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Water Treatment Plant Geotechnical Design Report Faro Mine Remediation Project

PREPARED FOR: Government of Yukon

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Introduction

Purpose and Scope of Work

This Water Treatment Plant Geotechnical Design technical memorandum (TM) presents the data, findings, evaluations and recommendations for the proposed Faro Water Treatment Plant (WTP) design. The scope of work is defined in Task 13.SD.GT – *Geotechnical Design* under *Task Authorization Request (TAR) 013(A), WTP Design* (CH2M HILL Canada Limited [CH2M HILL], 2012a). Task 13.SD.GT scope includes the following:

- Work with the TAR 007(A) engineering lead to develop a plan for geotechnical investigations of the WTP site. (All field work was performed under TAR 007(A), Field Planning and Investigation, Subtask 07.01.04.20 – 101.1, Construct New Faro Water Treatment Plant and Piping [CH2M HILL, 2012b].)
- Establish geotechnical design criteria required for structural design and the design of earthen features, including site preparation beneath structural foundations and engineered slopes.
- Evaluate onsite soils for use in construction, and determining other project-specific geotechnical requirements (e.g., excavation, fill, and slope stability).
- Develop preliminary foundation and site grading recommendations and coordinating with the structural and site civil engineers.
- Prepare this geotechnical design report using data obtained during the geotechnical investigation.

A separate geotechnical data TM (CH2M HILL, 2012c) has been prepared under TAR 007(A), Field Planning and Investigation, Subtask 07.01.04.20 – 101.1, Construct New Faro Water Treatment Plant and Piping (CH2M HILL, 2012c). That TM contains the borings logs and laboratory test data.

Project Description

The proposed Faro WTP will treat contaminated water at the Faro Mine Complex (FMC) and is anticipated to include (approximate dimensions): a 33-metre (m) by 37-m Water Treatment Building, a 55-m-diameter Thickener, and a 25-m by 15-m lime silo/grit building. A 30-m by 85-m Filter Building may be constructed at a later date, south of the proposed thickener.

The WTP site will be excavated 3 to 12 m below the current site grade to construct the WTP structures, including a cut-and-cover concrete box tunnel connecting the Water Treatment Building and the Thickener. The tunnel will be constructed of reinforced concrete. Layouts for access and service roads, parking, and utility corridors are in design. Surface drainage will shed runoff away from the WTP site. The proposed Faro WTP will be designed to operate year-round when required; however, during most years it is expected that there will be a winter shutdown period. Additional design information is presented in the Schematic Design Report (CH2M HILL, 2013a).

Geologic Conditions and Seismicity

Geologic Setting

Bulletin 11 of the Exploration and Geological Services Division, Yukon Region (Bond, 2001) describes the FMC as being located in the Anvil district of the central portion of the Yukon physiographic subdivision. The Anvil district is bound by the Pelly Mountains and the Tintina Fault to the southwest and Tay River to the north. Bedrock at the WTP site consists of weathered calcareous phyllite and schist of the Vangorda formation (Pigage, 1999). Surficial geology (overburden) includes residual soils and possible glacial till.

Seismicity

Seismic design parameters for the project were developed in accordance with 2010 National Building Code of Canada (NBCC) seismic design guidelines and procedures (National Research Council Canada [NRC], 2010). The NBCC seismic design parameters are based on ground motions with 2 percent probability of being exceeded in 50 years. Site-specific seismic assessments have been prepared by CH2M HILL (2013b) and Atkinson and Assatourians (2013).

The following seismic parameters for horizontal ground motion were estimated at the WTP site and should be used for the design (Atkinson and Assatourians, 2013):

- Peak ground acceleration (PGA) = 0.118 g (with g being acceleration due to gravity)
- Spectral acceleration at a period of 0.2 second, $S_a(0.2)$ = 0.264 g
- Spectral acceleration at a period of 0.5 second, $S_a(0.5)$ = 0.152 g
- Spectral acceleration at a period of 1.0 second, $S_a(1.0)$ = 0.082 g
- Spectral acceleration at a period of 2.0 seconds, $S_a(2.0)$ = 0.039 g

These parameters are for Site Class C, according to the NBCC (NRC, 2010). Based on the conditions encountered during the subsurface soil investigations, the WTP site is Site Class C, as defined in Table 4.1.8.4.A of the NBCC.

