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HDD Design Report
Alexauken Creek HDD Crossing

PennEast Pipeline Project

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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 Alexauken 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 Alexauken 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), and a seismic refraction survey completed by Hager-Richter Geoscience Inc. 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 is provided in Appendix A. The horizontal length of the proposed HDD is approximately 6,300 feet (with a true length of approximately 6,361 feet). An elevation difference of approximately 66 feet exists between the north and south HDD entry locations, with the north HDD entry location at the lower elevation.

The pipe staging area for the drag section is located on the southeast side of the crossing. It is envisioned that, due to limited workspace, this pipe string will be fabricated into three sections prior to pullback operations.

This crossing has been designed to utilize the drill and intersect method to complete the pilot bore phase of the installation. To accommodate the drill and intersect method, a flat horizontal tangent of 2,564 feet has been incorporated into the design profile between STA 5283+55 and 5309+19 as shown on the crossing drawing in Appendix A. The exact location of the intersection will be determined by the HDD contractor.

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 four (4) borings, designated as B-38B, B-40, B-ALEX-1, and B-ALEX-2 were completed as part of the geotechnical investigation program to support the evaluation and design of the Alexauken Creek Crossing. Borehole B-38B was drilled northwest of Alexauken Creek (approximately 1,566 feet southeast of the north HDD entry location) to a depth of 300 feet (EL -127) below ground surface. Borehole B-40 was drilled southeast of Alexauken Creek (approximately 299 feet northwest of Alexauken Creek road) to a depth of 175 feet (EL -57) below ground surface. Borehole B-Alex-1 was drilled southeast of Alexauken Creek (approximately 449 feet northwest of U.S. Highway 202) to a depth of 215 feet (EL -51) below ground surface. Borehole B-ALEX-2 was drilled southeast of U.S. Highway 202 (approximately 1,290 feet northwest of the south HDD entry location) to a depth 250 feet (EL -17) below ground surface.

A seismic refraction survey (Seismic Line 4) was also completed along the alignment near the north HDD entry location to determine the elevation of the soil to bedrock interface. The geophysical survey was completed by Hager-Richter Geosciences, Inc. (Hager-Richter) in lieu of Boring B-38A due to site access conditions.

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

2.2 Geotechnical Observations

2.2.1 Geotechnical Observations Northwest of Alexauken Creek

The HDD installation on the northwest side of Alexauken Creek is anticipated to encounter soils overlying bedrock materials. Based on Boring B-38B, the site soils are anticipated to include the following:

- Medium to very dense sand with decomposed rock to a depth of 10 feet (from Elev. 173 to 162 feet).
- Very dense decomposed rock with trace sand to a depth of 20 feet (Elev. 153 feet).
- Very fine grained to fine grained, highly weathered to fresh, and weak to strong siltstone to a depth of 188 feet (Elev. -15 feet). RQD values ranged between 0 and 93 percent (avg. 62 percent) with RQD increasing with depth. Recovery values ranged between 35 to 100 percent (avg. 95 percent). A clay seam 0.9 feet thick exist at the bottom of the siltstone bedrock.
- Coarse grained, moderately weathered, and strong breccia to a depth of 190 feet (Elev. -17 feet). RQD value was 83 percent and recover value was 100 percent.
- Coarse to fine grained, slightly weathered, and medium strong siltstone to a depth of 195 ft (Elev. -22 feet. RQD value was 67 percent and recovery value was 100 percent.
- Very fine grained, slightly weathered to fresh, and medium strong to strong shale to a depth of 225 feet (Elev. -52 feet). RQD values ranged between 15 and 75 percent (avg. 49 percent). Recovery values ranged between 85 to 100 percent (avg. 95 percent).

- Very fine grained, slightly weathered to fresh, and strong siltstone to a depth of 255 feet (Elev. -82 feet). RQD values ranged between 7 and 78 percent (avg. 35 percent). Recovery values ranged between 50 to 100 percent (avg. 84 percent).
- Very fine grained, fresh, and medium strong to very strong siltstone to a termination depth of 300 feet (Elev. -127 feet). RQD values ranged between 33 and 95 percent (avg. 62 percent). Recovery value were 100 percent.

The bedrock materials are anticipated to include predominantly highly weathered to fresh, weak to very strong siltstone based on information collected from Boring B-38B. The strength of the siltstone appears to be weakest at the soil to bedrock interface and increases with depth. Isolated areas of poor-quality siltstone exist at depth but are bounded be rock layers with higher good to excellent quality.

2.2.2 Geotechnical Observations Southeast of Alexauken Creek

The HDD installation on the southeast side of Alexauken Creek is anticipated to encounter soils overlying bedrock materials. Based on Boring B-40, the geotechnical materials are anticipated to include the following:

- Loose clayey sand with silt from the ground surface to a depth of 5 feet (from Elev. 118 to 113 feet).
- Very dense decomposed rock fragments to a depth of 30 feet (to Elev. 88 feet).
- Slightly weathered to fresh and medium strong siltstone to a termination depth of 175 feet (to Elev. -57 feet). The RQD values ranged from 48 to 100 percent (avg. 84.6 percent), with the RQD increasing with depth.

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

- Loose clayey sand from the ground surface to a depth of 3.5 feet (from Elev. 164 to 160.5 feet).
- Hard sandy clay to a depth of 25 feet (to Elev. 139 feet).
- Slightly weathered to fresh and medium strong siltstone to a depth of 95 feet (to Elev. 69 feet). The RQD values ranged from 38 to 100 percent (avg. 80.8 percent), with the RQD increasing with depth.
- Slightly weathered to fresh and medium strong shale to a depth of 104 feet (to Elev. 60 feet). The RQD values ranged from 40 to 85 percent (avg. 62.5 percent), with the RQD increasing with depth.
- Fresh and medium strong to strong siltstone to a termination depth of 215 feet (to Elev. -51 feet). The RQD values ranged from 60 to 100 percent (avg. 90.7 percent), with RQD increasing with depth.

The HDD installation on the southeast side of Alexauken Creek in the vicinity of the south entry location is anticipated to encounter soils overlying bedrock materials. Based on boring B-ALEX-2, the geotechnical materials are anticipated to include the following:

- Very loose decomposed rock fragments with silt and the occasional roots to a depth of 8.5 feet (from Elev. 233 to 224.5 feet).
- Very dense silty sand with weathered rock fragments to a depth of 13.5 feet (Elev. 219.5 feet).
- Very dense decomposed rock fragments to a depth of 20 feet (Elev. 213 feet).
- Fine grained, highly weathered, and medium strong sandstone interbedded with siltstone to a depth of 25 feet (Elev. 208 feet). RQD value was 15 percent and recovery value was 57 percent.
- Fine grained, highly to slightly weathered, and medium strong siltstone interbedded with sandstone to a depth of 35 feet (Elev. 198 feet). RQD values ranged between 0 and 50 percent (avg. 25 percent). Recovery values ranged between 50 to 93 percent (avg. 72 percent).
- Fine grained, fresh, and strong sandstone interbedded with siltstone to a depth of 40 feet (Elev. 193 feet). RQD value was 75 percent and recovery value was 100 percent.

- Fine grained, slightly weathered to fresh, medium strong siltstone to a depth of 65 feet (Elev. 168 feet). RQD values ranged between 47 and 73 percent (avg. 60 percent). Recovery values were 100 percent.
- Medium to fine grained, fresh, and strong to very strong sandstone to a depth of 105 feet (Elev. 128 feet). Sandstone was interbedded with siltstone to a depth of 85 feet (Elev. 148 feet). RQD values ranged between 47 and 85 percent (avg. 71 percent). Recovery values ranged between 93 to 100 percent (avg. 99 percent).
- Fine grained, fresh and very strong siltstone to a depth of 110 feet (Elev. 123 feet). RQD value was 95 percent and recovery value was 100 percent.
- Fine grained, slightly weathered to fresh, medium strong to very strong sandstone to a termination depth of 250 feet (Elev. -17 feet). RQD values ranged between 53 and 100 percent (avg. 87 percent). Recovery values ranged between 98 to 100 percent (avg. 100 percent).

