EARTH ENGINEERING INCORPORATED
*Geotechnical Engineers & Geologists*

July 2, 2021
EEI Project No. 31585.00

Mr. Edward J. Weirsky, Jr.
STV Energy Services, Inc.
205 West Welsh Drive
Douglassville, PA  19518

*Phone:* *610.385.8390*
*Email:* *edward.weirsky@stvinc.com*

**RE: Response to Questions**
**Twin Oaks to Newark 14 Inch Pipeline**
**Jacobs Creek HDD Pipeline Relocation**
**Upper Makefield Township, PA**
**Hopewell Township, NJ**

Dear Mr. Weirsky:

Earth Engineering Incorporated (EEI) reviewed the questions by STV Energy Services Inc. for the above referenced project. The Questions were issued to EEI on June 24th, 2021. Based on our review of these questions, the following serves as our response to each of the specific questions:

Question #2

> "Also, regarding the Report of Geotechnical Investigation prepared by Earth Engineering Inc, dated January 7, 2020 ("Geotechnical Report"). Boring logs in the report indicate that that an additional bed of red siltstone was encountered between 57 feet and 80.5 feet in boring SB-4. The red siltstone was not encountered in borings SB-1 or SB-2. Based on the Geologic Map of Central and Southern New Jersey (1998), the 3 borings appear to be aligned generally along strike and therefore should show a similar lithology. The same map shows numerous faults in the area. Please provide additional information regarding the correlation of the strata encountered in the borings and discuss the possibility of a fault or other structure located between borings SB-3 and SB-4. Please also assess the need to further characterize the lithology between borings SB-3 and SB-4 with additional boring(s)."

**EEI Response**

After further review of the rock cores from the field and the referenced geologic map: we believe that the red siltstone encountered in SB-4 is sub-unit which is part of the Lockatong Formation($T_R$l). The Newark Quadrangle geologic map (Geologic Map of the Newark Quadrangle, New Jersey, Pennsylvania, and New York 1987) shows that the Upper Triassic age gray and black siltstone and shale of the Lockatong Formation ($T_R$l), contains interbedded, ($T_R$l) reddish-brown, sandy siltstone in units ($T_R$lr).

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Our review of the rock cores indicates that this dark reddish-brown siltstone encountered in SB-4 from approximately 57 and 80.5 feet deep is an interbedded layer ($T_R$lr). It is noted at the base of this layer the rock returns to the more typical argillite of the Lockatong formation ($T_R$l).

We have also reviewed the *Bedrock Geologic Map of Central and Southern New Jersey* (1998) and agree that a fault is located in the vicinity of the site, specifically a fault is mapped approximately 0.5 miles to the east of SB-4. EEI did not observe evidence of faulting (ie scour, breccia, or slicken-lines) within the rock cores. It is our opinion that the siltstone encountered at boring SB-4 is consistent with the geologic literature and not associate with the presence of a fault.

Consequently, we feel that the 3 borings conducted should provide sufficient geologic information to the perspective directional drilling contractors and no additional borings are needed.

Topographic and Geologic Map Plates of the site location, map unit descriptions and photos of the rock cores are attached to this report for reference.

Question #4

> "The boring logs in the Geotechnical Report contain information on the relative dip. In each note 2 dip angles are provided. Please describe what the 2 dip angles represent."

**EEI Response:**

The two dip angles are representative of relative bedding dip of the formation bedding and relative dip of the fractures encountered. The Bedding dip ranges from 5-10 degrees and the natural fracture dip is steeper between 70-75 degrees.

Question #5

> "The Geotechnical report describes the shale bedrock as having extremely close spaced fractures, laminated and medium hard to very hard. The rock was additionally characterized to be broken to massive with degrees of weathering ranging from highly weathered to fresh. Information in the HDD Drill Analysis Report, prepared by STV, dated January 2021 indicated that the rock cores taken from the geotechnical borings on site show very little to no fracturing. Please provide more information on the frequency and nature of the fractures/joints encountered at the site"

**EEI Response:**

The rock core samples recovered from the field investigation were examined and visually classified by EEI utilizing NAVFAC DM 7.01 Section 5 in the field. The natural fracturing observed was generally filled with calcite and quartz. With few portions where the fractures are open. Also, the cores show breaks in the rock that are perpendicular (across/low angle 5 - 10 degrees). These are mostly mechanical fracture/breaks caused by drilling. These breaks tend to happen along bedding planes. A copy of NAVFAC DM 7.01 Section 5 is attached to this report for reference.

Question #6

"The Geotechnical Report indicated that slightly weathered to fresh bedrock of fair to excellent quality encountered in borings SB-1, SB-3 and SB-4 is characterized as "Difficulties May Occur" per the referenced publication. Please describe what difficulties may occur and what Sunoco plans to avoid or minimize these difficulties."

**EEI Response:**

Our Geotechnical report references a table found in *Standard Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduct Under Obstacles, Including River Crossings* (ASTM F1962-11). The referenced table indicates the "Difficulties May Occur" for Horizontal Directional Drilling in slightly weathered to unweathered rocks. This table in ASTM F1962-11 is referenced from a report entitled, *Site Investigation Requirements for Large Diameter HDD Projects (Hair, C.W. III, 1995).* The aforementioned report states:

> Softer and/or partially weathered lithified materials offer HDD performance akin to that of hard strength clay. If in a solid state, boring technology – although time consuming and expensive – is available to drill through more competent rock, especially in the weaker horizontal plane.

Accordingly, as per the referenced ASTM standard the rock encountered should be classified as "Difficulties May Occur". What type of difficulties and preventative and/or corrective measures should be evaluated by the perspective HDD contractors. A copy of ASTM F1962-11 referenced table is attached to this report.

We trust this is the information is responsive to your request for additional information require. If you have any questions, please contact our office.

Sincerely,
***Earth Engineering Incorporated***

David M Rude, P.G.
Project Manager/Senior Geologist

Patrick McNamara, P.E.
Director - Geotechnical Investigations

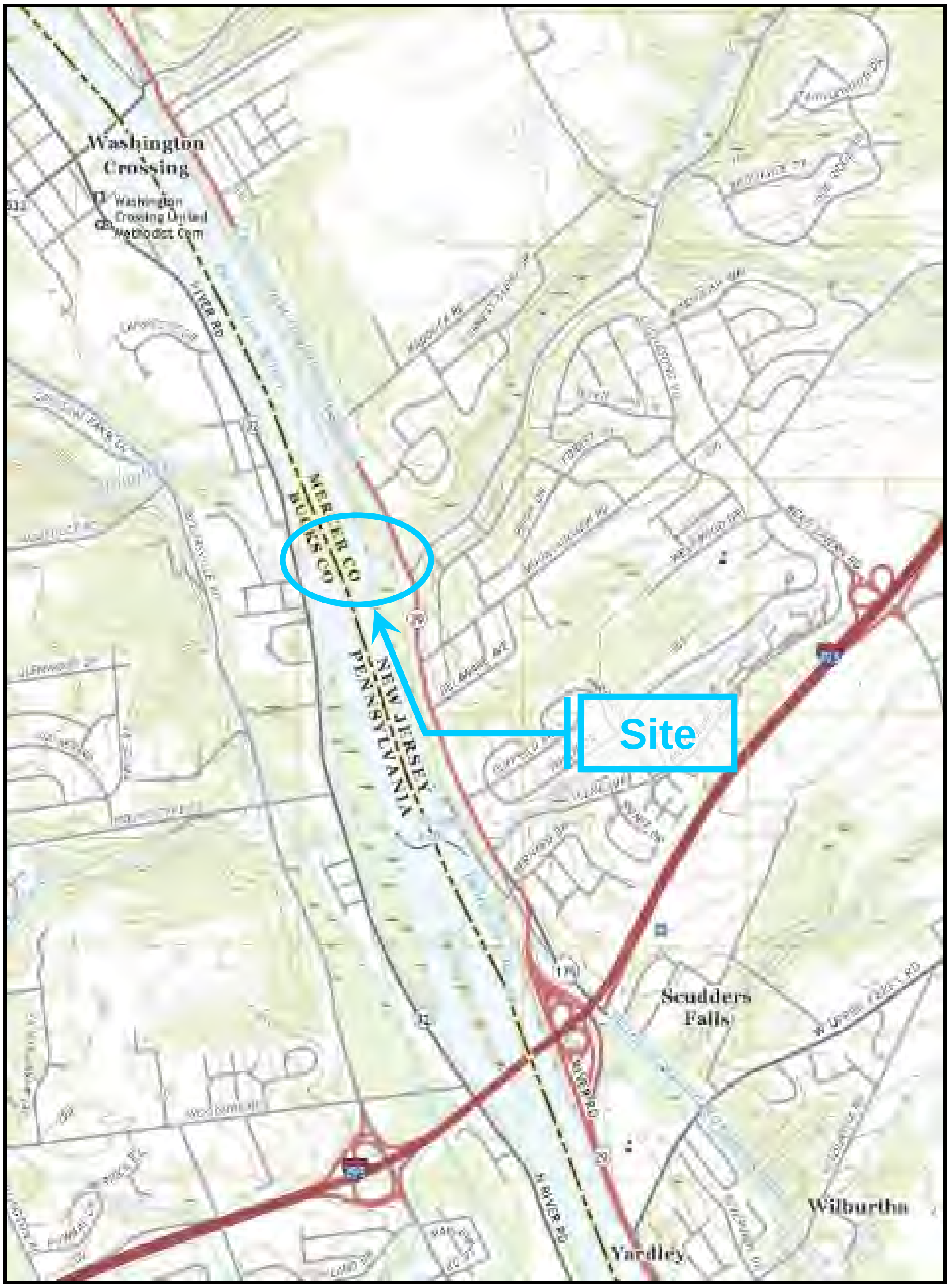



**PLATE 1 – TOPOGRAPHIC MAP OF SITE**

Reprinted from the United States Geological Survey, Topographic Maps of Pennsylvania and New Jersey, Pennington, NJ Quadrangle, Photorevised 2019.