Geotechnical Field Investigation

A geotechnical field investigation was performed from June 18 through June 24, 2012, at the proposed Faro WTP site. Results of the investigation and the data gathered are presented in the Geotechnical Data TM (CH2M HILL, 2012c). Figure 1 presents the proposed replacement WTP location and a vicinity map (figures are located at the end of this TM). The field investigation consisted of advancing soil boreholes, collecting soil and rock samples, and constructing open standpipe piezometers. The borehole identifiers are CH12-101-BH001 through CH12-101-BH008, CH12-101-PZ001, and CH12-101-PZ002. The latter two boreholes were completed as open standpipe piezometers. Figure 1 shows the borehole locations.

Surface and Subsurface Conditions

The proposed Faro WTP site is on a relatively flat equipment and material storage yard above a sloping hillside, west of the existing Mill Building Area. The existing site is at approximately 1,137 m above mean sea level (amsl) at the north end of the site and slopes gently to approximately 1,135 amsl at the south end. The aerial photograph in Figure 1 shows the site features and locations of borings drilled. The FMC office and main security gate are located to the north. According to FMC site personnel, an old mill building was once located at the south end of the WTP site but was reportedly demolished decades ago. Piping, broken-down equipment, and debris are scattered across the surface. Small trees and brush are growing at the south end of the site. Active overhead and underground power lines run east-west across the WTP site. A below-grade, timber-lined chute or channel that has a concrete cover and is oriented approximately east–west was observed between boreholes CH12-101-PZ002 and CH12-101-BH005. The location of this feature is identified on Figure 1. Other abandoned subsurface facilities may exist in the vicinity.

The subsurface profile at the proposed Faro WTP site is random fill and native soils that overlie moderately to highly weathered phyllite bedrock that has a Rock Quality Designation of less than 26 percent. The fill consists of sands and gravels with varying cobble and fines content. The thickness of the fill encountered in the soil boreholes ranges from 0.2 to 4.3 m. The native soils encountered include organic topsoil and silty to clayey sands and gravels. The native soils are medium-dense to very dense. Some of the native soils are interpreted to be glacial till and residual soils. Residual soils derived from completely weathered phyllite bedrock were encountered in several boreholes. There is a bedrock surface outcrop on the hillside south of borehole CH12-101-BH004; however, possible bedrock was interpreted, but not confirmed, within the depth drilled in borehole CH12-101-BH002.

Analytical test data indicating elevated concentrations of heavy metals, including arsenic, lead, and zinc in the site soils are presented in the Geotechnical Data TM (CH2M HILL, 2012c).

Other than borehole CH12-101-BH002, the depth to sound bedrock in the WTP boreholes ranged up to 6.1 m. The rock quality is very low and did not consistently increase with depth in the limited depths explored in the WTP borings.

Neither permafrost nor frozen soil was encountered in any of the WTP boreholes.

Open standpipe piezometers were installed in CH12-101-PZ001 and CH12-101-PZ002 to measure groundwater levels. These piezometers have been monitored periodically since installation. The groundwater elevations measured between April and October 2013 in CH12-101-PZ001 ranged from 1,130.07 to 1,132.00 m amsl; in CH12-101-PZ002 elevations ranged from 1,126.17 to 1,129.36 m amsl. No emerging groundwater springs were observed during the WTP field investigation. The groundwater profile is expected to generally follow the existing ground surface profile and the bedrock surface. A groundwater surface approximately 4 m below the existing ground surface is recommended for design purposes. This recommended depth corresponds to elevation (el.) 1,133 m amsl at the north end of the Water Treatment Building and el. 1,131 m amsl at the south end of the Thickener.