Along the proposed HDD alignment on the southeast side of Alexauken Creek, the bedrock materials are anticipated to include slightly weathered to fresh and medium strong siltstone and slightly weathered to fresh and strong sandstone materials with fair to excellent quality rock. The strength of the siltstone and sandstone appears to be weakest at the soil to bedrock interface and increases with depth.

Unconfined compressive strength tests on samples from Borings B-40 and B-ALEX-1 indicate strengths of 6,215 to 10,628 psi. Point load tests indicate compressive strengths of 2,332 to 3,964 psi of diametral direction and 15,963 to 25,998 psi in the axial direction.

2.3 Geophysical Survey Results

A geophysical survey was conducted by Hager-Richter at the proposed B-38A location in lieu of a boring. The survey consisted of four seismic refraction lines, totaling a length of 1,840 feet along the proposed alignment. The geophysical survey results approximate that the bedrock depths ranged from 4 feet to 24 feet. Additional information regarding the geophysical survey can be found in the site-specific GDR.

3 Alexauken 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 Alexauken Creek Crossing, the north entry and south entry angles have been both set at 12°, 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 wetlands, waterbodies, roads, and a railroad. From a northwest to southeast orientation, the following minimum depths of cover are noted:

- Wetland 052318_HS_1005_PEM: Approximately 37 feet.
- Waterbody 052418_HS_1002_P_MI: Approximately 82 feet.
- Waterbody 032519_JM_1002_E_MI: Approximately 105 feet.
- Waterbody 052418_HS_1001_P_MI: Approximately 174 feet.
- Waterbody 052418_HS_1002_P_IN: Approximately 187 feet.
- Existing pipelines: Approximately 281 feet.
- Wetland 031219_CM_1001_PFO: Approximately 159 feet.
- Alexauken Creek (Waterbody 031219_CM_1002_P_IN): Approximately 157 feet.
- Black & Western Corp. Railroad: Approximately 174 feet.
- Wetland 111416_SQ_1001_PEM_Swale: Approximately 174 feet.
- Alexauken Creek Road: Approximately 204 feet.
- Wetland 032619_JM_1003_PEM: Approximately 210 feet.
- Existing pipelines: Approximately 242 feet.
- U.S. Highway 202: Approximately 240 feet.
- Waterbody 101517_RP_1004_P_IN: Approximately 56 feet.
- Wetland 010517_SQ_1005_PEM: Approximately 37 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 gyroscopic guidance system to reduce the risks associated with laying a survey coil across U.S. Highway 202. If a ParaTrack system is proposed by the HDD Contractor, the HDD Contractor must assure adequate coverage of surveying with no gaps in coverage with a surface coil and/or beacon.

3.3 Required Workspace and Staging Areas

For the proposed HDD installation, the staging area for the north side of the crossing has been established at 300 feet by 385 feet, and the staging area for the south side of the crossing has been established at 400 feet by 490 feet (to accommodate use of the drill and intersect strategy). 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 south side of the crossing. The available length of the staging area is approximately 2,750 feet, resulting in the need for fabricating the pipe string into three (3) drag sections and the need for two (2) intermediate welds during pullback operations. The HDD Contractor will need to minimize delays during intermediate welding operations. To accommodate fabricating three (3) pipe strings, the staging width is 125 feet.

The temporary work space established for the Alexauken Creek Crossing is sufficient for HDD operations.

3.4 Requirement for Temporary Conductor Casing

Surface features, specifically Wetland 052318_HS_1005_PEM and Wetland 010517_SQ_1005_PEM, are located relatively close to the proposed north and south entry points, respectively. The limited setback distance from these features does not provide for a sufficient depth of cover for the alignment at these respective locations. To support the overburden soils (containing decomposed rock fragments), lower the annular pressure, and mitigate the risks associated with drilling fluid loss at these locations, a temporary conductor casing is recommended on each side of the HDD installation. The approximate casing length required on the both sides is approximately 100 feet, depending on where the soil/bedrock interface is encountered within the HDD alignment and the extent of the decomposed rock fragment layer above the soil/bedrock interface.

The minimum conductor casing diameter is recommended to be 56 inches to allow for the free passage of the 48-inch bottom hole reamer assembly. All conductor casing pipe shall be removed once pullback operations have been completed.

3.5 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 three (3), the estimated total water usage (assuming no loss in circulation) is approximately 2,109,500 gallons (282,000 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 264,000 gallons).

3.6 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 1,800,000 gallons (9,218 yd^3) and 113,000 ft^3 (4,185 yd^3) respectively. During pullback operations, the estimated displaced fluid volume is approximately 850,000 gallons (1,648 yd^3).

3.7 Schedule

The duration of the HDD installation is conservatively estimated to take a total of 231 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	6
Casing Installation	10
Pilot Bore Drilling	44
Reaming	150
Swab Pass	3
Product Pipe Pullback	4
Casing Removal	6
Rig Down and Demobilization	5
Total Number of Shifts	**231**

4 HDD Engineering Evaluation

4.1 Pipeline Properties

The pipeline properties used for the evaluation of the Alexauken Creek 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 Alexauken 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	55,553	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.

A start-up factor of 1.5 has been applied to the estimated pullback forces to replicate the higher installation loads observed during stoppages and recommencing of pullback operations for intermediate welds. This is referred to as the initial start-up pullback force in Table 4.

Table 4: Summary of anticipated pullback loads

Drilling Fluid Weight (ppg)	Product Pipe Buoyancy Condition	Estimated Pullback Force (lbs)	Start-Up Force After Intermediate Weld 1 (lbs)	Start-Up Force After Intermediate Weld 2 (lbs)
10 (Case 1)	Empty	1,296,215	843,857	1,439,189
10 (Case 2)	Full	816,585	474,114	827,133
11 (Case 3)	Empty	1,470,563	938,936	1,633,539
11 (Case 4)	Full	686,200	434,200	704,094
12 (Case 5)	Empty	1,657,940	1,025,087	1,827,599
12 (Case 6)	Full	579,464	425,9642	605,928

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)	15,366 psi (22.0%)	9,683 psi (13.8%)	17,433 psi (24.9%)	8,135 psi (10.9%)	19,654 psi (28.1%)	6,897 psi (9.8%)
Maximum Bending Stress (Percent of Allowable)	12,083 psi (17.3%)	12,083 psi (17.3%)	12,083 psi (17.3%)	12,083 psi (17.3%)	12,083 psi (17.3%)	12,083 psi (17.3%)
Maximum Hoop Stress (Percent of Allowable)	4,291 psi (6.1%)	711 psi (1.0%)	4,720 psi (6.7%)	1,140 psi (1.6%)	5,149 psi (7.4%)	1,569 psi (2.2%)
Maximum Unity Check – Tensile and Bending	0.53	0.42	0.57	0.40	0.61	0.38
Maximum Unity Check – Tensile, Bending, and Hoop	0.63	0.15	0.74	0.16	0.86	0.17

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/sandstone 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 and 8 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, stiff silt overlying siltstone/sandstone bedrock. For this evaluation, it has also been assumed that the Drill and Intersect method will be used to complete the pilot bore.

Table 7: Material property assumptions for the overburden soils

Evaluation Parameter	Value
Soil Unit Weight Above / Below Water Table	125 lb./ft^3 / 130 lb./ft^3
Effective Cohesion	2,000 psf
Internal Friction Angle	0°
Young's Modulus	626,563 psf
Poisson's Ratio	0.35

Table 8: 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	4,000 psf
Internal Friction Angle	9°
Young's Modulus	1,044,272 psf
Poisson's Ratio	0.33

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. Hence, the risk of a hydraulic fracture or inadvertent return is relatively low for this crossing.

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.

