
Planar	P	Slickensided	K
Not Determined	X	Wavy	Wa
		Not Determined	X

Weathering/Alteration of Discontinuity Surfaces

Description	Symbol	Criteria
Fresh	FR	No visible sign of weathering on the rock discontinuity surfaces.
Discolored	DS	Discoloration of rock material discontinuity surfaces. Degree of discoloration and specific discolored mineral constituents (if applicable) indicated.
Disintegrated	DG	Discontinuity surface rock material is weathered to a soil with the rock material fabric intact. Rock material is friable, but the mineral grains are not decomposed.
Decomposed	DE	Discontinuity surface rock material is weathered to a soil with the rock material fabric intact and with some or all mineral grains decomposed.

Aperture

Description	Symbol	Aperture (in.)	
Very Tight	VT	< 0.004	"Closed" Features
Tight*	T	0.004 – 0.010	
Partly Open	PO	0.01 – 0.02	
Open**	O	0.02 – 0.10	"Gapped" Features
Moderately Wide	MW	0.1 – 0.4	
Wide	W	> 0.4	
Very Wide	VW	0.4 – 4.0	"Open" Features
Extremely Wide	EW	4.0 – 40.0	
Cavernous	CA	> 40	

*Note: The Uniaxial Compressive Strength ranges are approximate; therefore, a geotechnical engineer should be consulted for verification of rock strength.

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BOREHOLE LOG GRAPHIC LEGEND

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Wick Creek, Stockton, NJ	**Project Manager:**	Vatsal Shah
Client:	PennEast Pipeline	**Project Director:**	Michael Wilcox

Soil Log Graphic Legend


CL: USCS Low Plasticity Clay


DECOMPOSED ROCK: Decomposed Rock


GM: USCS Silty Gravel


ML: USCS Silt


SM: USCS Silty Sand


TOPSOiL: Topsoil

Rock Log Graphic Legend


MUDSTONE - Mudstone


SANDSTONE - Sandstone


SHALE - Shale


SILTSTONE - Siltstone

▽ Ground Water Level
(Note that due to drilling process disturbance the ground water levels obtained during drilling are not as representative as those obtained from monitoring wells)

This legend reports all soil and rock graphics which have been used in the logs of this project only.

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SOIL BORING LOG

BORING NO.: **B-54**
Page 1 of 2

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Wick Creek, Stockton, NJ	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Thileepan Rajah/ Kyle Hansen
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	March 28, 2019 at 12:40 pm
Driller/Helper:	Nick Beehler /Miles Neipert	**Date/Time Finished:**	April 1, 2019 at 2:30 pm

Elevation: 303 ft. **Vertical Datum:** NAVD 1988

Boring Location: Adjacent to powerline ROW approx. 550' southeast of Rosemont - Ringoes Road

Coord.: N: **40.43553** E: **-74.97302**

Horizontal Datum: NAD 1983

Item	Casing	Sampler	Core Barrel
Type	HW	SS	NQ2
Length (ft)	5	2	5
Inside Dia. (in.)	4	1.375	2.0
Hammer Wt. (lb.)	140	140	-
Hammer Fall (in.)	30	30	-

Rig Make & Model: CME-55LC

☐ Truck ☐ Tripod ☐ Cat-Head
☐ ATV ☐ Geoprobe ☑ Winch
☑ Track ☐ Air Track ☑ Roller Bit
☐ Skid ☐ ☐ Cutting Head

Hammer Type
☐ Safety
☐ Doughnut
☑ Automatic
☐

Drilling Fluid
☐ Bentonite
☐ Polymer
☑ Water
☐ None

Drill Rod Size:
Casing Advance
Mud Rotary

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Group Symbol	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
300	S-1 0.0'- 2.0'	14	2 3 3 5		ML	Medium stiff, reddish brown SILT, trace Clay, dry (ML)	-	-	-	-	
						3.5					
5	S-2 5.0'- 7.0'	14	11 10 11 10		SM	Medium dense, dark brown Silty medium to fine SAND, moist (SM)	-	-	-	-	Installed 4 inch Casing at 5 feet BGS
10	S-3 10.0'- 12.0'	16	13 17 15 17		SM	Dense, dark brown Silty medium to fine SAND, trace fine Gravel, moist (SM)	-	-	-	-	
290						13.5					
15	S-4 15.0'- 17.0'	12	8 12 13 16			Dense, reddish brown DECOMPOSED ROCK with Silt, moist	-	-	-	-	Installed 4-inch casing at 15 feet BGS

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water

Sample Type

O Open End Rod
T Thin-Wall Tube
U Undisturbed Sample
S Split Spoon Sample
G Grab Sample

Notes:
PP = Pocket Penetrometer
TV = Torvane

Boring No.: **B-54**

Field Test Legend: Dilatancy: N - None S - Slow R - Rapid; Toughness: L - Low M - Medium H - High; Plasticity: NP - Non-Plastic L - Low M - Medium H - High; Dry Strength: N - None L - Low M - Medium H - High VH - Very High

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

MOTT MACDONALD M M

SOIL BORING LOG
(continued)

BORING NO.: B-54

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Symbol Group	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
	S-5 20.0'-22.0'	20	25 17 24 30			Dense, reddish brown DECOMPOSED ROCK, trace Silt, dry	-	-	-	-	
280											
25	S-6 25.0'-27.0'	11	28 50/5"			Very dense, reddish brown DECOMPOSED ROCK fragments, dry	-	-	-	-	
						30.0					
30											
270											
35											
40											
260											
45											

NOTES: PP = Pocket Penetrometer
TV = Torvane

PROJECT NO.: 353754

BORING NO.: B-54

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

MOTT MACDONALD M M

CORE BORING LOG

BORING NO.: **B-54**

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Wick Creek, Stockton, NJ	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Thileepan Rajah/ Kyle Hansen
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	March 28, 2019 at 12:40 pm
Driller/Helper:	Nick Beehler /Miles Neipert	**Date/Time Finished:**	April 1, 2019 at 2:30 pm

Elevation: 303 ft. **Vertical Datum:** NAVD 1988

Item	Casing	Core Barrel	Core Bit
Type	HW	NQ2	Imp. Diamond
Length (ft)	5	5	3.25
Inside Dia. (in.)	4	2.0	2.0

Boring Location: Adjacent to powerline ROW approx. 550' southeast of Rosemont - Ringoes Road

Horizontal Datum: NAD 1983

Rig Make & Model: CME-55LC

Coord.: N: **40.43553** E: **-74.97302**

Drilling Method: Wireline

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec (in. / %)	RQD (in / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
									SEE TEST BORING LOG FOR OVERBURDEN DETAILS								
	1.67	30.0							SILTSTONE, reddish brown, fine grained, highly weathered, very weak, closely spaced discontinuities 30'-35' Fractured zone								Installed 20 feet of Casing
	1.58																
	1.83		R-1	59 98%	4 7%	R1	H										
270	3.33																
	4.13	35.0															
35	7.5	35.0							SILTSTONE, reddish brown, fine grained, highly weathered, very weak, very close spaced discontinuities 35' - 36.2' Fractured zone								Low water return 35 feet BGS No water return 35.75 to 40 feet BGS
	5.9																
	5.1		R-2	15 25%	0 0%	R1	H										
	5																
	4.8	40.0															
40	3.75	40.0							SILTSTONE, reddish brown, fine grained, moderately weathered, very weak, very close to close spaced discontinuities 40' - 41.9' Fractured zone								No water return 40 to 45 feet BGS
	2.7																
	2.6		R-3	60 100%	13 22%	R1	M		42.65' - 45' Fractured zone								
260	3																
	2.9	45.0															
45	3.4	45.0							SILTSTONE, reddish brown, fine grained, moderately weathered, weak, very close to close spaced discontinuities 45' - 46.3' Highly fractured zone								
	3.1									46.45	J	50	P,R	FR	PO	N	
	1.7		R-4	56 93%	17 28%	R2	M			47.00	J	20	P,R	FR	PO	N	
	2									48.60	J	25	P,Sm	FR	PO	N	
	1.6	50.0															

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water

Notes:

CORE BORING LOG
(continued)

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	1.5	50.0							SILTSTONE, reddish brown, fine grained, slightly weathered, medium strong, very close to moderate spaced discontinuities								
										50.90	J	25	P,R	FR	PO	N	
	2									51.50	J	20	P,Sm	FR	PO	N	
	1.9		R-5	57 95%	37 62%	R3	SL		51.95' - 54.4' Sub-vertical fracture								
250	1.6																
	2.3	55.0															
55	1.3	55.0							SILTSTONE, reddish brown, very fine to fine grained, slightly weathered, medium strong, very close to moderate spaced discontinuities								
										55.83	J	20	P,R	FR	PO	N	
	1.4									56.35	J	15	P,Sm	FR	T	N	
										56.82	J	10	P,Sm	FR	T	N	
	2		R-6	57 95%	37 62%	R3	SL		57.4' - 58.15' Fractured zone								
	1.3																
										58.90	J	10	P,Sm	FR	PO	N	
	2.2	60.0															
60	1.9	60.0							SILTSTONE, reddish brown, fine grained, slightly weathered, strong, very close to moderate spaced discontinuities								
										60.68	J	20	P,Sm	FR	T	N	
	1.4									61.35	J	20	P,Sm	FR	T	N	
	1.5		R-7	60 100%	13 22%	R3	SL		62' - 62.75' Sub-vertical fracture 62.75' - 68.12' Fractured zone								
240	1.5																
	2.4	65.0															
65	1.3	65.0							SILTSTONE, reddish brown, fine grained, slightly weathered, medium strong, very close to close spaced discontinuities 65' - 66.8' Fractured zone								
	2.2									66.80	J	15	P,Sm	FR	O	N	
	2.5		R-8	57 95%	16 27%	R3	SL		67.35' - 68.12' Fractured zone	67.35	J	10	U,R	FR	O	N	
	3.3									68.47	J	15	P,R	FR	PO	N	
	2.6	70.0								69.27	J	10	P,Sm	FR	PO	N	
70	1.7	70.0							SILTSTONE, reddish brown, fine grained, slightly weathered, medium strong, very close to close spaced discontinuities	70.60	J	5	S,Sm	FR	PO	N	
	1.6																
										71.83	J	15	P,Sm	FR	PO	N	
	1.8		R-9	60 100%	25 42%	R3	SL										
230	1.9																
										73.70	J	15	P,Sm	FR	T	N	
	2	75.0								74.05	J	10	P,Sm	FR	T	N	

NOTES:

PROJECT NO.: 353754

Boring No.: B-54

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: **B-54**

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	1.4	75.0							SILTSTONE, reddish brown, fine grained, slightly weathered, medium strong, close to moderate spaced discontinuities								
	1.6									76.35	J	30	P,Sm	FR	T	N	
	1.9		R-10	60 100%	27 45%	R3	SL			76.90	J	35	P,R	FR	PO	N	
										77.20	J	10	P,Sm	FR	T	N	
	1.8									77.72	J	20	U,R	FR	T	N	
										77.95	J	45	P,R	FR	T	N	
	1.8	80.0								78.70	J	20	P,Sm	FR	T	N	
80										78.95	J	25	P,Sm	FR	T	N	
	1.5	80.0							SILTSTONE, reddish brown, fine grained, moderately weathered, weak, very close to close spaced discontinuities 80' - 81.8' Fractured zone								
	0.9																
	0.6		R-11	54 90%	6 10%	R2	M		81.8' - 82.4' Clay seam 82.4' - 84.45' Fractured zone								
220																	
	1.3									83.60	J	40	P,Sm	FR	PO	N	
	1.8	85.0															
85																	
	1.5	85.0							SILTSTONE, reddish brown, fine grained, slightly weathered, medium strong, very close to moderate spaced discontinuities 85.9' - 86.7' Fractured zone								
	2.7																
	2.3		R-12	56 93%	31 52%	R3	SL			86.70	J	30	P,Sm	FR	PO	N	
										87.50	J	25	P,R	FR	PO	N	
	1.4																
	1.8	90.0								88.88	J	40	P,Sm	FR	PO	N	
90																	
	2.1	90.0							SILTSTONE, reddish brown to gray, fine grained, slightly weathered, medium strong, very close to moderate spaced discontinuities 90.45' - 92.05' Fractured zone								
	1.2																
	1.5		R-13	60 100%	27 45%	R3	SL		92.55' - 93.5' Fractured zone								
210																	
	1.6									93.50	J	10	P,Sm	FR	PO	N	
	1.8	95.0															
95																	
	1	95.0							SILTSTONE, reddish brown to gray, fine grained, slightly weathered, medium strong, very close to moderate spaced discontinuities								
	1.1									95.87	J	40	P,R	FR	T	N	
	1.7		R-14	60 100%	42 70%	R3	SL			96.80	J	15	P,R	FR	PO	N	
										97.83	J	15	P,Sm	FR	PO	N	
	2.2																
	1.9	100.0							100.0								

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-54**

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: **B-54**

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
200									End of boring at 100 feet BGS Borehole grouted with cement and bentonite holeplug.								
105																	
110																	
190																	
115																	
120																	
180																	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-54**

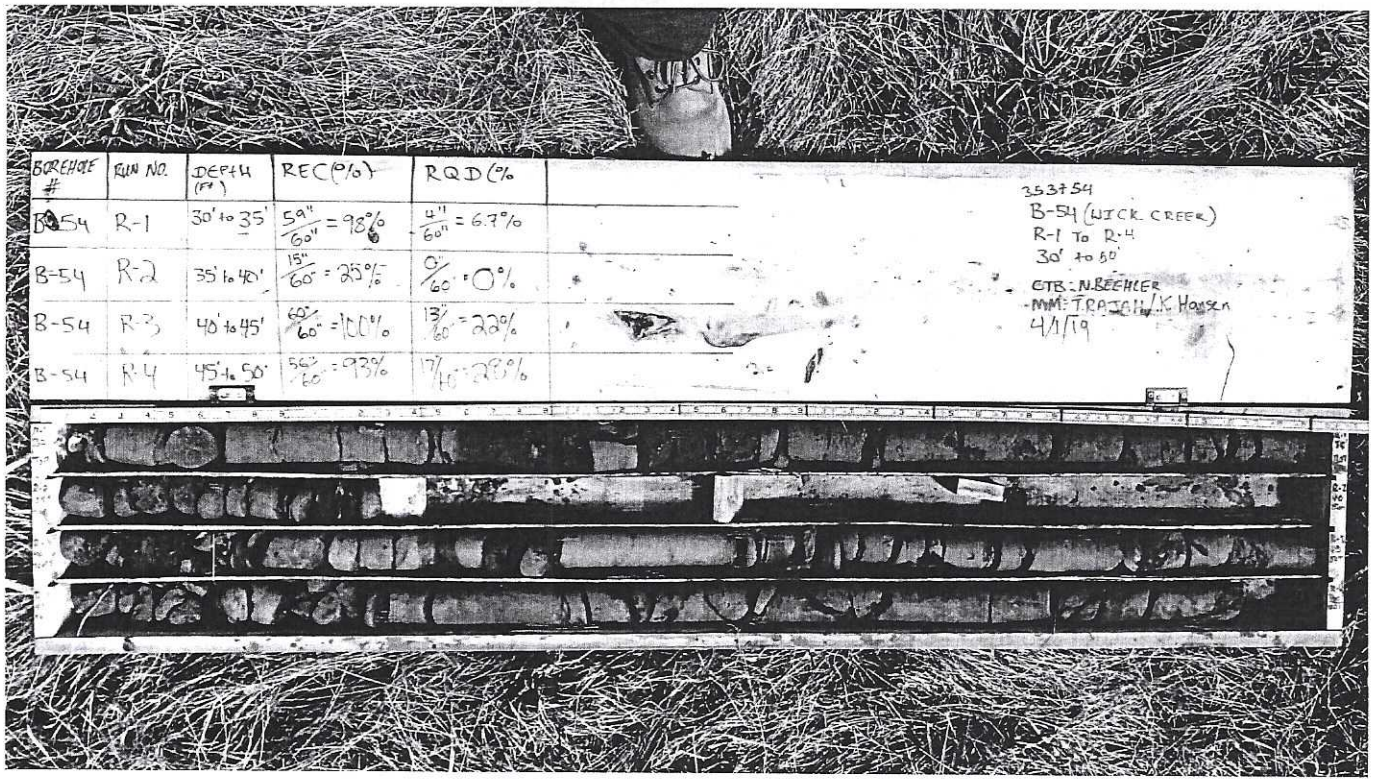

Figure B-54.1
B-54 Box 1 Runs 1-4 Dry

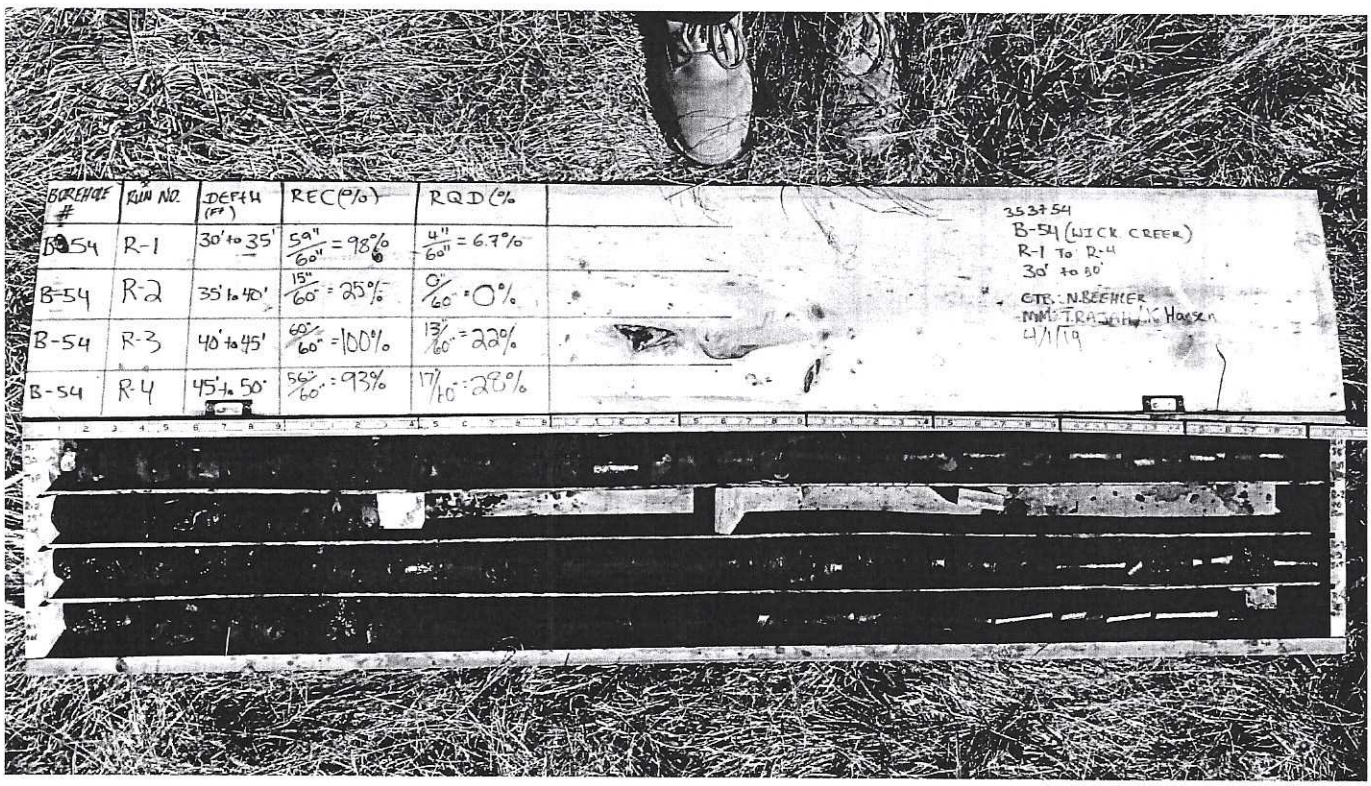

Figure B-54.2
B-54 Box 1 Runs 1-4 Wet

MOTT MACDONALD	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-54

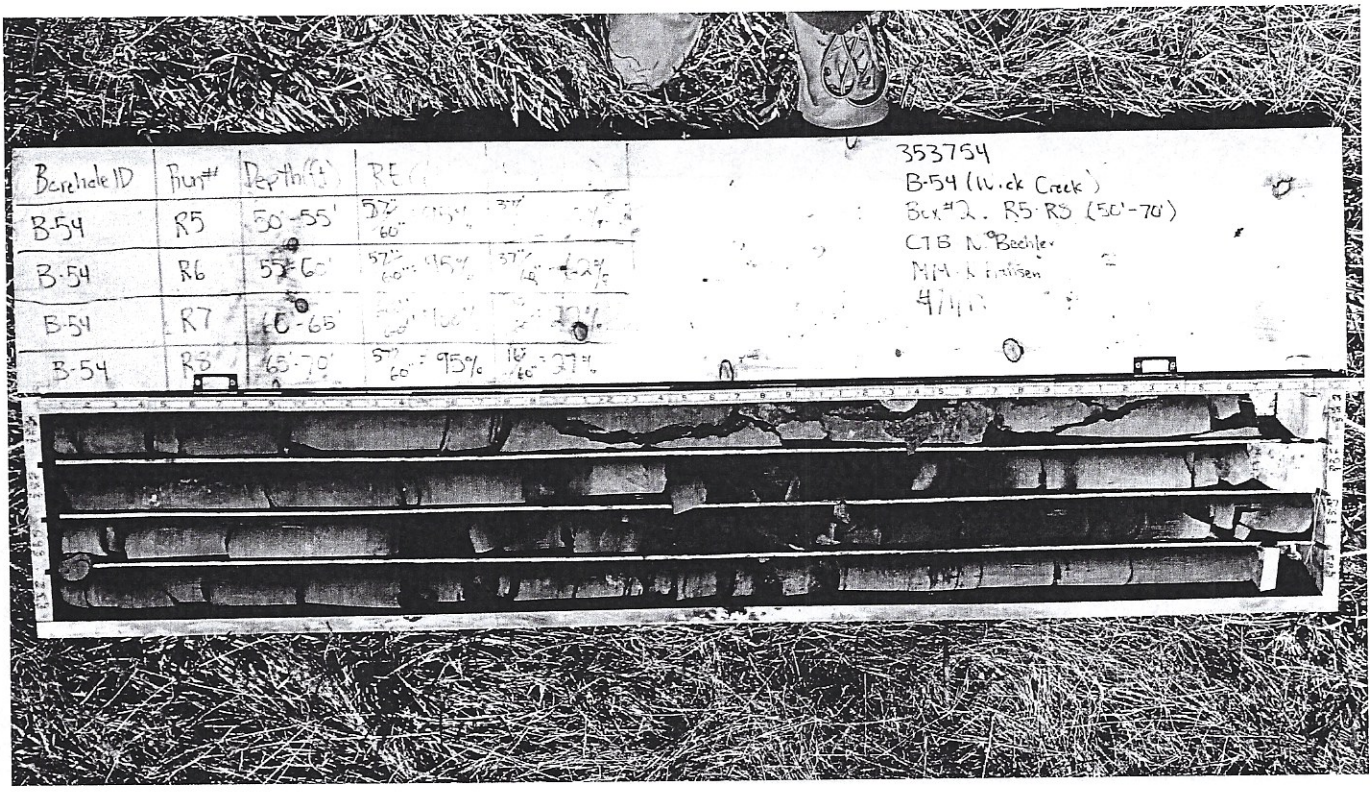

Figure B-54.3
B-54 Box 2 Runs 5-8 Dry

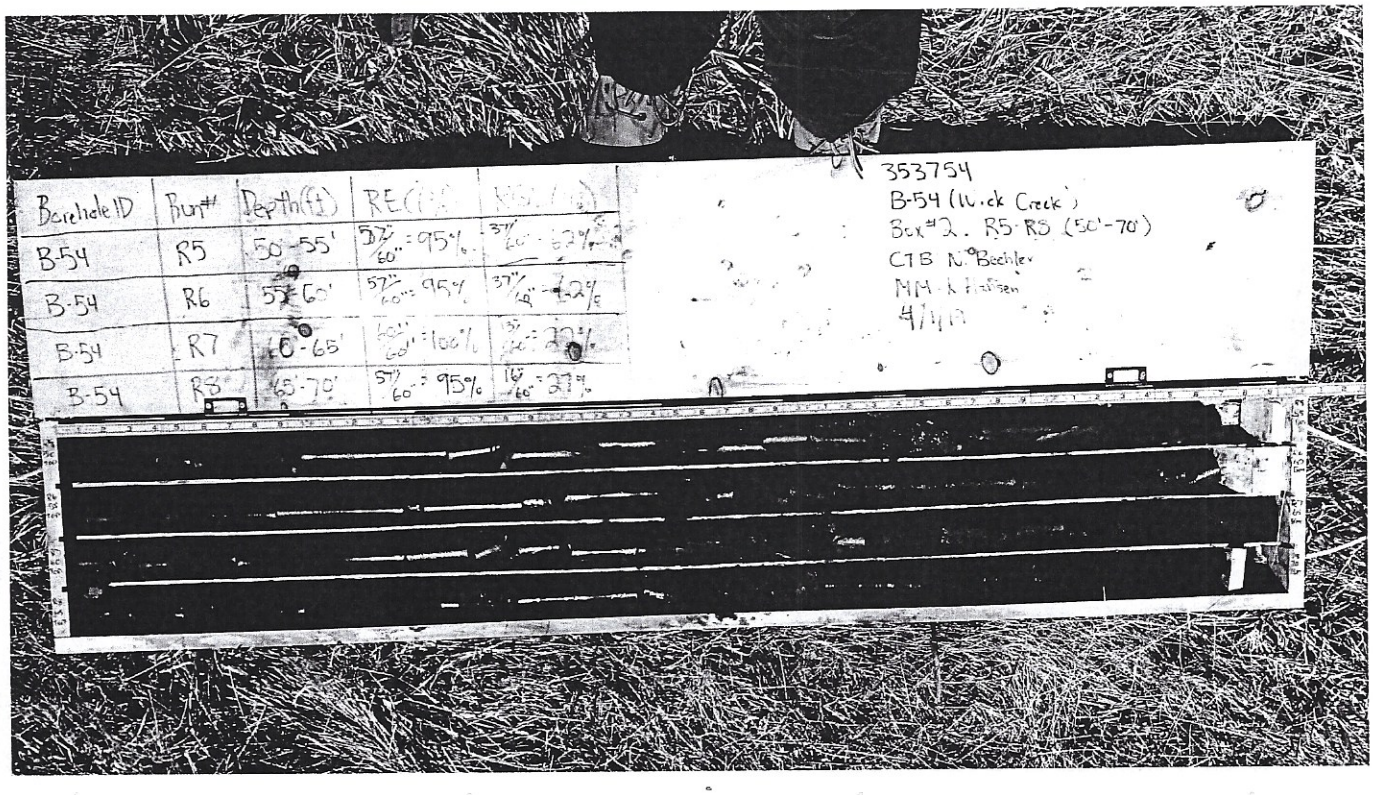

Figure B-54.4
B-54 Box 2 Runs 5-8 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-54

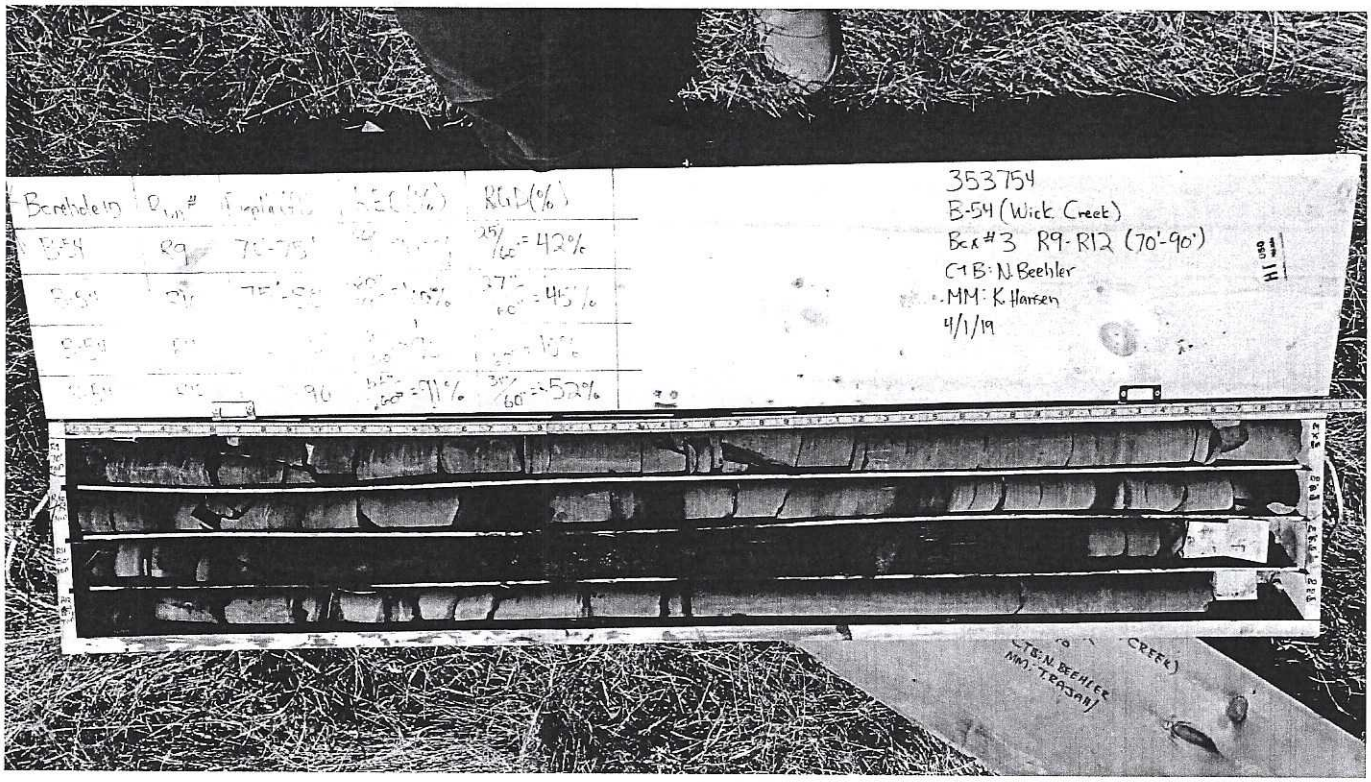

Figure B-54.5
B-54 Box 3 Runs 9-12 Dry

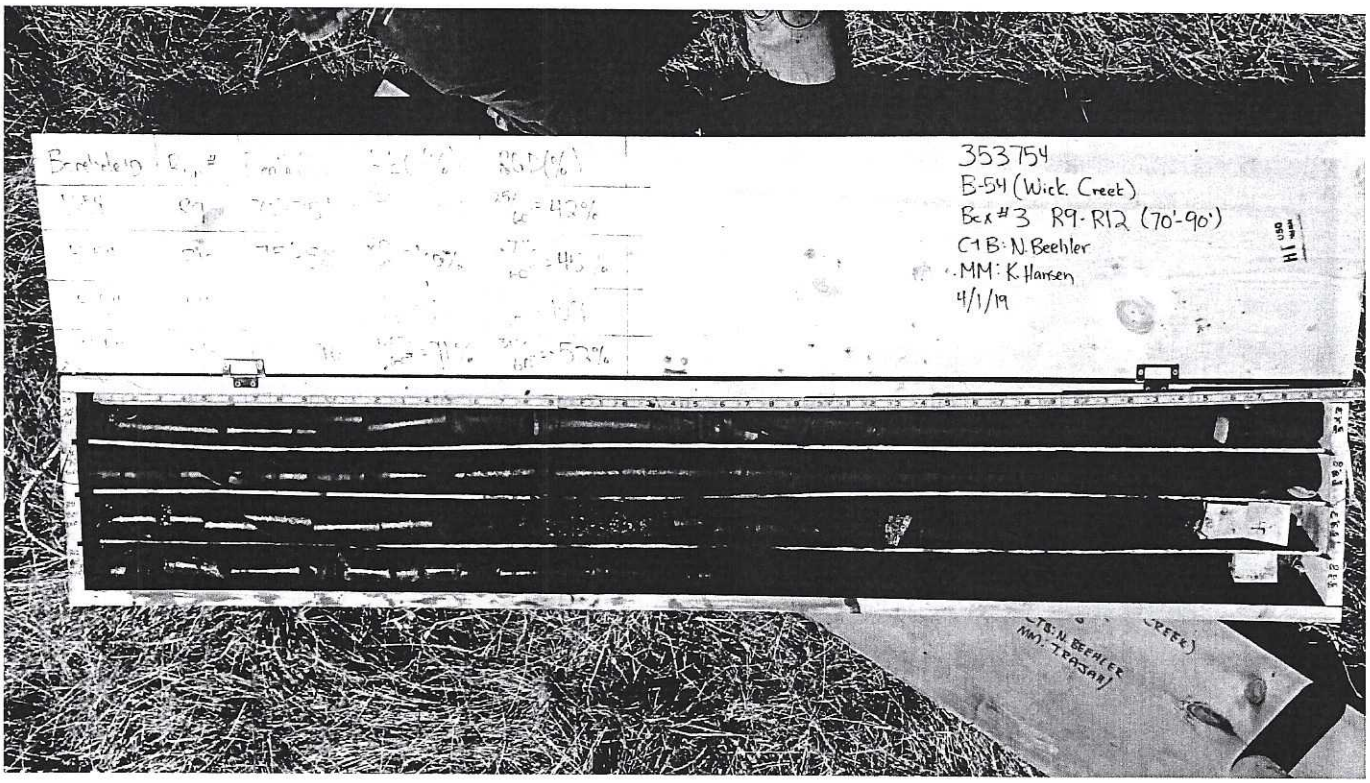

Figure B-54.6
B-54 Box 3 Runs 9-12 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-54

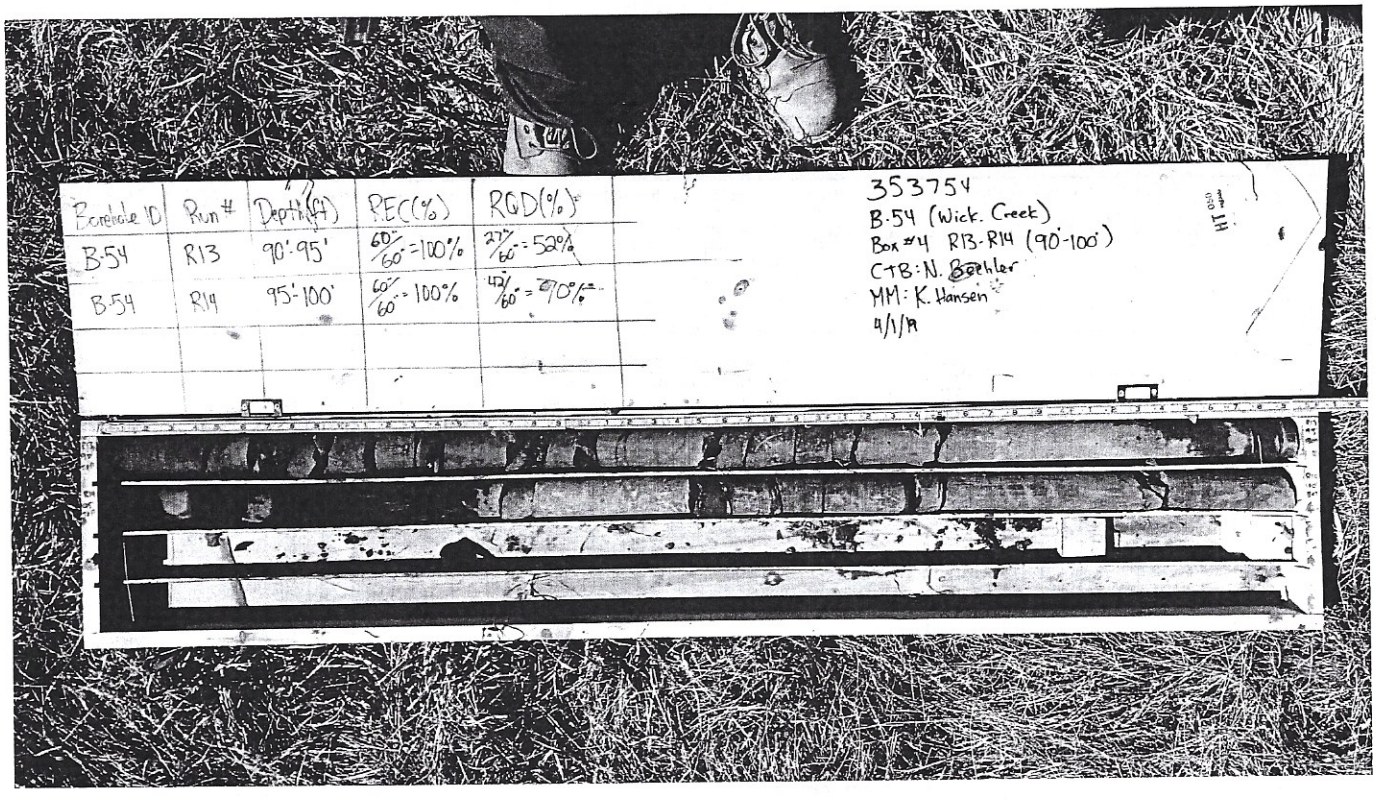

Figure B-54.7
B-54 Box 4 Runs 13-14 Dry

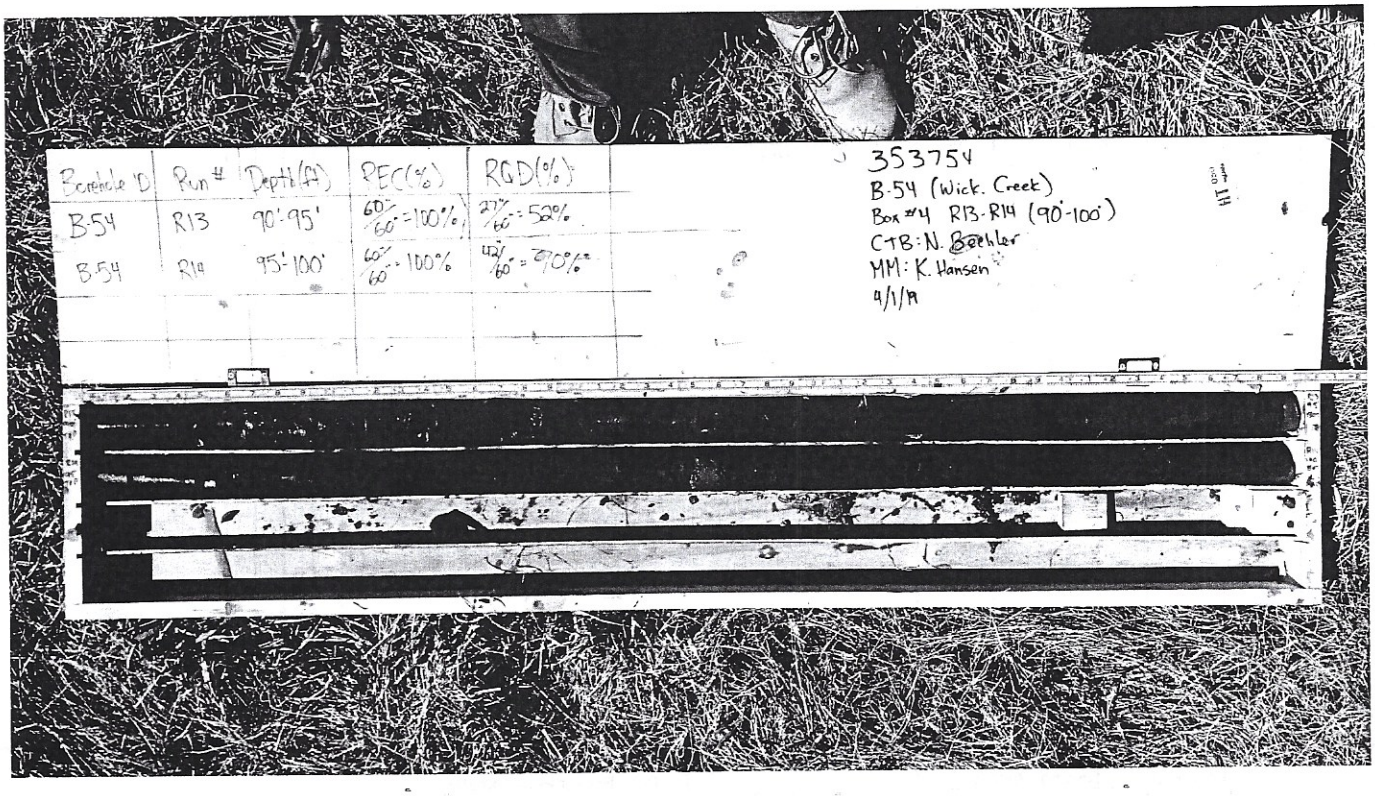

Figure B-54.8
B-54 Box 4 Runs 13-14 Wet

MOTT MACDONALD	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-54

MOTT MACDONALD M M

SOIL BORING LOG

BORING NO.: **B-55**
Page 1 of 1

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Wick Creek, Stockton, NJ	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Kyle Hansen
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	April 2, 2019 at 12:00 pm
Driller/Helper:	Nick Beehler /Miles Neipert	**Date/Time Finished:**	April 4, 2019 at 5:00 pm

Elevation: 261 ft. **Vertical Datum:** NAVD 1988

Boring Location: Adjacent to powerline ROW approx. 1100' southeast of Rosemont - Ringoes Road

Coord.: N: **40.434275** E: **-74.971819**
Horizontal Datum: NAD 1983

Item	Casing	Sampler	Core Barrel
Type	HW	SS	NQ2
Length (ft)	5	2	5
Inside Dia. (in.)	4	1.375	2.0
Hammer Wt. (lb.)	140	140	-
Hammer Fall (in.)	30	30	-

Rig Make & Model: CME-55LC

☐ Truck ☐ Tripod ☐ Cat-Head
☐ ATV ☐ Geoprobe ☑ Winch
☑ Track ☐ Air Track ☑ Roller Bit
☐ Skid ☐ ☐ Cutting Head

Hammer Type: ☐ Safety ☐ Doughnut ☑ Automatic ☐

Drilling Fluid: ☐ Bentonite ☐ Polymer ☑ Water ☐ None

Drill Rod Size:

Casing Advance: Mud Rotary

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Group Symbol	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
260	S-1 0.0'- 2.0'	19	2 4 12 12		ML	Very stiff, reddish brown SILT, trace coarse to fine Sand, moist (ML)	S	L	NP	L	PP = 4.0 tsf
5	S-2 5.0'- 7.0'	14	6 4 5 7		ML	Stiff, reddish brown SILT, with coarse to fine Sand, trace coarse to fine Gravel, moist (ML)	S	L	NP	L	PP = 1.0 tsf
10 250	S-3 10.0'- 12.0'	16	49 56 64 87		ML	Hard, reddish brown SILT, with coarse to fine Sand, trace coarse to fine Gravel, moist (ML)	-	-	-	-	
						13.5					
15	S-4 15.0'- 17.0'	9	60 50/3"			Very dense, reddish brown DECOMPOSED ROCK fragments, moist	-	-	-	-	
						16.0					

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
4/3/19	8:30	-	4.0	25.0	16.1
4/4/19	8:30	-	4.0	90.0	16.9
4/5/19	9:00	-	4.0	220.0	19.45

Sample Type

O Open End Rod
T Thin-Wall Tube
U Undisturbed Sample
S Split Spoon Sample
G Grab Sample

Notes:

PP = Pocket Penetrometer
TV = Torvane

Boring No.: **B-55**

Field Test Legend: Dilatancy: N - None S - Slow R - Rapid
Toughness: L - Low M - Medium H - High
Plasticity: NP - Non-Plastic L - Low M - Medium H - High
Dry Strength: N - None L - Low M - Medium H - High VH - Very High

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

MOTT MACDONALD M M

CORE BORING LOG

BORING NO.: **B-55**
Page 1 of 9

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Wick Creek, Stockton, NJ	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Kyle Hansen
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	April 2, 2019 at 12:00 pm
Driller/Helper:	Nick Beehler /Miles Neipert	**Date/Time Finished:**	April 4, 2019 at 5:00 pm

Elevation: 261 ft. **Vertical Datum:** NAVD 1988

Item	Casing	Core Barrel	Core Bit
Type	HW	NQ2	Imp. Diamond
Length (ft)	5	5	3.25
Inside Dia. (in.)	4	2.0	2.0

Boring Location: Adjacent to powerline ROW approx. 1100' southeast of Rosemont - Ringoes Road
Horizontal Datum: NAD 1983
Rig Make & Model: CME-55LC

Coord.: N: **40.434275** E: **-74.971819**
Drilling Method: Wireline

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec (in. / %)	RQD (in / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
									SEE TEST BORING LOG FOR OVERBURDEN DETAILS								
	2.6	16.0							SILTSTONE, reddish brown, fine grained, highly weathered, weak, very close to close spaced discontinuities 16' - 20' Fractured zone								
	1.8		R-1	48 100%	0 0%	R2	H										
	2																
	3.6	20.0															
20	3.5	20.0							SILTSTONE, reddish brown, fine grained, moderately weathered, weak, extremely close to close spaced discontinuities 20' - 22.35' Fractured zone								
240	4.5																
	1.8		R-2	59 98%	15 25%	R2	M			22.85	J	35	P,R	DG	T	N	
	1.5									23.20	J	30	P,R	DG	PO	N	
										23.65	J	20	P,Sm	FR	PO	N	
	1.1	25.0								24.07	J	25	U,R	DG	O	N	
25	4.4	25.0							24.7' - 25' Fractured zone SILTSTONE, reddish brown, fine grained, highly weathered, weak, very close to close spaced discontinuities 25' - 25.6' Highly weathered Clay seam 25.6' - 28.9' Fractured zone								No water return 29.5 to 30 feet BGS
	4.9																
	5.7		R-3	59 98%	16 27%	R2	H			28.75	J	25	P,R	FR	O	N	
	5.6									29.35	J	45	P,R	FR	PO	N	
	17.1	30.0															
30	2.4	30.0							SILTSTONE, reddish brown, fine grained, moderately weathered, weak, very close to close spaced discontinuities 30.75' - 31.68' Highly fractured zone								
230	2																
	1.4		R-4	59 98%	27 45%	R2	M			32.30	J	30	P,Sm	FR	PO	N	
	1.7								32.8' - 34.3' Highly fractured zone	32.84	J	15	P,R	FR	PO	N	
	1.4	35.0															
35	2.1	35.0							SILTSTONE, reddish brown, fine grained, slightly weathered, medium strong, very close to moderate spaced discontinuities Calcareous inclusions throughout								

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
4/3/19	8:30	-	4.0	25.0	16.1
4/4/19	8:30	-	4.0	90.0	16.9
4/5/19	9:00	-	4.0	220.0	19.5

Notes:

CORE BORING LOG
(continued)

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	2.3									36.55	J	20	U,R	FR	PO	N	
	2.2		R-5	60 100%	36 60%	R3	SL			37.00	J	15	U,R	FR	O	N	
	1.9																
	2.4	40.0								38.68	J	10	U,R	FR	PO	N	
40										39.50	J	40	U,R	FR	PO	N	
	1.8	40.0							SILTSTONE, reddish brown, fine grained, slightly weathered, medium strong, close to moderate spaced discontinuities Calcareous inclusions throughout								
220										41.10	J	20	P,R	FR	T	N	
	2.2									41.45	J	15	P,Sm	FR	PO	N	
	1.6		R-6	60 100%	37 62%	R3	SL										
	1.8									43.13	J	35	P,Sm	FR	T	N	
	1.7	45.0								44.25	J	15	U,R	FR	PO	N	
45																	
	2.6	45.0							SILTSTONE, reddish brown, fine to very fine grained, slightly weathered, medium strong, very close to moderate spaced discontinuities Calcareous inclusions throughout								
	3.5									46.10	J	25	P,Sm	FR	T	N	
	3.8		R-7	59 98%	40 67%	R3	SL			46.70	J	15	P,R	DS	PO	N	
	3.6									47.55	J	40	P,R	FR	PO	N	
	4.3	50.0								47.97	J	50	P,R	FR	O	N	
50										49.30	J	20	P,Sm	FR	PO	N	
	3.5	50.0							SILTSTONE, reddish brown, fine grained, fresh, medium strong, close to moderate spaced discontinuities Calcareous inclusions throughout								
210										50.88	J	10	U,R	FR	T	N	
	3.6									51.55	J	60	P,R	FR	T	N	
	3.8		R-8	59 98%	53 88%	R3	FR										
	3.7									53.20	J	40	P,Sm	DS	PO	N	
	4.1	55.0								54.38	J	50	U,R	FR	PO	N	
55																	
	3.3	55.0							SILTSTONE, reddish brown, very fine grained, moderately weathered, medium strong, very close to close spaced discontinuities 55.55' - 56.15' Highly fractured zone								
	3.6																
	3.4		R-9	50 83%	14 23%	R3	M			57.35	J	45	P,R	FR	PO	N	
	6.5								57.7' - 58.4' Highly fractured zone								
	5.9	60.0															
60																	
	3.1	60.0							SILTSTONE, reddish brown to gray, very fine grained, slightly weathered, medium strong, extremely close to close spaced discontinuities Calcareous inclusions throughout	60.58	J	20	P,Sm	FR	T	N	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-55**

CORE BORING LOG
(continued)

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
200	3.3									61.08	J	20	P,Sm	FR	T	N	
	2.9		R-10	51 85%	28 47%	R3	SL		61.75' - 63.2' Highly fractured zone	61.75	J	20	P,R	FR	PO	N	Short loss of water return at 62.5 feet BGS
	5.6								63.2' - 63.8' Sub-vertical fracture	63.50	J	75	P,R	FR	PO	N	
	2	65.0							65.0								
65	1.5	65.0							SHALE, gray, very fine grained, fresh, medium strong, very close to moderate spaced discontinuities								Water color change from reddish brown to gray at 66.5' BGS
	1.8									66.14	J	20	P,Sm	DS	PO	Fe	
	1.6		R-11	54 90%	46 77%	R3	FR			67.20	J	35	U,Sm	FR	PO	N	
	1.8									67.95	J	20	P,Sm	FR	PO	N	
									68.35' - 69.25' Sub-vertical fracture	68.38	J	25	P,R	DS	PO	Fe	No water return 69.5 to 70 feet BGS
	3.2	70.0								69.00	J	20	P,Sm	DS	PO	Fe	
70	2.6	70.0							SHALE, gray, very fine grained, slightly weathered, medium strong, very close to moderate spaced discontinuities 70.5' - 71.85' Fractured zone								
190	2.5																
	1.7		R-12	60 100%	32 53%	R3	SL			71.85	J	25	P,Sm	FR	O	N	
									72.75' - 73.25 Fractured zone	73.27	J	30	P,Sm	FR	PO	N	
	1.5									73.80	J	60	P,R	DS	PO	Fe	
	2.5	75.0								74.30 74.54	J J	40 20	P,R P,R	DS DG	PO PO	Fe SD	
75	1.3	75.0							SANDSTONE, light brown, fine to medium grained, slightly weathered, medium strong, close spaced discontinuities								
	1.2									76.27	J	5	U,R	FR	O	N	
										76.80	J	25	U,R	DS	PO	N	
	1.4		R-13	60 100%	46 77%	R3	SL			77.24	J	20	P,Sm	FR	T	N	
	1.5									78.67	J	10	P,R	DS	O	Fe	
	1.9	80.0								79.12	J	15	P,Sm	DG	O	CL	
80	2	80.0							80.0 SILTSTONE, reddish brown, fine grained, slightly weathered, medium strong, very close to close spaced discontinuities								
180	1.8									81.24	J	15	U,Sm	FR	T	N	
										81.70	J	20	P,R	FR	T	N	
	1.8		R-14	60 100%	43 72%	R3	SL		82.4' - 83.45' Fractured zone	82.39	J	10	P,R	FR	PO	N	
	1.8									83.43	J	20	P,R	FR	O	N	
									84' - 85' Fractured zone								
	2	85.0															
85	2.3	85.0							SILTSTONE, reddish brown, fine grained, slightly weathered, medium strong, very close to moderate spaced discontinuities Calcareous inclusions throughout								Water color change to reddish brown at 85.5 feet BGS

NOTES:

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Boring No.: B-55

CORE BORING LOG
(continued)

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	2.5									86.00	J	20	P,Sm	FR	T	N	
										86.35	J	10	P,R	FR	PO	N	
	2.6		R-15	54 90%	34 57%	R3	SL			87.36	J	15	P,R	FR	PO	N	
										87.77	J	10	P,Sm	FR	PO	N	
	3.1									88.50	J	45	P,Sm	FR	T	N	
	2.8	90.0															
90	2.2	90.0							SILTSTONE, reddish brown, fine grained, slightly weathered, medium strong, very close to moderate spaced discontinuities								
170	1.1									91.26	J	25	P,Sm	FR	PO	N	
	1.4		R-16	60 100%	32 53%	R3	SL		92.28' - 92.42' Clay seam 92.6' - 92.7' Weathered Clay seam	91.90	J	25	P,Sm	FR	T	N	
	3.2									93.10	J	15	P,Sm	FR	T	N	
	2.1	95.0							94.2' - 95' Fractured zone	94.20	J	20	P,R	FR	PO	N	
95	2	95.0							SILTSTONE, reddish brown, fine grained, slightly weathered, medium strong, close to wide spaced discontinuities Calcareous inclusions throughout								
	1.2									96.24	J	10	P,Sm	FR	PO	N	
	1.2		R-17	60 100%	47 78%	R3	SL										
	2																
	2.4	100.0								98.83	J	15	U,Sm	FR	O	N	
100	1.5	100.0							99.62' - 100' Highly fractured zone SILTSTONE, reddish brown to gray, fine grained, slightly weathered, strong, very close to wide spaced discontinuities Calcareous inclusions throughout								
160	1.3									101.10	J	15	P,Sm	FR	T	N	
	1.5		R-18	60 100%	53 88%	R4	SL			101.74	J	15	P,Sm	FR	T	N	
	1.2																
	1.1	105.0								104.22	J	10	U,R	FR	PO	N	
105	1.1	105.0							105.0 ARGILLITE, grayish brown, fine grained, fresh, very strong, close to wide spaced discontinuities								
	1.1									105.81	J	20	P,Sm	FR	T	N	
	1.2		R-19	58 97%	49 82%	R5	FR			107.74	J	10	P,Sm	FR	T	N	
	0.9									108.12	J	10	U,R	FR	O	N	
	2.9	110.0															
110	1.4	110.0							ARGILLITE, grayish brown, fine grained, fresh, very strong, very close to moderate spaced discontinuities 110' - 110.7' Sub-vertical fracture	110.35	V	85	P,R	FR	PO	Ca	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-55**

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: B-55

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
150										110.93	J	10	P,Sm	FR	PO	N	
	0.9																
										111.90	J	20	P,R	FR	T	Ca	
	1.3		R-20	60 100%	53 88%	R5	FR			112.28	J	5	P,Sm	FR	T	N	
	1.1																
	1.4	115.0							114.05' - 114.33' Fractured zone	114.05	J	5	P,R	FR	PO	N	
115									ARGILLITE, reddish gray, fine grained, slightly weathered, strong, close to moderate spaced discontinuities								
	1	115.0								115.73	J	30	P,Sm	FR	T	N	
	1.2								116.5' - 116.98' Sub-vertical fracture	116.75	J	35	P,Sm	FR	PO	N	
	1		R-21	59 98%	52 87%	R4	SL			117.40	J	80	P,R	FR	PO	N	
										118.18	J	35	U,R	FR	PO	N	
	1									118.72	J	20	P,R	FR	PO	N	
	1	120.0							119.47' - 119.95' Fractured zone								
120									120.0 SILTSTONE, reddish gray to brown, fine grained, slightly weathered, strong, very close to moderate spaced discontinuities								
	1.5	120.0								120.65	J	40	P,R	FR	T	N	
140																	
	1.4									121.80	J	65	P,R	FR	PO	N	
										122.07	J	30	P,Sm	FR	T	N	
	1		R-22	60 100%	45 75%	R4	SL		122.85' - 124.8' Fractured zone with sub-vertical fractures								
	1																
	1.1	125.0															
125									SILTSTONE, reddish gray, fine grained, slightly weathered, strong, very close to moderate spaced discontinuities								
	1	125.0							125' - 126.3' Sub-vertical fracture	125.75	J	85	P,R	FR	T	N	
	1.1									126.40	J	10	P,R	FR	PO	N	
	1		R-23	60 100%	47 78%	R4	SL		127.85' - 128.35' Sub-vertical fracture	127.70	J	5	P,Sm	FR	PO	N	
	1.2																
	1.1	130.0							128.9' - 129.5' Sub-vertical fracture	128.90	J	20	P,Sm	FR	PO	N	
										129.20	J	75	P,R	FR	PO	N	
130									SILTSTONE, reddish gray, fine grained, fresh, strong, close to wide spaced discontinuities	130.04	J	10	P,R	FR	PO	N	
	1.3	130.0															
130	1.6																
	1		R-24	57 95%	47 78%	R4	FR			132.33	J	15	P,Sm	FR	O	N	
	0.9																
	1.2	135.0								134.38	J	10	U,R	FR	PO	N	
135									SILTSTONE, reddish gray, fine grained, slightly weathered, strong, very close to close spaced discontinuities								
	0.9	135.0							135.7' - 136.65' Sub-vertical fracture	135.60	J	20	P,Sm	FR	PO	N	

