APPENDIX D-2
GEOTECHNICAL ENGINEERING REPORT

North Branch Forest River Dam #1 (Bylin Dam)
Walsh County, North Dakota

National Inventory of Dams ID: ND00036

Prepared For
HOUSTON ENGINEERING, INC.
Fargo, North Dakota

Houston Project No. R007135-0037

Owner
WALSH COUNTY WATER RESOURCE DISTRICT
Grafton, North Dakota

Prepared By

Gannett Fleming

Excellence Delivered ***As Promised***

GF Project No. 066442

Greenwood Village, Colorado
January 20, 2021
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Gannett Fleming

GEOTECHNICAL ENGINEERING REPORT
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WALSH COUNTY, NORTH DAKOTA

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GEOTECHNICAL ENGINEERING REPORT
NORTH BRANCH FOREST RIVER DAM # 1 (Bylin Dam)
WALSH COUNTY, NORTH DAKOTA

1 INTRODUCTION

This geotechnical engineering report (GER) summarizes data collected as part of the preliminary geologic investigation for North Branch Forest River Dam No. 1, hereinafter referred to as Bylin Dam. The investigation was performed by Gannett Fleming, Inc (GF) as part of a subconsultant services agreement with Houston Engineering, Inc. and conducted pursuant to the Natural Resource and Conservation Service (NRCS) Statement of Work for its Cooperative Agreement NR196633XXXXC004 with the Walsh County Water Resource District (WCWRD). The purpose of the Statement of Work is to develop a Supplemental Watershed Plan-Environmental Assessment (EA) of the Environmental Impact Statement (EIS) for Bylin Dam. The purpose of the preliminary geologic investigation was to develop profiles and geotechnical data for evaluation of the spillway integrity and for characterization of the embankment and foundation soils.

2 PROJECT DESCRIPTION AND LOCATION

Bylin Dam is a high hazard earth embankment constructed in 1964 for flood control and recreation. The dam, which is approximately 61.7 feet high and 760 feet long, straddles the boundary between the northern portions of Sections 5 and 6 of Township 156N, Range 57W (Exhibit 1). An aerial photograph showing the general site layout is provided in Exhibit 2. A Norton Township gravel road (121st Avenue NE) trends northwest-southeast on the crest of the dam and provides access to the project.

Table 1 lists the storage capacity of the reservoir and pool surface area at various pool levels per Gannett Fleming's 2010 Dam Assessment Report. All elevations reported herein are referenced to NAVD88. The elevations shown in the As-Built Drawings (USDA SCS, 1964) are thought to be referenced to NGVD29 as evidenced by the "msl" datum indicated in the USACE (1978) Phase I Inspection Report (USACE, 1978), and the 2010 Dam Assessment Report (Gannett Fleming, Inc., 2010). Elevations are converted from NGVD29 to NAVD88 by adding a correction factor of 1.2 feet (NOAA, 2020).

Table 1. Reservoir Storage Capacity and Pool Area

Pool Level	Elevation (ft)	Volume (acre-ft)	Surface Area (acres)
Principal Spillway Orifice Invert (1st Stage Inlet)	1490.2	524	57
Principal Spillway Weir Crest (2nd Stage Inlet)	1511.3	3,073.3	179.5
Auxiliary Spillway Crest	1518.6	4,223	230
Maximum Pool (Top of Dam)	1523.8[1]	5,819.7	-

Notes: 1) Maximum top of dam was surveyed at El. 1524.7 approximately 200 ft left of the principal spillway conduit which corresponds to the maximum allowance for settlement per the As-Built drawings. The minimum surveyed elevation is 1523.8 ft which corresponds to the elevation of the maximum storage pool – an increase in pool elevation above 1523.8 ft would result in overtopping of the embankment.

The Bylin Dam drainage area is approximately 22.1 square miles (14,144 acres) per the As-Built Drawings (USDA SCS, 1964); however, a watershed area of 20.46 square miles (13,094 acres) was used for the hydrologic analyses in Gannett Fleming's 2010 Dam Assessment Report based on watershed delineation using USGS 12-digit hydrologic unit codes (HUCs).

The outlet works are designed to discharge freely whenever the pool rises to the level of the first and second stage inlets of the Principal Spillway (Elevations 1490.2 and 1511.3 feet, respectively) or the crest of the Auxiliary Spillway (Elevation 1518.6 feet). Below Bylin Dam, the North Branch of the Forest River flows generally southeastward and joins the Forest River just west of Fordville. The Forest River flows generally eastward and northward to its confluence with the Red River, which forms the border between North Dakota and Minnesota. The Red River flows northward into Canada and Lake Winnipeg, which is drained by the Nelson River into Hudson Bay.

3 GENERAL CONDITIONS

This section of the GER discusses physiography, soils, bedrock, seismicity, and general geological conditions based on published reports and mapping.

3.1 Physiography

Bylin Dam lies within Glaciated Plains Section of the Central Lowland Province (Exhibit 3). Waldkirch (1999) describes the Glaciated Plains as a *"rolling, glaciated landscape; more than 80 percent of the area is gently sloping with local relief generally less than 100 feet in most places but ranging up to 300 feet in some places."*

Just east of the project lies the eastward-facing Pembina escarpment, which separates the Glaciated Plains from the topographically lower and flatter Red River Valley section of the Central Lowland province. Waldkirch (1999) describes the Red River Valley as a *"flat plain resulting from sedimentation on the floor of glacial Lake Agassiz; more than 95 percent of the area is gently sloping with local relief less than 25 feet in most places."*

Multiple geologic forces have combined to shape the Pembina Escarpment including preglacial differential erosion of the underlying shale bedrock, scouring and erosion by glaciers moving southward into North Dakota from the Keewatin center west of Hudson Bay, erosion by wave action along the shorelines of Glacial Lake Agassiz, and erosion by periodic outbursts of floodwater from ice-dammed lakes to the west (Bluemle, 2016; Bluemle, 1988). Areas of eolian sand are mapped within the Red River Valley Section east of the Pembina Escarpment (Anderson, 2018).

3.2 Soils

Soils information was obtained from the USDA online Web Soil Survey (2019). A soil map is provided on page 9 of the NRCS custom soil resource report, which can be made available upon request. Table 2 summarizes the four soil units mapped in the vicinity of the dam, spillway, and borrow area.

The dam embankment is mapped as F641F soils, which have a typical profile including loam, sandy clay loam, clay loam, and gravelly loam to a depth of 60 inches. Under the Unified Soil Classification System (USCS), they are classified as clay (CL) and clayey sand (SC), and their parent material is described as till.

Table 2. USDA Soil Map Units

Unit Symbol	Unit Name	Landform – Parent Material
F641F	Udarents loamy, earthen dam, 1 to 75 percent slopes	n/a - Till
F592F	Kloten-Walsh-Edgeley loams, 6 to 35 percent slopes	Escarpments – Residuum weathered from shale
F143A	Barnes-Svea loams, 0 to 3 percent slopes	Ground moraines – Fine-loamy till
F122A	Svea-Cresbard loams, 0 to 3 percent slopes	Rises – Fine-loamy till

F592F soils are mapped on both abutments, both sides of the reservoir, within the general area of the auxiliary spillway (ASW), and below the downstream toe of the embankment. The Kloten soils are derived from residuum weathered from shale and have a typical profile consisting of loam and parachannery clay loam to 14 inches, and bedrock to 79 inches. The Walsh soils are derived from shaley fine-loamy colluvium and typically consist of loam to 79 inches. The Edgeley soils are derived from colluvium and residuum weathered from shale and have a typical profile consisting of loam to 15 inches, clay loam to 23 inches, parachannery silty clay loam to 32 inches, and bedrock to 79 inches. Per USCS, the soils above bedrock are classified as clay (CL) and silt (ML). The As-Built Drawings indicate the excavation for the upper part of the ASW was used as a borrow area, so colluvial and residual soils from map unit F592F may have been used in some of the placed fills.

The As-Built Drawings indicate Borrow Area A was located on the upland north of the proposed reservoir and upstream of the proposed dam. Borrow Area A is mapped primarily as soil map unit F143A—Barnes-Svea loams, 0 to 3 percent slopes. These soils are derived from fine loamy till and have a typical profile consisting of loam to a depth of 79 inches. Per USCS, these soils are classified as clay (CL) and silt (ML). A portion of Borrow Area A is mapped as Svea-Cresbard loams, 0 to 3 percent slopes (map unit F122A), which are also derived from fine loamy till and feature a typical soil profile consisting of loam to a depth of 60 inches (Svea soils) or loam, clay loam, and silty clay to a depth of 60 inches (Cresbard soils). These soils are primarily clay (CL) and clayey sand (SC).

3.3 Geologic Mapping

According to the geologic map of Walsh County (Bluemle, 1973), the two main geologic units present in the dam and reservoir area are, from youngest to oldest:

1) Pleistocene glacial till of the Coleharbor Formation, and

2) Cretaceous shale of the Pierre Formation.

The location of the dam is shown on a portion of the geologic map of Walsh County in Exhibit 4.

3.3.1 Glacial Deposits

Bluemle (1973) maps glacial till (map unit Cb1) of the Coleharbor Formation on the uplands adjacent to the valley of the North Branch of the Forest River (Exhibit 4). According to Bluemle (1973), the *"till typically consists of a nonsorted, nonstratified mixture of angular, subangular and rounded blocks of rock, gravel and sand in a stiff matrix of silt and clay,"* which *"were deposited directly from the glacier ice."* The silt and clay fraction is olive-gray to light gray where unweathered, and brownish to yellowish-gray where weathered. Bluemle reports that the oxidized zone is about 25 feet thick in the western part of Walsh County. The glacial deposits are less than 50 feet thick and absent on the flanks of the North Branch of the Forest River in the vicinity of Bylin Dam (Bluemle, 1986).

The glacial till includes the areas mapped as Barnes-Svea loams, 0 to 3 percent slopes (NRCS map unit F143A) and Svea-Cresbard loams, 0 to 3 percent slopes (NRCS map unit F122A). Borrow Area A on the north side of the reservoir lies within the area of glacial till.

Based on analyses of 19 till samples from northern Walsh County, Bluemle (1973) reports the till averages about 6 percent gravel, 30 percent sand, 40 percent silt, and 24 percent clay. On average, the gravel fraction consists of 40 percent shale (probably locally derived), 35 percent carbonate rock (apparently derived from Paleozoic carbonate sequences of southern Canada), and 25 percent granite and basic igneous rocks (derived from the Canadian Shield). Bluemle notes that the percentage of shale gravel is locally much higher in the western part of Walsh County where the Pierre Formation is near the surface, as is the case at Bylin Dam.

Bluemle (1973) reports that the till is generally non-bedded and uncemented and that crude jointing is common and gypsum crystals are commonly oriented parallel to the joint faces. Bluemle considers the map unit Cb1 till to be a ground moraine consisting areas of lodgement till (deposits directly influenced by the base of the moving glacier) and ablation materials (deposits lowered from upon and within the melting ice). According to Bluemle (1973), ablation materials, which probably slid into place as mudflow deposits, account for most of the glacial till included in the ground moraine.

3.3.2 Bedrock

In the vicinity of Bylin Dam, Bluemle (1973) maps the flanks of the North Fork of the Forest River valley as Cretaceous marine shales of the Pierre Formation (Exhibit 4). The Pierre Formation is 70 to 84 million years old (Bluemle, 2016) and unconformably underlies glacial drift and conformably overlies the Niobrara Formation. The Pierre Formation and the overlying Fox Hills and Hell Creek Formations constitute the Upper Cretaceous Montana Group in North Dakota (Murphy, et al., 2009).

In northeastern North Dakota, the Pierre Shale has been divided into four units, in descending order: Odanah Member, DeGrey Member, Gregory Member, and Pembina Member (Gill and Cobban, 1965). Exhibit 5 provides a stratigraphic correlation of the Pierre Shale across eastern North and South Dakota. Bylin Dam is closest to the section from Pembina Mountain in the Tongue River area on the left side of the correlation diagram.

Bluemle's description of the Pierre Formation in Walsh County is summarized in Table 3, with members listed youngest to oldest in descending order. Due to its siliceous composition, the Odanah Member is harder than the underlying members of the Pierre Shale and forms the resistant bed supporting the Pembina Escarpment (Bluemle, 1988).

Bylin Dam is thought to be underlain by the upper part of the Pierre Shale (Odanah Member) based on its location relative to the exposure localities listed in Table 3. According to the Summary of Foundation, Embankment, and Structural Engineering Data found in the Phase I Report (USACE, 1978, p. D-1), "the valley and abutments are underlain by very hard Pierre Shale." The description of the shale as "very hard" is consistent with Bluemle's (1973) description of the Odanah Member as a "hard, siliceous, gray shale."

Table 3. Pierre Formation in Walsh County (Bluemle, 1973, p. 12)

Member	Description	Exposure Localities
Odanah	Hard, siliceous, gray shale; reddish-brown and purple stains on joint faces and on concretions; jointing extensive in some exposures; commonly weathers to thin plates or flakes, but cube-shaped blocks and chunks about 6 inches across occur in some exposures; appears to be fractured along a north-south zone through western Walsh County and central Nelson County, perhaps by glacial movement or loading on the brittle shale.	Abundant along the South Branch of the Park River in T 157 to 158 N., R 57 to 58 W. (about 6 to 9.5 miles north of Bylin Dam) and along the Middle Branch of the Forest River (about 10 miles south of Bylin Dam).
DeGrey	Undifferentiated from Odonah Member: *"Most Pierre Formation exposures above the Gregory Member probably belong to the Odanah Member."*	Poorly exposed or absent.
Gregory	Bentonitic shale with conspicuous ironstone banding; exposed surfaces tend to form a loose granular surface mulch as a result of wetting, drying, freezing, and thawing; commonly slumped along the valley walls and is poorly exposed.	Overlying the Pembina Member in nearby river cuts.
Pembina	Soft, black shale interbedded with yellowish beds of bentonite and high concentrations of iron oxide near the contact with the underlying Niobrara Formation.	Sec. 13, T. 157 N., R. 57 W. (South Branch of Park River about 5 miles northeast of Bylin Dam).

The centerline profile of the dam indicates shale underlies the dam along its centerline, and the maximum cross section of the dam indicates the contractor was to "excavate to shale" beneath the embankment and that excavated shale was placed as an upstream slope buttressing berm to

Elevation 1481.2 feet and as a downstream slope buttressing berm to Elevation 1498.2 feet per Plate C 6 of the As-Built Drawings. The auxiliary spillway (ASW) was only partially excavated into the Pierre Shale per the topographic map of the dam site and the profile along the centerline of the ASW provided in Plates C-5 and C-6 of the As-Built Drawings.

3.4 Bedrock Structure

According to Bluemle (1973, p. 6), Walsh County is *"situated on the eastern edge of the Williston basin, an intracratonic, structural basin consisting of a thick sequence of sedimentary rocks,"* so *"all the formations below the Coleharbor have a westerly regional dip and become thicker westward."*

3.5 Seismicity

According to published mapping of earthquakes in North Dakota (Anderson, 2012), the closest earthquake to Bylin Dam occurred on November 15, 2008 near Goodrich, which is about 113 miles southwest of the dam. The 2008 Goodrich earthquake had a reported Modified Mercalli Earthquake Intensity value of II, which means the earthquake would have been felt only by a few persons at rest, especially on the upper floors of buildings.

A search of the USGS online earthquake catalog (https://earthquake.usgs.gov/earthquakes/search/, accessed, December 2020) for earthquakes of Magnitude 1 or greater within 200 miles of Bylin Dam indicated only the 2008 Magnitude 2.6 Goodrich earthquake mentioned above. The USGS online catalog reported a depth of 18.0 kilometers for the 2008 Goodrich earthquake.

The Precambrian basement of eastern North Dakota is part of the Superior Craton, which is an extremely old and deformed but geologically stable region (Bluemle, 2018). The North Dakota Geological Survey, Note 4, (Bluemle, 2018, p. 1) considers the state to be in an area of low earthquake probability:

> *"North Dakota is located in an area of low earthquake probability. Infrequent, small earthquakes may occur near or within the state, but it is unlikely they will cause any serious damage."*

The USGS Unified Hazard Tool (https://earthquake.usgs.gov/hazards/interactive/index.php, accessed December 2020) assigns horizontal Peak Ground Accelerations of 0.0105 g, 0.0192 g, and 0.0470 g for return periods of 1,000 years, 2,500 years, and 10,000 years, respectively; however, these values assume a V_{S30} of 760 m/sec with no correction factor for site specific conditions.

4 PREVIOUS STUDIES AND CONSTRUCTION RECORDS

This section of the GER discusses project conditions based on the previous field investigation, laboratory testing, the As-Built Drawings (USDA SCS, 1964), the USACE Phase I inspection reports (USACE, 1978), and Gannett Fleming's 2010 Dam Assessment Report (Gannett Fleming, Inc., 2010).

The 1964 As-Built Drawings (USDA SCS, 1964), available as an appendix to the USACE Phase I report (USACE, 1978) and included as Appendix D-1 of the Existing Conditions Report (HEI, 2021), provide boring locations along with boring log stick figures with general soil and rock descriptions. During the original dam design, seven test borings were drilled along the centerline of the dam. Fifteen additional test borings were drilled - six in the dam foundation, seven in the auxiliary spillway (ASW), and two in the borrow area. The ASW was originally referred to as the "emergency spillway" in earlier Bylin Dam documents (1964 through 2008).

4.1 Previous Subsurface Exploration

Table 4 provides a list of the 22 test holes (TH) shown on the As-Built Drawings – Plates C-2 and C-5 show the locations of the borrow area borings and the locations of the other 20 boring, respectively whereas graphic logs of all the borings except TH-1 are provided on Plate C-6 of the As-Built Drawings. TH-1 through TH-7 were drilled on the dam embankment centerline; however, TH-1 (on the left abutment) and TH-7 (on the left ASW slope) are outside the footprint of the dam embankment. TH-8 was drilled approximately 20 feet upstream of the dam centerline. TH-101 and TH-102 are located on the left side of the valley upstream of the dam in the vicinity of Borrow Area A. TH-206 through TH-211 were drilled in the Auxiliary Spillway. TH-208 and TH-211 are also on the projection of the dam embankment centerline. TH-301 and TH-302 were drilled along the Principal Spillway, with TH-301 near the inlet structure and TH-302 in the area of the downstream slope bench. TH-601 to TH-604 were drilled within the dam embankment footprint left of the Principal Spillway.

4.1.1 Embankment Foundation

The As-Built Drawings indicate twelve test borings were drilled in the embankment foundation area. Six test borings (TH-2 through TH-6, and TH-8) are located along the proposed dam centerline. Six additional test borings (TH-301, TH-302, and TH-601 through TH-604) were drilled in the floodplain below the embankment to the north and south of the centerline. The Phase I Inspection Report (USACE, 1978, p. D-1) describes the pre-construction foundation as follows:

> *"Twelve holes, 14 to 25 feet deep were drilled in the embankment foundation area. Six were located along the centerline and are located as shown on Plate C-5. The logs are shown in profile on Plate C-6. Detailed logs were not available for preparation of this report. The alluvium material encountered consisted of low density silts and clays which contained large quantities of shale fragments and organic material. It classified as MH and CL and was from 7 to 20 feet thick. The thickest section was in the left side of the valley. Glacial till consisting of clay, silt, and sand that varied from very shallow to 28 feet thick covered the abutments. The valley and abutments are underlain by very hard Pierre shale. Ground water in the valley holes was from 2 to 12 feet below ground surface. It was not encountered in the abutments except in sand lenses within the till."*

Table 4 summarizes the approximate elevations of the top of the Pierre Shale shown in the graphic logs in the As-Built Drawings. The elevation of the top of the Pierre Shale varies from approximately 1452.2 to 1463.2 feet in the test holes within the footprint of the embankment. The Pierre Shale surface elevation varies from approximately 1452.2 to 1454.2 feet in the test holes along the Principal Spillway (TH-4, TH-301, and TH-302) in the central portion of the valley.

The Phase I Inspection Report (USACE, 1978, p. 2) describes the constructed embankment and foundation conditions as follows:

> *"The embankment consists entirely of impervious glacial till material. All the existing valley foundation material was excavated to shale bedrock below the entire embankment width for nearly its entire length. A cutoff trench with 1V on 2H side slopes runs along the entire length of the embankment. It was excavated to firm shale and is 24 feet wide below the valley section of the embankment and 12 feet wide in the abutments."*

Table 4. Dam Site Borings, Circa 1960

Boring	Location[1]	Surface Elevation[2] (ft)	USCS Classification	Top of Pierre Shale Elevation[2] (ft)
TH-1	Dam A; left abutment	>1525.2	-	-
TH-8	Dam A; Sta. 12+00, 20' US	1481.2	CL	1463.2
TH-2	Dam A; Sta. 12+50	1476.2	CL	1462.2
TH-3	Dam A; Sta. 13+00	1470.2	CL	1458.2
TH-4	Dam A; Sta. 14+50	1468.2	CL	1454.2
TH-5	Dam A; Sta. 15+50	1464.2	CL	1454.2
TH-6	Dam A; Sta. 16+00	1465.2	CL	1455.2
TH-601	Upstream Berm, Sta. 13+00,150' US	1470.8	CL, MH	1459.2
TH-602	Downstream Berm, Sta. 13+00, 100' DS	1470.6	CL	1457.2
TH-603	Downstream Toe, Sta. 12+20, 150' DS	1475.7	CH, CL	1463.2
TH-604	Upstream Berm, Sta. 11+80, 150' US	1481.4	MH, CL	1459.2
TH-301	Principal Spillway Alignment, 170' US	1468.2	CL, SC	1452.2
TH-302	Principal Spillway Alignment, 100' DS	1467.2	CL	1453.2
TH-206	Auxiliary Spillway	1528.2	CL	1502.2
TH-7	Left ASW slope	1531.2	CL	1500.2
TH-207	Auxiliary Spillway	1533.2	CL, SC	1511.2
TH-208	Auxiliary Spillway	1542.2	CL	<1523.2
TH-209	Auxiliary Spillway	1536.2	ML, CL	1526.2
TH-210	Auxiliary Spillway	1532.2	ML, CL	1518.2
TH-211	Auxiliary Spillway	1537.2	CL	1520.2
TH-101	Borrow Area A	>1531.2	CL, SM	-
TH-102	Borrow Area A	>1531.2	CL	>1517.2

Notes: 1) Listed offsets are approximate. DS = downstream, US = upstream.
2) Converted to NAVD88

4.1.2 Auxiliary Spillway (ASW) and Borrow Area

The As-Built Drawings indicate nine test borings were drilled in the auxiliary spillway and borrow areas. Seven test borings (TH-7, and TH-206 through TH-211) are located within the spillway area. Two additional test borings (TH-101 and TH-102) were drilled in the left abutment borrow area. The Phase I Inspection Report (USACE, 1978, p. D-1) describes the spillway and borrow areas as *"mostly glacial till consisting of silts, sands and clay."* The elevation of the top of the Pierre Shale varied from 1500.2 to 1526.2 feet in the Auxiliary Spillway borings.