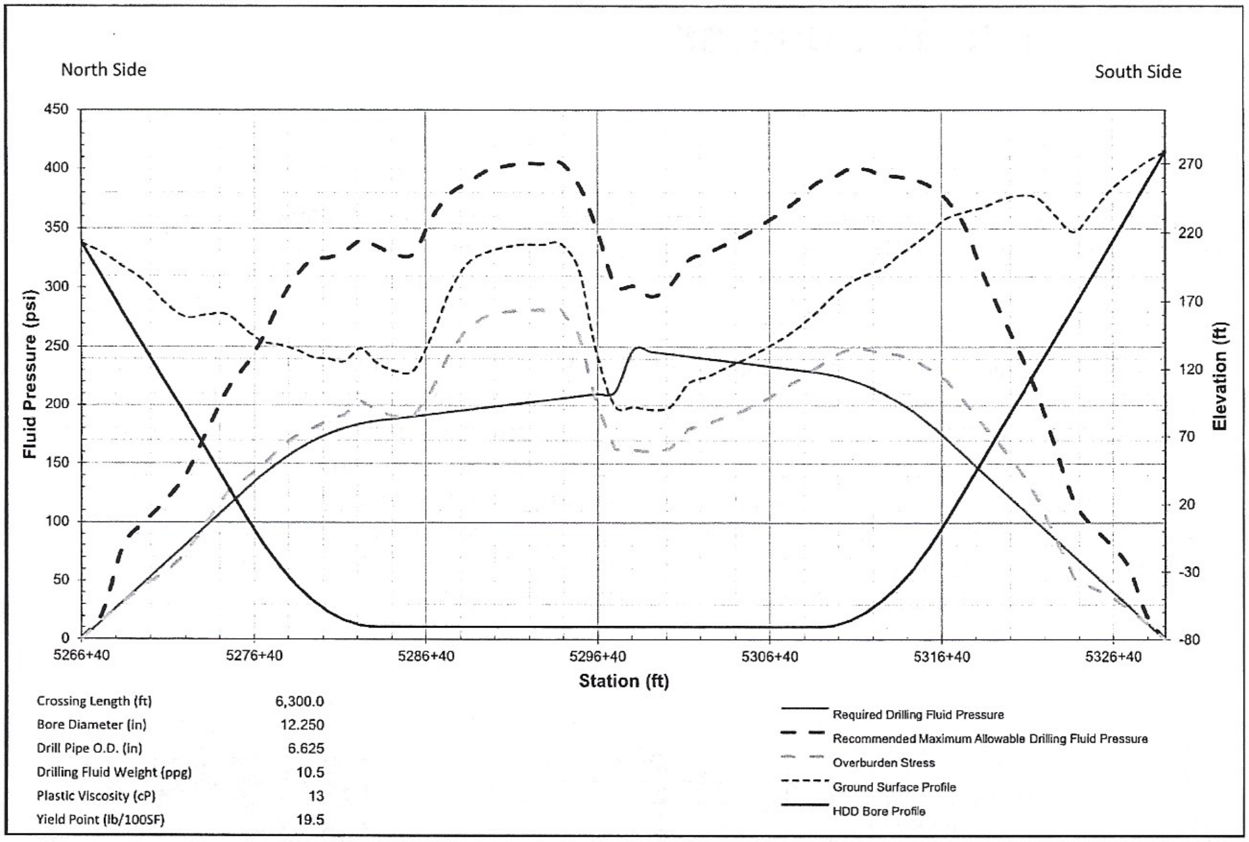

Figure 1: Calculated, recommended, and allowable drilling fluid pressures

5 HDD Risk Discussions

5.1 HDD Risk Characterization

Risk identification and mitigation is paramount to successfully completing the Alexauken Creek Crossing. 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 9 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 9: 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 9 below, 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 6,300 feet, with a true pipe length of approximately 6,361 feet, required for this crossing. Therefore, from a constructability standpoint, the Alexauken Creek Crossing 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, 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.

To mitigate risks associated with the anticipated soils containing decomposed rock fragments, temporary conductor casings have been incorporated into the design of the profile on each end of the installation.

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 drill and intersect method was chosen to mitigate risks associated with the geotechnical data provided during the investigation, such as drilling through decomposed rock fragments and gravel at the entry and exit points, and hydraulic fracture through the overburden materials above the alignment. However, the drill and intersect method provides an added level of complexity and technical proficiency to the drilling process. Mott MacDonald recommends that an intersection plan be discussed with the HDD contractor and that they demonstrate they are technically proficient using the drill and intersect method.

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 Alexauken Creek Crossing, the rock quality is typically greater than 60 percent based on the borings. The strength of the bedrock appears to be weakest at the soil to bedrock interface and increases with depth. Isolated areas of poor-quality siltstone exist at depth but are bounded be rock layers with good to excellent quality. The areas of lower rock quality are not anticipated to significantly increase risks associated with the installation.

The strength of the bedrock can impact construction duration, with higher strength leading to more frequent trips out of the bore to replace worn tooling. The laboratory tests completed to date indicate unconfined compressive strengths ranging from 6,215 to 10,628 psi. Point load tests yielded strengths between 2,332 and 3,964 psi in the diametral direction and between 15,963 and 25,998 psi in the axial direction. Splitting tensile tests ranged from 1,114 to 2,054 psi.

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

A drill and intersect installation strategy has been adopted for this crossing due the required installation length and to lower the drilling fluid pressures associated with this installation strategy. The use of the drill and intersect method provides an added level of complexity and technical proficiency to the drilling process. Mott MacDonald recommends that an intersection plan be discussed with the contractor and that they demonstrate their technically proficient using the drill and intersect method.

The length of the pipe staging area for the proposed crossing is insufficient to fabricate the pipe into a single string prior to pullback operations, and intermediate welds will be required. Intermediate welds will require stoppage of pullback operations each time a new pipe segment is welded on. These stoppages represent a risk to the installation since the bore is required to remain open much longer than what would be required for the installation of a single pipe string. Stoppages for the intermediate welds also provide downtime, while welding occurs, that allows the drilling fluids to "gel", making it harder to resume pullback operations due to the increased friction between the gelled fluids and the product pipe. Start-up loads will increase each time pullback operations are resumed. In some cases, the gel strength of the fluids is too great and the resulting loads lead to damage to the pipe, or the pipe may become stuck at its current position in the bore. This risk increases with each additional intermediate weld. Prior to pullback operations, a swab pass should be completed to gauge whether the bore has been conditioned to accept the 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 pipe should be installed with the shortest sections of pipe first and the longest pipe section last to decrease the startup loads on the pipe required to resume drilling operations.

6 Summary

For the Alexauken Creek Crossing, 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 Alexauken Creek Crossing. 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

MOTT MACDONALD **M M**

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.)		
	Clean Gravels (Less than 5% fines)	
Gravels More than 50% of coarse fraction larger than N.4 sieve size	GW	Well-graded gravels, gravel-sand mixtures, little or no fines
	GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines
	Gravels with fines (more than 12% fines)	
	GM	Silty gravels, gravel-sand-silt mixtures
	GC	Clayey gravels, gravel-sand-clay mixtures
	Clean Sands (Less than 5% fines)	
Sands More than 50% of coarse fraction larger than N.4 sieve size	SW	Well-graded sands, gravelly sands, little or no fines
	SP	Poorly-graded sands, gravelly sands, little or no fines
	Sands with fines (More than 12% fines)	
	SM	Silty sands, sand-silt mixtures
	SC	Clayey sands, sand-clay mixtures

FINE-GRAINED SOILS (more than 50% of material is smaller than No. 200 sieve size.)		
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
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
	OL	Organic silts and organic silty clays of low plasticity
SILTS AND CLAYS Liquid limit 50% or greater	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
	CH	Inorganic clays of high plasticity, fats clays
	OH	Organic clays of medium to high plasticity, organic silts
HIGHLY ORGANIC SOILS	PT	Peat and other highly organic soils

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:

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

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/Talc	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 – 240
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	

*Note: The Uniaxial Compressive Strength ranges are approximate; therefore, a geotechnical engineer

Soil Log Graphic Legend

- CL: USCS Low Plasticity Clay
- DECOMPOSED ROCK: Decomposed Rock
- SC: USCS Sandy Clay to Clayey Sand
- SM: USCS Silty Sand
- SP: USCS Poorly-graded Sand
- TOPSOIL: Topsoil

Rock Log Graphic Legend

- BRECCIA - Breccia
- CL - USCS Low Plasticity Clay
- 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.