NOTES:

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CORE BORING LOG
(continued)

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	1																
	0.8		R-25	54 90%	27 45%	R4	SL		137.2' - 137.96' Highly fractured zone	136.70	J	15	P,R	FR	PO	N	
	0.9									138.46	J	20	P,Sm	FR	T	N	
	0.9	140.0															
140	0.7	140.0							SILTSTONE with interbedded Sandstone, reddish brown, fine grained, moderately weathered, medium strong, very close to moderate spaced discontinuities Calcareous inclusions throughout								
120	0.7								140' - 142.65' Fractured zone								
	0.6		R-26	52 87%	25 42%	R3	M			142.65	J	15	P,R	FR	PO	N	
	1.7									143.38	J	20	P,R	DG	O	CL	
	1.7	145.0															
145	2.1	145.0							SILTSTONE, reddish brown, very fine grained, fresh, strong, close to wide spaced discontinuities Calcareous inclusions throughout								
	1.8									145.58	J	10	P,Sm	FR	T	N	
	1.7		R-27	59 98%	56 93%	R4	FR										
	1.9																
	2	150.0															
150	2.1	150.0							SILTSTONE, reddish brown, very fine grained, fresh, strong, close to moderate spaced discontinuities Calcareous inclusions throughout	149.70	J	10	P,Sm	FR	PO	N	
110	2									150.75	J	25	P,Sm	FR	PO	N	
	1.4		R-28	60 100%	49 82%	R4	FR			151.95	J	15	U,R	FR	PO	N	
	2.5									153.30	J	30	P,R	DG	O	CL	
	2.2	155.0															
155	1.7	155.0							SILTSTONE, reddish brown, very fine grained, slightly weathered, strong, very close to close sapced discontinuities								
	2.4									155.77	J	15	U,R	FR	T	N	
	1.3		R-29	60 100%	33 55%	R4	FR		157' - 158.73' Fractured zone	156.40	J	10	P,Sm	FR	PO	N	
	0.9									157.00	J	5	U,Sm	FR	PO	N	
	1.3	160.0								159.00	J	45	U,R	FR	PO	N	
160	1.9	160.0							SILTSTONE, reddish brown, fine grained, fresh, strong, close to moderate spaced discontinuities Calcareous inclusions throughout	160.48	J	25	P,Sm	FR	PO	N	

CORE BORING LOG
(continued)

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
100	1.2									161.40	J	60	P,R	FR	PO	N	
	1.6		R-30	60 100%	52 87%	R4	FR										
	2									162.95	J	20	P,R	FR	PO	N	
	1.1	165.0								163.40	J	30	P,Sm	FR	T	N	
165	2.6	165.0							SILTSTONE, reddish brown, very fine grained, fresh, strong, close to wide spaced discontinuities	164.70	J	15	U,R	FR	PO	N	
	2.6									166.00	J	5	U,R	FR	PO	N	
	1.2		R-31	57 95%	54 90%	R4	FR			166.85	J	10	P,Sm	FR	PO	N	
	1.9																
	1.7	170.0								169.20	J	70	P,R	FR	PO	N	
170	0.9	170.0							SILTSTONE, reddish brown, very fine grained, slightly weathered, strong, close to moderate spaced discontinuities Calcareous inclusions throughout								
90	1.5									171.26	J	30	P,Sm	FR	T	N	
	1.2		R-32	60 100%	55 92%	R4	FR			172.75	J	15	P,Sm	FR	PO	N	
	1.7								173.2' - 173.58' Highly fractured zone								
	1.4	175.0								174.35	J	10	P,R	DG	PO	CL	
175	3.2	175.0							SILTSTONE, reddish brown, very fine grained, fresh, strong, close to moderate spaced discontinuities								
	3.4									176.06	J	10	P,Sm	FR	PO	N	
	3		R-33	58 97%	58 97%	R4	FR			177.70	J	20	P,Sm	FR	T	N	
	2.8									178.33	J	15	P,Sm	FR	PO	N	
	2.1	180.0								179.50	J	15	P,Sm	FR	T	N	
180	2.1	180.0							SILTSTONE, reddish brown, very fine grained, slightly weathered, medium strong, close to moderate spaced discontinuities Calcareous inclusions throughout								
80	1.6									181.10	J	35	P,Sm	FR	T	N	
	1.2		R-34	60 100%	45 75%	R3	SL			181.85	J	30	P,Sm	FR	PO	N	
										182.30	J	50	U,R	FR	PO	N	
										182.65	J	15	U,R	FR	T	N	
	2									183.15	J	30	P,Sm	FR	T	N	
	2	185.0								183.88	J	25	P,Sm	FR	PO	N	
185	2.6	185.0							SILTSTONE, reddish brown, very fine grained, slightly weathered, medium strong, very close to moderate spaced discontinuities	184.30	J	25	U,R	FR	PO	N	

CORE BORING LOG
(continued)

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	1.6								186.3' - 187' Fractured zone	186.25	J	15	U,R	FR	PO	N	
	2.3		R-35	59 98%	45 75%	R3	SL		187.5' - 187.8' Highly fractured zone	187.00	J	10	P,Sm	FR	PO	N	
	2.6									187.80	J	15	P,R	FR	O	N	
	2.9	190.0								188.40	J	15	P,R	FR	PO	N	
190	1.8	190.0							SILTSTONE, reddish brown, very fine grained, slightly weathered, strong, very close to moderate spaced discontinuities								
70	1.9									191.05	J	30	P,Sm	FR	O	N	
	3.1		R-36	60 100%	50 83%	R4	SL			192.48	J	5	P,Sm	FR	PO	N	
	2.3									193.64	J	40	P,Sm	FR	PO	N	
	2	195.0								193.90	J	5	P,Sm	FR	PO	N	
195	1.8	195.0							194.5' - 195' Highly fractured zone SILTSTONE, reddish brown, very fine grained, fresh, strong, close to wide spaced discontinuities	195.50	J	30	U,R	FR	PO	N	
	2																
	1.3		R-37	59 98%	48 80%	R4	FR										
	1.4																
	1.6	200.0								199.00	J	10	U,R	FR	PO	N	
200	1	200.0							SILTSTONE, reddish brown, very fine grained, fresh, strong, close to wide spaced discontinuities Calcareous inclusions throughout								
60	1.2									200.90	J	20	P,Sm	FR	T	N	
	1.3		R-38	59 98%	52 87%	R4	FR			201.25	J	10	P,Sm	FR	T	N	
	1.6									201.92	J	15	P,R	FR	T	N	
	1.5	205.0								203.72	J	20	P,R	FR	PO	N	
205	2	205.0							SILTSTONE, reddish brown, very fine grained, fresh, strong, close to wide spaced discontinuities Calcareous inclusions throughout	203.92	J	10	P,Sm	FR	PO	N	
	1.6																
	1.2		R-39	60 100%	54 90%	R4	FR			207.27	J	20	P,Sm	FR	PO	Ca	
	1.2									207.83	J	10	P,Sm	FR	PO	N	
	1.5	210.0								208.60	J	10	P,Sm	FR	PO	N	
210	1.6	210.0							SILTSTONE, reddish brown, very fine grained, fresh, strong, very close to moderate spaced discontinuities Calcareous inclusions throughout	209.24	J	10	P,R	FR	PO	N	
										210.55	J	30	P,Sm	FR	T	N	

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: B-55

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
50	1.2									211.46	J	20	P,Sm	FR	T	N	
										211.66	J	10	P,Sm	FR	T	N	
	1.7		R-40	60 100%	44 73%	R4	FR										
	1.5								213' - 213.25' Fractured zone	213.00	J	10	P,R	FR	PO	N	
	1	215.0								214.22	J	5	P,Sm	FR	T	N	
215		215.0							SILTSTONE, reddish brown, very fine grained, slightly weathered, strong, very close to moderate spaced discontinuities								
	1.2								215' - 216.3' Fractured zone								
	1.3																
	2.5		R-41	60 100%	43 72%	R4	SL			217.33	J	20	P,Sm	FR	T	N	
	2.1									218.50	J	20	P,Sm	FR	PO	N	
	2	220.0								219.30	J	10	P,Sm	FR	T	N	
220									220.0 End of boring at 220 feet BGS Borehole grouted with cement and bentonite holeplug.								
40																	
225																	
230																	
30																	
235																	

NOTES:

PROJECT NO.: 353754

Boring No.: B-55

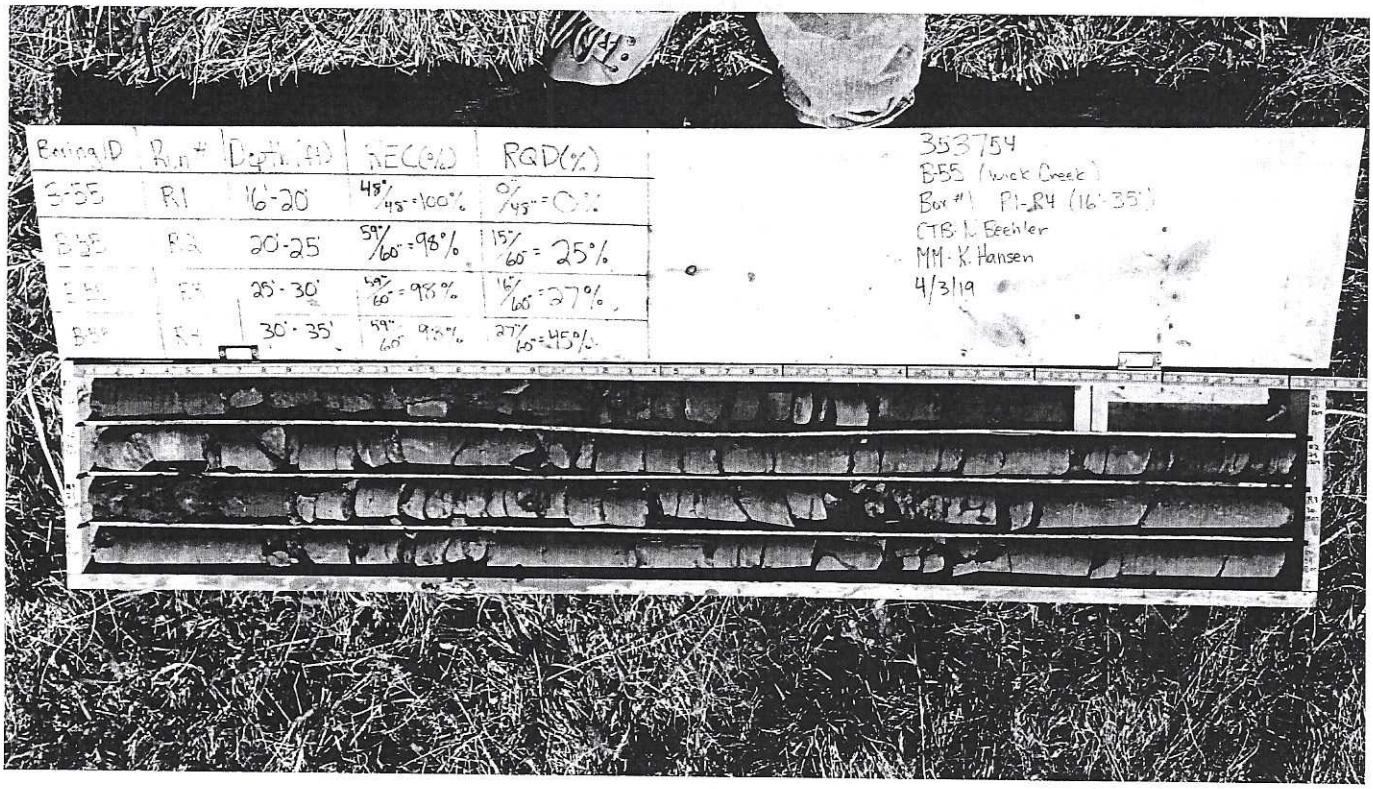


Figure B-55.1
B-55 Box 1 R1-R4 Dry

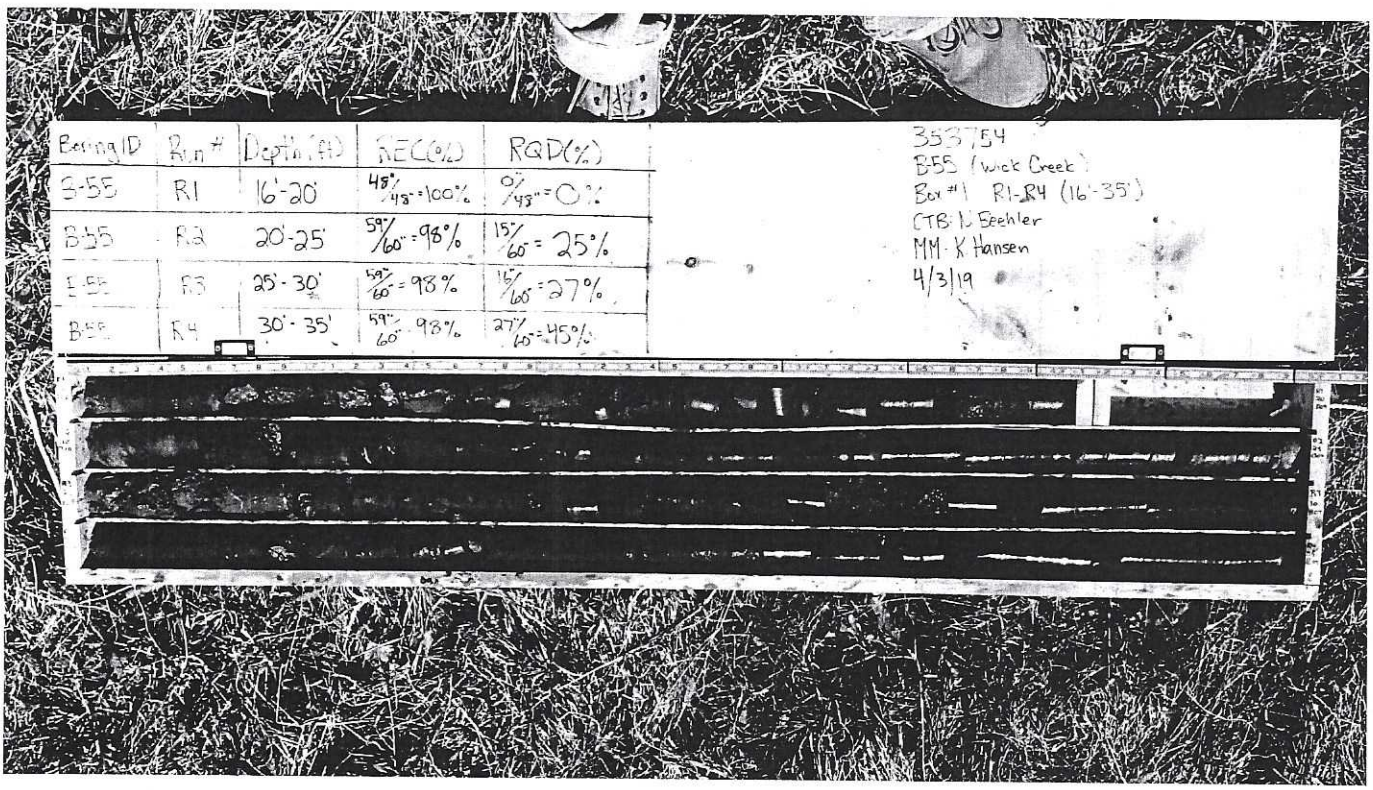


Figure B-55.2
B-55 Box 1 Runs 1-4 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-55

Figure B-55.3
B-55 Box 2 Runs 5-8 Dry

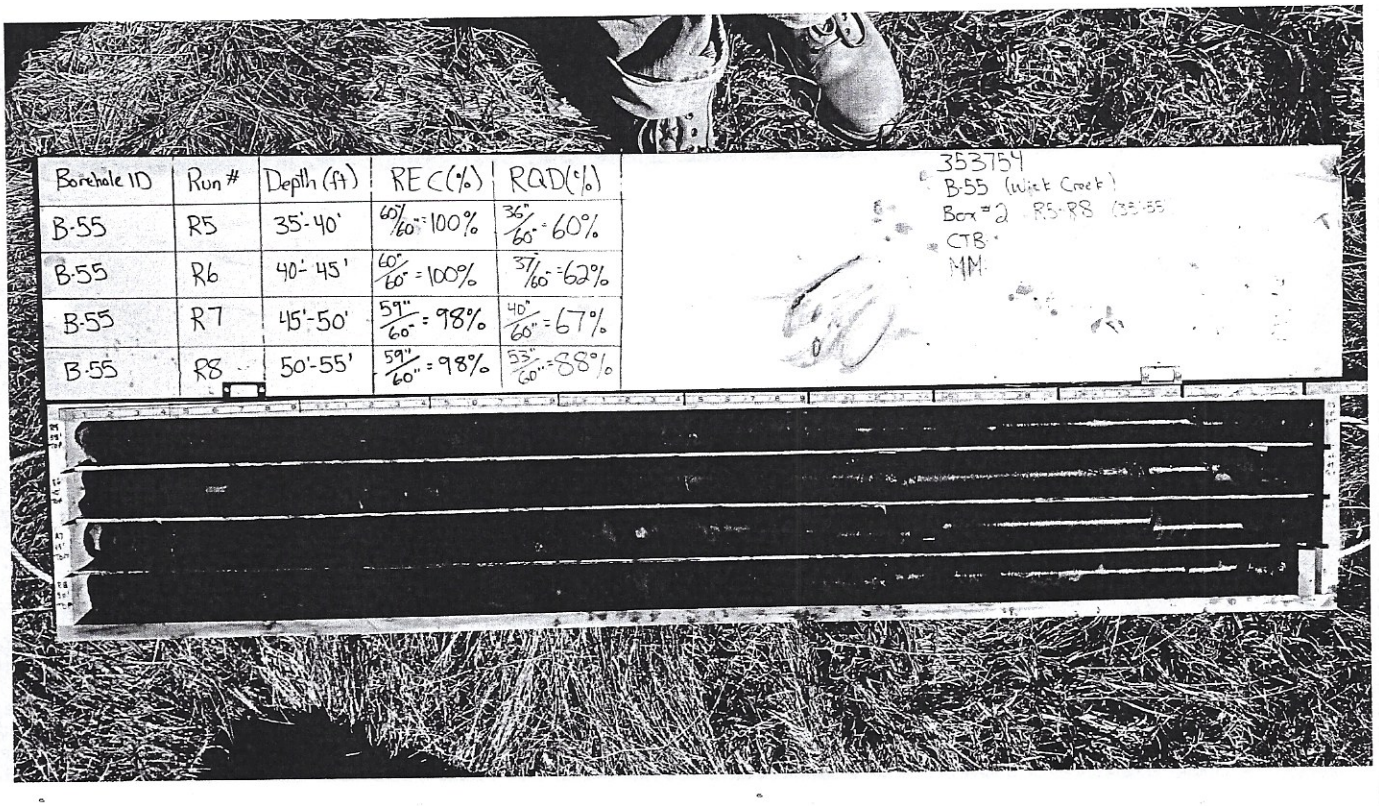


Figure B-55.4
B-55 Box 2 Runs 5-8 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-55

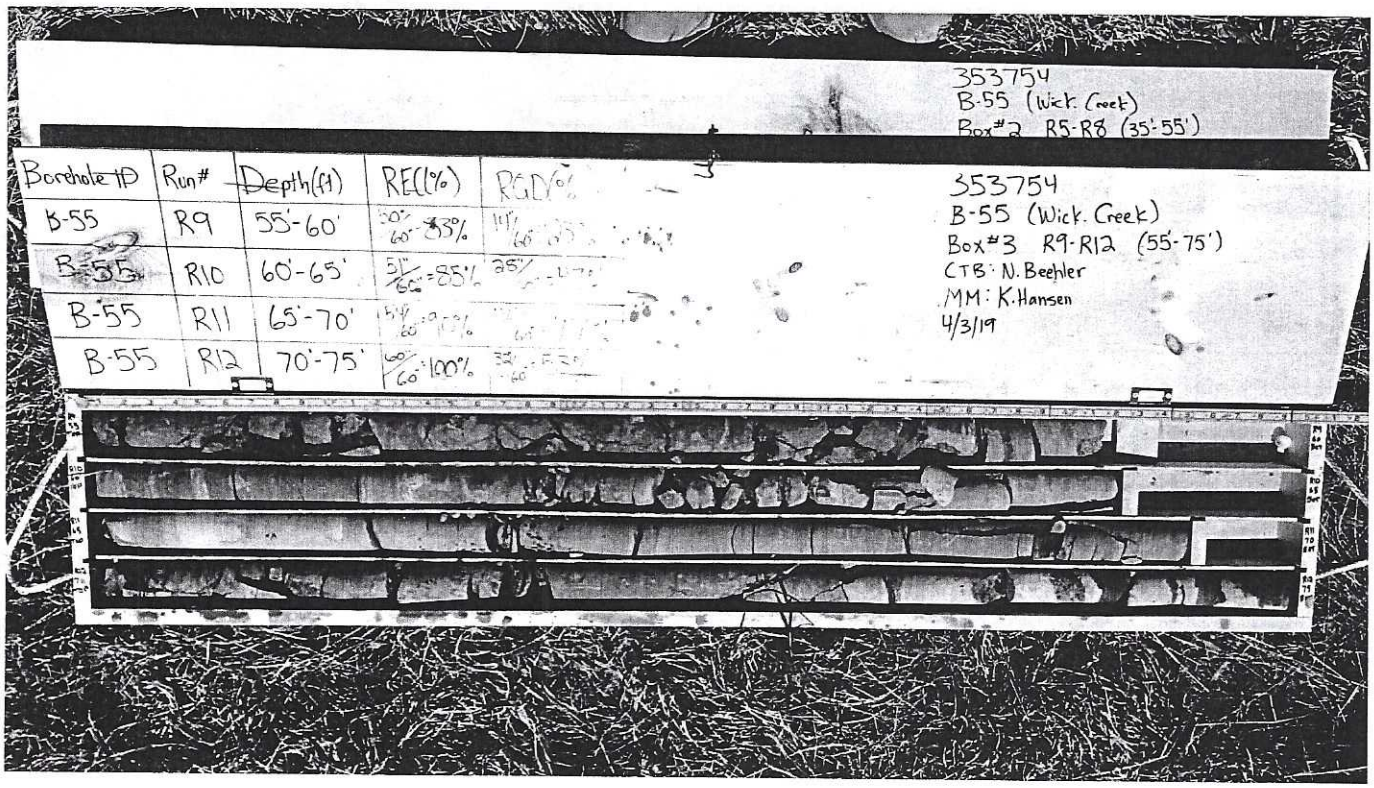


Figure B-55.5
B-55 Box 3 Runs 9-12 Dry

Figure B-55.6
B-55 Box 3 Runs 9-12 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-55

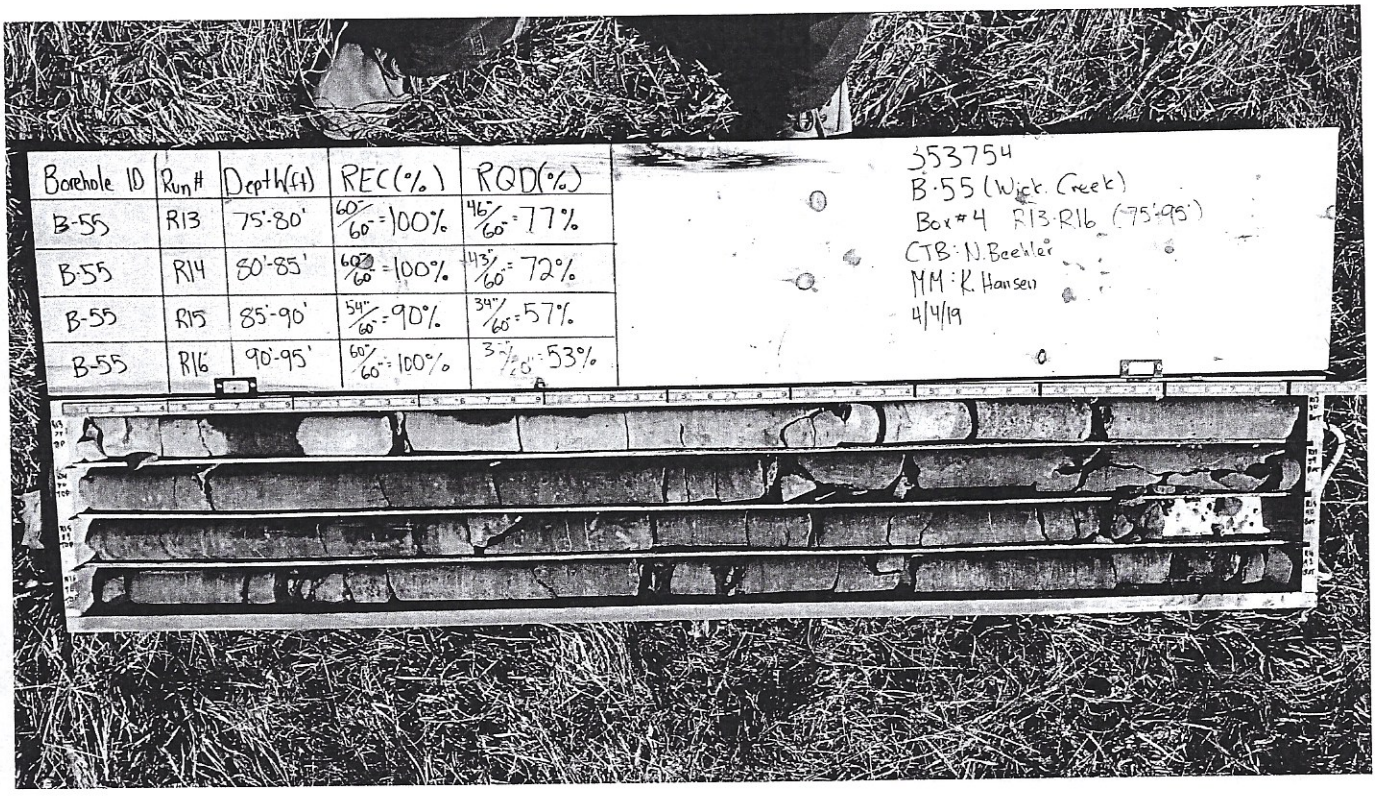


Figure B-55.7
B-55 Box 4 Runs 13-16 Dry

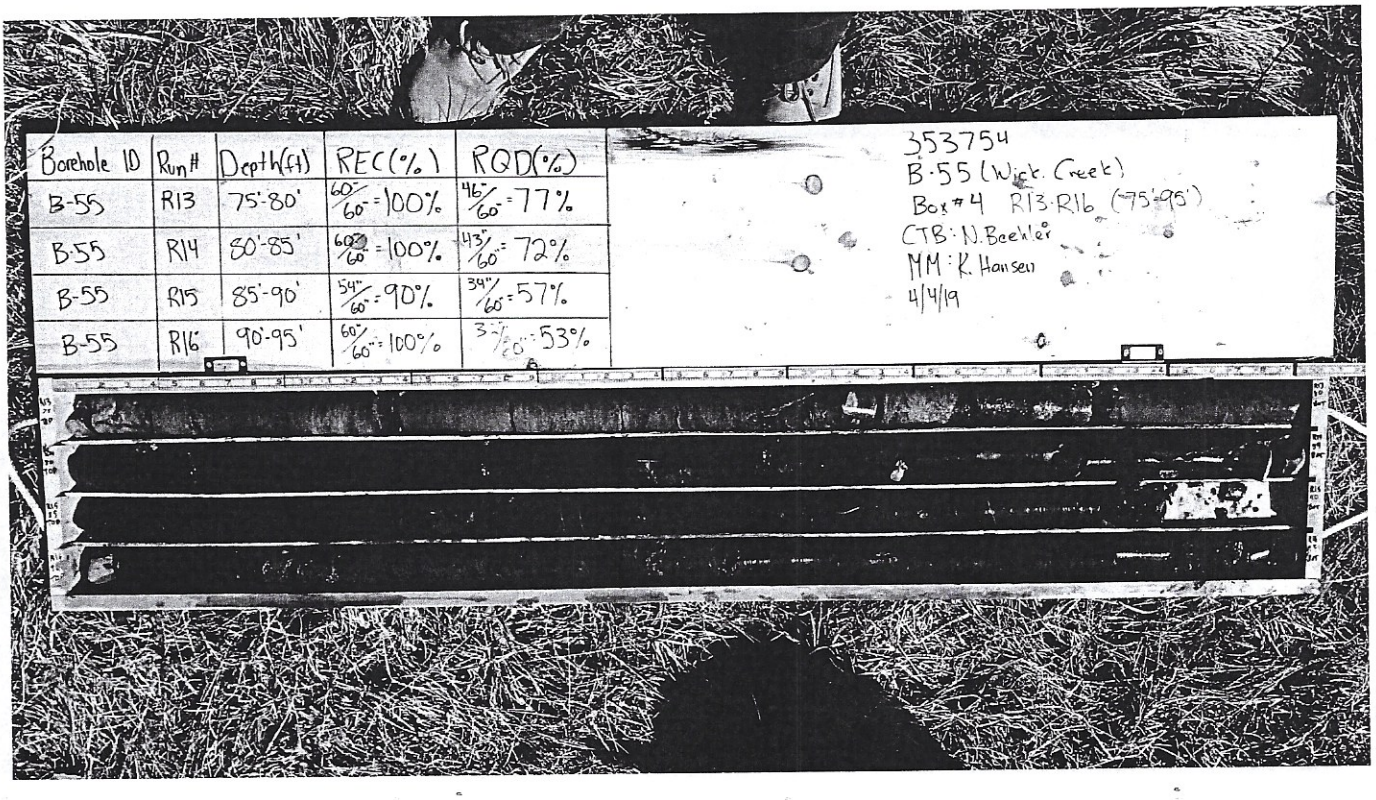


Figure B-55.8
B-55 Box 4 Runs 13-16 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-55

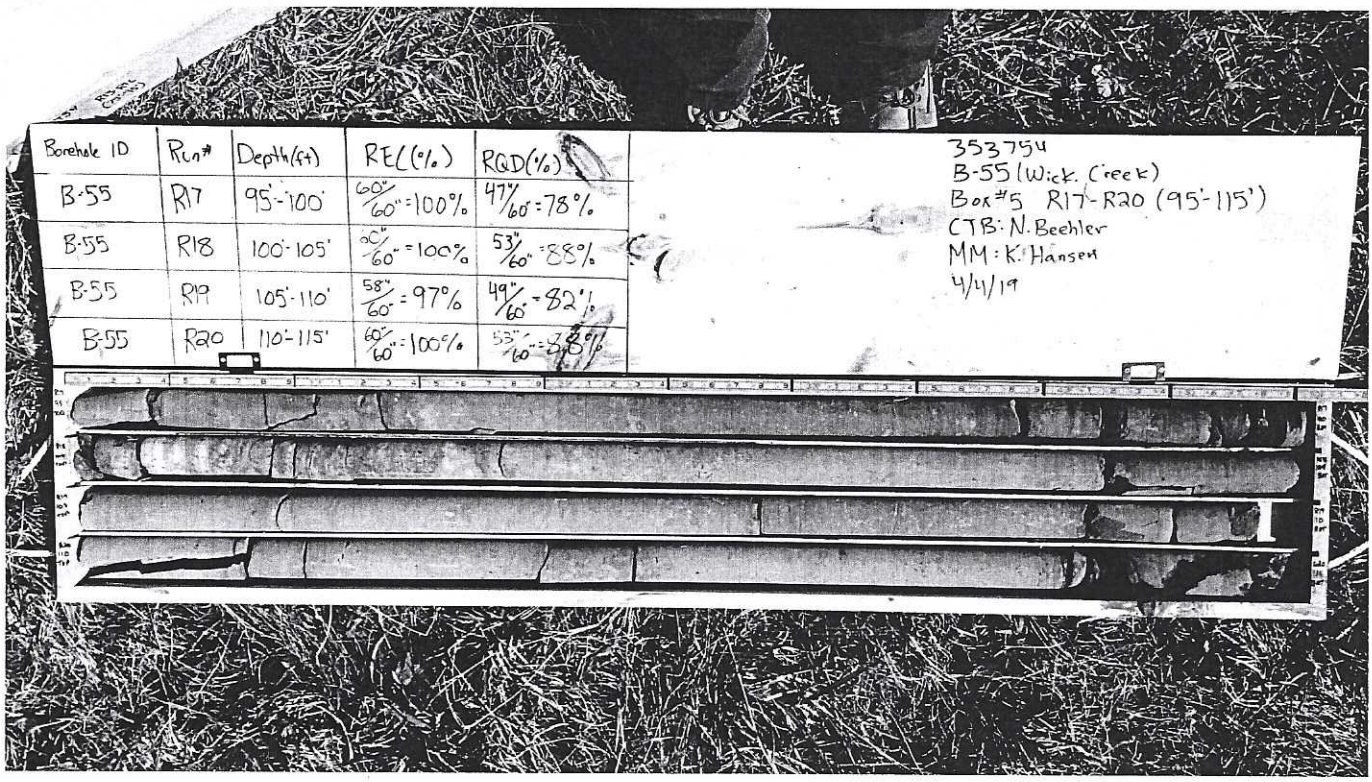


Figure B-55.9
B-55 Box 5 Runs 17-20 Dry

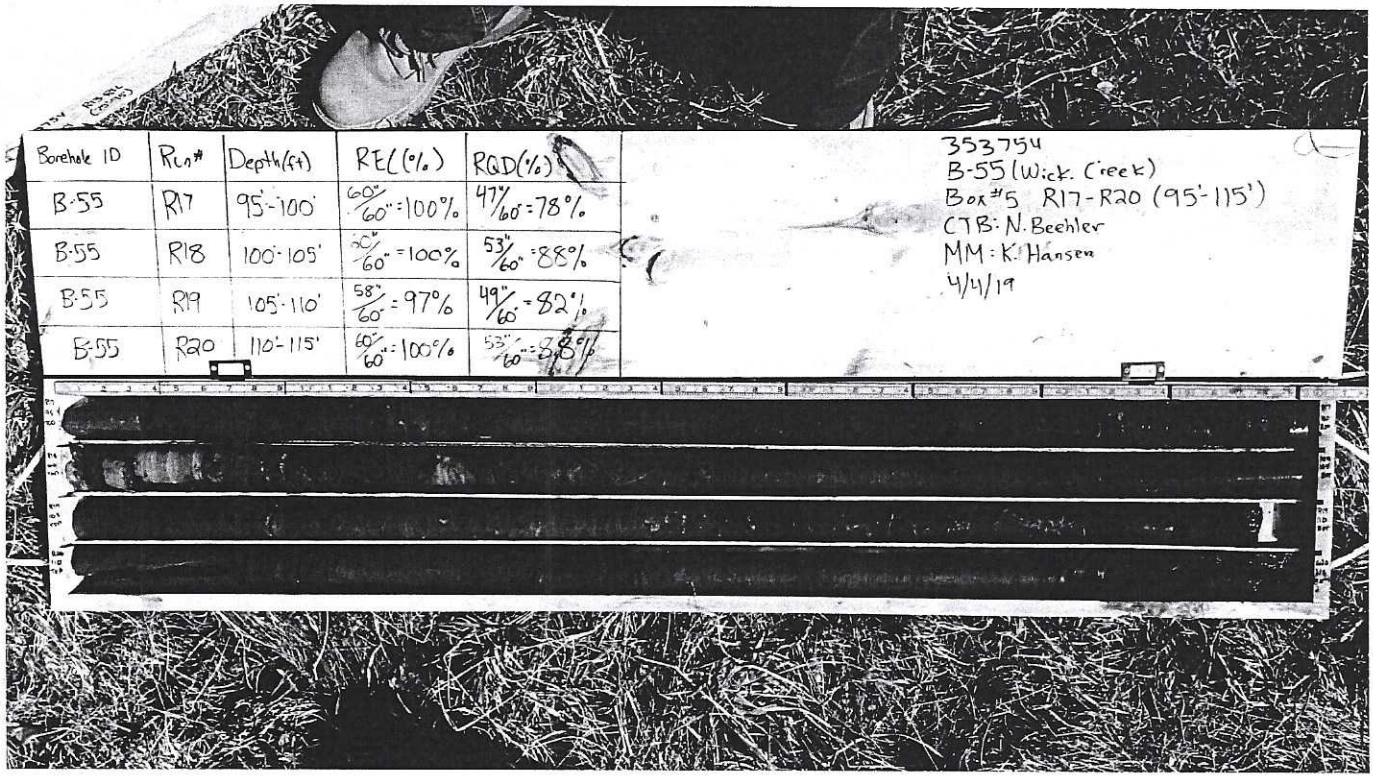
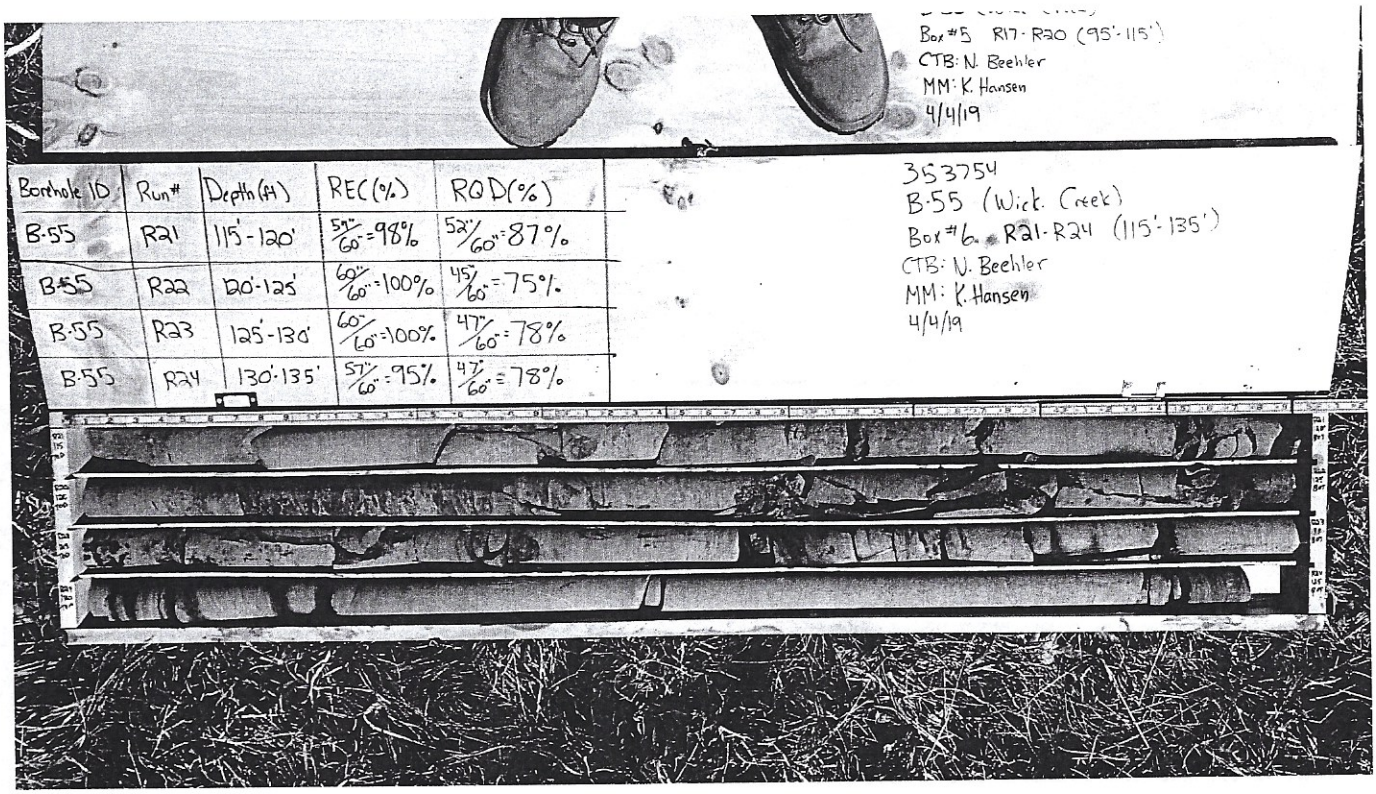


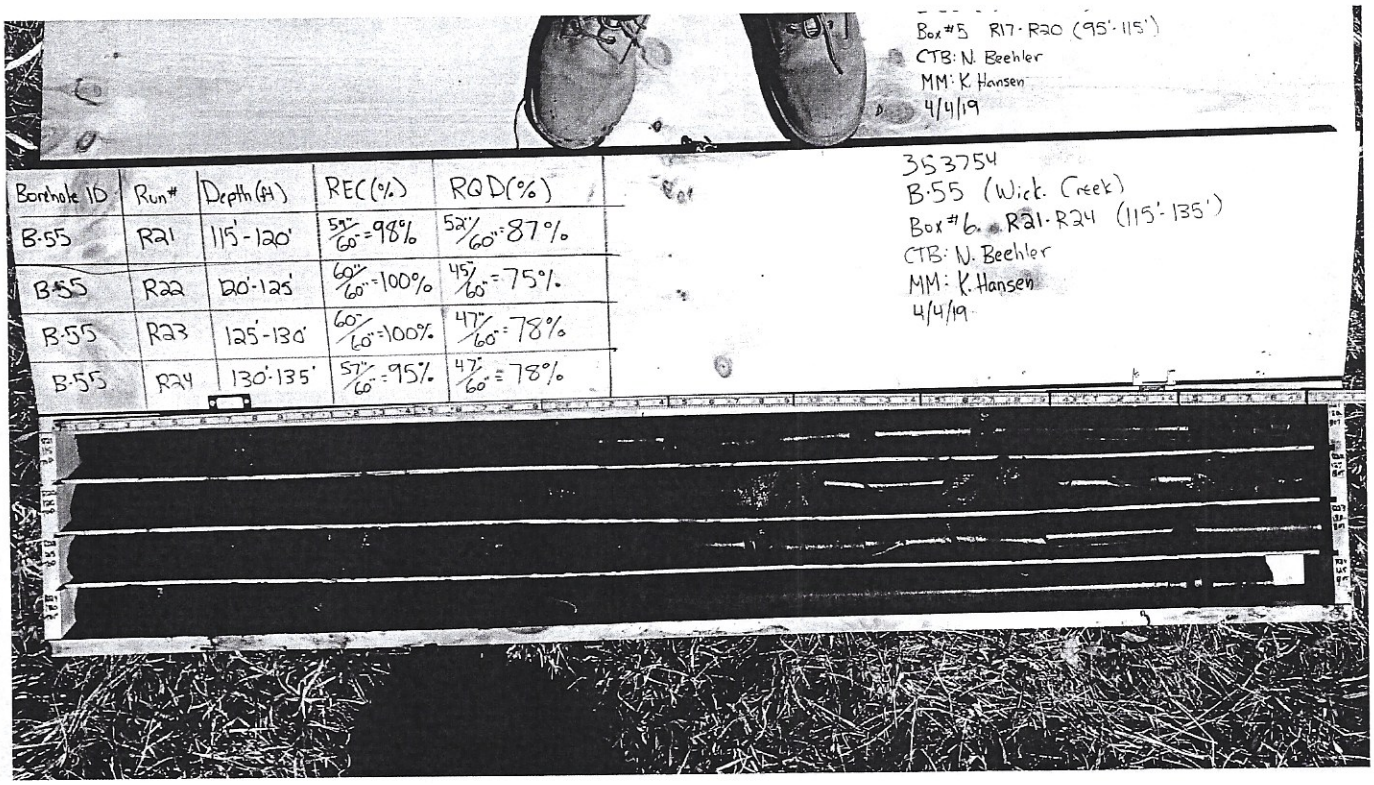
Figure B-55.10
B-55 Box 5 Runs 17-20 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-55



Borehole ID	Run#	Depth (ft)	REC (%)	RQD (%)
B-55	R21	115'-120'	59"/60" = 98%	52"/60" = 87%
B-55	R22	120'-125'	60"/60" = 100%	45"/60" = 75%
B-55	R23	125'-130'	60"/60" = 100%	47"/60" = 78%
B-55	R24	130'-135'	57"/60" = 95%	47"/60" = 78%

Figure B-55.11
B-55 Box 6 Runs 21-24 Dry



Borehole ID	Run#	Depth (ft)	REC (%)	RQD (%)
B-55	R21	115'-120'	59"/60" = 98%	52"/60" = 87%
B-55	R22	120'-125'	60"/60" = 100%	45"/60" = 75%
B-55	R23	125'-130'	60"/60" = 100%	47"/60" = 78%
B-55	R24	130'-135'	57"/60" = 95%	47"/60" = 78%

Figure B-55.12
B-55 Box 6 Runs 21-24 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-55

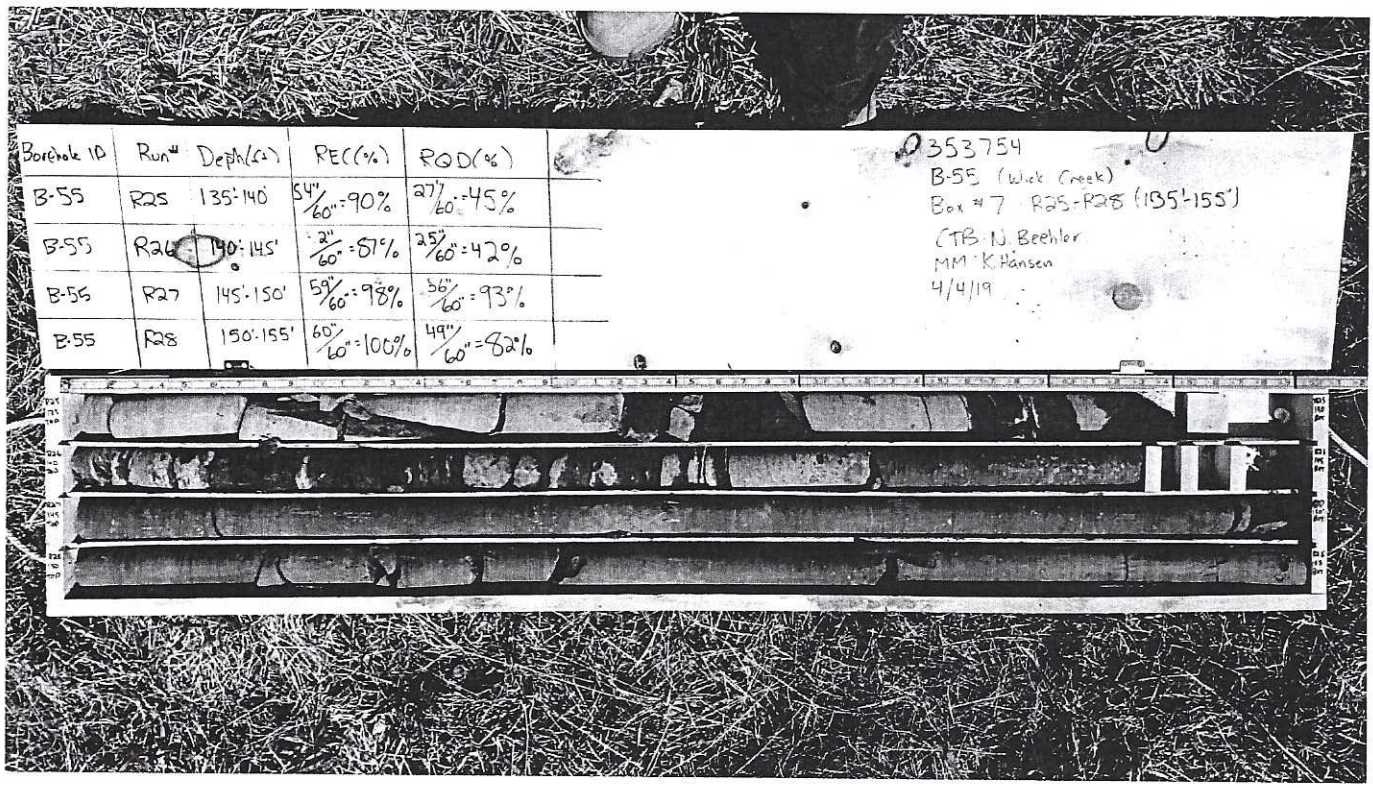


Figure B-55.13
B-55 Box 7 Runs 25-28 Dry

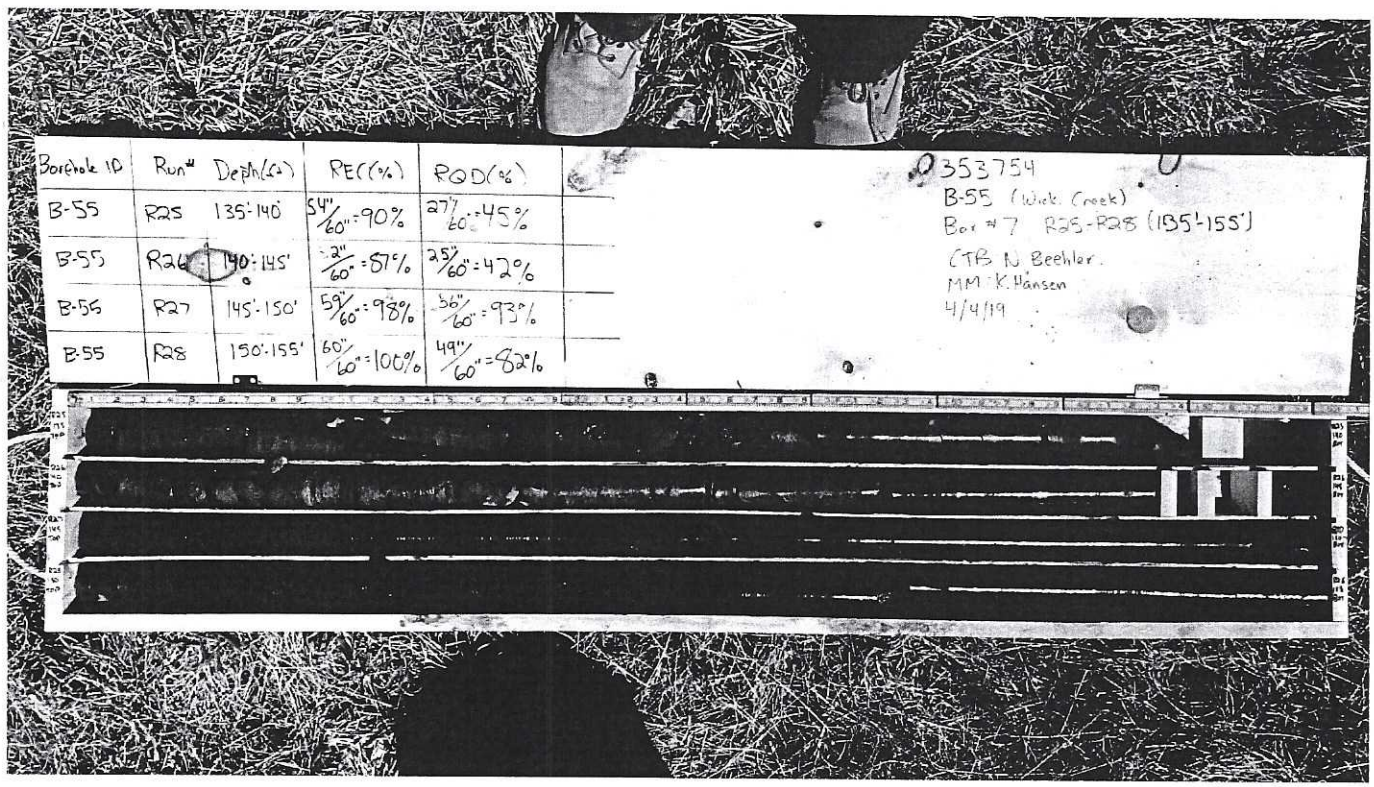


Figure B-55.14
B-55 Box 7 Runs 25-28 Wet

MOTT MACDONALD	PennEast Pipeline Project	BORING NO.:
	Rock Core Photographs	B-55

Figure B-55.15
B-55 Box 8 Runs 29-32 Dry

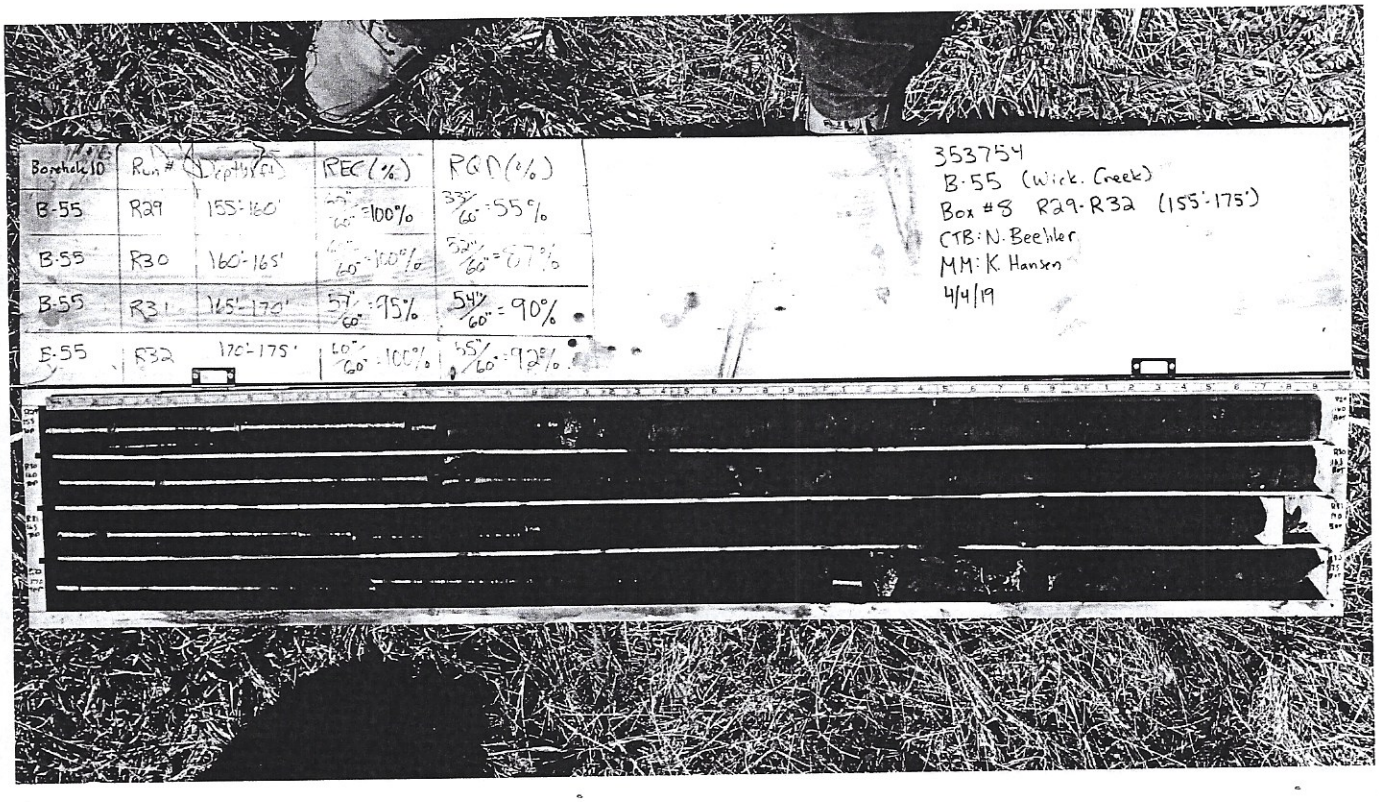


Figure B-55.16
B-55 Box 8 Runs 29-32 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-55

Figure B-55.17
B-55 Box 9 Runs 33-36 Dry

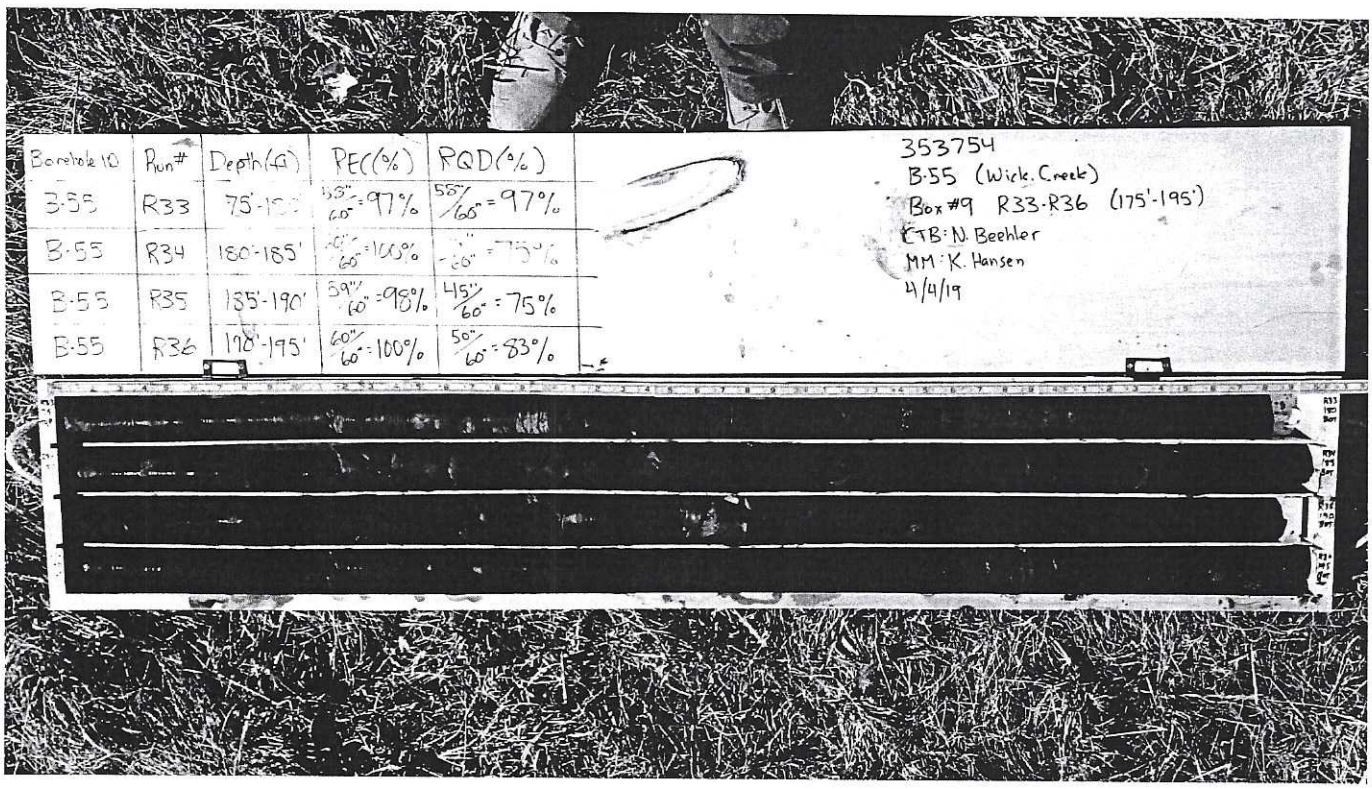


Figure B-55.18
B-55 Box 9 Runs 33-36 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-55