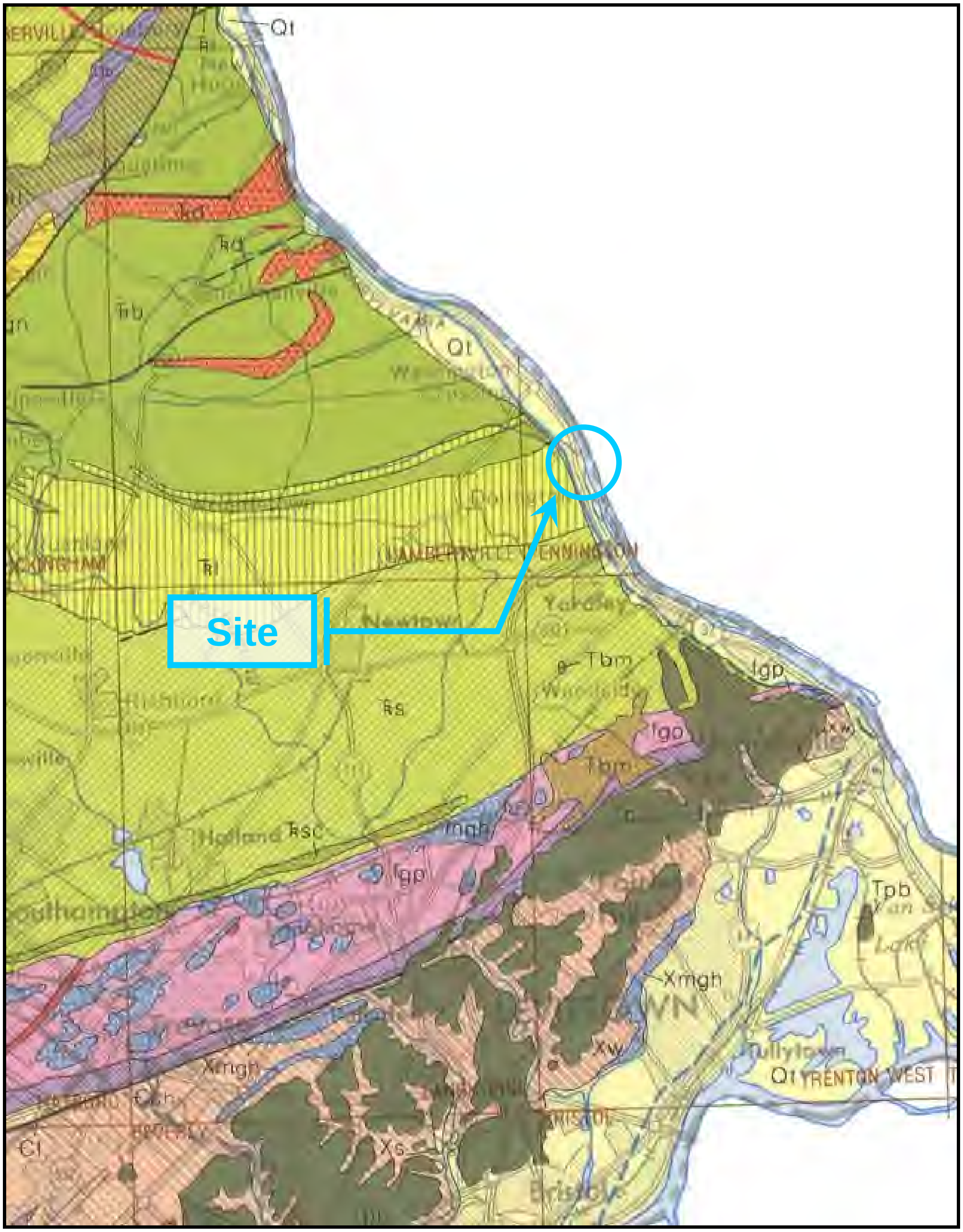



**PLATE 2 - GEOLOGIC MAP OF SITE**

Reprinted from the Pennsylvania Geological Survey, Geologic Map of Pennsylvania,1980.

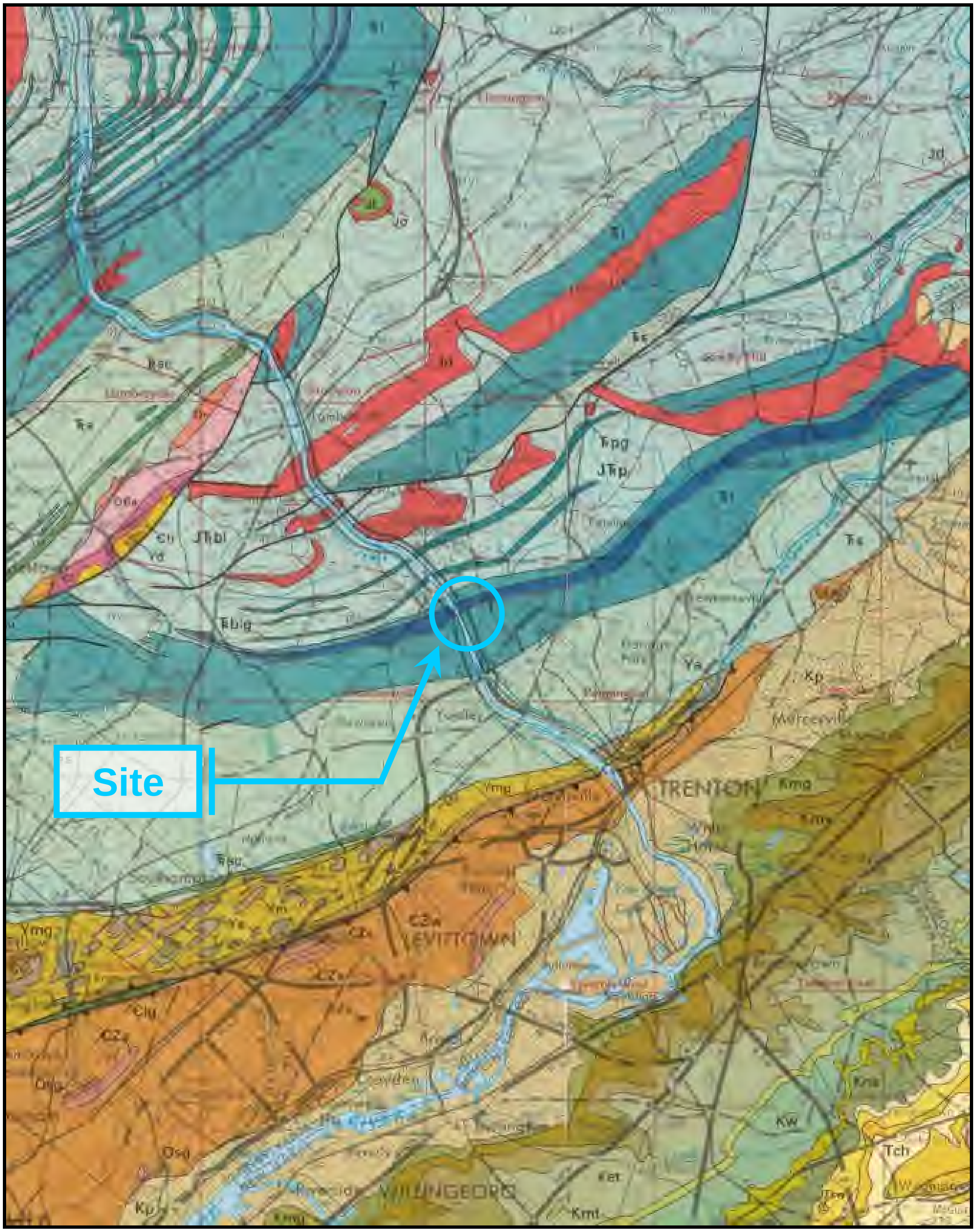



**PLATE 3 - GEOLOGIC MAP OF SITE**

Reprinted from the U.S. Geological Survey, Geologic Map of the Newark Quadrangle, New Jersey, Pennsylvania and New York ,1987.

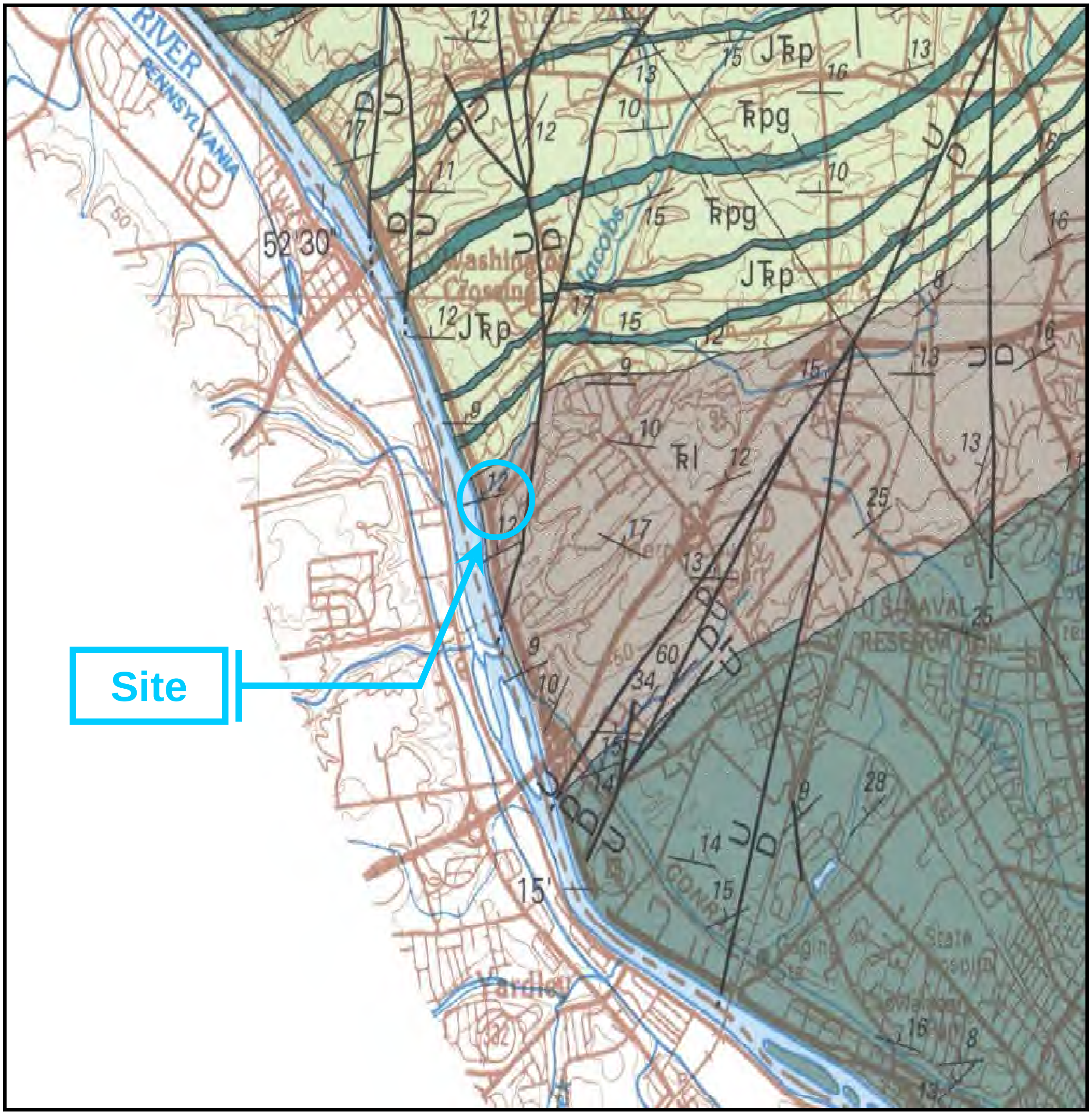



**PLATE 4 - GEOLOGIC MAP OF SITE**

Reprinted from the U.S. Geological Survey, Bedrock Geologic Map Of Central and Southern New Jersey 1998.