MOTT MACDONALD M M

SOIL BORING LOG

BORING NO.: **B-38B**

Project: PennEast Pipeline Project
Location: Alexauken Creek, Delaware Township, Hunterdon County, NJ
Client: PennEast Pipeline
Drilling Co.: Boring Brothers, Inc.
Driller/Helper: Rob Dollar /Matt Daniel

Project No.: 353754
Project Mgr: Vatsal Shah
Field Eng. Staff: Vasikan Vijayashanthar
Date/Time Started: June 4, 2018 at 11:00 am
Date/Time Finished: June 12, 2018 at 11:39 am

Elevation: 173 ft. **Vertical Datum:** NAVD 1988
Boring Location: ~1,750 ft. Off Lambertville Headquarters Rd
Coord.: N: 40.397875 E: -74.939289
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 ☐ ATV ☑ Track ☐ Skid
☐ Tripod ☐ Geoprobe ☐ Air Track ☐
☐ Cat-Head ☑ Winch ☑ Roller Bit ☐ 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)	Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
	S-1 0.0'- 2.0'	6	1, 7, 5, 3		SP	Medium dense, Reddish brown coarse to fine SAND with Decomposed Rock fragments, dry (SP)	-	-	-	-	
170	S-2 2.0'- 4.0'	16	8, 9, 11, 12		SP	Medium dense, Reddish brown coarse to fine SAND with Decomposed Rock fragments, dry (SP)	-	-	-	-	Mottling observed throughout.
5	S-3 4.0'- 6.0'	14	14, 12, 9, 11		SP	Medium dense, Reddish brown coarse to fine SAND with Decomposed Rock fragments, dry (SP)	-	-	-	-	Mottling observed throughout.
	S-4 6.0'- 8.0'	22	15, 18, 25, 35		SP	Dense, Reddish brown coarse to fine SAND with Decomposed Rock fragments, dry (SP)	-	-	-	-	
▽	S-5 8.0'- 10.0'	24	42, 37, 42, 36		SP	Very dense, Reddish brown coarse to fine SAND with Decomposed Rock fragments, dry (SP)	-	-	-	-	
10	S-6 10.0'- 12.0'	9	50, 50/3"		10.0	Very dense, Reddish brown DECOMPOSED ROCK fragments, trace coarse to fine Sand, moist	-	-	-	-	Manganese staining.
160	12.0'- 15.0'						-	-	-	-	Washed out to 15 feet BGS.
15	S-7 15.0'- 17.0'	4	50/4"			Reddish brown DECOMPOSED ROCK fragments, moist	-	-	-	-	
					20.0						

Water Level Data

Date	Time	Elapsed Time (hr)	Depth in feet to: Bot. of Casing	Bottom of Hole	Water
6/5/18	8:00	-	8.5	12.0	8.41

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

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

Boring No.: **B-38B**

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.

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)	Dilatancy	Toughness	Plasticity	Dry Strength	Remarks
						Top of Rock at 20 feet BGS. See Rock Coring Log.					
150											
25											
30											
140											
35											
40											
130											
45											

NOTES: PP = Pocket Penetrometer
TV = Torvane

PROJECT NO.: **353754**

BORING NO.: **B-38B**

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-38B**

Project:	PennEast Pipeline Project		
Location:	Alexauken Creek, Delaware Township, Hunterdon County, NJ	**Project No.:**	353754
Client:	PennEast Pipeline	**Project Mgr:**	Vatsal Shah
Drilling Co.:	Boring Brothers, Inc.	**Field Eng. Staff:**	Vasikan Vijayashanthar
Driller/Helper:	Rob Dollar /Matt Daniel	**Date/Time Started:**	June 4, 2018 at 11:00 am
Elevation: 173 ft.	**Vertical Datum:** NAVD 1988	**Date/Time Finished:**	June 12, 2018 at 11:39 am

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: ~1,750 ft. Off Lambertville Headquarters Rd

Coord.: N: **40.397875** E: **-74.939289**

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.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
									SEE TEST BORING LOG FOR OVERBURDEN DETAILS								
	7.50	20.0							SILTSTONE, Reddish brown, fine grained, highly weathered, weak, extremely close to close spaced discontinuities								Washed out to 20 feet BGS.
	7.00								20' - 25' Highly Fractured zone								
	4.20		R-1	21 35%	0 0%	R2	H										
150	7.00																
25	6.10	25.0															
	2.50	25.0							SILTSTONE, Reddish brown, very fine grained, moderately weathered, weak, extremely close to close spaced discontinuities								
	6.50								Calcareous inclusions throughout.								
	5.80		R-2	48 80%	17 28%	R2	M		25' - 25.9' Highly Fractured zone 27.8' - 30' Highly Fractured zone	26.30	J	8	U,Sm	DS	PO	N	
	4.00									27.00 27.10 27.50 27.80	J J J J	5 15 5 20	U,Sm U,Sm U,Sm U,Sm	DS DS DS DS	T T T T	N N N N	
30	6.80	30.0															
	3.00	30.0							SILTSTONE, Reddish brown, very fine grained, moderately weathered, weak, extremely close to close spaced discontinuities								
	2.80								30.45' - 35' Highly Fractured zone 31.2' - 31.7' SILT Seam								
	3.60		R-3	55 92%	5 8%	R2	M										
140	3.80																
35	7.00	35.0															
	2.80	35.0							SILTSTONE, Reddish brown, very fine grained, moderately weathered, weak, extremely close to close spaced discontinuities								
	3.30								Calcareous inclusions throughout. 35' - 38.3' Highly Fractured zone								
	3.20		R-4	46 77%	6 10%	R2	M										
	4.10																
	4.00	40.0															

(Discontinuities: See Legend for Rock Description System)

Water Level Data

Date	Time	Elapsed Time (hr)	Bot. of Casing	Bottom of Hole	Water
6/5/18	8:00	-	8.5	12.0	8.4

Notes:

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 Re... (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	4.00	40.0	R-5	60 100%	11 18%	R2	M		SILTSTONE, Reddish brown, fine grained, moderately weathered, weak, extremely close to close spaced discontinuities Calcareous inclusions throughout 40.55' - 43.9' Highly Fractured zone 44.4' - 45' Highly Fractured zone								
	3.50																
	3.30																
130	3.20																
	10.20	45.0															
-45	3.80	45.0	R-6	60 100%	44 73%	R2	SL		SILTSTONE, Reddish brown with interbedded gray seams, fine grained, slightly weathered, weak, close to moderately spaced discontinuities Calcareous inclusions throughout 45'-45.9' Highly Fractured zone								
	4.20									47.15	J	0	P,Sm	DS	T	N	
	3.20									47.85	J	0	P,Sm	DS	T	N	
	1.80									48.95 49.15	J J	3 0	P,Sm P,R	DS DG	T O	N SD	
	3.20	50.0															
-50	3.60	50.0	R-7	60 100%	39 65%	R3	SL		SILTSTONE, Reddish brown with interbedded gray seams, fine grained, slightly weathered, medium strong, very close to moderately spaced discontinuities Calcareous inclusions throughout Quartzite vugs throughout 51.5' - 51.7' Highly Fractured zone 52.6' - 53' Highly Fractured zone 53.5' - 54.3' Highly Fractured zone	50.80 50.90	J J	0 5	P,Sm P,Sm	DS DS	PO PO	N ML	
	3.80									52.10	J	8	P,Sm	DS	T	N	
	3.80																
120	3.60																
	3.20	55.0															Used approximately 250 gallons of water from 50 to 60 feet BGS.
-55	3.60	55.0	R-8	60 100%	25 42%	R2	M		SILTSTONE, Reddish brown, fine grained, moderately weathered, weak, very close to moderately spaced discontinuities Calcareous inclusions throughout 57.1' - 60' Highly Fractured zone with consistent vertical fractures	56.00	J	0	P,Sm	FR	T	N	
	3.70																
	3.50																
	3.20																
	3.10	60.0															
-60	3.80	60.0	R-9	60 100%	56 93%	R3	SL		SILTSTONE, Reddish brown to gray, very fine grained, slightly weathered, medium strong, close to moderately spaced discontinuities Calcareous inclusions throughout	60.55 60.95 61.30	J J J	5 10 25	U,Sm U,Sm U,R	FR FR DG	T T O	N N N	
	3.60									61.95	J	60	P,Sm	DS	T	N	
	3.60									62.75	J	10	U,Sm	DS	T	N	
110	3.30									64.30	J	40	U,Sm	FR	T	N	
	3.20	65.0															