4.2 Previous Laboratory Testing

Previous laboratory testing is summarized below based on the summary of foundation, embankment, and structural engineering data provided in the Phase I Inspection Report (USACE, 1978).

4.2.1 Foundation Materials

No laboratory testing was performed on the foundation material. According to the Phase I Inspection Report (USACE, 1978, p. D-1 – D-2):

> *"Specific tests were not made on the foundation alluvium material. The alluvium was considered to be a low-density material similar to that encountered on the Tongue River M-3* [Senator Young] *dam, another SCS project. The unconsolidated-undrained "R" strengths tested on the Tongue River M-3 project were $\phi = 10^{\circ}$, cohesion = 250 psf. These strengths were assumed in the stability for this dam, but the strengths were too low, and the material was excavated from beneath the embankment section. The shale below the soft alluvium was described as hard and considered non-yielding; therefore, laboratory tests were not run."*

4.2.2 Embankment Materials

The Phase I Inspection Report (USACE, 1978, p. D-2) describes the embankment materials as follows:

> *"The embankment contains mostly glacial till of silts, sands, and clay. A section is shown on Plate C-6* [of the As-Built Drawings]. *Tests were run on typical materials that would be placed in the embankment…Consolidation tests were run on typical fill samples to determine the expected embankment consolidation on which the 1.6-foot overbuild was based. Construction compaction specifications state that all embankment materials shall be compacted to 95% of modified maximum density and moisture above optimum."*

Consolidated-undrained "R" test results are summarized in Table 5, and embankment field density test results are summarized in Table 6.

4.2.3 Auxiliary Spillway (ASW) Materials

No laboratory testing was performed on the material from the auxiliary spillway based on the documents provided for review.

Table 5. Consolidated-Undrained "R" Tests (USACE, 1978)

Type Material	Liquid Limit	Plasticity Index	ϕ (degrees)	Cohesion (psf)
ML	32	6	23	375
ML	46	17	18	1000
SM	38	12	20.5	800
CL	36	16	30.5	4750
CL	36	16	11	1150
MH (Shale)	--	--	18	900

Table 6. Embankment Field Density Tests (USACE, 1978)

Number of Tests	Dry Density (pounds/ft^3)			% Compaction Modified AASHO
	Minimum	Maximum	Predominant Range	
186	97	115.7	102 - 108	96 to 100+

4.3 Foundation Treatment

The Phase I Inspection Report (USACE, 1978, p. D-1) describes the foundation treatment as follows:

> *"The foundation alluvium in the valley was determined to be weak material and was, therefore, excavated to shale bedrock beneath the entire embankment section. A core trench cutoff was excavated to firm shale or glacial till below the entire length of the embankment. The extent of this excavation and cutoff is shown in profile and section of Plate C-6* [of the As-Built Drawings]. *The excavated material was used in the berm areas and the excess was dumped downstream of the embankment. The excavation and cutoff were backfilled with embankment material."*

Portions of the Auxiliary Spillway in cut were overexcavated a half-foot and backfilled with suitable topsoil per the sections provided in Plate C-6 of the As-Built Drawings.

4.4 Drains

The Phase I Inspection Report (USACE, 1978, p. 2) describes the foundation drain as follows:

> *"There is a minimum 4-foot thick, 570-foot long, trapezoidal-shaped filter drain that is set on shale below the valley and abutment sections of the embankment. It is located primarily 102 feet downstream of the centerline. 6-inch diameter perforated pipe extends through the valley section of the drain and non-perforated pipe empties seepage into the stilling basin on both sides of the outlet pipe."*

Plan and profile drawings of the foundation drains are provided in Plate C-7 of the As-Built Drawings. Details indicate the transverse drain is 11 feet wide at the top and three feet wide at the base with four-foot-high 1H:1V side slopes. The six-inch-diameter perforated drain pipe in the valley section is centered one foot below the top of the drain. During construction, the foundation drain aggregate gradation limits were modified to allow placement of a coarser aggregate than designed (see Table 16 in Section 6.2 for the gradation).

Plate C-7 of the As-Built Drawings provides a summary of foundation drain quantities, reproduced as Table 7, and the following notes regarding construction of the drain:

1. *"Plug upper end of asbestos cement pipe with 6" of concrete or prefabricated end plug.*
2. *Place compacted fill to top of drain (where drain is above bottom of foundation excavation) and excavate drain in compacted fill.*
3. *Provide 1"x1", 12 ga. galvanized woven wire mesh over outlet ends of outlet pipes: clamp in place with 1"x 1/16" galvanized strap, 2'-2" long, use ¼" dia. galvanized bolts."*

Table 7. Foundation Drain Quantities (USACE, 1978)

Item	Quantity	Units
Excavation	560	Cu. Yds.
Graded Filter Material	578	Cu. Yds.
Backfill	20	Cu. Yds.
6" Dia. Asbestos Cement Perforated Pipe (Johns-Manville Transite, Class 150, pressure pipe or equal)	400	Lin. Ft.
6" Dia. Asbestos Cement Non-Perforated Pipe (Johns-Manville Transite, Class 150, pressure pipe or equal)	196	Lin. Ft.

4.5 Previous Repairs and Inspection Observations

Based on the documents provided for review, no major repairs have been made to Bylin Dam since its construction in 1964. Dam inspections have provided periodic observations on the condition of the dam and its appurtenances. The 1978 Phase 1 Inspection Report and appended reports of dam inspections conducted between 1978 and 2008 identified numerous small aspects of the dam that could be improved but nothing that could significantly impact the safety of the dam. Gannett Fleming's 2010 Bylin Dam Assessment Report identified many similar concerns as well as some additional deficiencies. The most recent inspection of Bylin Dam was completed by the North Dakota State Water Commission (ND SWC) in 2018. Summary of the findings from these site visits are provided in the following sections.

4.5.1 Embankment Slopes

Gannett Fleming's 2010 Dam Assessment Report (p. 8) identified the following deficiencies associated with the embankment slopes:

- *"Knee to waist high weeds and grass observed on the upstream and downstream embankment slopes, at the abutment contacts, and around the PSW plunge pool and outlet channel obscured proper inspection of these areas.*
- *Saplings observed on the embankment slopes.*
- *Two apparent sloughs found on upstream embankment slope.*
- *Vehicle tracks noted along toe of downstream embankment slope and with deep ruts on the upstream embankment slope and ASW inlet channel.*
- *Standing water observed at downstream embankment toe.*
- *Numerous pocket gopher burrows on the embankment slopes.*
- *Erosion along the shoreline to the left of the riser structure, possibly due to sparse riprap."*

"Note: It is recommended that all vegetation growing on the dam embankment slopes, within a minimum of 15 feet of the downstream toe and abutment contacts, at any downstream wet areas, drain outlets, and in the vicinity of the PSW outlet channel be cut and removed. It is recommended that cutting and removal of vegetation at the above locations be followed by a proper dam safety inspection and documentation of conditions at the dam."

Additional potential geotechnical deficiencies identified in the 2010 Dam Assessment Report (p. 16) include the following:

- *"Anti-seep collars were built along PSW, and a filter diaphragm was not constructed.*
- *Possible jugholes on downstream slope above PSW. The possible jugholes found on the downstream slope is potentially strong evidence for dispersive soils. Glacial and alluvial soils can be dispersive.*
- *The downstream slope appears to be irregular.*

- *Dense vegetation surrounding drain outlets limits flow and obstructs proper observation.*
- *Unknown amounts of settlement for embankment, PSW, and structures. As-Built Plans predict 1.6 feet of settlement at the embankment crest.*
- *Slope stability factors of safety for all applicable design conditions using field verified phreatic surfaces are unknown.*
- *No instrumentation has been installed on the dam site."*

The Watershed Structure Inspection Report (Inspection Checklist) dated July 27, 2010, (Gannett, 2010, p. A-2) states,

- *"Woody vegetation observed growing on downstream embankment slope.*
- *Upstream embankment slope: A 33' long slough observed near left abutment. Slough was 2' to 3' wide by 1' high with an uphill scarp. Slough is oblique to the slope and may follow a previous haul road. A second slough observed about 50 feet left of the riser structure and above the upper level berm (El. 1489.0). Slide material was fully vegetated.*
- *Downstream embankment slope: Slope above principal spillway conduit is disturbed. Surface appearance similar to numerous pocket gopher holes. Jugholes formed by dispersive soils could also cause these features. The slope is irregular.*
- *Vehicle tracks along toe on the right side of downstream embankment slope.*
- *Animal trails with erosion observed starting from outlet channel, up the downstream embankment slope to the berm, across the berm, and up and across the ASW."*

The 2018 Bylin Dam Inspection Report (p. 1), included the following key inspection findings:

- *"The upstream slope has minor scarping along the waterline in several areas to the left of the principal spillway inlet.*
- *There are vehicle tracks on the upstream and downstream slopes. There is some rutting in the tracks on the upstream slope.*
- *The downstream slope has scattered young trees and bushes and young trees. There are also a few trees growing towards the downstream end of auxiliary spillway.*
- *The interior of the principal spillway conduit was inspected, and no significant concerns were noted."*

4.5.2 Flood Levels

According to the Phase I Inspection Report (USACE, 1978, p. 4):

> *"In the spring of 1965, the pool filled to elevation 1502.5 m.s.l.* [1503.7 NAVD88]. *This is 13.5 feet above the normal pool and 14.5 feet below the crest elevation of the emergency spillway. Records of other flood elevations are not available.*

> *Conversations with the SCS indicate that all significant flood levels in the past have been due to snow melt or snow melt with rain."*

4.5.3 Erosion

The Phase I Inspection Report (USACE, 1978, p. 4-5) describes the following areas of damage by ice or erosion and their repair.

Operation and Maintenance History: *"There are maintenance items that have been repaired in the past. These include: (1) trash rack damage caused by ice; (2) erosion around the scour hole* [i.e., a rock-lined scour hole for stilling principal spillway conduit outflows]*, the worst case having occurred from the 1965 flows; (3) runoff erosion at the exit end of the emergency spillway; and (4) runoff erosion along the slopes and berms. No major items considered to constitute a hazard were discovered during past inspections."*

Abutments: *"There is a runoff erosion gully along the left abutment-embankment contact."*

Emergency Spillway: *"The base and side slopes have an adequate grass cover. Erosion areas mentioned in the past inspections had been repaired."*

4.5.4 Seepage

The USACE (1983, p. F-1) Reinspection report of Bylin Dam states,

> *"There was no visible seepage coming into the downstream channel, however, tall coarse grass was observed on the floodplain. This would indicate a low flow rate, but steady type of seepage."*

The USACE (1991, p. F-6) Reinspection report of Bylin Dam states,

> *"A pit containing gravel and shale particles was located immediately downstream of the embankment on the left abutment. Some seepage was coming from the pit. There is a small ditch at the lower end of the pit which collects the seepage and carries it away. A wet type grass was growing in and along this ditch. This area was well above the reservoir elevation and, therefore, is not pool related."*

Gannett Fleming's 2010 Dam Assessment Report (Gannett Fleming, Inc., 2010, p. A-2) states,

> *"Wet area with standing water observed downstream of the toe of the downstream embankment slope near the left abutment." The report also states, "Seepage area that includes cattails and water-filled tire ruts observed at left downstream toe area."*

The 2018 inspection of Bylin Dam did not identify any seepage concerns.

4.5.3 Foundation Drains

Review of the historical inspections of the Bylin Dam indicates that obstruction of the foundation drains by weeds and moss have been an ongoing concern at the site. Gannett Fleming's 2010 Dam Assessment Report (p. A-2) states,

> *"Right foundation drain observed with estimated 2 gpm discharge. Left foundation drain was not accessible due* [to] *significant amount of flow through PSW and dense weed and brush growth. Dense vegetation limits flow from drains."*

The 2018 Bylin Dam Inspection Report (p. 1) states:

> *"The left toe drain outlet was almost completely clogged. There was substantial flow from the drain when it was cleaned out. The end of the right toe drain outlet was also almost covered with moss."*

A summary of the foundation drain inspection data is provided in Table 8. Potential geotechnical deficiencies associated with the foundation drain identified in the 2010 Dam Assessment Report (p. 16) include the following:

- *"Single broadly graded coarse aggregate was used in the drains. The large maximum particle size, 3 inches, will encourage segregation of the material*
- *Records of drain flow at varying reservoir levels are not available."*

Table 8. Foundation Drain Inspection Summary

Inspection Date	Left Foundation Drain Flow	Right Foundation Drain Flow	Reservoir Elevation* (feet)
19-Jul-1978	NR	NR	1490.2
19-Oct-1983	0.5" Deep = 4 gpm	Est 1 to 2 gpm	1489.9
29-Sep-1987	Calc = 2.68 gpm	Calc = 1.61 gpm	1490.0
20-Aug-1991	Est = 2.6 gpm	Est = 1.6 gpm	1490.2
08-Jul-1995	Calc = 2.1 gpm	Calc = 0.401 gpm	1490.2
27-May-2008	Est = 1.5 gpm	Est = 0.5 gpm	1490.2
27-Jul-2010	NA	Est = 2 gpm	1490.2 (+) **
18-Jul-2018	NR	NR	1490.3

Notes: * Normal Pool Elevation = 1490.2 feet
** Reservoir elevation > 1490.2 feet since PSW conduit is flowing.
NR = Not Recorded; NA = Not Accessible; Calc = Calculated; Est = Estimated

4.5.5 Principal Spillway (PSW)

Gannett Fleming's 2010 Dam Assessment Report (p. 15) states the following as a potential spillway-related dam safety deficiency:

> *"Existing riser structure is non-standard for NRCS structures. If the dam would go through a rehabilitation process, consideration should be given to upgrading the riser structure to current NRCS standards."*

Gannett Fleming's 2010 Dam Assessment Report (p. 16) states:

> *"Anti-seep collars were built along PSW, and a filter diaphragm was not constructed."* The report also states, *"The time period for original design and construction was before the current NRCS geotechnical design criteria had been established. The anti-seep collars along the PSW and the use of single coarse aggregates in drains are two examples of deficiencies that appear to be a result of significant changes in design criteria since original design and construction."*

4.5.6 Low-Level Outlet of PSW

Gannett Fleming's 2010 Dam Assessment Report (p. 5) states:

> *"The 12-inch low-level drawdown is provided to drain or lower the reservoir to water surface elevations below the orifice. The 12- inch low-level drawdown consists of a headwall structure at the upstream intake, a 12-inch outside diameter 14 gauge welded steel pipe connecting the headwall to about six-inches above the riser structure invert, and a gate valve along the steel pipe housed in a valve well immediately upstream of the exterior of the riser structure."*

The operational status of the gate for the PSW low-level outlet is "unknown". The previous inspections (1978 – 2008) and the 2018 Inspection also list the status as unknown.

4.5.7 PSW Conduit

Gannett Fleming's 2010 Dam Assessment Report (p. A-2) states:

> *"Mortar deterioration/spalls observed at the downstream end of PSW conduit on the last section of reinforced concrete pipe. However, the deterioration/spalls appear to be limited to the mortared end of the pipe."*

The 2018 Bylin Dam Inspection Report includes a table summarizing the PSW conduit inspection results between 1987 and 2018. Per the notes in the table, the PSW conduit has 21 joints (despite only 19 joints being shown in the plans), and the joints are numbered in ascending order from upstream to downstream. During the 2018 inspection, most of the top and bottom joint gaps were rated as "Cl," which means the joint gap is tight to 0.25 inch. "Small gaps" were noted at the top of Joints 7 and 10 and at the bottom of Joints 2, 3, 5, 6, 7, 8, 9, 10, 12, 15, 18, 19, 20, and 21.

4.5.8 Auxiliary Spillway (ASW)

Gannett Fleming's 2010 Dam Assessment Report (p. 8) states: *"Tree and brush growth observed on the ASW"*. Utilizing pre-construction subsurface data, an integrity evaluation of the ASW was conducted by Gannett Fleming (2010). Results using the parameters shown in Table 9 yielded a complete breach of the ASW crest during passage of the 24-hour FBH.

Table 9. Parameters for 2010 ASW Integrity Analysis

Material Description	Assumed ASW Material Erosion Parameters				
	Dry Density (lb/ft^3)	Head Cut Index (K_h)	Percent Clay	Plasticity Index	D_{75} / Rep. Dia. (in)
Soil	110	0.16	5	2	0.2
Rock	90	0.5	0	0	3

Additional comments from the Watershed Structure Inspection Report (Inspection Checklist) dated July 27, 2010 (Gannett Fleming, 2010, p. A-2) associated with the ASW include the following:

- *"Trees observed growing near downstream end of ASW along the right side of the spillway and in the center of the spillway.*
- *Several animal trails were present on the ASW.*
- *Vehicle ruts and erosion was present on the ASW approach channel (the boat ramp entrance from the road).*
- *Hay bales observed in ASW*
- *Drainage from the road across the ASW has eroded a gully in the ASW approach channel, about 14" deep by 3' to 4' wide. Erosion/material slides observed upstream of boat ramp and ASW approach channel."*

4.5.9 Hydrologic Capacity

Gannett Fleming's 2010 Dam Assessment Report (p. 10) states:

- *"With respect to the 100-year flood activation criterion, the ASW crest elevation is 3.2 feet lower than required for a NRCS High Hazard Structure and 2.9 feet lower than required for a ND SWC High Hazard Structure. This criterion stipulates that the ASW be utilized only for events greater than a 100-year flood.*

- *For a NRCS High-Hazard Structure, the top of dam would need to be raised 4.0 feet to pass the Freeboard Design Hydrograph (FBH) without overtopping the dam if the ASW crest is raised 3.2 feet.*
- *For a ND SWC High Hazard Structure, the top of dam would need to be raised 3.7 feet to pass the Freeboard Design Hydrograph (FBH) without overtopping the dam if the ASW crest is raised 2.9 feet.*
- *For a NRCS High Hazard Structure and a ND SWC High Hazard Structure, the principal spillway capacity should be adequate to empty the retarding pool in 10 days or less. This requirement is considered met if 15 percent or less of the maximum volume of retarding storage remains after 10 days. Because more than 15 percent of the retarding storage volume remains after 10 days as indicated in Table 3, the elevation of the crest of the auxiliary spillway must [be] raised beyond the peak pool level corresponding to the 100-year PSH routing with a starting pool level at the lowest ungated inlet."*

4.5.10 Hydraulic Capacity

Gannett Fleming's 2010 Dam Assessment Report (p. 12) states: *"The SITES ASW Analysis indicates that the existing ASW crest is anticipated to completely breach during passage of the 24-hour FBH for a ND SWC Class V structure."*

5 2020 PRELIMINARY GEOLOGIC INVESTIGATION

5.1 General

GF drilled six borings in June 23-July 2, 2020 to develop profiles and geotechnical data for evaluation of the spillway integrity and for characterization of the embankment and foundation soils. The locations of the six test borings are shown in Exhibit 6, hand-written field logs and typed boring logs are provided in Attachment A. The core run photos and split spoon photos can be made available upon request. A subsurface profile of the auxiliary spillway is shown in Exhibit 7.

Borings BD2020-212, -213, and -214 were drilled in the ASW to develop a geologic profile for use in evaluating the spillway integrity. Borings BD2020-9 and -605 were drilled within the dam embankment, at the dam crest and downstream bench, respectively, to characterize embankment and foundation soils. Boring BD2020-606 was drilled beyond the toe of the embankment to characterize foundation materials. Borings BD2020-9, -605, and -606 are in alignment with one another, perpendicular to the dam centerline at Sta. 14+00, to provide an embankment cross section.

Interstate Drilling Services LLP (IDS) of Grand Forks, ND drilled the test borings. IDS is certified as a Monitoring Well Contractor (#427) and a Water Well Contractor (#201) in North Dakota. Gannett Fleming provided full-time observation of subsurface exploration activities.

5.2 Standard Penetration Testing

Hollow stem augers (4.25-inch ID) were used for drilling, and continuous Standard Penetration Testing (SPT) soil samples were collected using s 2.5-foot-long sampler (2-inch OD). Blow counts from the SPT performed during drilling provide an indication of the relative density of granular soils and the relatively consistency of fine-grained cohesive soils. SPT results are typically expressed as an "N-value," which represents the number of blows required to advance the 2-inch-OD sampler two consecutive 6-inch increments using a 140-pound hammer falling 30 inches or an equivalent autohammer. Table 10 lists the range and average N values based on the SPT results. The N values do not factor in cases where refusal occurred. SPT refusal is defined as when 50 hammer blows are insufficient to advance the sampler six inches and is often indicative of a dense or hard material. A total of 17 refusals were observed, 16 of which occurred in the upper portions of the encountered Pierre Shale. The number of refusals and percentage of tests refusing are also listed in Table 10.