**Lockatong Formation (Upper Triassic)**—Predominantly laminated to thick-bedded gray and black siltstone and shale, rich in fossils, including plants, reptiles, fish, and diagnostic spores and pollen. Unit composed of alternating detrital and chemical-lacustrine cycles. *Detrital cycles*: lower part laminated, medium-dark-gray to black, calcareous, pyritic siltstone and shale overlain by platy to massive, disrupted (mudcracked and burrowed) dark-gray, calcareous siltstone, ripple-bedded siltstone, and fine-grained sandstone; more common in the lower Lockatong. Averages about 5.2 m (17.1 ft) in thickness. *Chemical cycles*: Lower part platy, medium-dark-gray to black, dolomitic siltstone and marlstone with shrinkage cracks and lenses of pyritic limestone, overlain by massive, gray or red, analcime- and carbonate-rich, disrupted siltstone. Average thickness about 3.2 m (10.5 ft). Lower contact of Lockatong gradational, placed at base of lowest continuous black siltstone bed. Contains interbedded, reddish-brown, sandy siltstone in units from about 3 to 82 m (10 to 270 ft) thick (TRlr). Interfingers laterally with and gradationally into the underlying Stockton Formation (TRs) as well as up into the Passaic Formation (JTRp) and lower part of the Brunswick Group (JTRb). Wedges out between the Stockton (TRs) and Hammer Creek (TRh) Formations west of the Schuylkill River. Maximum thickness about 1,180 m (3,871 ft).

**PLATE 3 - GEOLOGIC DESCRIPTION**

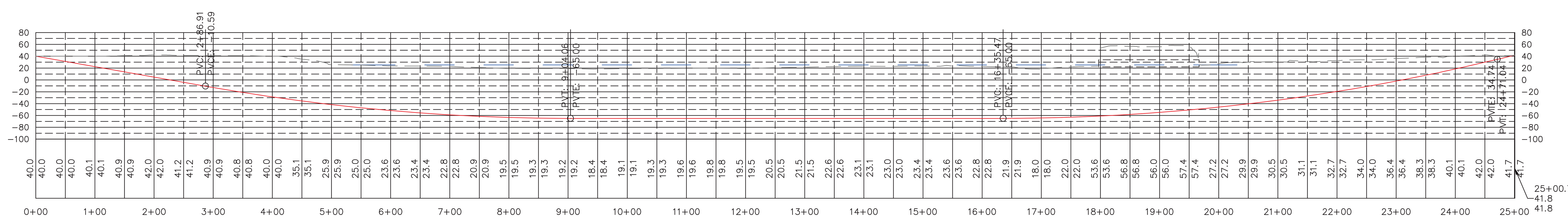
Description reprinted from the U.S. Geological Survey, Geologic Map of the Newark Quadrangle, New Jersey, Pennsylvania and New York ,1987.

| |
|---|
| TRl |
| TRlr |
| TRla |
| TRls |
| TRlcq |

**Lockatong Formation (Upper Triassic) (Kümmel, 1897)**—Cyclically deposited sequences consisting of light- to dark-gray, greenish-gray, and black, dolomitic or analcime-bearing silty argillite, laminated mudstone, silty to calcareous, argillaceous, very fine grained pyritic sandstone and siltstone, and minor silty limestone (**TRl**). Grayish-red, grayish-purple, and dark-brownish-red sequences (**TRlr**) common in upper half. Two types of cycles are recognized: detrital and chemical. Detrital cycles average 5.2 m (17 ft) thick and consist of basal, argillaceous, very fine grained sandstone to coarse siltstone; medial, dark-gray to black, laminated siltstone, silty mudstone, or silty limestone; and upper, light- to dark-gray, silty to dolomitic or analcime-rich mudstone, argillitic siltstone, or very fine grained sandstone. Chemical cycles are similar to detrital cycles, but thinner, averaging 3.2 m (10.5 ft). Cycles in northern Newark basin are thinner and have arkosic sandstone in lower and upper parts. Upper part of formation in northern basin composed mostly of light-gray to light-pinkish-gray or light-brown, coarse- to fine-grained, thick- to massive-bedded arkosic sandstone (**TRla**) . Thermally metamorphosed into hornfels where intruded by diabase (**Jd**). Interfingers laterally and gradationally with quartz sandstone and conglomerate (**TRls**) and quartzite conglomerate (**TRlcq**) near Triassic border fault in southwestern area of map. Maximum thickness of Lockatong Formation about 1,070 m (3,510 ft)

**PLATE 4 - GEOLOGIC DESCRIPTION**

Description reprinted from the U.S. Geological Survey, Bedrock Geologic Map Of Central and Southern New Jersey, 1998 & Bedrock Geologic Map of Northern New Jersey, 1996


LEGEND:

- EXISTING SXL PIPELINE
- PROPOSED SXL PIPELINE
- EXISTING PIPELINE RIGHT-OF-WAY
- PROPERTY LINE
- EDGE OF WATER
- EXISTING FENCE
- EXISTING TREE LINE
- POLITICAL BOUNDARY
- 100 YEAR FLOODPLAIN
- FLOODWAY
- EXISTING WETLAND (STV DELINIATED)
- EXISTING WETLAND (NWI)
- SOIL BORING

PROFILE LEGEND:

- PROPOSED PIPELINE
- EXISTING GRADE
- EXISTING GRADE ELEV
- PROPOSED TOP OF PIPE ELEV

825.2
821.3

| NOAA DELAWARE RIVER AT WASHINGTON CROSSING GAUGE ELEVATION CHART | | |
|---|---|---|
| DATUM | GAUGE ELEVATION | FLOOD STAGE ELEVATION |
| NAVD88 | 25.18' | 41.175 |

KEY:

APPROXIMATE BORING LOCATION

BASE PLAN PROVIDED BY: STV ENERGY SERVICES, INC.

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Geotechnical Engineers & Geologists
115 W Germantown Pike
East Norriton, PA 19401
(610)277-0880
FAX (610)277-0878
www.earthengineering.com

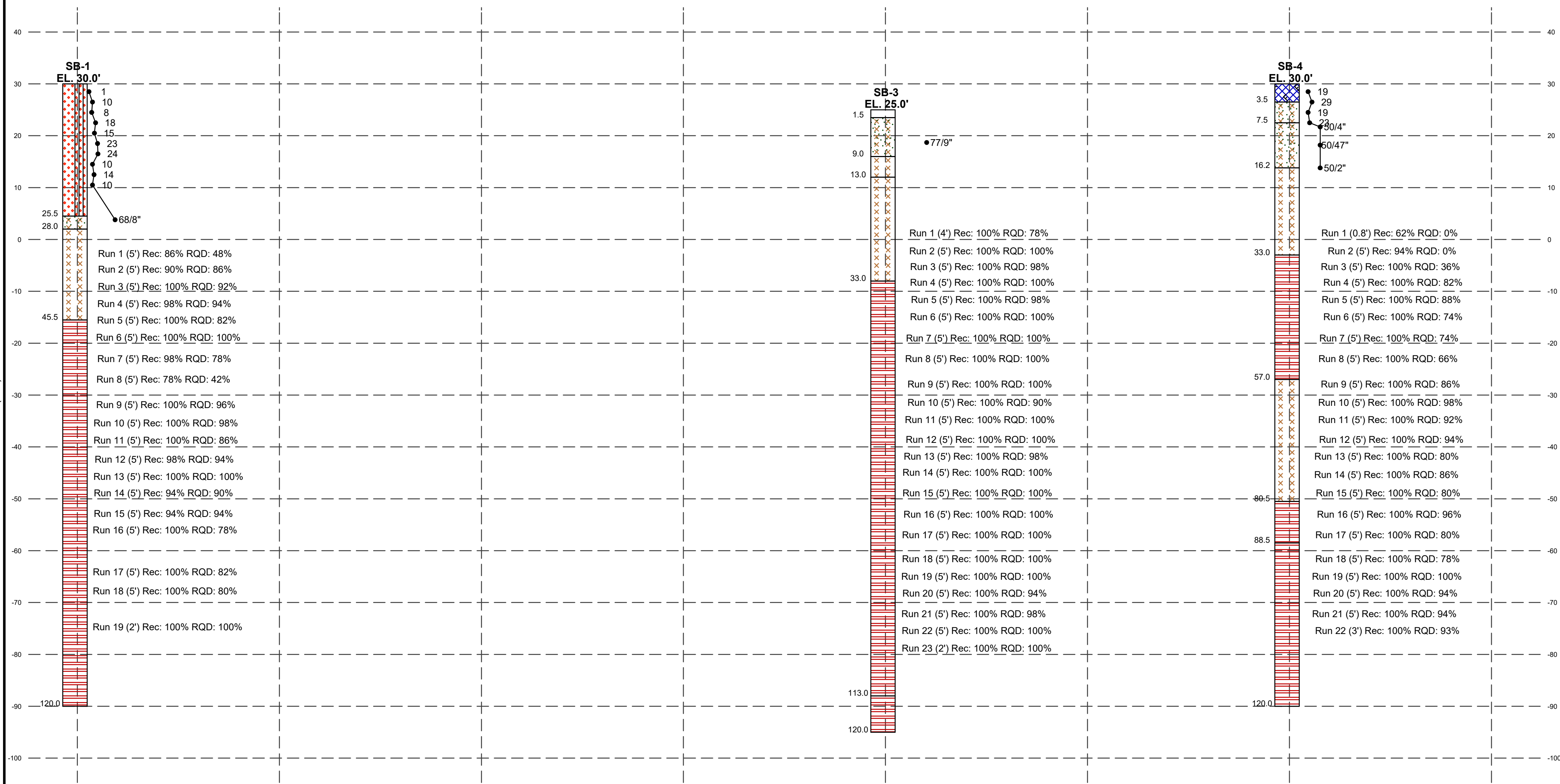
# TESTING LOCATION PLAN

PREPARED FOR

## STV JACOBS CREEK RELOCATION HDD

HOPEWELL & EWING TOWNSHIP NEW JERSEY – UPPER MAKEFIELD TOWNSHIP PENNSYLVANIA

| Scale: | Date: | Drawn By: | Checked By: |
|---|---|---|---|
| AS SHOWN | 12/31/2019 | JRK | JMC |
| Drawing Number: 31585.00-D-101 | | Approved By: PMM | |




**Lithology Graphics**

- Stratum I - fine to coarse SAND trace GRAVEL, COBBLES and BOULDERS
- Stratum II - Silty SAND to Silty GRAVEL trace to some COBBLES and BOULDERS (Decomposed to Weathered Siltstone)
- Siltstone Bedrock
- Shale Bedrock
- FILL - Silty fine SAND trace GRAVEL, STONE and BRICK