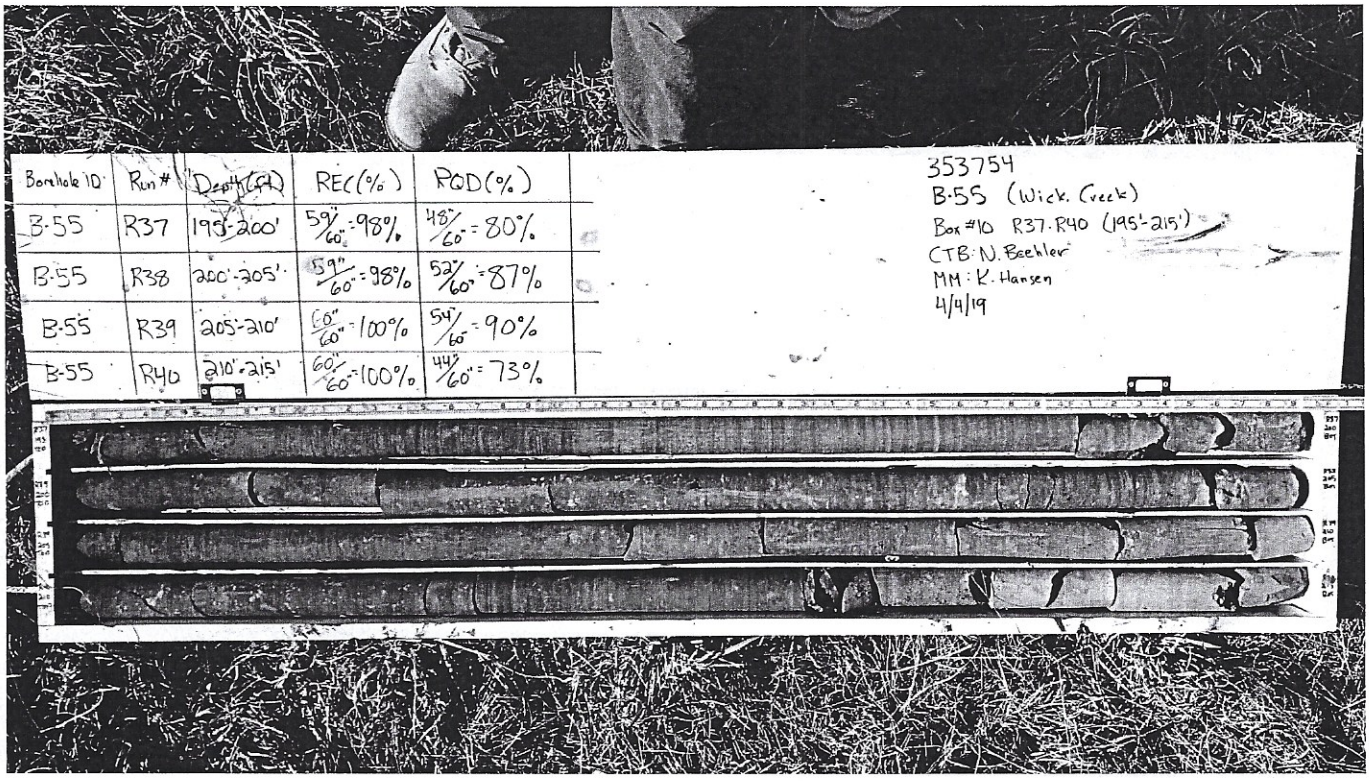


Figure B-55.19
B-55 Box 10 Runs 37-40 Dry

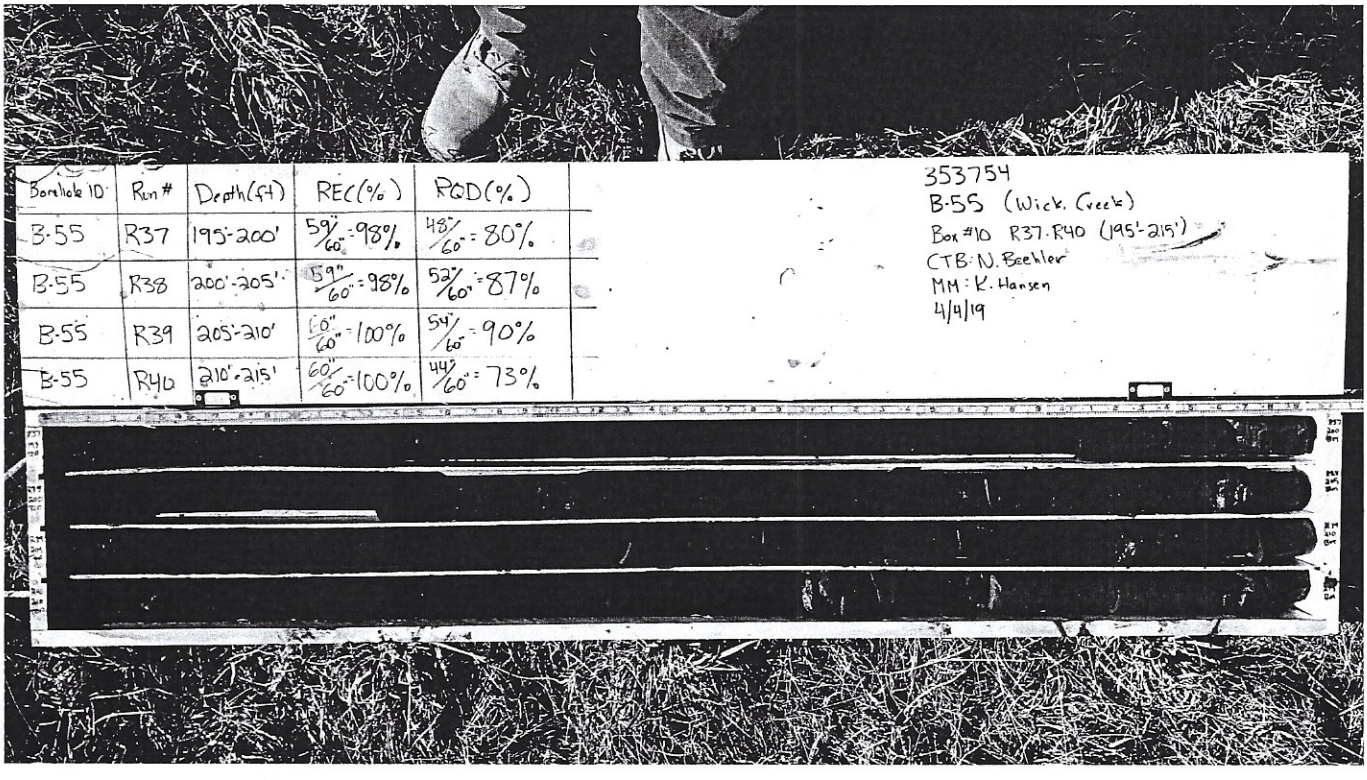


Figure B-55.20
B-55 Box 10 Runs 37-40 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-55

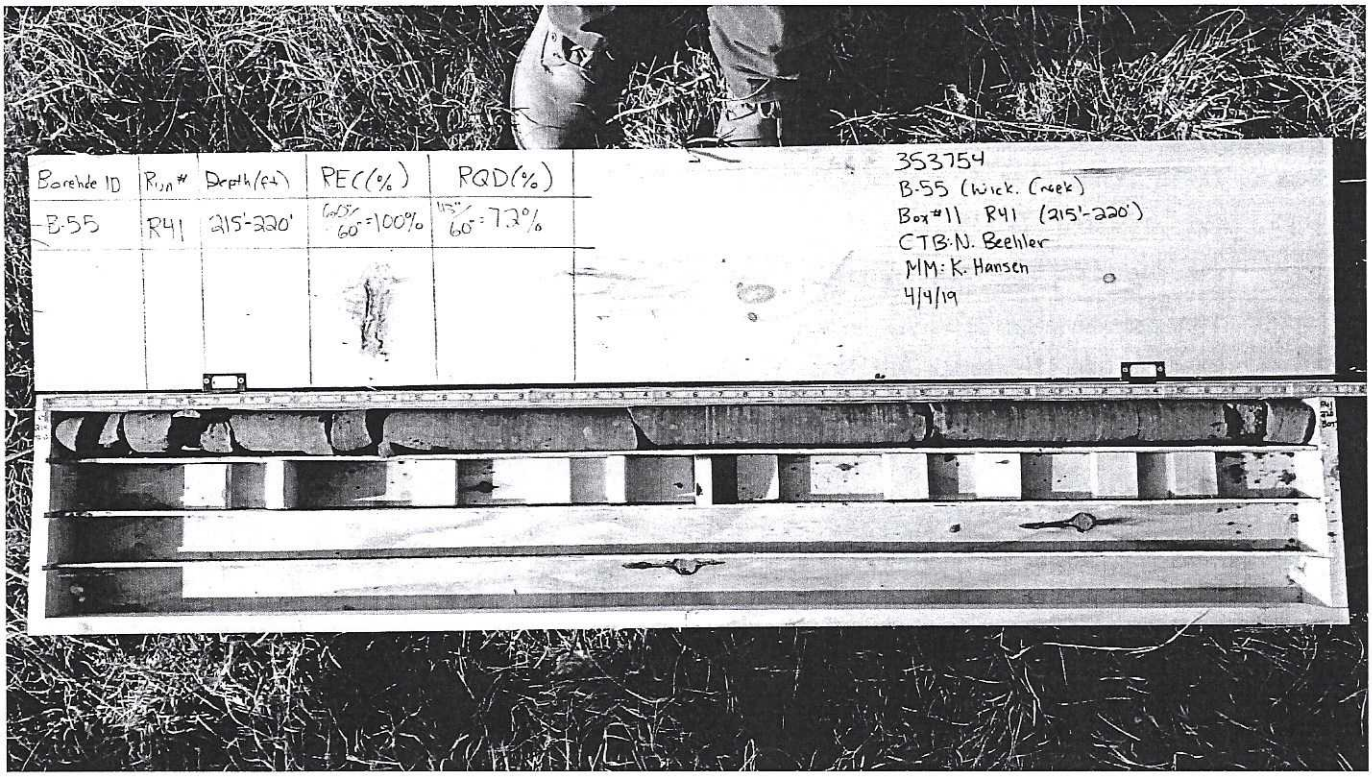


Figure B-55.21
B-55 Box 11 Run 41 Dry

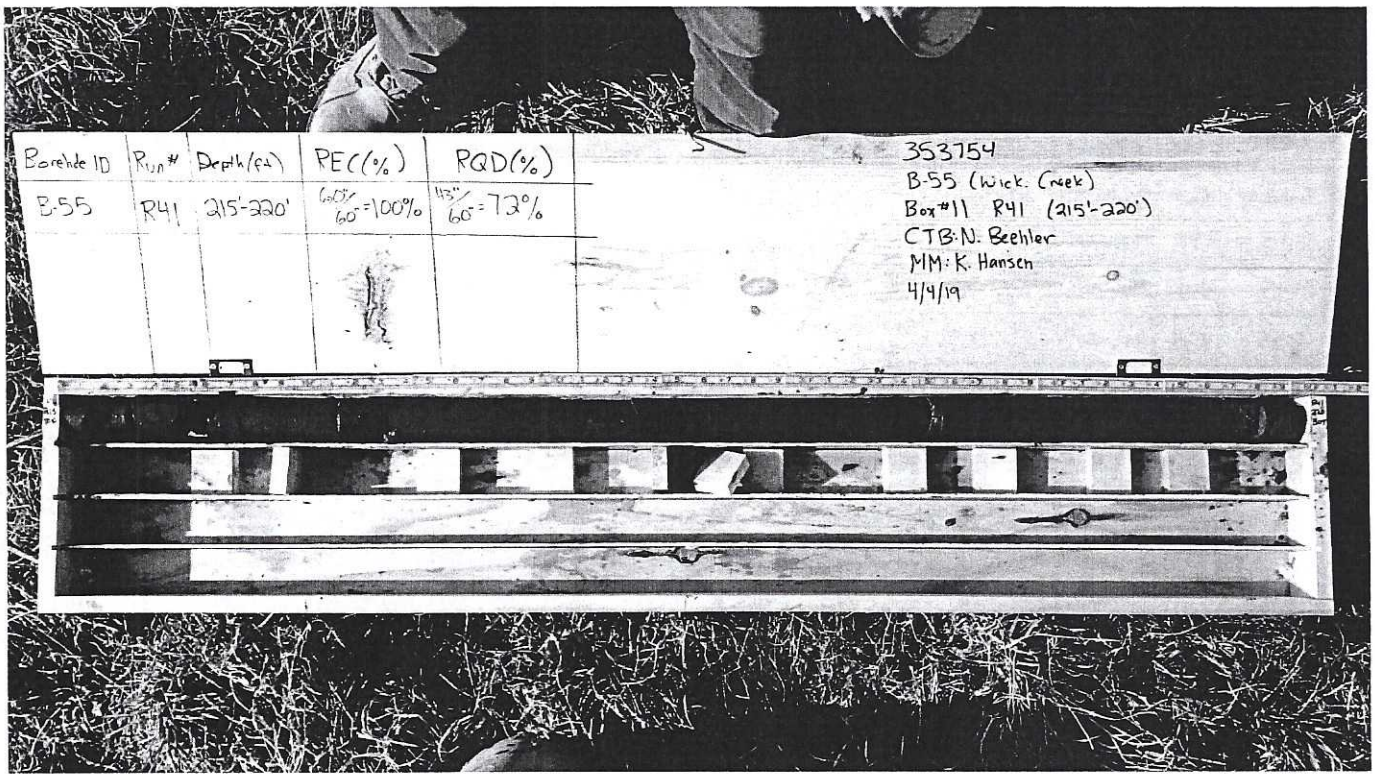


Figure B-55.22
B-55 Box 11 Run 41 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-55

MOTT MACDONALD M M

SOIL BORING LOG

BORING NO.: **B-56**
Page 1 of 1

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Wick Creek, Stockton, NJ	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Thileepan Rajah
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	April 10, 2018 at 9:33 am
Driller/Helper:	Nick Beehler /Miles Neipert/Eddy Sousa	**Date/Time Finished:**	April 13, 2018 at 2:30 pm

Elevation: 166 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** Adjacent to driveway

Coord.: N: **40.432255** E: **-74.970402**
Horizontal Datum: NAD 1983

Item	Casing	Sampler	Core Barrel
Type	HW	SS	NQ2
Length (ft)	5	2	5
Inside Dia. (in.)	4	1.375	2.0
Hammer Wt. (lb.)	140	140	-
Hammer Fall (in.)	30	30	-

Rig Make & Model: CME-55LC

☐ Truck ☐ Tripod ☐ Cat-Head
☐ ATV ☐ Geoprobe ☑ Winch
☑ Track ☐ Air Track ☑ Roller Bit
☐ Skid ☐ ☐ Cutting Head

Hammer Type: ☐ Safety ☐ Doughnut ☑ Automatic ☐

Drilling Fluid: ☑ Bentonite ☐ Polymer ☑ Water ☐ None

Drill Rod Size: / **Casing Advance**: Mud Rotary

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Group Symbol	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
	S-1 0.0'- 2.0' 1.0'-'	6	6 4 2 5			12" - TOPSOIL with roots 1.0	-	-	-	-	Fill approximately 1 to 4 feet BGS.
	S-2 2.0'- 4.0'	2	8 15 15 16		ML	Very stiff, Reddish brown SILT, moist (ML)	S	L	L	L	Advanced casing to 3.5 feet BGS.
5 160	S-3 4.0'- 6.0'	18	5 6 7 8		ML	Stiff, Brownish yellow SILT, trace Sand, moist (ML)	S	L	L	N	
	S-4 6.0'- 8.0'	22	5 8 10 12		ML	Very stiff, Brownish yellow SILT, trace Sand, moist (ML)	S	L	L	L	
10	S-5 8.0'- 10.0'	14	7 8 11 23		ML	Very stiff, Brown SILT with Decomposed Rock fragments, moist (ML)	N	M	NP	N	Gravel zone at 8 feet BGS. Advanced casing to 8.5 feet BGS.
	S-6 10.0'- 12.0'	14	13 20 22 13		ML	Very stiff, Reddish brown SILT with Decomposed Rock fragments, moist (ML)	N	M	NP	N	
	13.5'-'					13.5 Very dense, Reddish brown Decomposed Rock fragments, dry	-	-	-	-	Advanced casing to 13.5 feet BGS.
15 150	S-7 15.0'- 17.0'	6	59/6"				N	M	NP	N	
						17.0 Top of Rock at 17 feet BGS. See Rock Coring Log.					

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
4/10/18	10:16	-	8.5	10.0	9.9
4/11/18	8:30	0:00	13.5	48.0	8
4/12/18	8:35	0:00	13.5	110.0	4.5
4/13/18	8:30	0:00	13.5	138.0	6

Sample Type

O Open End Rod
T Thin-Wall Tube
U Undisturbed Sample
S Split Spoon Sample
G Grab Sample

Notes:
PP = Pocket Penetrometer
TV = Torvane

Boring No.: **B-56**

Field Test Legend: Dilatancy: N - None S - Slow R - Rapid; Toughness: L - Low M - Medium H - High; Plasticity: NP - Non-Plastic L - Low M - Medium H - High; Dry Strength: N - None L - Low M - Medium H - High VH - Very High

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

MOTT MACDONALD M M

CORE BORING LOG

BORING NO.: **B-56**
Page 1 of 6

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Wick Creek, Stockton, NJ	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Thileepan Rajah
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	April 10, 2018 at 9:33 am
Driller/Helper:	Nick Beehler /Miles Neipert/Eddy Sousa	**Date/Time Finished:**	April 13, 2018 at 2:30 pm

Elevation: 166 ft. **Vertical Datum:** NAVD 1988

Item	Casing	Core Barrel	Core Bit
Type	HW	NQ2	Imp. Diamond
Length (ft)	5	5	3.25
Inside Dia. (in.)	4	2.0	2.0

Boring Location: Adjacent to driveway
Horizontal Datum: NAD 1983
Rig Make & Model: CME-55LC
Coord.: N: **40.432255** E: **-74.970402**
Drilling Method: Wireline

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec (in. / %)	RQD (in / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities Type	Dip	Rgh	Wea	Aper	Infill	Remarks
									SEE TEST BORING LOG FOR OVERBURDEN DETAILS								
	1.37	17.0							SILTSTONE, Reddish brown, fine grained, highly weathered, very weak to weak, close spaced discontinuities								
	2.26		R-1	36 100%	11 31%	R1	H			17.90	J	70	S,R	DE	MW	ML	
	2.08	20.0							18.9' - 19.3' Residual soil to completely weathered rock	19.55	J	10	S,R	DE	PO	ML	
20	1.26	20.0							20' - 22.45' SILTSTONE, Reddish brown, fine grained, moderately weathered, weak to medium strong, close spaced discontinuities								
	1.23									21.20	J	35	S,R	DE	PO	ML	
										21.60	J	40	S,R	DE	PO	ML	
	1.20		R-2	56 93%	22 37%	R2	M		22.5								
	1.40								22.45' - 25' SANDSTONE, Reddish brown to gray, fine to coarse grained, moderately weathered, weak to medium strong, very close spaced discontinuities	23.20	J	55	S,R	DE	PO	N	
	1.02	25.0							24' - 25' Coarse Sandstone								
25	1.27	25.0							SANDSTONE, Reddish brown to gray, fine to coarse grained, moderately weathered, weak to medium strong, very close spaced discontinuities								
140	1.35								25' - 30' Fractured zone								
	1.36		R-3	58 97%	4 7%	R2	M		26.57' - 27.3' Coarse grained Sandstone								
	0.50																
	1.40	30.0															
30	1.15	30.0							30' - 33.2' SANDSTONE, Reddish brown to gray, fine to coarse grained, moderately weathered, weak to medium strong, very close to close spaced discontinuities								
	1.17																
	1.01		R-4	59 98%	12 20%	R2	M		33.2								
	1.13								33.2' - 35' SILTSTONE, Reddish brown to gray, fine grained, moderately weathered, weak to medium strong, very close spaced discontinuities	33.30	J	80	S,R	DS	T	N	
	1.30	35.0								34.40	J	85	S,R	DS	T	N	
35	1.36	35.0							SILTSTONE, Reddish brown, fine grained, moderately weathered, medium strong, very close to close spaced discontinuities								
130	1.36									36.00	J	35	S,R	DS	T	N	
										36.65	J	33	S,R	DS	T	N	

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
4/10/18	10:16	-	8.5	10.0	9.9
4/11/18	8:30	0:00	13.5	48.0	8.0
4/12/18	8:35	0:00	13.5	110.0	4.5
4/13/18	8:30	0:00	13.5	138.0	6.0

Notes:

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: B-56

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities Type	Dip	Rgh	Wea	Aper	Infill	Remarks
										37.00	J	75	S,R	DS	PO	N	
	1.50		R-5	60 100%	32 53%	R2	M										
	2.00									38.00	J	68	S,R	DE	PO	ML	
	2.03	40.0								39.10	J	50	S,R	DS	PO	ML	
40	2.10	40.0							SILTSTONE, Reddish brown, fine grained, moderately weathered, weak to medium strong, very close to close spaced discontinuities	40.60	J	0	S,R	DS	T	N	
	2.15								41.7' Color transition from reddish brown to gray								
	2.15		R-6	60 100%	38 63%	R3	M			42.10	J	50	S,R	DS	T	N	
	2.20								42.7' - 44.1' SANDSTONE, gray coarse to fine grained, moderately weathered, weak to medium strong, close spaced discontinuities	43.30	J	53	S,R	DS	T	N	
	2.05	45.0							44.1 44.1' - 44.7' SILTSTONE, Gray 45.0 44.7' - 45' Color transition from gray to reddish brown	44.70	S	95	P,Sm	DS	PO	Fe	Loss of water at approximately 46.5 feet BGS.
45	2.13	45.0							SANDSTONE, Reddish brown to gray, coarse to fine grained, moderately weathered, weak to medium strong, close spaced discontinuities								
120	2.20								46.5' - 47.5' Fractured zone								
	2.00		R-7	60 100%	45 75%	R3	M			47.50	J	85	S,R	DS	PO	N	
	2.50								48.5' - 49' Siltstone interbedded with Sandstone								
	2.30	50.0							49' Fractured vein at 85 degrees								
50	2.33	50.0							SANDSTONE, Reddish brown to gray, coarse to fine grained, slightly weathered, medium strong, very close to close spaced discontinuities								
	1.30									51.40	J	5	S,R	FR	T	N	
	5.23		R-8	36 60%	24 40%	R2	M		52.0 MUDSTONE, Reddish brown, highly weathered 52' - 55' Fractured zone	52.00	J	0	U,R	DS	O	N	Loss of water from 52 to 53 feet BGS.
	5.35	53.0															
	5.15	55.0															
55	2.45	55.0							MUDSTONE, Reddish brown, fine grained, slightly weathered, medium strong, very close spaced discontinuities Calcite veins and pockets throughout 55.5' Calcite infill	55.80	J	70	S,R	FR	T	N	
110	2.30									56.30	J	80	S,R	FR	T	N	
	2.25		R-9	58 97%	41 68%	R3	SL			57.40	J	5	S,Sm	FR	T	N	
	2.37									58.80	J	55	S,R	FR	T	Ca	
	2.40	60.0															
60	2.15	60.0							MUDSTONE, Reddish brown, fine grained, slightly weathered, weak to medium strong, very close spaced discontinuities Calcite veins throughout	60.90	J	45	S,R	FR	T	Ca	
	2.20									61.20	J	40	U,Sm	FR	T	N	

NOTES:

PROJECT NO.: 353754

Boring No.: B-56

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	2.30		R-10	57 95%	48 80%	R2	SL			61.95	J	5	U,R	FR	T	N	
	2.50									62.90	J	50	S,Sm	FR	T	N	
	2.45	65.0								64.00	J	10	S,R	FR	T	ML	
65									65.0								
	2.15	65.0							65' - 67.1' SILTSTONE, Reddish brown, fine grained, moderately weathered, weak to medium strong, very close spaced discontinuities	65.40	J	80	S,Sm	FR	T	N	66.8' - 67.15' Highly Fractured zone
100	2.30								67.1 66.8' - 67.15' Highly Fractured zone								
	2.15	67.0	R-11	60 100%	26 43%	R2	M		67.1' - 68.7' SANDSTONE, Reddish brown to gray, fine grained, moderately weathered, medium strong, extremely close spaced discontinuities	67.10	J	40	S,Sm	FR	T	N	
	2.30								68.7								
	3.00	69.0							68.7' - 70' SILTSTONE, Reddish brown, fine grained, moderately weathered, weak to medium strong, very close spaced discontinuities	68.75	J	50	S,R	FR	T	N	
		70.0								69.20	J	60	S,Sm	FR	T	ML	
70									70.0								
	3.00	70.0							MUDSTONE, Reddish brown, fine grained, moderately weathered, weak to medium strong, very close spaced discontinuities	70.55	J	85	S,R	DS	T	N	Iron stains at end of breaks.
	2.50								71' - 72.6' Interbedded gray Siltstone	71.00	J	45	S,R	FR	T	N	
	2.30		R-12	60 100%	37 62%	R2	M										
	3.00									72.95	J	40	S,R	FR	T	N	
										73.55	J	5	S,R	FR	T	N	
	2.00	75.0															
75																	
	2.15	75.0							MUDSTONE with interbedded Siltstone, Reddish brown, fine grained, fresh to moderately weathered, weak to medium strong, very close spaced discontinuities	75.65	J	50	S,R	FR	T	N	
90	3.13									76.80	J	55	S,R	FR	T	N	
	4.00		R-13	60 100%	39 65%	R2	M			77.00	J	45	S,Sm	FR	T	N	
										77.40	J	30	S,R	FR	T	N	
										77.80	J	60	S,R	FR	T	N	
	3.50									78.30	J	60	S,R	FR	T	N	
	2.00	80.0								78.93	J	20	S,R	FR	T	N	
80									80.0								
	2.43	80.0							SILTSTONE, Reddish brown, fine grained, fresh to moderately weathered, weak to medium strong, very close spaced discontinuities								
	3.15									81.00	J	50	S,R	FR	T	N	
	2.30		R-14	60 100%	31 51%	R2	M			82.40	J	45	S,R	FR	T	N	
										82.80	J	45	S,R	FR	T	N	
	2.54																
										83.75	J	50	S,R	FR	T	N	
	3.00	85.0								84.30	J	60	S,R	FR	T	N	
85																	
	2.52	85.0							SILTSTONE, Reddish brown, fine grained, moderately weathered, weak to medium strong, very close spaced discontinuities								
80	3.00									86.30	J	90	S,R	FR	T	N	
										86.50	J	60	S,R	FR	T	N	

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	3.30		R-15	60 100%	31 52%	R2	M										
	3.15									88.55	J	40	S,R	FR	T	N	
	2.50	90.0								89.40	J	30	S,R	FR	T	N	
90									90.0 MUDSTONE with interbedded Siltstone, Reddish brown, fine grained, slightly weathered, medium strong, close spaced discontinuities								
	4.00	90.0															
	4.00									91.50	J	90	S,Sm	FR	T	N	
	4.10		R-16	60 100%	54 89%	R3	SL										
	3.50																
	3.45									94.10	J	30	S,Sm	FR	T	N	
		95.0								94.30	J	40	S,Sm	FR	T	N	
95									95' - 96.5' MUDSTONE, Reddish brown, fine grained, moderately weathered, weak to medium strong, very close spaced discontinuities								
70	3.15	95.0															
	5.20								96.5	96.50	J	10	S,R	FR	T	N	
	6.25	97.0	R-17	60 100%	45 74%	R2	M		96.5' - 97.9' SILTSTONE, Reddish brown to gray, fine grained, slightly weathered, medium strong, close spaced discontinuities								
	6.30								97.9	98.45	J	60	S,R	FR	T	N	
	8.10	99.0							97.9' - 100' SANDSTONE, Gray to reddish brown, fine grained, slightly weathered, medium strong, close spaced discontinuities	99.50	J	40	S,R	FR	T	N	
100		100.0															
	5.50	100.0							SANDSTONE, Reddish brown to gray, fine grained, fresh to slightly weathered, strong to medium strong, wide spaced discontinuities								
	7.45																
	8.00		R-18	59 98%	59 98%	R3	SL										
	5.25									103.00	J	30	S,R	FR	T	N	
	6.00	105.0															
105																	
	8.43	105.0							SANDSTONE, Reddish brown to gray, coarse to fine grained, fresh, strong, wide spaced discontinuities								Used approximately 4000 gallons of water from 48 to 110 feet BGS.
60																	
	8.03																
	6.50		R-19	60 100%	53 88%	R4	FR		107.55' - 108.2' Interbedded Siltstone	107.55	J	90	S,R	FR	T	Ca	
	9.18																
	10.11	110.0															
110										109.80	J	90	S,R	FR	T	Ca	Five foot solid rock core.
	8.26	110.0							SANDSTONE, Reddish brown to gray, coarse to fine grained, fresh, very strong, wide spaced discontinuities								
	7.27																

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	8.27		R-20	60 100%	60 100%	R5	FR										
	10.31																
	17.05	115.0															
115	10.27	115.0							SANDSTONE, Reddish brown to gray, coarse to fine grained, fresh, very strong, wide spaced discontinuities								Core bit changed at 115 feet BGS.
50	15.21									116.50	MB						
	3.50		R-21	60 100%	60 100%	R5	FR										
	3.15									118.60	MB						
	3.11	120.0								119.60	MB						
120	2.49	120.0							SANDSTONE, Reddish brown to gray, coarse to fine grained, fresh, very strong, wide spaced discontinuities								
	3.47																
	4.20		R-22	60 100%	60 100%	R5	FR										
	2.30								123' - 125' Coarse Sandstone								
	2.00	125.0							125.0								
125	3.13	125.0							125' -126' SANDSTONE, Reddish brown to gray, fine to coarse grained, fresh, strong								
40	3.04								126.0 126' - 130' MUDSTONE, Reddish brown, fine grained, fresh, strong to medium strong, close to very close spaced discontinuities								
	4.28		R-23	57 95%	35 58%	R4	FR										
	2.45																
	2.30	130.0															
130	2.13	130.0							MUDSTONE, Reddish brown, fine grained, fresh to moderately weathered, close to very close spaced discontinuities	130.50	J	15	S,R	FR	T	N	Loss of water from 130 to 135 feet BGS.
	3.34								131.7	131.00	J	20	S,R	FR	T	N	
	6.04		R-24	60 100%	56 93%	R3	FR		131.7' - 135' SANDSTONE, Reddish brown to gray, fine grained, fresh, strong, close spaced discontinuities	131.90	J	30	S,R	FR	T	N	
	6.14	133.0								133.00	J	20	S,R	FR	T	N	
	5.14	135.0								133.90 134.30	J J	25 25	S,R S,R	FR FR	T T	N N	
135	6.15	135.0							SANDSTONE, Reddish brown to gray, fine grained, fresh, strong, very close to moderately spaced discontinuities	135.50	J	20	S,R	DS	O	N	
30	6.51									136.40	J	30	S,R	FR	PO	N	

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: **B-56**

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)
	34.27		R-25	60 100%	34 57%	R4	SL		
	3.00								
	2.42	140.0							139' - 140' Fractured zone
140									140.0
	2.47	140.0							SILTSTONE, Reddish brown to gray, fine grained, fresh, strong, close to moderately spaced discontinuities
	3.06								
	3.35		R-26	60 100%	53 88%	R4	FR		
	2.52								
	2.45	145.0							
145									
	2.50	145.0							SILTSTONE, Reddish brown to gray, fine grained, fresh, strong, wide spaced discontinuities
20									
	2.48								
	2.49		R-27	60 100%	60 100%	R4	FR		
	2.57								
	2.58	150.0							
150									
	3.18	150.0							SILTSTONE, Reddish brown to gray, fine grained, fresh, strong, close to wide spaced discontinuities
	3.45								
	4.15		R-28	60 100%	52 87%	R4	FR		
	4.21								
	4.39	155.0							
155									
	6.15	155.0							SILTSTONE, Reddish brown to gray, fine grained, fresh, strong, very close to close spaced discontinuities
10									
	8.33								
	9.01		R-29	59 98%	30 50%	R4	SL		
	8.28								
	7.28	160.0							
160									160.0
									End of Boring at 160 feet BGS. Borehole grouted with cement and bentonite holeplug.

Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
137.00	J	25	S,R	DS	O	N	
137.50	J	40	S,R	FR	PO	N	
138.80	J	30	S,R	FR	T	N	
140.60	J	15	U,R	FR	T	N	
141.90	J	30	S,R	FR	T	N	
142.70	J	30	S,R	FR	T	N	
149.10	J	20	U,R	DS	T	N	
154.50	J	10	S,R	FR	T	N	
156.00	J	45	U,R	FR	VT	N	
156.20	J	10	U,R	FR	VT	N	
156.70	J	10	S,R	FR	T	N	
156.90	J	20	S,R	FR	T	N	
157.20	J	30	S,R	FR	T	N	
157.40	J	20	S,R	FR	T	N	
157.70	J	10	S,R	FR	VT	N	
157.80	J	10	S,R	FR	VT	N	
158.00	J	10	S,R	FR	T	N	
158.20	J	40	S,R	FR	T	N	
158.70	J	30	P,R	FR	T	N	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-56**

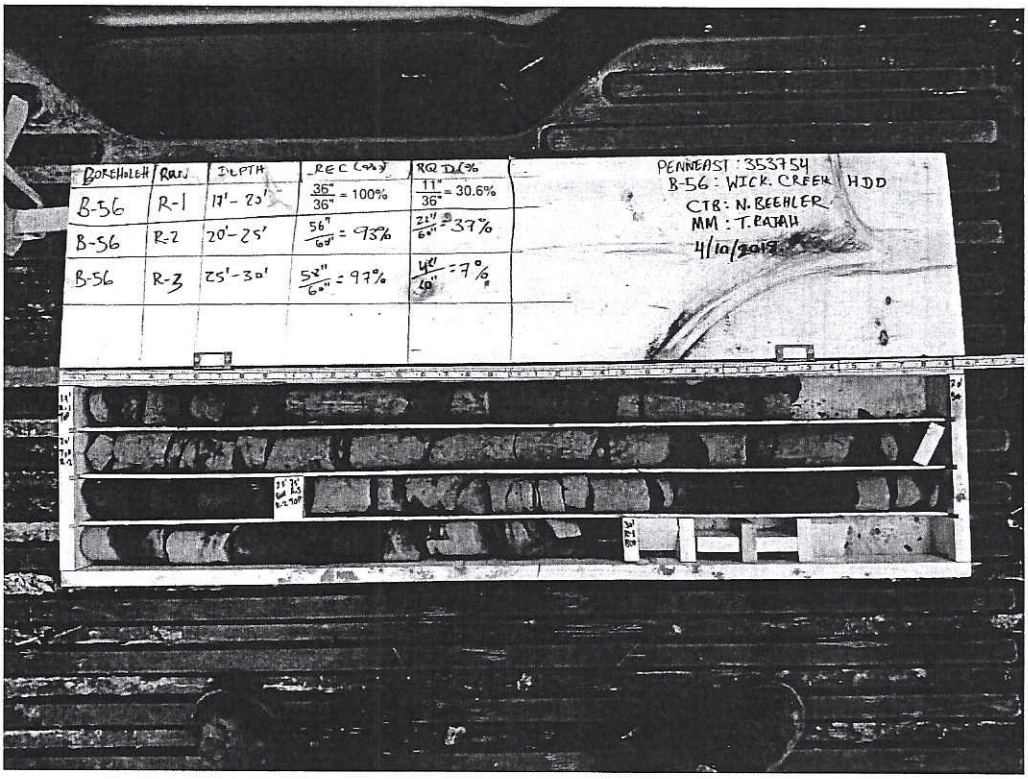


Figure B-56.1
B-56 Box 1 Runs 1-3 Dry

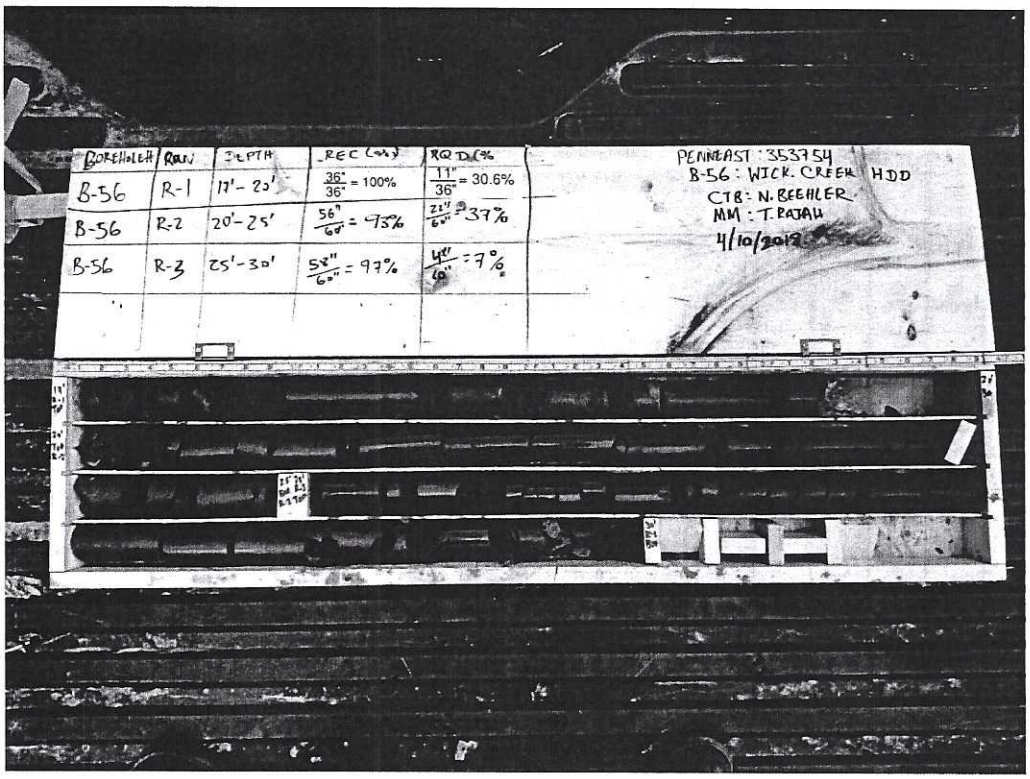


Figure B-56.2
B-56 Box 1 Runs 1-3 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-56

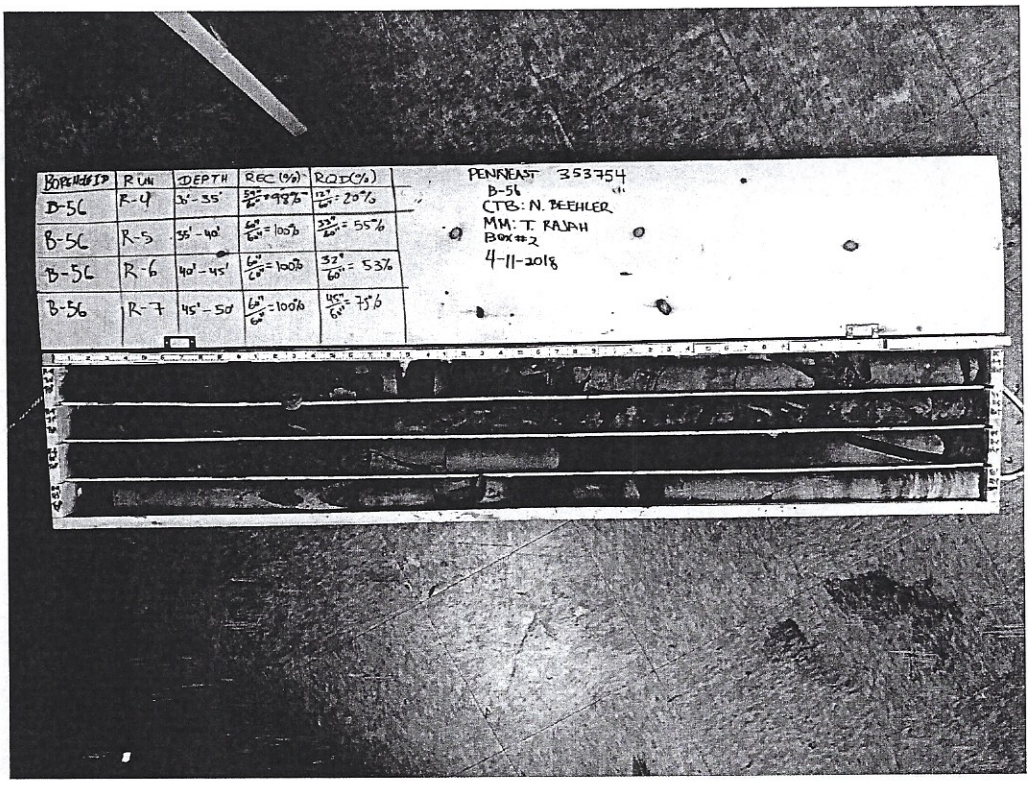


Figure B-56.3
B-56 Box 2 Runs 4-7 Dry

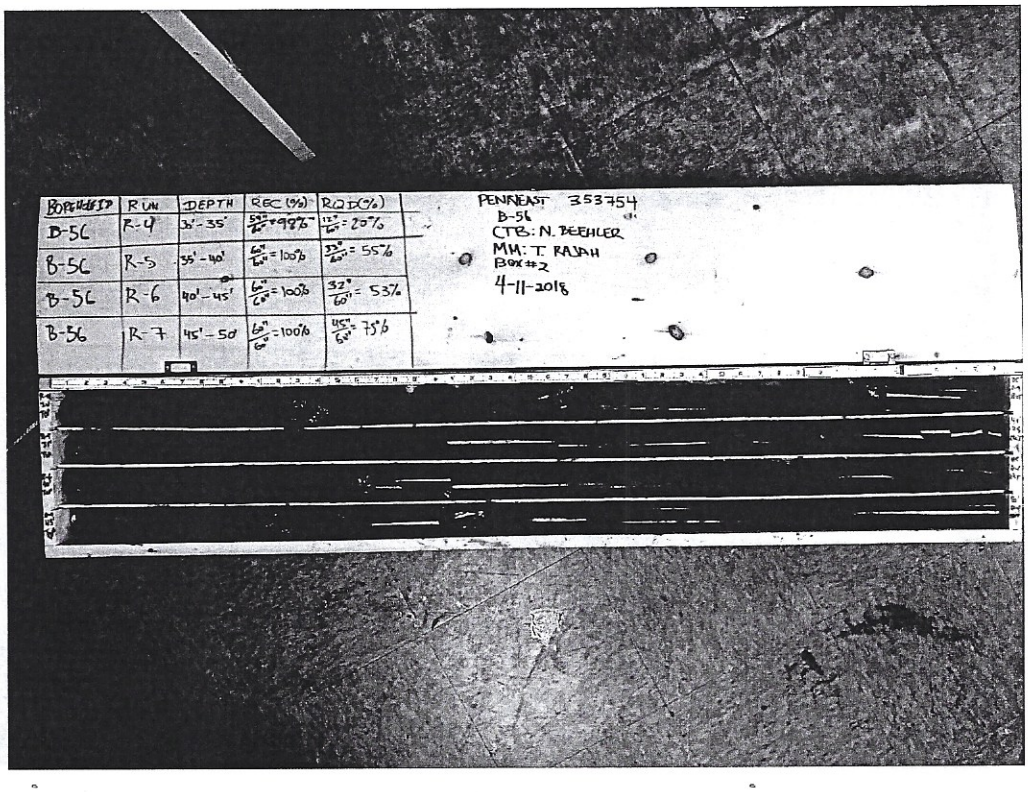


Figure B-56.4
B-56 Box 2 Runs 4-7 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-56

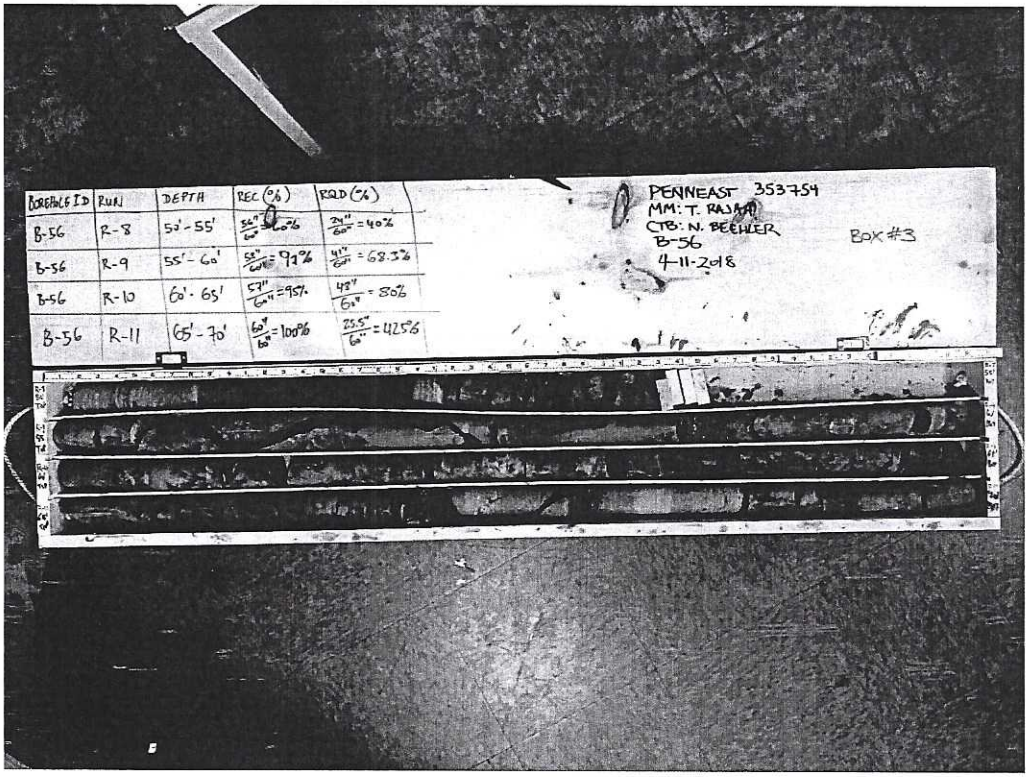


Figure B-56.5
B-56 Box 3 Runs 8-11 Dry

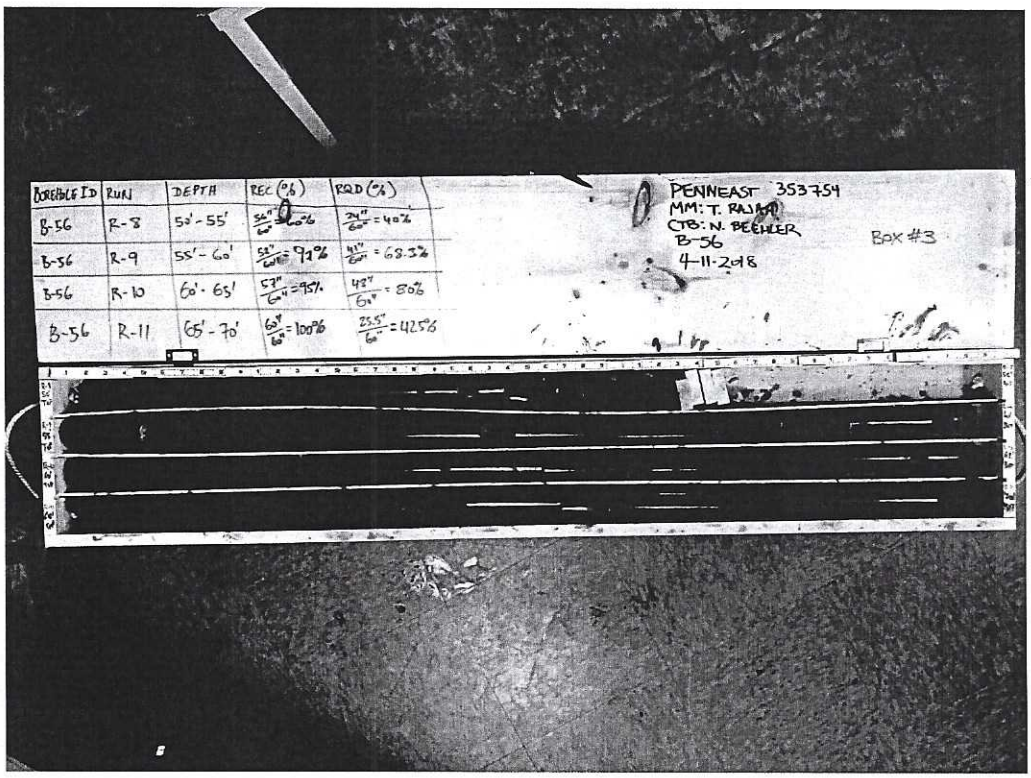


Figure B-56.6
B-56 Box 3 Runs 8-11 Wet

MOTT MACDONALD	PennEast Pipeline Project	BORING NO.:
	Rock Core Photographs	B-56

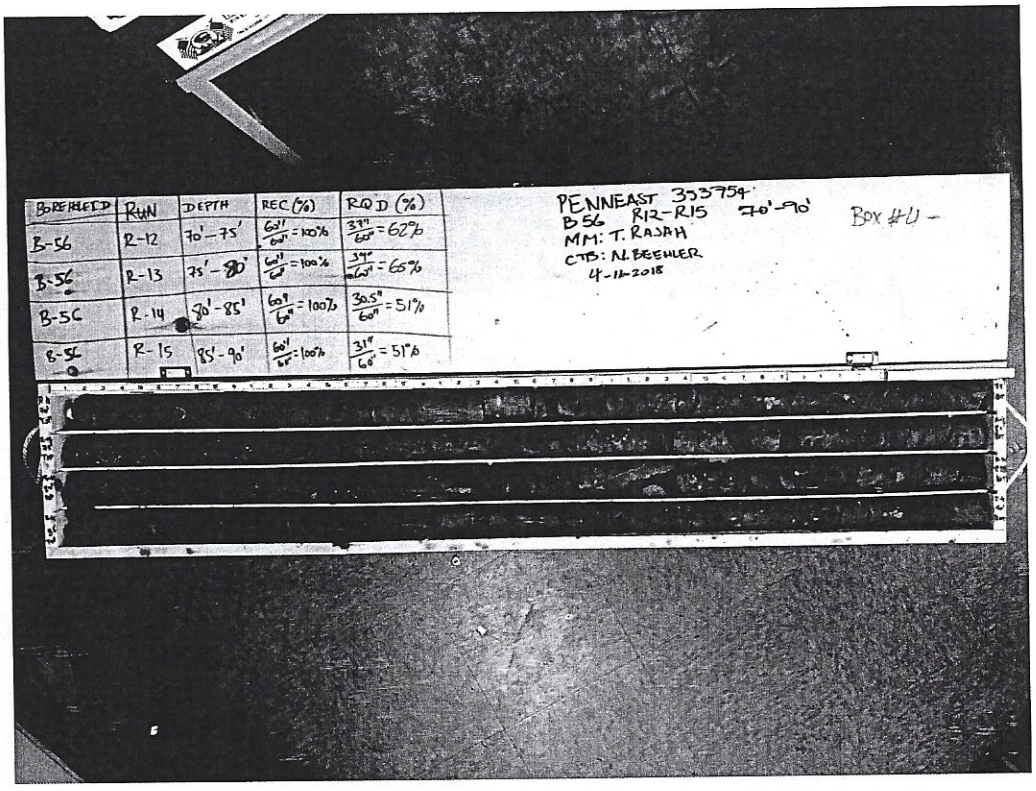


Figure B-56.7
B-56 Box 4 Runs 12-15 Dry

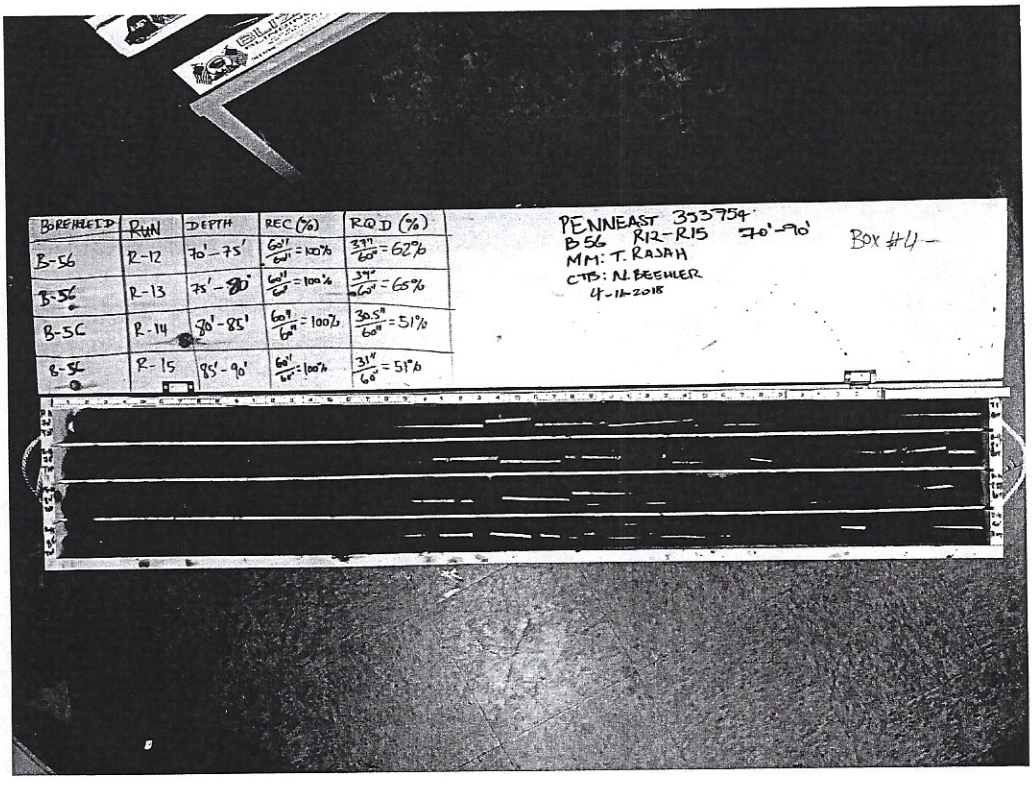


Figure B-56.8
B-56 Box 4 Runs 12-15 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-56