Table 10. SPT Refusals and N-Value Ranges and Averages

Stratum	Boring	Number of Tests	Test Refusals		N Values		
			Number	%	Range	Mean	Median
Embankment	BD2020-9	26	1	4%	7 - 18	13	13
	BD2020-605	15	0	0%	5 - 20	12	11
Downstream Overburden	BD2020-606	3	0	0%	5 - 12	7	5
Auxiliary Spillway Overburden	BD2020-212	5	0	0%	7 - 24	17	18
	BD2020-213	5	0	0%	7 - 25	13	11
	BD2020-214	1	0	0%	n/a	7	7
Pierre Shale	BD2020-605	1	1	100%	n/a	-	-
	BD2020-606	2	1	50%	n/a	4	4
	BD2020-212	5	4	80%	n/a	61	61
	BD2020-213	9	9	100%	n/a	-	-
	BD2020-214	7	1	14%	39 - 61	54	57

5.3 Undisturbed Soil Sampling

A total of five attempts at collecting undisturbed soil samples were made, four of which were successful in obtaining samples. Undisturbed sampling was conducted in accordance with ASTM D1587. A summary of the undisturbed soil sampling is presented in Table 11. Undisturbed tube samples were used to perform laboratory shear strength and permeability testing on embankment and downstream overburden soils.

Table 11. Summary of Undisturbed Soil Samples

Boring	Sample ID	Depth (ft)	Recovery (ft)	Stratum
BD2020-9	U-1	25.0 – 27.5	1.8	Embankment
BD2020-9	U-X	47.5 – 50.0	0	Embankment
BD2020-9	U-2	52.5 – 55.0	1.7	Embankment
BD2020-605	U-1	20.0 – 22.5	1.8	Embankment
BD2020-606	U-1	7.5 – 10.0	0	Embankment Foundation

5.4 Rock Coring

Rock coring was conducted in all borings after SPT sampling was determined to be ineffective means of material recovery. Borings BD2020-212, -213, and -214 were cored with NQ diameter tooling while borings BD2020-9, -605, and -606 were cored with HQ diameter tooling to allow for nested piezometer construction. A total of 116 feet of rock was cored, all of which was the Pierre Shale, with 90% recovery and 71% Rock Quality Designation (RQD), indicating good quality rock. A summary of recovery and RQD per borehole is presented in Table 12. The rock was generally very soft as core specimens could be broken by hand and gouged with a fingernail. The core developed hairline fractures parallel to bedding over time. The rock was soft enough to be generally penetrable using SPT sampling techniques immediately below the top of rock.

Table 12. Summary of Rock Coring

Boring	Total Footage	Recovery		RQD	
		Length	%	Length	%
BD2020-9	17	10	59	7.6	45
BD2020-605	17	16.7	98	12.4	73
BD2020-606	12	11.9	99	11.1	93
BD2020-212	14	12.9	92	7.8	56
BD2020-213	25	25	100	22.7	91
BD2020-214	31	27.8	90	21.2	68

5.5 Piezometer Installation

Borings BD2020-9, -605 and -606, were equipped with vibrating wire pressure transducers, which were grouted in place in the borehole. The two pressure transducers were connected to a datalogger housed in a lockable steel enclosure affixed to a raised casing. Piezometer construction logs can be made available upon request. Piezometric data obtained from the vibrating wire pressure transducers through November 19, 2020 can also be made available upon request.

5.6 Field Crumb Dispersion Testing

Field crumb dispersion tests were performed on 12 soil samples in accordance with ASTM D6572 except that Solo No. 9 cups were used in lieu of ceramic bowls. Test results are summarized in Table 13. The results suggest the embankment is non-dispersive, however the auxiliary spillway overburden soils and Pierre Shale exhibit dispersive characteristics. Photos of the field crumb dispersion tests can be made available upon request.

Table 13. Field Crumb Dispersion Test Results

Stratum		Boring	Sample Depth (ft)		Grade
Dam	Embankment	BD2020-9	27.5	32.5	1: Non-dispersive
			55.0	67.5	1: Non-dispersive
		BD2020-605	12.5	25.0	1: Non-dispersive
			35.0	40.0	1: Non-dispersive
	Downstream Overburden	BD2020-606	0.0	5.0	1: Non-dispersive
			5.0	12.5	1: Non-dispersive
Auxiliary Spillway	Overburden	BD2020-212	0	12.5	1: Non-dispersive
		BD2020-213	0	11.6	3: Dispersive
		BD2020-214	0	2.7	1: Non-dispersive
	Pierre Shale	BD2020-212	12.5	20.2	3: Dispersive
		BD2020-213	11.6	20	1: Non-dispersive
		BD2020-214	21.7	30	3: Dispersive

5.7 Lab Testing

Laboratory testing of soil and rock samples collected during the 2020 subsurface exploration program was performed for use in geotechnical analysis. Soil gradation data was used for drain fill compatibility analysis, auxiliary spillway integrity parameter selection and to estimate parameters for embankment seepage and stability models. All testing was performed in accordance with ASTM test standards.

The 2020 laboratory testing program was conducted by Terracon Consulting Engineers located in Grand Forks, ND. Soil and rock testing included the following:

- 13 moisture content tests (ASTM D2216)
- 8 USCS Classifications: sieve (ASTM D422), hydrometer (ASTM D7928), and Atterberg Limits ASTM D4318)
- 6 Specific gravity tests (ASTM D854)
- 10 Unit weight of soil and rock tests (direct measure)
- 12 Crumb dispersion tests (ASTM D6572)
- 3 Flexible wall permeability tests (ASTM D5084)
- 9 Consolidated, undrained triaxial shear strength tests with pore pressures monitored (ASTM D4767)
- 3 Slake durability tests (ASTM D4644)
- 3 Point Load Strength Index of Rock tests (ASTM D5731)

The triaxial permeability and CU_{bar} shear strength tests were performed on intact specimens obtained from Shelby tube sampling. Laboratory soil classifications are presented in Table 14. Laboratory test results are included in Exhibit 8.

Table 14. Summary of Laboratory Classifications

Test Boring Number	Sample Depth (ft)	Stratum	USCS Class	Material Description	LL	PI	w (%)
BD2020-9	25 - 27.3	Embankment	SC	Clayey SAND	41	21	25.7
BD2020-9	52.5 - 54.8	Embankment	CL	Sandy lean CLAY	30	12	22.4
BD2020-213	2.5 - 10	Spillway	SC	Clayey SAND	36	17	26.2
BD2020-212	12.5 - 17.5	Spillway	CL	Lean CLAY	44	23	24.2
BD2020-605	20 - 22.5	Embankment	SC	Clayey SAND w/ gravel	44	22	17.7
BD2020-605	41 - 41.5	Pierre Shale	MH	Elastic SILT w/ sand	64	31	17.7
BD2020-606	7.5 - 10	Downstream Overburden	MH	Elastic SILT w/ sand	66	27	43.9
BD2020-606	12.5 - 14.3	Pierre Shale	MH	Elastic SILT w/ sand	61	23	18.3

5.8 Subsurface Exploration Findings

The available data from all previous and current subsurface exploration programs were evaluated and considered in the current analyses. The following discussion is focused on the results of the 2020 exploration. The reader should take note that lower case USCS symbols indicate field classifications, performed in accordance with ASTM D2488, whereas upper case USCS symbols indicate laboratory classifications, performed in accordance with ASTM D2487.

5.8.1 Embankment

The typical embankment section, reproduced from the As-Built Drawings (USACE, 1978) is shown in Figure 1 and indicates a homogeneous embankment comprised of glacial till with a shale buttress on the downstream slope.

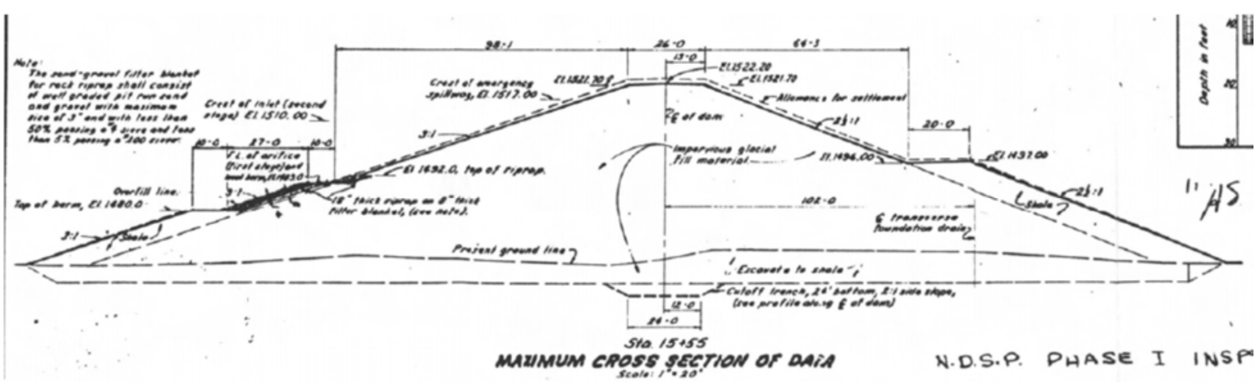

Figure 1. Typical Embankment Section from As-Built Drawings

Embankment material was encountered in borings BD2020-9 and BD2020-605 and classified as clayey sand (SC), clayey sand with gravel (SC), sandy clay (cl), and sandy lean clay (CL). This compares reasonably well with the Phase I report (USACE, 1978) that indicates the embankment is comprised of a glacial till classified as silt (ML), silty sand (SM), clay (CL) and shale (MH). The engineer's field log indicates a relatively consistent material with N values ranging between 5 and 20 blows per foot (bpf) and averaging 13 bpf with pocket penetrometer readings ranging from 1 tons per square foot (tsf) to greater than 4.5 tsf. Laboratory testing confirms a relatively low permeable material with measured hydraulic conductivities of 5.0×10^{-8} and 2.9×10^{-7} cm/sec. Crumb dispersion testing performed in the field indicates embankment soils are non-dispersive, however this was not corroborated with the laboratory testing as one specimen was graded as "intermediate" and two specimens were graded as "dispersive". Shear strength testing indicated a drained friction angle of 33°.

The boring logs for BD2020-605 did not discern a difference between the embankment fill comprised of glacial till and embankment fill comprised of shale. It is assumed that the shale fill would have been substantially broken down into a mixture of gravel, sand, and fine-grained particles during placement. Therefore, engineering properties of the shale buttress are assumed to be similar to the rest of the embankment.

The As-Built drawings show the crest constructed to El. 1525.0 (converted to NAVD88) and predicted to be at El. 1523.4 (converted to NAVD88) after settlement. The 2020 survey measured the crest at El. 1524.7 indicating the dam has settled 0.3 feet, which is 1.3 feet less than the predicted settlement of 1.6 feet. The As-Built drawings indicate that extra fill was placed elsewhere on the embankment as an allowance for settlement – the thickness of this allowance appears to increase with increasing dam height, but the over-build is only quantified at the dam crest. Based on a comparison of elevations identified on the As-Built drawings with surveyed elevations, the actual settlement appears to be less than expected. Time-rate of settlement curves from the consolidation testing conducted prior to construction are not available, however it is assumed that consolidation of the embankment and foundation soils is complete.

5.8.2 Foundation Soil

Per the As-Built Drawings (USACE, 1978) and substantiated by borings BD2020-9 and -605, the embankment is founded directly on the Pierre Shale. However, downstream of the embankment toe, BD2020-606 encountered overburden soils consisting of elastic silt with sand (MH) and sandy clay (cl). Per the engineer's field logs, the N values in the overburden ranged from 5 to 12 bpf and averaged 7 bpf. Pocket penetrometer readings ranged from 0 to 3.3. tsf. Crumb dispersion testing results varied between "non-dispersive" and "highly dispersive". Laboratory permeability testing yielded a hydraulic conductivity of 3.5×10^{-8} cm/sec and shear strength testing indicated a drained friction angle of 38°.

5.8.3 Auxiliary Spillway Soils

Auxiliary spillway soils were encountered in borings BD2020-212, -213, and -214 and consisted of clayey sand (SC), sandy clay (cl), and lean clay (CL). Per the 2020 engineer's field logs, the N-values ranged from 7 to 25 bpf with an average of 14 bpf. Pocket penetrometer readings ranged from 1 tsf to 4.5 tsf. Dispersion testing on spillway soils indicates soils are generally non-dispersive, however one field test was characterized as “dispersive”. No permeability or shear strength testing was completed on spillway soils.

5.8.4 Foundation Rock

The rock underlying the project site was identified as Pierre Shale and was encountered in all six borings. The foundation rock was field described as a very dark gray to dark gray clayey shale but was classified in the laboratory as an elastic silt with sand (MH) per USCS. The Pierre Shale was noted to be very soft, and thinly bedded with occasional sandstone and chert interbeds and soft enough to be sampled with SPT methods near top of rock. Per the engineer’s field logs, N-values ranged from 39 to 61 bpf with an average of 54 bpf, but 67% of the SPT attempts yielded refusal blows. When cored, the rock yielded 90% recovery and 71% RQD. For the purposes of this report, the depths to which the Pierre Shale can be sampled with SPT methods is considered to be “weathered” whereas where the Pierre Shale is cored is considered to be “unweathered”.

Dispersion testing of the Pierre Shale indicate a potential for dispersion as several samples were characterized as “intermediate” and “dispersive”. Three slake durability tests on “unweathered” rock samples yielded slake durability index values of 20%, 29%, and 50%, and Type 3 degradation after two cycles, indicating that site bedrock has low durability with respect to weathering and is anticipated to revert to soil upon exposure to the elements. Additionally, point load index testing indicates a compressive strength ranging between 822 and 1405 psi. No permeability or shear strength testing was completed on the Pierre Shale encountered at Bylin Dam due to poor sample integrity.

6. GEOTECHNICAL ANALYSES

6.1 Auxiliary Spillway SITES Analysis

The following geotechnical engineering parameters were developed for use in the auxiliary spillway integrity analysis (SITES). The SITES evaluation will be completed under the Hydraulics task and results will be included in that report. Headcut erodibility index was determined following guidelines given in National Engineering Handbook, Chapter 52, *Field Procedures for Headcut Erodibility Index* (USDA NRCS, 1997). Other parameters were developed from laboratory test data and correlation with published values. The calculations for the recommendations can be made available upon request.

Three test borings were completed at the control section of the existing auxiliary spillway: BD2020-213 is located on the inside (left) edge, BD2020-212 is in the middle, and BD2020-214 is on the outside (right) edge. Boring locations are shown on Exhibit 6. A summary of the SITES model geotechnical input parameters is presented in Table 15. Exhibit 7 provides subsurface profile of auxiliary spillway for use in the SITES analysis.

Table 15. Geotechnical Input Parameters and Stratigraphy for use in SITES Analysis

Strata	Dry Unit Weight (pcf)	% Clay	Kh	D75 (mm)	PI	BD2020-212 Depth (ft)	BD2020-213 Depth (ft)	BD2020-214 Depth (ft)
Spillway Overburden	80	17.7	0.08	0.32	17	0 – 12.5	0 – 12.5	0 – 2.5
Weathered Pierre Shale	95	40.9	0.19	0.04	23	12.5 – 20.2	12.5 – 25.0	2.5 – 19.1
Unweathered Pierre Shale	90	N/A[1]	1.8	6	N/A[1]	> 20.2	> 25.0	> 19.1

Notes:
1. Inputs for percent clay and plasticity are not required to model rock in SITES.

6.2 Compatibility Analysis

6.2.1 Drain Fill

Modern embankment dams are designed to control seepage and reduce the risks of seepage problems related to soil migration. A series of calculations were completed to evaluate compatibility of existing materials and to design drain aggregates to filter site soils. The calculations were performed using the procedures in Chapter 26 of the National Engineering Handbook Part 633 (NRCS, 2017) and can be made available upon request. Results are summarized below.

Embankment soils are predominantly clayey sand (SC) and sandy lean clay (CL). The embankment is founded directly on the Pierre Shale, which when broken down can be classified as an elastic silt with sand (MH). Additionally, the embankment and Pierre Shale exhibit dispersive characteristics.

Per the As-Built drawings (USACE, 1978) the existing foundation drain built during construction is comprised of an apparent non-standard mixture of sand and gravel, ranging in size from 3 inches to 0.003 inches (i.e., #200 sieve). The drain fill gradation from the As-Built drawings is reproduced in Table 16. Note that during construction, the gradation was modified to allow for coarser aggregate.

By inspection, the drain fill does not meet state-of-the-practice gradation criteria for seepage control/conveyance due to being too coarser and/or too broadly graded. Subsequent gradational analyses of the embankment and Pierre Shale substantiate that the existing drain fill is too coarse to provide adequate filtration. Drain fill lack of compatibility with site soils and weathered Pierre Shale and coarseness / broad gradation of drain fill is considered a deficiency with respect to current dam safety criteria. Lack of filtration can lead to embankment or weathered Pierre Shale particle migration into the drain. ND DOT fine aggregate would be an appropriate aggregate selection for drain fill adjacent to potentially dispersive site soils (i.e., both the embankment and downstream overburden soils) and weathered portions of the Pierre Shale if required during a future rehabilitation effort.

6.2.2 Embankment and Overburden

Upon review of the 2020 gradational analyses of the embankment fill, downstream overburden and Pierre Shale, there does not appear to be a concern for incompatibility of these strata with respect to each other. That is, the fines content in each material appears to be sufficient to prevent piping or suffusion with respect to adjacent materials.

Table 16. Foundation Drain Aggregate Gradation Limits (USACE, 1978)

Sieve Size	Percent Passing	
	Design	As-Built
3”	100	100
2”	97 - 100	79 - 100
1 ½”	96 - 100	71 - 100
1”	93 - 100	61 - 100
¾”	91 - 97	55 - 100
½”	86 - 94	47 - 82
3/8”	80 - 90	43 - 73
#4	67 - 78	33 - 57
#10	50 - 61	24 - 42
#20	33 - 45	15 - 30
#50	13 - 25	7 - 19
#100	6 - 10	0 - 12
#200	< 5	< 5

6.3 Seepage Analyses

Gannett Fleming performed seepage analyses to estimate the phreatic surface in the embankment during normal pool and flood surcharge pool levels for the purpose of evaluating slope stability. Seepage conditions were analyzed at the maximum-height embankment cross section, Station 14+00, which is the approximate location of the 2020 test borings. The analysis was developed using stratigraphy interpreted from the historic As-Built drawings and supplemented with existing topography and subsurface data from borings BD2020-9, -605 and -606. Seepage modeling was performed using the SEEP/W module of GeoStudio 2020, Version 10.20 by GEO-SLOPE International.

Permeabilities of site soil and rock strata were estimated based on laboratory testing and engineering judgement based on material descriptions and gradations. A detailed summary of the inputs and assumptions used to generate the seepage model can be made available upon request.

A seepage model was created to calibrate soil and rock layer permeabilities using observed piezometer data from August 2020 through November 2020 to improve understanding of the phreatic surface and pore pressures in the dam and foundation. In the calibration process, permeabilities of subsurface strata were adjusted until the seepage model results matched reasonably well with the observed piezometer and pool data. Table 17 compares the actual head observed in the piezometers to the predicted head modeled in SEEP/W for steady-state seepage at Normal Pool (model output can be made available upon request).

Table 17. Comparison of Observed and Modeled Piezometric Heads[1]

Piezometer	Observed in Field[2] (ft)	Modeled (ft)	Delta[3]
BD2020-9 Upper	1484.2	1477.7	-6.5
BD2020-9 Lower	1476.4	1477.7	1.3
BD2020-605 Upper	1467.9	1467.9	0.0
BD2020-605 Lower	1469.6	1468.6	-1.0
BD2020-606 Upper	1459.6	1465.5	5.8
BD2020-606 Lower	1459.3	1465.5	6.2

Notes:

1) For normal pool conditions
2) Average observed head over a 30-day period from 10/21/20 through 11/19/20.
3) Negative delta value indicates modeled head is lower than field observed head.

All instruments are believed to be functioning properly as the measured piezometric heads decrease as the offset downstream of the dam centerline increases. An observation that is substantiated by the calibration model. In general, the pore pressures measured by the piezometers correlate reasonably well with the calibrated model. Some difference between the observed and modeled piezometeric heads can be expected due to heterogeneity of the soil and rock materials, instrumentation input parameters, accuracy of assumed boundary conditions, or other variables. However, these differences are not believed to have a significant impact on the conclusions that will be drawn from the model. For example, the piezometric heads at the downstream embankment toe (i.e., BD2020-606 Upper and Lower) are modeled to be greater than observed which adds conservatism into the model as higher pore pressures at the toe tend to correlate to decreased slope stability. The observed and modeled head within BD2020-9 Upper differs by 6.5 feet, however this difference is not great enough to affect the critical slope stability failure surface due to this piezometer's location within the embankment. In other words, the head within the embankment at the dam centerline is less critical than the head within the embankment at the toe. Therefore, the calibration model is considered adequate for use in stability analyses.

The gradient at the downstream embankment toe was reviewed in each model condition. It was determined that the critical gradient was not exceeded for any of the modeled conditions. A plot showing total water head at the downstream embankment toe for each modeled condition is presented in Figure 2.