- Initial Groundwater Level
- Subsequent Groundwater Level

EARTH ENGINEERING INCORPORATED
*Geotechnical Engineers & Geologists*

**BORING PROFILES**
**PREPARED FOR**
**STV - JACOBS CREEK HDD**
UPPER MAKEFIELD TOWNSHIP, BUCKS COUNTY, PENNSYLVANIA

| Project Number: 31585.00 | Date: 12/31/19 | Check: P. McNamara |
|---|---|---|

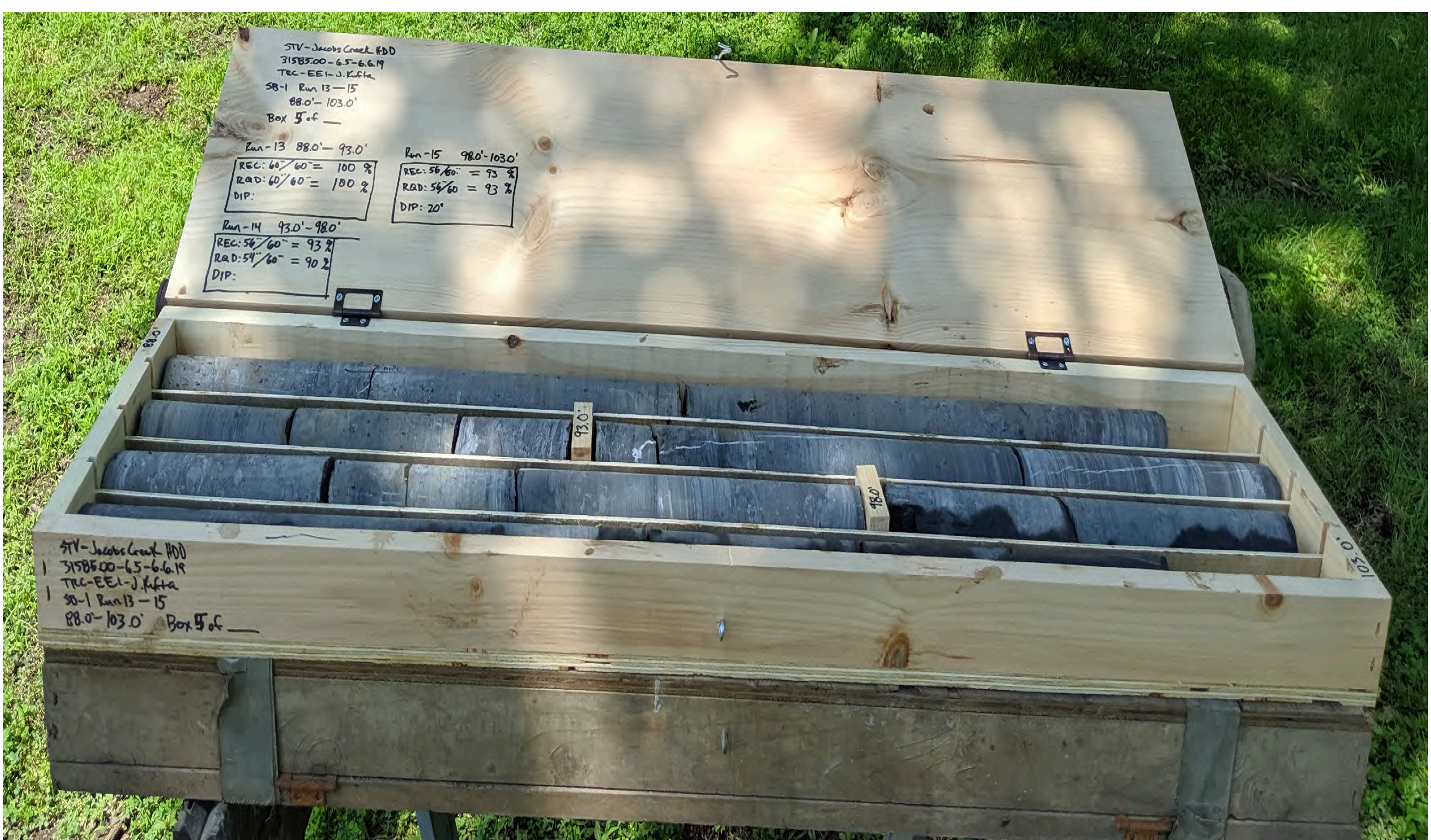

STV-Jacobs Creek HDD
31585.00-6.5.19
TRC-EEI-J.Kufta
SB-1 Run 1-
28.0'-43.0'
Box 1 of
Run 1 28.0'-33.0'
Run 2 33.0'-38.0'
Run 3 38.0'-43.0'
28.0'
33.0'
38.0'
43.0


STV-Jacobs Creek HDD
31585.00-6.5.19
TRC-EEI-J.Kufta
SB-1 Run 4-
43.0'-
Box 2 of
Run 4 43.0'-48.0'
Run 5 48.0'-53.0'
Run 6 53.0'-58.0'
43.0'
48.0'
53.0'
58.0'


STV-Jacobs Creek HDD
31585.00-6.5.19
TRC-EE1-J.Kufta
SB-1 Run 4-6
43.0'-58.0'
Box 2 of ___
Run 4 43.0'-48.0'
REC: 58"/60" = 97%
RQD: 56"/60" = 93%
DIP: 75° to 90°
Run 5 48.0'-53.0'
REC: 60/60" ⇒ 100%
RQD: 49"/60" ⇒ 82%
DIP: 75°
Run 5 53.0'-58.0'
REC: 60/60 ⇒ 100%
RQD: 60/60 ⇒ 100%
DIP: 65°
43.0'
48.0'
53.0'
58.0'


STV-Jacobs Creek HDD
31585.00-6.5-6.6.19
TRC-EE1-J.Kufta
SB-1 Run 7-9
58.0'-73.0'
Box 3 of ___
Run 7 58.0'-63.0'
REC: 58"/60" = 97%
RQD: 47"/60" = 78%
DIP: 15°
Run 8 63.0'-68.0'
REC: 46"/60" = 77%
RQD: 25"/60" = 42%
DIP
Run 9 68.0'-73.0'
REC: 60"/60" = 100%
RQD: 57"/60" = 95%
DIP:
58.0'
63.0'
68.0'
73.0'


STV-Jacobs Creek HDD
31585.00-6.5-6.6.19
TRC-EE1-J.Kufta
SB-1 Run 10-12
73.0'-88.0'
Box 4 of
Run 10 73.0'-78.0'
REC: 60"/60" = 100 %
RQD: 58"/60" = 97 %
DIP:
Run 11 78.0'-83.0'
REC: 60"/60" = 100%
RQD: 51/60" = 85%
DIP: 15°
Run 12 83.0'-88.0"
REC: 58"/60" = 97 %
RQD: 55"/60" = 92 %
DIP:
78.0
83.0


STV-Jacobs Creek HDD
31585.00-6.5-6.6.19
TRC-EE1-J.Kufta
SB-1 Run 13-15
88.0'-103.0'
Box 5 of
Run-13 88.0'-93.0'
REC: 60"/60" = 100 %
RQD: 60"/60" = 100 %
DIP:
Run-14 93.0'-98.0'
REC: 56"/60" = 93 %
RQD: 54"/60" = 90 %
DIP:
Run-15 98.0'-103.0'
REC: 56/60" = 93 %
RQD: 56"/60 = 93 %
DIP: 20°
93.0
98.0
103.0'


STV-Jacobs Creek HDD
31585.00-6.5-6.6.19
TRC-EE1-J.Kufta
SB-1 Run 16 — 18
103.0'—118.0'
Run-16 103.0'—108.0'
REC: 60"/60" = 100%
RQD: 47"/60" = 78%
DIP
Run 17 108.0'—113.0'
REC: 60"/60" = 100%
RQD: 49"/60" = 82 %
DIP 75°
Run 18 113.0'-
REC: 60"/60" = 100%
RQD: 48"/60" = 80%
DIP:
103.0'
108.0'
113.0'
118.0'
STV-Jacobs Creek HDD
31585.00-6.5-6.6.19
TRC-EE1-J.Kufta
SB-1 Run 16-18
103.0'-118.0' Box 6 of 7


STV-Jacobs Creek HDD
31585.00-6.5-6.6.19
TRC-EE1-J.Kufta
SB-1 Run 19
118.0'-120.0'
Box 7 of 7
Run 19 118.0'-120.0'
REC: 24"/24" = 100%
RQD: 24"/24" = 100%
DIP:
118.0'
120.0'
STV-Jacobs Creek HDD
31585.00-6.5-6.6.19
TRC-EE1-J.Kufta
SB-1 Run 19 118.0'-120.0'
Box 7 of 7

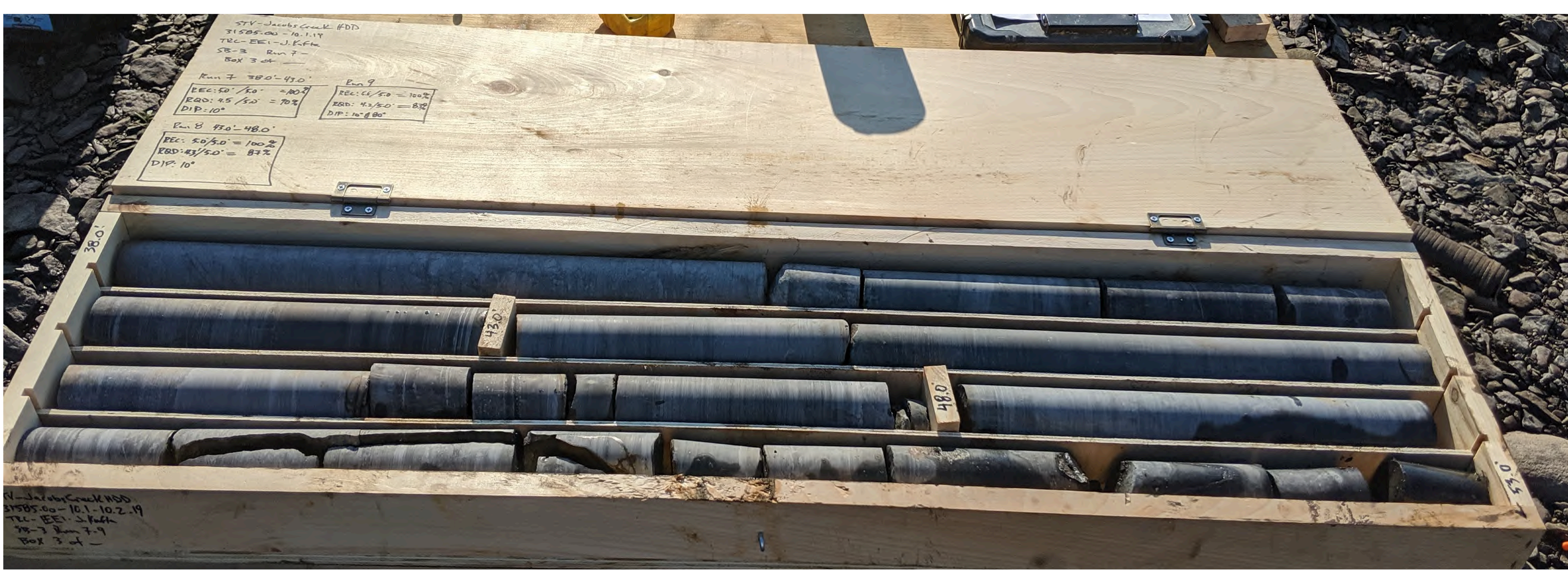

STV- Jacobs Creek-HDD
31585.00 - 8.13.19
TRC-EEI-J.Kufta
SB-4
Run 1-4
16.2' - 32.0'
Box 1 of
Run 1 16.2'-17.0'
REC: 0.5/0.8 63 %
RQD 0.0/0.8 0%
DIP:
Run 2 17.0'-22.0'
REC: 4.7/5.0 95 %
RQD: 0/5.0' 0 %
DIP
Run 3 22.0'-27.0'
REC: 5.0/5.0 100%
RQD: 1.8/5.0 35 %
DIP:
Run 4 27.0'-32.0
REC: 5.0'/5.0 100 %
RQD: 4.1/5.0 82 %
DIP
16.2
17.0'
22.0'
27.0'
32.0'