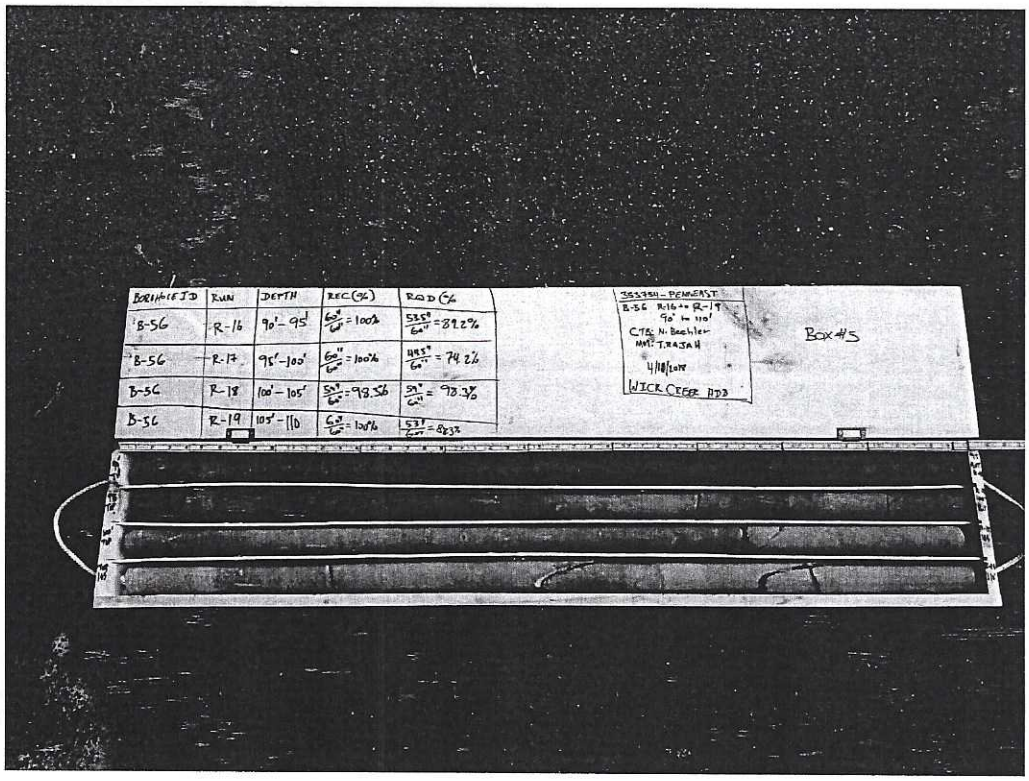


Figure B-56.9
B-56 Box 5 Runs 16-19 Dry

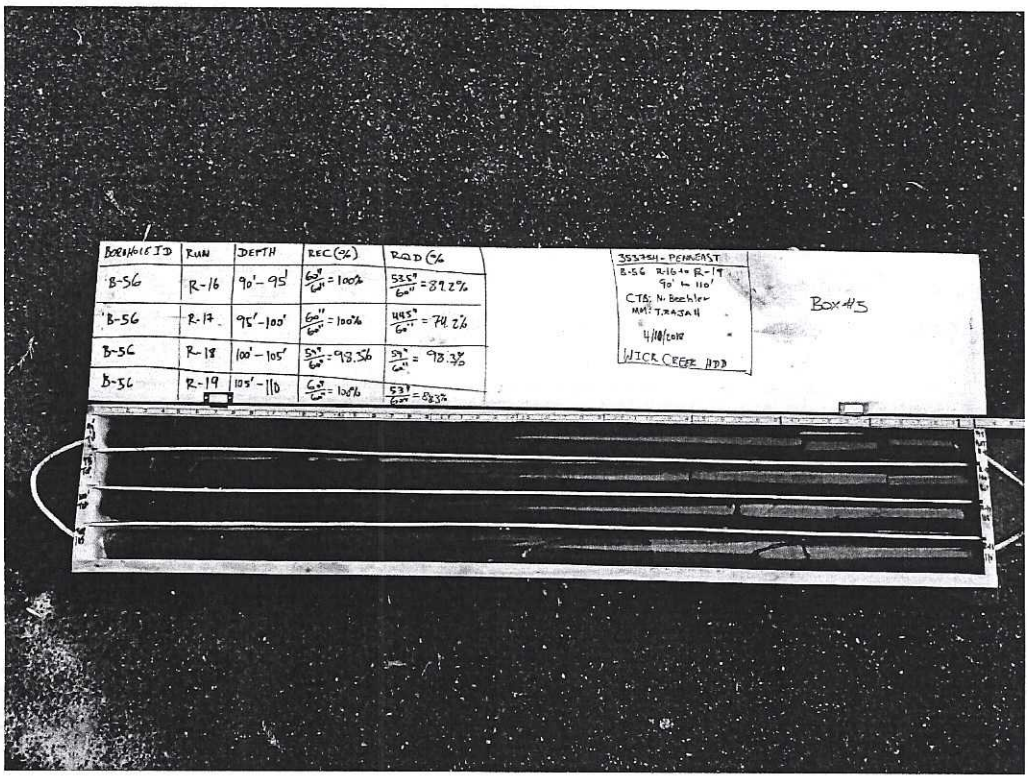


Figure B-56.10
B-56 Box 5 Runs 16-19 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-56

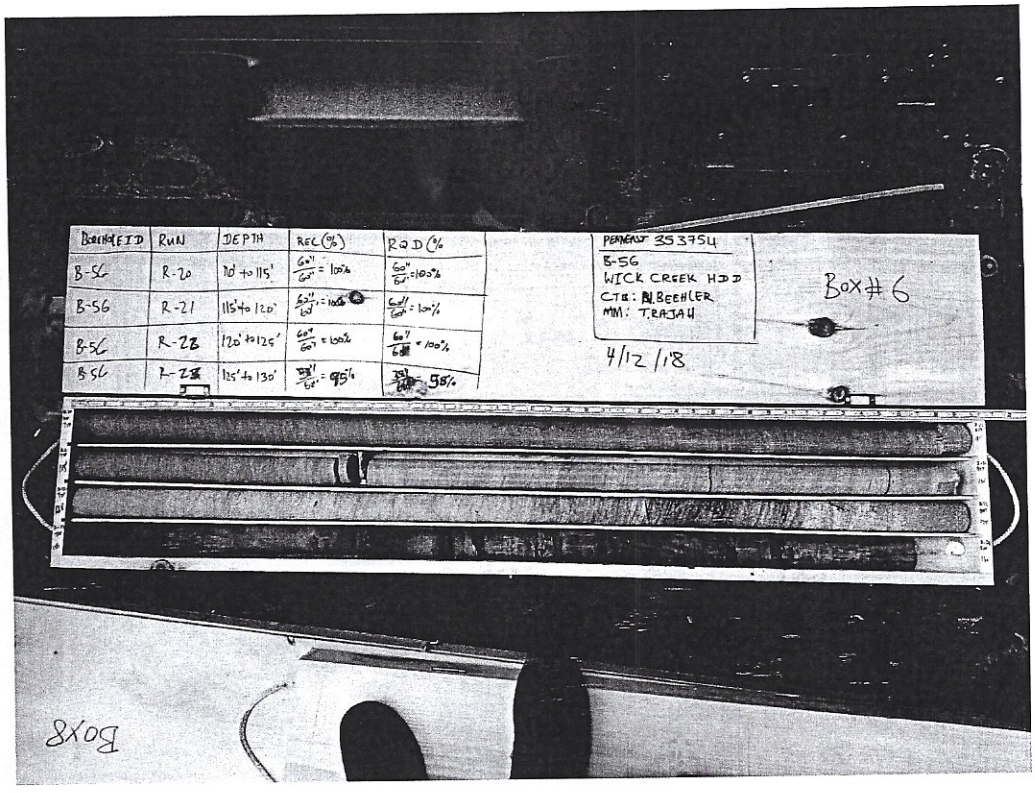


Figure B-56.11
B-56 Box 6 Runs 20-23 Dry

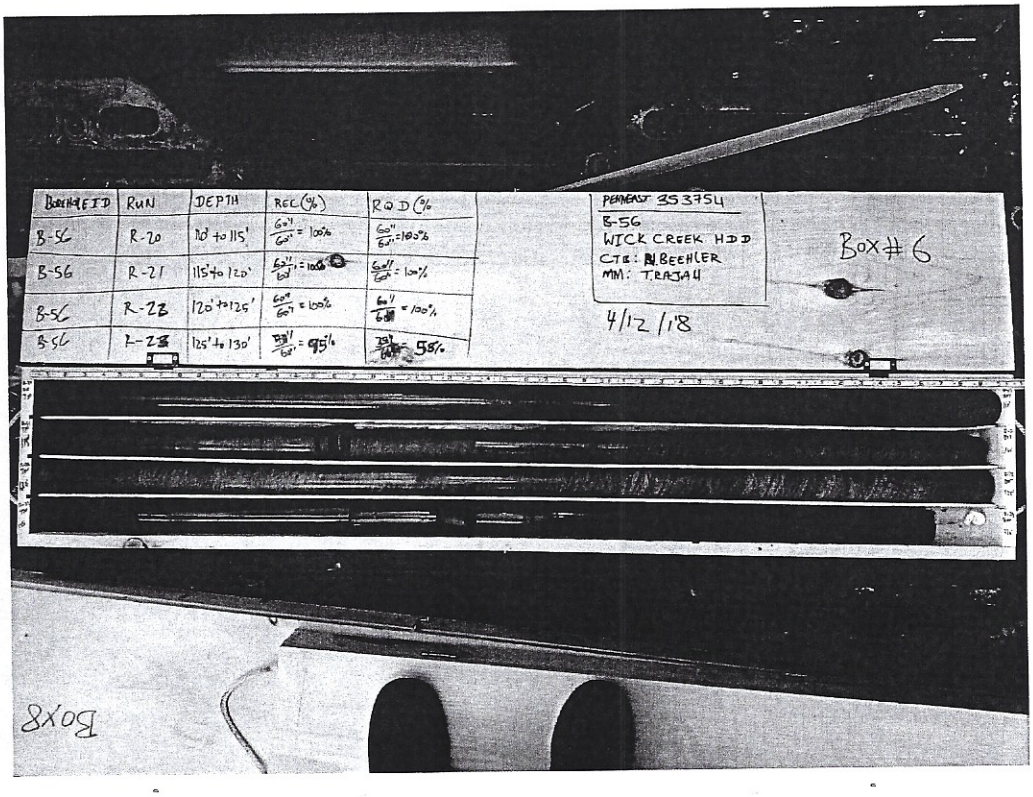


Figure B-56.12
B-56 Box 6 Runs 20-23 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-56

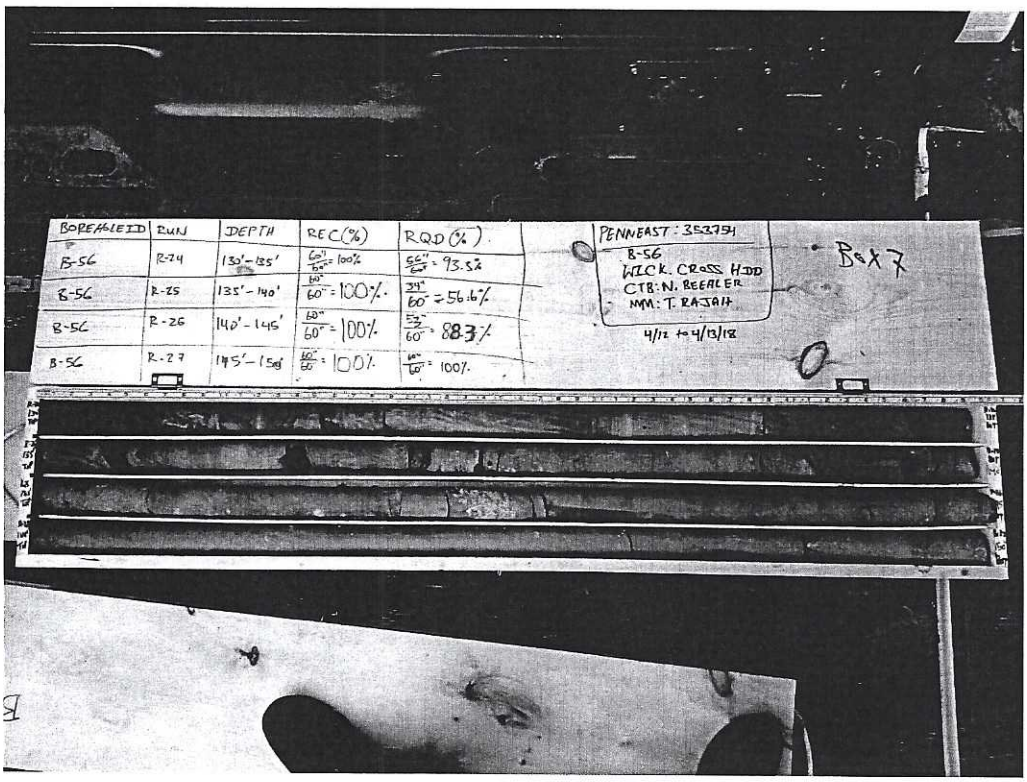


Figure B-56.13
B-56 Box 7 Runs 24-27 Dry

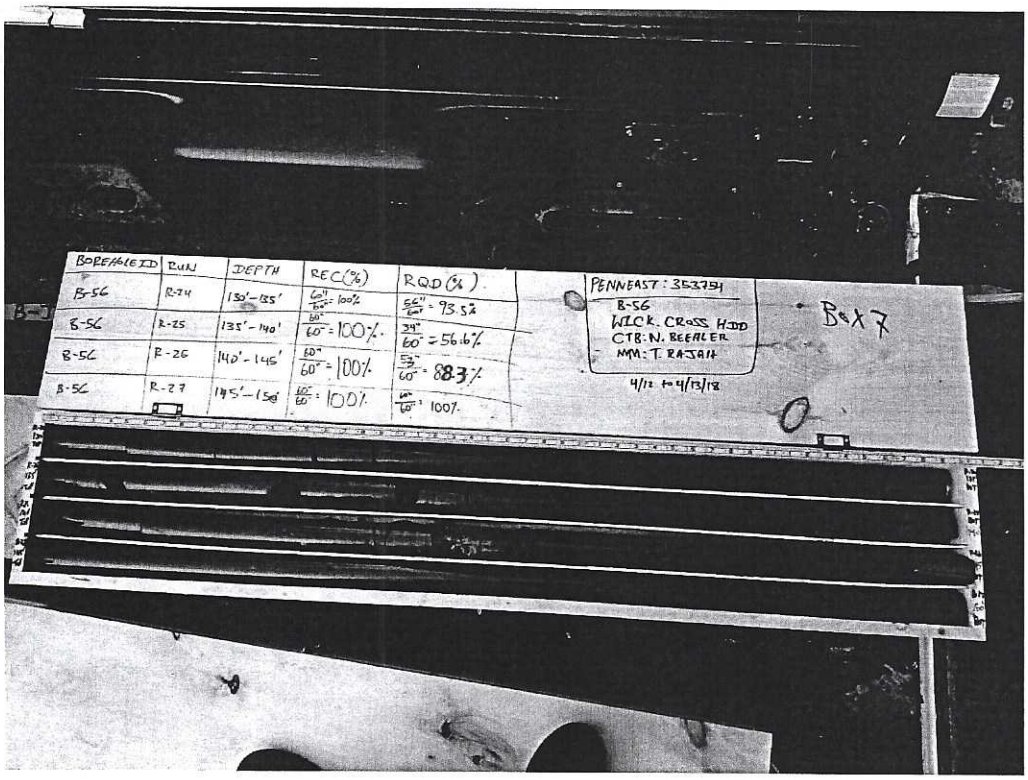


Figure B-56.14
B-56 Box 7 Runs 24-27 Wet

MOTT MACDONALD	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-56

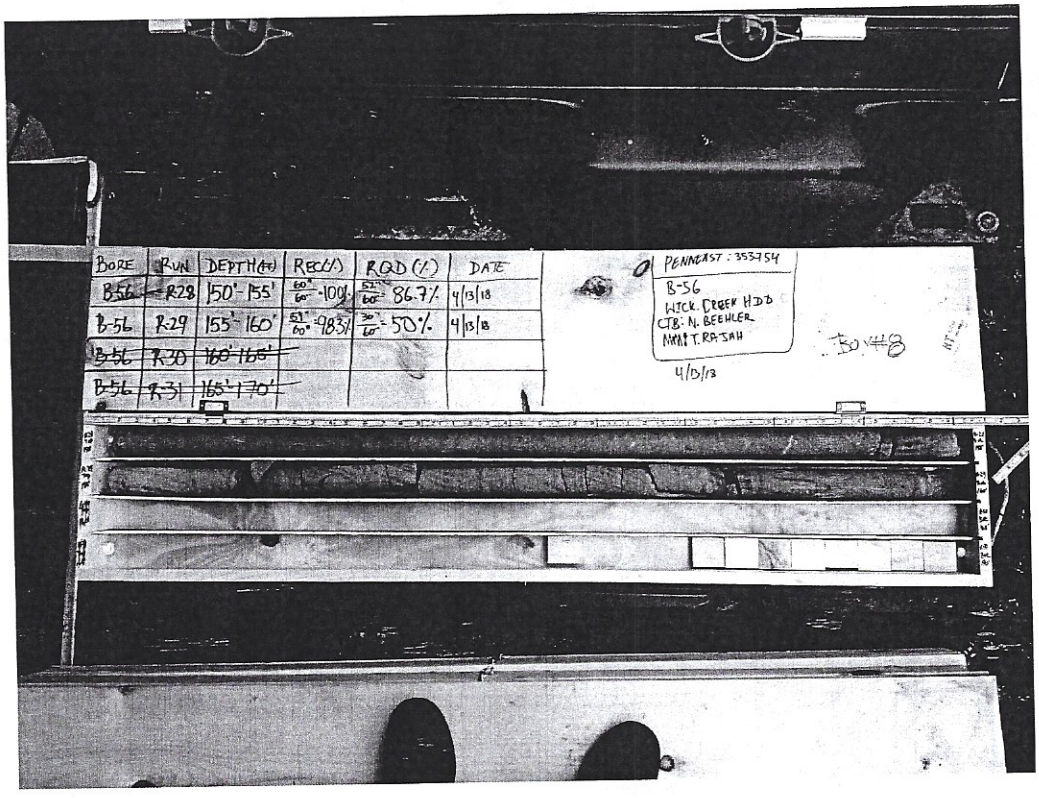


Figure B-56.15
B-56 Box 8 Runs 28-29 Dry

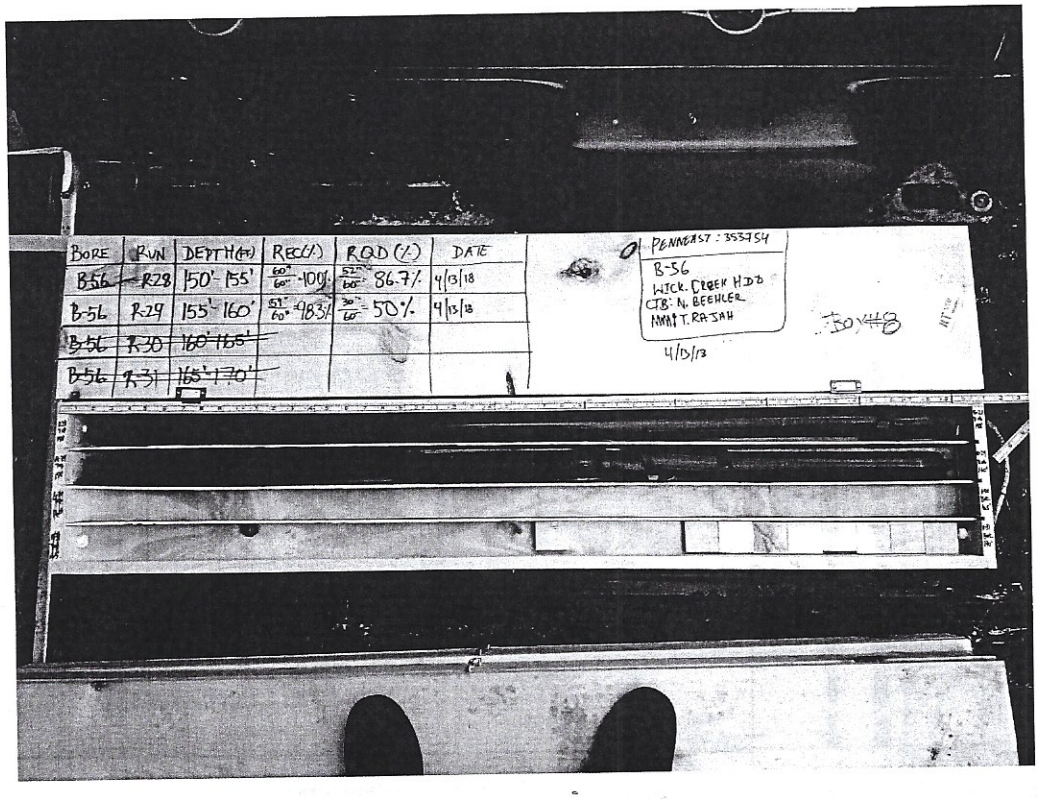


Figure B-56.16
B-56 Box 8 Runs 28-29 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-56

MOTT MACDONALD M M

SOIL BORING LOG

BORING NO.: **B-57**
Page 1 of 1

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Wick Creek, Stockton, NJ	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Kyle Hansen
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	March 8, 2019 at 2:20 pm
Driller/Helper:	Nick Beehler /Miles Neipert	**Date/Time Finished:**	March 11, 2019 at 12:15 pm

Elevation: 204 ft. **Vertical Datum:** NAVD 1988

Boring Location: Adjacent to southeast end of driveway

Coord.: N: **40.431134** E: **-74.968926**

Horizontal Datum: NAD 1983

Item	Casing	Sampler	Core Barrel
Type	HW	SS	NQ2
Length (ft)	5	2	5
Inside Dia. (in.)	4	1.375	2.0
Hammer Wt. (lb.)	140	140	-
Hammer Fall (in.)	30	30	-

Rig Make & Model: CME-55LC

☐ Truck ☐ Tripod ☐ Cat-Head
☐ ATV ☐ Geoprobe ☑ Winch
☑ Track ☐ Air Track ☑ Roller Bit
☐ Skid ☐ ☐ Cutting Head

Hammer Type
☐ Safety
☐ Doughnut
☑ Automatic
☐

Drilling Fluid
☑ Bentonite
☑ Polymer
☑ Water
☐ None

Drill Rod Size:
Casing Advance
Mud Rotary

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Group Symbol	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
	S-1 0.0'- 2.0'	17	1 2 2 2		CL	0.1 1" - TOPSOIL Soft, brownish yellow, Silty CLAY, trace fine Sand, moist (CL)	S	M	M	L	PP = 0.5 tsf
200						3.5					
5	S-2 5.0'- 7.0'	19	7 14 14 13		ML	Very stiff, reddish brown, Clayey SILT with Gravel and coarse to fine Sand, moist (ML)	S	L	L	L	PP = 3.0 tsf
						8.5					
10	S-3 10.0'- 12.0'	19	3 9 9 8		GM	Medium dense, reddish brown GRAVEL with Clay and Silt, moist (GM)	-	-	-	-	
						13.5					
190											
15	S-4 15.0'- 17.0'	9	50 50/1"			Very dense, reddish brown DECOMPOSED ROCK fragments with Clay and Silt, moist	-	-	-	-	
	19.0'-					Top of Rock at 20 feet BGS. See Rock Coring Log.	-	-	-	-	Installed 4-inch casing to 19 feet BGS.
						20.0					

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
3/9/19	7:45	-	4.0	15.0	Dry

Sample Type

O Open End Rod
T Thin-Wall Tube
U Undisturbed Sample
S Split Spoon Sample
G Grab Sample

Notes:
PP = Pocket Penetrometer

Boring No.: **B-57**

Field Test Legend:
Dilatancy: N - None S - Slow R - Rapid
Toughness: L - Low M - Medium H - High
Plasticity: NP - Non-Plastic L - Low M - Medium H - High
Dry Strength: N - None L - Low M - Medium H - High VH - Very High

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

MOTT MACDONALD M M

CORE BORING LOG

BORING NO.: **B-57**
Page 1 of 6

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Wick Creek, Stockton, NJ	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Kyle Hansen
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	March 8, 2019 at 2:20 pm
Driller/Helper:	Nick Beehler /Miles Neipert	**Date/Time Finished:**	March 11, 2019 at 12:15 pm

Elevation: 204 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** Adjacent to southeast end of driveway **Coord.:** N: **40.431134** E: **-74.968926**

Item	Casing	Core Barrel	Core Bit
Type	HW	NQ2	Imp. Diamond
Length (ft)	5	5	3.25
Inside Dia. (in.)	4	2.0	2.0

Horizontal Datum: NAD 1983
Rig Make & Model: CME-55LC
Drilling Method: Wireline

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec (in. / %)	RQD (in / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities Type	Dip	Rgh	Wea	Aper	Infill	Remarks
									SEE TEST BORING LOG FOR OVERBURDEN DETAILS		(See Legend for Rock Description System)						
	1.80	20.0							SILTSTONE, reddish brown, fine grained, highly weathered, medium strong, extremely close to close spaced discontinuities	20.50	J	20	P,R	FR	O	N	Loss of water from 24 to 25 feet BGS.
										20.93	J	23	P,Sm	FR	O	N	
	2.00								21.35' - 21.55' Weathered soft rock								
	2.80		R-1	30 50%	10 17%	R3	H		21.9' - 22.5' Highly Fractured zone, weathered soft rock								
	3.30																
180	3.40	25.0															
25	1.60	25.0							SILTSTONE, reddish brown, fine grained, fresh, weak to medium strong, extremely close to moderately spaced discontinuities								
									25.85' - 26.5' Highly Fractured zone								
	1.70									26.50	J	10	P,R	FR	PO	N	
	2.00		R-2	57 95%	37 62%	R3	SL										
										27.94	J	15	P,R	DG	PO	CL	
	2.30									28.53	J	15	P,Sm	DS	T	N	
	1.40	30.0															
30	1.50	30.0							SILTSTONE, reddish brown, fine grained, slightly weathered, strong, very close to close spaced discontinuities 30' - 32.95' Fractured zone								
	1.40																
	1.50		R-3	60 100%	20 33%	R4	SL			32.97	B	30	S,R	DS	O	N	
	1.80									33.43	B	20	P,Sm	DS	O	N	
170	2.60	35.0								34.27	B	25	P,Sm	FR	O	N	
										34.73	B	30	P,Sm	FR	T	N	
35	1.40	35.0							SILTSTONE with interbedded Sandstone, reddish brown, fine grained, fresh, strong, very close to moderately spaced discontinuities								
										35.57	B	20	P,Sm	FR	T	N	
	1.30									36.35	B	25	P,Sm	FR	PO	N	
	1.60		R-4	60 100%	40 67%	R4	FR										
										37.85	B	20	P,Sm	FR	T	N	
	2.00																
	1.50	40.0															

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
3/9/19	7:45	-	4.0	15.0	

Notes:

CORE BORING LOG
(continued)

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
		40.0							SILTSTONE, reddish brown to light gray, fine grained, fresh, strong, close to wide spaced discontinuities								
	1.40																
	1.60																
	1.60		R-5	60 100%	50 83%	R4	FR			42.00	J	70	P,R	FR	PO	N	
									42.6' - 43.4' Vertical Fracture	42.60	J	15	P,Sm	FR	PO	N	
										42.90	J	80	P,Sm	DS	T	N	
	1.40									43.40	J	10	U,R	FR	O	N	
160	1.50	45.0															
45	1.40	45.0							SILTSTONE, brownish yellow to light gray, fine grained, slightly weathered, strong, very close to close spaced discontinuities								
									45' - 45.7' Iron staining 45.33' - 45.5' Highly Weathered Gravel seam	45.70	J	25	P,Sm	DS	T	Fe	
	1.00								46.35' - 50' Iron staining throughout	46.35	J	20	P,Sm	DS	T	CL	
	1.30		R-6	60 100%	20 33%	R4	SL										
	1.20									48.07	J	5	P,R	DS	PO	Fe	
	1.10	50.0								49.10	J	20	S,R	DS	PO	Fe	
50									50.0								
	1.00	50.0							SANDSTONE, brownish yellow to reddish brown, medium grained, moderately weathered to fresh, strong, extremely close to wide spaced discontinuities 50' - 51.3' Highly Weathered zone								Color change of water to light brown. Loss of water from 50 to 55 feet BGS.
	1.00									51.47	J	15	P,Sm	FR	T	N	
	1.10		R-7	51 85%	30 50%	R4	M										
	1.10																
150	2.40	55.0															
55	0.80	55.0							SANDSTONE, gray to reddish brown, medium grained, fresh, strong, close to moderately spaced discontinuities	55.55	J	5	P,R	FR	O	N	Loss of water from 56 to 60 feet BGS.
	1.90								56.8 56.45' - 56.8' Highly Weathered Gravel seam								
	2.70		R-8	59 98%	45 75%	R4	FR		SILTSTONE, reddish brown, fine grained, slightly weathered, strong, close spaced discontinuities	57.85	J	20	P,Sm	FR	T	N	
	3.00									58.40	J	10	U,R	FR	T	N	
										58.95	J	10	P,Sm	FR	PO	N	
	1.90	60.0															
60	2.50	60.0							SILTSTONE, reddish brown, fine grained, slightly weathered, strong, very close to moderately spaced discontinuities								Loss of water from 60 to 62 feet BGS.
	2.30									61.35	J	5	P,R	FR	O	N	
	1.70		R-9	54 90%	30 50%	R4	SL			62.47	J	25	P,R	FR	PO	N	
										63.05	J	20	U,Sm	FR	T	N	
	1.00																
140	1.10	65.0															

NOTES:

PROJECT NO.: 353754

Boring No.: B-57

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: **B-57**
Page 3 of 6

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	1.10	65.0							SILTSTONE, reddish brown, very fine grained, fresh, strong, close to wide spaced discontinuities Calcareous inclusions throughout	65.88	J	10	P,Sm	FR	PO	N	
	1.10									66.05	J	20	P,Sm	FR	T	N	
	1.30		R-10	58 97%	51 85%	R4	FR										
	1.30																
	1.00	70.0								69.05	J	25	U,Sm	FR	T	N	
										69.33	J	15	P,Sm	FR	T	N	
70	1.40	70.0							SILTSTONE, reddish brown, very fine grained, fresh, strong, close to moderately spaced discontinuities Calcareous inclusions throughout								Loss of water from 70 to 75 feet BGS.
	1.10									70.87	J	10	U,R	FR	T	N	
	1.10		R-11	60 100%	57 95%	R4	FR			71.27	J	20	P,Sm	FR	T	N	
	1.10									72.20	J	20	P,Sm	FR	T	N	
130	1.30	75.0								73.40	J	10	P,Sm	FR	PO	N	
75	1.40	75.0							SILTSTONE, reddish brown, very fine to fine grained, slightly weathered, medium strong, extremely close to moderately spaced discontinuities								Loss of water from 75 to 80 feet BGS.
	1.50								76.6' - 76.9' Highly Fractured zone	76.59	J	10	P,R	FR	PO	N	
										76.90	J	15	P,R	FR	T	N	
	1.20		R-12	60 100%	43 72%	R3	SL			77.62	J	10	P,Sm	FR	T	N	
	1.20								78.23' - 78.52' Fractured zone	78.53	J	10	P,Sm	FR	T	N	
	1.10	80.0								79.05	J	5	P,R	FR	T	N	
										79.13	J	10	P,Sm	DG	PO	N	
80	1.60	80.0						80.0	SANDSTONE, reddish brown to gray, very fine grained, slightly weathered, very strong Calcareous inclusions throughout 80' - 80.9' Vertical Fracture								Loss of water from 80 to 85 feet BGS.
	1.10									80.90	J	20	P,R	FR	T	N	
										81.40	J	25	P,Sm	FR	T	N	
	1.00		R-13	60 100%	58 97%	R5	SL										
	1.00																
120	1.20	85.0							83.97' - 84.1' Highly Fractured zone	83.97	J	10	P,R	DS	O	N	
										84.10	J	20	P,R	DS	O	N	
85	1.30	85.0							SANDSTONE, reddish brown to gray, very fine grained, fresh, very strong, close to wide spaced discontinuities Calcareous inclusions throughout 85.3' - 86.2' Vertical Calcite vein								Loss of water from 85 to 90 feet BGS.
	1.90																
	1.30		R-14	59 98%	54 90%	R5	FR			86.96	J	5	U,Sm	FR	PO	N	
	1.30																
	1.00	90.0								89.30	J	20	P,R	FR	T	N	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-57**

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	1.20	90.0							SANDSTONE, reddish brown to gray, very fine to fine grained, fresh, very strong, close to moderately spaced discontinuities Calcareous inclusions throughout								Loss of water from 90 to 95 feet BGS.
	1.40																
									91.67' - 92.2' Vertical Fracture	91.66	J	10	P,R	FR	O	N	
	2.00		R-15	60 100%	54 90%	R5	FR			92.15	J	10	P,Sm	FR	T	N	
										92.94	J	10	P,R	DG	T	ML	
	1.60									93.45	J	10	P,R	FR	PO	N	
110	1.20	95.0															
95	1.70	95.0							SANDSTONE, reddish brown to gray, very fine to fine grained, fresh, very strong, close to moderately spaced discontinuities	95.65	J	20	P,R	DG	O	ML	Loss of water from 95 to 100 feet BGS. Used approximately 2200 gallons from 0 to 95 feet BGS.
	1.70																
										96.65	J	10	P,R	FR	PO	N	
	1.10		R-16	55 92%	45 75%	R5	FR										
										97.75	J	20	P,R	DS	PO	N	
	1.60																
										98.74	J	15	P,R	FR	O	N	
	1.70	100.0															
100	0.50	100.0							SANDSTONE, reddish brown to gray, fine to medium grained, fresh, strong, wide spaced discontinuities Calcite infilling in healed joints	100.20	B	30	U,R	DS	T	N	Loss of water from 100 to 105 feet BGS.
	1.50																
	1.70		R-17	58 97%	55 92%	R4	FR										
	1.30																
100	1.60	105.0															
105	0.70	105.0							SANDSTONE, reddish brown to gray, fine to medium grained, fresh, medium strong, moderately spaced discontinuities	105.10	B	15	U,R	DG	O	CL	Loss of water from 105 to 110 feet BGS.
	1.00																
										106.60	J	75	S,R	FR	T	N	
	1.70		R-18	59 98%	43 72%	R3	FR			107.50	J	25	U,R	FR	T	N	
										107.90	J	75	S,R	FR	T	N	
	1.40									108.25	B	20	U,R	DE	PO	CL	
										108.75	J	70	S,R	FR	VT	N	
	1.40	110.0															
110	1.00	110.0							SANDSTONE with interbedded Shale, brown to reddish gray, medium to very fine grained, fresh, medium strong, moderately spaced discontinuities	110.10	J	50	S,R	FR	PO	N	Loss of water from 110 to 115 feet BGS.
	1.30								111.1' - 112' Fractured zone	111.10	J	80	P,R	FR	VT	N	
	1.25		R-19	60 100%	46 77%	R3	FR			112.70	B	15	S,Sm	FR	T	N	
	1.30									113.50	B	30	U,Sm	FR	VT	N	
90	1.50	115.0															

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-57**

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: B-57

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	2.30	115.0							SANDSTONE, gray to reddish brown, fine to medium grained, slightly weathered to fresh, medium strong, very close to close spaced discontinuities	115.70	J	80	S,R	DS	O	CL	Loss of water from 115 to 120 feet BGS.
	1.60																
	1.40		R-20	52 87%	17 28%	R3	SL										
	1.30									118.10	J	25	S,R	FR	PO	N	
	1.00	120.0								118.60	J	40	S,R	FR	T	N	
120	2.10	120.0							SANDSTONE, reddish brown, fine grained, very strong, moderate to close spaced discontinuities								Loss of water from 120 to 125 feet BGS.
	1.00																
	1.15		R-21	59 98%	57 95%	R4	FR										
	1.50																
80	1.20	125.0								124.25	J	25	S,Sm	FR	PO	N	
125	2.30	125.0							SANDSTONE, reddish brown, fine grained, very strong, moderate to close spaced discontinuities								Loss of water from 125 to 130 feet BGS.
	1.25																
	1.30		R-22	56 93%	20 33%	R5	SL			126.80	J	25	P,R	FR	VT	N	
	1.40									128.00	B	15	U,R	FR	O	N	
	1.15	130.0							128.6' - 129.7' Fractured zone								
130	1.00	130.0							SANDSTONE, reddish brown, fine grained, fresh, very strong, wide spaced discontinuities								Loss of water from 130 to 135 feet BGS.
	0.45																
	1.10		R-23	60 100%	60 100%	R5	FR			132.80	J	85	P,R	FR	VT	Ca	
	1.00																
70	1.00	135.0															
135	1.00	135.0							SANDSTONE, reddish brown to gray, fine grained, fresh, strong, wide spaced discontinuities								Loss of water from 135 to 140 feet BGS.
	1.25																
	1.30		R-24	60 100%	60 100%	R4	FR										
	1.60									138.55	B	25	P,R	FR	VT	N	
	0.75	140.0								139.20	J	75	S,R	FR	VT	N	

NOTES:

PROJECT NO.: 353754

Boring No.: B-57

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: **B-57**
Page **6** of **6**

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	1.05	140.0							SANDSTONE, reddish brown to gray, fine grained, fresh, medium strong, wide spaced discontinuities								Loss of water from 140 to 145 feet BGS.
	1.20																
	1.75		R-25	57 95%	57 95%	R3	FR										
	2.00																
60	1.15	145.0															
145	1.40	145.0							SANDSTONE, reddish brown to gray, fine to medium grained, fresh to slightly weathered, medium strong, very close to moderately spaced discontinuities	145.65	J	20	U,R	FR	VT	N	Loss of water from 145 to 150 feet BGS.
										145.90	J	30	S,R	FR	T	N	
	1.25								145' - 147.5' Crossbeds with light gray Sand.								
										146.70	J	45	P,R	FR	PO	N	
	1.10		R-26	60 100%	38 63%	R3	FR										
	1.20																
	1.20									149.00	J	85	S,R	DS	T	N	
150		150.0							150.0								
									End of Boring at 150 feet BGS. Borehole grouted with cement and bentonite holeplug.								
50																	
155																	
160																	
40																	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-57**

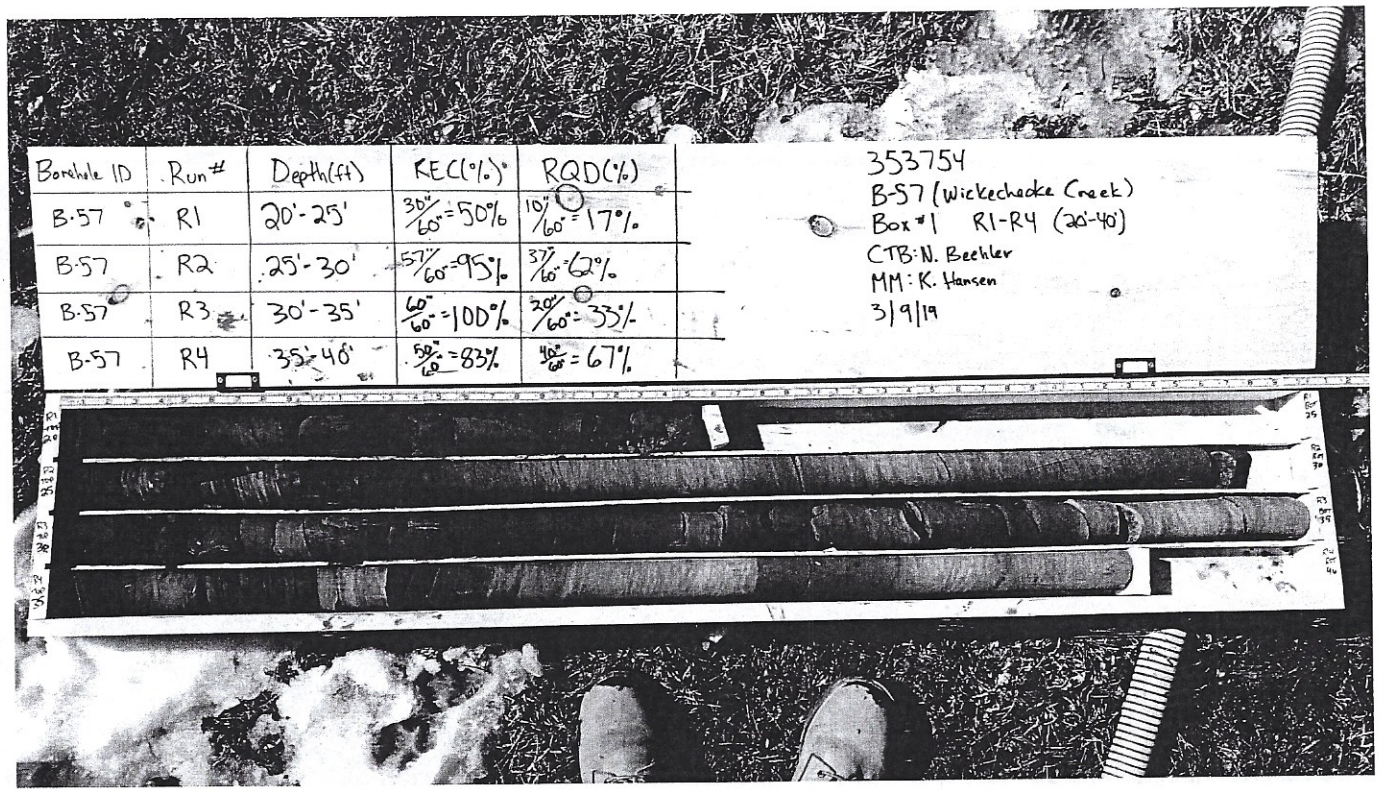


Figure B-57.1
B-57 Box 1 R1-R4 Dry

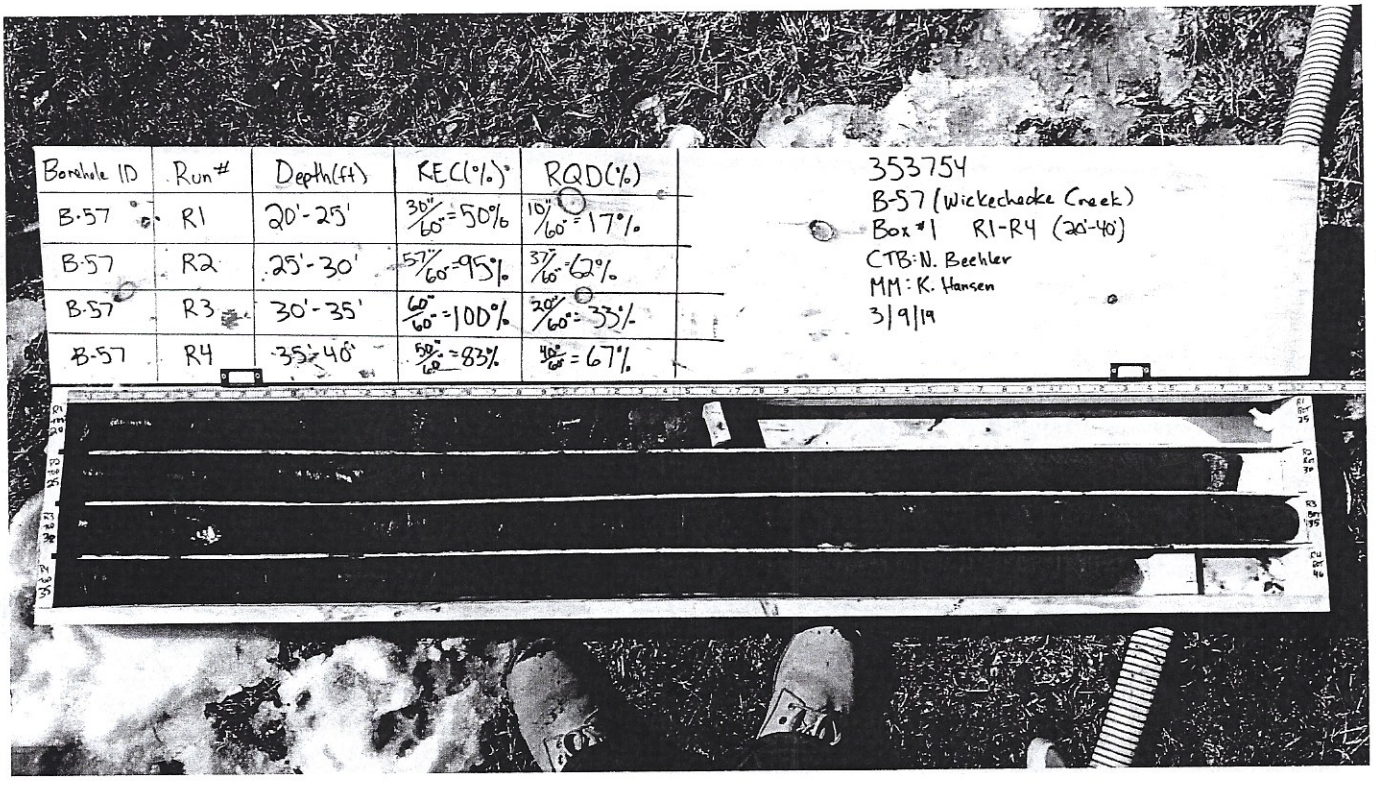


Figure B-57.2
B-57 Box 1 R1-R4 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-57

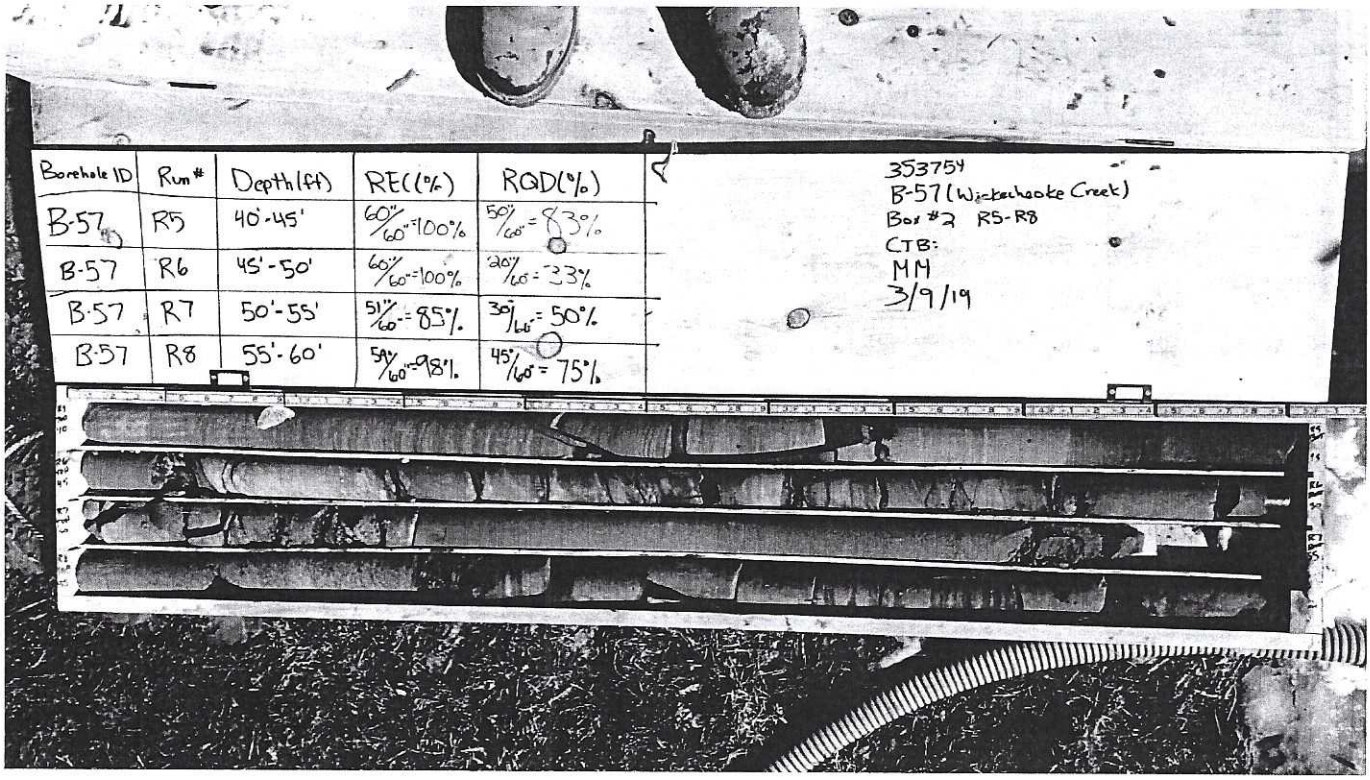


Figure B-57.3
B-57 Box 2 R5-R8 Dry

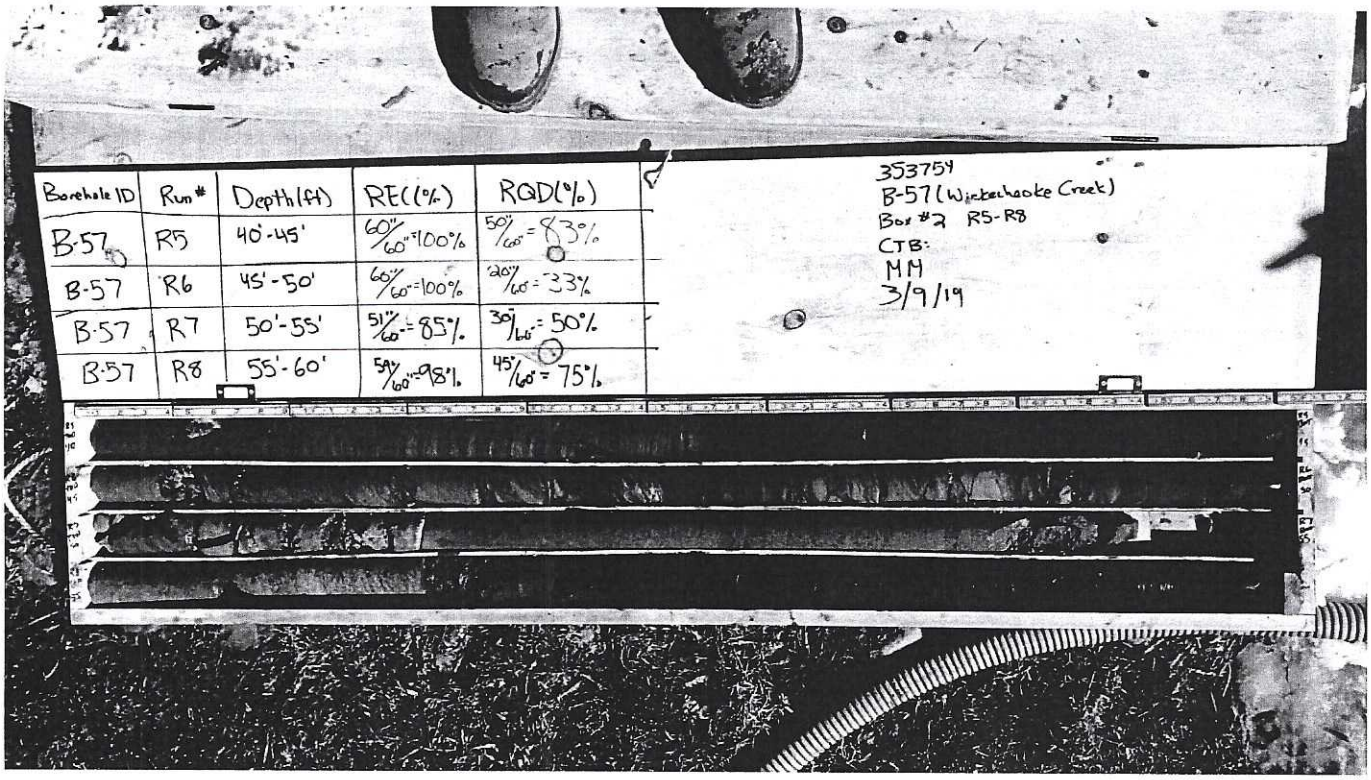


Figure B-57.4
B-57 Box 2 R5-R8 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-57

Figure B-57.5
B-57 Box 3 R9-R12 Dry

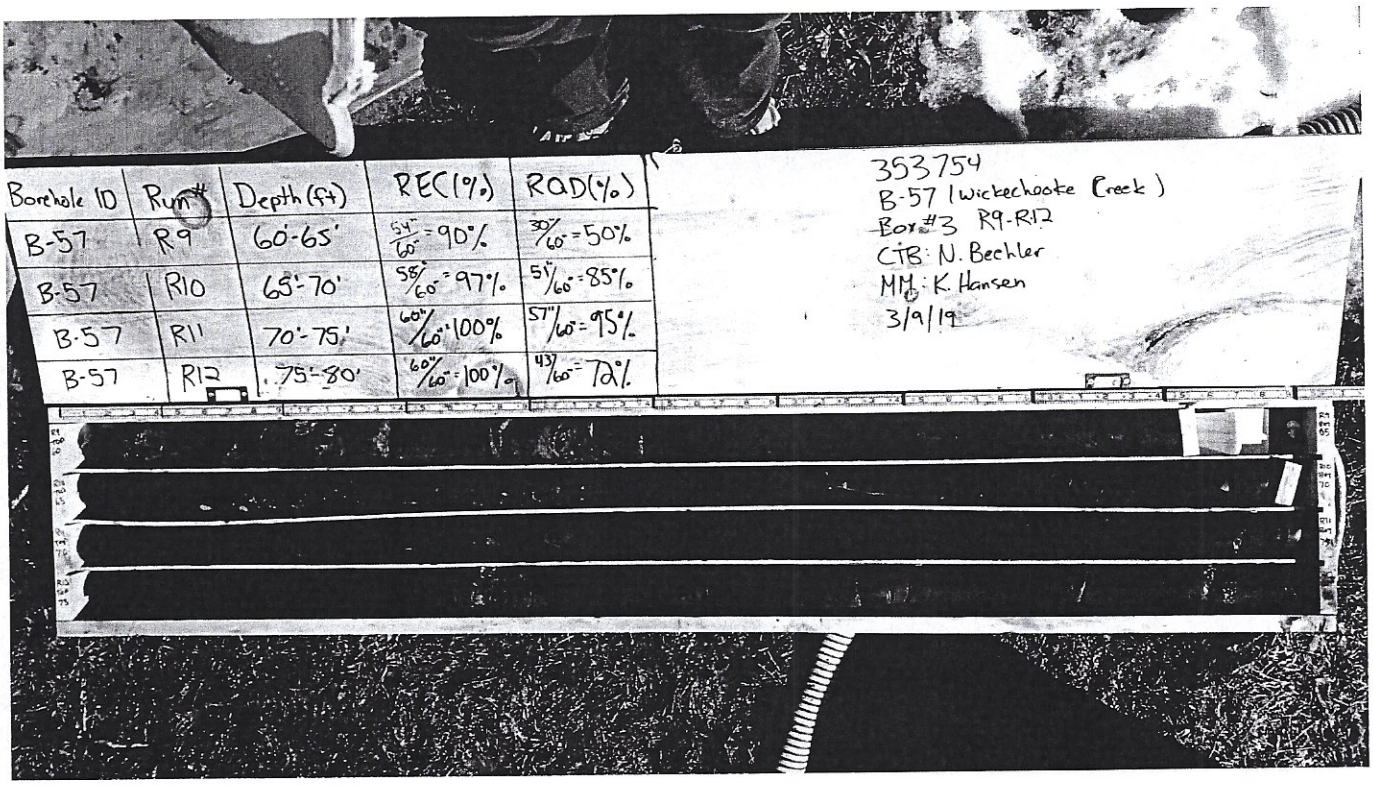


Figure B-57.6
B-57 Box 3 R9-R12 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-57