(See Legend for Rock Description System)

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-38B**

MOTT MACDONALD

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.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	3.30 3.30 3.40 4.00 3.20	65.0 70.0	R-10	58 97%	31 52%	R3	SL	× × ×	SILTSTONE, Reddish brown to gray, very fine grained, slightly weathered, medium strong, very close to moderately spaced discontinuities Calcareous inclusions throughout 67.6' - 69.35' Highly Fractured zone	65.75 66.40 66.55	J J J	35 0 5	P,Sm U,Sm P,R	DS DS DG	PO T O	N N SD	
70	2.90 3.20 2.50 3.00 2.00	70.0 75.0	R-11	60 100%	31 52%	R3	SL	× × ×	SILTSTONE, Reddish brown to gray, very fine grained, slightly weathered, medium strong, very close to moderately spaced discontinuities Calcareous inclusions throughout 70' - 71.3' Highly Fractured zone 73.4' - 73.9' Highly Fractured zone	71.90 72.10	J J	5 10	P,Sm U,Sm	FR FR	T T	N N	
75	3.60 4.20 4.40 3.40 4.00	75.0 80.0	R-12	60 100%	54 90%	R3	FR	× × ×	SILTSTONE, Reddish brown, very fine grained, fresh, medium strong, very close to wide spaced discontinuities Calcareous inclusions throughout	74.70 77.45 78.20	J J J	15 15 0	P,Sm U,Sm U,Sm	FR FR FR	T T T	N N N	
80	3.00 2.80 2.60 2.60 2.60	80.0 85.0	R-13	57 95%	44 73%	R3	SL	× × ×	SILTSTONE, Reddish brown to gray, very fine grained, slightly weathered, medium strong, very close to moderately spaced discontinuities Calcareous inclusions throughout 82.95' - 83.3' Highly Fractured zone 84.1' - 85' Highly Fractured zone	79.45 81.85 82.50	J J J	0 20 45	U,Sm P,R U,R	FR DG DG	T O O	N N N	
85	3.20 3.60 5.40 4.80 5.40	85.0 90.0	R-14	34 57%	8 13%	R3	SL	× × ×	SILTSTONE, Reddish brown, very fine grained, slightly weathered, medium strong, very close to close spaced discontinuities Calcareous inclusions throughout 85.65' - 90' Highly Fractured zone								Tripped hole because the rock core was caught in the outer barrel.

(See Legend for Rock Description System)

OTES:

Depth/ Elev. (ft)	Avg Core Rate (min/ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)
80	3.20 3.00 3.20 3.60 3.30	90.0 95.0	R-15	60 100%	50 83%	R3	FR	SILTSTONE, Reddish brown, very fine grained, fresh, medium strong, very close to moderately spaced discontinuities Calcareous inclusions throughout 92.4' - 92.6' Highly Fractured zone 93.2' - 93.7' Highly Fractured zone
95	3.30 3.40 3.40 3.50 3.30	95.0 100.0	R-16	60 100%	56 93%	R4	FR	SILTSTONE, Reddish brown to gray, very fine grained, fresh, strong, close to wide spaced discontinuities Calcareous inclusions throughout
100 70	3.30 3.40 3.80 3.20 4.30	100.0 105.0	R-17	56 93%	43 72%	R4	M	SILTSTONE, Gray to reddish brown, very fine grained, moderately weathered, strong, extremely close to moderately spaced discontinuities Calcareous inclusions throughout 101.9' - 102.1' Highly Fractured zone 102.55' - 102.75' Highly Fractured zone 103.25' - 103.65' Highly Fractured zone
105	4.40 4.60 5.20 5.00 4.00	105.0 110.0	R-18	59 98%	53 88%	R4	FR	SILTSTONE, Reddish brown, very fine grained, fresh, strong, close to wide spaced discontinuities Calcareous inclusions throughout
110 60	3.80 3.30 3.10 3.00 4.50	110.0 115.0	R-19	59 98%	41 68%	R4	SL	SILTSTONE, Reddish brown, very fine grained, slightly weathered, strong, close to moderately spaced discontinuities Calcareous inclusions throughout 110.3' - 110.6' Vertical Fracture Zone 114.3' - 115' Vertical Fracture Zone 114' - 115' Highly Fractured zone

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
90.50	J	5	U,Sm	FR	T	N	
90.90	J	10	U,Sm	FR	T	N	
91.85	B	0	P,R	DG	PO	SD	
94.60	J	35	P,Sm	FR	T	N	
96.10	J	0	P,Sm	FR	O	N	
96.50	J	0	P,Sm	FR	T	N	
101.50	J	5	P,Sm	FR	T	N	
104.10	J	0	P,Sm	FR	T	N	
105.20	J	0	P,Sm	FR	PO	N	
105.45	J	45	P,Sm	FR	T	N	
108.75	J	0	U,Sm	DS	PO	N	
110.30	J	15	U,Sm	DS	PO	N	
112.85	J	23	U,Sm	DS	PO	N	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-38B**

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)	Remarks
	3.60, 3.00, 2.80, 3.10, 2.40	115.0 – 120.0	R-20	60 100%	40 67%	R4	FR	× × ×	SILTSTONE, Reddish brown, very fine grained, fresh, strong, very close to moderately spaced discontinuities Calcareous inclusions throughout 118.1' - 119.4' Highly Fractured zone	Used approximately 300 gallons of water from 110 to 120 feet BGS.
120 / 50	2.50, 2.80, 2.70, 3.20, 3.10	120.0 – 125.0	R-21	60 100%	56 93%	R4	FR	× × ×	SILTSTONE, Reddish brown, very fine grained, fresh, strong, very close to moderately spaced discontinuities Calcareous inclusions throughout 121.65' - 122' Highly Fractured zone	Lost water return at approximately 122 feet BGS.
125	2.10, 2.10, 2.00, 2.10, 2.20	125.0 – 130.0	R-22	60 100%	45 75%	R4	FR	× × ×	SILTSTONE, Reddish brown, very fine grained, fresh, strong, very close to moderately spaced discontinuities Calcareous inclusions throughout 129' - 129.55' Highly Fractured zone	Rig chatter throughout. Used approximately 200 gallons of water from 125 to 130 feet BGS.
130 / 40	3.00, 5.20, 5.30, 4.60, 4.80	130.0 – 135.0	R-23	60 100%	46 77%	R4	FR	× × ×	SILTSTONE, Reddish brown, very fine grained, fresh, strong, very close to moderately spaced discontinuities Calcareous inclusions throughout 130' - 130.2' Highly Fractured zone 132.3' - 133.4' Highly Fractured zone	Excessive rig chatter throughout. Drilling speed slowed.
135	2.80, 3.20, 3.00, 2.60, 2.60	135.0 – 140.0	R-24	60 100%	43 72%	R4	FR	× × ×	SILTSTONE, Reddish brown to dark gray, very fine grained, fresh, strong, very close to moderately spaced discontinuities Calcareous inclusions throughout 135' - 136.1' Highly Fractured zone	Rig chattering throughout. Used approximately 300 gallons of water from 130 to 140 feet BGS.