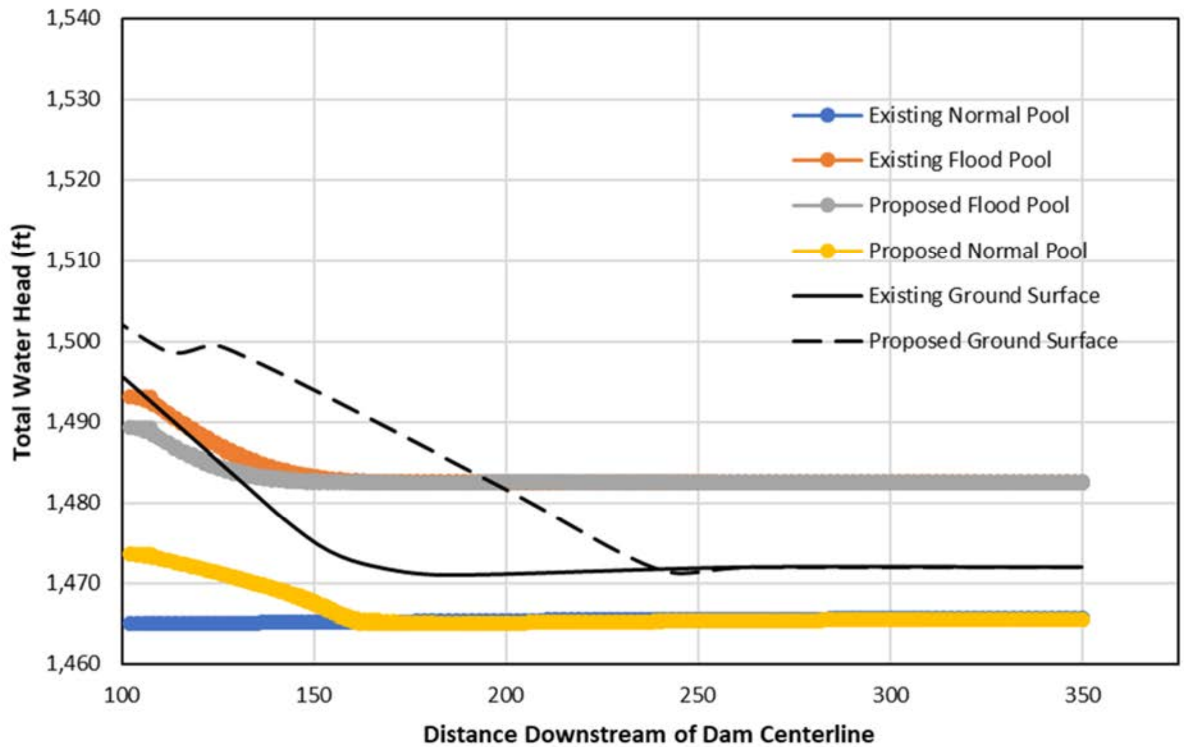

Figure 2. Total Water Head Modeled at the Toe of Dam

6.4 Slope Stability Analyses

Gannett Fleming performed slope stability analyses of the upstream and downstream embankment slopes based on the requirements of TR-60 (USDA NRCS, 2019). Analyses were performed at the cross section representing the maximum height of the dam and utilizing pore water pressures computed by the seepage modeling. Slope stability modeling was performed using the SLOPE/W program, module of GeoStudio 2020, Version 10.2 by GEO-SLOPE International. Existing embankment slope angles were based on the site topography data. The existing upstream slope is approximately 3 H:1V and contains a bench at El. 1481.2 that is inundated by the normal pool. The existing downstream slope is approximately 2.5H:1V and contains an approximately 20-foot wide bench at El. 1500.

Recommended shear strength parameters were determined based on the results of the subsurface exploration and laboratory testing programs. Table 18 summarizes the recommended shear strengths and unit weights for site soils.

The shear strength parameters of the embankment fill and downstream overburden were determined based on results of consolidated, undrained (CU_{bar}) triaxial shear strength with pore pressures monitored. The triaxial test results were evaluated with respect to shear strength guidance provided in the U.S. Corps of Engineers EM 1110-2-1902 (2003). A linear Mohr-

Coulomb failure envelope was constructed for the Mohr circles at failure such that two thirds of the Mohr circle points of tangency are above the line and one-third below, in accordance with EM 1110-2-1902, Appendix D, Section D-6.b.1. The Mohr circles and the recommended design failure envelope are plotted together for both effective stress and total stress conditions and can be made available upon request. The shear strength parameters for the downstream embankment zone comprised of shale are assumed equal to the embankment fill. Shear strength parameters for the Pierre Shale are obtained from laboratory testing of intact specimens from Matejcek Dam (Gannett Fleming, 2021), which are detailed in the Shear Strength Calculations and can be made available upon request.

The SLOPE/W model utilizes effective strength parameters for the normal pool, steady-state seepage condition. To analyze the flood surcharge condition, the SLOPE/W model utilizes a composite envelope (bilinear strength), i.e., the lowest of the effective or consolidated total stress failure envelope as required by TR-60 (USDA NRCS, 2019). SLOPE/W requires the input of both effective and total stress parameters as well as the normal stress of the intersection of the two failure envelopes to perform a bilinear strength analysis. These parameters are presented in Table 18.

Rapid drawdown stability of the existing upstream slope was evaluated in accordance with TR-60 (USDA NRCS, 2019) using the composite failure envelope. It was assumed that rapid drawdown was instantaneous from normal pool to the elevation of the lowest lake drain invert, El. 1477.2 as indicated on the historic As-Built drawings (USACE, 1978) and adjusted to NAVD88. The piezometric line is then drawn to closely match the piezometric surface from the normal pool stability model through the embankment and downstream overburden.

Slope stability analysis results are included in Exhibits 9-11 and summarized in Table 19. Seepage and slope stability input details can be made available upon request. The required minimum factors of safety indicated in Table 19 are from TR-60 (USDA NRCS, 2019), Table 5-3 and are utilized to assess downstream embankment stability for normal pool and flood surcharge pool, and upstream slope stability during a rapid drawdown condition. Evaluation of the SLOPE/W model results indicate that the dam meets current TR-60 (USDA NRCS, 2019) requirements for normal pool and rapid drawdown conditions, however the flood surcharge condition is not met. Screen captures from the slope stability models performed to assess the existing conditions are provided in Figures 4 through 6.

Per the maximum flood hydrograph, the embankment overtops during the probable maximum flood (PMF) event with a peak pool elevation of 1527.2 ft (the flood surcharge pool was modeled at El. 1524.7) and a resulting tailwater at El. 1482.6. The flood surcharge stability model is somewhat conservative as utilized pore pressures assume that steady-state seepage conditions develop. It is unlikely that steady-state seepage conditions will develop during the PMF event, however this assumption satisfies the TR-60 requirement that considers "*the potential for increase in pore pressures in the normally saturated portion of the foundation or embankment that may result from the higher reservoir loading*" (USDA NRCS, 2019). Review of the flood surcharge stability models indicates that in addition to the elevated pore pressures, the existing embankment drain will become inundated by the tailwater and fail to provide a means of pore pressure dissipation (i.e., seepage conveyance). Reduction of the PMF headwater by spillway improvements or modification of the downstream slope to improve slope stability during the maximum flood surcharge event is recommended.

Table 18. Recommended Parameters for Slope Stability Analyses

Material	Unit Weight (pcf)	Shear Strength Parameters				
		Effective Stress		Total Stress		Bilinear Stress
		Cohesion, c' (psf)	Friction Angle, ϕ' (degrees)	Cohesion, c (psf)	Friction Angle, ϕ (degrees)	Normal Stress[1], σ_N (psf)
Embankment	125	0	33	700	15	1835
Shale Embankment	125	0	33	700	15	1835
Existing Drain Fill	110	0	36	0	36	-
Foundation Soil	105	0	30	0	21	0
Pierre Shale[2]	110	0	33	550	14	1375

Notes:

1) The normal stress, σ_N, is the normal stress coordinate of the intersection of the effective stress and total stress failure envelope (TR-60 (USDA NRCS, 2019) Figure 5-2 is replicated as Figure 3) and is calculated with the equation:

$$\sigma_N = \frac{c - c'}{\tan\phi' - \tan\phi}$$

2) From Matejcek Dam

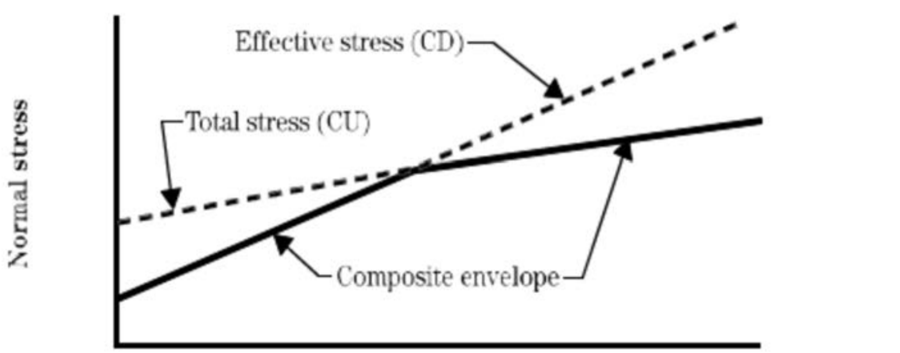

Figure 3. Composite Shear Strength Envelope

Due to potential overtopping during the PMF event, the existing embankment geometry was modified to include increasing the dam crest to El. 1527.7, i.e., a three to four foot raise, and a flattened downstream slope. To meet the requirements of TR-60 (USDA NRCS, 2019) for embankment stability during the flood surcharge pool condition, the downstream slope is proposed to be modified to 3H:1V from the dam crest to the mid-height at which point there is a 20-foot wide bench which transitions to a 4H:1V slope to the embankment toe. A three-foot thick, measured horizontally, chimney drain was also incorporated to reduce pore pressures within the embankment. Results of the stability analyses for the proposed geometry are summarized in Table 19 and detailed in Exhibits 12 and 13. Screen captures from the slope stability models performed to assess the proposed conditions are provided in Figures 7 and 8.

Table 19. Embankment Slope Stability Analysis Results.

Analysis	Required Minimum Factor of Safety	Calculated Minimum Factor of Safety
Rapid Drawdown (Composite Strength Failure Envelope)	1.2	1.5
Downstream Slope (Existing), Normal Pool, Steady-State Seepage	1.5	2.2
Downstream Slope (Existing), Flood Surcharge Pool, Steady-State Seepage	1.4	1.1
Downstream Slope (Proposed), Normal Pool, Steady-State Seepage	1.5	2.5
Downstream Slope (Proposed), Flood Surcharge Pool, Steady-State Seepage	1.4	1.4

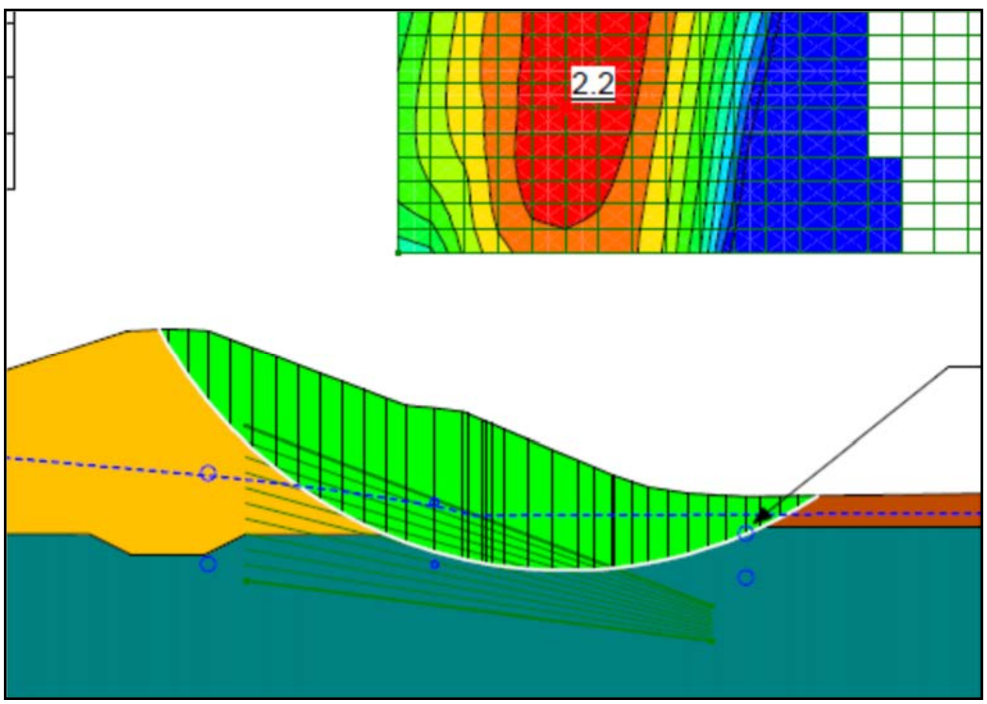

Figure 4. Slope Stability Failure Surface for Normal Pool, Existing Conditions

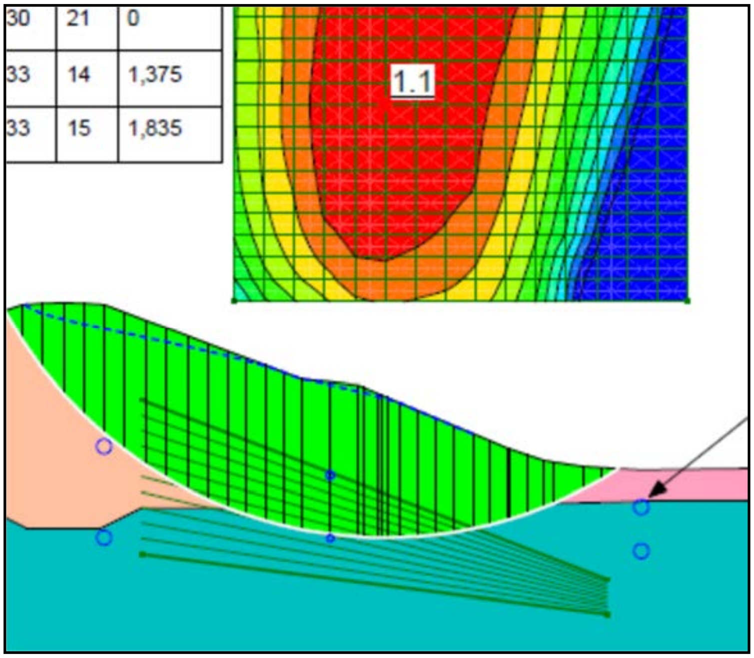

Figure 5. Slope Stability Failure Surface for Flood Surcharge Pool, Existing Conditions

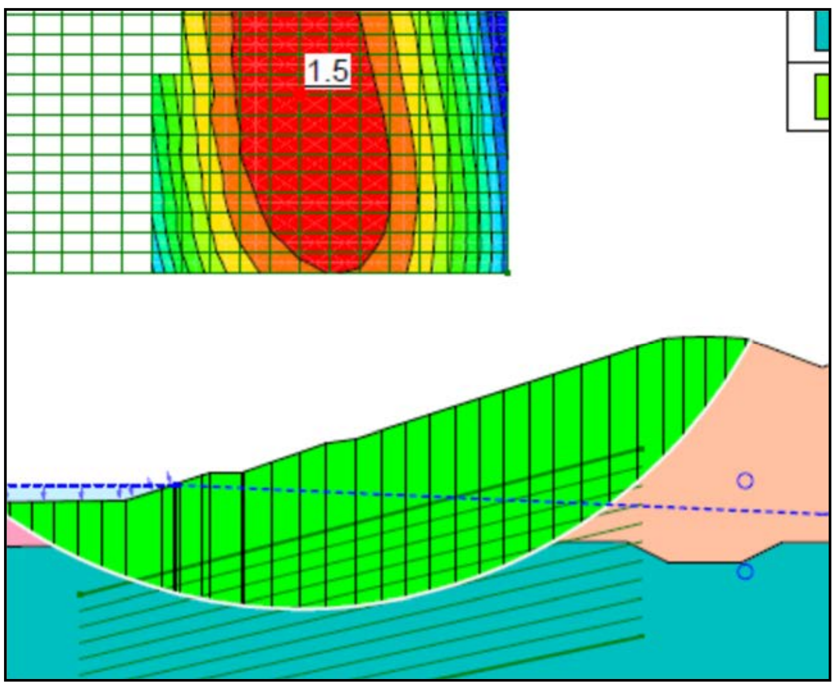

Figure 6. Slope Stability Failure Surface for Rapid Drawdown, Existing Conditions

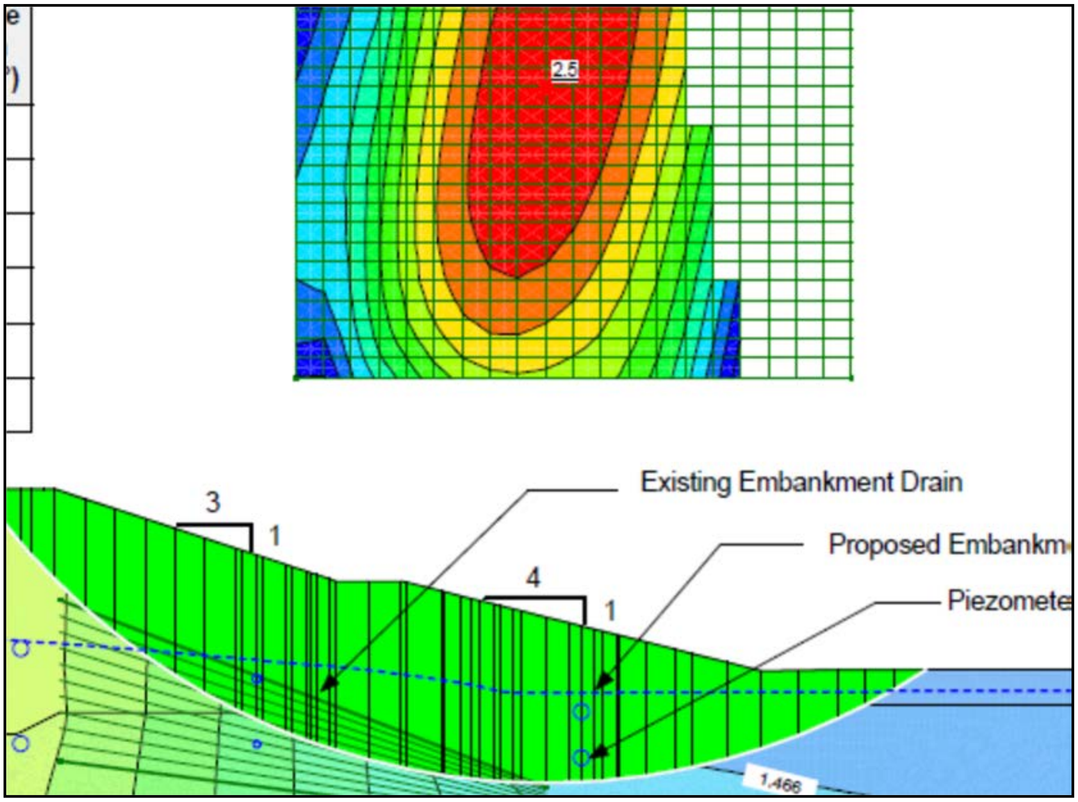

Figure 7. Slope Stability Failure Surface for Normal Pool, Proposed Conditions

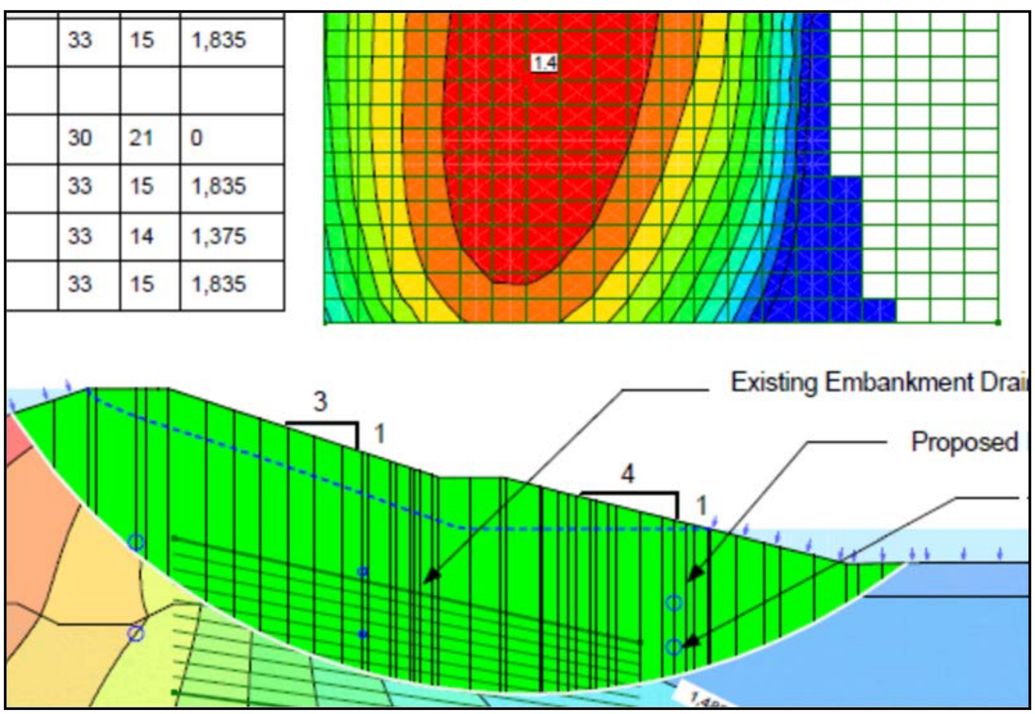

Figure 8. Slope Stability Failure Surface for Flood Surcharge Pool, Proposed Conditions

7 CONCLUSIONS AND RECOMMENDATIONS

The geotechnical analyses performed herein are intended to be used to develop alternative rehabilitation schemes for Bylin Dam. Based on the findings of the geotechnical analysis, the following dam rehabilitation components should be considered:

- Implementation of a new embankment drain that will be sufficient to arrest potential dispersive soils, as well as prevent particle migration.
- Raise the embankment crest to avoid potential overtopping during the PMF event and flattening the downstream slope as shown herein, i.e., 3H:1V upper slope, 20-foot wide bench and 4H:1V lower slope.
- Site seismicity and liquefaction susceptibility as required by TR-60 (USDA NRCS, 2019).
  - It is believed that the peak horizontal ground acceleration at Bylin Dam is below the minimum threshold indicated by TR-60 (USDA NRCS, 2019) and thus dynamic stability may not be required, however this should be confirmed during design.
  - The subsurface data obtained from the 2020 subsurface exploration do not indicate the presence of soils typically susceptible to liquefaction, such as loose sands. However, if additional explorations indicate the presence of loose, saturated sands, liquefaction analyses should be performed.