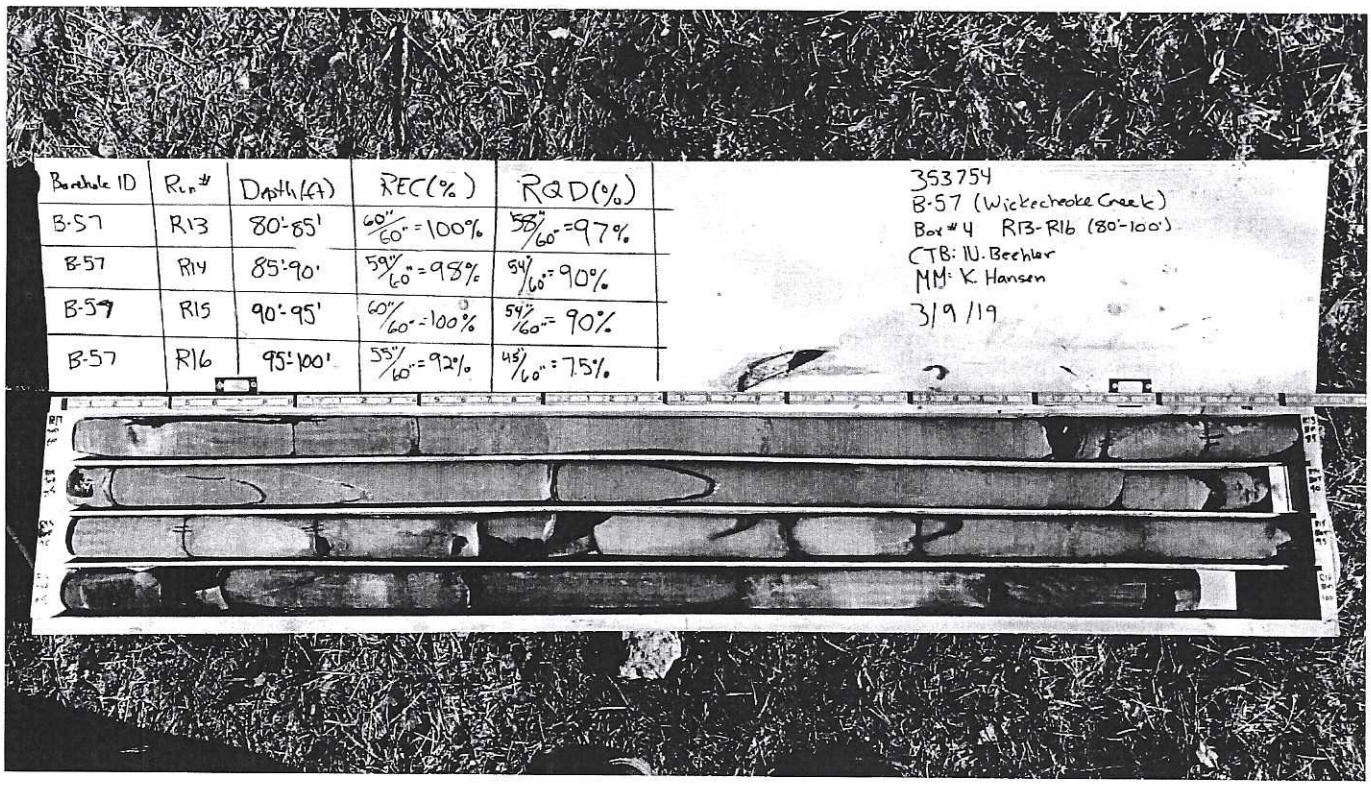


Figure B-57.7
B-57 Box 4 R13-R16 Dry

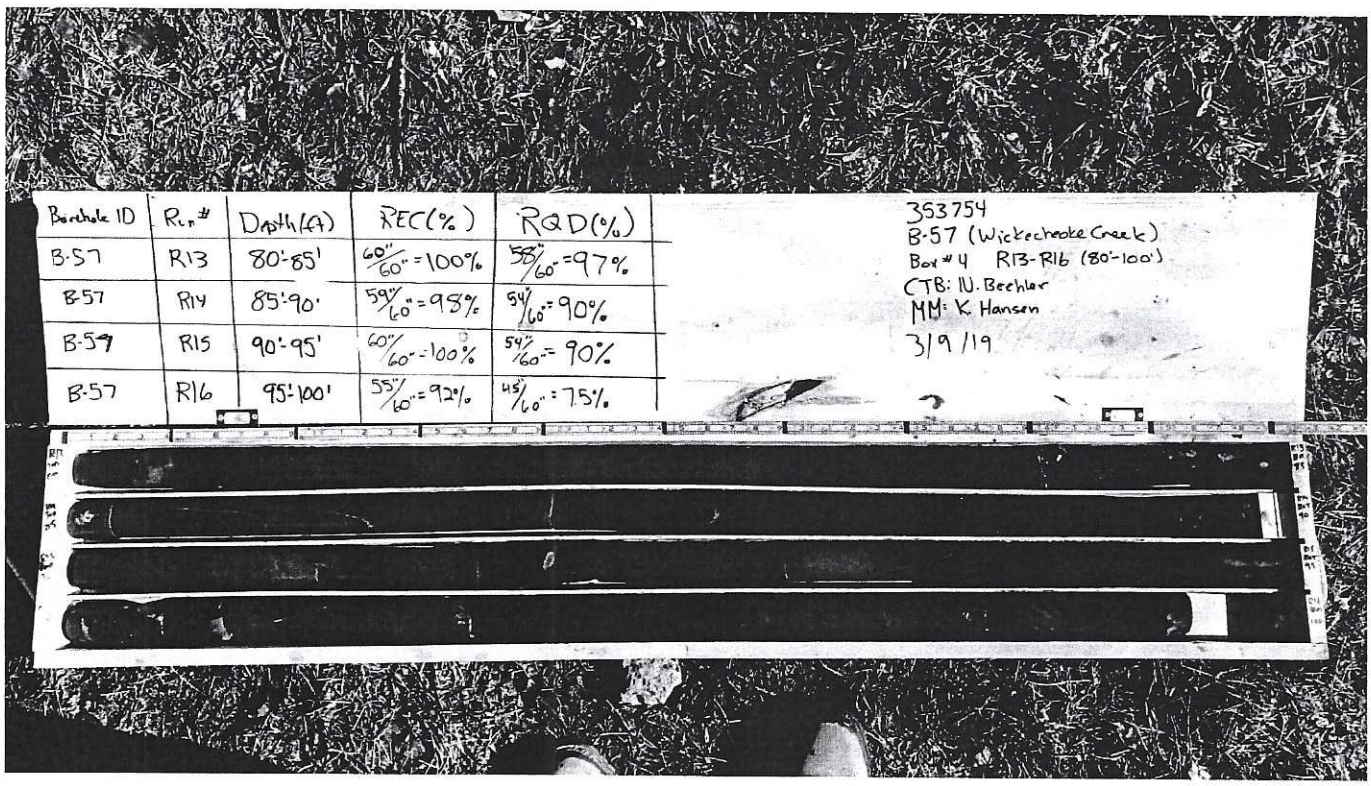


Figure B-57.8
B-57 Box 4 R13-R16 Wet

MOTT MACDONALD	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-57

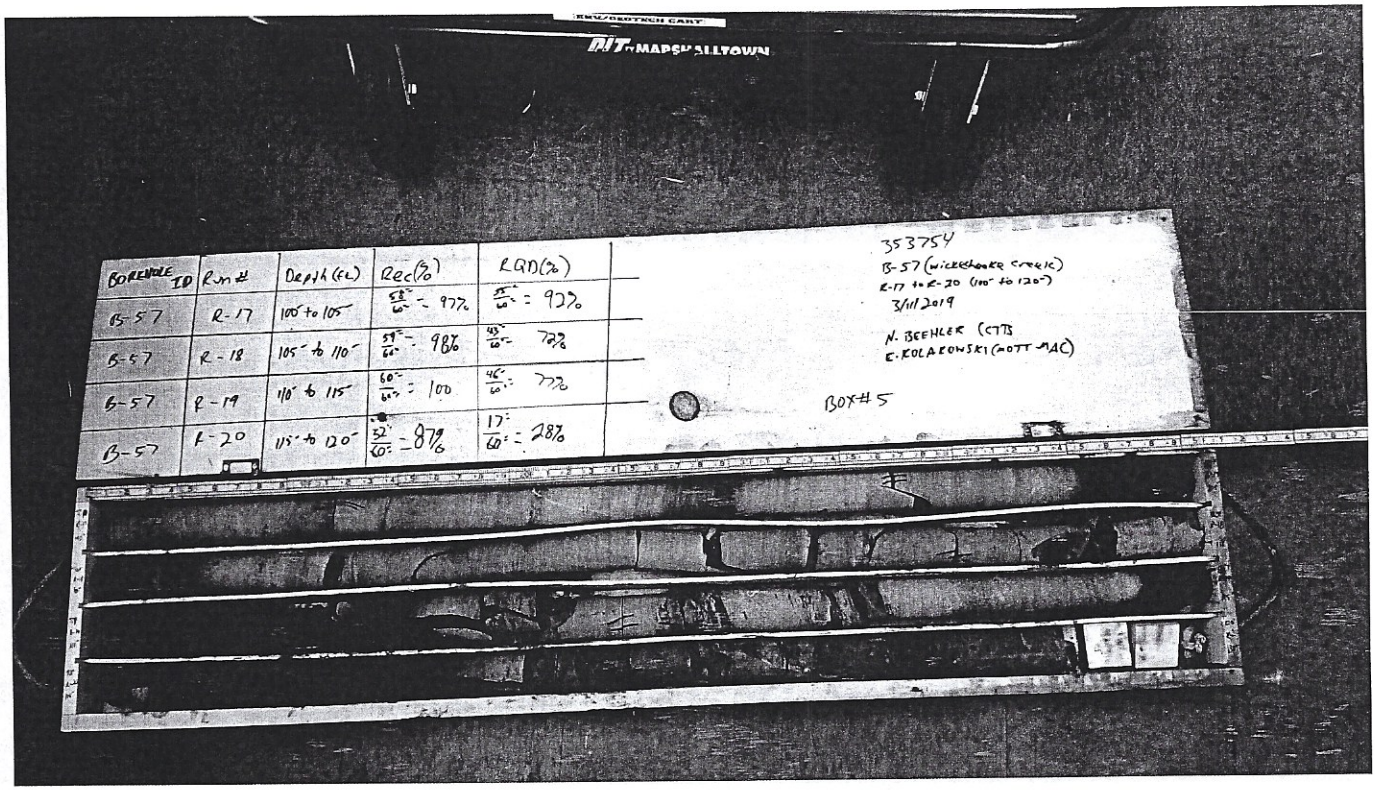


Figure B-57.9
B-57 Box 5 R17-R20 Dry

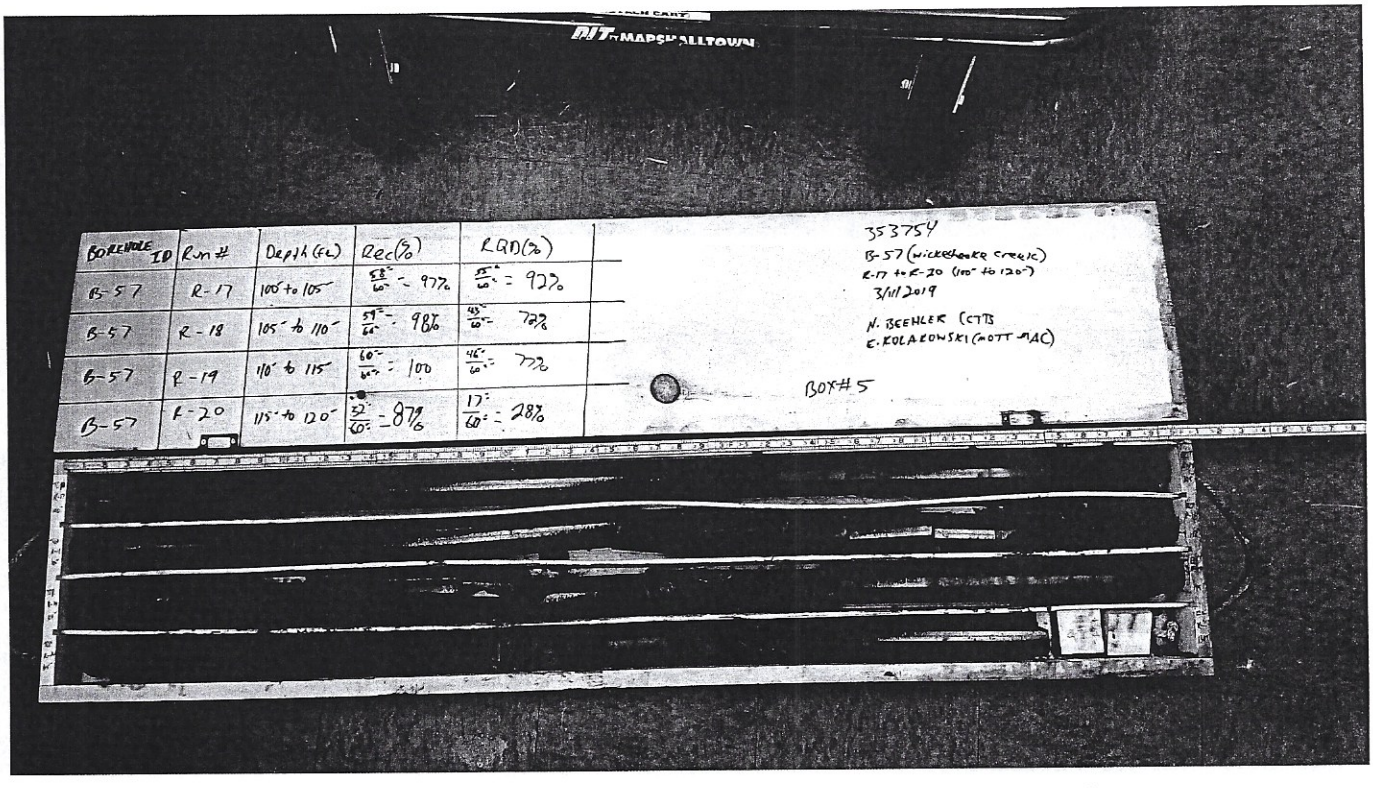


Figure B-57.10
B-57 Box 5 R17-R20 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-57

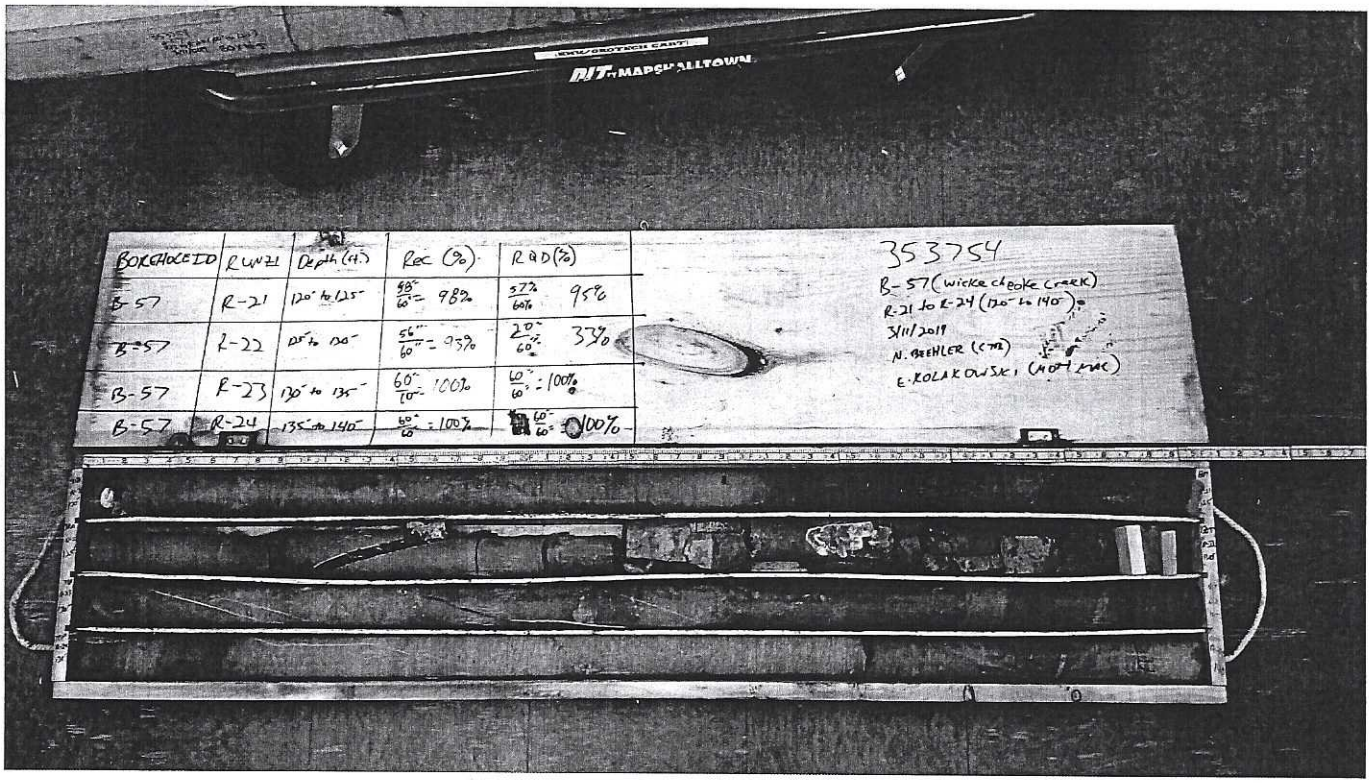


Figure B-57.11
B-57 Box 6 R21-R24 Dry

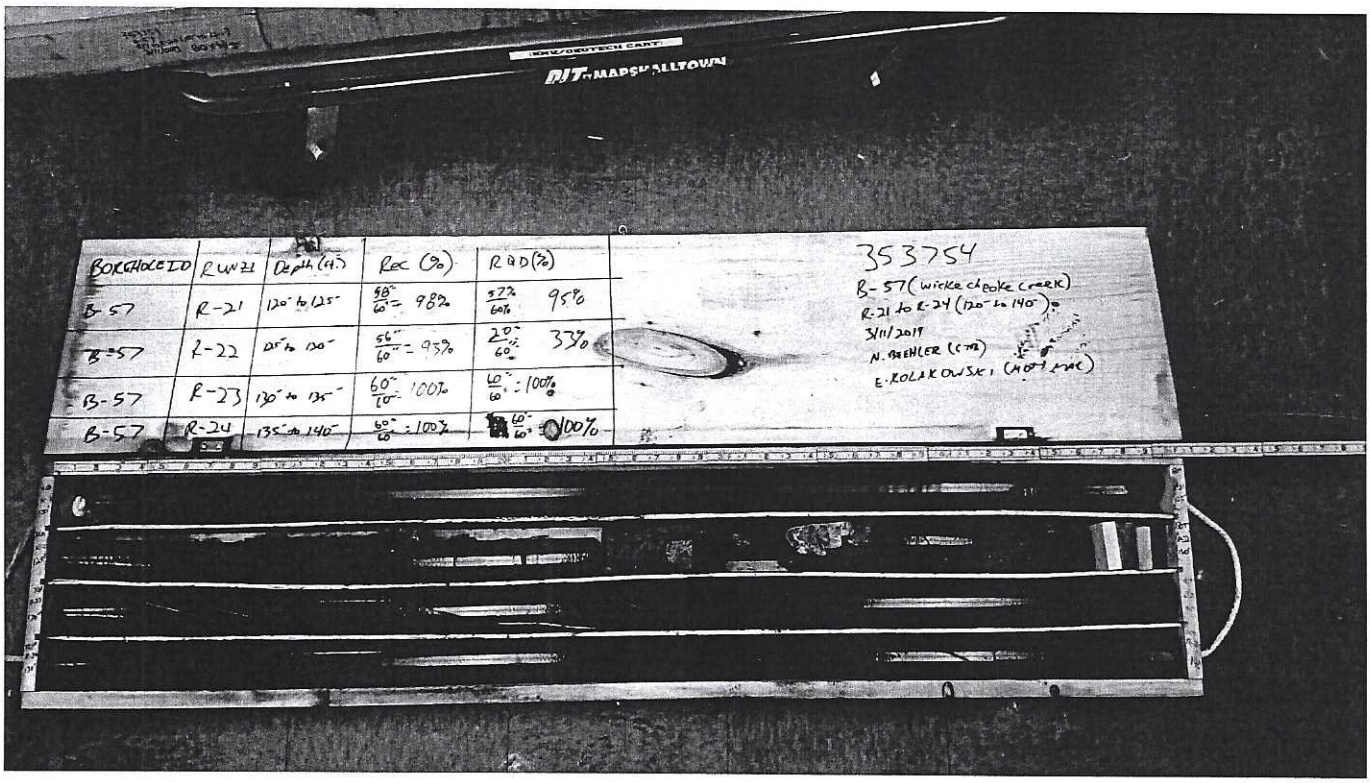


Figure B-57.12
B-57 Box 6 R21-R24 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-57

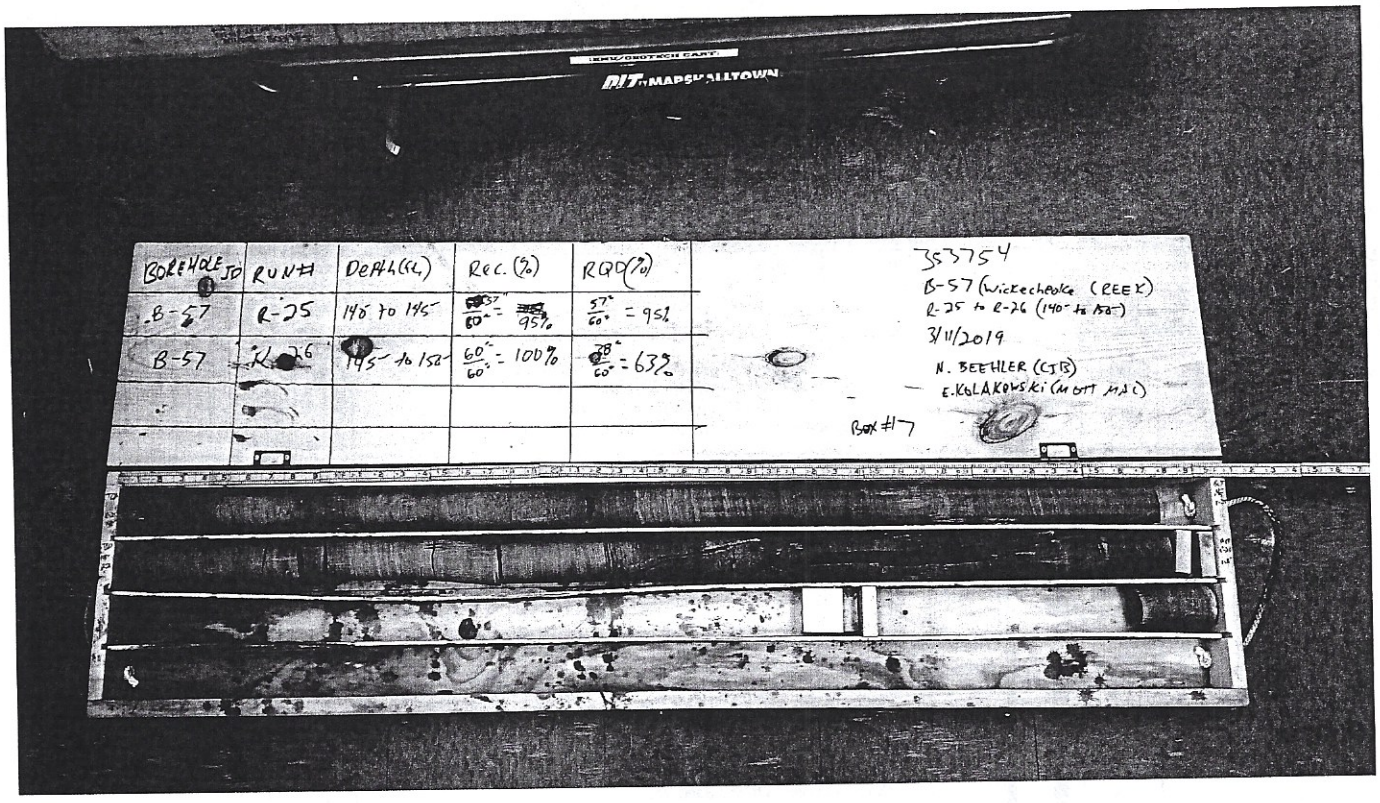


Figure B-57.13
B-57 Box 7 R25-R26 Dry

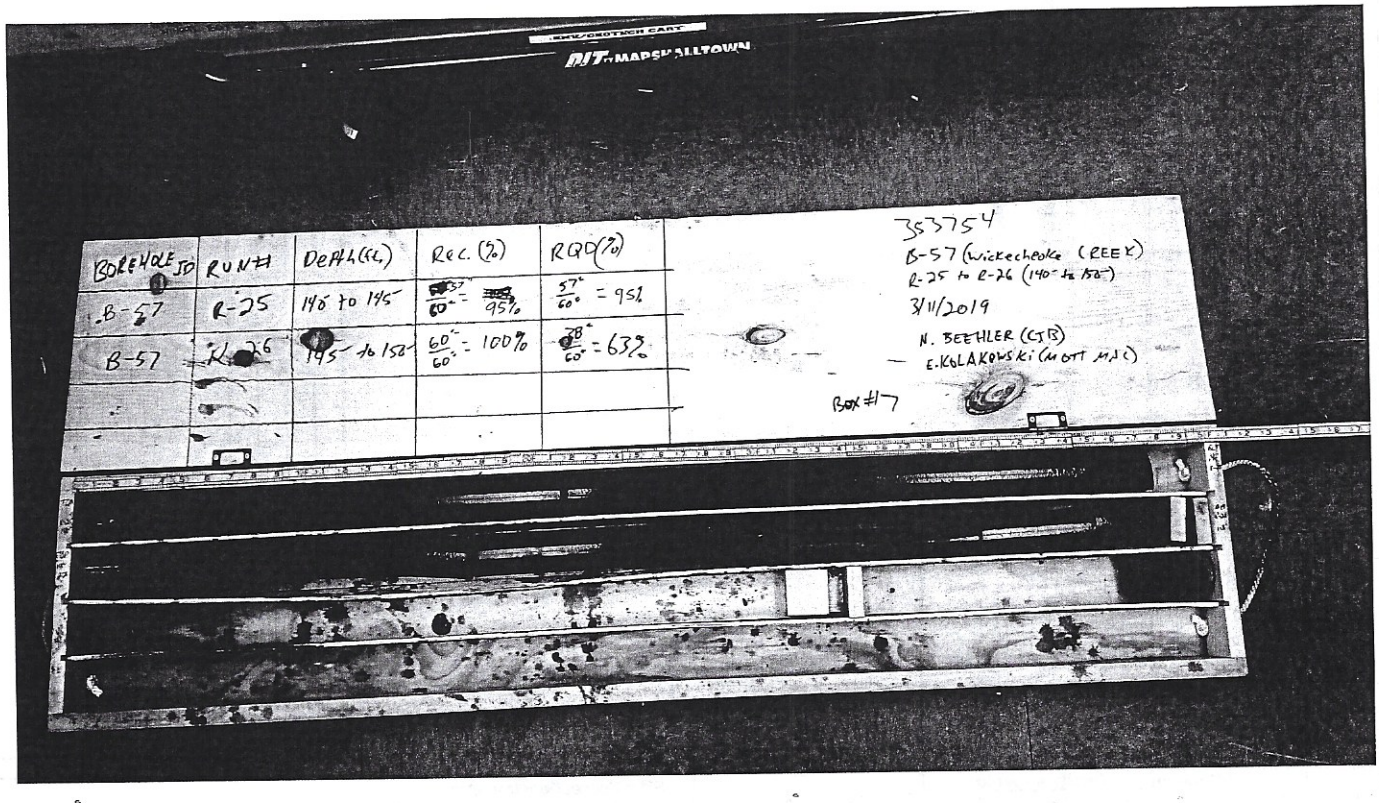


Figure B-57.14
B-57 Box 7 R25-R26 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-57

MOTT MACDONALD M M

SOIL BORING LOG

BORING NO.: **B-WICK-1**
Page 1 of 1

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Wick Creek, Stockton, NJ	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Kyle Hansen
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	March 5, 2019 at 12:45 pm
Driller/Helper:	Nick Beehler /Miles Neipert	**Date/Time Finished:**	March 8, 2019 at 11:35 am

Elevation: 247 ft. **Vertical Datum:** NAVD 1988

Boring Location: Near tree line adjacent to power lines

Coord.: N: **40.429655** E: **-74.967493**

Horizontal Datum: NAD 1983

Item	Casing	Sampler	Core Barrel
Type	HW	SS	NQ2
Length (ft)	5	2	5
Inside Dia. (in.)	4	1.375	2.0
Hammer Wt. (lb.)	140	140	-
Hammer Fall (in.)	30	30	-

Rig Make & Model: CME-55LC

☐ Truck ☐ Tripod ☐ Cat-Head
☐ ATV ☐ Geoprobe ☑ Winch
☑ Track ☐ Air Track ☑ Roller Bit
☐ Skid ☐ ☐ Cutting Head

Hammer Type
☐ Safety
☐ Doughnut
☑ Automatic
☐

Drilling Fluid
☐ Bentonite
☐ Polymer
☑ Water
☐ None

Drill Rod Size: / **Casing Advance**
Mud Rotary

Depth/ Elev. (ft)	Sample No. / Interval (ft)	Rec. (in)	Sample Blows per 6"	Stratum Graphic	USCS Group Symbol	Visual - Manual Identification & Description (Density/consistency, color, Group Name, constituents, particle size, structure, moisture, optional descriptions, geologic interpretation, Symbol)	Field Tests: Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
	S-1 0.0'- 2.0'	18	2 1 3 5		CL	Soft, reddish brown, Silty CLAY, trace fine Sand, moist (CL)	S	L	L	L	PP = 1.75 tsf
						3.5					
5	S-2 5.0'- 7.0'	9	41 36 46 46			Very dense, reddish brown, DECOMPOSED ROCK fragments with Gravel and coarse to fine Sand, dry	-	-	-	-	
240	8.0'-						-	-	-	-	Rapid water loss at 8 feet BGS while driving casing to 8 feet BGS.
10	S-3 10.0'- 12.0'	2	50/2"			Very dense, reddish brown, DECOMPOSED ROCK fragments with Gravel and coarse to fine Sand, dry	-	-	-	-	Rapid water loss while driving casing to 11 feet BGS.
						12.0					
						Top of Rock at 12 feet BGS. See Rock Coring Log.					
15											
230											

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
3/6/19	9:00	-	11.0	12.0	Dry
3/7/19	9:45	-	11.0	23.0	17.6
3/8/19	9:26	-	19.0	70.0	17.33

Sample Type

O Open End Rod
T Thin-Wall Tube
U Undisturbed Sample
S Split Spoon Sample
G Grab Sample

Notes:

PP = Pocket Penetrometer
TV = Torvane

Boring No.: **B-WICK-1**

Field Test Legend:
Dilatancy: N - None S - Slow R - Rapid
Toughness: L - Low M - Medium H - High
Plasticity: NP - Non-Plastic L - Low M - Medium H - High
Dry Strength: N - None L - Low M - Medium H - High VH - Very High

NOTES: 1.) "ppd" denotes soil sample average diametral pocket penetrometer reading. 2.) "ppa" denotes soil sample average axial pocket penetrometer reading.
3.) Maximum Particle Size is determined by direct observation within limitations of sampler size. 4.) Soil identifications and field tests based on visual-manual methods per ASTM D2488.

MOTT MACDONALD M M

CORE BORING LOG

BORING NO.: **B-WICK-1**
Page 1 of 4

Project:	PennEast Pipeline Project	**Project No.:**	353754
Location:	Wick Creek, Stockton, NJ	**Project Mgr:**	Vatsal Shah
Client:	PennEast Pipeline	**Field Eng. Staff:**	Kyle Hansen
Drilling Co.:	Craig Test Boring Co., Inc.	**Date/Time Started:**	March 5, 2019 at 12:45 pm
Driller/Helper:	Nick Beehler /Miles Neipert	**Date/Time Finished:**	March 8, 2019 at 11:35 am

Elevation: 247 ft. **Vertical Datum:** NAVD 1988 **Boring Location:** Near tree line adjacent to power lines **Coord.:** N: **40.429655** E: **-74.967493**

Item	Casing	Core Barrel	Core Bit
Type	HW	NQ2	Imp. Diamond
Length (ft)	5	5	3.25
Inside Dia. (in.)	4	2.0	2.0

Horizontal Datum: NAD 1983 **Drilling Method:** Wireline
Rig Make & Model: CME-55LC

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec (in. / %)	RQD (in / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities Type	Dip	Rgh	Wea	Aper	Infill	Remarks
									SEE TEST BORING LOG FOR OVERBURDEN DETAILS		(See Legend for Rock Description System)						
	2.10	12.0							SANDSTONE, grayish brown, medium to coarse grained, fresh, strong, close spaced discontinuities								Loss of water from 12 to 15 feet BGS.
										13.00	J	0	S,R	FR	O	N	
	1.60		R-1	36 100%	28 78%	R4	FR			13.40	J	10	U,R	DG	PO	SD	
										13.63	J	20	P,R	DG	PO	SD	
	2.30	15.0								14.17	J	15	P,R	DG	PO	CL	
15	1.70	15.0							SANDSTONE, grayish brown, medium grained, slightly weathered, strong, very close to close spaced discontinuities	15.60	J	20	P,R	FR	O	N	Loss of water from 15 to 20 feet BGS. Used approximately 200 gallons of water from 15 to 20 feet BGS.
	1.80								16.4' - 17' Fractured zone								
230	1.90		R-2	48 80%	24 40%	R4	SL		17' - 17.6' Highly Fractured zone	17.60	J	10	U,R	FR	O	N	
	2.50								18.4' - 18.65' Fractured zone								
	2.60	20.0															
20	3.20	20.0							SANDSTONE, grayish brown, medium grained, fresh, very strong, moderately spaced discontinuities								Loss of water from 20 to 25 feet BGS.
										20.95	J	15	P,Sm	FR	PO	N	
	3.40									21.17	J	15	P,Sm	FR	PO	CL	
	3.30		R-3	58 97%	56 93%	R5	FR			22.90	J	20	P,R	FR	PO	N	
	3.60																
	3.50	25.0								24.30	J	75	P,R	FR	PO	N	
25	3.80	25.0							SANDSTONE, brownish gray, medium to coarse grained, slightly weathered, strong, very close to close spaced discontinuities	25.60	J	10	U,R	FR	PO	N	Loss of water from 25 to 30 feet BGS. Used approximately 200 gallons of water from 25 to 30 feet BGS.
	2.20								26.2' - 27.25' Fractured zone	26.15	J	15	U,R	FR	PO	N	
220									27.4								
	2.30		R-4	59 98%	39 65%	R4	SL		SILTSTONE, grayish brown, fine grained, fresh, medium strong, close to moderately spaced discontinuities	27.75	J	80	P,R	FR	T	N	
	1.90									28.25	J	40	P,R	FR	T	N	
	2.50	30.0								29.40	J	15	U,R	DG	O	CL	
30	2.80	30.0							SILTSTONE, brownish gray, fine grained, fresh, strong, close to moderately spaced discontinuities	30.65	J	40	S,R	FR	O	N	Loss of water from 30 to 35 feet BGS.
	1.40									31.25	J	20	P,Sm	FR	PO	N	

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
3/6/19	9:00	-	11.0	12.0	
3/7/19	9:45	-	11.0	23.0	17.6
3/8/19	9:26	-	19.0	70.0	17.3

Notes:

CORE BORING LOG
(continued)

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	1.50		R-5	59 98%	43 72%	R4	FR			32.15	J	20	P,Sm	FR	PO	N	
										32.64	J	15	P,R	FR	PO	N	
	1.50																
	1.70	35.0								34.40	J	15	P,R	DG	PO	CL	
35	3.10	35.0							SILTSTONE, gray, fine grained, slightly weathered, strong, extremely close to wide spaced discontinuities								Loss of water from 35 to 40 feet BGS.
	1.80																
210	2.60		R-6	57 95%	54 90%	R4	FR		36.9' - 37.15' Highly Fractured zone	36.90	J	20	P,Sm	FR	O	N	
										37.15	J	10	P,Sm	DG	O	CL	
	2.40																
	2.70	40.0															
40	3.00	40.0							40.0 ARGILLITE, gray, very fine grained, fresh, very strong, close to wide spaced discontinuities								Used approximately 120 gallons of water per 5 feet.
	3.60																
	4.40		R-7	60 100%	51 85%	R5	FR										
	3.30									42.90	J	15	P,Sm	DS	PO	N	
										43.44	J	20	P,Sm	FR	T	N	
	4.10	45.0								44.10	J	65	P,Sm	DS	T	Fe	
										44.50	J	10	P,R	DG	PO	CL	
45	3.30	45.0							ARGILLITE, gray, fine grained, fresh, very strong, close to moderately spaced discontinuities								Loss of water from 45 to 50 feet BGS.
	2.00									46.27	J	15	P,Sm	FR	O	N	
200	2.40		R-8	60 100%	53 88%	R5	FR			47.32	J	15	P,Sm	FR	T	N	
	2.60																
	1.70	50.0							50.0	49.25	J	75	P,R	DS	T	Fe	
50	1.70	50.0							SILTSTONE, gray to reddish brown, fine to very fine grained, slightly weathered, strong, very close to moderately spaced discontinuities	50.30	J	10	P,R	FR	PO	N	Loss of water from 50 to 55 feet BGS.
	1.60																
	2.40		R-9	56 93%	29 48%	R4	SL			52.84	J	25	P,R	FR	PO	N	
	2.40								53.2' - 53.4' Weathered zone; Clay with Gravel								
	2.10	55.0							54' - 54.35' Highly Fractured zone								
55	1.30	55.0							SILTSTONE, reddish brown, fine grained, moderately weathered, strong, very close to moderately spaced discontinuities	55.50	J	15	P,Sm	FR	PO	N	Loss of water from 55 to 60 fee BGS.
	1.70									56.75	J	20	P,R	FR	PO	N	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-WICK-1**

MOTT MACDONALD M M

CORE BORING LOG
(continued)

BORING NO.: **B-WICK-1**
Page 3 of 4

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath.	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities Type	Dip	Rgh	Wea	Aper	Infill	Remarks
190	1.30		R-10	59 98%	28 47%	R4	M		57.85' - 58.8' Vertical Fracture								Loss of water from 57 to 60 feet BGS.
	1.80									58.45	J	85	U,R	FR	PO	N	
	1.60	60.0							59.1' - 59.9' Fractured zone with vertical fractures								
60	1.60	60.0							SILTSTONE, reddish brown, fine grained, slightly weathered, medium strong, extremely close to moderately spaced discontinuities								Loss of water from 60 to 65 feet BGS.
	1.50									61.40	J	5	P,R	FR	PO	N	
	2.30		R-11	59 98%	44 73%	R3	SL			62.55	J	10	P,Sm	FR	PO	N	
	2.10									63.67	J	20	U,R	FR	O	N	
	2.40	65.0							63.7' - 64.55' Vertical Fracture								
65	2.70	65.0							65.0 ARGILLITE with interbedded Sandstone, reddish brown, fine grained, fresh, very strong, close to wide spaced discontinuities								Loss of water from 65 to 70 feet BGS.
	2.70																Used approximately 2200 gallons of water from 40 to 65 feet BGS.
180	2.10		R-12	60 100%	48 80%	R5	FR			67.20	J	10	U,R	FR	PO	N	
										67.70	J	15	U,R	FR	MW	N	
	1.70									68.50	J	10	U,R	FR	PO	N	
	1.40	70.0							70.0								
70	2.00	70.0							SANDSTONE, brownish gray, fine to medium grained, fresh, very strong, wide spaced discontinuities								Loss of water from 70 to 75 feet BGS.
	0.80																
	1.40		R-13	60 100%	57 95%	R5	FR										
	1.00									73.20	J	60	P,R	DG	PO	CL	ML
	1.00	75.0															
75	1.30	75.0							SANDSTONE, gray, medium grained, fresh, very strong, wide spaced discontinuities								Loss of water from 75 to 80 feet BGS.
	1.40																
170	1.30		R-14	59 98%	58 97%	R5	FR										
	1.40																
	1.50	80.0															
80	1.50	80.0							SANDSTONE, reddish gray, medium grained, fresh, very strong, moderate to wide spaced discontinuities								Loss of water from 80 to 85 feet BGS.
	1.10																

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-WICK-1**

CORE BORING LOG
(continued)

Depth/ Elev. (ft)	Avg Core Rate (min /ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Stratum Graphic	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Discontinuities (See Legend for Rock Description System) Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	1.40		R-15	59 98%	59 98%	R5	FR			82.13	J	15	U,R	FR	PO	N	
	1.30									82.90	J	25	P,Sm	FR	T	N	
	1.30	85.0															
85	1.50	85.0							SANDSTONE, gray, fine to medium grained, fresh, very strong, wide spaced discontinuities								Loss of water from 85 to 90 feet BGS.
	1.50																
160	1.70		R-16	60 100%	59 98%	R5	FR										
	1.20									87.93	J	20	P,Sm	FR	PO	N	
	1.30	90.0															
90	1.10	90.0							SANDSTONE, brownish gray, fine to medium grained, fresh, strong, close spaced discontinuities								Loss of water from 90 to 95 feet BGS.
									91.0	90.50	J	40	P,R	FR	PO	N	
	1.60								SILTSTONE, reddish brown, fine grained, highly weathered, medium strong, extremely close to close spaced discontinuities								
	3.20		R-17	27 45%	11 18%	R4	FR										
	2.60																
	3.40	95.0															
95	1.40	95.0							SILTSTONE, reddish brown, fine grained, slightly weathered, strong, close to moderately spaced discontinuities								Loss of water from 95 to 100 feet BGS.
	1.20																
150	1.40		R-18	57 95%	43 72%	R4	SL		97.05' - 97.75' Vertical Fracture	96.95	J	10	P,Sm	FR	PO	N	
										97.90	J	85	P,R	FR	PO	N	
	1.50																
	1.50	100.0								99.23	J	5	U,R	FR	PO	N	
100									100.0 End of Boring at 100 feet BGS. Borehole grouted with cement and bentonite holeplug.								
105																	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-WICK-1**

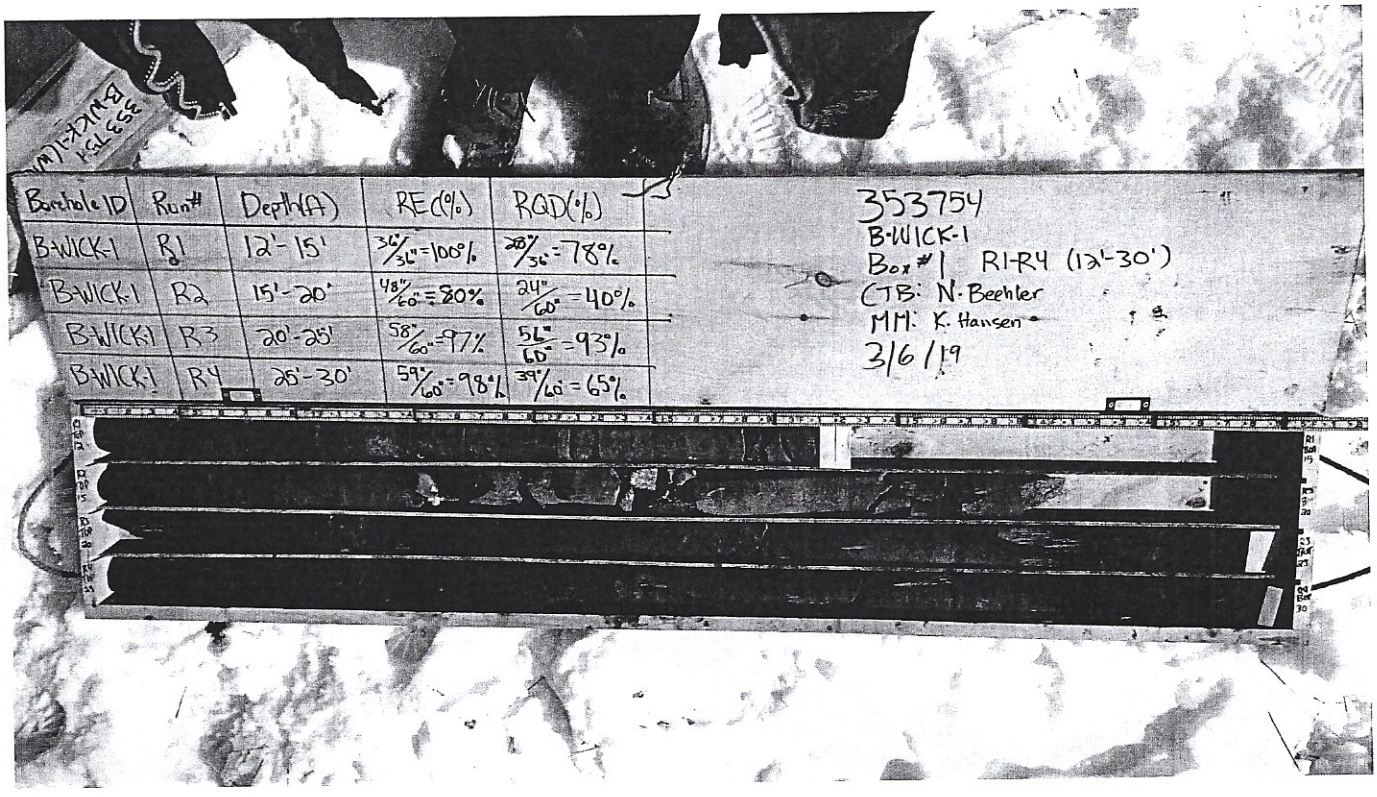


Figure B-WICK-1.1
B-WICK-1 Box 1 R1-R4 Dry

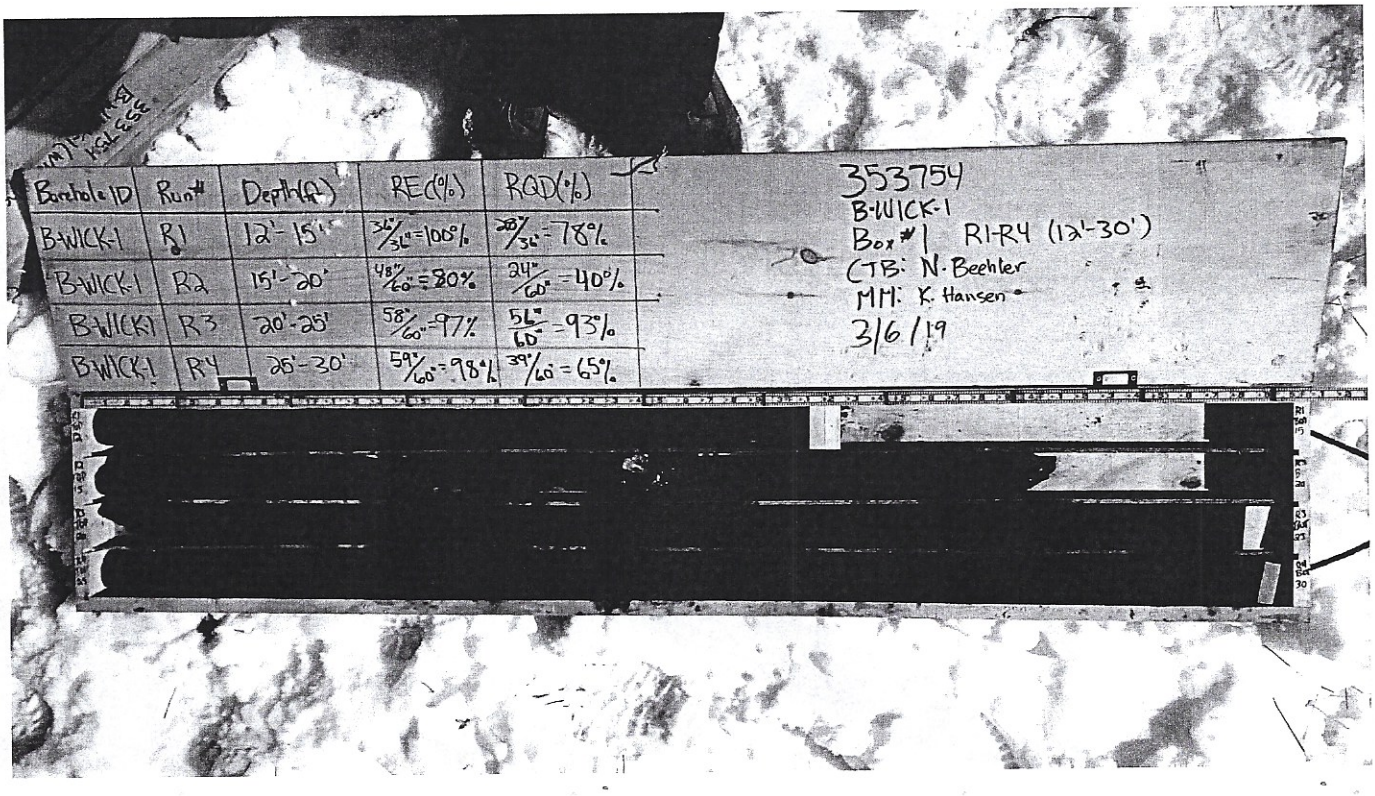


Figure B-WICK-1.2
B-WICK-1 Box 1 R1-R4 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-WICK-1

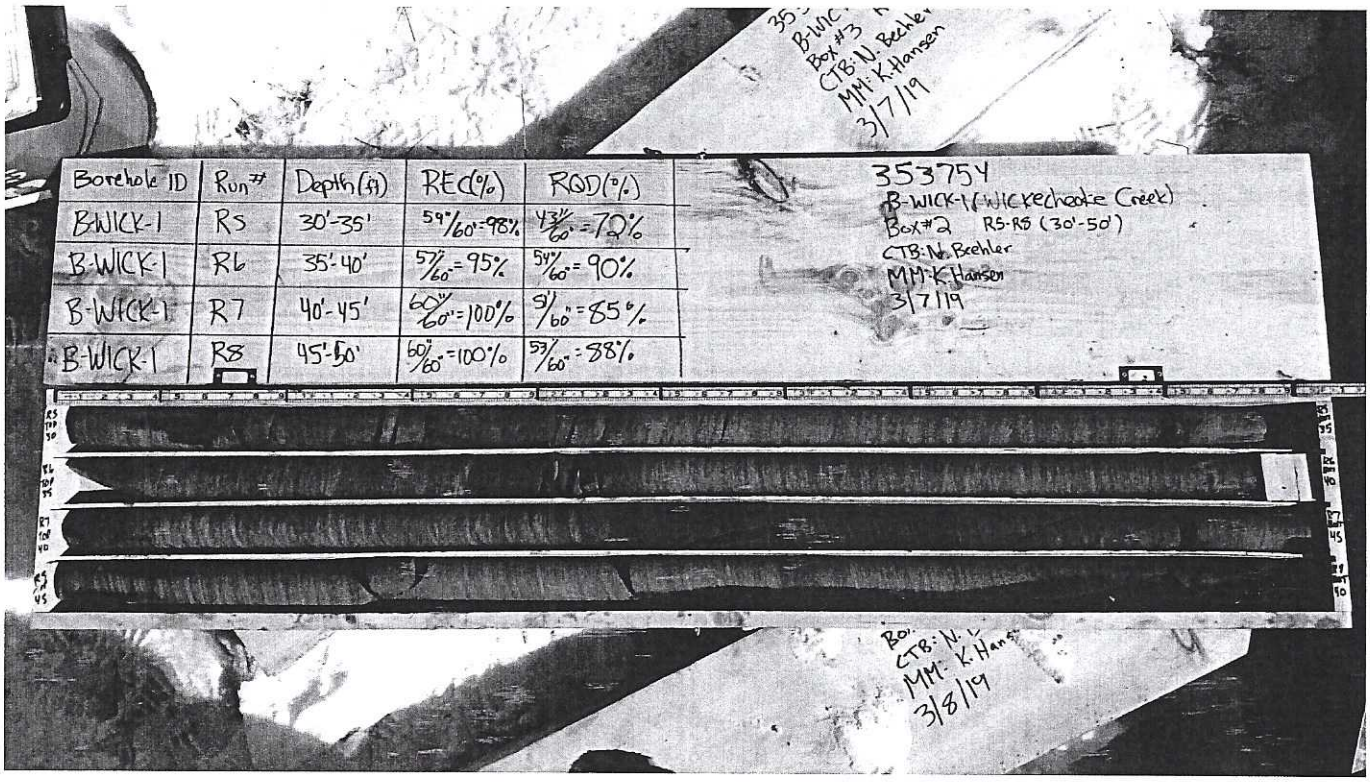


Figure B-WICK-1.3
B-WICK-1 Box 2 R5-R8 Dry

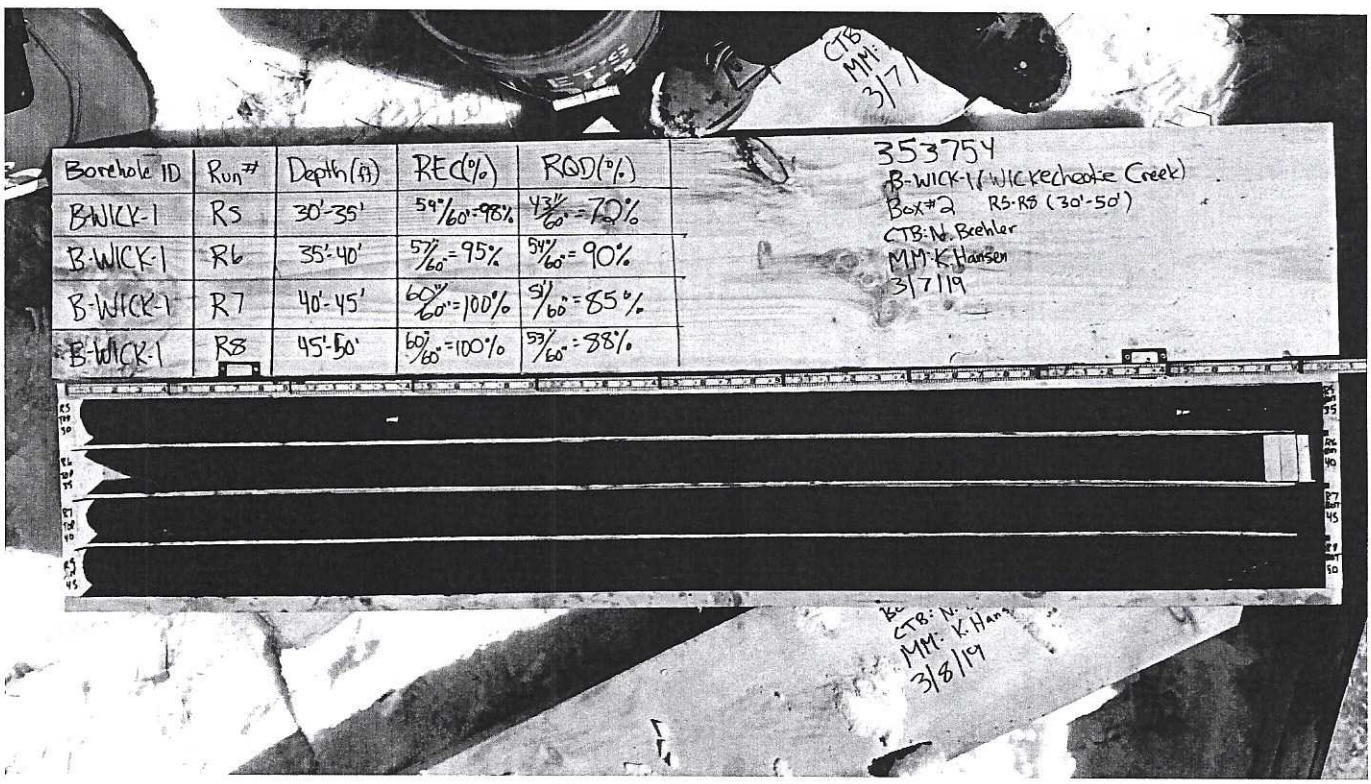


Figure B-WICK-1.4
B-WICK-1 Box 2 R5-R8 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-WICK-1