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill
116.00	J	30	P,Sm	FR	T	N
116.20	J	23	P,Sm	FR	T	N
116.90	J	18	P,Sm	FR	PO	N
123.00	J	20	U,Sm	FR	PO	N
124.30	J	18	U,Sm	FR	PO	N
125.30	J	35	U,Sm	FR	T	N
125.50	J	10	U,Sm	FR	T	N
126.20	J	5	P,Sm	DS	T	N
127.40	J	0	P,Sm	FR	T	N
127.55	J	5	P,Sm	FR	PO	N
130.80	J	40	P,Sm	FR	T	N
134.05	J	40	P,R	DS	T	QZ
134.35	J	35	P,Sm	DS	T	N
137.00	J	13	U,R	DS	O	N
137.20	J	23	P,Sm	DS	PO	N
137.80	J	45	P,Sm	FR	T	N
138.20	J	45	P,Sm	DS	PO	QZ
138.60	J	35	P,Sm	FR	T	N

NOTES:

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)
30	2.30 2.50 2.50 2.20 3.10	140.0 - 145.0	R-25	60 100%	43 72%	R4	FR	× × ×	SILTSTONE, Dark gray to reddish brown, very fine grained, fresh, strong, very close to moderately spaced discontinuities Calcareous inclusions throughout 141.3' - 141.9' Highly Fractured zone
145	3.60 3.20 3.30 3.10 3.00	145.0 - 150.0	R-26	60 100%	48 80%	R4	FR	× × ×	SILTSTONE, Reddish brown, very fine grained, fresh, strong, very close to moderately spaced discontinuities Calcareous inclusions throughout 145' - 145.75' Highly Fractured zone 146.2' - 146.4' Highly Fractured zone
150 20	2.50 2.60 2.60 2.30 2.00	150.0 - 155.0	R-27	60 100%	42 70%	R4	SL	× × ×	SILTSTONE, Reddish brown to dark gray, very fine grained, slightly weathered, strong, extremely close to moderately spaced discontinuities Calcareous inclusions throughout 152.5' - 152.6' Highly Fractured zone 153.3' - 153.8' Highly Fractured zone 154.2' SILT seam
155	2.50 2.50 2.50 2.50 2.50	155.0 - 160.0	R-28	60 100%	45 75%	R4	FR	× × ×	SILTSTONE, Reddish brown to gray, very fine grained, fresh, strong, close to moderately spaced discontinuities Calcareous inclusions throughout. 155.3' - 155.5' Highly Fractured zone 157.45' - 157.8' Highly Fractured zone
160 10	3.10 3.00 2.80 2.50 2.50	160.0 - 165.0	R-29	60 100%	44 73%	R4	FR	× × ×	SILTSTONE, Reddish brown to dark gray, very fine grained, fresh, strong, very close to moderately spaced discontinuities Calcareous inclusions throughout 161.65' - 162.5' Highly Fractured zone 164.4' - 164.55' Highly Fractured zone

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
140.40	J	54	U,Sm	FR	T	N	
140.70	J	25	U,Sm	DS	O	ML	
142.70	J	60	U,R	FR	T	N	
143.10	J	45	U,R	DS	PO	QZ	
143.80	J	0	U,R	DS	PO	N	
144.70	J	10	P,Sm	FR	T	N	
146.85	J	45	P,Sm	FR	T	N	
147.20	J	33	P,Sm	FR	T	N	
148.25	J	60	P,Sm	FR	T	N	
149.40	J	22	P,Sm	DS	T	N	
150.75	J	5	P,Sm	FR	T	N	
151.05	J	25	P,R	DS	PO	Ca	
154.20	J	0	P,R	DG	O	ML	
154.50	J	35	P,R	DG	O	ML	
156.35	J	0	P,Sm	FR	T	N	
158.15	J	20	P,Sm	FR	T	N	
158.35	J	0	P,Sm	FR	T	N	
159.85	J	30	P,Sm	FR	T	N	Used approximately 300 gallons of water from 160 to 165 feet BGS.
160.30	J	0	P,R	DG	O	N	
163.45	J	3	P,Sm	DS	T	N	

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-38B**

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)	Remarks
	2.80 1.70 2.30 3.00 3.30	165.0 170.0	R-30	60 100%	13 22%	R4	SL		SILTSTONE, Reddish brown, very fine grained, slightly weathered, strong, very close to moderately spaced discontinuities Calcareous inclusions throughout 165' - 165.5' Highly Fractured zone 166' - 166.7' Vertical Fractured 168.7' - 170' Highly Fractured zone	Used approximately 300 gallons of water from 165 to 170 feet BGS.
170 0	2.40 2.40 2.30 2.50 2.40	170.0 175.0	R-31	60 100%	50 83%	R4	FR		SILTSTONE, Reddish brown, very fine grained, fresh, strong, very close to moderately spaced discontinuities Calcareous inclusions throughout	Used approximately 200 gallons of water from 170 to 175 feet BGS.
175	2.40 2.20 2.30 2.30 2.30	175.0 180.0	R-32	60 100%	47 78%	R4	FR		SILTSTONE, Reddish brown, very fine grained, fresh, strong, close to moderately spaced discontinuities Calcareous inclusions throughout 179.25' - 179.3' CLAY Seam	
180 -10	2.80 3.30 3.30 3.00 2.50	180.0 185.0	R-33	60 100%	32 53%	R4	FR		SILTSTONE, Reddish brown to gray, very fine grained, fresh, strong, extremely close to close spaced discontinuities Calcareous inclusions throughout 180.4' - 181.1' Highly Fractured zone 180.7' - 181' CLAY Seam 182.05' - 182.8' Highly Fractured zone 183.5' - 184' Highly Fractured zone	
185	3.00 5.80 6.00 3.20 3.00	185.0 190.0	R-34	60 100%	50 83%	R4	M		SILTSTONE, Reddish brown to gray, very fine grained, moderately weathered, strong, close to moderately spaced discontinuities Calcareous inclusions throughout 187.1 CLAY SEAM with Gravel 188.0 BRECCIA, Black, coarse grained, moderately weathered, strong, moderately spaced discontinuities 190.0	

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill
167.70	J	0	P,Sm	DS	T	N
168.05	J	35	P,Sm	FR	T	N
170.20	J	0	P,Sm	FR	T	N
170.70	J	15	P,Sm	FR	T	N
172.30	J	45	P,Sm	FR	T	N
173.00	J	15	P,Sm	FR	T	N
173.70	J	23	U,R	FR	O	N
174.00	J	0	P,R	DS	O	N
175.35	J	20	U,R	DS	O	N
175.85	J	0	U,R	DS	PO	N
176.75	J	15	U,R	FR	PO	N
177.90	J	55	U,R	FR	PO	N
178.50	J	65	U,R	DS	PO	N
179.00	J	35	U,R	FR	T	N
179.40	J	0	P,R	FR	O	ML
181.50	J	0	P,Sm	FR	PO	N
185.40	J	40	P,Sm	FR	T	N
189.40	J	40	U,R	FR	PO	N