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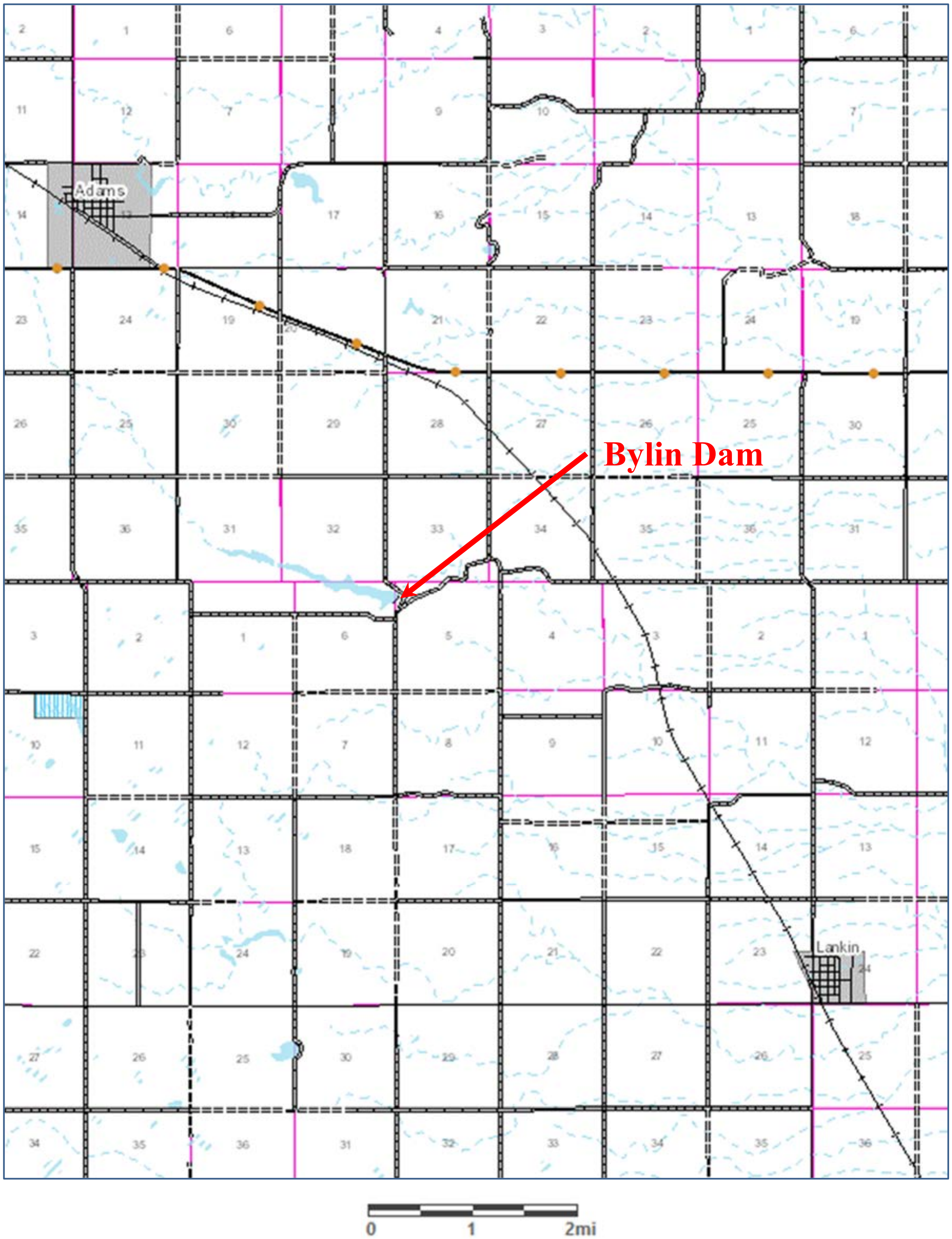


Exhibit 1. Location Map

Exhibit 2. Aerial Photo of Bylin Dam (USDA, 2019)

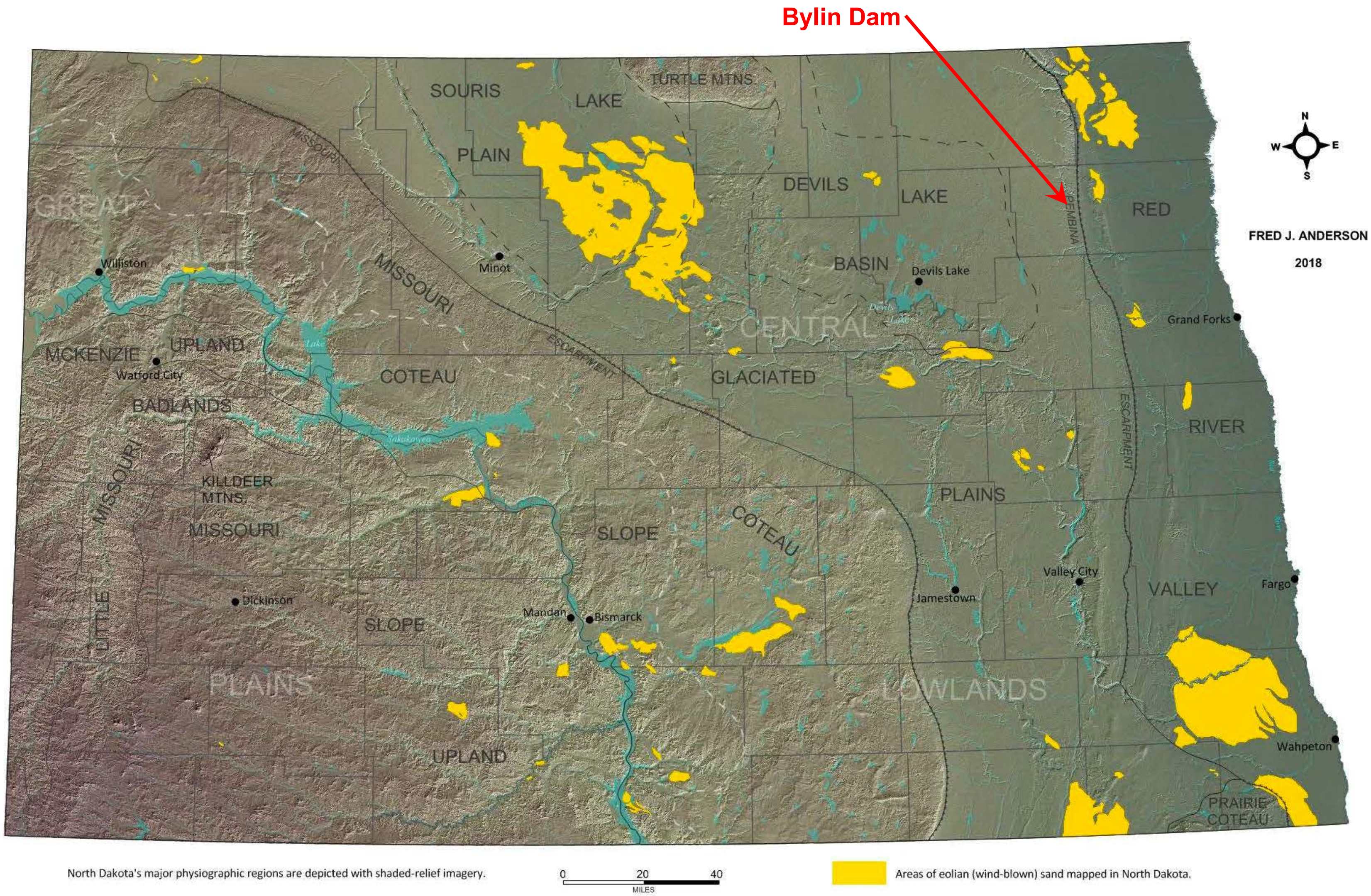
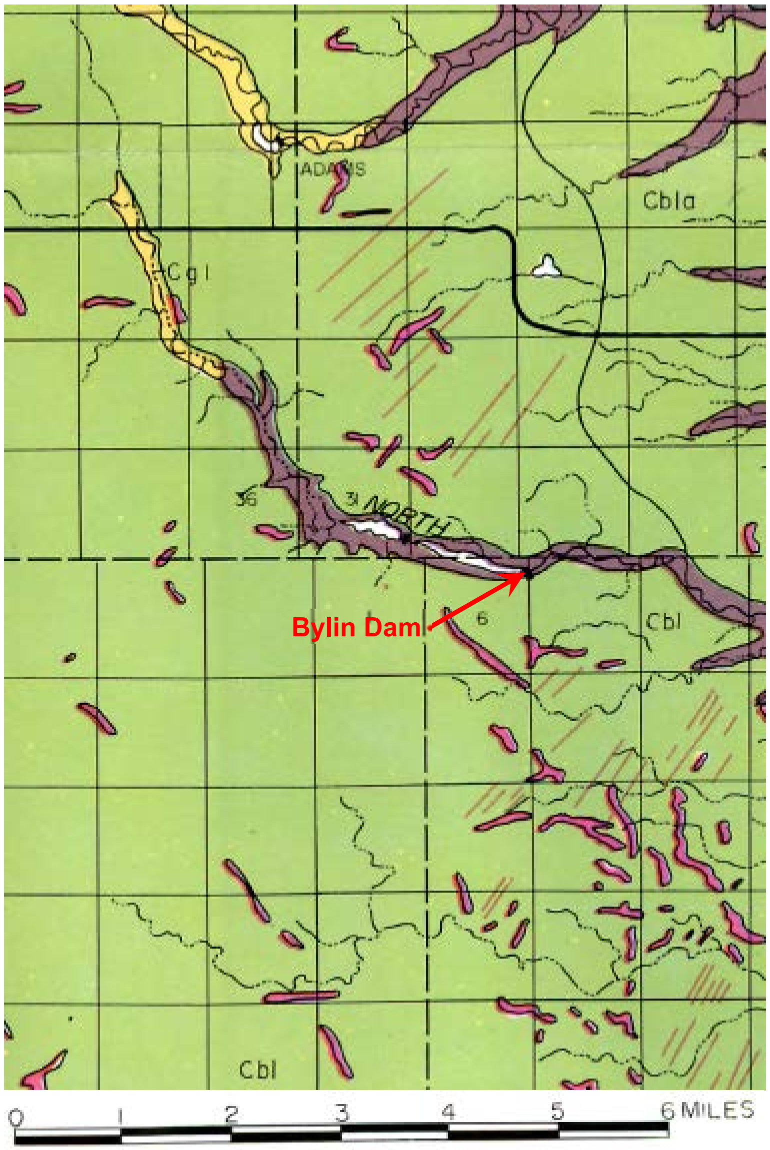


Exhibit 3. Physiographic Map of North Dakota (Anderson, 2018)



UNIT	SYMBOL	DESCRIPTION / ORIGIN
Coleharbor Formation	Cb l; washboard moraine lines	TILL FACIES Till typically consists of a nonsorted, non-stratified mixture of angular, subangular and rounded blocks of rock, gravel and sand in a stiff matrix of silt and clay; various size grades occur in all possible proportions. Material that was deposited at the base of the moving glacier along with mudflow deposits that formed on ablation of glacier. Cb1a—Surface of Cb1 that has been washed by wave action along the shore of a lake; beach remnants occur in places. Washboard Moraines: Low, linear ridges, either straight or arcuate in plan, in areas of till facies.
Coleharbor Formation	Cg l; Cg 4	SAND AND GRAVEL FACIES: Mainly sandy gravel; some gravel and gravelly sand; vague horizontal bedding; poor sorting; high shale percentages in areas underlain by Cretaceous shale formations. Materials washed out from the glacier by meltwater; includes alluvium of Pleistocene age that is present on terraces along trenches cut by glacial meltwater and on the floors of such trenches where it may be overlain by modern alluvium in many places. Sandy gravel; some gravel and gravelly sand; minor sandy silt and till; vague bedding plains; poor sorting; high shale percentages in areas underlain by Cretaceous shale formations. Disintegration features such as eskers and kames deposited in contact with glacial ice.
Pierre Formation		CRETACEOUS ROCK Gray to black shale with gray marl and numerous beds of bentonite; non-calcareous to calcareous; slumps in places. Marine shales.

Exhibit 4. Portion of Geologic Map of Walsh County (Bluemle, 1973)

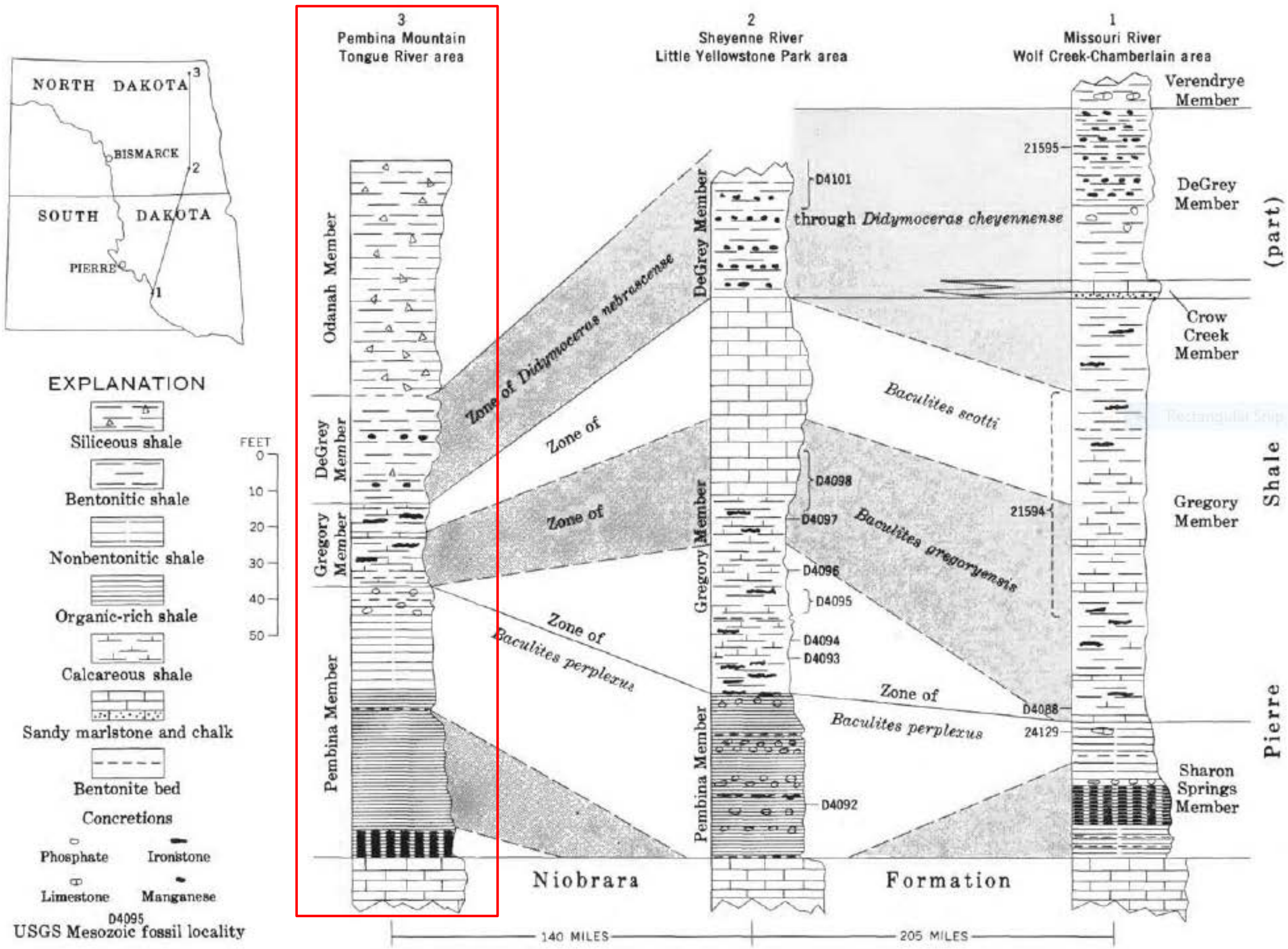


FIGURE 4.—Correlation of the lower part of the Pierre Shale in eastern North Dakota and central South Dakota, showing inferred stratigraphic range of ammonite zones (alternating stippled and blank areas) and position of fossil collections. Missouri River section is a composite of unpublished sections measured by H. A. Tourtelot and L. G. Schultz.

Exhibit 5. Stratigraphic Column of Pierre Shale (Gill and Cobban, 1965)