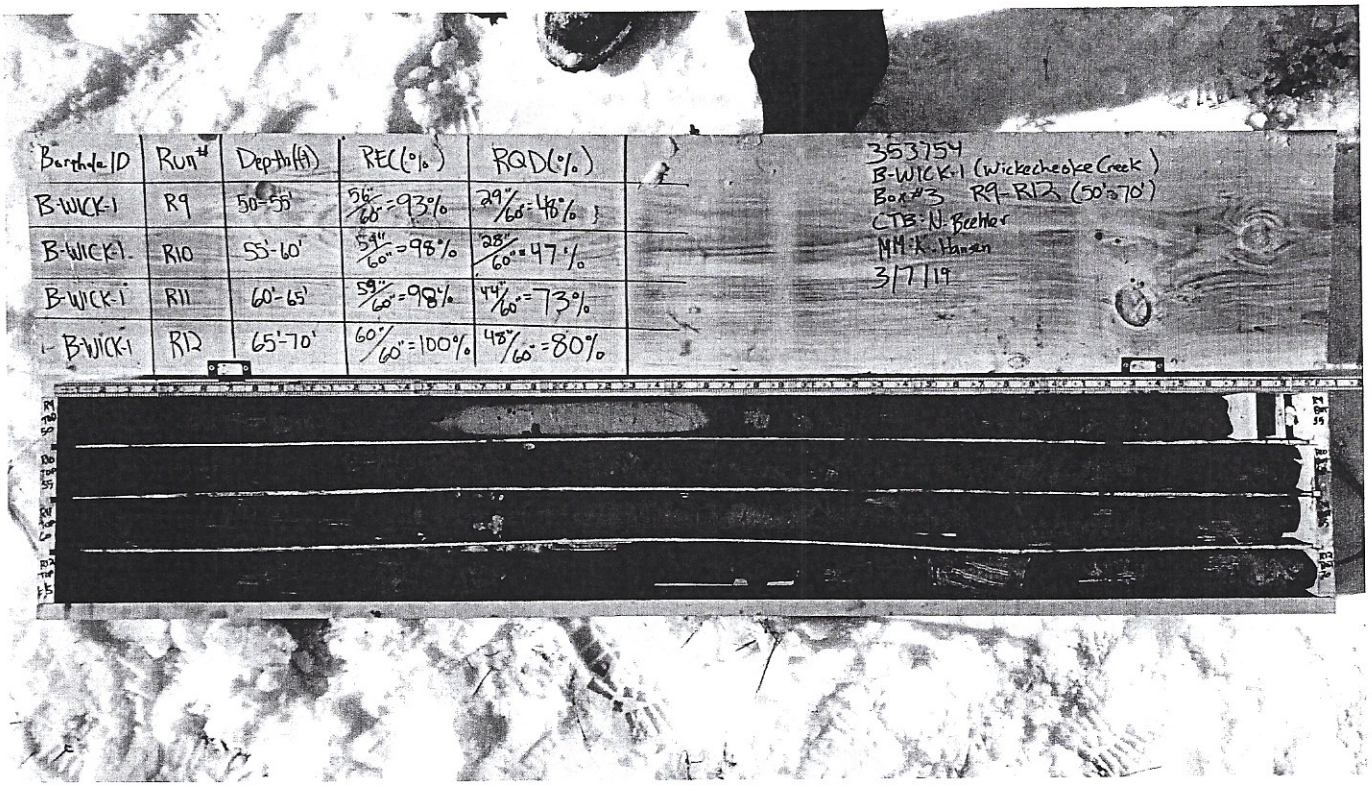


Figure B-WICK-1.5
B-WICK-1 Box 3 R9-R12 Dry

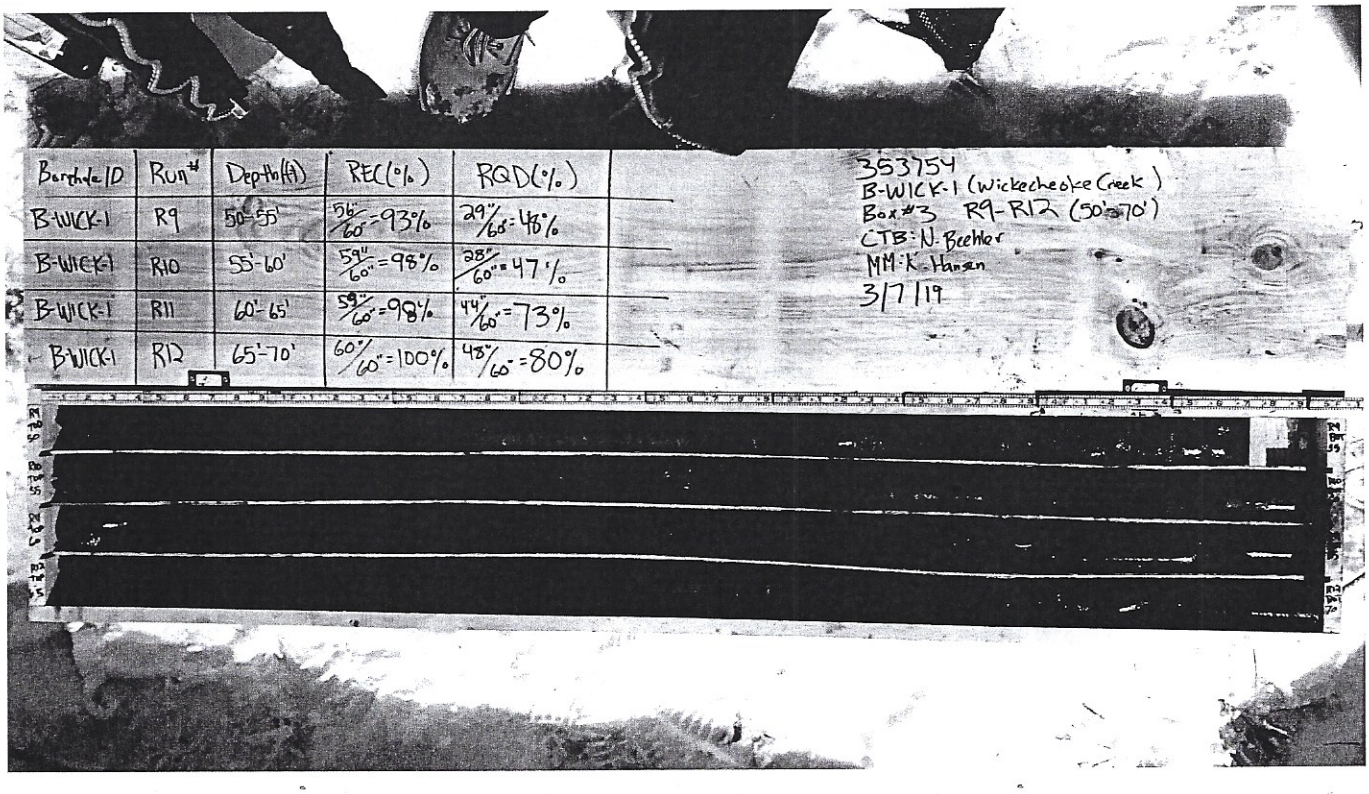


Figure B-WICK-1.6
B-WICK-1 Box 3 R9-R12 Wet

MOTT MACDONALD M M	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-WICK-1

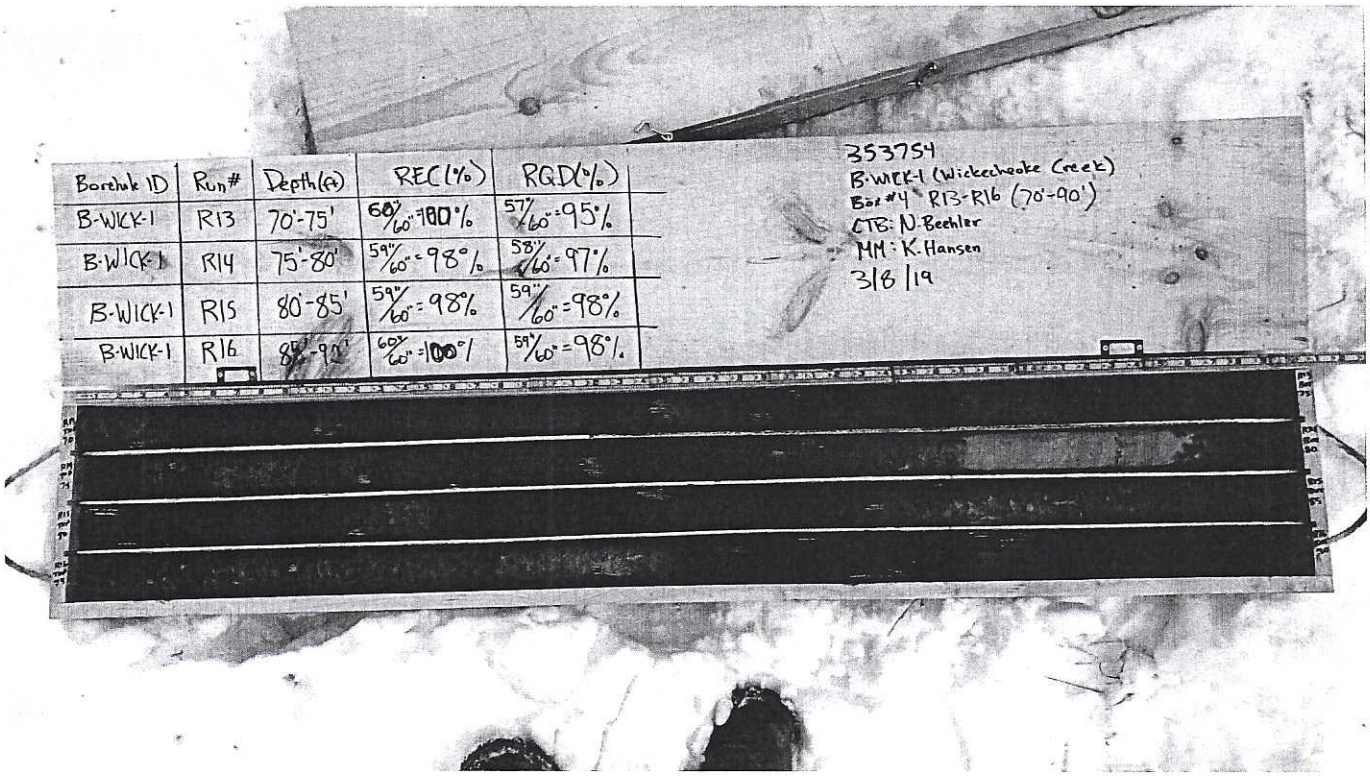


Figure B-WICK-1.7
B-WICK-1 Box 4 R13-R16 Dry

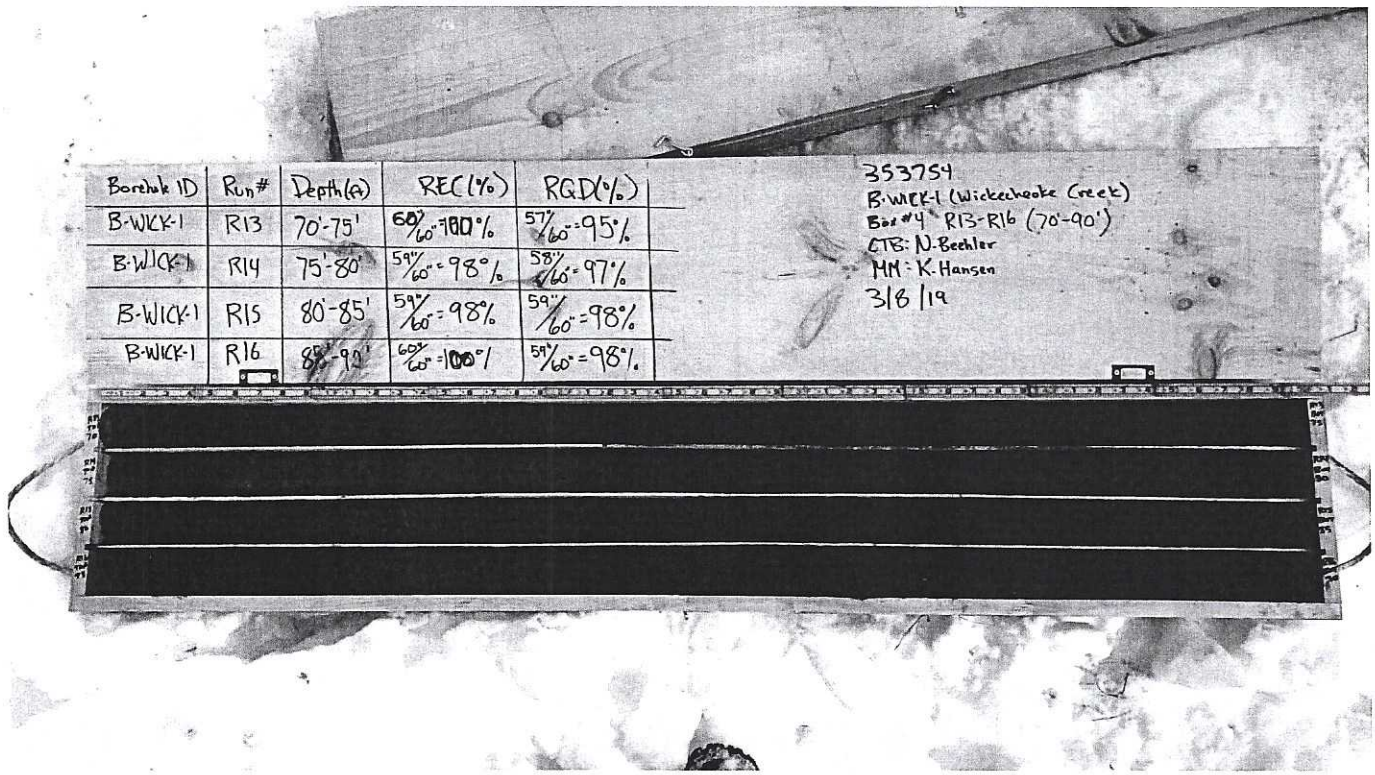


Figure B-WICK-1.8
B-WICK-1 Box 4 R13-R16 Wet

MOTT MACDONALD	PennEast Pipeline Project Rock Core Photographs	BORING NO.: B-WICK-1

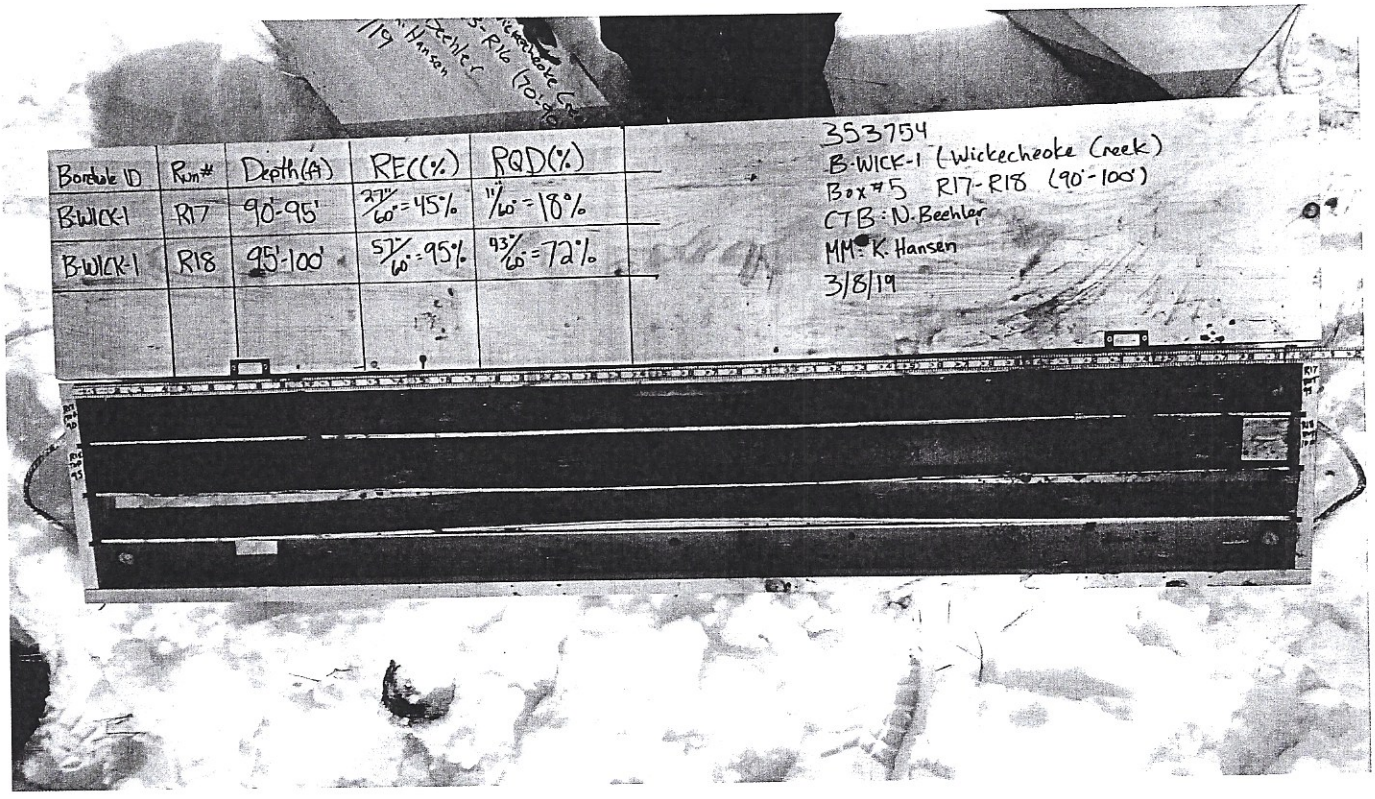


Figure B-WICK-1.9
B-WICK-1 Box 5 R17-R18 Dry

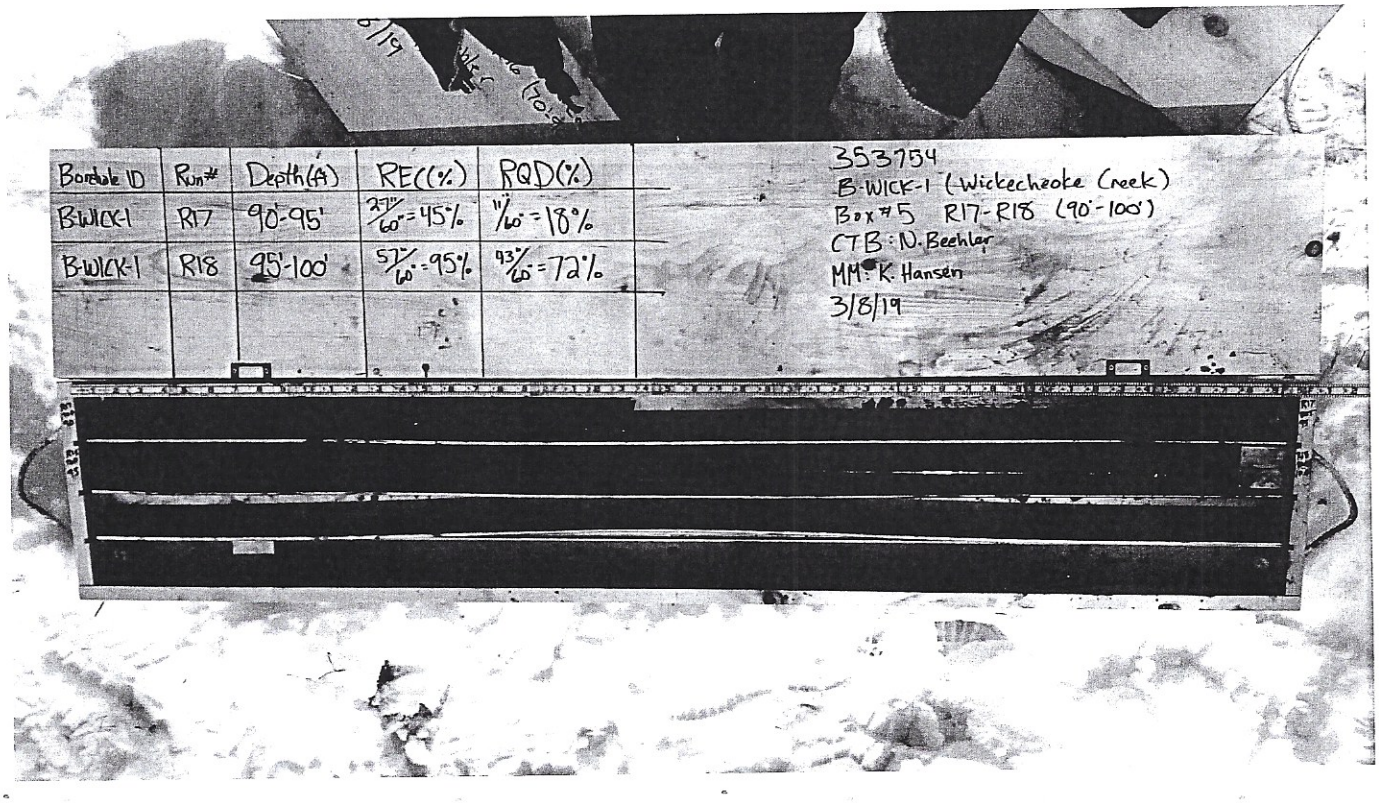


Figure B-WICK-1.10
B-WICK-1 Box 5 R17-R18 Wet

MOTT MACDONALD M M	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-WICK-1

Appendix C

Installation Load and Stress Evaluation

MOTT MACDONALD

Project Name: PennEast Pipeline Project
Project No: 353754
HDD Name: Wickecheoke Creek
Location: Hunterdon County, NJ

By: M. Lockwood
Checked: G. Duyvestyn
Owner: PennEast
Date: 5/17/2019

Horizontal Directional Drilling
Operating Stress Analysis - MAOP Based

References:

1. ASME/ANSI B31.4 section 402.3.2
2. ASME/ANSI B31.8 section 833.3
3. ASME/ANSI B31.8 section 833.4
4. ASME/ANSI B31.4 section 402.3.1

Design Parameters

Pipe Diameter	36 inches
Wall Thickness	0.762 inches
D/t Ratio	47
MAOP	1,480 psi
SMYS	70,000 psi
Modulus of Elasticity	2.92E+07 psi
Combined Design Factor	0.5
Poisson's Ratio	0.30
Design Minimum Allowable Radius of Curvature	2,600 feet
Coefficient of Thermal Expansion	6.50E-06 in/in/°F
Assumed Installation Temperature	45 °F
Assumed Operating Temperature	120 °F

Longitudinal Stress from Bending

Longitudinal Stress from Bending: 16,846 psi
Percent SMYS: 24.1%

Hoop Stress

Calculated Hoop Stress: 34,961 psi
Percent SMYS: 49.9%
Should be less than Design Factor x SMYS of 35,000 psi
Limited by Design Factor according to 49 CFR 192.11

Longitudinal Tensile Stress from Hoop Stress

Longitudinal Tensile Stress from Hoop Stress: 10,488 psi
Percent SMYS: 15.0%

Longitudinal Stress from Thermal Expansion

Longitudinal Stress from Thermal Expansion: -14,235 psi
Percent SMYS: 20.3%
Limited by 90% SMYS by ASME/ANSI B31.4 section 402.3.2

Net Longitudinal Stress (Compression Side of Curve)

Net Longitudinal Stress (Compression Side of Curve): -20,593 psi
Percent SMYS: 29.4%
Limited by 90% SMYS by ASME/ANSI B31.8 section 833.3

Net Longitudinal Stress Tension Side of Curve)

Net Longitudinal Stress (Tesion Side of Curve): 13,099 psi
Percent SMYS: 18.7%
Limited by 90% SMYS by ASME/ANSI B31.8 section 833.3

Maximum Shear Stress

Maximum Shear Stress: 27,777 psi
Percent SMYS: 39.7%
Limited by 45% SMYS by ASME/ANSI B31.4 section 402.3.1

Combined Biaxial Stress Check

Combined Biaxial Stress Check: 55,554 psi
Percent SMYS: 79.4%
Limited to 90% SMYS by ASME/ANSI B31.8 section 833.4

MOTT MACDONALD

Calculated by: M. Lockwood
Checked by: G. Duyvestyn
Date: 4/19/2019
Project No: 353754

Horizontal Directional Drilling
Calculation of Pull Loads and Stresses during Pipe Installation

PROJECT: PennEast Pipeline Project - Case 1

HDD CROSSING LOCATION: Wickecheoke Creek

Reference:

1. Installation of Pipelines by Horizontal Directional Drilling, an Engineering Guide, PRCI Publication 2015
2. Pipeline Design for Installation by Horizontal Directional Drilling, Manual of Practice, ASCE MREP 108, 2005

HDD Installation Load Analysis

Segment Type	Type of Curve	Bore Stationing		Installed Length		Bore Elevation		Bore Diameter		Geotechnical Friction Factor	TOTAL PULL LOADS	
		feet	metres	feet	metres	feet	metres	inch	mm			
Pipe Entry Location		5098+00	155+328	0.0	0.0	325.6	99.2	--	--		99,394 lb	49.7 tons
straight		5096+82	155+353	63.8	23.5	309.1	93.8	48.0	1219.2	0.3	112,828 lb	56.4 tons
straight		5097+64	155+378	167.6	51.1	293.7	89.6	48.0	1219.2	0.3	126,262 lb	63.1 tons
straight		5098+46	155+403	251.4	76.6	273.3	83.3	48.0	1219.2	0.3	139,696 lb	69.8 tons
straight		5099+28	155+428	335.2	102.2	255.9	78.0	48.0	1219.2	0.3	153,130 lb	76.6 tons
straight		5100+10	155+453	419.0	127.7	238.5	72.7	48.0	1219.2	0.3	166,564 lb	83.3 tons
straight		5100+92	155+478	502.8	153.2	221.0	67.4	48.0	1219.2	0.3	184,455 lb	92.2 tons
straight		5101+74	155+503	586.6	178.8	203.6	62.1	48.0	1219.2	0.3	202,347 lb	101.2 tons
straight		5102+56	155+528	670.3	204.3	186.2	56.8	48.0	1219.2	0.3	220,238 lb	110.1 tons
straight		5103+38	155+553	754.1	229.9	168.8	51.4	48.0	1219.2	0.3	238,129 lb	119.1 tons
straight		5104+20	155+578	837.9	255.4	151.3	46.1	48.0	1219.2	0.3	256,020 lb	128.0 tons
straight		5105+02	155+603	921.7	280.9	133.9	40.8	48.0	1219.2	0.3	273,911 lb	137.0 tons
straight		5105+84	155+628	1,005.5	306.5	116.5	35.5	48.0	1219.2	0.3	291,803 lb	145.9 tons
curve	vertical	5106+30	155+642	1,052.6	320.9	107.0	32.6	48.0	1219.2	0.3	339,179 lb	169.6 tons
curve	vertical	5106+76	155+656	1,099.8	335.2	98.1	29.9	48.0	1219.2	0.3	368,751 lb	184.4 tons
curve	vertical	5107+22	155+670	1,146.9	349.6	89.8	27.4	48.0	1219.2	0.3	365,861 lb	182.9 tons
curve	vertical	5107+69	155+684	1,194.0	363.9	82.2	25.0	48.0	1219.2	0.3	371,106 lb	185.6 tons
curve	vertical	5108+15	155+696	1,241.1	378.3	75.1	22.9	48.0	1219.2	0.3	379,531 lb	189.8 tons
curve	vertical	5108+62	155+713	1,288.3	392.7	68.6	20.9	48.0	1219.2	0.3	389,473 lb	194.7 tons
curve	vertical	5109+09	155+727	1,335.4	407.0	62.8	19.1	48.0	1219.2	0.3	400,210 lb	200.1 tons
curve	vertical	5109+56	155+741	1,382.5	421.4	57.6	17.5	48.0	1219.2	0.3	411,379 lb	205.7 tons
curve	vertical	5110+03	155+755	1,429.6	435.8	52.9	16.1	48.0	1219.2	0.3	422,773 lb	211.4 tons
curve	vertical	5110+50	155+770	1,476.8	450.1	48.9	14.9	48.0	1219.2	0.3	434,272 lb	217.1 tons
curve	vertical	5110+97	155+784	1,523.9	464.5	45.5	13.9	48.0	1219.2	0.3	445,798 lb	222.9 tons
curve	vertical	5111+44	155+798	1,571.0	478.8	42.8	13.0	48.0	1219.2	0.3	457,304 lb	228.7 tons
curve	vertical	5111+91	155+813	1,618.1	493.2	40.6	12.4	48.0	1219.2	0.3	468,758 lb	234.4 tons
curve	vertical	5112+38	155+827	1,665.3	507.6	39.1	11.9	48.0	1219.2	0.3	480,141 lb	240.1 tons
curve	vertical	5112+85	155+842	1,712.4	521.9	38.1	11.6	48.0	1219.2	0.3	491,441 lb	245.7 tons
curve	vertical	5113+32	155+856	1,759.5	536.3	37.8	11.5	48.0	1219.2	0.3	502,650 lb	251.3 tons
straight		5113+66	155+866	1,793.5	546.7	37.8	11.5	48.0	1219.2	0.3	508,295 lb	254.1 tons
straight		5114+00	155+877	1,827.5	557.0	37.8	11.5	48.0	1219.2	0.3	513,941 lb	257.0 tons
straight		5114+34	155+887	1,861.5	567.4	37.8	11.5	48.0	1219.2	0.3	519,586 lb	259.8 tons
straight		5114+68	155+897	1,895.5	577.8	37.8	11.5	48.0	1219.2	0.3	525,232 lb	262.6 tons
curve	vertical	5115+41	155+920	1,968.8	600.1	38.6	11.8	48.0	1219.2	0.3	564,471 lb	282.2 tons
curve	vertical	5116+15	155+942	2,042.1	622.4	40.8	12.4	48.0	1219.2	0.3	561,484 lb	280.7 tons
curve	vertical	5116+88	155+964	2,115.4	644.8	44.6	13.6	48.0	1219.2	0.3	585,658 lb	292.8 tons
curve	vertical	5117+61	155+987	2,188.7	667.1	49.8	15.2	48.0	1219.2	0.3	591,107 lb	295.6 tons
curve	vertical	5118+34	156+009	2,262.0	689.5	56.5	17.2	48.0	1219.2	0.3	610,915 lb	305.5 tons
curve	vertical	5119+07	156+031	2,335.3	711.8	64.7	19.7	48.0	1219.2	0.3	621,608 lb	310.8 tons
curve	vertical	5119+79	156+053	2,408.6	734.2	74.3	22.7	48.0	1219.2	0.3	639,513 lb	319.8 tons
curve	vertical	5120+52	156+075	2,481.9	756.5	85.5	26.1	48.0	1219.2	0.3	652,800 lb	326.4 tons
curve	vertical	5121+24	156+097	2,555.2	778.8	98.1	29.9	48.0	1219.2	0.3	699,665 lb	349.8 tons
curve	vertical	5121+96	156+119	2,628.5	801.2	112.2	34.2	48.0	1219.2	0.3	715,092 lb	357.5 tons
curve	vertical	5122+68	156+141	2,701.9	823.5	127.8	38.9	48.0	1219.2	0.3	730,257 lb	365.1 tons
curve	vertical	5123+39	156+163	2,775.2	845.9	144.8	44.1	48.0	1219.2	0.3	745,150 lb	372.6 tons
straight		5123+75	156+174	2,811.9	857.1	153.7	46.8	48.0	1219.2	0.3	748,961 lb	374.5 tons
straight		5124+10	156+185	2,848.6	868.3	162.5	49.5	48.0	1219.2	0.3	752,772 lb	376.4 tons
straight		5124+46	156+195	2,885.3	879.5	171.4	52.2	48.0	1219.2	0.3	756,584 lb	378.3 tons
straight		5124+81	156+206	2,922.0	890.8	180.3	55.0	48.0	1219.2	0.3	760,395 lb	380.2 tons
straight		5125+17	156+217	2,958.7	901.8	189.2	57.7	48.0	1219.2	0.3	764,207 lb	382.1 tons
straight		5125+53	156+228	2,995.5	913.0	198.1	60.4	48.0	1219.2	0.3	768,018 lb	384.0 tons
straight		5125+88	156+239	3,032.2	924.2	207.0	63.1	48.0	1219.2	0.3	771,829 lb	385.9 tons
straight		5126+24	156+250	3,068.9	935.4	215.8	65.8	48.0	1219.2	0.3	775,641 lb	387.8 tons
straight		5126+60	156+261	3,105.6	946.6	224.7	68.5	48.0	1219.2	0.3	779,452 lb	389.7 tons
straight		5126+95	156+271	3,142.3	957.8	233.6	71.2	48.0	1219.2	0.3	783,264 lb	391.6 tons
straight		5127+31	156+282	3,179.1	969.0	242.5	73.9	48.0	1219.2	0.3	787,075 lb	393.5 tons
straight		5127+66	156+293	3,215.8	980.2	251.4	76.6	48.0	1219.2	0.3	790,886 lb	395.4 tons
straight		5128+02	156+304	3,252.5	991.4	260.2	79.3	48.0	1219.2	0.3	794,698 lb	397.3 tons
straight		5128+38	156+315	3,289.2	1,002.6	269.1	82.0	48.0	1219.2	0.3	798,509 lb	399.3 tons
straight		5128+73	156+326	3,325.9	1,013.8	278.0	84.7	48.0	1219.2	0.3	802,321 lb	401.2 tons
HDD Rig Location		5129+09	156+337	3,362.7	1,024.9	286.9	87.4	48.0	1219.2	0.3	806,132 lb	403.1 tons

HDD Installation Stress Analysis

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	CombinedTensile and Bending <1.0	Combined Tensile, Bending and Hoop Factor	Combined Tensile, Bending and Hoop <1.0
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS				
1,178	8.12	1.68%	0	0.00	0.00%	0.0	0.00	0.00%	0.02	Yes	0.00	Yes
1,338	9.22	1.91%	0	0.00	0.00%	213.8	1.47	0.31%	0.02	Yes	0.00	Yes
1,497	10.32	2.14%	0	0.00	0.00%	427.5	2.95	0.61%	0.03	Yes	0.00	Yes
1,656	11.42	2.37%	0	0.00	0.00%	641.3	4.42	0.92%	0.03	Yes	0.01	Yes
1,815	12.52	2.59%	0	0.00	0.00%	855.1	5.90	1.22%	0.03	Yes	0.01	Yes
1,975	13.61	2.82%	0	0.00	0.00%	1,068.8	7.37	1.53%	0.04	Yes	0.02	Yes
2,167	15.08	3.12%	0	0.00	0.00%	808.2	5.57	1.15%	0.04	Yes	0.03	Yes
2,399	16.54	3.43%	0	0.00	0.00%	1,022.0	7.05	1.46%	0.04	Yes	0.04	Yes
2,611	18.00	3.73%	0	0.00	0.00%	1,235.7	8.52	1.77%	0.05	Yes	0.05	Yes
2,823	19.46	4.03%	0	0.00	0.00%	1,449.5	9.99	2.07%	0.05	Yes	0.07	Yes
3,035	20.93	4.34%	0	0.00	0.00%	1,663.3	11.47	2.38%	0.05	Yes	0.08	Yes
3,247	22.39	4.64%	0	0.00	0.00%	1,877.0	12.94	2.68%	0.06	Yes	0.10	Yes
3,459	23.85	4.94%	0	0.00	0.00%	2,090.8	14.42	2.99%	0.06	Yes	0.12	Yes
4,021	27.72	5.74%	12,167	83.89	17.38%	2,207.3	15.22	3.15%	0.34	Yes	0.25	Yes
4,371	30.14	6.24%	12,167	83.89	17.38%	2,316.4	15.97	3.31%	0.35	Yes	0.26	Yes
4,337	29.90	6.20%	12,167	83.89	17.38%	2,418.1	16.67	3.45%	0.35	Yes	0.28	Yes
4,399	30.33	6.28%	12,167	83.89	17.38%	2,512.2	17.32	3.59%	0.35	Yes	0.29	Yes
4,499	31.02	6.43%	12,167	83.89	17.38%	2,599.0	17.92	3.71%	0.35	Yes	0.30	Yes
4,617	31.83	6.60%	12,167	83.89	17.38%	2,678.2	18.47	3.83%	0.35	Yes	0.31	Yes
4,744	32.71	6.78%	12,167	83.89	17.38%	2,749.9	18.96	3.93%	0.36	Yes	0.32	Yes
4,877	33.62	6.97%	12,167	83.89	17.38%	2,814.1	19.40	4.02%	0.36	Yes	0.33	Yes
5,012	34.55	7.16%	12,167	83.89	17.38%	2,870.8	19.79	4.10%	0.36	Yes	0.34	Yes
5,148	35.49	7.35%	12,167	83.89	17.38%	2,919.9	20.13	4.17%	0.36	Yes	0.35	Yes
5,285	36.44	7.55%	12,167	83.89	17.38%	2,961.5	20.42	4.23%	0.37	Yes	0.35	Yes
5,421	37.38	7.74%	12,167	83.89	17.38%	2,995.6	20.65	4.28%	0.37	Yes	0.36	Yes
5,557	38.31	7.94%	12,167	83.89	17.38%	3,022.0	20.84	4.32%	0.37	Yes	0.37	Yes
5,692	39.24	8.13%	12,167	83.89	17.38%	3,041.0	20.97	4.34%	0.37	Yes	0.37	Yes
5,826	40.17	8.32%	12,167	83.89	17.38%	3,052.3	21.04	4.36%	0.38	Yes	0.38	Yes
5,959	41.06	8.51%	12,167	83.89	17.38%	3,056.1	21.07	4.37%	0.38	Yes	0.38	Yes
6,026	41.55	8.61%	0	0.00	0.00%	3,056.1	21.07	4.37%	0.11	Yes	0.24	Yes
6,093	42.01	8.70%	0	0.00	0.00%	3,056.1	21.07	4.37%	0.11	Yes	0.24	Yes
6,159	42.47	8.80%	0	0.00	0.00%	3,056.1	21.07	4.37%	0.11	Yes	0.24	Yes
6,226	42.93	8.89%	0	0.00	0.00%	3,056.1	21.07	4.37%	0.11	Yes	0.24	Yes
6,692	46.14	9.56%	12,167	83.89	17.38%	3,046.9	21.01	4.35%	0.39	Yes	0.39	Yes
6,656	45.89	9.51%	12,167	83.89	17.38%	3,019.5	20.82	4.31%	0.39	Yes	0.38	Yes
6,943	47.87	9.92%	12,167	83.89	17.38%	2,973.7	20.50	4.25%	0.40	Yes	0.38	Yes
7,007	48.31	10.01%	12,167	83.89	17.38%	2,909.7	20.06	4.16%	0.40	Yes	0.37	Yes
7,242	49.93	10.35%	12,167	83.89	17.38%	2,827.4	19.49	4.04%	0.40	Yes	0.37	Yes
7,369	50.81	10.53%	12,167	83.89	17.38%	2,726.8	18.80	3.90%	0.40	Yes	0.36	Yes
7,581	52.27	10.83%	12,167	83.89	17.38%	2,606.1	17.96	3.73%	0.41	Yes	0.35	Yes
7,739	53.36	11.06%	12,167	83.89	17.38%	2,471.3	17.04	3.53%	0.41	Yes	0.33	Yes
8,294	57.19	11.85%	12,167	83.89	17.38%	2,316.4	15.97	3.31%	0.42	Yes	0.32	Yes
8,477	58.45	12.11%	12,167	83.89	17.38%	2,143.5	14.78	3.06%	0.42	Yes	0.31	Yes
8,657	59.69	12.37%	12,167	83.89	17.38%	1,952.7	13.46	2.79%	0.43	Yes	0.29	Yes
8,833	60.90	12.62%	12,167	83.89	17.38%	1,744.0	12.02	2.49%	0.43	Yes	0.27	Yes
8,879	61.22	12.68%	0	0.00	0.00%	1,635.0	11.27	2.34%	0.16	Yes	0.12	Yes
8,924	61.53	12.75%	0	0.00	0.00%	1,526.0	10.52	2.18%	0.16	Yes	0.11	Yes
8,969	61.84	12.81%	0	0.00	0.00%	1,417.0	9.77	2.02%	0.16	Yes	0.10	Yes
9,014	62.15	12.88%	0	0.00	0.00%	1,308.0	9.02	1.87%	0.16	Yes	0.10	Yes
9,059	62.46	12.94%	0	0.00	0.00%	1,199.0	8.27	1.71%	0.16	Yes	0.09	Yes
9,104	62.77	13.01%	0	0.00	0.00%	1,090.0	7.52	1.56%	0.16	Yes	0.08	Yes
9,150	63.08	13.07%	0	0.00	0.00%	981.0	6.76	1.40%	0.16	Yes	0.08	
9,195	63.40	13.14%	0	0.00	0.00%	872.0	6.01	1.25%	0.16	Yes	0.07	
9,240	63.71	13.20%	0	0.00	0.00%	763.0	5.26	1.09%	0.17	Yes	0.06	
9,285	64.02	13.26%	0	0.00	0.00%	654.0	4.51	0.93%	0.17	Yes	0.06	
9,330	64.33	13.33%	0	0.00	0.00%	545.0	3.76	0.78%	0.17	Yes	0.06	
9,375	64.64	13.39%	0	0.00	0.00%	436.0	3.01	0.62%	0.17	Yes	0.05	Yes
9,421	64.95	13.46%	0	0.00	0.00%	327.0	2.25	0.47%	0.17	Yes	0.05	Yes
9,466	65.27	13.52%	0	0.00	0.00%	218.0	1.50	0.31%	0.17	Yes	0.04	Yes
9,511	65.58	13.59%	0	0.00	0.00%	109.0	0.75	0.16%	0.17	Yes	0.04	Yes
9,556	65.89	13.65%	0	0.00	0.00%	0.0	0.00	0.00%	0.17	Yes	0.04	Yes

NOTE: Hoop stress taken as an empty pipe for no buoyancy control and with water with buoyancy control

	Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	Combined Tensile, Bending and Hoop Factor
	psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS		
Maximum Values	9,556	65.9	13.65%	12,167	83.9	17.38%	3,056	21.1	4.37%	0.43	0.39

Ground Elevation at Pipe Entry	325.56	feet
	99.23	metres
Ground Elevation at Pipe Exit	268.90	feet
	67.45	metres

	TOTAL PULL LOADS	
Maximum Values	806,132 lb	403.1 tons

Input Pipe Properties

Pipe Outer Diameter	36	in
	914.4	mm
Pipe Wall Thickness	0.762	in
	19.3548	mm
DR	47.2	
Pipe Weight (in air)	287.04	lbs/ft
	428.05	kg/m
Weight of Water in pipe	0.0	lbs/ft
	0.00	kg/m
Net Buoyant Weight of pipe	-241.7	lbs/ft
	-360.42	kg/m
Young's Modulus of Elasticity	2.92E+07	psi
	201327	MPa
Yield Strength	70,000	psi
	482.6	MPa
Poisson Ratio	0.3	
Drill Pipe Diameter	6.625	in
	168.275	mm
Minimum Radius of Curvature	2,500	ft
	762	m

Ultimate Safe Pull Load	3,542,953	lb
	15,760	kN
Maximum Calculated Pull Load	806,132	lb
	3,586	kN
Factor of Safety	4.4	

Start-Up Load Factor	2	
Maximum Calculated Start-Up Pipe Pull Load	1,612,264	lb
	7,172	kN
Factor of Safety	2.2	

Soil and Mud Properties

Mud Weight	10	ppg of drill fluid and solids (typically 9.5 to 11 lb/gal)
	1,199	Specific Gravity
Friction Coeff. (GS or rollers)	0.1	rollers typically 0.10 to 0.30 (along ground surface is higher range)
Yield Point	19.5	lb/100ft² (Based on HDD experience from previous installations)
	93.356	dyne/cm²
Plastic Viscosity	13	cP (Based on HDD experience from previous installations)
Drilling mud pumping rate	600	GPM (typically 200 to 300 gpm for soil or 400 to 800 gpm bedrock)
	2,271	m³/min
Drilling mud pumping rate	1129	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)
	4.273	m³/min
Pipe Pullback Rate	10	feet/min (Based on HDD experience)
	3.05	m/min

MOTT MACDONALD

Calculated by: M. Lockwood
Checked by: G. Duyvestyn
Date: 4/19/2019
Project No: 353754

ontal Directional Drilling
ulation of Pull Loads and Stresses during Pipe Installation

PROJECT: PennEast Pipeline Project - Case 2

HDD CROSSING LOCATION: Wickecheoke Creek

Reference:
1. Installation of Pipelines by Horizontal Directional Drilling, an Engineering Guide, PRCI Publication 2015
2. Pipeline Design for Installation by Horizontal Directional Drilling, Manual of Practice, ASCE MREP 108, 2005

HDD Installation Load Analysis

Segment Type	Type of Curve	Bore Stationing		Installed Length		Bore Elevation		Bore Diameter		Geotechnical Friction Factor	TOTAL PULL LOADS	
		feet	metres	feet	metres	feet	metres	Inch	mm			
Pipe Entry Location		5096+00	155+328	0.0	0.0	325.6	99.2	--	--		99,394 lb	49.7 tons
straight		5096+82	155+353	83.8	25.5	308.1	93.9	48.0	1219.2	0.3	103,842 lb	51.9 tons
straight		5097+64	155+378	167.6	51.1	290.7	88.6	48.0	1219.2	0.3	108,289 lb	54.1 tons
straight		5098+46	155+403	251.4	76.6	273.3	83.3	48.0	1219.2	0.3	112,737 lb	56.4 tons
straight		5099+28	155+428	335.2	102.2	255.9	78.0	48.0	1219.2	0.3	117,185 lb	58.6 tons
straight		5100+10	155+453	419.0	127.7	238.5	72.7	48.0	1219.2	0.3	121,633 lb	60.8 tons
straight		5100+92	155+478	502.8	153.2	221.0	67.4	48.0	1219.2	0.3	129,084 lb	64.5 tons
straight		5101+74	155+503	586.6	178.8	203.6	62.1	48.0	1219.2	0.3	136,535 lb	68.3 tons
straight		5102+56	155+528	670.3	204.3	186.2	56.8	48.0	1219.2	0.3	143,986 lb	72.0 tons
straight		5103+38	155+553	754.1	229.9	168.8	51.4	48.0	1219.2	0.3	151,437 lb	75.7 tons
straight		5104+20	155+578	837.9	255.4	151.3	46.1	48.0	1219.2	0.3	158,889 lb	79.4 tons
straight		5105+02	155+603	921.7	280.9	133.9	40.8	48.0	1219.2	0.3	166,339 lb	83.2 tons
straight		5105+84	155+628	1,005.5	306.5	116.5	35.5	48.0	1219.2	0.3	173,790 lb	86.9 tons
curve	vertical	5106+30	155+642	1,052.6	320.9	107.0	32.6	48.0	1219.2	0.3	217,820 lb	108.9 tons
curve	vertical	5106+76	155+656	1,099.8	335.2	98.1	29.9	48.0	1219.2	0.3	216,569 lb	108.3 tons
curve	vertical	5107+22	155+670	1,146.9	349.6	89.8	27.4	48.0	1219.2	0.3	196,773 lb	98.4 tons
curve	vertical	5107+69	155+684	1,194.0	363.9	82.2	25.0	48.0	1219.2	0.3	185,267 lb	92.6 tons
curve	vertical	5108+15	155+699	1,241.1	378.3	75.1	22.9	48.0	1219.2	0.3	177,127 lb	88.6 tons
curve	vertical	5108+62	155+713	1,288.3	392.7	68.6	20.9	48.0	1219.2	0.3	183,100 lb	91.6 tons
curve	vertical	5109+09	155+727	1,335.4	407.0	62.8	19.1	48.0	1219.2	0.3	189,857 lb	94.9 tons
curve	vertical	5109+56	155+741	1,382.5	421.4	57.6	17.5	48.0	1219.2	0.3	196,057 lb	98.0 tons
curve	vertical	5110+03	155+755	1,429.6	435.8	52.9	16.1	48.0	1219.2	0.3	201,921 lb	101.0 tons
curve	vertical	5110+50	155+770	1,476.8	450.1	48.9	14.9	48.0	1219.2	0.3	207,536 lb	103.8 tons
curve	vertical	5110+97	155+784	1,523.9	464.5	45.5	13.9	48.0	1219.2	0.3	212,983 lb	106.5 tons
curve	vertical	5111+44	155+798	1,571.0	478.8	42.8	13.0	48.0	1219.2	0.3	218,310 lb	109.2 tons
curve	vertical	5111+91	155+813	1,618.1	493.2	40.6	12.4	48.0	1219.2	0.3	223,553 lb	111.8 tons
curve	vertical	5112+38	155+827	1,665.3	507.6	39.1	11.9	48.0	1219.2	0.3	228,734 lb	114.4 tons
curve	vertical	5112+85	155+842	1,712.4	521.9	38.1	11.6	48.0	1219.2	0.3	233,873 lb	116.9 tons
curve	vertical	5113+32	155+856	1,759.5	536.3	37.8	11.5	48.0	1219.2	0.3	238,984 lb	119.5 tons
straight		5113+65	155+866	1,793.5	546.7	37.8	11.5	48.0	1219.2	0.3	243,222 lb	121.6 tons
straight		5114+00	155+877	1,827.5	557.0	37.8	11.5	48.0	1219.2	0.3	247,460 lb	123.7 tons
straight		5114+34	155+887	1,861.5	567.4	37.8	11.5	48.0	1219.2	0.3	251,698 lb	125.8 tons
straight		5114+68	155+897	1,895.5	577.8	37.8	11.5	48.0	1219.2	0.3	255,936 lb	128.0 tons
curve	vertical	5115+41	155+920	1,966.8	600.1	38.6	11.8	48.0	1219.2	0.3	284,516 lb	142.3 tons
curve	vertical	5116+15	155+942	2,042.1	622.4	40.8	12.4	48.0	1219.2	0.3	283,492 lb	141.7 tons
curve	vertical	5116+88	155+964	2,115.4	644.8	44.6	13.6	48.0	1219.2	0.3	271,048 lb	135.5 tons
curve	vertical	5117+61	155+987	2,188.7	667.1	49.8	15.2	48.0	1219.2	0.3	274,282 lb	137.1 tons
curve	vertical	5118+34	156+009	2,262.0	689.5	56.5	17.2	48.0	1219.2	0.3	286,052 lb	143.0 tons
curve	vertical	5119+07	156+031	2,335.3	711.8	64.7	19.7	48.0	1219.2	0.3	290,799 lb	145.4 tons
curve	vertical	5119+79	156+053	2,408.6	734.2	74.3	22.7	48.0	1219.2	0.3	306,961 lb	153.5 tons
curve	vertical	5120+52	156+075	2,481.9	756.5	85.5	26.1	48.0	1219.2	0.3	316,774 lb	158.4 tons
curve	vertical	5121+24	156+097	2,555.2	778.8	98.1	29.9	48.0	1219.2	0.3	326,363 lb	163.2 tons
curve	vertical	5121+96	156+119	2,628.5	801.2	112.2	34.2	48.0	1219.2	0.3	335,810 lb	167.9 tons
curve	vertical	5122+68	156+141	2,701.9	823.5	127.8	38.9	48.0	1219.2	0.3	345,172 lb	172.6 tons
curve	vertical	5123+39	156+163	2,775.2	845.9	144.8	44.1	48.0	1219.2	0.3	354,487 lb	177.2 tons
straight		5123+75	156+174	2,811.9	857.1	153.7	46.8	48.0	1219.2	0.3	360,417 lb	180.2 tons
straight		5124+10	156+185	2,848.6	868.3	162.5	49.5	48.0	1219.2	0.3	366,347 lb	183.2 tons
straight		5124+46	156+195	2,885.3	879.5	171.4	52.2	48.0	1219.2	0.3	372,277 lb	186.1 tons
straight		5124+81	156+206	2,922.0	890.6	180.3	55.0	48.0	1219.2	0.3	378,207 lb	189.1 tons
straight		5125+17	156+217	2,958.7	901.8	189.2	57.7	48.0	1219.2	0.3	384,137 lb	192.1 tons
straight		5125+53	156+228	2,995.5	913.0	198.1	60.4	48.0	1219.2	0.3	390,067 lb	195.0 tons
straight		5125+88	156+239	3,032.2	924.2	207.0	63.1	48.0	1219.2	0.3	395,998 lb	198.0 tons
straight		5126+24	156+250	3,068.9	935.4	215.8	65.8	48.0	1219.2	0.3	401,928 lb	201.0 tons
straight		5126+60	156+261	3,105.6	946.6	224.7	68.5	48.0	1219.2	0.3	407,858 lb	203.9 tons
straight		5126+95	156+271	3,142.3	957.8	233.6	71.2	48.0	1219.2	0.3	413,788 lb	206.9 tons
straight		5127+31	156+282	3,179.1	969.0	242.5	73.9	48.0	1219.2	0.3	419,718 lb	209.9 tons
straight		5127+66	156+293	3,215.8	980.2	251.4	76.6	48.0	1219.2	0.3	425,648 lb	212.8 tons
straight		5128+02	156+304	3,252.5	991.4	260.2	79.3	48.0	1219.2	0.3	431,578 lb	215.8 tons
straight		5128+38	156+315	3,289.2	1,002.6	269.1	82.0	48.0	1219.2	0.3	437,508 lb	218.8 tons
straight		5128+73	156+326	3,325.9	1,013.8	278.0	84.7	48.0	1219.2	0.3	443,438 lb	221.7 tons
HDD Rig Location		5129+09	156+337	3,362.7	1,024.9	286.9	87.4	48.0	1219.2	0.3	449,368 lb	224.7 tons

HDD Installation Stress Analysis

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	CombinedTensile and Bending <1.0	Combined Tensile, Bending and Hoop Factor	Combined Tensile, Bending and Hoop <1.0
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS				
1,178	8.12	1.68%	0	0.00	0.00%	0.0	0.00	0.00%	0.02	Yes	0.00	Yes
1,231	8.49	1.76%	0	0.00	0.00%	35.4	0.24	0.05%	0.02	Yes	0.00	Yes
1,284	8.85	1.83%	0	0.00	0.00%	70.9	0.49	0.10%	0.02	Yes	0.00	Yes
1,336	9.21	1.91%	0	0.00	0.00%	106.3	0.73	0.15%	0.02	Yes	0.00	Yes
1,389	9.58	1.98%	0	0.00	0.00%	141.8	0.98	0.20%	0.02	Yes	0.00	Yes
1,442	9.94	2.06%	0	0.00	0.00%	177.2	1.22	0.25%	0.03	Yes	0.00	Yes
1,530	10.55	2.19%	0	0.00	0.00%	134.0	0.92	0.19%	0.03	Yes	0.00	Yes
1,619	11.16	2.31%	0	0.00	0.00%	169.4	1.17	0.24%	0.03	Yes	0.00	Yes
1,707	11.77	2.44%	0	0.00	0.00%	204.9	1.41	0.29%	0.03	Yes	0.00	Yes
1,795	12.38	2.56%	0	0.00	0.00%	240.3	1.66	0.34%	0.03	Yes	0.00	Yes
1,884	12.99	2.69%	0	0.00	0.00%	275.7	1.90	0.39%	0.03	Yes	0.00	Yes
1,972	13.60	2.82%	0	0.00	0.00%	311.2	2.15	0.44%	0.04	Yes	0.00	Yes
2,060	14.20	2.94%	0	0.00	0.00%	346.6	2.39	0.50%	0.04	Yes	0.01	Yes
2,582	17.80	3.69%	12,167	83.89	17.38%	365.9	2.52	0.52%	0.32	Yes	0.08	Yes
2,567	17.70	3.67%	12,167	83.89	17.38%	384.0	2.65	0.55%	0.32	Yes	0.08	Yes
2,333	16.08	3.33%	12,167	83.89	17.38%	400.9	2.76	0.57%	0.31	Yes	0.08	Yes
2,196	15.14	3.14%	12,167	83.89	17.38%	416.5	2.87	0.59%	0.31	Yes	0.08	Yes
2,100	14.48	3.00%	12,167	83.89	17.38%	430.8	2.97	0.62%	0.31	Yes	0.08	Yes
2,171	14.97	3.10%	12,167	83.89	17.38%	444.0	3.06	0.63%	0.31	Yes	0.08	Yes
2,251	15.52	3.22%	12,167	83.89	17.38%	455.9	3.14	0.65%	0.31	Yes	0.08	Yes
2,324	16.03	3.32%	12,167	83.89	17.38%	466.5	3.22	0.67%	0.31	Yes	0.08	Yes
2,394	16.50	3.42%	12,167	83.89	17.38%	475.9	3.28	0.68%	0.31	Yes	0.08	Yes
2,460	16.96	3.51%	12,167	83.89	17.38%	484.1	3.34	0.69%	0.32	Yes	0.08	Yes
2,525	17.41	3.61%	12,167	83.89	17.38%	490.9	3.38	0.70%	0.32	Yes	0.08	Yes
2,588	17.84	3.70%	12,167	83.89	17.38%	496.6	3.42	0.71%	0.32	Yes	0.08	Yes
2,650	18.27	3.79%	12,167	83.89	17.38%	501.0	3.45	0.72%	0.32	Yes	0.08	Yes
2,712	18.70	3.87%	12,167	83.89	17.38%	504.1	3.48	0.72%	0.32	Yes	0.09	Yes
2,772	19.12	3.96%	12,167	83.89	17.38%	506.0	3.49	0.72%	0.32	Yes	0.09	Yes
2,833	19.53	4.05%	12,167	83.89	17.38%	506.6	3.49	0.72%	0.32	Yes	0.09	Yes
2,933	19.88	4.12%	0	0.00	0.00%	506.6	3.49	0.72%	0.05	Yes	0.01	Yes
2,934	20.23	4.19%	0	0.00	0.00%	506.6	3.49	0.72%	0.05	Yes	0.01	Yes
2,985	20.57	4.26%	0	0.00	0.00%	506.6	3.49	0.72%	0.05	Yes	0.01	Yes
3,034	20.92	4.33%	0	0.00	0.00%	506.6	3.49	0.72%	0.05	Yes	0.01	Yes
3,373	23.25	4.82%	12,167	83.89	17.38%	505.1	3.48	0.72%	0.33	Yes	0.09	Yes
3,361	23.17	4.80%	12,167	83.89	17.38%	500.6	3.45	0.72%	0.33	Yes	0.09	Yes
3,213	22.15	4.59%	12,167	83.89	17.38%	493.0	3.40	0.70%	0.33	Yes	0.09	Yes
3,251	22.42	4.64%	12,167	83.89	17.38%	482.3	3.33	0.69%	0.33	Yes	0.09	Yes
3,391	23.38	4.84%	12,167	83.89	17.38%	468.7	3.23	0.67%	0.33	Yes	0.09	Yes
3,518	24.26	5.03%	12,167	83.89	17.38%	452.0	3.12	0.65%	0.34	Yes	0.09	Yes
3,639	25.09	5.20%	12,167	83.89	17.38%	432.4	2.98	0.62%	0.34	Yes	0.09	Yes
3,755	25.89	5.36%	12,167	83.89	17.38%	409.7	2.82	0.59%	0.34	Yes	0.09	Yes
3,869	26.67	5.53%	12,167	83.89	17.38%	384.0	2.65	0.55%	0.34	Yes	0.09	Yes
3,981	27.45	5.69%	12,167	83.89	17.38%	355.3	2.45	0.51%	0.34	Yes	0.09	Yes
4,092	28.21	5.85%	12,167	83.89	17.38%	323.7	2.23	0.46%	0.35	Yes	0.09	Yes
4,202	28.97	6.00%	12,167	83.89	17.38%	289.1	1.99	0.41%	0.35	Yes	0.09	Yes
4,273	29.46	6.10%	0	0.00	0.00%	271.0	1.87	0.38%	0.08	Yes	0.01	Yes
4,343	29.94	6.20%	0	0.00	0.00%	253.0	1.74	0.36%	0.08	Yes	0.01	Yes
4,413	30.43	6.30%	0	0.00	0.00%	234.9	1.62	0.34%	0.08	Yes	0.01	Yes
4,483	30.91	6.40%	0	0.00	0.00%	216.8	1.49	0.31%	0.08	Yes	0.01	Yes
4,554	31.40	6.51%	0	0.00	0.00%	198.8	1.37	0.28%	0.08	Yes	0.01	Yes
4,624	31.88	6.61%	0	0.00	0.00%	180.7	1.25	0.26%	0.08	Yes	0.01	Yes
4,694	32.37	6.71%	0	0.00	0.00%	162.6	1.12	0.23%	0.08	Yes	0.01	Yes
4,765	32.85	6.81%	0	0.00	0.00%	144.6	1.00	0.21%	0.09	Yes	0.01	Yes
4,835	33.34	6.91%	0	0.00	0.00%	126.5	0.87	0.18%	0.09	Yes	0.01	Yes
4,905	33.82	7.01%	0	0.00	0.00%	108.4	0.75	0.15%	0.09	Yes	0.01	Yes
4,976	34.31	7.11%	0	0.00	0.00%	90.3	0.62	0.13%	0.09	Yes	0.01	Yes
5,046	34.79	7.21%	0	0.00	0.00%	72.3	0.50	0.10%	0.09	Yes	0.01	Yes
5,116	35.27	7.31%	0	0.00	0.00%	54.2	0.37	0.08%	0.09	Yes	0.01	Yes
5,186	35.76	7.41%	0	0.00	0.00%	36.1	0.25	0.05%	0.09	Yes	0.01	Yes
5,257	36.24	7.51%	0	0.00	0.00%	18.1	0.12	0.03%	0.09	Yes	0.01	Yes
5,327	36.73	7.61%	0	0.00	0.00%	0.0	0.00	0.00%	0.10	Yes	0.01	Yes