STV- Jacobs Creek HDD
31585.00 - 8.13.19
TRC-EEI-J-Kufta
SB-4 Run 8-10
47.0'-62.0'
Box 3 of
Run 8 47.0'-52.0'
REC: 5.0'/5.0' 100 %
RQD: 3.3/5.0' 73 %
DIP
Run 9 52.0'-57.0'
REC: 5.0/5.0 100 %
RQD: 4.3/5.0' 87 %
DIP
Run 10 57.0'-62.0'
REC: 5.0/5.0 100 %
RQD: 4.9/5.0' 98 %
DIP
47.0
52.0'
57.0'
62.0'

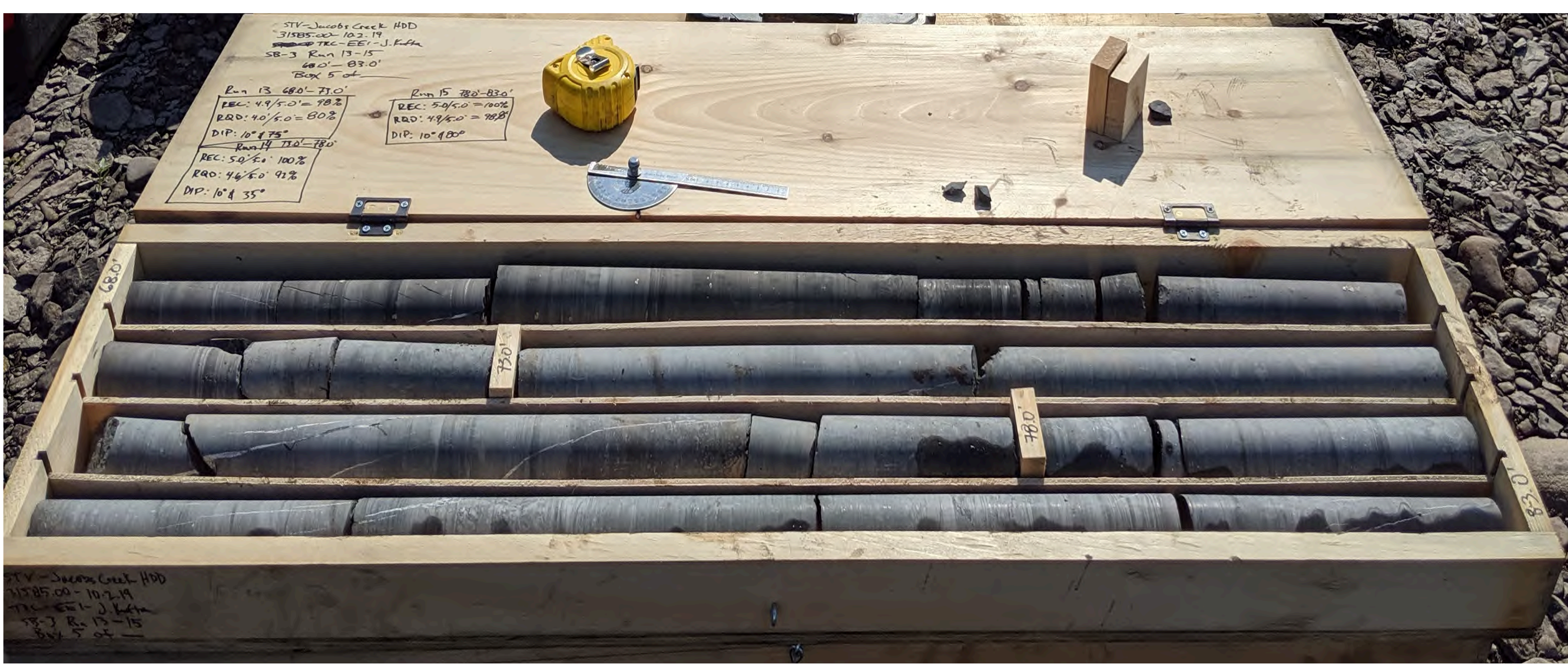

STV - Jacobs Creek HDD
31585.00 - 8.13.19
TRC - EEI - J. Kufta
SB-4 Run 17 - 19.0'
92.0' - 107.0'
Box 6 of
Run 17 92.0' - 97.0'
REC: 5.0'/5.0 100 %
RQD: 4.0'/5.0 80 %
DIP
Run 18 97.0'
REC: 5.0'/5.0' 100 %
RQD: 3.9/5.0' 77 %
DIP
Run 19
REC: 5.0'/5.0' 100 %
RQD: 5.0'/5.0' 100 %
DIP:
92.0'
97.0
102.0
107.0

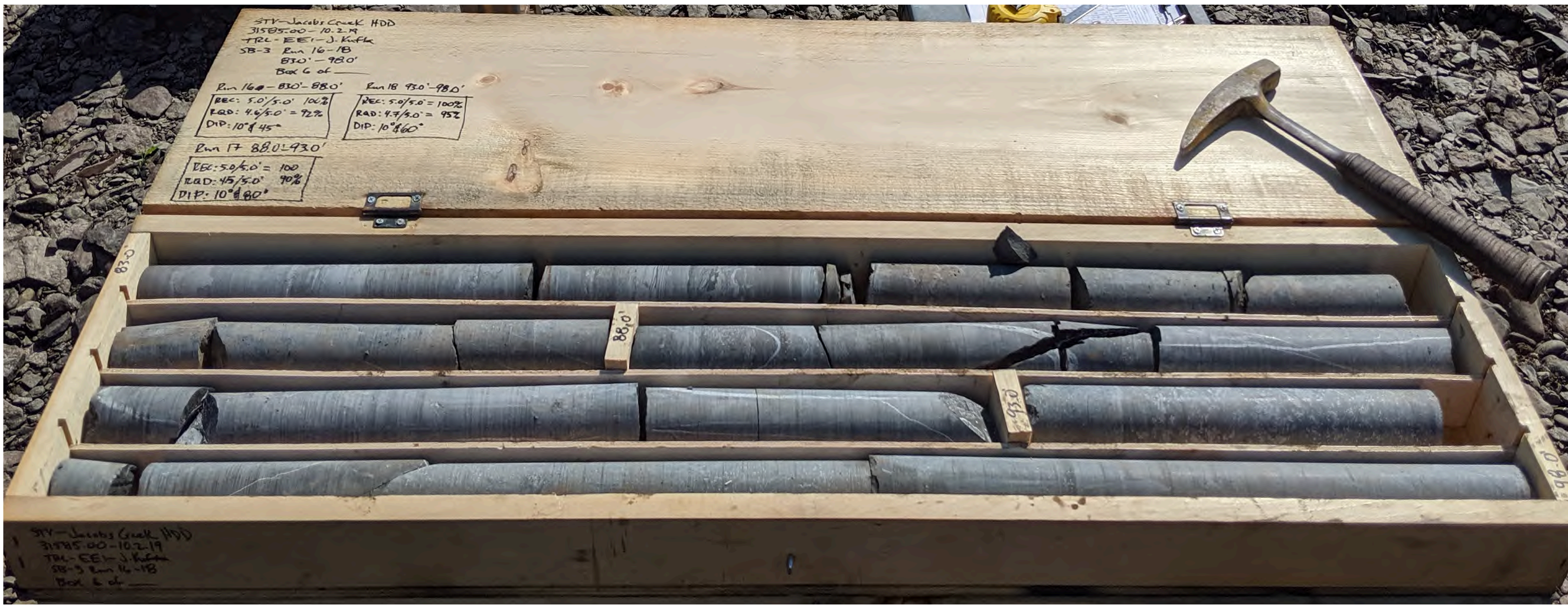

STV - Jacobs Creek HDD
31585.00 - 10.1-19
TRC - EEI - J. Kufta
SB-3 Run 1 - 3
9.0' - 23.0'
Box 1 of
Run 1 - 9.0' - 13.0'
REC: 3.1/4.0' = 77 %
RQD: 0.4/4.0' = 10%
DIP: 10°
Run 2 - 13.0' - 18.0'
REC: 5.0/5.0' = 100 %
RQD: 1.9'/5.0' = 37 %
DIP: 10° & 70
Run 3
REC: 4.9/5.0' = 97 %
RQD: 1.8/5.0' = 35 %
DIP: 10°
KOBALT
9.0'
13.0'
18.0'
23.0'


STV - Jacobs Creek HDD
SB-3 Run 4 — 6
23.0' – 38.0'
Box 2 of
Run 4 23.0' – 28.0'
REC: 5.0/5.0' = 100%
DIP: 35°
Run 5 28.0' – 33.0'
REC: 5.0'/5.0' = 100%
Run 6 33.0' – 38.0'
REC: 5.0'/5.0' = 100%
RQD: 5.0'/5.0' = 100%
DIP: 15°


STV - Jacobs Creek HDD
31585.00 - 10.1.19
SB-3 Run 7 -
Box 3 of
Run 7 38.0' – 43.0'
REC: 5.0'/5.0' = 100%
RQD: 4.5/5.0' = 90%
DIP: 10°
Run 8 43.0' – 48.0'
REC: 5.0'/5.0' = 100%
DIP: 10°
Run 9


STV-Jacobs Creek HDD
31585.00-10.2.19
TRC-EEI-J. Kofta
SB-3 Run 10-12
53.0'-68.0'
Box 4 of
Run 10 53.0'-58.0'
REC: 4.5/5.0' = 90%
RQD: 2.9/5.0' = 57%
DIP:
Run 11 58.0'-63.0'
REC: 5.0/5.0' = 100%
RQD: 5.0/5.0' = 100%
DIP: 10°-80°
Run 12 63.0'-68.0'
REC: 5.0/5.0' = 100%
RQD: 4.4/5.0' = 88%
DIP: 10°-80°
53.0'
58.0'
63.0'
68.0'
68.0'


STV-Jacobs Creek HDD
31585.00-10.2.19
TRC-EEI-J. Kofta
SB-3 Run 13-15
68.0'-83.0'
Box 5 of
Run 13 68.0'-73.0'
REC: 4.9/5.0' = 98%
RQD: 4.0/5.0' = 80%
DIP: 10° & 75°
Run 14 73.0'-78.0'
REC: 5.0/5.0' 100%
RQD: 4.6/5.0' 92%
DIP: 10° & 35°
Run 15 78.0'-83.0'
REC: 5.0/5.0' = 100%
RQD: 4.9/5.0' = 98%
DIP: 10° 80°
68.0'
73.0'
78.0'
83.0'


STV-Jacobs Creek HDD
31585.00-10.2.19
TRC-EE1-J. Kufta
SB-3 Run 16-18
83.0'-98.0'
Box 6 of
Run 16 83.0'-88.0'
REC: 5.0'/5.0' 100%
RQD: 4.6/5.0' = 92%
DIP: 10° & 45°
Run 17 88.0'-93.0'
REC: 5.0/5.0' = 100
RQD: 4.5/5.0' 90%
DIP: 10° & 80°
Run 18 93.0'-98.0'
REC: 5.0/5.0' = 100%
RQD: 4.7/5.0' = 95%
DIP: 10° & 60°
83.0'
88.0'
93.0'
98.0'