Figures 2 and 3 show cross sections of the proposed Faro WTP site.

Geologic Hazards

Liquefaction

The low probability to experience major seismic shaking and the typically dense overburden soils suggest the potential for liquefaction is low at the proposed Faro WTP site.

Landslide and Slope Instability

The proposed Faro WTP site is on a relatively flat, horizontal bench at the top of a hill that slopes at approximately 20 percent. Signs of slope instability were not observed in the slopes in the vicinity. Many of the slopes are human-made embankment fills and cuts. The potential for slope instability in the existing embankments and cuts is low. New slopes for the replacement WTP should be constructed in accordance with the recommendations provided in this TM.

Foundation Recommendations

The proposed Faro WTP will be constructed on an excavated bench at an el. 1,135 m amsl. The cut-and-cover tunnel is expected to be constructed at approximately el. 1,128 m amsl.

Because bedrock was encountered at a shallow depth in all borings and the native soil is generally competent, shallow foundations appear to be appropriate for the proposed Faro WTP structures. Suitable shallow foundation types include spread footings and mat foundations. Deep foundations are not recommended.

The Water Treatment Building foundation is a slab on grade with perimeter stem wall. The Thickener foundation is a slab on grade. The cut-and-cover tunnel concrete box structure bottom will bear directly on bedrock. The future Filter Building foundation type is not yet selected.

Using currently-available information in the Schematic Design Report (CH2M HILL, 2013a), Table 1 lists the structure floor (bottom) elevations and the estimated bearing strata, based on the WTP boreholes. The foundations must not bear on the random fill, most of which will be removed as part of the WTP site earthwork.

TABLE 1
WTP Foundation-bearing Strata
Faro Mine Remediation Project

Structure	Assumed Foundation Elevation (m)	Bearing Stratum	Required Thickness of Structural Fill (m)	Thickness of Native Soil Beneath Foundation (m)	Borings
Water Treatment Building	1,124 to 1,133	Native soil and structural fill over native soil or bedrock	0–2.7	0.4–1.6	CH12-101-BH001 CH12-101-BH002
Thickener	1,131 to 1,135.0	Structural fill over native soil or bedrock	0–4.0	0–1.2	CH12-101-BH003 BH12-101-BH004
Tunnel	1,127.0	Bedrock	None	None	CH12-101-BH007 CH12-101-PZ001

The proposed Faro WTP structures are anticipated to be reinforced concrete and designed using the Working Stress Design method. Working loads for walls are expected to range from 300 to 550 kilonewtons per metre (kN/m). Working loads for mat foundations are expected to range from 200 to 300 kilopascals (kPa).

Foundation recommendations follow the Canadian Foundation Engineering Manual (CFEM) (Canadian Geotechnical Society [CGS], 2006). Foundation elevations are still preliminary, but the cut-and-cover tunnel and possibly other structural elements are expected to be below the top of bedrock. Foundations for the WTP structures are expected to bear on (1) bedrock, (2) structural fill over native soils or bedrock, or (3) native soil. Laboratory strength testing of undisturbed samples of native soil and intact bedrock was not possible because the high gravel content in the soils and the poor rock quality prevented collection of undisturbed samples. Standard penetration test (SPT) blowcounts in the native soils are not reliable because of the gravel content in the soils. Therefore, following Table 9.3 in the CFEM, presumptive bearing capacities for shallow foundations are provided in Table 2.

Spread and strip footings bearing on bedrock should have a minimum width of 0.3 m and footings bearing on structural fill and native soil should have a minimum width of 1 m. On-grade slabs may not be supported on the random site fill but may be supported on the native overburden, structural fill, or bedrock. Bearing capacity recommendations should be re-evaluated for specific footing depths and widths so that the estimated settlement is within an acceptable range.