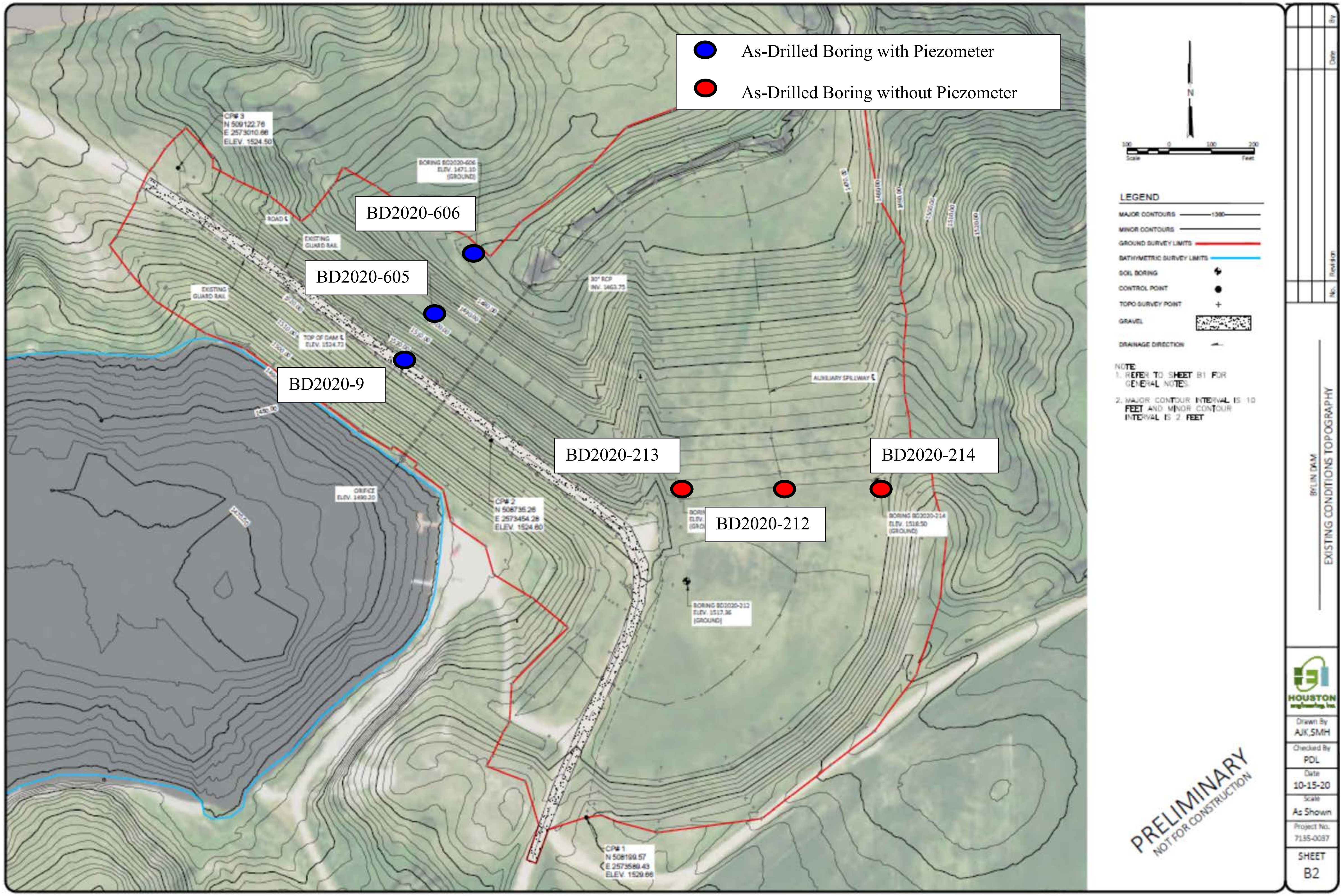


Exhibit 6. As-Drilled Boring Location Plan

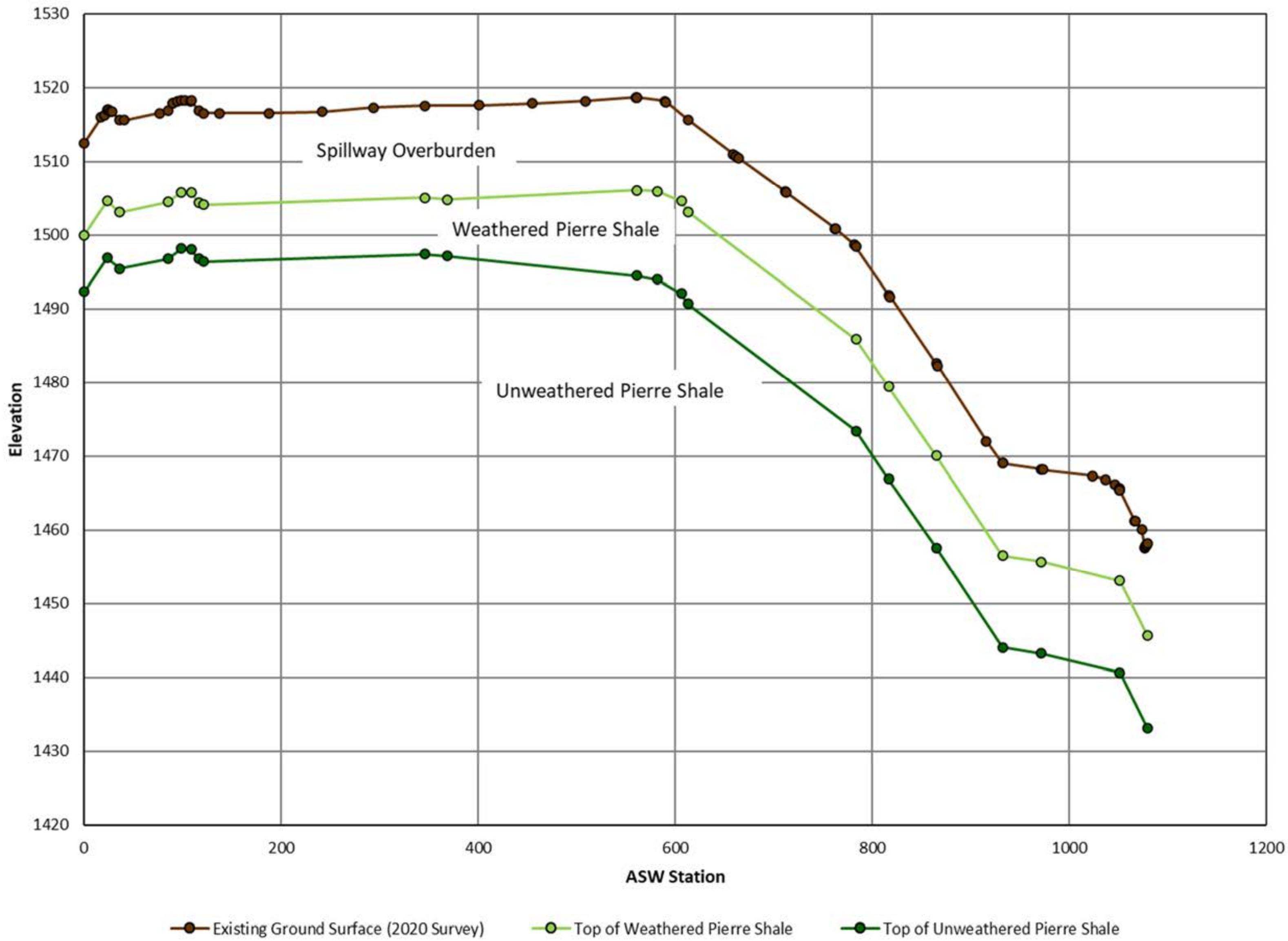


Exhibit 7. Auxiliary Spillway Profile for SITES Analysis

Gannett Fleming

Bylin Dam
Summary of Laboratory Soil Test Results

EJB, 12/2020
TNK, 01/2021

Test Boring Number	Sample Number	Sample Depth	Elevation Top of Sample (ft)	Stratum	Material Description	USCS Class	% Gravel	% Sand	% Silt	% Clay	LL (%)	PL (%)	Plasticity Index	Natural Moisture (%)	Specific Gravity (dim.)	Dry Unit Weight (pcf)	Moist Unit Weight (pcf)	Crumb Dispersion Grade
BD2020-9	U-1	25.0 - 27.3	1499.5	Embankment	Clayey SAND	SC	6.1	47.2	29.7	17	41	20	21	25.7	2.35	100.6	126.6	3
BD2020-9	U-2	52.5 - 54.8	1472.0	Embankment	Sandy lean CLAY	CL	0.0	45.7	43.4	10.9	30	18	12	22.4	2.60	102.2	125.1	3
BD2020-213	S-2,3,4	2.5 - 10.0	1514.6	Spillway	Clayey SAND	SC	0.9	52.5	31.6	15.0	36	19	17	26.2		90.2	122.9	1
BD2020-212	S-6	12.5 - 15.0	1504.9	Spillway	Lean CLAY	CL	0.0	13.1	46.8	40.1	44	21	23	24.2		95.6	118.7	1
BD2020-605	U-1	20.0 - 22.5	1479.3	Embankment	Clayey SAND with Gravel	SC	17.1	52.2	22.8	8.0	44	22	22	17.7	2.61	103.9	122.3	2
BD2020-605	S-16	40.0 - 41.5	1459.3	Pierre Shale	Elastic SILT with Sand	MH	0.0	29.3	41.6	29.1	64	33	31	17.7	2.72	97.0	118.9	
BD2020-606	U-1	7.5 - 10.0	1463.6	Downstream Overburden	Elastic SILT with Sand	MH	0.0	18.7	58.3	23.0	66	39	27	43.9	2.50	73.1	105.2	4
BD2020-606	S-5	12.5 - 14.3	1458.6	Pierre Shale	Elastic SILT with Sand	MH	0.0	25	44.5	30.5	61	38	23	18.3	2.64	81.1	103.2	1
BD2020-605	R-1 to R-4	41.5 - 49.5	1457.8	Pierre Shale	Claystone (Shale)									17.7		102.0	120.1	2
BD2020-606	R-1 to R-4	14.5 - 24.5	1456.6	Pierre Shale	Claystone (Shale)									18.8		86.2	102.4	1
BD2020-213	R-3	29.0 - 34.0	1488.1	Pierre Shale	Claystone (Shale)									20.7				2
BD2020-213	R-4	34.0 - 36.7	1483.1	Pierre Shale	Claystone (Shale)									19.5				1
BD2020-213	R-5	36.7 - 40.0	1480.4	Pierre Shale	Claystone (Shale)									18.5				2

PERMEABILITY

Test Boring Number	Sample Number	Sample Depth (ft)	Elevation Top of Sample (ft)	Stratum	Material Description	Permeability (cm/s)
BD2020-9	U-1	25.0 - 27.3	1499.5	Embankment	Clayey SAND	5.00E-08
BD2020-9	U-2	52.5 - 54.8	1472.0	Embankment	Sandy lean CLAY	2.90E-07
BD2020-606	U-1	7.5 - 10.0	1463.6	Downstream Overburden	Elastic SILT with Sand	3.50E-08

CU TRIAXIAL SHEAR

Test Boring Number	Sample Number	Sample Depth (ft)	Elevation Top of Sample (ft)	Stratum	Material Description	USCS Class	Moisture (%)	Dry Unit Weight (pcf)	Moist Unit Weight (pcf)	Total Stress Cohesion[1] (psf)	Total Stress Friction Angle[1] (°)	Effective Stress Cohesion[1] (psf)	Effective Stress Friction Angle[1] (°)
BD2020-9	U-1	25 - 27.3	1499.5	Embankment	Clayey SAND	SC	20.2	102.7	123.4	821	14.2	432.0	31.4
							21.3	97.4	118.1				
BD2020-605	U-1	20 - 22.5	1479.3	Embankment	Clayey SAND with Gravel	SC	19.8	99.5	119.2				
							19.0	99.3	118.2				
BD2020-606	U-1	7.5 - 10.0	1463.6	Downstream Overburden	Elastic Silt with Sand	MH	43.5	69.7	100.0	0	21.6	63.0	39.1
							38.3	78.3	108.3				
							41.1	75.9	107.1				
BD2020-9	U-2	52.5 - 54.8	1472.0	Embankment	Sandy lean CLAY	CL	20.3	99.1	119.2	72	25.5	47.0	36.2
							19.7	105.2	125.9				

Rock Testing

Test Boring Number	Sample Number	Sample Depth (ft)	Elevation Top of Sample (ft)	Stratum	Material Description	Slake Durability			Compressive Strength[2] (psi)
						Index (%)	Fragment Type	Fragment Description	
BD2020-213	R-3	29.0 - 34.0	1488.1	Pierre Shale	Claystone (Shale)	19.8	III	Retained material is exclusively small pieces	822
BD2020-213	R-4	34.0 - 36.7	1483.1	Pierre Shale	Claystone (Shale)	29.3	III	Retained material is exclusively small pieces	1285
BD2020-213	R-5	36.7 - 40.0	1480.4	Pierre Shale	Claystone (Shale)	49.5	III	Retained material is exclusively small pieces	1405

Notes:
1) As reported on laboratory test sheets. Listed values may not match strength parameters used in slope stability analyses. See "Shear Strength" calculation in Appendix G.
2) Obtained from point load testing. Average value is presented.

Exhibit 8. Laboratory test results summary

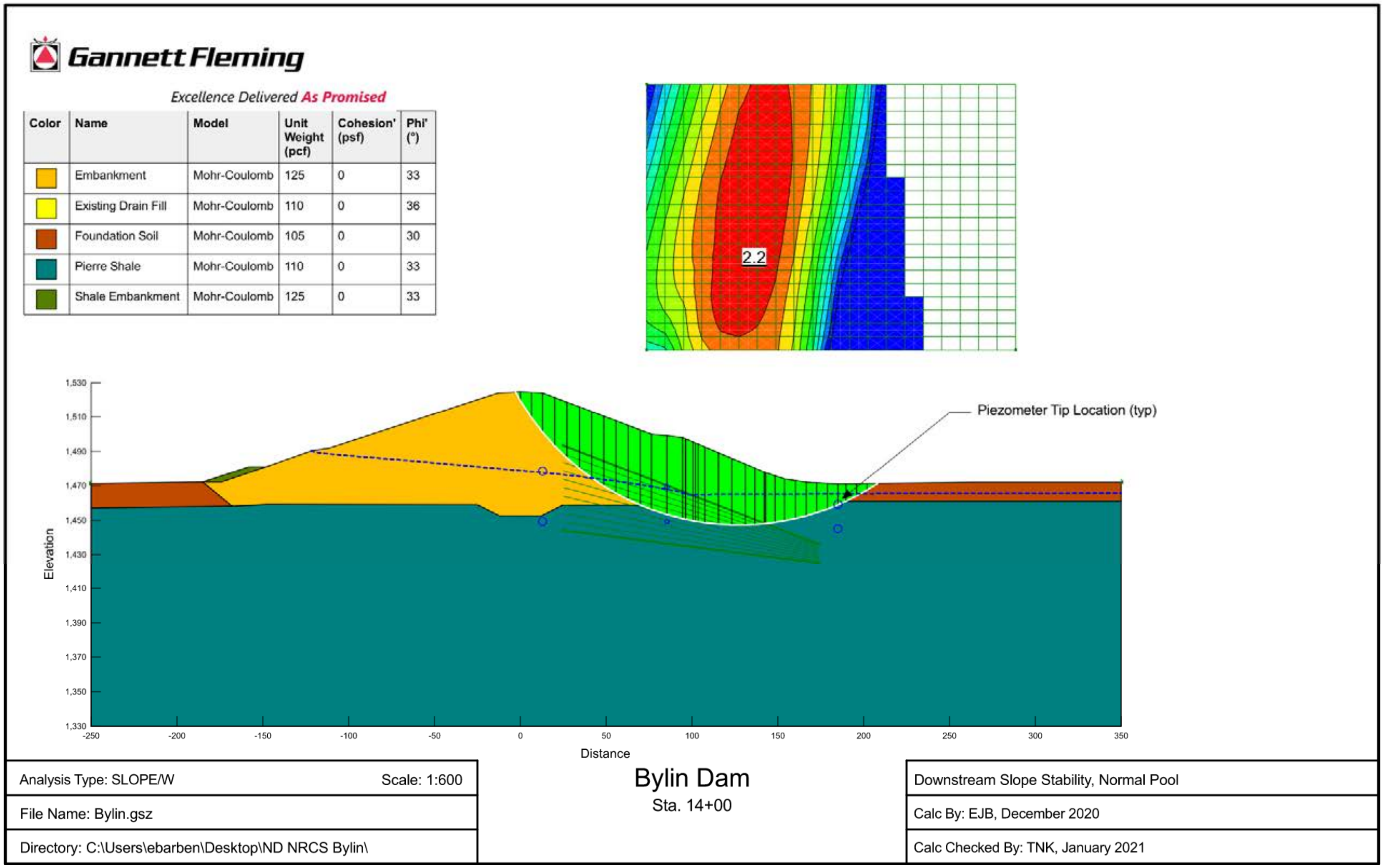
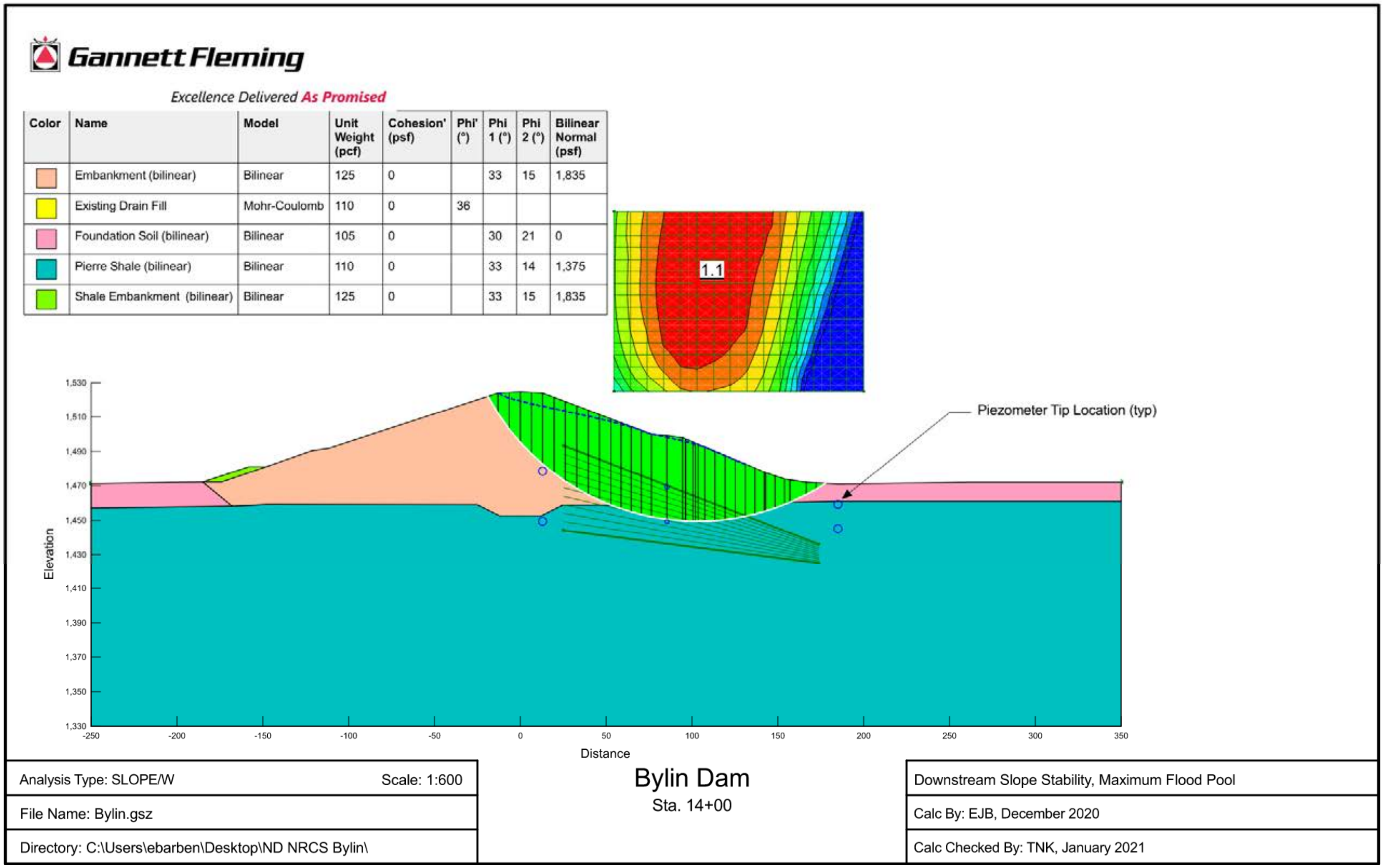
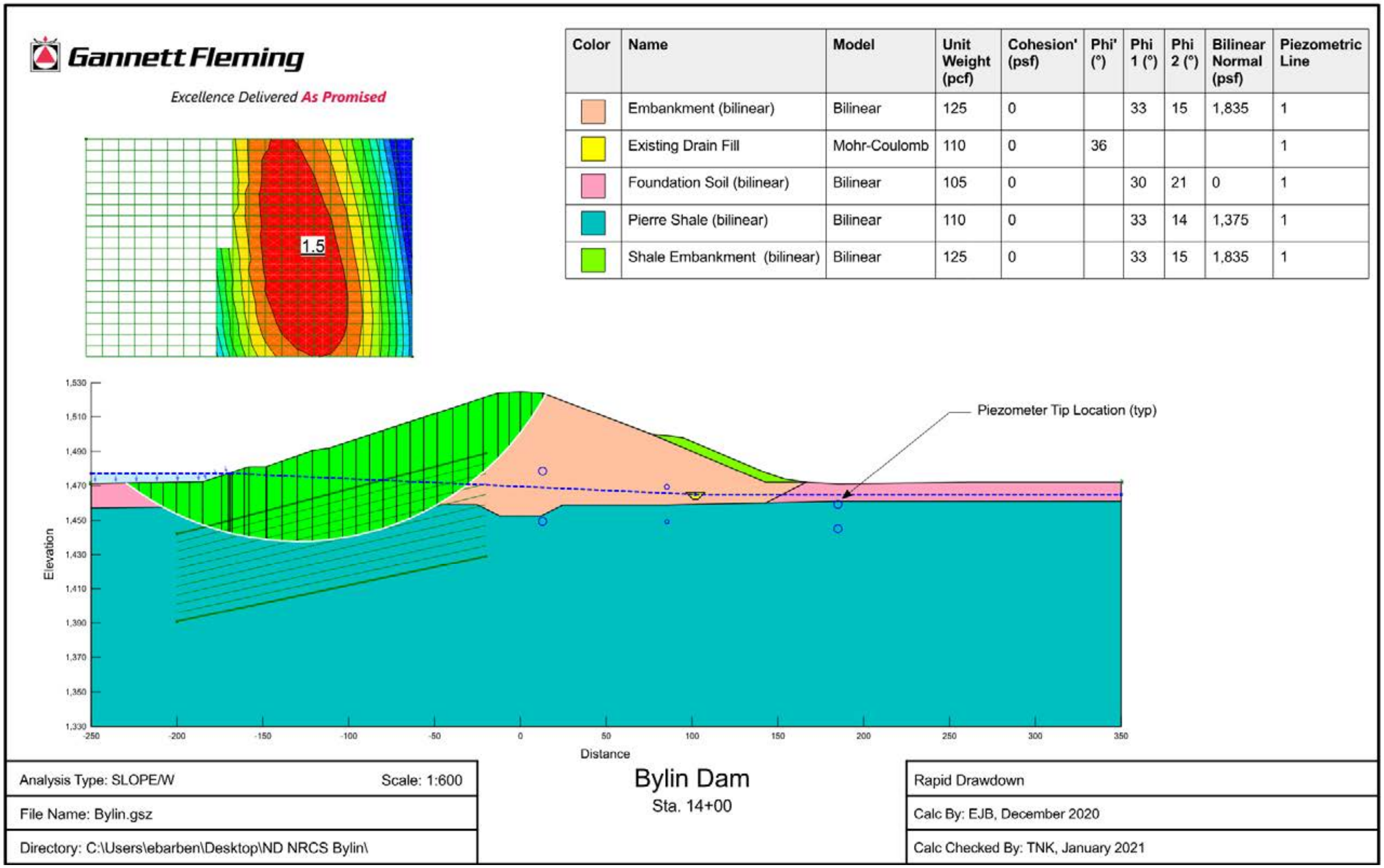


Exhibit 9. Downstream Slope Stability, Normal Pool



Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (psf)
	Embankment (bilinear)	Bilinear	125	0		33	15	1,835
	Existing Drain Fill	Mohr-Coulomb	110	0	36			
	Foundation Soil (bilinear)	Bilinear	105	0		30	21	0
	Pierre Shale (bilinear)	Bilinear	110	0		33	14	1,375
	Shale Embankment (bilinear)	Bilinear	125	0		33	15	1,835

Exhibit 10. Downstream Slope Stability, Maximum Flood Pool



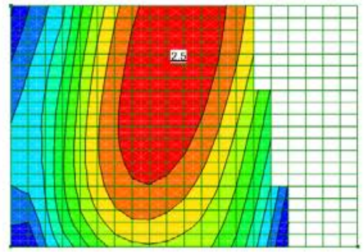
Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (psf)	Piezometric Line
	Embankment (bilinear)	Bilinear	125	0		33	15	1,835	1
	Existing Drain Fill	Mohr-Coulomb	110	0	36				1
	Foundation Soil (bilinear)	Bilinear	105	0		30	21	0	1
	Pierre Shale (bilinear)	Bilinear	110	0		33	14	1,375	1
	Shale Embankment (bilinear)	Bilinear	125	0		33	15	1,835	1