STV-Jacobs Creek HDD
31585.00-10.2.19
TRC-EE1-J. Kufta
SB-3 Run 19-21
98.0'-113.0'
Box 7 of 8
Run 19 98.0'-103.0'
REC 5.0/5.0' = 100%
RQD: 4.6/5.0' = 92%
DIP: 10° & 75°
Run 20 103.0'-108.0'
REC: 4.7/5.0' = 95%
RQD: 4.6/5.0' = 92%
DIP: 10° & 75°
Run 21 108.0'-113.0'
REC: 4.9/5.0 = 98%
RQD: 4.6/5.0 = 92%
DIP: 10° & 80°
98.0'
103.0'
108.0'
113.0'


STV-Jacobs Creek HDD
31585.00-10.2.19
TRC-EE1-J.Kuffa
SB-3 Run 22-23
113.0'-120.0'
Box 8 of 8
Run 1 113.0'-118.0'
REC: 5.0'/5.0' = 100%
RQD: 3.5/5.0' = 70%
DIP: 10° & 80°
Run 2 118.0'-120.0'
REC: 2.0'/2.0' = 100%
RQD: 1.3/2.0' = 67%
DIP: 10° & 80°
113.0'
118.0'
120.0'


STV-Jacobs Creek-HDD
31585.00-8.13.19
TRC-EE1-J.Kufle
SB-4 - Run 5-
32.0'-47.0'
Box 2 of
Run 5 32.0'-37.0'
REC: 5.0/5.0 100%
RQD: 4.4/5.0 88%
DIP
Run 6 37.0'-42.0'
REC: 5.0/5.0 100%
RQD: 3.7/5.0' 75%
DIP
Run 7 Run 42.0'-47.0'
REC: 5.0'/5.0' 100%
RQD: 3.7/5.0 75%
DIP:
32.0'
37.0'
42.0'
47.0'


STV-Jacobs Creek HDD
31585.00-8.13.19
TRC-EE1-J.Kufta
SB-4 Run 11-13
62.0'-77.0
Box 4 of
Run 11 62.0'-67.0'
REC: 5.0'/5.0 100 %
RQD: 4.6'/5.0' 92 %
DIP
Run 12 67.0'-72.0'
REC: 5.0'/5.0' 100 %
RQD: 4.7/5.0' 95 %
DIP:
Run 13 72.0'-77.0'
REC: 5.0'/5.0' 100 %
RQD: 4.0'/5.0' 80 %
DIP:
62.0'
67.0'
72.0'
77.0'


STV-Jacobs Creek HDD
31585.00-8.13.19
TRC-EE1-J.Kufta
SB-4 Run 14-16
77.0'-92.0'
Box 5 of
Run 14 77.0'-82.0'
REC: 5.0'/5.0' 100 %
RQD: 4.3/5.0' 87 %
DIP
Run 15 82.0'-87.0'
REC: 5.0'/5.0' 100%
RQD: 4.0'/5.0' 80%
DIP:
Run 16 87.0'-92.0'
REC: 5.0'/5.0' 100 %
RQD: 4.8'/5.0' 97 %
DIP
77.0'
82.0'
87.0'
92.0'


STV-Jacobs Creek HDD
31585.00-8.13.19
TRC-EE1-J.Kufta
SB-4 Run 20-22
107.0'-120.0'
Box 7 of 7
Run 20 107.0'-112.0'
REC: 5.0'/5.0' 100%
RQD: 4.8'/5.0' 95%
DIP
Run 21 112.0'-117.0'
REC: 5.0/5.0' 100%
RQD: 4.7/5.0' 93%
DIP
Run 22 117.0'-120.0'
REC: 3.0'/3.0' 100%
RQD: 2.8/3.0' 94%
DIP
107.0'
112.0'
117.0'
120.0'

Therefore, Table 5 (Reference 4, unpublished work by Ayers and Plum) is provided for a more useful classification of organic soils.

For the characteristics of the Unified Soil Classification System pertinent to roads and airfields, see NAVFAC DM-5.4.

3. TYPICAL PROPERTIES. Some typical properties of soils classified by the Unified System are provided in Table 6 (Reference 5, Basic Soils Engineering, by Hough). More accurate estimates should be based on laboratory and/or field testing, and engineering evaluation.

## Section 5. ROCK CLASSIFICATION AND PROPERTIES

1. VISUAL CLASSIFICATION. Describe the rock sample in the following sequence:

a. Weathering Classification. Describe as fresh, slightly weathered, etc. in accordance with Table 7 (Reference 6, Suggested Methods of the Description of Rock Masses, Joints and Discontinuities, by ISRM Working Party).

b. Discontinuity Classification. Describe spacing of discontinuities as close, wide, etc., in accordance with Table 8. In describing structural features, describe rock mass as thickly bedded or thinly bedded, in accordance with Table 8. Depending on project requirements, identify the form of joint (stepped, smooth, undulating, planar, etc.), its dip (in degrees), its surface (rough, smooth, slickensided), its opening (giving width), and its filling (none, sand, clay, breccia, etc.).

c. Color and Grain Size. Describe with respect to basic colors on rock color chart (Reference 7, Rock Color Chart, by Geological Society of America). Use the following term to describe grain size:

(1) For Igneous and Metamorphic Rocks:

coarse-grained - grain diameter >5mm

medium-grained - grain diameter 1 - 5mm

fine-grained - grain diameter <1mm

aphanitic - grain size is too small to be perceived by unaided eye

glassy - no grain form can be distinguished.

(2) For Sedimentary Rocks

coarse-grained - grain diameter >2mm

medium-grained - grain diameter = 0.06 - 2mm

TABLE 5
Soil Classification for Organic Soils

| Category | Name | Organic Content (% by wt.) | Group Symbols (See Table 3) | Distinguishing Characteristics For Visual Identification | Range of Laboratory Test Values |
|---|---|---|---|---|---|
| ORGANIC MATTER | FIBROUS PEAT (woody, mats, etc.) | 75 to 100% Organics either visible or inferred | Pt | Light weight, spongy and often elastic at $w_n$--shrinks considerably on air drying. Much water squeezes from sample. | $w_n$--500 to 1200%<br>$\gamma$--60 to 70 pcf<br>G--1.2 to 1.8<br>$C_c/(1+e_o)$=.4+ |
| | FINE GRAINED PEAT (amorphous) | | | Light weight, spongy but not often elastic at $w_n$--shrinks considerably on air drying. Much water squeezes from sample. | $w_n$--400 to 800%<br>LL--400 to 900%<br>PI--200 to 500<br>$\gamma$--60 to 70 pcf<br>G--1.2 to 1.8<br>$C_c/(1+e_o)$=.35 to .4+ |
| HIGHLY ORGANIC SOILS | Silty Peat | 30 to 75% Organics either visible or inferred | Pt | Relatively light weight, spongy. Thread usually weak and spongy near PL Shrinks on air drying; medium dry strength. Usually can squeeze water from sample readily--slow dilatency. | $w_n$--250 to 500%<br>LL--250 to 600%<br>PI--150 to 350<br>$\gamma$--65 to 90 pcf<br>G--1.8 to 2.3<br>$C_c/(1+e_o)$=.3 to .4 |
| | Sandy Peat | | | Sand fraction visible. Thread weak and friable near PL; shrinks on air drying; low dry strength. Usually can squeeze water from sample readily--high dilatency--"gritty." | $w_n$--100 to 400%<br>LL--150 to 300% (plot below A line)<br>PI--50 to 150<br>$\gamma$--70 to 100 pcf<br>G--1.8 to 2.4<br>$C_c/(1+e_o)$=.2 to .3 |

TABLE 5 (continued)
Soil Classification for Organic Soils

| Category | Name | Organic Content (% by wt.) | Group Symbols (See Table 3) | Distinguishing Characteristics For Visual Identification | Range of Laboratory Test Values |
|---|---|---|---|---|---|
| ORGANIC SOILS | Clayey ORGANIC SILT | 5 to 30% Organics either visible or inferred | OH | Often has strong $H_2S$ odor. Thread may be tough depending on clay fraction. Medium dry strength, slow dilatency. | $w_n$--65 to 200%<br>LL--65 to 150%<br>(usually plot at or near A line)<br>PI-- 50 to 150<br>$\gamma$ --70 to 100 pcf<br>G--2.3 to 2.6<br>$C_c/(1+e_o)$=.20 to .35 |
| | Organic SAND or SILT | | OL | Threads weak and friable near PL--or may not roll at all. Low dry strength; medium to high dilatency. | $w_n$--30 to 125%<br>LL--30 to 100%<br>(usually plot well below A line)<br>PI--non-plastic to 40<br>$\gamma$ --90 to 110 pcf<br>G--2.4 to 2.6<br>$C_c/(1+e_o)$=.1 to .25 |
| SLIGHTLY ORGANIC SOILS | SOIL FRACTION add slightly Organic | Less than 5% Organics combined visible and inferred | Depend upon inorganic fraction | Depend upon the characteristics of the inorganic fraction. | Depend upon inorganic fractions. |