Depth/ Elev. (ft)	Avg Core Rate (min/ft)	Depth (ft)	Run/ (Box) No.	Rec. (in. / %)	RQD (in. / %)	Rock Core Hard.	Rock Core Weath	Visual Identification, Description and Remarks (Rock type, colour, texture, weathering, field strength, discontinuity spacing, optional additional geological observations)	Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
-20	2.00 2.00 2.10 2.00 2.00	190.0 195.0	R-35	60 100%	40 67%	R3	SL	SILTSTONE, Dark gray to gray, coarse to fine grained, slightly weathered, medium strong, extremely close to moderately spaced discontinuities Calcareous inclusions throughout 193.7' - 195' Highly Fractured zone 195.0	190.40 191.50 191.80 192.95	J J J J	45 75 68 0	U,R U,R U,R P,R	DS DS DS DS	PO PO O T	N N N N	
195	2.50 2.00 3.00 3.00 3.50	195.0 200.0	R-36	60 100%	9 15%	R3	SL	SHALE, Dark gray to light gray, very fine grained, slightly weathered, medium strong, extremely close to moderately spaced discontinuities Calcareous inclusions throughout								Used approximately 400 gallons of water from 195 to 200 feet BGS.
200 -30	2.90 2.50 2.60 2.20 2.20	200.0 205.0	R-37	51 85%	18 30%	R3	SL	SHALE, Dark gray, very fine grained, slightly weathered, medium strong, extremely close to close spaced discontinuities Calcareous inclusions throughout 200' - 201' Highly Fractured zone 201.9' - 203' Highly Fractured zone 203.6' - 205' Highly Fractured zone	201.40	J	0	P,Sm	FR	T	N	Used approximately 300 gallons of water from 200 to 205 feet BGS.
205	4.30 3.30 3.50 1.80 2.50	205.0 210.0	R-38	60 100%	45 75%	R4	FR	SHALE, Dark gray to reddish brown, very fine grained, fresh, medium strong, very close to close spaced discontinuities Calcareous inclusions throughout 207.3' - 208.2' Highly Fractured zone	205.65 206.20 206.60 208.60	J J J J	30 35 30 25	P,Sm P,Sm P,Sm P,Sm	DS DS DS DS	T T PO T	N ML ML ML	
210 -40	2.00 2.00 2.00 1.50 1.80	210.0 215.0	R-39	60 100%	45 75%	R4	SL	SHALE, Reddish brown to dark gray, very fine grained, slightly weathered, strong, very close to close spaced discontinuities Calcareous inclusions throughout 210' - 210.2' Highly Fractured zone 212.8' - 213.3' Highly Fractured zone 213.85' - 215' Highly Fractured zone	210.70 211.30 212.10	J J J	20 40 35	P,Sm P,Sm P,Sm	DS DS DS	PO PO O	ML ML ML	

(See Legend for Rock Description System)

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-38B**

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.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	2.00	215.0	R-40	60 100%	32 53%	R4	FR		SHALE, Light gray to reddish brown, very fine grained, fresh, strong, extremely close to close spaced discontinuities Calcareous inclusions throughout 216.4' - 217.55' Highly Fractured zone 218.3' - 220' Highly Fractured zone	215.25 215.85	J J	30 40	P,Sm P,R	DS DS	PO T	Ca Ca	
	2.00																
	2.10																
	2.30																
	3.00	220.0															
220	3.00	220.0	R-41	52 87%	29 48%	R4	SL		SHALE, Light gray, very fine grained, slightly weathered, strong, extremely close to close spaced discontinuities Calcareous inclusions throughout 220' - 220.5' Highly Fractured zone 222.9' - 225' Highly Fractured zone								
	3.00									221.50	J	50	P,Sm	FR	T	N	
	3.50									222.25	J	0	P,R	DS	T	Ca	
-50	3.00																
	3.00	225.0							225.0								
225	3.00	225.0	R-42	60 100%	16 27%	R4	SL		SILTSTONE, Light gray, very fine grained, slightly weathered, strong, extremely close to moderately spaced discontinuities Calcareous inclusions throughout 225.7' - 228.65' Highly Fractured zone 229.3' - 230' Highly Fractured zone								
	2.00																
	2.20																
	1.60																
	1.70	230.0															
230	4.00	230.0	R-43	30 50%	4 7%	R4	M		SILTSTONE, Light gray, very fine grained, moderately weathered, strong, extremely close to close spaced discontinuities Calcareous inclusions throughout 230.4' CLAY seam								
	4.20																
	4.40																
-60	3.80																
	4.00	235.0															
235	2.40	235.0	R-44	60 100%	33 55%	R4	SL		SILTSTONE, Gray to reddish brown, very fine grained, slightly weathered, strong, extremely close to moderately spaced discontinuities Calcareous inclusions throughout 235.5' - 237.15' Highly Fractured zone								
	2.10																
	2.00									237.85	J	5	P,Sm	DS	PO	N	
	2.00									238.60 238.90	J J	35 0	U,Sm U,Sm	DS DS	PO T	N N	
	2.00	240.0															

(See Legend for Rock Description System)

NOTES:

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)	Remarks
	2.00	240.0							SILTSTONE, Reddish brown to light gray, very fine grained, moderately weathered, strong, extremely close to moderately spaced discontinuities	
	2.00								Calcareous inclusions throughout	
	2.00		R-45	50 83%	20 33%	R4	M		240.7' - 242.25' Highly Fractured zone	
-70	2.00								243.3' - 245' Highly Fractured zone	
	2.50	245.0							243.6' Silty SAND seam	
245	2.50	245.0							SILTSTONE, Reddish brown, very fine grained, moderately weathered, strong, extremely close to close spaced discontinuities	
	2.50								Calcareous inclusions throughout	
	3.00		R-46	42 70%	6 10%	R4	M		246' - 250' Highly Fractured zone	
	3.00								245' - 245.2' CLAY seam	
	5.50	250.0								
250	2.00	250.0							SILTSTONE, Reddish brown to gray, very fine grained, fresh, strong, close to moderately spaced discontinuities	
	2.00								Calcareous inclusions throughout	
	2.00		R-47	60 100%	47 78%	R4	FR		253.55' - 253.65' CLAY seam	
-80	1.80									
	1.60	255.0							255.0	
255	1.60	255.0							SHALE, Gray to dark gray, very fine grained, fresh, medium strong, extremely close to close spaced discontinuities	
	1.80								Calcareous inclusions throughout	
	2.00		R-48	60 100%	20 33%	R3	FR		255' - 255.2' Highly Fractured zone	
	1.50								256.4' - 260' Highly Fractured zone	
	1.50	260.0								
260	3.00	260.0							SHALE, Gray to dark gray, very fine grained, fresh, medium strong, extremely close to moderately spaced discontinuities	
	3.50								260' - 261' Highly Fractured zone	
	3.20		R-49	60 100%	38 63%	R3	FR		264.7' - 265' Highly Fractured zone	
-90	3.20									
	3.20	265.0								

Discontinuities (See Legend for Rock Description System)

Depth (ft.)	Type	Dip	Rgh	Wea	Aper	Infill
251.60	J	10	P,Sm	FR	T	N
252.30	J	20	P,Sm	FR	T	N
253.25	J	15	P,Sm	FR	PO	N
254.30	J	0	P,R	DG	O	ML
254.70	J	0	P,R	DS	PO	N
255.95	J	20	P,R	DG	O	N
261.45	J	0	P,Sm	FR	PO	N
262.30	J	20	P,Sm	FR	T	N
262.80	J	58	P,Sm	DS	T	N
263.15	J	45	P,Sm	DS	T	N
263.80	J	0	P,Sm	DS	O	N

NOTES:

PROJECT NO.: **353754**

Boring No.: **B-38B**

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.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	5.00 5.00 4.00 3.50 4.00	265.0 270.0	R-50	60 100%	43 72%	R5	FR		SHALE, Gray to reddish brown, very fine grained, fresh, very strong, extremely close to moderately spaced discontinuities 265'-265.25' Highly Fractured zone 269' - 269.1' CLAY seam 269.35' - 269.45' CLAY seam 269.8' - 270' Highly Fractured zone	267.40 267.65 267.90 268.80	J J J J	0 65 45 15	P,Sm P,Sm P,Sm P,Sm	FR FR FR DS	T T T T	N N N CL	Rig chattering throughout.
270 -100	4.00 4.20 3.60 4.00 4.00	270.0 275.0	R-51	60 100%	44 73%	R5	FR		SHALE, Reddish brown to dark gray, very fine grained, fresh, very strong, close to moderately spaced discontinuities Calcareous inclusions throughout 272.2' - 272.4' CLAY seam 273.7' - 274.55' Highly Fractured zone	270.50 271.60 271.75 273.10	J J J J	0 0 5 30	P,Sm P,Sm P,R P,Sm	FR FR DS FR	T T PO T	N N CL CL	
275	3.00 2.50 2.50 2.00 2.00	275.0 280.0	R-52	60 100%	43 72%	R5	FR		SHALE, Reddish brown to gray, very fine grained, fresh, very strong, extremely close to moderately spaced discontinuities Calcareous inclusions throughout 277.1' - 277.25' CLAY seam 278.1' - 279.5' Highly Fractured zone	275.50 275.95	J J	0 20	P,Sm P,Sm	FR DS	PO T	N Ca	
280 -110	2.40 2.40 2.50 2.40 2.40	280.0 285.0	R-53	60 100%	33 55%	R5	FR		SHALE, Gray to dark gray, very fine grained, fresh, very strong, very close to moderately spaced discontinuities Calcareous inclusions throughout 281.7' - 282.1' Highly Fractured zone 283.3' - 285' Highly Fractured zone	280.95 282.65	J J	0 0	P,R P,Sm	DS FR	PO T	CL CL	
285	2.00 2.00 2.00 2.00 2.00	285.0 290.0	R-54	60 100%	29 48%	R5	FR		SHALE, Gray to dark gray, very fine grained, fresh, very strong, very close to moderately spaced discontinuities Calcareous inclusion throughout 286.45' - 287.3' Highly Fractured zone 288.1' - 288.8' Highly Fractured zone 289.4' - 290' Highly Fractured zone	286.00	J	28	P,Sm	FR	T	N	