TABLE 2
Bearing Capacities for WTP Shallow Foundations
Faro Mine Remediation Project

Material	Allowable Bearing Capacity	Ultimate Bearing Capacity
Weathered Bedrock	500 kPa (10,000 psf)	1,500 kPa (30,000 psf)
Structural Fill over Bedrock	250 kPa (5,000 psf)	750 kPa (15,000 psf)
Structural Fill over Native Soil	200 kPa (4,000 psf)	600 kPa (12,000 psf)
Native Soil	100 kPa (2,000 psf)	300 kPa (6,000 psf)

Notes:
Allowable bearing capacities are gross and have an applied factor of safety equal to 3.
Structural fill should have a minimum thickness of 0.6 m when placed over native soil.
psf = pounds per square foot

An interface friction angle (δ) of 29° is recommended for cast-in-place concrete on native soil and on structural fill. An interface friction angle (δ) of 35° is recommended for cast-in-place concrete on bedrock.

In accordance with CFEM, Table 7.1 (CGS, 2006), recommended values of subgrade modulus for use in mat foundation and slab-on-grade design are provided in Table 3.

TABLE 3
Subgrade Modulus for WTP Foundation Materials
Faro Mine Remediation Project

Material	Subgrade Modulus
Bedrock	300 MPa/m (1,800 kcf)
Structural Fill over Bedrock	50 MPa/m (300 kcf)
Structural Fill over Native Soil	20 MPa/m (120 kcf)
Native Soil	20 MPa/m (120 kcf)

Notes:
These subgrade modulus values have been adjusted for the anticipated range of actual foundation sizes.
kcf = kips per cubic foot
MPa/m = megaascals per metre

The subgrade modulus recommendations should be re-evaluated when specific mat foundation dimensions and loads are defined.

Frost Action

Historical data for the proposed WTP site at the FMC are not available. Table 4 summarizes the climatic conditions for the town of Faro, which is the nearest location with historical data (Environment Canada, 2012); however the proposed Faro WTP site is approximately 420 m higher in elevation than the town of Faro. Therefore, the design freezing index presented in Table 4 may be slightly unconservative.

TABLE 4
Summary of Temperature Conditions for the Water Treatment Plant
Faro Mine Remediation Project

Parameter	Value
Average Annual Air Temperature (°C)	-2.2
Design Freezing Index (°C-days)	3,380

Note:
°C = degrees Celsius

The design freezing index is calculated in accordance with CFEM, Section 13.4 (CGS, 2006). Seasonal frost depths in the area may penetrate to 3.5 m in cleared areas where structural fill and native soils are present and the ground surface is kept clear of snow. Potential effects of frost penetration should also be considered in the design of foundations and pipelines. Consideration should be given to the current plan for the structures to be in operation and to contain liquids year-around. Where foundations will not be supported on bedrock, use of ground insulation should be considered to prevent frost from penetrating beneath the foundations. Cellular concrete can also be considered a form of insulation for trenched-in utilities. Cost comparisons should identify the most economical means of frost protection for piping and foundations. It will not generally be cost effective to carry the foundations down to the seasonal frost depth.

Settlement

Soils at the proposed Faro WTP site are relatively thin, dense, unsaturated, and underlain by bedrock. Structural backfill materials should be granular, compacted and dense. Therefore, settlement is expected to be immediate (i.e., it will occur during construction) and relatively minor. Consolidation (time-dependent) settlement is not expected to occur. Total settlement of spread footings on native soil or structural fill is expected to be less than 25 millimetres (mm). Based on the foundation recommendations, total settlement of footings on bedrock is expected to be less than 12 mm. Differential settlement is expected to be less than half of the total settlement.

Lateral Earth Pressures

Lateral earth pressures are estimated assuming free-draining, select, granular backfill will be used to backfill behind walls. It is assumed that the backfill will be placed in controlled, compacted lifts. Table 5 lists design recommendations for lateral earth pressures.