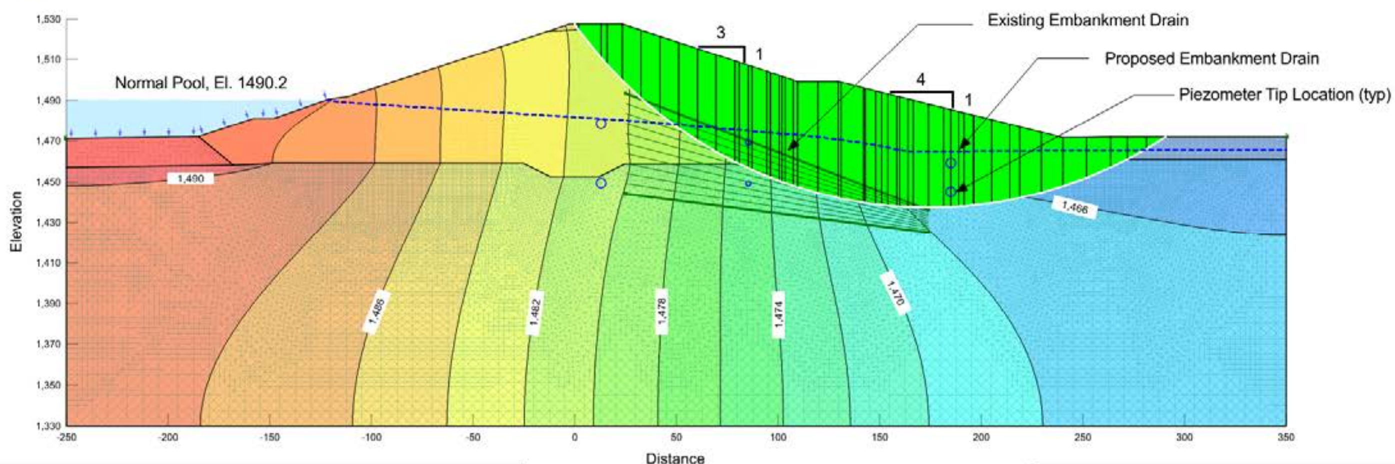
Exhibit 11. Rapid Drawdown

Gannett Fleming

*Excellence Delivered **As Promised***

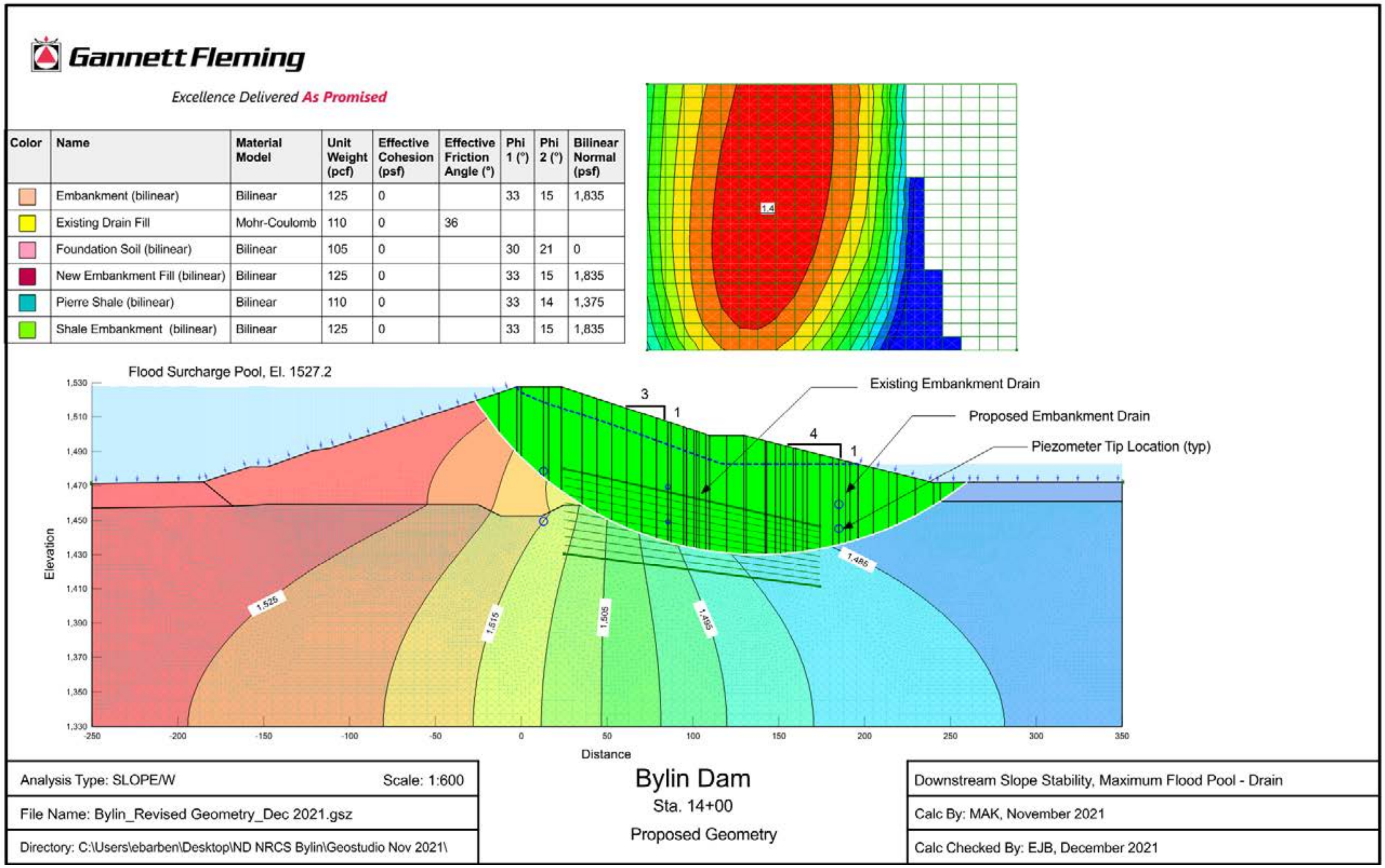
Color	Name	Material Model	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)
	Embankment	Mohr-Coulomb	125	0	33
	Existing Drain Fill	Mohr-Coulomb	110	0	36
	Foundation Soil	Mohr-Coulomb	105	0	30
	New Embankment Fill	Mohr-Coulomb	125	0	33
	Pierre Shale	Mohr-Coulomb	110	0	33
	Shale Embankment	Mohr-Coulomb	125	0	33





Analysis Type: SLOPE/W Scale: 1:600	Bylin Dam	Downstream Slope Stability, Normal Pool - Drain
File Name: Bylin_Revised Geometry_Dec 2021.gsz	Sta. 14+00	Calc By: MAK, November 2021
Directory: C:\Users\ebarben\Desktop\ND NRCS Bylin\Geostudio Nov 2021\	Proposed Geometry	Calc Checked By: EJB, December 2021

Exhibit 12. Downstream Slope Stability, Normal Pool, Proposed Geometry



Color	Name	Material Model	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (psf)
	Embankment (bilinear)	Bilinear	125	0		33	15	1,835
	Existing Drain Fill	Mohr-Coulomb	110	0	36			
	Foundation Soil (bilinear)	Bilinear	105	0		30	21	0
	New Embankment Fill (bilinear)	Bilinear	125	0		33	15	1,835
	Pierre Shale (bilinear)	Bilinear	110	0		33	14	1,375
	Shale Embankment (bilinear)	Bilinear	125	0		33	15	1,835

Exhibit 13. Downstream Slope Stability, Maximum Flood Pool, Proposed Geometry

ATTACHMENT A

Boring Logs

Date Started: 6/23/20	DRILLING LOG	Hole Number: BD2020-9
Date Finished: 6/26/20	Gannett Fleming	Sheet: 1 of 3
Soil Drilling: 71.5 ft		Line & Station:
Rock Drilling: 17.0 ft	Project: Bylin Dam	Offset:
Total Depth of Hole: 88.5 ft	Drilling Agency: Interstate Drilling Services, Inc.	N Coordinate: 508852.4 ft
No. of Undist. Samples: 2	Driller: Dave Tokar	E Coordinate: 2573335.8 ft
Total Number of Core Boxes: 3	Bit Size and Type: HQ; Spoon Size: 2.0 " OD	Elev. Top of Hole: +1524.5 ft
GROUNDWATER OBSERVATIONS At 44.8 ft after 24 Hrs At 17.8 ft after 48 Hrs Elev. 1506.7 ft after 48 Hrs	Casing Size: N/A; Hammer Wt.: 140 lb Hollow Stem Auger: 4.25 " ID x 8.0 " OD; Hammer Drop: 30.0 " Drilling Fluid: Water; Hammer Type: Automatic Drill Rig: Dietrich 50 Track Rig	Direction of Hole Vertical ☒ Inclined ☐ Degrees from Vertical --- Logged By: T. Kent

Depth (Ft.)	Sample No.	Blows or RQD (%)	Rec. (ft.)	Rec. (%)	USCS	Description Of Materials	Remarks
0.0 - 2.5	S-1	3-3-9-4-5	1.8	72		0'-71.5': Sandy CLAY (cl). 5% gravel, 25% sand, 70% fines. Gravel is shale and hard rock pieces, fine to coarse, angular to subangular, some flat pieces, max. particle size 1", hard, yellow (2.5Y 7/6) and gray (2.5Y 6/1). Sand is fine to coarse, subangular to subrounded, max. particle size 2 mm, pale brown (2.5Y 8/2), Fines, low plasticity, high dry strength, light yellowish brown (2.5Y 6/4), olive brown (2.5Y 4/3), and black (2.5Y 2.5/1). Dry to moist.	P.P. = 1.75 tsf
2.5 - 5.0	S-2	5-5-5-6-8	1.2	48			P.P. = 2.0 tsf
5.0 - 7.5	S-3	3-3-4-5-5	2.0	80			P.P. = 0.7 tsf
7.5 - 10.0	S-4	3-4-5-6-9	1.5	60		7.5': 3/4"-1" subrounded to rounded gravel	P.P. = 2.1 tsf
10.0 - 12.5	S-5	2-3-5-6-10	1.8	72			P.P. = 3.8 tsf
12.5 - 15.0	S-6	3-4-6-7-8	1.5	60		12.5': 1.25" gravel, subangular	P.P. = 1.3 tsf
15.0 - 17.5	S-7	4-5-6-9-9	2.4	96		15.0': Angular shale clast, 1" max	P.P. = 3.1 tsf
17.5 - 20.0	S-8	4-6-7-9-10	1.8	72			P.P. = 4.1 tsf
20.0 - 22.5	S-9	4-6-7-8-9	2.0	80		22.0': Sand lens, wet dark layer @ 21.0'; 4"	P.P. = 1.0 tsf
22.5 - 25.0	S-10	5-5-5-7-10	2.0	80		23.0': Higher clay content	P.P. = 0 tsf

Purpose: Sample embankment material and foundation soils/rock
Drilling Method: Continuous split spoon sampling using hollow stem auger to 71.5', HQ rock coring 71.5' to 88.5'.
Termination: 15 feet into rock
Abandonment: Two pressure transducers in sand-socks cement grouted in place at 46' (S/N: 2024386) and 75' (S/N: 2024384)
Additional Remarks: Drilled just off roadway on crest of dam

Agency: Interstate Drilling Services, Inc.	DRILLING LOG	Hole Number: BD2020-9
Driller: Dave Tokar	Gannett Fleming	Sheet: 2 of 3
Inspector: T. Kent		Elev. Top of Hole: +1524.5 ft

Bylin Dam

Depth (Ft.)	Sample No.	Blows or RQD (%)	Rec. (ft.)	Rec. (%)	USCS	Description Of Materials	Remarks
25.0 - 27.5	U-1	Shelby Tube	1.8	72		25.0'-27.3': Laboratory classified as Clayey SAND (SC)	
27.5 - 30.0	S-11	7-7-10-12-12	2.1	84		29.2': 1" subangular gravel	P.P. = 3.75 tsf
30.0 - 32.5	S-12	5-7-9-9-12	1.8	72		31.3': 6" soft clay	P.P. = 4.25 tsf
32.5 - 35.0	S-13	13-10-8-8-10	1.9	76		33.5': 1" subangular gravel	P.P. = 3.8 tsf
35.0 - 37.5	S-14	4-5-7-9-12	1.8	72		36.2': 1" gravel 37.0': 1" gravel, iron oxide staining	P.P. = 1.3 tsf
37.5 - 40.0	S-15	2-4-9-10-10	2.3	92			P.P. = 3.1 tsf
40.0 - 42.5	S-16	4-6-7-9-12	1.9	76			P.P. = >4.5 tsf
42.5 - 45.0	S-17	3-7-11-8-10	2.2	88		42.5': Oxidation and chemical weathering 44.3': 0.25' soft clay layer	P.P. = 3.4 tsf
45.0 - 47.5	S-18	4-6-10-10-11	2.0	80		46.2': Sand layer 1/16"	P.P. = 1.4 tsf
47.5 - 50.0	U-X	Shelby Tube	0.0	0		47.5': No recovery on undisturbed sample attempt	47.5': Shelby tube attempt with no recovery (U-X) and not idenfied on original field log. Subsequent shelby tube attempt at 52.5' identified in the field as U-2.
50.0 - 52.5	S-19	8-8-10-10-11	2.1	84		50.0': Iron oxide staining, 1/2" gravel pieces	P.P. = 2.5 tsf
52.5 - 55.0	U-2	Shelby Tube	1.7	68		52.5'-54.8': Laboratory classified as Sandy lean CLAY (CL)	
55.0 - 57.5	S-20	5-6-6-7-6	2.0	80		55.5'-58.0': Wet gravel 1/4"-1/2"	P.P. = 0.9 tsf
57.5 - 60.0	S-21	2-4-5-6-7	2.2	88		58.3': 1/2" gravel	P.P. = 2.1 tsf

Agency: Interstate Drilling Services, Inc.	DRILLING LOG	Hole Number: BD2020-9
Driller: Dave Tokar	Gannett Fleming	Sheet: 3 of 3
Inspector: T. Kent		Elev. Top of Hole: +1524.5 ft

Bylin Dam

Depth (Ft.)	Sample No.	Blows or RQD (%)	Rec. (ft.)	Rec. (%)	USCS	Description Of Materials	Remarks
60.0 - 62.5	S-22	3-4-5-6-7	1.5	60			P.P. = 1.5 tsf
62.5 - 65.0	S-23	2-4-12-14-17	1.1	44			P.P. = 0 tsf
65.0 - 67.5	S-24	4-8-9-11-13	2.5	100			P.P. = 0.8 tsf
67.5 - 70.0	S-25	4-7-11-11-14	2.5	100			P.P. = 3.1 tsf
70.0 - 71.5	S-26	4-7-50/0.5	1.5	100		70.2': Sand Top of Rock @ 71.5 ft El. 1453.0	P.P. = 0.4 tsf
71.5 - 73.5	R-1	1.0' / 50%	1.0	50		71.5' to 88.5': Clayey SHALE [Pierre Fm.] comprised of clay to silt sized particles, pieces of sandstone interbedded, and sand layers. Dark gray (2.5Y 4/1) to black (2.5Y 2.5/1). Sandstone is light gray (2.5Y 7/2). Core easily broken by hand. Fractures are nearly horizontal, and most appear to be mechanical. Core develops horizontal hairline fractures. Sand is clean, fine to coarse max. particle size 2 mm, subangular to subrounded, dark gray (2.5Y 4/1) and light yellowish brown (2.5Y 6/4). 73.0': Loose sand, coarse grains on bottom, fine grains on top indicate particles setting out of water 73.5' Pierre shale with rounded gravel, 0.25' of gravel on top of sample. 74.5': Loose sand	71.5'-72.5': Washed away, tan drilling water, getting some water return, losing some potentially subsurface or around augers 73.5': Assumed rounded gravel preventing recovery. Assumed gravel sloughed off hole side 75.5': 1.0' drilled, 1.0' recovery, gravel on top assumed to be slough 76.5': 2.0' drilled, 1.75' of sand recovered assumed to be slough, 0.25' of pierre shale, sand is clean and assumed to be pushing out from outside of augers Sand sloughed into hole so split spoon sampler was used to remove slough from 73'-78' after it was already cored 78.5': 0.7' missing from top of core run 80.5': 1.7' missing core, sand jammed core barrel
73.5 - 75.5	R-2	0.3' / 15%	0.3	15			
75.5 - 76.5	R-3	0.3' / 30%	1.0	100			
76.5 - 78.5	R-4	0.0' / 0%	0.3	15			
78.5 - 80.5	R-5	0.9' / 45%	1.3	65			
80.5 - 82.5	R-6	0.3' / 15%	0.3	15			
82.5 - 84.5	R-7	1.0' / 50%	2.0	100			
84.5 - 86.0	R-8	1.5' / 100%	1.5	100			
86.0 - 88.5	R-9	2.3' / 92%	2.3	92		El. 1436.0	

Bottom of Borehole at 88.5 feet.

Date Started: 7/2/20	**DRILLING LOG**		Hole Number: BD2020-212	
Date Finished: 7/2/20	Gannett Fleming		Sheet: 1 of 2	
Soil Drilling: 20.2 ft			Line & Station:	
Rock Drilling: 14.0 ft	Project: Bylin Dam		Offset:	
Total Depth of Hole: 34.2 ft	Drilling Agency: Interstate Drilling Services, Inc.		N Coordinate: 508535.3 ft	
No. of Undist. Samples: 0	Driller: Dave Tokar		E Coordinate: 2573731.7 ft	
Total Number of Core Boxes: 2	Bit Size and Type: NQ	Spoon Size: 2.0 " OD	Elev. Top of Hole: +1517.4 ft	
GROUNDWATER OBSERVATIONS Not recorded	Casing Size: N/A	Hammer Wt.: 140 lb	Direction of Hole Vertical ☒ Inclined ☐ Degrees from Vertical ---	
	Hollow Stem Auger: 4.25 " ID x 8.0 " OD	Hammer Drop: 30.0 "		
	Drilling Fluid: Quik-Gel	Hammer Type: Automatic		
	Drill Rig: Dietrich 50 Track Rig		Logged By: T. Kent	

Depth (Ft.)	Sample No.	Blows or RQD (%)	Rec. (ft.)	Rec. (%)	USCS	Description Of Materials	Remarks
0.0 - 2.5	S-1	2-3-4-6-7	1.4	56		0.0'-12.5': Sandy CLAY (cl), 5% gravel, 25% sand, 70% fines. Gravel consists of shale and hard rock pieces, fine to coarse, angular to subangular, not flat or elongated, max. particle size 1.5", soft to hard, light gray (2.5Y 7/1). Sand is fine to medium, subangular to subrounded, max. particle size 1 mm, yellow (10YR 7/6). Fines, low plasticity, high dry strength, dark grayish brown (2.5Y 4/2) to light yellowish brown (2.5Y 6/3). Dry to moist. Stratified layers of differing colored fines about 6".	P.P. = 4.5 tsf
2.5 - 5.0	S-2	3-4-7-9-9	2.5	100		2.5': Shale pieces up to 3/4" throughout	P.P. = 4.5 tsf
5.0 - 7.5	S-3	5-7-11-13-15	1.8	72		6.7': Gravel up to 1.5"	P.P. = 2.3 tsf
7.5 - 10.0	S-4	5-10-14-17-20	2.5	100		7.5': Gravel up to 1.5"	P.P. = 4.5 tsf
10.0 - 12.5	S-5	5-8-16-18-30	2.0	80		Top of Rock @ 12.5 ft El. 1504.9	P.P. = 4.5 tsf
12.5 - 15.0	S-6	15-26-35-42-31	2.5	100		12.5'-34.2': Clayey SHALE. [Pierre Fm.] comprised of clay and silt sized particles and pieces of sandstone interbedded. Core easily broken by hand. Fractures are nearly horizontal and most appear to be mechanical. Core develops horizontal hairline fractures.	P.P. = 3.8 tsf
15.0 - 16.6	S-7	16-38-50/0.6	1.3	81		12.5'-15.0': Laboratory classified as lean CLAY (CL)	P.P. = 4.5 tsf
16.6 - 17.7	S-8	28-50/0.6	1.3	100			P.P. = 2.4 tsf
17.7 - 18.6	S-9	34-50/0.4	0.9	100			P.P. = 4.0 tsf
18.6 - 20.2	S-10	31-38-50/0.6	1.6	100			P.P. = 4.5 tsf
20.2 - 22.2	R-1	0.9' / 45%	1.6	80			
22.2 - 24.2	R-2	0.9' / 45%	1.9	95			

Purpose: Sample spillway material and foundation soils/rock
Drilling Method: Continuous split spoon sampling using hollow stem auger to 20.2', NQ rock coring 20.2' to 34.2'
Termination: 20 feet into rock
Abandonment: Grouted with tremie pipe
Additional Remarks: Relocated to 139.2 ft east of BD2020-213 and 138.5 ft west of BD2020-214

Agency: Interstate Drilling Services, Inc.	DRILLING LOG	Hole Number: BD2020-212
Driller: Dave Tokar	Gannett Fleming	Sheet: 2 of 2
Inspector: T. Kent		Elev. Top of Hole: +1517.4 ft

Bylin Dam

Depth (Ft.)	Sample No.	Blows or RQD (%)	Rec. (ft.)	Rec. (%)	USCS	Description Of Materials	Remarks
24.2 - 29.2	R-3	2.9' / 58%	4.5	90			
29.2 - 34.2	R-4	3.1' / 62%	4.9	98		31.0': Chert interbeds El. 1483.2	

Bottom of Borehole at 34.2 feet.