NOTE: Hoop stress taken as an empty pipe for no buoyancy control and with water with buoyancy control

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	Combined Tensile, Bending and Hoop Factor
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS		
5,327	36.7	7.61%	12,167	83.9	17.38%	507	3.5	0.72%	0.35	0.09

Ground Elevation at Pipe Entry	325.56	feet
	99.23	metres
Ground Elevation at Pipe Exit	286.90	feet
	87.45	metres

	TOTAL PULL LOADS	
Maximum Values	449,368 lb	224.7 tons

Input Pipe Properties

Pipe Outer Diameter	36	in
	914.4	mm
Pipe Wall Thickness	0.762	in
	19.3548	mm
DR	47.2	
Pipe Weight (in air)	287.04	lbs/ft
	428.06	kg/m
Weight of Water in pipe	404.5	lbs/ft
	603.26	kg/m
Net Buoyant Weight of pipe	162.8	lbs/ft
	242.84	kg/m
Young's Modulus of Elasticity	2.92E+07	psi
	201327	MPa
Yield Strength	70,090	psi
	482.6	MPa
Poisson Ratio	0.3	
Drill Pipe Diameter	6.625	in
	168.275	mm
Minimum Radius of Curvature	2,500	ft
	762	m

Ultimate Safe Pull Load	3,542,953	lb
	15,760	kN
Maximum Calculated Pull Load	449,368	lb
	1,999	kN
Factor of Safety	7.9	

Start-Up Load Factor	2	
Maximum Calculated Start-Up Pipe Pull Load	898,736	lb
	3,998	kN
Factor of Safety	3.9	

Soil and Mud Properties

Mud Weight	10	ppg of drill fluid and solids (typically 9.5 to 11 lb/gal)
	1,199	Specific Gravity
Friction Coeff. (GS or rollers)	0.1	rollers typically 0.10 to 0.30 (along ground surface is higher range)
Yield Point	19.5	lb/100ft² (Based on HDD experience from previous installations)
	93.366	dyne/cm²
Plastic Viscosity	13	cP (Based on HDD experience from previous installations)
Drilling mud pumping rate	600	GPM (typically 200 to 300 gpm for soil or 400 to 800 gpm bedrock)
	2.271	m³/min
Drilling mud pumping rate	1125	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)
	4.273	m³/min
Pipe Pullback Rate	10	feet/min (Based on HDD experience)
	3.05	m/min

MOTT MACDONALD

Calculated by: M. Lockwood
Checked by: G. Duyvestyn
Date: 4/19/2019
Project No: 353754

Horizontal Directional Drilling
Calculation of Pull Loads and Stresses during Pipe Installation

PROJECT: PennEast Pipeline Project - Case 3

HDD CROSSING LOCATION: Wickecheoke Creek

Reference:
1. Installation of Pipelines by Horizontal Directional Drilling, an Engineering Guide, PRCI Publication 2015
2. Pipeline Design for Installation by Horizontal Directional Drilling, Manual of Practice, ASCE MREP 108, 2005

HDD Installation Load Analysis

Segment Type	Type of Curve	Bore Stationing		Installed Length		Bore Elevation		Bore Diameter		Geotechnical Friction Factor	TOTAL PULL LOADS	
		feet	metres	feet	metres	feet	metres	inch	mm			
Pipe Entry Location		5096+00	155+328	0.0	0.0	325.6	99.2	--	--		99,394 lb	49.7 tons
straight		5096+82	155+353	83.8	25.5	306.1	93.9	48.0	1219.2	0.3	115,049 lb	57.6 tons
straight		5097+64	155+378	167.6	51.1	290.7	88.6	48.0	1219.2	0.3	130,704 lb	65.4 tons
straight		5098+46	155+403	251.4	76.6	273.3	83.3	48.0	1219.2	0.3	146,360 lb	73.2 tons
straight		5099+28	155+428	335.2	102.2	255.9	78.0	48.0	1219.2	0.3	157,447 lb	83.7 tons
straight		5100+10	155+453	419.0	127.7	236.5	72.7	48.0	1219.2	0.3	188,535 lb	94.3 tons
straight		5100+92	155+478	502.8	153.2	221.0	67.4	48.0	1219.2	0.3	209,622 lb	104.8 tons
straight		5101+74	155+503	586.6	178.8	203.6	62.1	48.0	1219.2	0.3	230,710 lb	115.4 tons
straight		5102+56	155+528	670.3	204.3	186.2	56.8	48.0	1219.2	0.3	251,797 lb	125.9 tons
straight		5103+38	155+553	754.1	229.9	168.8	51.4	48.0	1219.2	0.3	272,884 lb	136.4 tons
straight		5104+20	155+578	837.9	255.4	151.3	46.1	48.0	1219.2	0.3	293,972 lb	147.0 tons
straight		5105+02	155+603	921.7	280.9	133.9	40.8	48.0	1219.2	0.3	315,059 lb	157.5 tons
straight		5105+84	155+628	1,005.5	306.5	116.5	35.5	48.0	1219.2	0.3	336,147 lb	168.1 tons
curve	vertical	5106+30	155+642	1,052.6	320.9	107.0	32.6	48.0	1219.2	0.3	383,164 lb	191.6 tons
curve	vertical	5106+76	155+656	1,099.8	335.2	98.1	29.9	48.0	1219.2	0.3	377,091 lb	188.5 tons
curve	vertical	5107+22	155+670	1,146.9	349.6	89.8	27.4	48.0	1219.2	0.3	400,373 lb	200.2 tons
curve	vertical	5107+69	155+684	1,194.0	363.9	82.2	25.0	48.0	1219.2	0.3	425,229 lb	212.6 tons
curve	vertical	5108+15	155+698	1,241.1	378.3	75.1	22.9	48.0	1219.2	0.3	436,015 lb	218.0 tons
curve	vertical	5108+62	155+713	1,288.3	392.7	68.6	20.9	48.0	1219.2	0.3	448,270 lb	224.1 tons
curve	vertical	5109+09	155+727	1,335.4	407.0	62.8	19.1	48.0	1219.2	0.3	461,271 lb	230.6 tons
curve	vertical	5109+56	155+741	1,382.5	421.4	57.6	17.5	48.0	1219.2	0.3	474,649 lb	237.3 tons
curve	vertical	5110+03	155+755	1,429.6	435.8	52.9	16.1	48.0	1219.2	0.3	488,202 lb	244.1 tons
curve	vertical	5110+50	155+770	1,476.8	450.1	48.9	14.9	48.0	1219.2	0.3	501,810 lb	250.9 tons
curve	vertical	5110+97	155+784	1,523.9	464.5	45.5	13.9	48.0	1219.2	0.3	515,398 lb	257.7 tons
curve	vertical	5111+44	155+798	1,571.0	478.8	42.8	13.0	48.0	1219.2	0.3	528,923 lb	264.5 tons
curve	vertical	5111+91	155+813	1,618.1	493.2	40.6	12.4	48.0	1219.2	0.3	542,357 lb	271.2 tons
curve	vertical	5112+38	155+827	1,665.3	507.6	39.1	11.9	48.0	1219.2	0.3	555,663 lb	277.8 tons
curve	vertical	5112+85	155+842	1,712.4	521.9	38.1	11.6	48.0	1219.2	0.3	568,894 lb	284.4 tons
curve	vertical	5113+32	155+856	1,759.5	536.3	37.8	11.5	48.0	1219.2	0.3	581,982 lb	291.0 tons
straight		5113+66	155+866	1,793.5	546.7	37.8	11.5	48.0	1219.2	0.3	588,571 lb	294.3 tons
straight		5114+00	155+877	1,827.5	557.0	37.8	11.5	48.0	1219.2	0.3	595,161 lb	297.6 tons
straight		5114+34	155+887	1,861.5	567.4	37.8	11.5	48.0	1219.2	0.3	601,750 lb	300.9 tons
straight		5114+68	155+897	1,895.5	577.8	37.8	11.5	48.0	1219.2	0.3	608,339 lb	304.2 tons
curve	vertical	5115+41	155+920	1,968.8	600.1	36.6	11.2	48.0	1219.2	0.3	648,898 lb	324.4 tons
curve	vertical	5116+15	155+942	2,042.1	622.4	40.8	12.4	48.0	1219.2	0.3	648,125 lb	324.1 tons
curve	vertical	5116+88	155+964	2,115.4	644.8	44.6	13.6	48.0	1219.2	0.3	674,627 lb	337.3 tons
curve	vertical	5117+61	155+987	2,188.7	667.1	49.8	15.2	48.0	1219.2	0.3	682,767 lb	341.4 tons
curve	vertical	5118+34	156+009	2,262.0	689.5	56.5	17.2	48.0	1219.2	0.3	705,238 lb	352.6 tons
curve	vertical	5119+07	156+031	2,335.3	711.8	64.7	19.7	48.0	1219.2	0.3	718,701 lb	359.4 tons
curve	vertical	5119+79	156+053	2,408.6	734.2	74.3	22.7	48.0	1219.2	0.3	739,299 lb	369.6 tons
curve	vertical	5120+52	156+075	2,481.9	756.5	85.5	26.1	48.0	1219.2	0.3	755,279 lb	377.6 tons
curve	vertical	5121+24	156+097	2,555.2	778.8	98.1	29.9	48.0	1219.2	0.3	810,055 lb	405.0 tons
curve	vertical	5121+98	156+119	2,628.5	801.2	112.2	34.2	48.0	1219.2	0.3	827,928 lb	414.0 tons
curve	vertical	5122+68	156+141	2,701.9	823.6	127.8	38.9	48.0	1219.2	0.3	845,463 lb	422.7 tons
curve	vertical	5123+39	156+163	2,775.2	845.9	144.8	44.1	48.0	1219.2	0.3	862,655 lb	431.3 tons
straight		5123+75	156+174	2,811.9	857.1	153.7	46.8	48.0	1219.2	0.3	866,986 lb	433.5 tons
straight		5124+10	156+185	2,848.6	868.3	162.5	49.5	48.0	1219.2	0.3	871,316 lb	435.7 tons
straight		5124+46	156+195	2,885.3	879.5	171.4	52.2	48.0	1219.2	0.3	875,647 lb	437.8 tons
straight		5124+81	156+206	2,922.0	890.6	180.3	55.0	48.0	1219.2	0.3	879,978 lb	440.0 tons
straight		5125+17	156+217	2,958.7	901.8	189.2	57.7	48.0	1219.2	0.3	884,309 lb	442.2 tons
straight		5125+53	156+228	2,995.5	913.0	198.1	60.4	48.0	1219.2	0.3	888,639 lb	444.3 tons
straight		5125+88	156+239	3,032.2	924.2	207.0	63.1	48.0	1219.2	0.3	892,970 lb	446.5 tons
straight		5126+24	156+250	3,068.9	935.4	215.8	65.8	48.0	1219.2	0.3	897,301 lb	448.7 tons
straight		5126+60	156+261	3,105.6	946.6	224.7	68.5	48.0	1219.2	0.3	901,631 lb	450.8 tons
straight		5126+95	156+271	3,142.3	957.8	233.6	71.2	48.0	1219.2	0.3	905,962 lb	453.0 tons
straight		5127+31	156+282	3,179.1	969.0	242.5	73.9	48.0	1219.2	0.3	910,293 lb	455.1 tons
straight		5127+66	156+293	3,215.8	980.2	251.4	76.6	48.0	1219.2	0.3	914,623 lb	457.3 tons
straight		5128+02	156+304	3,252.5	991.4	260.2	79.3	48.0	1219.2	0.3	918,954 lb	459.5 tons
straight		5128+38	156+315	3,289.2	1,002.6	269.1	82.0	48.0	1219.2	0.3	923,285 lb	461.6 tons
straight		5128+73	156+326	3,325.9	1,013.8	278.0	84.7	48.0	1219.2	0.3	927,616 lb	463.8 tons
HDD Rig Location		5128+09	156+337	3,362.7	1,024.9	286.9	87.4	48.0	1219.2	0.3	931,946 lb	466.0 tons

HDD Installation Stress Analysis

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	CombinedTensile and Bending <1.0	Combined Tensile, Bending and Hoop Factor	Combined Tensile, Bending and Hoop <1.0
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS				
1,178	8.12	1.68%	0	0.00	0.00%	0.0	0.00	0.00%	0.02	Yes	0.00	Yes
1,364	9.40	1.95%	0	0.00	0.00%	235.1	1.62	0.34%	0.02	Yes	0.00	Yes
1,549	10.68	2.21%	0	0.00	0.00%	470.3	3.24	0.67%	0.03	Yes	0.01	Yes
1,735	11.96	2.48%	0	0.00	0.00%	705.4	4.85	1.01%	0.03	Yes	0.01	Yes
1,985	13.69	2.84%	0	0.00	0.00%	418.7	2.89	0.60%	0.04	Yes	0.02	Yes
2,235	15.41	3.19%	0	0.00	0.00%	653.9	4.51	0.93%	0.04	Yes	0.03	Yes
2,485	17.13	3.55%	0	0.00	0.00%	889.0	6.13	1.27%	0.04	Yes	0.04	Yes
2,735	18.86	3.91%	0	0.00	0.00%	1,124.2	7.75	1.61%	0.05	Yes	0.05	Yes
2,985	20.58	4.26%	0	0.00	0.00%	1,359.3	9.37	1.94%	0.05	Yes	0.07	Yes
3,235	22.30	4.62%	0	0.00	0.00%	1,594.4	10.99	2.28%	0.06	Yes	0.08	Yes
3,465	24.03	4.98%	0	0.00	0.00%	1,829.6	12.61	2.61%	0.06	Yes	0.10	Yes
3,735	25.75	5.34%	0	0.00	0.00%	2,064.7	14.24	2.95%	0.07	Yes	0.12	Yes
3,985	27.47	5.69%	0	0.00	0.00%	2,299.9	15.86	3.29%	0.07	Yes	0.15	Yes
4,542	31.32	6.49%	12,167	83.89	17.38%	2,428.1	16.74	3.47%	0.35	Yes	0.28	Yes
4,470	30.82	6.39%	12,167	83.89	17.38%	2,546.1	17.57	3.64%	0.35	Yes	0.30	Yes
4,746	32.72	6.78%	12,167	83.89	17.38%	2,659.9	18.34	3.80%	0.36	Yes	0.31	Yes
5,041	34.76	7.20%	12,167	83.89	17.38%	2,763.5	19.05	3.95%	0.36	Yes	0.33	Yes
5,169	35.64	7.36%	12,167	83.89	17.38%	2,858.9	19.71	4.08%	0.36	Yes	0.35	Yes
5,314	36.64	7.59%	12,167	83.89	17.38%	2,946.0	20.31	4.21%	0.37	Yes	0.36	Yes
5,468	37.70	7.81%	12,167	83.89	17.38%	3,024.9	20.86	4.32%	0.37	Yes	0.37	Yes
5,627	38.79	8.04%	12,167	83.89	17.38%	3,095.5	21.34	4.42%	0.37	Yes	0.38	Yes
5,787	39.90	8.27%	12,167	83.89	17.38%	3,157.9	21.77	4.51%	0.38	Yes	0.40	Yes
5,949	41.01	8.50%	12,167	83.89	17.38%	3,211.9	22.15	4.59%	0.38	Yes	0.41	Yes
6,110	42.13	8.73%	12,167	83.89	17.38%	3,257.7	22.46	4.65%	0.38	Yes	0.41	Yes
6,270	43.23	8.96%	12,167	83.89	17.38%	3,295.1	22.72	4.71%	0.38	Yes	0.42	Yes
6,429	44.33	9.18%	12,167	83.89	17.38%	3,324.2	22.92	4.75%	0.39	Yes	0.43	Yes
6,587	45.42	9.41%	12,167	83.89	17.38%	3,345.1	23.06	4.78%	0.39	Yes	0.43	Yes
6,744	46.50	9.63%	12,167	83.89	17.38%	3,357.5	23.15	4.80%	0.39	Yes	0.44	Yes
6,699	47.57	9.86%	12,167	83.89	17.38%	3,361.7	23.18	4.80%	0.40	Yes	0.44	Yes
6,977	48.11	9.97%	0	0.00	0.00%	3,361.7	23.18	4.80%	0.12	Yes	0.29	Yes
7,055	48.64	10.08%	0	0.00	0.00%	3,361.7	23.18	4.80%	0.13	Yes	0.29	Yes
7,133	49.18	10.19%	0	0.00	0.00%	3,361.7	23.18	4.80%	0.13	Yes	0.29	Yes
7,212	49.72	10.30%	0	0.00	0.00%	3,361.7	23.18	4.80%	0.13	Yes	0.29	Yes
7,692	53.04	10.99%	12,167	83.89	17.38%	3,351.8	23.11	4.79%	0.41	Yes	0.45	Yes
7,693	52.97	10.98%	12,167	83.89	17.38%	3,321.4	22.90	4.74%	0.41	Yes	0.45	Yes
7,997	55.14	11.42%	12,167	83.89	17.38%	3,271.1	22.55	4.67%	0.42	Yes	0.45	Yes
8,094	55.81	11.56%	12,167	83.89	17.38%	3,203.6	22.07	4.57%	0.42	Yes	0.44	Yes
8,360	57.64	11.94%	12,167	83.89	17.38%	3,110.1	21.44	4.44%	0.42	Yes	0.43	Yes
8,525	58.74	12.17%	12,167	83.89	17.38%	2,999.5	20.68	4.29%	0.42	Yes	0.42	Yes
8,764	60.43	12.52%	12,167	83.89	17.38%	2,868.9	19.78	4.10%	0.43	Yes	0.40	Yes
8,953	61.73	12.79%	12,167	83.89	17.38%	2,718.4	18.74	3.88%	0.43	Yes	0.39	Yes
9,603	65.21	13.72%	12,167	83.89	17.38%	2,548.1	17.57	3.64%	0.44	Yes	0.38	Yes
9,815	67.67	14.02%	12,167	83.89	17.38%	2,357.9	16.26	3.37%	0.45	Yes	0.36	Yes
10,023	69.10	14.32%	12,167	83.89	17.38%	2,147.9	14.81	3.07%	0.45	Yes	0.34	Yes
10,226	70.51	14.61%	12,167	83.89	17.38%	1,918.4	13.23	2.74%	0.45	Yes	0.32	Yes
10,276	70.86	14.68%	0	0.00	0.00%	1,798.5	12.40	2.57%	0.18	Yes	0.15	Yes
10,329	71.22	14.76%	0	0.00	0.00%	1,678.6	11.57	2.40%	0.18	Yes	0.14	Yes
10,380	71.57	14.83%	0	0.00	0.00%	1,558.7	10.75	2.23%	0.19	Yes	0.13	Yes
10,432	71.92	14.90%	0	0.00	0.00%	1,438.8	9.92	2.06%	0.19	Yes	0.12	Yes
10,483	72.28	14.98%	0	0.00	0.00%	1,318.9	9.09	1.88%	0.19	Yes	0.11	Yes
10,534	72.63	15.05%	0	0.00	0.00%	1,199.0	8.27	1.71%	0.19	Yes	0.10	Yes
10,586	72.99	15.12%	0	0.00	0.00%	1,079.1	7.44	1.54%	0.19	Yes	0.10	
10,637	73.34	15.20%	0	0.00	0.00%	959.2	6.61	1.37%	0.19	Yes	0.09	
10,686	73.69	15.27%	0	0.00	0.00%	839.3	5.79	1.20%	0.19	Yes	0.08	
10,740	74.05	15.34%	0	0.00	0.00%	719.4	4.96	1.03%	0.19	Yes	0.08	
10,791	74.40	15.42%	0	0.00	0.00%	599.5	4.13	0.86%	0.19	Yes	0.07	
10,842	74.76	15.49%	0	0.00	0.00%	479.6	3.31	0.69%	0.19	Yes	0.07	Yes
10,894	75.11	15.56%	0	0.00	0.00%	359.7	2.48	0.51%	0.19	Yes	0.06	Yes
10,945	75.46	15.64%	0	0.00	0.00%	239.8	1.65	0.34%	0.20	Yes	0.06	Yes
10,996	75.82	15.71%	0	0.00	0.00%	119.9	0.83	0.17%	0.20	Yes	0.05	Yes
11,048	76.17	15.78%	0	0.00	0.00%	0.0	0.00	0.00%	0.20	Yes	0.05	Yes

NOTE: Hoop stress taken as an empty pipe for no buoyancy control and with water with buoyancy control

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	Combined Tensile, Bending and Hoop Factor
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS		
11,048	76.2	15.78%	12,167	83.9	17.38%	3,362	23.2	4.80%	0.45	0.45

	TOTAL PULL LOADS	
Maximum Values	931,946 lb	466.0 tons

Ground Elevation at Pipe Entry	325.56	feet
	99.23	metres
Ground Elevation at Pipe Exit	286.90	feet
	87.45	metres

Input Pipe Properties

Pipe Outer Diameter	36	in
	914.4	mm
Pipe Wall Thickness	0.762	in
	19.3548	mm
DR	47.2	
Pipe Weight (in air)	267.04	lbs/ft
	428.06	kg/m
Weight of Water in pipe	0.0	lbs/ft
	0.00	kg/m
Net Buoyant Weight of pipe	-294.8	lbs/ft
	-439.27	kg/m
Young's Modulus of Elasticity	2.92E+07	psi
	201327	MPa
Yield Strength	70,000	psi
	482.6	MPa
Poisson Ratio	0.3	
Drill Pipe Diameter	6.625	in
	168.275	mm
Minimum Radius of Curvature	2,500	ft
	762	m
Ultimate Safe Pull Load	3,542,953	lb
	15,760	kN
Maximum Calculated Pull Load	931,946	lb
	4,146	kN
Factor of Safety	3.8	
Start-Up Load Factor	2	
Maximum Calculated Start-Up Pipe Pull Load	1,863,892	lb
	8,291	kN
Factor of Safety	1.9	

Soil and Mud Properties

Mud Weight	11	ppg of drill fluid and solids (typically 9.5 to 11 lb/gal)
	1,319	Specific Gravity
Friction Coeff. (GS or rollers)	0.1	rollers typically 0.10 to 0.30 (along ground surface is higher range)
Yield Point	19.5	lb/100ft² (Based on HDD experience from previous installations)
	93,356	dyne/cm²
Plastic Viscosity	13	cP (Based on HDD experience from previous installations)
Drilling mud pumping rate	600	GPM (typically 200 to 300 gpm for soil or 400 to 800 gpm bedrock)
	2.271	m³/min
Drilling mud pumping rate	1129	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)
	4.273	m³/min
Pipe Pullback Rate	10	feet/min (Based on HDD experience)
	3.05	m/min

MOTT MACDONALD

Calculated by: M. Lockwood
Checked by: G. Duyvestyn
Date: 4/19/2019
Project No: 353754

ontal Directional Drilling
lation of Pull Loads and Stresses during Pipe Installation

PROJECT: PennEast Pipeline Project - Case 4

HDD CROSSING LOCATION: Wickecheoke Creek

Reference:
1. Installation of Pipelines by Horizontal Directional Drilling, an Engineering Guide, PRCI Publication 2015
2. Pipeline Design for Installation by Horizontal Directional Drilling, Manual of Practice, ASCE MREP 108, 2005

HDD Installation Load Analysis

Segment Type	Type of Curve	Bore Stationing		Installed Length		Bore Elevation		Bore Diameter		Geotechnical Friction Factor	TOTAL PULL LOADS		
		feet	metres	feet	metres	feet	metres	inch	mm				
Pipe Entry Location		5096+00	155+328	0.0	0.0	325.6	99.2	--	--		99,394	lb	49.7 tons
straight		5096+82	155+353	63.8	25.5	308.1	93.9	48.0	1219.2	0.3	103,463	lb	51.7 tons
straight		5097+64	155+378	167.6	51.1	290.7	88.6	48.0	1219.2	0.3	107,532	lb	53.8 tons
straight		5098+46	155+403	251.4	76.6	273.3	83.3	48.0	1219.2	0.3	111,601	lb	55.8 tons
straight		5099+28	155+428	335.2	102.2	255.9	78.0	48.0	1219.2	0.3	117,698	lb	58.8 tons
straight		5100+10	155+453	419.0	127.7	238.5	72.7	48.0	1219.2	0.3	123,794	lb	61.9 tons
straight		5100+92	155+478	502.8	153.2	221.0	67.4	48.0	1219.2	0.3	129,891	lb	64.9 tons
straight		5101+74	155+503	586.6	178.8	203.6	62.1	48.0	1219.2	0.3	135,988	lb	68.0 tons
straight		5102+56	155+528	670.3	204.3	186.2	56.8	48.0	1219.2	0.3	142,085	lb	71.0 tons
straight		5103+38	155+553	754.1	229.9	168.8	51.4	48.0	1219.2	0.3	148,182	lb	74.1 tons
straight		5104+20	155+578	837.9	255.4	151.3	46.1	48.0	1219.2	0.3	154,279	lb	77.1 tons
straight		5105+02	155+603	921.7	280.9	133.9	40.8	48.0	1219.2	0.3	160,376	lb	80.2 tons
straight		5105+84	155+628	1,005.5	306.5	116.5	35.5	48.0	1219.2	0.3	166,473	lb	83.2 tons
curve	vertical	5106+30	155+642	1,052.6	320.9	107.0	32.6	48.0	1219.2	0.3	212,205	lb	106.1 tons
curve	vertical	5106+76	155+656	1,099.8	335.2	98.1	29.9	48.0	1219.2	0.3	213,342	lb	106.7 tons
curve	vertical	5107+22	155+670	1,146.9	349.6	89.8	27.4	48.0	1219.2	0.3	195,569	lb	97.8 tons
curve	vertical	5107+69	155+684	1,194.0	363.9	82.2	25.0	48.0	1219.2	0.3	186,069	lb	93.0 tons
curve	vertical	5108+15	155+698	1,241.1	378.3	75.1	22.9	48.0	1219.2	0.3	179,916	lb	90.0 tons
curve	vertical	5108+62	155+713	1,288.3	392.7	68.8	20.9	48.0	1219.2	0.3	175,470	lb	87.7 tons
curve	vertical	5109+09	155+727	1,335.4	407.0	62.8	19.1	48.0	1219.2	0.3	174,847	lb	87.4 tons
curve	vertical	5109+56	155+741	1,382.5	421.4	57.6	17.5	48.0	1219.2	0.3	179,893	lb	89.9 tons
curve	vertical	5110+03	155+755	1,429.6	435.8	52.9	16.1	48.0	1219.2	0.3	184,574	lb	92.3 tons
curve	vertical	5110+50	155+770	1,476.8	450.1	48.9	14.9	48.0	1219.2	0.3	189,005	lb	94.5 tons
curve	vertical	5110+97	155+784	1,523.9	464.5	45.5	13.9	48.0	1219.2	0.3	193,260	lb	96.6 tons
curve	vertical	5111+44	155+798	1,571.0	478.8	42.6	13.0	48.0	1219.2	0.3	197,387	lb	98.7 tons
curve	vertical	5111+91	155+813	1,618.1	493.2	40.6	12.4	48.0	1219.2	0.3	201,421	lb	100.7 tons
curve	vertical	5112+38	155+827	1,665.3	507.6	39.1	11.9	48.0	1219.2	0.3	205,385	lb	102.7 tons
curve	vertical	5112+85	155+842	1,712.4	521.9	38.1	11.6	48.0	1219.2	0.3	209,299	lb	104.6 tons
curve	vertical	5113+32	155+856	1,759.5	536.3	37.8	11.5	48.0	1219.2	0.3	213,176	lb	106.6 tons
straight		5113+66	155+866	1,793.5	546.7	37.8	11.5	48.0	1219.2	0.3	216,470	lb	108.2 tons
straight		5114+00	155+877	1,827.5	557.0	37.8	11.5	48.0	1219.2	0.3	219,765	lb	109.9 tons
straight		5114+34	155+887	1,861.5	567.4	37.8	11.5	48.0	1219.2	0.3	223,059	lb	111.5 tons
straight		5114+68	155+897	1,895.5	577.8	37.8	11.5	48.0	1219.2	0.3	226,353	lb	113.2 tons
curve	vertical	5115+41	155+920	1,968.8	600.1	38.6	11.8	48.0	1219.2	0.3	256,473	lb	128.2 tons
curve	vertical	5116+15	155+942	2,042.1	622.4	40.8	12.4	48.0	1219.2	0.3	258,117	lb	129.1 tons
curve	vertical	5116+88	155+964	2,115.4	644.8	44.6	13.6	48.0	1219.2	0.3	247,667	lb	123.8 tons
curve	vertical	5117+61	155+987	2,188.7	667.1	49.6	15.2	48.0	1219.2	0.3	242,709	lb	121.4 tons
curve	vertical	5118+34	156+009	2,262.0	689.5	56.5	17.2	48.0	1219.2	0.3	245,255	lb	122.6 tons
curve	vertical	5119+07	156+031	2,335.3	711.8	64.7	19.7	48.0	1219.2	0.3	253,717	lb	126.9 tons
curve	vertical	5119+79	156+053	2,408.6	734.2	74.3	22.7	48.0	1219.2	0.3	261,596	lb	130.8 tons
curve	vertical	5120+52	156+075	2,481.9	756.5	85.5	26.1	48.0	1219.2	0.3	269,117	lb	134.6 tons
curve	vertical	5121+24	156+097	2,555.2	778.8	98.1	29.9	48.0	1219.2	0.3	276,408	lb	138.2 tons
curve	vertical	5121+98	156+119	2,628.5	801.2	112.2	34.2	48.0	1219.2	0.3	283,544	lb	141.8 tons
curve	vertical	5122+68	156+141	2,701.9	823.5	127.8	38.9	48.0	1219.2	0.3	290,575	lb	145.3 tons
curve	vertical	5123+39	156+163	2,775.2	845.9	144.8	44.1	48.0	1219.2	0.3	297,547	lb	148.8 tons
straight		5123+75	156+174	2,811.9	857.1	153.7	46.8	48.0	1219.2	0.3	302,019	lb	151.0 tons
straight		5124+10	156+185	2,848.6	868.3	162.5	49.5	48.0	1219.2	0.3	306,490	lb	153.2 tons
straight		5124+46	156+195	2,885.3	879.5	171.4	52.2	48.0	1219.2	0.3	310,962	lb	155.5 tons
straight		5124+81	156+206	2,922.0	890.6	180.3	55.0	48.0	1219.2	0.3	315,433	lb	157.7 tons
straight		5125+17	156+217	2,958.7	901.8	189.2	57.7	48.0	1219.2	0.3	319,904	lb	160.0 tons
straight		5125+53	156+228	2,995.5	913.0	198.1	60.4	48.0	1219.2	0.3	324,376	lb	162.2 tons
straight		5125+88	156+239	3,032.2	924.2	207.0	63.1	48.0	1219.2	0.3	328,847	lb	164.4 tons
straight		5126+24	156+250	3,068.9	935.4	215.8	65.8	48.0	1219.2	0.3	333,319	lb	166.7 tons
straight		5126+60	156+261	3,105.6	946.6	224.7	68.5	48.0	1219.2	0.3	337,790	lb	168.9 tons
straight		5126+95	156+271	3,142.3	957.8	233.6	71.2	48.0	1219.2	0.3	342,251	lb	171.1 tons
straight		5127+31	156+282	3,179.1	969.0	242.5	73.9	48.0	1219.2	0.3	346,733	lb	173.4 tons
straight		5127+66	156+293	3,215.8	980.2	251.4	76.6	48.0	1219.2	0.3	351,204	lb	175.6 tons
straight		5128+02	156+304	3,252.5	991.4	260.2	79.3	48.0	1219.2	0.3	355,676	lb	177.8 tons
straight		5128+38	156+315	3,289.2	1,002.6	269.1	82.0	48.0	1219.2	0.3	360,147	lb	180.1 tons
straight		5128+73	156+326	3,325.9	1,013.8	278.0	84.7	48.0	1219.2	0.3	364,619	lb	182.3 tons
HDD Rig Location		5129+09	156+337	3,362.7	1,024.9	286.9	87.4	48.0	1219.2	0.3	369,090	lb	184.5 tons

HDD Installation Stress Analysis

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	CombinedTensile and Bending <1.0	Combined Tensile, Bending and Hoop Factor	Combined Tensile, Bending and Hoop <1.0
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS				
1,178	8.12	1.68%	0	0.00	0.00%	0.0	0.00	0.00%	0.02	Yes	0.00	Yes
1,226	8.46	1.75%	0	0.00	0.00%	56.8	0.39	0.08%	0.02	Yes	0.00	Yes
1,275	8.79	1.82%	0	0.00	0.00%	113.6	0.78	0.16%	0.02	Yes	0.00	Yes
1,323	9.12	1.89%	0	0.00	0.00%	170.4	1.18	0.24%	0.02	Yes	0.00	Yes
1,395	9.62	1.99%	0	0.00	0.00%	101.2	0.70	0.14%	0.02	Yes	0.00	Yes
1,468	10.12	2.10%	0	0.00	0.00%	158.0	1.09	0.23%	0.03	Yes	0.00	Yes
1,540	10.62	2.20%	0	0.00	0.00%	214.8	1.48	0.31%	0.03	Yes	0.00	Yes
1,612	11.11	2.30%	0	0.00	0.00%	271.6	1.87	0.39%	0.03	Yes	0.00	Yes
1,684	11.61	2.41%	0	0.00	0.00%	328.4	2.26	0.47%	0.03	Yes	0.01	Yes
1,757	12.11	2.51%	0	0.00	0.00%	385.2	2.65	0.55%	0.03	Yes	0.01	Yes
1,829	12.61	2.61%	0	0.00	0.00%	442.1	3.05	0.63%	0.03	Yes	0.01	Yes
1,901	13.11	2.72%	0	0.00	0.00%	498.9	3.44	0.71%	0.03	Yes	0.01	Yes
1,973	13.61	2.82%	0	0.00	0.00%	555.7	3.83	0.79%	0.04	Yes	0.01	Yes
2,516	17.34	3.59%	12,167	83.89	17.38%	586.7	4.04	0.84%	0.32	Yes	0.09	Yes
2,529	17.44	3.61%	12,167	83.89	17.38%	615.6	4.24	0.88%	0.32	Yes	0.09	Yes
2,318	15.98	3.31%	12,167	83.89	17.38%	642.7	4.43	0.92%	0.31	Yes	0.09	Yes
2,206	15.21	3.15%	12,167	83.89	17.38%	667.7	4.60	0.95%	0.31	Yes	0.09	Yes
2,133	14.71	3.05%	12,167	83.89	17.38%	690.7	4.76	0.99%	0.31	Yes	0.09	Yes
2,080	14.34	2.97%	12,167	83.89	17.38%	711.8	4.91	1.02%	0.31	Yes	0.09	Yes
2,073	14.29	2.96%	12,167	83.89	17.38%	730.9	5.04	1.04%	0.31	Yes	0.09	Yes
2,133	14.70	3.05%	12,167	83.89	17.38%	747.9	5.16	1.07%	0.31	Yes	0.09	Yes
2,188	15.09	3.13%	12,167	83.89	17.38%	763.0	5.26	1.09%	0.31	Yes	0.09	Yes
2,241	15.45	3.20%	12,167	83.89	17.38%	776.0	5.35	1.11%	0.31	Yes	0.09	Yes
2,291	15.80	3.27%	12,167	83.89	17.38%	787.1	5.43	1.12%	0.31	Yes	0.09	Yes
2,340	16.13	3.34%	12,167	83.89	17.38%	795.1	5.49	1.14%	0.31	Yes	0.10	Yes
2,388	16.46	3.41%	12,167	83.89	17.38%	803.2	5.54	1.15%	0.31	Yes	0.10	Yes
2,435	16.79	3.48%	12,167	83.89	17.38%	808.2	5.57	1.15%	0.32	Yes	0.10	Yes
2,481	17.11	3.54%	12,167	83.89	17.38%	811.2	5.59	1.16%	0.32	Yes	0.10	Yes
2,527	17.42	3.61%	12,167	83.89	17.38%	812.2	5.60	1.16%	0.32	Yes	0.10	Yes
2,566	17.69	3.67%	0	0.00	0.00%	812.2	5.60	1.16%	0.05	Yes	0.02	Yes
2,605	17.96	3.72%	0	0.00	0.00%	812.2	5.60	1.16%	0.05	Yes	0.02	Yes
2,644	18.23	3.78%	0	0.00	0.00%	812.2	5.60	1.16%	0.05	Yes	0.02	Yes
2,683	18.50	3.83%	0	0.00	0.00%	812.2	5.60	1.16%	0.05	Yes	0.02	Yes
3,040	20.96	4.34%	12,167	83.89	17.38%	809.8	5.58	1.16%	0.33	Yes	0.10	Yes
3,060	21.10	4.37%	12,167	83.89	17.38%	802.5	5.53	1.15%	0.33	Yes	0.10	Yes
2,936	20.24	4.19%	12,167	83.89	17.38%	790.3	5.45	1.13%	0.32	Yes	0.10	Yes
2,877	19.84	4.11%	12,167	83.89	17.38%	773.3	5.33	1.10%	0.32	Yes	0.10	Yes
2,907	20.05	4.15%	12,167	83.89	17.38%	751.4	5.18	1.07%	0.32	Yes	0.10	Yes
3,000	20.74	4.30%	12,167	83.89	17.38%	724.7	5.00	1.04%	0.33	Yes	0.10	Yes
3,101	21.38	4.43%	12,167	83.89	17.38%	693.2	4.78	0.99%	0.33	Yes	0.10	Yes
3,190	22.00	4.56%	12,167	83.89	17.38%	656.8	4.53	0.94%	0.33	Yes	0.10	Yes
3,277	22.59	4.68%	12,167	83.89	17.38%	615.6	4.24	0.88%	0.33	Yes	0.10	Yes
3,361	23.18	4.80%	12,167	83.89	17.38%	569.7	3.93	0.81%	0.33	Yes	0.10	Yes
3,445	23.75	4.92%	12,167	83.89	17.38%	519.0	3.58	0.74%	0.33	Yes	0.10	Yes
3,527	24.32	5.04%	12,167	83.89	17.38%	463.5	3.20	0.66%	0.34	Yes	0.09	Yes
3,580	24.69	5.11%	0	0.00	0.00%	434.5	3.00	0.62%	0.05	Yes	0.01	Yes
3,633	25.05	5.19%	0	0.00	0.00%	405.6	2.80	0.58%	0.05	Yes	0.01	Yes
3,686	25.42	5.27%	0	0.00	0.00%	376.6	2.60	0.54%	0.07	Yes	0.01	Yes
3,739	25.78	5.34%	0	0.00	0.00%	347.6	2.40	0.50%	0.07	Yes	0.01	Yes
3,792	26.15	5.42%	0	0.00	0.00%	318.7	2.20	0.46%	0.07	Yes	0.01	Yes
3,845	26.51	5.49%	0	0.00	0.00%	289.7	2.00	0.41%	0.07	Yes	0.01	Yes
3,898	26.88	5.57%	0	0.00	0.00%	260.7	1.80	0.37%	0.07	Yes	0.01	Yes
3,951	27.24	5.64%	0	0.00	0.00%	231.8	1.60	0.33%	0.07	Yes	0.01	Yes
4,004	27.61	5.72%	0	0.00	0.00%	202.8	1.40	0.29%	0.07	Yes	0.01	Yes
4,057	27.97	5.80%	0	0.00	0.00%	173.8	1.20	0.25%	0.07	Yes	0.01	Yes
4,110	28.34	5.87%	0	0.00	0.00%	144.8	1.00	0.21%	0.07	Yes	0.01	Yes
4,163	28.71	5.95%	0	0.00	0.00%	115.9	0.80	0.17%	0.07	Yes	0.01	Yes
4,216	29.07	6.02%	0	0.00	0.00%	86.9	0.60	0.12%	0.08	Yes	0.01	Yes
4,269	29.44	6.10%	0	0.00	0.00%	57.9	0.40	0.08%	0.08	Yes	0.01	Yes
4,322	29.80	6.17%	0	0.00	0.00%	29.0	0.20	0.04%	0.08	Yes	0.01	Yes
4,375	30.17	6.25%	0	0.00	0.00%	0.0	0.00	0.00%	0.08	Yes	0.01	Yes

NOTE: Hoop stress taken as an empty pipe for no buoyancy control and with water with buoyancy control

	Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	Combined Tensile, Bending and Hoop Factor
	psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS		
Maximum Values	4,375	30.2	6.25%	12,167	83.9	17.38%	812	5.6	1.16%	0.34	0.10

	TOTAL PULL LOADS	
Maximum Values	369,090 lb	184.5 tons

Ground Elevation at Pipe Entry	325.56	feet
	99.23	metres
Ground Elevation at Pipe Exit	286.90	feet
	87.45	metres

Input Pipe Properties

Pipe Outer Diameter	36	in
	914.4	mm
Pipe Wall Thickness	0.762	in
	19.3548	mm
DR	47.2	
Pipe Weight (in air)	287.04	lbs/ft
	428.06	kg/m
Weight of Water in pipe	404.5	lbs/ft
	603.26	kg/m
Net Buoyant Weight of pipe	110.0	lbs/ft
	163.99	kg/m
Young's Modulus of Elasticity	2.92E+07	psi
	201327	MPa
Yield Strength	70,000	psi
	482.6	MPa
Poisson Ratio	0.3	
Drill Pipe Diameter	6.625	in
	168.275	mm
Minimum Radius of Curvature	2,500	ft
	762	m

Ultimate Safe Pull Load	3,542,953	lb
	15,760	kN
Maximum Calculated Pull Load	369,090	lb
	1,642	kN
Factor of Safety	9.6	

Start-Up Load Factor	2	
Maximum Calculated Start-Up Pipe Pull Load	738,180	lb
	3,284	kN
Factor of Safety	4.8	

Soil and Mud Properties

Mud Weight	11	ppg of drill fluid and solids (typically 9.5 to 11 lb/gal)
	1.319	Specific Gravity
Friction Coeff. (GS or rollers)	0.1	rollers typically 0.10 to 0.30 (along ground surface is higher range)
Yield Point	19.5	lb/100ft² (Based on HDD experience from previous installations)
	93.366	dyne/cm²
Plastic Viscosity	13	cP (Based on HDD experience from previous installations)
Drilling mud pumping rate	600	GPM (typically 200 to 300 gpm for soil or 400 to 800 gpm bedrock)
	2.271	m³/min
Drilling mud pumping rate	1129	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)
	4.273	m³/min
Pipe Pullback Rate	10	feet/min (Based on HDD experience)
	3.05	m/min

MOTT MACDONALD

Calculated by: M. Lockwood
Checked by: G. Duyvestyn
Date: 4/19/2019
Project No: 353754

Horizontal Directional Drilling
Calculation of Pull Loads and Stresses during Pipe Installation

PROJECT: PennEast Pipeline Project - Case 5

HDD CROSSING LOCATION: Wickecheoke Creek

Reference:
1. Installation of Pipelines by Horizontal Directional Drilling, an Engineering Guide, PRCI Publication 2015
2. Pipeline Design for Installation by Horizontal Directional Drilling, Manual of Practice, ASCE MREP 108, 2005

HDD Installation Load Analysis

Segment Type	Type of Curve	Bore Stationing		Installed Length		Bore Elevation		Bore Diameter		Geotechnical Friction Factor	TOTAL PULL LOADS	
		feet	metres	feet	metres	feet	metres	inch	mm			
Pipe Entry Location		5096+00	155+328	0.0	0.0	325.6	99.2	--	--		99,394 lb	49.7 tons
straight		5096+82	155+353	83.8	25.5	308.1	93.9	48.0	1219.2	0.3	117,270 lb	58.6 tons
straight		5097+64	155+378	167.6	51.1	290.7	88.6	48.0	1219.2	0.3	135,147 lb	67.6 tons
straight		5098+46	155+403	251.4	76.6	273.3	83.3	48.0	1219.2	0.3	159,430 lb	79.7 tons
straight		5099+28	155+428	335.2	102.2	255.9	78.0	48.0	1219.2	0.3	183,714 lb	91.9 tons
straight		5100+10	155+453	419.0	127.7	238.5	72.7	48.0	1219.2	0.3	207,998 lb	104.0 tons
straight		5100+92	155+478	502.8	153.2	221.0	67.4	48.0	1219.2	0.3	232,282 lb	116.1 tons
straight		5101+74	155+503	586.6	178.8	203.6	62.1	48.0	1219.2	0.3	256,565 lb	128.3 tons
straight		5102+56	155+528	670.3	204.3	186.2	56.8	48.0	1219.2	0.3	280,849 lb	140.4 tons
straight		5103+38	155+553	754.1	229.9	168.8	51.4	48.0	1219.2	0.3	305,133 lb	152.6 tons
straight		5104+20	155+578	837.9	255.4	151.3	46.1	48.0	1219.2	0.3	329,417 lb	164.7 tons
straight		5105+02	155+603	921.7	280.9	133.9	40.8	48.0	1219.2	0.3	353,700 lb	176.9 tons
straight		5105+84	155+628	1,005.5	306.5	116.5	35.5	48.0	1219.2	0.3	377,984 lb	189.0 tons
curve	vertical	5106+30	155+642	1,052.6	320.9	107.0	32.6	48.0	1219.2	0.3	424,632 lb	212.3 tons
curve	vertical	5106+76	155+656	1,099.8	335.2	98.1	29.9	48.0	1219.2	0.3	421,377 lb	210.7 tons
curve	vertical	5107+22	155+670	1,146.9	349.6	89.8	27.4	48.0	1219.2	0.3	445,680 lb	222.8 tons
curve	vertical	5107+69	155+684	1,194.0	363.9	82.2	25.0	48.0	1219.2	0.3	449,053 lb	224.5 tons
curve	vertical	5108+15	155+698	1,241.1	378.3	75.1	22.9	48.0	1219.2	0.3	467,773 lb	233.9 tons
curve	vertical	5108+62	155+713	1,288.3	392.7	68.6	20.9	48.0	1219.2	0.3	476,731 lb	238.4 tons
curve	vertical	5109+09	155+727	1,335.4	407.0	62.8	19.1	48.0	1219.2	0.3	493,699 lb	246.8 tons
curve	vertical	5109+56	155+741	1,382.5	421.4	57.6	17.5	48.0	1219.2	0.3	505,953 lb	253.0 tons
curve	vertical	5110+03	155+755	1,429.6	435.8	52.9	16.1	48.0	1219.2	0.3	522,273 lb	261.1 tons
curve	vertical	5110+50	155+770	1,476.8	450.1	48.9	14.9	48.0	1219.2	0.3	536,238 lb	268.1 tons
curve	vertical	5110+97	155+784	1,523.9	464.5	45.5	13.9	48.0	1219.2	0.3	552,204 lb	276.1 tons
curve	vertical	5111+44	155+798	1,571.0	478.8	42.8	13.0	48.0	1219.2	0.3	566,941 lb	283.5 tons
curve	vertical	5111+91	155+813	1,618.1	493.2	40.6	12.4	48.0	1219.2	0.3	613,022 lb	306.5 tons
curve	vertical	5112+38	155+827	1,665.3	507.6	39.1	11.9	48.0	1219.2	0.3	628,260 lb	314.1 tons
curve	vertical	5112+85	155+842	1,712.4	521.9	38.1	11.6	48.0	1219.2	0.3	643,350 lb	321.7 tons
curve	vertical	5113+32	155+856	1,759.5	536.3	37.8	11.5	48.0	1219.2	0.3	658,290 lb	329.1 tons
straight		5113+66	155+866	1,793.5	546.7	37.8	11.5	48.0	1219.2	0.3	665,823 lb	332.9 tons
straight		5114+00	155+877	1,827.5	557.0	37.8	11.5	48.0	1219.2	0.3	673,356 lb	336.7 tons
straight		5114+34	155+887	1,861.5	567.4	37.8	11.5	48.0	1219.2	0.3	680,889 lb	340.4 tons
straight		5114+68	155+897	1,895.5	577.8	37.8	11.5	48.0	1219.2	0.3	688,422 lb	344.2 tons
curve	vertical	5115+41	155+920	1,968.8	600.1	38.6	11.8	48.0	1219.2	0.3	730,279 lb	365.1 tons
curve	vertical	5116+15	155+942	2,042.1	622.4	40.8	12.4	48.0	1219.2	0.3	731,697 lb	365.8 tons
curve	vertical	5116+88	155+964	2,115.4	644.8	44.6	13.6	48.0	1219.2	0.3	760,486 lb	380.2 tons
curve	vertical	5117+61	155+987	2,188.7	667.1	49.8	15.2	48.0	1219.2	0.3	771,269 lb	385.6 tons
curve	vertical	5118+34	156+009	2,262.0	689.5	56.5	17.2	48.0	1219.2	0.3	796,347 lb	398.2 tons
curve	vertical	5119+07	156+031	2,335.3	711.8	64.7	19.7	48.0	1219.2	0.3	812,521 lb	406.3 tons
curve	vertical	5119+79	156+053	2,408.6	734.2	74.3	22.7	48.0	1219.2	0.3	835,753 lb	417.9 tons
curve	vertical	5120+52	156+075	2,481.9	756.5	85.5	26.1	48.0	1219.2	0.3	854,368 lb	427.2 tons
curve	vertical	5121+24	156+097	2,555.2	778.8	98.1	29.9	48.0	1219.2	0.3	916,899 lb	458.4 tons
curve	vertical	5121+96	156+119	2,628.5	801.2	112.2	34.2	48.0	1219.2	0.3	937,163 lb	468.6 tons
curve	vertical	5122+68	156+141	2,701.9	823.5	127.8	38.9	48.0	1219.2	0.3	957,026 lb	478.5 tons
curve	vertical	5123+39	156+163	2,775.2	845.9	144.8	44.1	48.0	1219.2	0.3	976,475 lb	488.2 tons
straight		5123+75	156+174	2,811.9	857.1	153.7	46.8	48.0	1219.2	0.3	981,325 lb	490.7 tons
straight		5124+10	156+185	2,848.6	868.3	162.5	49.5	48.0	1219.2	0.3	986,175 lb	493.1 tons
straight		5124+46	156+195	2,885.3	879.5	171.4	52.2	48.0	1219.2	0.3	991,025 lb	495.5 tons
straight		5124+81	156+206	2,922.0	890.6	180.3	55.0	48.0	1219.2	0.3	995,875 lb	497.9 tons
straight		5125+17	156+217	2,958.7	901.8	189.2	57.7	48.0	1219.2	0.3	1,000,725 lb	500.4 tons
straight		5125+53	156+228	2,995.5	913.0	198.1	60.4	48.0	1219.2	0.3	1,005,575 lb	502.8 tons
straight		5125+88	156+239	3,032.2	924.2	207.0	63.1	48.0	1219.2	0.3	1,010,425 lb	505.2 tons
straight		5126+24	156+250	3,068.9	935.4	215.8	65.8	48.0	1219.2	0.3	1,015,275 lb	507.6 tons
straight		5126+60	156+261	3,105.6	946.6	224.7	68.5	48.0	1219.2	0.3	1,020,125 lb	510.1 tons
straight		5126+95	156+271	3,142.3	957.8	233.6	71.2	48.0	1219.2	0.3	1,024,975 lb	512.5 tons
straight		5127+31	156+282	3,179.1	969.0	242.5	73.9	48.0	1219.2	0.3	1,029,825 lb	514.9 tons
straight		5127+67	156+293	3,215.8	980.2	251.4	76.6	48.0	1219.2	0.3	1,034,675 lb	517.3 tons
straight		5128+02	156+304	3,252.5	991.4	260.2	79.3	48.0	1219.2	0.3	1,039,525 lb	519.8 tons
straight		5128+38	156+315	3,289.2	1,002.6	269.1	82.0	48.0	1219.2	0.3	1,044,375 lb	522.2 tons
straight		5128+73	156+326	3,325.9	1,013.8	278.0	84.7	48.0	1219.2	0.3	1,049,225 lb	524.6 tons
HDD Rig Location		5129+09	156+337	3,362.7	1,024.9	286.9	87.4	48.0	1219.2	0.3	1,054,075 lb	527.0 tons

HDD Installation Stress Analysis

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	CombinedTensile and Bending <1.0	Combined Tensile, Bending and Hoop Factor	Combined Tensile, Bending and Hoop <1.0
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS				
1,178	8.12	1.66%	0	0.00	0.00%	0.0	0.00	0.00%	0.02	Yes	0.00	Yes
1,390	9.58	1.99%	0	0.00	0.00%	266.5	1.77	0.37%	0.02	Yes	0.00	Yes
1,602	11.05	2.29%	0	0.00	0.00%	513.0	3.54	0.73%	0.03	Yes	0.01	Yes
1,890	13.03	2.70%	0	0.00	0.00%	200.3	1.38	0.29%	0.03	Yes	0.01	Yes
2,178	15.02	3.11%	0	0.00	0.00%	456.8	3.15	0.65%	0.04	Yes	0.02	Yes
2,466	17.00	3.52%	0	0.00	0.00%	713.3	4.92	1.02%	0.04	Yes	0.03	Yes
2,754	18.99	3.93%	0	0.00	0.00%	969.8	6.69	1.39%	0.05	Yes	0.05	Yes
3,041	20.97	4.34%	0	0.00	0.00%	1,226.3	8.46	1.75%	0.05	Yes	0.06	Yes
3,329	22.95	4.76%	0	0.00	0.00%	1,482.9	10.22	2.12%	0.06	Yes	0.08	Yes
3,617	24.94	5.17%	0	0.00	0.00%	1,739.4	11.99	2.48%	0.06	Yes	0.10	Yes
3,905	26.92	5.58%	0	0.00	0.00%	1,995.9	13.76	2.85%	0.07	Yes	0.12	Yes
4,193	28.91	5.99%	0	0.00	0.00%	2,252.4	15.53	3.22%	0.07	Yes	0.15	Yes
4,481	30.89	6.40%	0	0.00	0.00%	2,509.0	17.30	3.58%	0.08	Yes	0.18	Yes
5,034	34.71	7.19%	12,167	83.89	17.38%	2,648.8	18.26	3.78%	0.36	Yes	0.32	Yes
4,995	34.44	7.14%	12,167	83.89	17.38%	2,779.7	19.17	3.97%	0.36	Yes	0.34	Yes
5,283	36.43	7.55%	12,167	83.89	17.38%	2,901.7	20.01	4.15%	0.37	Yes	0.36	Yes
5,323	36.70	7.60%	12,167	83.89	17.38%	3,014.7	20.79	4.31%	0.37	Yes	0.38	Yes
5,545	38.23	7.92%	12,167	83.89	17.38%	3,116.8	21.50	4.45%	0.37	Yes	0.39	Yes
5,681	39.17	8.07%	12,167	83.89	17.38%	3,213.6	22.16	4.59%	0.37	Yes	0.41	Yes
5,853	40.35	8.36%	12,167	83.89	17.38%	3,299.9	22.75	4.71%	0.38	Yes	0.42	Yes
5,998	41.35	8.57%	12,167	83.89	17.38%	3,376.9	23.28	4.82%	0.38	Yes	0.44	Yes
6,191	42.69	8.84%	12,167	83.89	17.38%	3,444.9	23.75	4.92%	0.38	Yes	0.45	Yes
6,357	43.83	9.08%	12,167	83.89	17.38%	3,503.9	24.16	5.01%	0.39	Yes	0.46	Yes
6,548	45.13	9.35%	12,167	83.89	17.38%	3,553.8	24.50	5.08%	0.39	Yes	0.47	Yes
6,721	46.34	9.60%	12,167	83.89	17.38%	3,594.7	24.78	5.14%	0.39	Yes	0.48	Yes
7,267	50.10	10.38%	12,167	83.89	17.38%	3,626.4	25.00	5.18%	0.40	Yes	0.50	Yes
7,448	51.35	10.64%	12,167	83.89	17.38%	3,649.1	25.16	5.21%	0.41	Yes	0.50	Yes
7,627	52.58	10.90%	12,167	83.89	17.38%	3,662.8	25.25	5.23%	0.41	Yes	0.51	Yes
7,804	53.80	11.15%	12,167	83.89	17.38%	3,667.3	25.29	5.24%	0.41	Yes	0.51	Yes
7,893	54.42	11.28%	0	0.00	0.00%	3,667.3	25.29	5.24%	0.14	Yes	0.35	Yes
7,982	55.04	11.40%	0	0.00	0.00%	3,667.3	25.29	5.24%	0.14	Yes	0.35	Yes
8,072	55.65	11.53%	0	0.00	0.00%	3,667.3	25.29	5.24%	0.14	Yes	0.35	Yes
8,161	56.27	11.66%	0	0.00	0.00%	3,667.3	25.29	5.24%	0.15	Yes	0.35	Yes
8,657	59.69	12.37%	12,167	83.89	17.38%	3,656.3	25.21	5.22%	0.43	Yes	0.53	Yes
8,674	59.80	12.39%	12,167	83.89	17.38%	3,623.4	24.98	5.18%	0.43	Yes	0.52	Yes
9,015	62.16	12.88%	12,167	83.89	17.38%	3,568.4	24.60	5.10%	0.43	Yes	0.52	Yes
9,143	63.04	13.06%	12,167	83.89	17.38%	3,491.6	24.07	4.99%	0.44	Yes	0.51	Yes
9,440	65.09	13.49%	12,167	83.89	17.38%	3,392.8	23.39	4.85%	0.44	Yes	0.50	Yes
9,632	66.41	13.76%	12,167	83.89	17.38%	3,272.2	22.56	4.67%	0.44	Yes	0.48	Yes
9,907	68.31	14.15%	12,167	83.89	17.38%	3,129.8	21.58	4.47%	0.45	Yes	0.47	Yes
10,128	69.83	14.47%	12,167	83.89	17.38%	2,965.6	20.45	4.24%	0.45	Yes	0.45	Yes
10,869	74.94	15.53%	12,167	83.89	17.38%	2,779.7	19.17	3.97%	0.47	Yes	0.44	Yes
11,110	76.60	15.87%	12,167	83.89	17.38%	2,572.2	17.73	3.67%	0.47	Yes	0.41	Yes
11,345	78.22	16.21%	12,167	83.89	17.38%	2,343.2	16.16	3.35%	0.47	Yes	0.39	Yes
11,576	79.81	16.54%	12,167	83.89	17.38%	2,092.8	14.43	2.99%	0.48	Yes	0.36	Yes
11,633	80.21	16.62%	0	0.00	0.00%	1,962.0	13.53	2.80%	0.21	Yes	0.18	Yes
11,691	80.60	16.70%	0	0.00	0.00%	1,831.2	12.63	2.62%	0.21	Yes	0.17	Yes
11,748	81.00	16.78%	0	0.00	0.00%	1,700.4	11.72	2.43%	0.21	Yes	0.16	Yes
11,806	81.40	16.87%	0	0.00	0.00%	1,569.6	10.82	2.24%	0.21	Yes	0.15	Yes
11,863	81.79	16.95%	0	0.00	0.00%	1,438.8	9.92	2.06%	0.21	Yes	0.14	Yes
11,921	82.19	17.03%	0	0.00	0.00%	1,308.0	9.02	1.87%	0.21	Yes	0.13	Yes
11,978	82.59	17.11%	0	0.00	0.00%	1,177.2	8.12	1.68%	0.21	Yes	0.12	
12,036	82.98	17.19%	0	0.00	0.00%	1,046.4	7.21	1.49%	0.21	Yes	0.11	
12,093	83.38	17.28%	0	0.00	0.00%	915.6	6.31	1.31%	0.22	Yes	0.10	
12,151	83.78	17.36%	0	0.00	0.00%	784.8	5.41	1.12%	0.22	Yes	0.09	
12,208	84.17	17.44%	0	0.00	0.00%	654.0	4.51	0.93%	0.22	Yes	0.09	
12,266	84.57	17.52%	0	0.00	0.00%	523.2	3.61	0.75%	0.22	Yes	0.08	Yes
12,323	84.96	17.60%	0	0.00	0.00%	392.4	2.71	0.56%	0.22	Yes	0.06	Yes
12,381	85.36	17.69%	0	0.00	0.00%	261.6	1.80	0.37%	0.22	Yes	0.07	Yes
12,438	85.76	17.77%	0	0.00	0.00%	130.8	0.90	0.19%	0.22	Yes	0.07	Yes
12,496	86.15	17.85%	0	0.00	0.00%	0.0	0.00	0.00%	0.22	Yes	0.06	Yes