# TABLE 6
## Typical Values of Soil Index Properties

| | Particle Size and Gradation | | | | Voids[1] | | | | | Unit Weight[2] (lb./cu.ft.) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Approximate Size Range (mm) | | Approx. $D_{10}$ (mm) | Approx. Range Uniform Coefficient $C_u$ | Void Ratio | | | Porosity (%) | | Dry Weight | | | Wet Weight | | Submerged Weight | |
| | $D_{max}$ | $D_{min}$ | | | $e_{max}$ loose | $e_{cr}$ | $e_{min}$ dense | $n_{max}$ loose | $n_{min}$ dense | Min loose | 100% Mod. AASHO | Max dense | Min loose | Max dense | Min loose | Max dense |
| GRANULAR MATERIALS | | | | | | | | | | | | | | | | |
| Uniform Materials | | | | | | | | | | | | | | | | |
| a. Equal spheres (theoretical values) | - | - | - | 1.0 | 0.92 | - | 0.35 | 47.6 | 26 | - | - | - | - | - | - | - |
| b. Standard Ottawa SAND | 0.84 | 0.59 | 0.67 | 1.1 | 0.80 | 0.75 | 0.50 | 44 | 33 | 92 | - | 110 | 93 | 131 | 57 | 69 |
| c. Clean, uniform SAND (fine or medium) | - | - | - | 1.2 to 2.0 | 1.0 | 0.80 | 0.40 | 50 | 29 | 83 | 115 | 118 | 84 | 136 | 52 | 73 |
| d. Uniform, inorganic SILT | 0.05 | 0.005 | 0.012 | 1.2 to 2.0 | 1.1 | - | 0.40 | 52 | 29 | 80 | - | 118 | 81 | 136 | 51 | 73 |
| Well-graded Materials | | | | | | | | | | | | | | | | |
| a. Silty SAND | 2.0 | 0.005 | 0.02 | 5 to 10 | 0.90 | - | 0.30 | 47 | 23 | 87 | 122 | 127 | 88 | 142 | 54 | 79 |
| b. Clean, fine to coarse SAND | 2.0 | 0.05 | 0.09 | 4 to 6 | 0.95 | 0.70 | 0.20 | 49 | 17 | 85 | 132 | 138 | 86 | 148 | 53 | 86 |
| c. Micaceous SAND | - | - | - | - | 1.2 | - | 0.40 | 55 | 29 | 76 | - | 120 | 77 | 138 | 48 | 76 |
| d. Silty SAND & GRAVEL | 100 | 0.005 | 0.02 | 15 to 300 | 0.85 | - | 0.14 | 46 | 12 | 89 | - | 146[3] | 90 | 155[3] | 56 | 92 |
| MIXED SOILS | | | | | | | | | | | | | | | | |
| Sandy or Silty CLAY | 2.0 | 0.001 | 0.003 | 10 to 30 | 1.8 | - | 0.25 | 64 | 20 | 60 | 130 | 135 | 100 | 147 | 38 | 85 |
| Skip-graded Silty CLAY with stones or rk fgmts | 250 | 0.001 | - | - | 1.0 | - | 0.20 | 50 | 17 | 84 | - | 140 | 115 | 151 | 53 | 89 |
| Well-graded GRAVEL, SAND, SILT & CLAY mixture | 250 | 0.001 | 0.002 | 25 to 1000 | 0.70 | - | 0.13 | 41 | 11 | 100 | 140 | 148[4] | 125 | 156[4] | 62 | 94 |
| CLAY SOILS | | | | | | | | | | | | | | | | |
| CLAY (30%-50% clay sizes) | 0.05 | 0.5μ | 0.001 | - | 2.4 | - | 0.50 | 71 | 33 | 50 | 105 | 112 | 94 | 133 | 31 | 71 |
| Colloidal CLAY (-0.002 mm: 50%) | 0.01 | 10Å | - | - | 12 | - | 0.60 | 92 | 37 | 13 | 90 | 106 | 71 | 128 | 8 | 66 |
| ORGANIC SOILS | | | | | | | | | | | | | | | | |
| Organic SILT | - | - | - | - | 3.0 | - | 0.55 | 75 | 35 | 40 | - | 110 | 87 | 131 | 25 | 69 |
| Organic CLAY (30% - 50% clay sizes) | - | - | - | - | 4.4 | - | 0.70 | 81 | 41 | 30 | | 100 | 81 | 125 | 18 | 62 |

TABLE 6 (continued)
Typical Values of Soil Index

(1). Granular materials may reach $e_{max}$ when dry or only slightly moist. Clays can reach $e_{max}$ only when fully saturated.

(2) Granular materials reach minimum unit weight when at $e_{max}$ and with hygroscopic moisture only. The unit submerged weight of any saturated soil is the unit weight minus the unit weight of water.

(3) Applicable for very compact glacial till. Unusually high unit weight values for tills are sometimes due to not only an extremely compact condition but to unusually high specific gravity values.

(4) Applicable for hardpan.

General Note: Tabulation is based on G = 2.65 for granular soil, G = 2.7 for clays, and G = 2.6 for organic soils.

TABLE 7
Weathering Classification

| GRADE | SYMBOL | DIAGNOSTIC FEATURES |
|---|---|---|
| Fresh | F | No visible sign of decomposition or discoloration. Rings under hammer impact. |
| Slightly Weathered | WS | Slight discoloration inwards from open fractures, otherwise similar to F. |
| Moderately Weathered | WM | Discoloration throughout. Weaker minerals such as feldspar decomposed. Strength somewhat less than fresh rock but cores cannot be broken by hand or scraped by knife. Texture preserved. |
| Highly Weathered | WH | Most minerals somewhat decomposed. Specimens can be broken by hand with effort or shaved with knife. Core stones present in rock mass. Texture becoming indistinct but fabric preserved. |
| Completely Weathered | WC | Minerals decomposed to soil but fabric and structure preserved (Saprolite). Specimens easily crumbled or penetrated. |
| Residual Soil | RS | Advanced state of decomposition resulting in plastic soils. Rock fabric and structure completely destroyed. Large volume change. |

TABLE 8
Discontinuity Spacing

| Description for Structural Features: Bedding, Foliation, or Flow Banding | Spacing | Description for Joints, Faults or Other Fractures |
|---|---|---|
| Very thickly (bedded, foliated,or banded) | More than 6 feet | Very widely (fractured or jointed) |
| Thickly | 2 - 6 feet | Widely |
| Medium | 8 - 24 inches | Medium |
| Thinly | 2-1/2 - 8 inches | Closely |
| Very thinly | 3/4 - 2-1/2 inches | Very closely |

| Description for Micro-Structural Features: Lamination, Foliation, or Cleavage | Spacing | Description for Joints, Faults or Other Fractures |
|---|---|---|
| Intensely (laminated, foliated, or cleaved) | 1/4 - 3/4 inch | Extremely close |
| Very intensely | Less than 1/4 inch | |

fine-grained - grain diameter = 0.002 - 0.06mm

very fine-grained - grain diameter <0.002mm

(3) Use 10X hand lens if necessary to examine rock sample.

d. Hardness Classification. Describe as very soft, soft, etc. in accordance with Table 9 (from Reference 5), which shows range of strength values of intact rock associated with hardness classes.

e. Geological Classification. Identify the rock by geologic name and local name (if any). A simplified classification is given in Table 10. Identify subordinate constituents in rock sample such as seams or bands of other type of minerals, e.g., dolomitic limestone, calcareous sandstone, sandy limestone, mica schist. Example of typical description:

Fresh gray coarse moderately close fractured Mica Schist.

2. CLASSIFICATION BY FIELD MEASUREMENTS AND STRENGTH TESTS.

a. Classification by Rock Quality Designation and Velocity Index.

(1) The Rock Quality Designation (RQD) is only for NX size core samples and is computed by summing the lengths of all pieces of core equal to or longer than 4 inches and dividing by the total length of the coring run. The resultant is multiplied by 100 to get RQD in percent. It is necessary to distinguish between natural fractures and those caused by the drilling or recovery operations. The fresh, irregular breaks should be ignored and the pieces counted as intact lengths. Depending on the engineering requirements of the project, breaks induced along highly anisotropic planes, such as foliation or bedding, may be counted as natural fractures. A qualitative relationship between RQD, velocity index and rock mass quality is presented in Table 11 (Reference 8, Predicting Insitu Modulus of Deformation Using Rock Quality Indexes, by Coon and Merritt).

(2) The velocity index is defined as the square of the ratio of the field compressional wave velocity to the laboratory compressional wave velocity. The velocity index is typically used to determine rock quality using geophysical surveys. For further guidance see Reference 9, Design of Surface and Near Surface Construction in Rock, by Deere, et al.

b. Classification by Strength.

(1) Uniaxial Compressive Strength and Modulus Ratio. Determine the uniaxial compressive strength in accordance with ASTM Standard D2938, Unconfined Compressive Strength of Intact Rock Core Specimens. Describe the strength of intact sample tested as weak, strong, etc., in accordance with Figure 3 (Reference 10, The Point Load Strength Test, by Broch and Franklin).

(2) Point Load Strength. Describe the point load strength of specimen tested as low, medium, etc. in accordance with Figure 3. Point load strength tests are sometimes performed in the field for larger projects where rippability and rock strength are critical design factors. This simple field test can be performed on core samples and irregular rock specimens. The point

TABLE 9
Hardness Classification of Intact Rock

| CLASS | HARDNESS | FIELD TEST | APPROXIMATE RANGE OF UNIAXIAL COMPRESSION STRENGTH kg/cm$^2$ (tons/ft$^2$) |
|---|---|---|---|
| I | Extremely hard | Many blows with geologic hammer required to break intact specimen. | >2000 |
| II | Very hard | Hand held specimen breaks with hammer end of pick under more than one blow. | 2000- 1000 |
| III | Hard | Cannot be scraped or peeled with knife, hand held specimen can be broken with single moderate blow with pick. | 1000 - 500 |
| IV | Soft | Can just be scraped or peeled with knife. Indentations 1mm to 3mm show in specimen with moderate blow with pick. | 500 - 250 |
| V | Very soft | Material crumbles under moderate blow with sharp end of pick and can be peeled with a knife, but is too hard to hand-trim for triaxial test specimen. | 250 - 10 |

TABLE 10
Simplified Rock Classification

COMMON IGNEOUS ROCKS

<table>
<tr><td>Color</td><td colspan="2">Light</td><td>Intermediate</td><td colspan="2">Dark</td></tr>
<tr><td>Principal Mineral<br>Texture</td><td>Quartz & Feldspar Other Minerals Minor</td><td>Feldspar</td><td>Feldspar & Hornblende</td><td>Augite and Feldspar</td><td>Augite Hornblende, Olivine</td></tr>
<tr><td>Coarse, Irregular, Crystalline</td><td>Pegmatite</td><td>Syenite pegmatite</td><td>Diorite pegmatite</td><td>Gabbro pegmatite</td><td></td></tr>
<tr><td rowspan="2">Coarse and Medium Crystalline</td><td rowspan="2">Granite</td><td rowspan="2">Syenite</td><td>Diorite</td><td>Gabbro</td><td rowspan="2">Peridotite</td></tr>
<tr><td colspan="2">Dolerite</td></tr>
<tr><td>Fine Crystalline</td><td colspan="3">Aplite</td><td colspan="2">Diabase</td></tr>
<tr><td>Aphanitic</td><td colspan="3">Felsite</td><td colspan="2">Basalt</td></tr>
<tr><td>Glassy</td><td colspan="3">Volcanic glass</td><td colspan="2">Obsidian</td></tr>
<tr><td>Porous (Gas Openings)</td><td colspan="2">Pumice</td><td colspan="3">Scoria or vesicular basalt</td></tr>
<tr><td>Fragmental</td><td colspan="5">Tuff (fine), breccia (coarse), cinders (variable)</td></tr>
</table>

TABLE 10 (continued)
Simplified Rock Classification

COMMON SEDIMENTARY ROCKS

| Group | Grain Size | Composition | | Name |
|---|---|---|---|---|
| Clastic | Mostly Coarse Grains | Rounded pebbles in medium-grained matrix | | Conglomerate |
| | | Angular coarse rock fragments, often quite variable | | Breccia |
| | More than 50% of medium grains | Medium quartz grains | Less than 10% of other minerals | Siliceous sandstone |
| | | | Appreciable quantity of clay minerals | Argillaceous sandstone |
| | | | Appreciable quantity of calcite | Calcareous sandstone |
| | | | Over 25% feldspar | Arkose |
| | | | 25-50% feldspar and darker minerals | Graywacke |
| | More than 50% fine grain size | Fine to very fine quartz grains with clay minerals | | Siltstone (if laminated, shale) |
| | | Microscopic clay minerals | <10% other minerals | Shale |
| | | | Appreciable calcite | Calcareous shale |
| | | | Appreciable carbonaceous material | Carbonaceous shale |
| | | | Appreciable iron oxide cement | Ferruginous shale |