Date Started: 6/30/20	**DRILLING LOG**		Hole Number: BD2020-213
Date Finished: 7/1/20	Gannett Fleming		Sheet: 1 of 2
Soil Drilling: 25.0 ft			Line & Station:
Rock Drilling: 25.0 ft	Project: Bylin Dam		Offset:
Total Depth of Hole: 50.0 ft	Drilling Agency: Interstate Drilling Services, Inc.		N Coordinate: 508667.3 ft
No. of Undist. Samples: 0	Driller: Dave Tokar		E Coordinate: 2573723.5 ft
Total Number of Core Boxes: 3	Bit Size and Type: NQ	Spoon Size: 2.0 " OD	Elev. Top of Hole: +1517.1 ft
GROUNDWATER OBSERVATIONS At 19.1 ft after 48 Hrs Elev. 1498.0 ft after 48 Hrs	Casing Size: N/A	Hammer Wt.: 140 lb	Direction of Hole
	Hollow Stem Auger: 4.25 " ID x 8.0 " OD	Hammer Drop: 30.0 "	Vertical ☒ Inclined ☐
	Drilling Fluid: Quik-Gel	Hammer Type: Automatic	Degrees from Vertical ---
	Drill Rig: Dietrich 50 Track Rig		Logged By: T. Kent

Depth (Ft.)	Sample No.	Blows or RQD (%)	Rec. (ft.)	Rec. (%)	USCS	Description Of Materials	Remarks
0.0 - 2.5	S-1	2-3-4-4-5	1.2	48		0.0'-12.5': Clayey SAND (SC), 1% gravel, 52% sand, 47% fines. Gravel is shale and hard rock pieces, fine to coarse, angular to subangular, not flat or elongated, max. particle size 1", soft to hard, very dark gray (5Y 3/1). Sand is fine to coarse, subangular to subrounded, max. particle size 2 mm, light gray (2.5Y 7/1) and yellow (5Y 7/6). Fines, soft to stiff, dry to moist, low plasticity, high dry strength, olive (5Y 5/6). 0.0'-12.5': Field classified as Sandy CLAY (cl) 2.5': Gravel up to 3/4" 4.5': 1" gravel	P.P. = 4.5 tsf
2.5 - 5.0	S-2	4-4-6-7-8	1.7	68			P.P. = 1.6 tsf
5.0 - 7.5	S-3	4-5-9-9-10	2.0	80			P.P. = 1.3 tsf
7.5 - 10.0	S-4	4-5-6-7-8	2.5	100			P.P. = 4.5 tsf
10.0 - 12.5	S-5	6-9-16-22-36	1.5	60		Top of Rock @ 12.5 ft El. 1504.6	P.P. = 1.8 tsf
12.5 - 15.0	S-6	11-13-40-48-50/0.5	2.5	100		12.5'-50': Clayey SHALE. [Pierre Fm.] comprised of clay to silt sized particles and pieces of sandstone interbedded. Dark olive gray (5Y 3/2) to very dark gray (5Y 3/1). Sandstone pieces light olive gray (5Y 6/2). Core easily broken by hand. Fractures nearly horizontal and most appear to be mechanical. Core develops horizontal hairline fractures as it dries. Wet from 12.5' to 13.5'.	P.P. = 4.5 tsf
15.0 - 16.5	S-7	20-48-50/0.3	1.4	93		13.0': Bentonite shale, wet 0.5' above and below it 15.2': Wet at 15.2' for 0.4', broken up, clayey	P.P. = 4.5 tsf
16.5 - 17.5	S-8	16-50/0.5	1.0	100		16.5': Dry, light gray, extra from slough	P.P. = 4.5 tsf
17.5 - 18.6	S-9	19-50/0.6	1.0	91		17.5': Gray (light and dark), iron oxide staining	P.P. = 4.5 tsf
18.6 - 20.2	S-10	23-38-50/0.6	1.8	100		18.6': Light gray, crumbly, dry	P.P. = 4.5 tsf
20.2 - 21.2	S-11	33-50/0.5	0.9	90			
21.2 - 22.8	S-12	31-42-50/0.6	2.0	100		21.2': Light gray, crumbly dry, extra due to slough, iron oxide	P.P. = 4.1 tsf
22.8 - 23.9	S-13	42-50/0.6	1.0	91		22.8': Light to dark gray, crumbly, iron oxide to small of pieces to PP test	

Purpose: Sample spillway material and foundation soils/rock
Drilling Method: Continuous split spoon sampling using hollow stem auger to 25', NQ rock coring 25' to 50'
Termination: 20 feet into rock
Abandonment: Grouted with tremie pipe
Additional Remarks: Drilled on east side of auxiliary spillway, hole caved at 17.5' bgs

Log Checked By: EJB, 1/12/21

Agency: Interstate Drilling Services, Inc.	DRILLING LOG	Hole Number: BD2020-213
Driller: Dave Tokar	Gannett Fleming	Sheet: 2 of 2
Inspector: T. Kent		Elev. Top of Hole: +1517.1 ft

Bylin Dam

Depth (Ft.)	Sample No.	Blows or RQD (%)	Rec. (ft.)	Rec. (%)	USCS	Description Of Materials	Remarks
23.9 - 25.0	S-14	32-50/0.6	0.9	82		23.9': Light to dark gray, iron oxide	P.P. = 4.5 tsf
25.0 - 27.0	R-1	1.3' / 65%	1.9	95		25.0': Dark gray and brown	
27.0 - 29.0	R-2	0.8' / 40%	1.6	80		27.0': Dark gray and brown until 28.0' where it turns to dark gray with no brown	
29.0 - 34.0	R-3	5.0' / 93%	5.4	100			34.0': Actual recovery length of R-3 noted to be 5.4', extra length assumed to be loss from R-2.
34.0 - 36.7	R-4	2.7' / 100%	2.7	100		34.0'-50.0': Pieces of chert (sandstone) present in core	
36.7 - 40.0	R-5	3.3' / 100%	3.3	100			Driller stopped core run short due to barrel jam, continued coring without sleeve inside barrel. Finished what was left from last run and went to 36.7'.
40.0 - 45.0	R-6	4.6' / 88%	5.2	100			45.0': Actual recovery length of R-6 noted to be 5.2', extra length to be slough.
45.0 - 50.0	R-7	5.0' / 94%	5.3	100		El. 1467.1	50.0': Actual recovery length of R-7 noted to be 5.3', extra length assumed to be slough.

Bottom of Borehole at 50.0 feet.

Date Started: 7/1/20	**DRILLING LOG** Gannett Fleming		Hole Number: BD2020-214	
Date Finished: 7/1/20			Sheet: 1 of 2	
Soil Drilling: 19.1 ft			Line & Station:	
Rock Drilling: 31.0 ft	Project: Bylin Dam		Offset:	
Total Depth of Hole: 50.1 ft	Drilling Agency: Interstate Drilling Services, Inc.		N Coordinate: 508677.1 ft	
No. of Undist. Samples: 0	Driller: Dave Tokar		E Coordinate: 2574002.9 ft	
Total Number of Core Boxes: 3	Bit Size and Type: NQ	Spoon Size: 2.0 " OD	Elev. Top of Hole: +1518.5 ft	
GROUNDWATER OBSERVATIONS At 10.2 ft after 24 Hrs Elev. 1508.3 ft after 24 Hrs	Casing Size: N/A	Hammer Wt.: 140 lb	Direction of Hole	
	Hollow Stem Auger: 4.25 " ID x 8.0 " OD	Hammer Drop: 30.0 "	Vertical ☒ Inclined ☐	
	Drilling Fluid: Quik-Gel	Hammer Type: Automatic	Degrees from Vertical ---	
	Drill Rig: Dietrich 50 Track Rig		Logged By: T. Kent	

Depth (Ft.)	Sample No.	Blows or RQD (%)	Rec. (ft.)	Rec. (%)	USCS	Description Of Materials	Remarks
0.0 - 2.5	S-1	1-3-4-13-16	1.6	64		0.0'-2.5': Sandy CLAY (cl). 5% gravel, 25% sand, 70% fines. Gravel is shale and hard rock pieces, fine, angular to subangular, not flat or elongated, max. particle size ½", hard, very dark gray (5Y 3/1). Sand is fine to coarse, subangular to subrounded, max. particle size 2 mm, yellow (5Y 7/6). Fines, low plasticity, high dry strength, dark grayish brown (2.5Y 4/2) to olive yellow (2.5 6/6). Dry to moist. Top of Rock @ 2.5 ft (El. 1516.0)	P.P. = 1.0 tsf
2.5 - 5.0	S-2	11-13-26-29-41	2.5	100		2.5'-50.1': Clayey SHALE [Pierre Fm.] comprised of clay to silt sized particles and pieces of sandstone interbedded. Very dark gray (2.5Y 3/1) to light gray (2.5Y 7/2). Sandstone pieces light gray (2.5Y 7/2). Core easily broken by hand. Fractures are nearly horizontal, and most appear to be mechanical. Core develops horizontal hairline fractures.	P.P. = 4.5 tsf
5.0 - 7.5	S-3	14-26-30-31-37	1.9	76			P.P. = 4.5 tsf
7.5 - 10.0	S-4	15-27-30-36-46	2.5	100		2.5'-10.0': Dry, crumbly	P.P. = 3.3 tsf
10.0 - 12.5	S-5	15-32-29-26-30	1.9	76		10.0': Dry to slightly moist, mud on outside of split spoon, damp past ~1" thick at 11:0'	P.P. = 4.5 tsf
12.5 - 15.0	S-6	9-26-29-32-46	2.5	100		12.5': Light gray to 14.5' then darker gray	P.P. = 4.5 tsf
15.0 - 16.6	S-7	26-42-50/0.6	1.4	88		15.0': Dark gray, dry	P.P. = 4.5 tsf
16.6 - 19.1	S-8	17-25-32-46-50/0.5	2.5	100		16.6': Light gray outside, dark gray inside	P.P. = 4.5 tsf
19.1 - 21.1	R-1	0.8' / 40%	1.5	75		19.1': Dark gray	19.1': Core barrel clogged; some sample loss when core ejected from barrel
21.1 - 23.1	R-2	0.0' / 0%	1.0	50			
23.1 - 24.1	R-3	0.1' / 10%	0.1	10			

Purpose: Sample spillway material and foundation soils/rock
Drilling Method: Continuous split spoon sampling using hollow stem auger to 19.1', NQ rock coring 19.1' to 50.1'
Termination: 30 feet into rock
Abandonment: Grouted with tremie pipe
Additional Remarks: Drilled on west side of auxiliary spillway, hole caved at 7.8' bgs

Agency: Interstate Drilling Services, Inc.	**DRILLING LOG**	Hole Number: BD2020-214
Driller: Dave Tokar	Gannett Fleming	Sheet: 2 of 2
Inspector: T. Kent		Elev. Top of Hole: +1518.5 ft

Bylin Dam

Depth (Ft.)	Sample No.	Blows or RQD (%)	Rec. (ft.)	Rec. (%)	USCS	Description Of Materials	Remarks
24.1 - 25.1	R-4	0.4' / 40%	0.9	90			
25.1 - 27.1	R-5	0.8' / 40%	1.8	90			
27.1 - 29.1	R-6	1.9' / 86%	2.2	100			29.1': Actual recovery length of R-6 noted to be 2.2', extra length assumed to be loss from R-5.
29.1 - 34.1	R-7	3.5' / 70%	3.7	74		30.1'-49.1': Chert pieces	
34.1 - 36.1	R-8	1.8' / 75%	2.4	100			36.1': Actual recovery length of R-8 noted to be 2.4', extra length assumed to be loss from R-7.
36.1 - 39.1	R-9	2.3' / 74%	3.1	100			
39.1 - 44.1	R-10	4.5' / 90%	5.0	100			
44.1 - 49.1	R-11	4.8' / 91%	5.3	100			
49.1 - 50.1	R-12	0.3' / 30%	0.8	80		El. 1468.4	

Bottom of Borehole at 50.1 feet.

Date Started: 6/26/20	**DRILLING LOG**		Hole Number: BD2020-605
Date Finished: 6/29/20	Gannett Fleming		Sheet: 1 of 2
Soil Drilling: 41.5 ft			Line & Station:
Rock Drilling: 17.0 ft	Project: Bylin Dam		Offset:
Total Depth of Hole: 58.5 ft	Drilling Agency: Interstate Drilling Services, Inc.		N Coordinate: 508914.7 ft
No. of Undist. Samples: 1	Driller: Dave Tokar		E Coordinate: 2573375.1 ft
Total Number of Core Boxes: 3	Bit Size and Type: HQ	Spoon Size: 2.0 " OD	Elev. Top of Hole: +1499.3 ft
GROUNDWATER OBSERVATIONS At 14.3 ft after 72 Hrs Elev. 1485.0 ft after 72 Hrs	Casing Size: N/A	Hammer Wt.: 140 lb	Direction of Hole Vertical ☒ Inclined ☐ Degrees from Vertical ---
	Hollow Stem Auger: 4.25 " ID x 8.0 " OD	Hammer Drop: 30.0 "	
	Drilling Fluid: Water	Hammer Type: Automatic	
	Drill Rig: Dietrich 50 Track Rig		Logged By: T. Kent

Depth (Ft.)	Sample No.	Blows or RQD (%)	Rec. (ft.)	Rec. (%)	USCS	Description Of Materials	Remarks
0.0 - 2.5	S-1	2-4-8-6-6	2.0	80		0.0'-40.5': Clayey SAND with gravel (SC) 17% gravel, 52% sand, 69% fines. Gravel is shale and hard rock pieces, fine to coarse, angular to subangular, max. particle size 2", hard, gray (2.5Y 5/1). Sand is fine to coarse, subangular to subrounded, max. particle size 2 mm, gray (2.5Y 5/1) and pale brown (2.5Y 8/4). Fines, soft to stiff, dry to moist, low plasticity, high dry strength, light olive brown (2.5Y 5/6) and dark grayish brown (2.5Y 4/2). 0.0'-40.5': Field classified as sandy CLAY (cl). 2.5': Rock caught in tip made little recovery	P.P. = 4.1 tsf
2.5 - 5.0	S-2	3-4-4-4-5	0.8	32			P.P. = 3.3 tsf
5.0 - 7.5	S-3	2-2-3-4-5	1.5	60		5.0': 1/4" gravel	P.P. = 3.75 tsf
7.5 - 10.0	S-4	3-5-6-6-7	0.9	36		7.5': 1" gravel, rock caught in tip 11.5"	P.P. = 1.3 tsf
10.0 - 12.5	S-5	4-6-7-7-12	1.8	72			P.P. = 3.3 tsf
12.5 - 15.0	S-6	4-5-6-8-10	1.8	72			P.P. = 2.3 tsf
15.0 - 17.5	S-7	5-8-10-10-11	2.4	96		15.0': 3/4" gravel	P.P. = 2.1 tsf
17.5 - 20.0	S-8	4-5-6-8-11	2.1	84			P.P. = 1.6 tsf
20.0 - 22.5	U-1	Shelby Tube	1.8	72			
22.5 - 25.0	S-9	3-5-7-8-9	2.0	80		22.5': 2" rock	P.P. = 2.0 tsf

Purpose: Sample embankment material and foundation soils/rock
Drilling Method: Continuous split spoon sampling using hollow stem auger to 41.5', HQ rock coring 41.5' to 58.5'.
Termination: 15 feet into rock
Abandonment: Two pressure transducers in sand-socks cement grouted in place at 30' (S/N: 2024385) and 50' (S/N: 2024383)
Additional Remarks: Drilled middle of downstream bench.

Agency: Interstate Drilling Services, Inc.	DRILLING LOG	Hole Number: BD2020-605
Driller: Dave Tokar	Gannett Fleming	Sheet: 2 of 2
Inspector: T. Kent		Elev. Top of Hole: +1499.3 ft

Bylin Dam

Depth (Ft.)	Sample No.	Blows or RQD (%)	Rec. (ft.)	Rec. (%)	USCS	Description Of Materials	Remarks
						24.6': Sand lens 25.0': Stiff rock prevented full recovery	P.P. = 3.0 tsf
25.0 - 27.5	S-10	7-9-10-12-14	1.0	40		27.5': 1/4" gravel pieces	P.P. = 3.3 tsf
27.5 - 30.0	S-11	2-4-5-6-8	2.0	80		30.0': Gravel up to 1.5"	P.P. = 2.3 tsf
30.0 - 32.5	S-12	6-5-4-7-8	2.2	88			P.P. = 3.3 tsf
32.5 - 35.0	S-13	5-6-5-6-7	2.3	92			P.P. = 4.5 tsf
35.0 - 37.5	S-14	4-9-11-12-11	2.3	92			P.P. = 2.3 tsf
37.5 - 40.0	S-15	4-5-6-7-11	1.9	76		El. 1458.8	P.P. = 0.6 tsf
40.0 - 41.5	S-16	3-29-50/0.5	1.3	87		40.5'-58.5': Clayey SHALE [Pierre Fm.] comprised of clay to silt sized particles, pieces of sandstone interbedded, and sand layers. Dark gray (2.5Y 4/1) to black (2.5Y 2.5/1). Sandstone is light gray (2.5Y 7/2). Core easily broken by hand. Fractures are nearly horizontal, and most appear to be mechanical. Core develops horizontal hairline fractures. Sand, fine to coarse max. particle size 2 mm, subangular to subrounded, dark gray (2.5Y 4/1) and light yellowish brown (2.5Y 6/4). Top of Rock @ 41.5 ft 41.5'-42.0': Sandy clay 45.5': Broken up shale with sandy clay mixed in, gray water return	
41.5 - 43.5	R-1	1.5' / 75%	1.5	75			
43.5 - 45.5	R-2	2.0' / 83%	2.4	100			45.5': Actual recovery length of R-2 noted to be 2.5', extra length likely loss from R-1.
45.5 - 47.5	R-3	0.0' / 0%	1.5	75			
47.5 - 49.5	R-4	1.5' / 75%	2.0	100			
49.5 - 51.5	R-5	1.9' / 95%	2.0	100			
51.5 - 53.5	R-6	2.0' / 100%	2.0	100			
53.5 - 56.5	R-7	1.5' / 50%	3.0	100			58.5': Actual recovery length of R-8 noted to be 2.3', extra length likely loss from R-7.
56.5 - 58.5	R-8	2.0' / 87%	2.3	100		El. 1440.8	Hole drilled to 58.5' per tooling but tagged at 57.5', assumed to be due to slough.

Bottom of Borehole at 58.5 feet.

DRILLING LOG

Gannett Fleming

Date Started: 6/29/20			Hole Number: BD2020-606
Date Finished: 6/30/20			Sheet: 1 of 2
Soil Drilling: 14.5 ft			Line & Station:
Rock Drilling: 12.0 ft	Project: Bylin Dam		Offset:
Total Depth of Hole: 26.5 ft	Drilling Agency: Interstate Drilling Services, Inc.		N Coordinate: 508999.1 ft
No. of Undist. Samples: 1	Driller: Dave Tokar		E Coordinate: 2573428.3 ft
Total Number of Core Boxes: 2	Bit Size and Type: HQ	Spoon Size: 2.0 " OD	Elev. Top of Hole: +1471.1 ft
GROUNDWATER OBSERVATIONS At 7.1 ft after 24 Hrs Elev. 1464.0 ft after 24 Hrs	Casing Size: N/A	Hammer Wt.: 140 lb	Direction of Hole
	Hollow Stem Auger: 4.25 " ID x 8.0 " OD	Hammer Drop: 30.0 "	Vertical ☒ Inclined ☐
	Drilling Fluid: Water	Hammer Type: Automatic	Degrees from Vertical ---
	Drill Rig: Dietrich 50 Track Rig		Logged By: T. Kent

Depth (Ft.)	Sample No.	Blows or RQD (%)	Rec. (ft.)	Rec. (%)	USCS	Description Of Materials	Remarks
0.0 - 2.5	S-1	2-2-3-3-3	2.0	80		0.0'-5.0': Sandy CLAY (cl). 5% gravel, 25% sand, 70% fines. Gravel is shale and hard rock pieces, fine, angular to subangular, not flat or elongated, max. particle size ¾", hard, yellow (2.5Y 8/6). Sand is fine, subangular to subrounded, max. particle size 1 mm, yellow (2.5Y 7/6). Fines, medium soft to soft, moist to very moist, low plasticity, high dry strength, dark olive brown (2.5Y 3/3).	P.P. = 1.1 tsf
2.5 - 5.0	S-2	1-2-3-2-3	1.3	52		El. 1466.1	P.P. = 0 tsf
5.0 - 7.5	S-3	3-5-7-7-8	2.4	96		5.0'-10.0': Elastic SILT with Sand (MH). 19% sand, 81% fines. Soft to stiff, dry to moist, low plasticity, high dry strength, very dark gray (2.5Y 3/1). 5.0'-10.0': Field classified as CLAY (cl)	P.P. = 3.3 tsf
7.5 - 10.0	U-1	Shelby Tube	2.1	84		Top of Rock @ 10.0 ft El. 1461.1	
10.0 - 12.5	S-4	1-2-2-3-10	2.0	80		10.0'-26.5': Clayey SHALE [Pierre Fm.] comprised of clay to silt sized particles and pieces of sandstone interbedded. Dark gray (2.5Y 4/1) to very dark gray (2.5Y 3/1). Sandstone is light gray (2.5Y 7/2). Core easily broken by hand. Fractures are nearly horizontal, and most appear to be mechanical. Core develops horizontal hairline fractures.	P.P. = 0.8 tsf
12.5 - 14.5	S-5	12-24-39-50/0.5	2.0	100		12.5'-14.3': Laboratory classified as Elastic SILT with Sand (MH)	P.P. = 4.5 tsf
14.5 - 16.5	R-1	1.8' / 90%	2.0	100		14.5': End of split spoon sampling, auger refusal at 14.5', dry to slightly moist, light gray	14.5': Begin coring.
16.5 - 18.5	R-2	1.3' / 65%	1.8	90			
18.5 - 21.5	R-3	3.3' / 100%	3.3	100			21.5': Actual recovery length of R-3 noted to be 3.3', extra length assumed to be loss from R-2.
21.5 - 24.5	R-4	2.7' / 90%	2.7	90		21.5': Chert (sandstone) interbedded	

Purpose: Sample embankment material and foundation soils/rock
Drilling Method: Continuous split spoon sampling using hollow stem auger to 10', HQ rock coring 10' to 26.5'
Termination: 15 feet into rock
Abandonment: Two pressure transducers in sand-socks cement grouted in place at 26.1' (S/N: 2024618) and 11.8' (S/N: 2024619)
Additional Remarks: Drilled at toe of dam

Agency: Interstate Drilling Services, Inc.	DRILLING LOG	Hole Number: BD2020-606
Driller: Dave Tokar	Gannett Fleming	Sheet: 2 of 2
Inspector: T. Kent		Elev. Top of Hole: +1471.1 ft

Bylin Dam

Depth (Ft.)	Sample No.	Blows or RQD (%)	Rec. (ft.)	Rec. (%)	USCS	Description Of Materials	Remarks
24.5 - 26.5	R-5	2.0' / 95%	2.1	100		El. 1444.6	26.5': Actual recovery length of R-5 noted to be 2.1', extra length assumed to be loss from R-4.

Bottom of Borehole at 26.5 feet.

24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58