NOTE: Hoop stress taken as an empty pipe for no buoyancy control and with water with buoyancy control

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	Combined Tensile, Bending and Hoop Factor
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS		
12,496	86.2	17.85%	12,167	83.9	17.38%	3,667	25.3	5.24%	0.48	0.53

	Ground Elevation at Pipe Entry		Ground Elevation at Pipe Exit	
	325.56	feet	286.90	feet
	99.23	metres	87.45	metres

	TOTAL PULL LOADS	
Maximum Values	1,054,075 lb	527.0 tons

Input Pipe Properties

Pipe Outer Diameter	36	in
	914.4	mm
Pipe Wall Thickness	0.762	in
	19.3548	mm
DR	47.2	
Pipe Weight (in air)	287.04	lbs/ft
	426.06	kg/m
Weight of Water in pipe	0.0	lbs/ft
	0.00	kg/m
Net Buoyant Weight of pipe	-347.4	lbs/ft
	-518.11	kg/m
Young's Modulus of Elasticity	2.92E+07	psi
	201327	MPa
Yield Strength	70,000	psi
	482.6	MPa
Poisson Ratio	0.3	
Drill Pipe Diameter	6.625	in
	168.275	mm
Minimum Radius of Curvature	2,500	ft
	762	m

Ultimate Safe Pull Load	3,542,993	lb
	15,760	kN
Maximum Calculated Pull Load	1,054,075	lb
	4,689	kN
Factor of Safety	3.4	

Start-Up Load Factor	2	
Maximum Calculated Start-Up Pipe Pull Load	2,108,151	lb
	9,378	kN
Factor of Safety	1.7	

Soil and Mud Properties

Mud Weight	12	ppg of drill fluid and solids (typically 9.5 to 11 lbs/gal)
	1.439	Specific Gravity
Friction Coeff. (GS or rollers)	0.1	rollers typically 0.10 to 0.30 (along ground surface is higher range)
Yield Point	19.5	lb/100ft² (Based on HDD experience from previous installations)
	93,366	dyne/cm²
Plastic Viscosity	13	cP (Based on HDD experience from previous installations)
Drilling mud pumping rate	600	GPM (typically 200 to 300 gpm for soil or 400 to 800 gpm bedrock)
	2.271	m³/min
Drilling mud pumping rate	1129	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)
	4.273	m³/min
Pipe Pullback Rate	10	feet/min (Based on HDD experience)
	3.05	m/min

MOTT MACDONALD

Calculated by: M. Lockwood
Checked by: G. Duyvestyn
Date: 4/19/2019
Project No: 353754

ontal Directional Drilling
ulation of Pull Loads and Stresses during Pipe Installation

PROJECT: PennEast Pipeline Project - Case 6

HDD CROSSING LOCATION: Wickecheoke Creek

Reference:
1. Installation of Pipelines by Horizontal Directional Drilling, an Engineering Guide, PRCI Publication 2015
2. Pipeline Design for Installation by Horizontal Directional Drilling, Manual of Practice, ASCE MREP 108, 2005

HDD Installation Load Analysis

Segment Type	Type of Curve	Bore Stationing		Installed Length		Bore Elevation		Bore Diameter		Geotechnical Friction Factor	TOTAL PULL LOADS		
		feet	metres	feet	metres	feet	metres	inch	mm				
Pipe Entry Location		5096+00	155+328	0.0	0.0	325.6	99.2	--	--		99,394	lb	49.7 tons
straight		5096+82	155+353	83.8	25.5	308.1	93.9	48.0	1219.2	0.3	103,084	lb	51.5 tons
straight		5097+64	155+378	167.6	51.1	290.7	88.6	48.0	1219.2	0.3	106,774	lb	53.4 tons
straight		5098+46	155+403	251.4	76.6	273.3	83.3	48.0	1219.2	0.3	111,517	lb	55.8 tons
straight		5099+28	155+428	335.2	102.2	255.9	78.0	48.0	1219.2	0.3	116,260	lb	58.1 tons
straight		5100+10	155+453	419.0	127.7	238.5	72.7	48.0	1219.2	0.3	121,003	lb	60.5 tons
straight		5100+92	155+478	502.8	153.2	221.0	67.4	48.0	1219.2	0.3	125,745	lb	62.9 tons
straight		5101+74	155+503	586.6	178.8	203.6	62.1	48.0	1219.2	0.3	130,488	lb	65.2 tons
straight		5102+56	155+528	670.3	204.3	186.2	56.8	48.0	1219.2	0.3	135,231	lb	67.6 tons
straight		5103+38	155+553	754.1	229.9	168.8	51.4	48.0	1219.2	0.3	139,974	lb	70.0 tons
straight		5104+20	155+578	837.9	255.4	151.3	46.1	48.0	1219.2	0.3	144,717	lb	72.4 tons
straight		5105+02	155+603	921.7	280.9	133.9	40.8	48.0	1219.2	0.3	149,460	lb	74.7 tons
straight		5105+84	155+628	1,005.5	306.5	116.5	35.5	48.0	1219.2	0.3	154,203	lb	77.1 tons
curve	vertical	5106+30	155+642	1,052.6	320.9	107.0	32.6	48.0	1219.2	0.3	201,618	lb	100.8 tons
curve	vertical	5106+76	155+656	1,099.8	335.2	98.1	29.9	48.0	1219.2	0.3	205,080	lb	102.5 tons
curve	vertical	5107+22	155+670	1,146.9	349.6	89.8	27.4	48.0	1219.2	0.3	189,288	lb	94.6 tons
curve	vertical	5107+69	155+684	1,194.0	363.9	82.2	25.0	48.0	1219.2	0.3	181,752	lb	90.9 tons
curve	vertical	5108+15	155+698	1,241.1	378.3	75.1	22.9	48.0	1219.2	0.3	177,544	lb	88.8 tons
curve	vertical	5108+62	155+713	1,288.3	392.7	68.6	20.9	48.0	1219.2	0.3	175,022	lb	87.5 tons
curve	vertical	5109+09	155+727	1,335.4	407.0	62.8	19.1	48.0	1219.2	0.3	173,484	lb	86.7 tons
curve	vertical	5109+56	155+741	1,382.5	421.4	57.6	17.5	48.0	1219.2	0.3	172,578	lb	86.3 tons
curve	vertical	5110+03	155+755	1,429.6	435.8	52.9	16.1	48.0	1219.2	0.3	172,110	lb	86.1 tons
curve	vertical	5110+50	155+770	1,476.8	450.1	48.9	14.9	48.0	1219.2	0.3	171,965	lb	86.0 tons
curve	vertical	5110+97	155+784	1,523.9	464.5	45.5	13.9	48.0	1219.2	0.3	172,059	lb	86.0 tons
curve	vertical	5111+44	155+798	1,571.0	478.8	42.8	13.0	48.0	1219.2	0.3	172,372	lb	86.2 tons
curve	vertical	5111+91	155+813	1,618.1	493.2	40.6	12.4	48.0	1219.2	0.3	174,757	lb	87.4 tons
curve	vertical	5112+38	155+827	1,665.3	507.6	39.1	11.9	48.0	1219.2	0.3	177,524	lb	88.8 tons
curve	vertical	5112+85	155+842	1,712.4	521.9	38.1	11.6	48.0	1219.2	0.3	180,230	lb	90.1 tons
curve	vertical	5113+32	155+856	1,759.5	536.3	37.8	11.5	48.0	1219.2	0.3	182,889	lb	91.4 tons
straight		5113+66	155+866	1,793.5	546.7	37.8	11.5	48.0	1219.2	0.3	185,239	lb	92.6 tons
straight		5114+00	155+877	1,827.5	557.0	37.8	11.5	48.0	1219.2	0.3	187,590	lb	93.8 tons
straight		5114+34	155+887	1,861.5	567.4	37.8	11.5	48.0	1219.2	0.3	189,940	lb	95.0 tons
straight		5114+68	155+897	1,895.5	577.8	37.8	11.5	48.0	1219.2	0.3	192,291	lb	96.1 tons
curve	vertical	5115+41	155+920	1,968.8	600.1	38.6	11.8	48.0	1219.2	0.3	223,922	lb	112.0 tons
curve	vertical	5116+15	155+942	2,042.1	622.4	40.8	12.4	48.0	1219.2	0.3	228,149	lb	114.1 tons
curve	vertical	5116+88	155+964	2,115.4	644.8	44.6	13.6	48.0	1219.2	0.3	219,644	lb	109.8 tons
curve	vertical	5117+61	155+987	2,188.7	667.1	49.8	15.2	48.0	1219.2	0.3	216,549	lb	108.3 tons
curve	vertical	5118+34	156+009	2,262.0	689.5	56.5	17.2	48.0	1219.2	0.3	215,702	lb	107.9 tons
curve	vertical	5119+07	156+031	2,335.3	711.8	64.7	19.7	48.0	1219.2	0.3	216,050	lb	108.0 tons
curve	vertical	5119+79	156+053	2,408.6	734.2	74.3	22.7	48.0	1219.2	0.3	217,147	lb	108.6 tons
curve	vertical	5120+52	156+075	2,481.9	756.5	85.5	26.1	48.0	1219.2	0.3	218,769	lb	109.4 tons
curve	vertical	5121+24	156+097	2,555.2	778.8	98.1	29.9	48.0	1219.2	0.3	222,259	lb	111.1 tons
curve	vertical	5121+96	156+119	2,628.5	801.2	112.2	34.2	48.0	1219.2	0.3	227,092	lb	113.5 tons
curve	vertical	5122+68	156+141	2,701.9	823.5	127.8	38.9	48.0	1219.2	0.3	231,807	lb	115.9 tons
curve	vertical	5123+39	156+163	2,775.2	845.9	144.8	44.1	48.0	1219.2	0.3	236,438	lb	118.2 tons
straight		5123+75	156+174	2,811.9	857.1	153.7	46.8	48.0	1219.2	0.3	239,451	lb	119.7 tons
straight		5124+10	156+185	2,848.6	868.3	162.5	49.5	48.0	1219.2	0.3	242,464	lb	121.2 tons
straight		5124+46	156+195	2,885.3	879.5	171.4	52.2	48.0	1219.2	0.3	245,476	lb	122.7 tons
straight		5124+81	156+206	2,922.0	890.6	180.3	55.0	48.0	1219.2	0.3	248,489	lb	124.2 tons
straight		5125+17	156+217	2,958.7	901.8	189.2	57.7	48.0	1219.2	0.3	251,502	lb	125.8 tons
straight		5125+53	156+228	2,995.3	913.0	198.1	60.4	48.0	1219.2	0.3	254,515	lb	127.3 tons
straight		5125+88	156+239	3,032.2	924.2	207.0	63.1	48.0	1219.2	0.3	257,527	lb	128.8 tons
straight		5126+24	156+250	3,068.9	935.4	215.8	65.8	48.0	1219.2	0.3	260,540	lb	130.3 tons
straight		5126+60	156+261	3,105.6	946.6	224.7	68.5	48.0	1219.2	0.3	263,553	lb	131.8 tons
straight		5126+95	156+271	3,142.3	957.8	233.6	71.2	48.0	1219.2	0.3	266,565	lb	133.3 tons
straight		5127+32	156+282	3,179.1	969.0	242.5	73.9	48.0	1219.2	0.3	269,578	lb	134.8 tons
straight		5127+66	156+293	3,215.8	980.2	251.4	76.6	48.0	1219.2	0.3	272,591	lb	136.3 tons
straight		5128+02	156+304	3,252.5	991.4	260.2	79.3	48.0	1219.2	0.3	275,604	lb	137.8 tons
straight		5128+38	156+315	3,289.2	1,002.6	269.1	82.0	48.0	1219.2	0.3	278,617	lb	139.3 tons
straight		5128+73	156+326	3,325.9	1,013.8	278.0	84.7	48.0	1219.2	0.3	281,629	lb	140.8 tons
HDD Rig Location		5129+09	156+337	3,362.7	1,024.9	286.9	87.4	48.0	1219.2	0.3	284,642	lb	142.3 tons

Ground Elevation at Pipe Entry	325.56	feet
	99.23	metres
Ground Elevation at Pipe Exit	286.90	feet
	87.45	metres

	TOTAL PULL LOADS		
Maximum Values	284,642	lb	142.3 tons

HDD Installation Stress Analysis

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	CombinedTensile and Bending <1.0	Combined Tensile, Bending and Hoop Factor	Combined Tensile, Bending and Hoop <1.0
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS				
1,178	8.12	1.68%	0	0.00	0.00%	0.0	0.00	0.00%	0.02	Yes	0.00	Yes
1,222	8.43	1.75%	0	0.00	0.00%	78.2	0.54	0.11%	0.02	Yes	0.00	Yes
1,266	8.73	1.81%	0	0.00	0.00%	156.4	1.08	0.22%	0.02	Yes	0.00	Yes
1,322	9.11	1.89%	0	0.00	0.00%	61.0	0.42	0.09%	0.02	Yes	0.00	Yes
1,378	9.50	1.97%	0	0.00	0.00%	139.2	0.96	0.20%	0.02	Yes	0.00	Yes
1,434	9.89	2.05%	0	0.00	0.00%	217.4	1.50	0.31%	0.03	Yes	0.00	Yes
1,491	10.28	2.13%	0	0.00	0.00%	295.6	2.04	0.42%	0.03	Yes	0.01	Yes
1,547	10.67	2.21%	0	0.00	0.00%	373.8	2.58	0.53%	0.03	Yes	0.01	Yes
1,603	11.05	2.29%	0	0.00	0.00%	452.0	3.12	0.65%	0.03	Yes	0.01	Yes
1,659	11.44	2.37%	0	0.00	0.00%	530.2	3.66	0.76%	0.03	Yes	0.01	Yes
1,716	11.83	2.45%	0	0.00	0.00%	608.4	4.19	0.87%	0.03	Yes	0.01	Yes
1,772	12.22	2.53%	0	0.00	0.00%	686.6	4.73	0.98%	0.03	Yes	0.01	Yes
1,828	12.60	2.61%	0	0.00	0.00%	764.8	5.27	1.09%	0.03	Yes	0.02	Yes
2,390	16.48	3.41%	12,167	83.89	17.38%	807.4	5.57	1.15%	0.31	Yes	0.10	Yes
2,431	16.76	3.47%	12,167	83.89	17.38%	847.3	5.84	1.21%	0.32	Yes	0.10	Yes
2,244	15.47	3.21%	12,167	83.89	17.38%	884.5	6.10	1.26%	0.31	Yes	0.10	Yes
2,155	14.86	3.08%	12,167	83.89	17.38%	918.9	6.34	1.31%	0.31	Yes	0.10	Yes
2,103	14.51	3.01%	12,167	83.89	17.38%	950.6	6.55	1.36%	0.31	Yes	0.10	Yes
2,075	14.31	2.96%	12,167	83.89	17.38%	979.6	6.75	1.40%	0.31	Yes	0.10	Yes
2,057	14.18	2.94%	12,167	83.89	17.38%	1,005.8	6.94	1.44%	0.31	Yes	0.11	Yes
2,046	14.11	2.92%	12,167	83.89	17.38%	1,029.3	7.10	1.47%	0.31	Yes	0.11	Yes
2,040	14.07	2.91%	12,167	83.89	17.38%	1,050.1	7.24	1.50%	0.31	Yes	0.11	Yes
2,039	14.06	2.91%	12,167	83.89	17.38%	1,068.0	7.36	1.53%	0.31	Yes	0.11	Yes
2,040	14.06	2.91%	12,167	83.89	17.38%	1,083.2	7.47	1.55%	0.31	Yes	0.11	Yes
2,043	14.09	2.92%	12,167	83.89	17.38%	1,095.7	7.55	1.57%	0.31	Yes	0.11	Yes
2,072	14.28	2.96%	12,167	83.89	17.38%	1,105.4	7.62	1.58%	0.31	Yes	0.11	Yes
2,104	14.51	3.01%	12,167	83.89	17.38%	1,112.3	7.67	1.59%	0.31	Yes	0.11	Yes
2,137	14.73	3.05%	12,167	83.89	17.38%	1,116.5	7.70	1.59%	0.31	Yes	0.11	Yes
2,168	14.95	3.10%	12,167	83.89	17.38%	1,117.8	7.71	1.60%	0.31	Yes	0.11	Yes
2,195	15.14	3.14%	0	0.00	0.00%	1,117.8	7.71	1.60%	0.04	Yes	0.03	Yes
2,224	15.33	3.18%	0	0.00	0.00%	1,117.8	7.71	1.60%	0.04	Yes	0.03	Yes
2,252	15.52	3.22%	0	0.00	0.00%	1,117.8	7.71	1.60%	0.04	Yes	0.03	Yes
2,280	15.72	3.26%	0	0.00	0.00%	1,117.8	7.71	1.60%	0.04	Yes	0.03	Yes
2,654	18.30	3.79%	12,167	83.89	17.38%	1,114.5	7.68	1.59%	0.32	Yes	0.12	Yes
2,705	18.65	3.86%	12,167	83.89	17.38%	1,104.4	7.61	1.58%	0.32	Yes	0.12	Yes
2,604	17.95	3.72%	12,167	83.89	17.38%	1,087.7	7.50	1.55%	0.32	Yes	0.12	Yes
2,567	17.70	3.67%	12,167	83.89	17.38%	1,064.3	7.34	1.52%	0.32	Yes	0.11	Yes
2,557	17.63	3.65%	12,167	83.89	17.38%	1,034.2	7.13	1.48%	0.32	Yes	0.11	Yes
2,561	17.66	3.66%	12,167	83.89	17.38%	997.4	6.88	1.42%	0.32	Yes	0.11	Yes
2,574	17.75	3.68%	12,167	83.89	17.38%	954.0	6.58	1.36%	0.32	Yes	0.11	Yes
2,593	17.88	3.70%	12,167	83.89	17.38%	903.9	6.23	1.29%	0.32	Yes	0.11	Yes
2,635	18.17	3.76%	12,167	83.89	17.38%	847.3	5.84	1.21%	0.32	Yes	0.10	Yes
2,692	18.56	3.85%	12,167	83.89	17.38%	784.0	5.41	1.12%	0.32	Yes	0.10	Yes
2,748	18.95	3.93%	12,167	83.89	17.38%	714.2	4.92	1.02%	0.32	Yes	0.10	Yes
2,803	19.33	4.00%	12,167	83.89	17.38%	637.9	4.40	0.91%	0.32	Yes	0.10	Yes
2,839	19.57	4.05%	0	0.00	0.00%	598.0	4.12	0.85%	0.05	Yes	0.01	Yes
2,874	19.82	4.11%	0	0.00	0.00%	558.2	3.85	0.80%	0.05	Yes	0.01	Yes
2,910	20.06	4.16%	0	0.00	0.00%	518.3	3.57	0.74%	0.05	Yes	0.01	Yes
2,946	20.31	4.21%	0	0.00	0.00%	478.4	3.30	0.68%	0.05	Yes	0.01	Yes
2,981	20.56	4.26%	0	0.00	0.00%	438.6	3.02	0.63%	0.05	Yes	0.01	Yes
3,017	20.80	4.31%	0	0.00	0.00%	398.7	2.75	0.57%	0.05	Yes	0.01	Yes
3,053	21.05	4.36%	0	0.00	0.00%	358.8	2.47	0.51%	0.05	Yes	0.01	Yes
3,089	21.29	4.41%	0	0.00	0.00%	318.9	2.20	0.46%	0.06	Yes	0.01	Yes
3,124	21.54	4.46%	0	0.00	0.00%	279.1	1.92	0.40%	0.06	Yes	0.01	Yes
3,160	21.79	4.51%	0	0.00	0.00%	239.2	1.65	0.34%	0.06	Yes	0.01	Yes
3,195	22.03	4.57%	0	0.00	0.00%	199.3	1.37	0.28%	0.06	Yes	0.01	Yes
3,231	22.28	4.62%	0	0.00	0.00%	159.5	1.10	0.23%	0.06	Yes	0.01	Yes
3,267	22.53	4.67%	0	0.00	0.00%	119.6	0.82	0.17%	0.06	Yes	0.01	Yes
3,303	22.77	4.72%	0	0.00	0.00%	79.7	0.55	0.11%	0.06	Yes	0.01	Yes
3,339	23.02	4.77%	0	0.00	0.00%	39.9	0.27	0.06%	0.06	Yes	0.01	Yes
3,374	23.26	4.82%	0	0.00	0.00%	0.0	0.00	0.00%	0.06	Yes	0.00	Yes

NOTE: Hoop stress taken as an empty pipe for no buoyancy control and with water with buoyancy control

Tensile (Axial) Stress			Bending Stress			Hoop Stress			Combined Tensile and Bending Factor	Combined Tensile, Bending and Hoop Factor
psi	MPa	% SMYS	psi	MPa	% SMYS	psi	MPa	% SMYS		
3,374	23.3	4.82%	12,167	83.9	17.38%	1,118	7.7	1.60%	0.32	0.12

Input Pipe Properties

Pipe Outer Diameter	36	in
	914.4	mm
Pipe Wall Thickness	0.762	in
	19.3548	mm
DR	47.2	
Pipe Weight (in air)	287.04	lbs/ft
	426.66	kg/m
Weight of Water in pipe	404.5	lbs/ft
	603.26	kg/m
Net Buoyant Weight of pipe	57.1	lbs/ft
	85.14	kg/m
Young's Modulus of Elasticity	2.92E+07	psi
	201327	MPa
Yield Strength	70,000	psi
	482.6	MPa
Poisson Ratio	0.3	
Drill Pipe Diameter	6.625	in
	168.275	mm
Minimum Radius of Curvature	2,500	ft
	762	m
Ultimate Safe Pull Load	3,542,953	lb
	15,760	kN
Maximum Calculated Pull Load	284,642	lb
	1,266	kN
Factor of Safety	12.4	
Start-Up Load Factor	2	
Maximum Calculated Start-Up Pipe Pull Load	569,285	lb
	2,532	kN
Factor of Safety	6.2	

Soil and Mud Properties

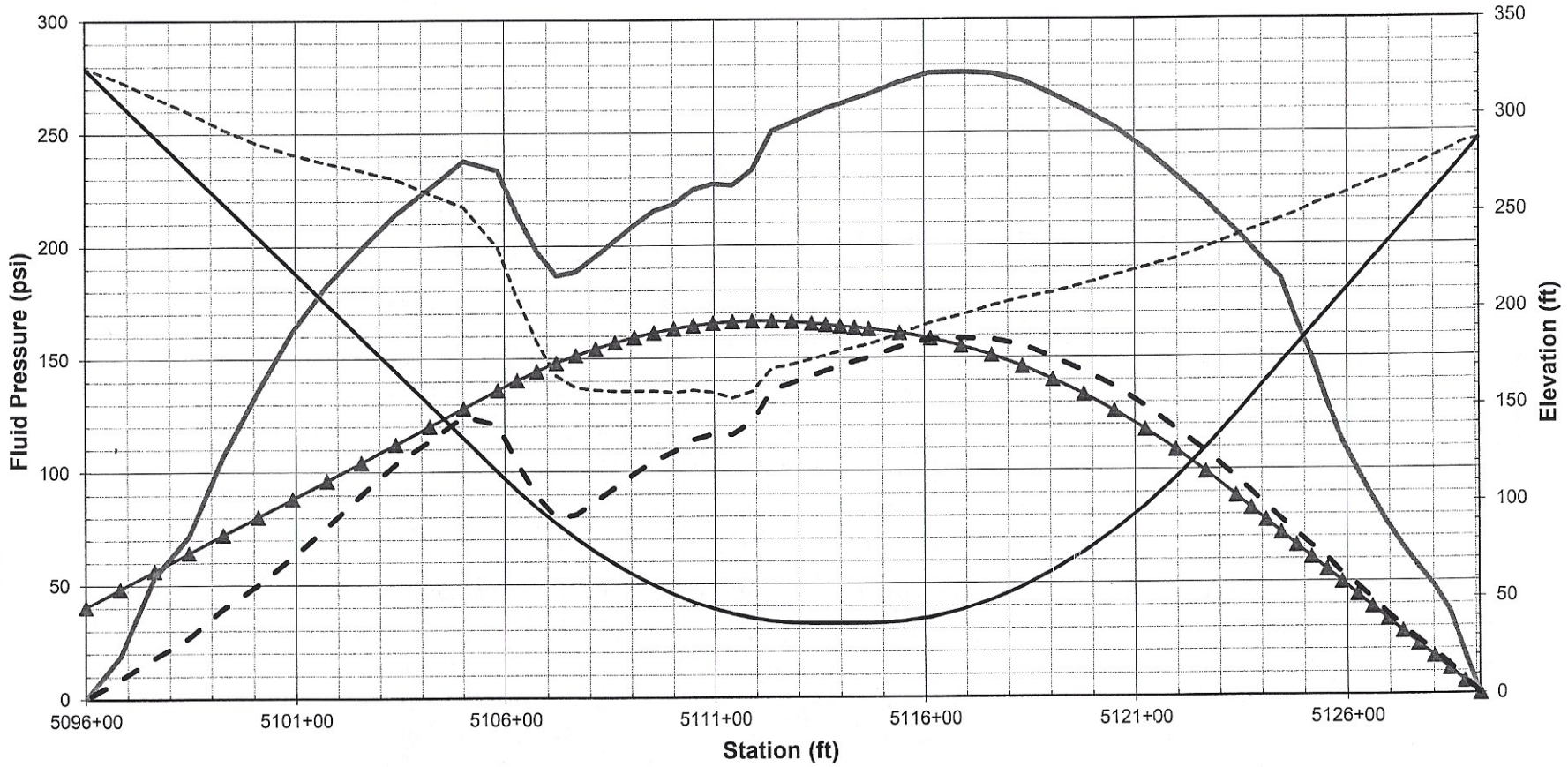
Mud Weight	12	ppg of drill fluid and solids (typically 9.5 to 11 lb/gal)
	1.439	Specific Gravity
Friction Coeff. (GS or rollers)	0.1	rollers typically 0.10 to 0.30 (along ground surface is higher range)
Yield Point	19.5	lb/100ft² (Based on HDD experience from previous installations)
	93.366	dyne/cm²
Plastic Viscosity	13	cP (Based on HDD experience from previous installations)
Drilling mud pumping rate	600	GPM (typically 200 to 300 gpm for soil or 400 to 800 gpm bedrock)
	2.271	m³/min
Drilling mud pumping rate	1129	GPM (equivalent mud rate accounting for slurry displaced by product pipe installation)
	4.273	m³/min
Pipe Pullback Rate	10	feet/min (Based on HDD experience)
	3.05	m/min

Appendix D

Hydraulic Fracture Evaluation

Pipe Side

Rig Side



Crossing Length (ft)	3,309.0
Bore Diameter (in)	12.250
Drill Pipe O.D. (in)	6.625
Drilling Fluid Weight (ppg)	10.5
Plastic Viscosity (cP)	13
Yield Point (lb/100SF)	19.5

- Required Drilling Fluid Pressure
- Recommended Maximum Allowable Drilling Fluid Pressure
- Overburden Stress
- Ground Surface Profile
- HDD Bore Profile

PennEast Pipeline
HORIZONTAL DIRECTIONAL DRILLING EVALUATION

MOTT MACDONALD

PennEast Pipeline Project
Wickecheoke Creek
DRILLING FLUID PRESSURE EVALUATION

Pilot Bore Drilling Fluid Pressure Evaluation

MOTT MACDONALD

Horizontal Directional Drilling
Drilling Fluid Hydraulic Fracture Calculations

Calculated by: M. Lockwood
Checked by: G. Duyvestyn
Date: 4/26/2019
Project No: 353754

PROJECT: PennEast Pipeline Project

CROSSING LOCATION: Wickecheoke Creek

Reference:
1. Latoore, C.A., Wakeley, L.D., and Conroy, P.J., Guidelines for Installation of Utilities Beneath Corps of Engineers Levees using Horizontal Directional Drilling, June 2002, ERDC/GSL TR-02-9
2. HDD Consortium, Horizontal Directional Drilling Good Practices Guidelines, Third Edition, North American Society of Trenchless Technology, 2008.

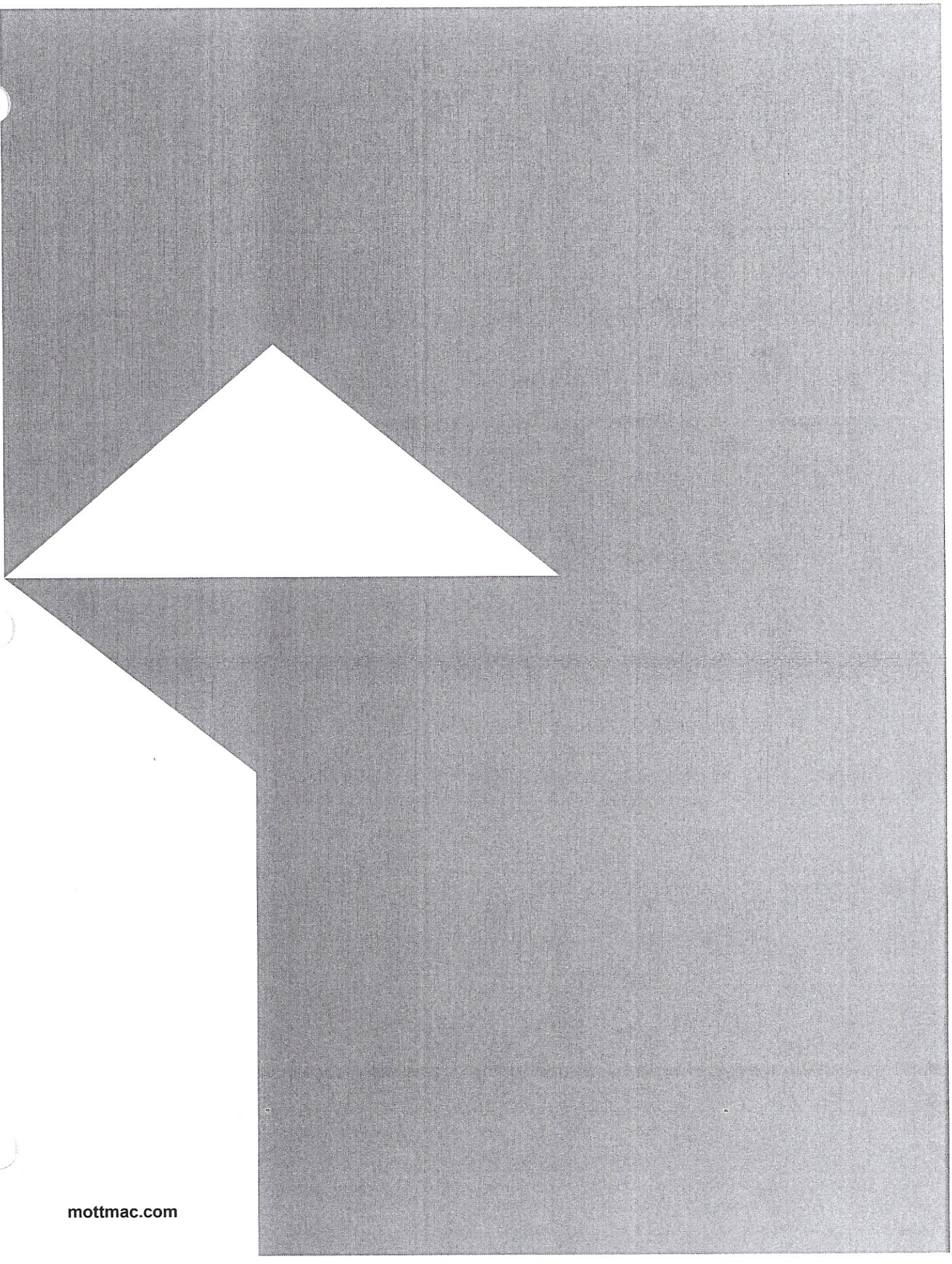
Geotechnical Inputs

Soil Properties	Soil Type 1	Soil Type 2	Soil Type 3	Soil Type 4	Soil Type 5
c , soil cohesion (psf)	1000	0	4500		
c , soil cohesion (N/m^2 or Pa)	47,880	0	215,461	0	0
ϕ, soil internal friction angle (deg)	0.0	22.0	6.0		0.0
ϕ, soil internal friction angle (rad)	0.00	0.38	0.10	0.0	0.0
Equivalent 'SPT Blow Count N60 (blows per 12 inch)	6				
E , Young's Modulus based on blow count (lb/ft^2)	240,000	0	0	0	0
E , Young's Modulus (kPa)	11,500	21,500	36,000		
E , Young's Modulus (lb/ft^2)	240,182	449,037	751,575	0	0
v , Poisson's ratio	0.30	0.30	0.30		
G , soil shear modulus (ksf)	92	173	289	0	0
G , soil shear modulus (kPa)	4,423	8,269	13,846	0	0
G , soil shear modulus (Pa)	4,423,077	8,269,231	13,846,154	0	0
γ_t soil total unit weight (pcf) below water table	120	135	150		
γ_t soil total unit weight (kN/m^3) below water table	18.9	21.2	23.6	0.0	0.0
γ_t soil total unit weight (pcf) above water table	115	130	145		
γ_t soil total unit weight (kN/m^3) above water table	18.1	20.4	22.8	0.0	0.0
Top Depth Soil Type encountered (feet)	GS	-10	-30		
Top Depth Soil Type encountered (metre)	GS	-3.0	-9.1		
Bottom Depth Soil Type encountered (feet)	-10	-30			
Bottom Depth Soil Type encountered (metre)	-3.0	-9.1			

HDD Installation Inputs

Drill and Intersect Used	no	
Target Drill and Intersect Location	0+000	
Drill Rig setup on Pipe Side (Single Rig Option Only). For Drill and Intersect, this must be "no"	no	
Drill Rig #1 Elevation	286.9	feet
	87.4	metre
Drill Rig #2 Elevation (Pipe Entry Location)	N/A	feet
	N/A	metre
Recommended Allowable Pressure Factor	2.00	Factor applied
Total Horizontal Installation Length	3,399.0	feet
	1,036.6	metre
True Installation Length	3,362.7	feet
	1,024.9	metre
Pilot Bore Diameter	12.250	inch
	311.15	mm
Drill Pipe Diameter	6.625	inch
	168.28	mm
Yield Point	19.5	lb/100ft^2
Plastic Viscosity	13	cP
Drilling Fluid Pumping Rate	600	gal/min
	2.27	m^3/min
Calculated Drilling Fluid Velocity	2.306	ft/sec
	0.703	m/sec
Pressure Required for Bore Slurry Flow	0.015	psi per ft of bore
	0.126	kPa per metre of bore
	0.548	psi per 30 ft drill pipe
Drilling Fluid Mud Weight	10.5	ppg
	78.6	lb/ft^3
	1.26	specific gravity

Location	Bore Stationing		Drilled Length wrt Drill Rig(s) and Locations (True Bore Length)		Bore Elevation		Ground Surface Elevation		Water Table Elevation		Depth of Cover		Soil Type	Theoretical Unfactored Drilling Fluid Pressure		Estimated Bore Fluid Pressure for Drilling Fluid Flow		Factor of Safety	Estimated Hydrostatic Fluid Pressure Within Bore		Factor of Safety	Estimated Bore Fluid Pressure for Drilling Fluid Flow and Hydrostatic Column		Factor of Safety	Recommended Upper Drilling Fluid Pressure Limit			Factor of Safety	Total Stress Evaluation	
	feet	metre	feet	metre	feet	metre	feet	metre	feet	metre	feet	metre		psi	kPa	psi	kPa		psi	kPa		psi	kPa		Factor	psi	kPa		psi	kPa
Pipe Exit Side	5125+09	156+337	0.0	0.0	285.9	87.4	286.9	87.4	271.9	443.0	0.0	0.0	Type 1	0.0	0.0	0.00	0.0	--	0.00	0.00	--	0.00	0.0	--		0.0	0.0	--	0.0	0.0
5126+73	156+326	39.7	11.2	278.9	84.7	285.2	86.9	270.2	443.0	7.2	2.2	Type 2	29.1	201.0	0.7	4.6	43.43	4.8	33.4	6.02	5.5	38.0	5.28	2.09	17.8	123.0	3.23	6.5	45.0
5128+38	156+315	73.4	22.4	269.1	82.0	281.4	85.8	268.4	443.0	12.3	3.8	Type 3	192.2	1325.0	1.3	9.3	143.15	9.7	66.8	19.63	11.0	76.1	17.42	7.50	36.7	253.3	3.33	12.8	88.4
5128+02	156+304	110.2	33.6	260.2	79.3	278.0	84.7	263.0	443.0	17.8	5.4	Type 3	207.9	1433.5	2.0	13.9	103.25	14.5	100.2	14.30	16.5	114.1	12.56	6.50	47.7	328.6	2.88	18.5	127.7
5127+68	156+283	146.9	44.8	251.4	76.6	274.1	83.6	259.1	443.0	22.8	6.9	Type 3	217.8	1501.6	2.7	18.5	81.11	19.4	133.6	11.24	22.1	152.1	9.87	6.00	56.1	386.5	2.54	23.7	163.5
5127+31	156+282	183.6	56.0	242.5	73.9	270.8	82.5	255.8	443.0	26.3	8.0	Type 3	227.0	1565.4	3.4	23.1	67.65	24.2	167.0	9.37	27.6	190.2	8.23	5.50	65.4	451.0	2.37	29.5	203.3
5126+95	156+271	220.3	67.2	233.6	71.2	267.7	81.6	252.7	443.0	34.1	10.4	Type 3	235.8	1625.9	4.0	27.8	58.55	29.1	200.4	8.11	33.1	228.2	7.13	5.00	75.6	521.0	2.26	35.5	244.7
5126+60	156+261	257.0	78.3	224.7	68.5	265.2	80.8	250.2	443.0	40.5	12.3	Type 3	245.1	1689.7	4.7	32.4	52.16	33.9	233.8	7.23	38.6	265.2	6.35	4.50	87.3	601.6	2.26	42.2	290.7
5126+24	156+250	293.7	89.5	215.8	65.8	262.0	79.9	247.0	443.0	46.2	14.1	Type 3	253.0	1744.7	5.4	37.0	47.12	38.8	267.2	6.53	44.1	304.3	5.73	4.00	99.3	684.9	2.25	48.1	331.7
5125+88	156+239	330.5	100.7	207.0	63.1	258.2	78.7	243.2	443.0	51.2	15.6	Type 3	260.0	1792.6	6.0	41.7	43.04	43.5	300.0	5.66	49.6	342.3	5.24	3.50	112.4	775.0	2.26	53.4	367.9
5125+53	156+228	367.2	111.9	198.1	60.4	256.1	78.1	241.1	443.0	58.0	17.7	Type 3	269.3	1856.7	6.7	46.3	40.12	48.4	334.0	5.58	55.2	380.3	4.88	3.00	130.1	896.8	2.36	60.5	416.9
5126+17	156+217	403.9	123.1	189.2	57.7	252.5	77.0	237.5	443.0	63.3	19.3	Type 3	276.4	1906.0	7.4	50.9	37.44	53.3	367.5	5.19	60.7	418.4	4.56	2.50	150.2	1,035.4	2.47	66.0	454.9
5124+81	156+206	440.6	134.3	180.3	55.0	249.1	75.9	234.1	443.0	68.8	21.0	Type 3	283.8	1956.8	8.1	55.5	35.24	58.1	400.9	4.88	66.2	456.4	4.29	2.25	166.0	1,144.3	2.51	71.7	494.3
5124+46	156+195	477.3	145.5	171.4	52.2	246.0	75.0	231.0	443.0	74.6	22.7	Type 3	291.6	2010.3	8.7	60.2	33.41	63.0	434.3	4.63	71.7	494.4	4.07	2.00	184.6	1,273.1	2.57	77.7	535.8
5124+10	156+185	514.1	156.7	162.5	49.5	242.9	74.0	227.9	443.0	80.3	24.5	Type 3	299.2	2062.9	9.4	64.8	31.84	67.8	467.7	4.41	77.2	532.5	3.87	2.00	191.4	1,319.9	2.48	83.7	576.9
5123+75	156+174	550.8	167.9	153.7	46.8	240.2	73.2	225.2	443.0	86.6	26.4	Type 3	307.5	2120.2	10.1	69.4	30.54	72.7	501.1	4.23	82.7	570.5	3.72	2.00	198.8	1,371.0	2.40	89.2	621.7
5123+39	156+163	587.5	179.1	144.8	44.1	237.3	72.3	222.3	443.0	92.5	28.2	Type 3	315.4	2174.4	10.7	74.0	29.36	77.5	534.5	4.07	88.3	608.5	3.57	2.00	205.8	1,419.3	2.33	95.3	664.2
5122+68	156+141	660.8	201.4	127.8	38.9	231.3	70.5	216.3	443.0	103.5	31.5	Type 3	330.0	2275.1	12.1	83.3	27.32	86.8	598.4	3.80	99.9	681.7	3.34	2.00	218.9	1,509.2	2.21	107.8	743.7
5121+96	156+119	734.1	223.8	112.2	34.2	225.5	68.7	210.5	443.0	113.3	34.5	Type 3	342.9	2364.5	13.4	92.5	25.55	95.3	656.9	3.60	108.7	749.5	3.16	2.00	230.5	1,589.2	2.12	118.0	813
5121+24	156+097	807.4	246.1	98.1	29.9	221.2	67.4	206.2	443.0	123.1	37.5	Type 3	355.8	2453.2	14.8	101.8	24.11	103.0	709.9	3.46	117.7	811.7	3.02	2.00	242.0	1,668.5	2.06	128.2	88
5120+52	156+075	880.7	268.4	85.5	26.1	217.0	66.1	202.0	443.0	131.5	40.1	Type 3	367.0	2530.1	16.1	111.0	22.79	109.8	757.4	3.34	125.9	868.4	2.91	2.00	252.0	1,737.3	2.00	137.0	94
5119+79	156+053	954.0	290.8	74.3	22.7	212.3	64.7	197.3	443.0	138.0	42.1	Type 3	375.5	2588.6	17.4	120.2	21.53	116.9	799.3	3.24	133.4	919.6	2.82	2.00	259.6	1,789.8	1.95	143.7	990
5119+07	156+031	1,027.3	313.1	64.7	19.7	208.5	63.5	193.5	443.0	143.8	43.8	Type 3	383.1	2641.4	18.8	129.5	20.40	121.2	835.7	3.16	140.0	965.2	2.74	2.00	266.4	1,837.0	1.90	149.8	1,032.6
5118+34	156+009	1,100.6	335.5	56.5	17.2	205.5	62.7	190.5	443.0	149.1	45.4	Type 3	390.0	2689.3	20.1	138.7	19.39	125.7	866.5	3.10	145.8	1005.2	2.68	2.00	272.7	1,880.0	1.87	155.3	1,070.6
5117+61	155+987	1,173.9	357.8	49.8	15.2	201.5	61.4	186.5	443.0	161.7	49.2	Type 3	393.5	2713.1	21.5	148.0	18.34	129.3	891.7	3.04	150.8	1039.7	2.61	2.00	275.8	1,901.3	1.83	158.0	1,089.5
5116+88	155+964	1,247.2	380.2	44.6	13.6	196.7	60.0	181.7	443.0	152.2	46.4	Type 3	394.1	2717.4	22.8	157.2	17.29	132.2	911.4	2.98	155.0	1068.6	2.54	2.00	276.3	1,905.2	1.78	158.5	1,092.9
5116+15	155+942	1,320.5	402.5	40.8	12.4	192.8	58.8	177.8	443.0	152.9	46.3	Type 3	393.9	2715.6	24.1	166.4	16.33	134.2	925.4	2.93	158.4	1091.8	2.49	2.00	276.1	1,903.6	1.74	158.3	1,091.5
5115+41	155+920	1,393.8	424.8	38.8	11.8	187.1	57.0	172.1	443.0	148.6	45.3	Type 3	393.4	2684.7	25.5	175.7	15.28	135.4	933.8	2.88	160.9	1109.5	2.42	2.00	272.1	1,875.8	1.69	154.8	1,067.0
5114+68	155+897	1,467.1	447.2	37.8	11.5	181.9	55.5	166.9	443.0	144.1	43.9	Type 3	363.5	2644.1	26.8	184.9	14.30	135.8	936.6	2.82	162.7	1121.5	2.36	2.00	266.8	1,839.5	1.64	150.1	1,034.9
5114+34	155+887	1,501.1	457.6	37.9	11.5	180.2	54.9	165.2	443.0	142.3	43.4	Type 3	361.2	2628.2	27.4	189.2	13.95	135.8	936.6	2.81	163.3	1125.8	2.33	2.00	264.7	1,825.2	1.62	148.3	1,022.2
5114+00	155+877	1,535.1	467.9	37.8	11.5	178.3	54.3	163.3	443.0	140.4	42.8	Type 3	378.7	2610.9	28.1	193.6	13.49	135.8	936.6	2.79	163.9	1130.1	2.31	2.00	262.5	1,809.7	1.60	146.3	1,008.5
5113+66	155+856	1,569.1	478.3	37.8	11.5	176.2	53.7	156.0	443.0	138.4	42.2	Type 3	377.0	2599.4	28.7	197.8	13.14	135.8	936.6	2.76	164.5	1134.4	2.29	2.00	260.6	1,796.6	1.59	144.2	993.5
5113+32	155+856	1,603.1	488.6	37.8	11.5	174.2	53.1	156.0	443.0	136.4	41.6	Type 3	374.0	2578.3	29.3	202.1	12.76	135.8	936.6	2.75	165.1	1138.7	2.26	2.00	258.0	1,778.8	1.59	142.0	979.4
5112+85	155+842	1,650.3	503.0	38.1	11.6	171.5	52.3	156.0	443.0	133.3	40.6	Type 3	369.4	2547.0	30.2	208.0	12.25	135.7	935.4	2.72	165.8	1143.4	2.23	2.00	254.1	1,752.3	1.53	138.9	957.5
5112+38	155+827	1,697.4	517.4	39.1	11.9	169.5	51.7	156.0	443.0	130.4	39.8	Type 3	365.3	2518.3	31.0	213.9	11.77	135.2	932.0	2.70	166.2	1145.9	2.20	2.00	250.6	1,727.6	1.51	135.9	936.6
5111+91	155+813	1,744.5	531.7	40.6	12.4	167.6	48.0	156.0	443.0	117.0	35.7	Type 3	345.2	2380.1	31.9	219.9	10.82	134.3	926.2	2.57	166.2	1145.0	2.08	2.00	233.5	1,610.3	1.41	121.9	840.4
5111+44	155+798	1,791.6	546.1	42.6	13.0	154.3	47.0	156.0	443.0	111.5	34.0	Type 3	337.3	2325.5	32.8	225.8	10.30	133.2	918.1	2.53	165.9	1143.9	2.03	2.00	228.7	1,583.2	1.37	118.2	800.9
5110+97	155+784	1,838.8	560.5	45.5	13.9	157.3	47.9	156.0	443.0	111.7	34.1	Type 3	338.1	2331.3	33.6	231.8	10.05	131.6	907.6	2.57	165.3	1139.4	2.05	2.00	227.2	1,566.8	1.38	116.4	802.3
5110+50	155+770	1,885.9	574.8	48.9	14.9	158.4	48.3	156.0	443.0	109.5	33.4	Type 3	335.4	2312.3	34.5	237.7	9.73	129.6	894.9	2.58	164.3	1132.6	2.04	2.00	224.7	1,549.2	1.37	114.0	786.1
5110+03	155+755	1,933.0	589.2	52.9	16.1	157.2	47.9	156.0	443.0	104.2	31.8	Type 3	328.2	2263.0	35.3	243.6	9.29	127.5	879.8	2.57	162.9	1123.5	2.01	2.00	218.4	1,505.8	1.34	108.6	748.6
5109+55	155+741	1,980.1	603.6	57.6	17.5	156.1	48.2	143.1	443.0	100.5	30.6	Type 3	326.0	2247.8	36.2	249.6	9.01	125.1	862.4	2.61	161.3	1112.0	2.02	2.00	215.4	1,484.9	1.34	104.7	721.9
5109+09	155+727	2,027.3	617.9	62.6	19.1	156.0	48.2	143.0	443.0	95.2	29.0	Type 3	319.0	2199.4	37.1	255.5	8.61	122.2	842.8	2.61	159.3	1098.3	2.00	2.00	209.1	1,441.6	1.31	99.2	683.9
5108+62	155+713	2,074.4	632.3	68.6	20.9	156.0	48.2	143.0	443.0	89.4	27.2	Type 3	311.2	2145.9	37.9	261.5	8.21	119.0	820.8	2.61	157.0	1082.2	1.98	2.00	202.2	1,393.9	1.29	93.1	641.9
5108+15	155+699	2,121.5	646.6	75.1	22.9	156.6	48.4	143.6	443.0	83.6	25.5	Type 3	303.5	2092.6	38.8	267.4	7.83	115.5	796.5	2.63	154.3	1063.9	1.97	2.00	195.3	1,348.4	1.27	87.0	600.1
5107+69	155+684	2,168.6	661.0	82.2	25.0	160.0	48.8	145.0	443.0	77.8	23.7	Type 3	295.8	2039.8	39.6	273.3	7.46	111.7	769.9	2.65	151.3	1043.3	1.96	2.00	188.4	1,299.3	1.25	81.0	558.8
5107+22	155+670	2,215.8	675.4	89.8	27.4	166.2	50.6	151.2	443.0	76.3	23.3	Type 3	293.9	2026.2	40.5	279.3	7.28	107.8	741.1	2.73	148.0	1020.3	1.99	2.00	186.7	1,287.2	1.26	79.5	548.2
5106+76	155+655	2,262.9	689.7	99.1	30.2	183.7	56.0	168.7	443.0	85.6	26.1	Type 3	306.2	2111.4	41.4	285.2	7.49	103.0	709.9	2.87	144.3	995.1	2.12	2.00	197.7	1,363.1	1.37	89.2	614.8
5106+30	155+642	2,310.0	704.1	107.0	32.6	206.3	62.9	191.3	443.0	99.3	30.3	Type 3	324.5	2237.0	42.2	291.2	7.68	98.1	676.5	3.31	140.3	967.6	2.31	2.00	214.0	1,475.2	1.52	103.5	713.4
5105+84	155+626	2,357.1	718.5	116.5	35.5	232.3	70.8	217.3	443.0	115.8	35.3	Type 3	346.3	2387.4	43.1	297.1	8.04	92.9	640.8	3.73	136.0	937.9	2.55	2.00	233.5	1,609.5	1.72	120.6	831.8
5105+02	155+603	2,440.9	744.0	133.9	40.8	253.4	77.2	238.4	443.0	119.5	36.4	Type 3	351.1	2420.7	44.6	307.7	7.87	83.4	575.3	4.21	128.1	882.9	2.74	2.00	237.8	1,639.4	1.86	124.5	858.1
5104+20	155+578	2,524.7	769.5	151.3	46.1	260.5	79.4	245.5	443.0	109.1	33.3	Type 3	337.4	2326.2	45.2	316.2	7.31	73.9	509.7	4.56	120.1	828.0	2.81	2.00	225.5	1,554.9	1.98	113.7	783.6
5103+38	155+553	2,606.5	795.1	166.8	51.4	268.1	81.7	253.1	443.0	99.4	30.3	Type 3	324.5	2237.3	47.7	326.8	6.80	64.4	444.2	5.04	112.1	773.0	2.89	2.00	214.0	1,475.5	1.91	103.5	713.6
5102+55	155+528	2,692.3	820.6	186.2	56.8	272.7	83.1	257.7	443.0	86.5	26.4	Type 3	307.4	2119.4	49.2	339.3	6.25	54.9	378.7	5.60	104.1	718.1	2.95	2.00	198.7	1,370.3	1.91	90.1	621.1
5101+74	155+503	2,776.1	846.2	203.6	62.1	276.5	84.3	261.5	443.0	72.9	22.2	Type 3	289.3	1994.5	50.7	349.9	5.70	45.4	313.2	6.37	96.2	663.1	3.01	2.00	182.6	1,259.0	1.90	75.9	523.5
5100+92	155+478	2,859.9	871.7	221.6	67.4	281.1	85.7	266.1	443.0	60.0	18.3	Type 3	272.0	1875.2	52.3	360.5	5.29	35.9	247.7	7.57	88.2	608.1	3.08	2.10	162.3	1,118.8	1.84	62.5	431.1
5100+10	155+453	2,943.7	897.2	238.5	72.7	285.8	87.4	271.5	443.0	46.1	14.1	Type 3	255.8	1763.4	53.8	371.0	4.75	26.4	182.2	9.68	80.2	553.2	3.19	2.40	135.8	936.5	1.69	50.1	345.8
5099+28	155+428	3,027.5	922.8	255.9	78.0	290.9	88.6	278.9	443.0	36.1	11.0	Type 3	241.6	1665.9	55.3	381.6	4.37	16.9	116.7	14.28	72.3	498.2	3.34	3.00	107.0	737.5	1.48	39.6	273.3
5098+46	155+403	3,111.3	948.3	273.3	83.3	303.0	92.4	288.0	443.0	29.7	9.1	Type 2	116.9	806.0	56.9	392.1	2.06	7.4	51.1	15.76	64.3	443.3	1.82	2.00	71.9	495.5	1.12	26.8	185.0
5097+64	155+378	3,195.1	973.9	290.7	88.6	310.8	94.7	295.8	443.0	20.0	6.1	Type 2	69.4	478.7	58.4	402.7	1.53	-2.1	-14.4	-42.91	56.3	388.3	1.59	2.00	53.8	370.7	0.95	18.1	124.7
5096+82	155+353	3,278.9	999.4	308.1	93.9	319.2	97.3	304.2	443.0	11.1	3.4	Type 1	43.2	297.9	59.9	413.3	0.72	-11.5	-79.9	-3.73	48.4	333.4	0.89	3.50	18.7	128.7	2.314703	8.8	61.0
Pipe Entry Side	5096+00	155+328	3,362.7	1,024.9	325.6	99.2	325.6	99.2	310.6	443.0	0.0	0.0	Type 1	0.0	0.0	61.5	423.8	--	-21.1	-145.4	--	40.4	278.4	--	2.00	0.0	0.0	--	0.0	0.0



MOTT MACDONALD

PennEast PIPELINE

HDD Design Report Brookville Hollow Road HDD Crossing

PennEast Pipeline Project

July 22, 2019