TABLE 10 (continued)
Simplified Rock Classification

COMMON SEDIMENTARY ROCKS

| Group | Grain Size | Composition | Name |
|---|---|---|---|
| Organic | Variable | Calcite and fossils | Fossiliferous limestone |
| | Medium to microscopic | Calcite and appreciable dolomite | Dolomite limestone or dolomite |
| | Variable | Carbonaceous material | Bituminous coal |
| Chemical | Microscopic | Calcite | Limestone |
| | | Dolomite | Dolomite |
| | | Quartz | Chert, Flint, etc. |
| | | Iron compounds with quartz | Iron formation |
| | | Halite | Rock salt |
| | | Gypsum | Rock gypsum |

TABLE 10 (continued)
Simplified Rock Classification

COMMON METAMORPHIC ROCKS

| Texture | Structure | |
|---|---|---|
| | Foliated | Massive |
| Coarse Crystalline | Gneiss | Metaquartzite |
| Medium Crystalline | Schist (Sericite) (Mica) (Talc) (Chlorite) (etc.) | Marble<br>Quartzite<br>Serpentine<br>Soapstone |
| Fine to Microscopic | Phyllite<br>Slate | Hornfels<br>Anthracite coal |

TABLE 11
Engineering Classification For In Situ Rock Quality

| RQD % | VELOCITY INDEX | ROCK MASS QUALITY |
|---|---|---|
| 90 - 100 | 0.80 - 1.00 | Excellent |
| 75 - 90 | 0.60 - 0.80 | Good |
| 50 - 75 | 0.40 - 0.60 | Fair |
| 25 - 50 | 0.20 - 0.40 | Poor |
| 0 - 25 | 0 - 0.20 | Very Poor |

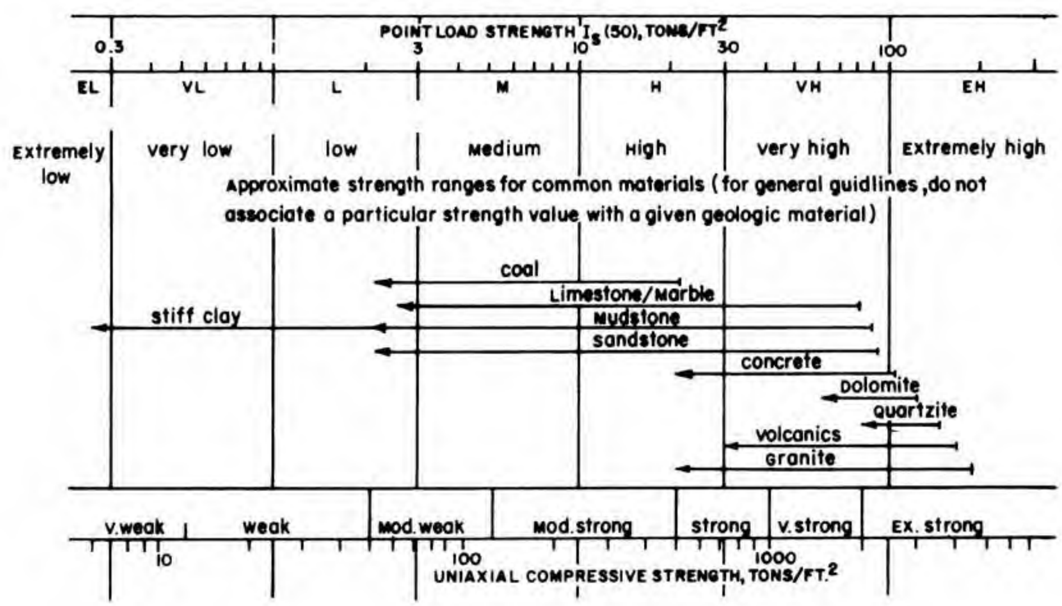



FIGURE 3
Strength Classification

load strength index is defined as the ratio of the applied force at failure to the squared distance between loaded points. This index is related to the direct tensile strength of the rock by a proportionality constant of 0.7 to 1.0 depending on the size of sample. Useful relationships of point load tensile strength index to other parameters such as specific gravity, seismic velocity, elastic modulus, and compressive strength are given in Reference 11, Prediction of Compressive Strength from Other Rock Properties, by DiAndrea, et al. The technique for performing the test is described in Reference 9.

c. Classification by Durability. Short-term weathering of rocks, particularly shales and mudstones, can have a considerable effect on their engineering performance. The weatherability of these materials is extremely variable, and rocks that are likely to degrade on exposure should be further characterized by use of tests for durability under standard drying and wetting cycle (see Reference 12, Logging Mechanical Character of Rock, by Franklin, et al.). If, for example, wetting and drying cycles reduce shale to grain size, then rapid slaking and erosion in the field is probable when rock is exposed (see Reference 13, Classification and Identification of Shales, by Underwood).

3. ENGINEERING AND PHYSICAL PROPERTIES OF ROCK. A preliminary estimate of the physical and engineering properties can be made based on the classification criteria given together with published charts, tables and correlations interpreted by experienced engineering geologists. (See Reference 8; Reference 13; Reference 14, Slope Stability in Residual Soils, by Deere and Patton; Reference 15, Geological Considerations, by Deere; Reference 16, Engineering Properties of Rocks, by Farmer.) Guidance is provided in Reference 14 for description of weathered igneous and metamorphic rock (residual soil, transition from residual to saprolite, etc.) in terms of RQD, percent core recovery, relative permeability and strength. Typical strength parameters for weathered igneous and metamorphic rocks are also given in Reference 14. Guidance on physical properties of some shales is given in Reference 13.

## Section 6. SPECIAL MATERIALS

1. GENERAL CLASSIFICATION AND TYPICAL ENGINEERING IMPLICATIONS. See Table 12 for general classification and typical engineering implications of special materials that influence foundation design.

2. EXPANSIVE SOILS.

a. Characteristics. Expansive soils are distinguished by their potential for great volume increase upon access to moisture. Soils exhibiting such behavior are mostly montmorillonite clays and clay shales.

b. Identification and Classification. Figure 4 (Reference 17, Shallow Foundations, by the Canadian Geotechnical Society) shows a method based on Atterberg limits and grain size for classifying expansive soils. Activity of clay is defined as the ratio of plasticity index and the percent by weight finer than two microns ($2\mu$). The swell test in a one dimensional consolidation test (see Chapter 3) or the Double Consolidometer Test (Reference 18, The Additional Settlement of Foundations Due to Collapse of Structures of

TABLE 1 Soil Conditions and Suitability of Horizontal Directional Drilling[A]

| Soil Conditions | Generally Suitable | Difficulties May Occur | Substantial Problems |
|---|---|---|---|
| Soft to very soft clays, silts, and organic deposits | | X | |
| Medium to very stiff clays and silts | X | | |
| Hard clays and highly weathered shales | X | | |
| Very loose to loose sands above and below the water table (not more than 30 % gravel by weight) | | X | |
| Medium to dense sands above or below the water table (not more than 30 % gravel by weight) | X | | |
| Very loose to dense gravelly sand, (30 % to 50 % gravel by weight) | | X | |
| Very loose to dense gravelly sand (50 % to 85 % gravel by weight) | | | X |
| Very loose to very dense gravel | | | X |
| Soils with significant cobbles, boulders, and obstructions | | | X |
| Weathered rocks, marls, chalks, and firmly cemented soils | X | | |
| Slightly weathered to unweathered rocks | | X | |

[A]For additional information, see Ref. (6).

drilling fluid capabilities are available for various ground conditions. The conditions under which "difficulties may occur" may require modifications of routine procedures or equipment, such as the use of special purpose drill heads or optimized drilling fluids. Some cases will entail "substantial problems" and may not be economically feasible for directional drilling using present technology. The potential for problems to occur increases with the presence of gravels, boulders, or cobbles or with transitions from non-lithified material into solid rock. In such cases, other drilling locations or construction alternatives should be considered unless special circumstances dictate the need for directional drilling at the present location, even at high costs associated with special rock drilling techniques, etc.

## 5. Safety and Environmental Considerations

5.1 *General Considerations*—Injury to personnel may result from the mechanical and hydraulic machine operations directly related to the drilling operation or from striking of electric power lines or buried pipelines. In addition, the scale of maxi-HDD operations may involve additional equipment and accessories required for the lifting and handling of heavy drill rods, drill heads, reamers, etc., as well as the product pipe or conduit. Additional precautions relating to specific auxiliary equipment must be followed, but is beyond the scope of this standard. Non-essential personnel and bystanders should not be allowed in the immediate vicinity of the maxi-HDD equipment. Barriers and warnings should be placed a minimum of 30 ft (10 m) from the edge of the equipment or associated hardware. Safety precautions are to be followed by all personnel and at both ends of the bore path. Inadvertent contact with electric power, natural gas, or petroleum lines may result in hazards to personnel or contamination. If possible, any in-service pipeline in the proximity of the bore should be de-activated during the construction. In general, the possibility of injury or environmental impact caused by damage to working or powered subsurface facilities or pipelines during the initial boring or backreaming operations is reduced by appropriate adherence to regulations and damage prevention procedures, as outlined in Section 6.

5.2 *Work Clothing*—**Caution:** Loose clothing or jewelry should not be worn since they may snag on moving mechanical parts. Safety glasses or OSHA approved goggles, or both, and OSHA approved head gear should be worn at all times. Protective work shoes and gloves must be worn by all personnel.

5.3 *Machine Safety Practices*—Contractors must comply with all applicable OSHA, state, and local regulations, and accepted industry practices. All personnel in the vicinity of the drill rig or at the opposite end of the bore must be properly trained and educated regarding the potential hazards associated with the maxi-HDD equipment. For electrical hazards, see OSHA 3075. Personnel shall be knowledgeable of safe operating procedures, safety equipment, and proper precautions. Courses and seminars are available in the industry, including training provided by the equipment suppliers.

5.3.1 The operation of the drill rig requires rotation and advancement or retraction of the drill rods. Drill rig operation is typically accomplished using chain drives, gear systems, and vises which may potentially lead to personal injury due to the moving mechanical components. All safety shields or guards must be properly mounted. The equipment must be checked at the beginning of each work day to verify proper operation.

5.3.2 *Hydraulic Fluid*—The hydraulic oil lines powering the drill rig operate under pressures of several thousand psi (hundreds of bars). The hoses and connectors must be properly maintained to avoid leaks.

5.3.2.1 *Caution:* If a leak is suspected, it should be checked by using a piece of cardboard or other object, but not hands or any other part of the body. The high pressure hydraulic fluid can penetrate the skin, burn, or cause blood poisoning. Before disconnecting any hydraulic lines, the system pressure should be relieved.

5.3.3 *Drilling Fluid*—Drilling fluid pressures will vary depending upon the equipment design and operator preference; pressures of several thousand psi (hundreds of bars) are possible. The hoses and connections must be properly maintained to avoid leaks.

5.3.3.1 *Caution:* Suspected leaks should be checked by using a piece of cardboard or other object. Avoid the use of hands or any other part of the body to check for a leak. Before individual drill rods are inserted or removed from the drill string, it must be verified that the drilling fluid pressure has been shut off and allowed to decrease; otherwise, high pressure fluid will squirt from the joint and possibly cause injury to