(See Legend for Rock Description System)

NOTES:

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.)	Type	Dip	Rgh	Wea	Aper	Infill	Remarks
	2.20	290.0							SHALE, Light gray to dark gray, very fine grained, fresh, very strong, very close to moderately spaced discontinuities 290' - 291.95' Highly Fractured zone								
	2.20																
	2.30		R-55	60 100%	26 43%	R5	FR			292.35	J	5	P,Sm	FR	T	CL	
										292.65	J	0	P,R	FR	T	N	
-120	2.10									293.15	J	25	P,Sm	FR	T	N	
										293.30	J	15	P,Sm	FR	T	CL	
										293.90	J	10	P,Sm	FR	T	CL	
	2.10	295.0								294.15	J	3	P,Sm	DS	PO	N	
295	1.60	295.0							SHALE, Light gray to dark gray, very fine grained, fresh, very strong, close to moderately spaced discontinuities	295.20	J	15	P,Sm	FR	PO	N	
	1.80									296.40	J	25	P,R	DS	T	N	
	1.80		R-56	60 100%	57 95%	R5	FR										
	1.60									298.20	J	30	P,R	FR	T	Py	
	1.60	300.0							300.0	299.40	J	40	P,R	DS	O	Ca	
300									End of Boring at 300 feet BGS. Borehole grouted with cement and bentonite holeplug.								
-130																	
305																	
310																	
-140																	

(See Legend for Rock Description System)

NOTES:

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Boring No.: **B-38B**

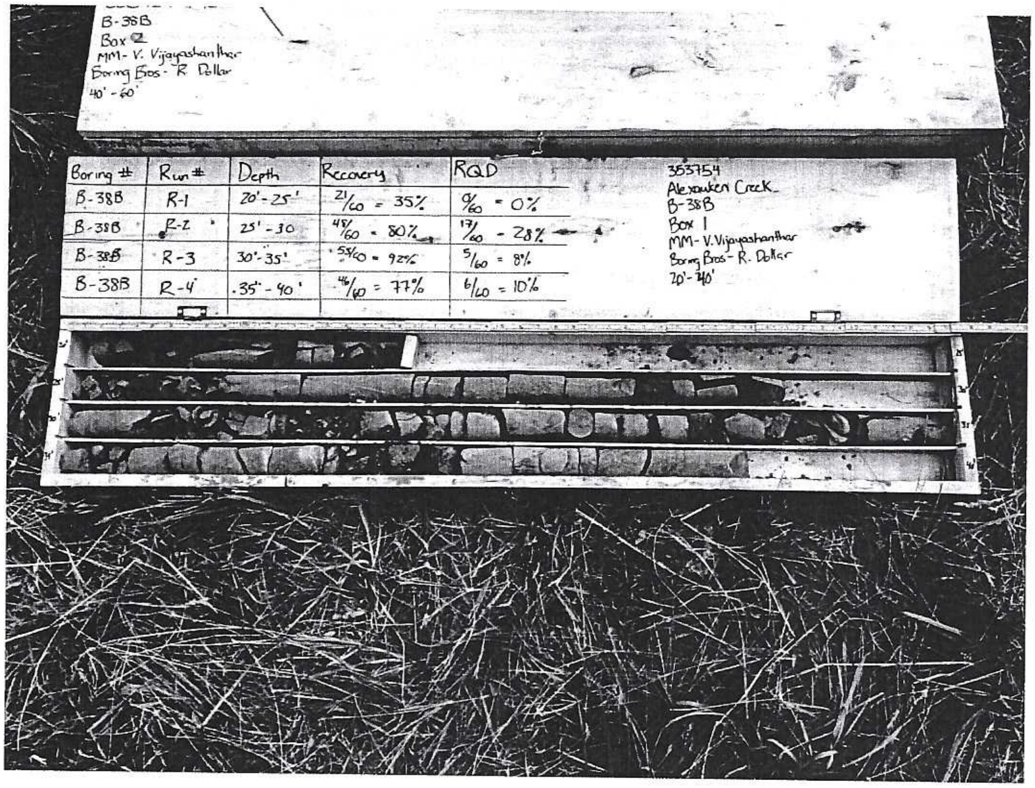

Figure B-38B.1
B-38B Box 1 Runs 1-4 Dry

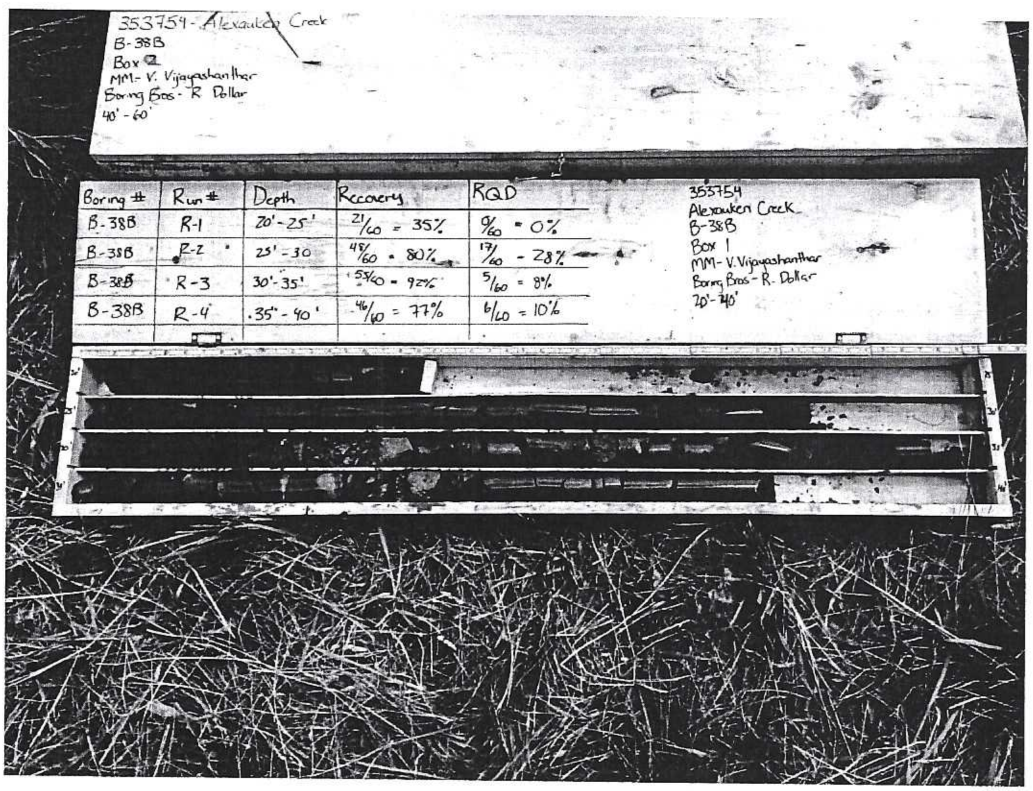

Figure B-38B.2
B-38B Box 1 Runs 1-4 Wet

MOTT MACDONALD	**PennEast Pipeline Project** **Rock Core Photographs**	**BORING NO.:** B-38B