TABLE 5
WTP Lateral Earth Pressure Recommendations
Faro Mine Remediation Project

Parameter	Design Recommendation
Backfill Condition	Level Backfill
Traffic Surcharge (if applicable)	12 kPa
Retaining Wall Soil Properties:	
Soil Internal Angle of Friction	35°
Unit Weight of Soil	19.6 kN/m^3
Maximum Allowable Soil Bearing Pressure	95.8 kPa
Coefficient of Active Earth Pressure (K_a)	0.26
Equivalent Active Fluid Pressure	5.7 kN/m^3
Coefficient of At-Rest Earth Pressure (K_o)	0.43
Equivalent At-Rest Fluid Pressure	8.4 kN/m^3
Coefficient of Passive Earth Pressure (K_p)	2.89
Equivalent Passive Fluid Pressure	56.5 kN/m^3
Coefficient of Friction Between Granular Backfill and Formed Concrete, tan δ	0.45

Note:
kN/m^3 = kilonewtons per cubic metre

Active and passive earth pressures are appropriate to analyze flexible walls or walls that can rotate. At-rest earth pressure is appropriate to analyze rigid walls or walls that that are restrained from rotating. Full mobilization of passive earth pressure requires the rotational displacement of the top of wall of 0.02H or more (where H is the height of the wall). The pressure distributions are triangular. The resultants will act at a point 0.33 times the wall height, measured up from the wall toe. Passive earth pressure against spread footings should be ignored.

If traffic will be allowed next to the wall, the effects of traffic loading can be represented by the traffic surcharge. The surcharge load is multiplied by the active earth pressure coefficient, and the resulting pressure distribution is uniformly applied to the back of the wall.

Earthwork and Site Grading

Figure 3 depicts the major strata, the current and excavated ground profile, the proposed foundation levels, and zones of structural and general fill. The existing fill is generally of poor quality and may include debris, trash, and soils with high organic content. It must be stripped and removed from beneath proposed structures, roads, and parking areas before foundations are constructed. In addition, the random fill should be removed from beneath buried utility corridors. Native topsoil that is exposed after stripping the existing fill should also be removed.

Analytical test data indicate the site soils have elevated levels of heavy metals including arsenic, lead, and zinc. These data are presented in the Geotechnical Data TM (CH2M HILL, 2012c). Affected soils from site excavations may require disposal in other locations within the FMC.

Footings and mats may be constructed directly on sound bedrock. However, if a footing or mat only partially bears directly on bedrock, to provide uniform support, the bedrock should be over-excavated at least 300 mm below the bottom of the footing or mat and replaced with compacted structural fill.

To avoid potential frost heaving, frost-susceptible soils (silts) encountered during foundation preparation work should either be over-excavated and replaced with free-draining structural fill, or ground insulation should be placed above them to limit the frost penetration. Foundation frost-protection methods are detailed in American Society of Civil Engineers (ASCE) Standard SEI/ASCE 32-01, *Design and Construction of Frost-Protected Shallow Foundations* (ASCE, 2001), Erranti and Lee (1986), and *Blueprints Services, Insulation for Geotechnical Applications* (Dow Chemical Canada Inc., 1998). Piping that will contain liquids year-around should also be designed for frost protection.

Structural fill placed beneath structures should extend a minimum of 3 m out from the structure walls and extend down to subgrade at an angle no steeper than 45°. Structural fill should be composed of select granular material. Pit run material or blended crushed and pit run material may be used. Select granular material should be well graded and relatively clean. In locations that are susceptible to frost, the select granular material should have no more than 3 percent passing the 75-micrometer (No. 200) sieve. No snow or ice is allowed. The material should be compacted in place, in thin lifts to at least 100 percent of the maximum dry density determined in accordance with ASTM International (ASTM) D698, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 [600 kN-m/m^3])* (ASTM, 2012).

Bedrock hardness and weathering is expected to vary, but it is anticipated that the bedrock can be excavated by a large bulldozer with a single-shank ripper. Blasting is not expected to be required.

Embankment fills may be constructed directly on cleared, grubbed, and proof-rolled native soils. Embankment slopes of 2 horizontal to 1 vertical (2H:1V) or flatter are recommended. Flatter slopes may be required for maintenance access. Cut slopes in soils of 1.5H:1V or flatter are recommended. Cut slopes in bedrock may be excavated vertical, but, if they are higher than 2 m, these should be inspected during construction by an engineering geologist or geotechnical engineer.

If embankment fills are constructed on ground slopes steeper than 5H:1V, the fill should be benched into the slope. Cut and fill slopes should be protected against erosion. Earthwork should not be performed during freezing conditions.

Additional Exploration

CH2M HILL recommend placement of an additional borehole at the center of the WTP building footprint to confirm foundation conditions assumed for the preparation of the design. Although we do not anticipate that the results of this additional boring will modify the design assumptions, the boring should be performed to reduce the risk of changes to the design during construction. This additional boring can be completed in conjunction with other field work planned for the FMC in 2014 or 2015.

Construction Considerations

Site Preparation

Site preparation for the proposed Faro WTP requires the removal of surface vegetation, organic soil, trash, debris, fencing, and other materials. Loose, soft, or wet materials also should be removed and replaced with competent backfill. Removed materials should not be used as structural fill or backfill. Existing utilities, drainage structures, and other existing structures also may need to be removed or protected.

Temporary Cuts

Temporary cuts will be required to construct the proposed structures and facilities. It is the responsibility of the contractor to provide stable excavations, shoring and erosion control, as needed, for all temporary cuts at the WTP site. Cuts and excavations should be constructed in accordance with all applicable safety rules and regulations. Shoring, if required, is the responsibility of the contractor and should be installed and constructed in accordance with all applicable safety requirements and regulations. For excavation planning purposes, cut slopes of 1.5H:1V in soil and vertical cuts in rock can be assumed.

Control of Water

Groundwater has been observed in the proposed Faro WTP site piezometers. However, it appears to be primarily contained in joints and fissures in the bedrock during most of the year. Control of surface water run-on and runoff, and control of groundwater are anticipated to be necessary during construction of the WTP.

Cement Type

Sulfate-resistant cement is recommended for below-grade portland cement concrete because seeps near the existing Mill Buildings have shown significant concentrations of sulfate, some of which are increasing with time.

Borrow Sources

A separate report addendum is being prepared to address the results of the field investigation and laboratory testing for borrow sources for construction materials, including backfill, structural fill, concrete aggregate, pipe zone material, and road base. Although suitable structural fill materials are present at the FMC, materials on the immediate Faro WTP site are not suitable for this purpose.

Review of Construction Plans and Specifications

The construction plans and specifications should be reviewed by the geotechnical engineer to verify that recommendations in this TM are properly incorporated into the design. The geotechnical recommendations in this TM are based on the geotechnical field investigation. If the location or configuration of the proposed plant varies from those used to develop the recommendations provided in this TM, the recommendations should be re-evaluated.

Geotechnical Observation

Subgrade preparation, foundation construction, and backfill placement should be observed by a geotechnical engineer or a technician under the supervision of a geotechnical engineer. Variations in soil and geologic conditions may be encountered during construction. To correlate the exploration data and the actual conditions encountered during construction, an experienced geotechnical engineer should perform onsite review during construction of the WTP.

Limitations

This TM is for the exclusive use of the Government of Yukon and CH2M HILL in accordance with locally accepted geotechnical engineering practice. No other warranty, express or implied, is made.

The information in this TM is based on data obtained from a field exploration performed in June 2012 and subsequent water level measurements. The exploration data indicate subsurface conditions only at the specific location and time of exploration, and only to the depth penetrated. The data do not necessarily reflect strata or water level variations that may exist between locations. If subsurface conditions that vary from those noted herein are discovered during the course of excavation or construction, re-evaluation of the design recommendations may be necessary.

Pavement design, utility trench design, and design of pipelines to and from the plant are not addressed in this TM. These design elements may be addressed in the future when site development and infrastructure concepts are available.

CH2M HILL is not responsible for any claims, damages, or liability associated with interpretation of subsurface data, reuse of the data, or reuse of engineering recommendations without the express, written authorization of CH2M HILL.

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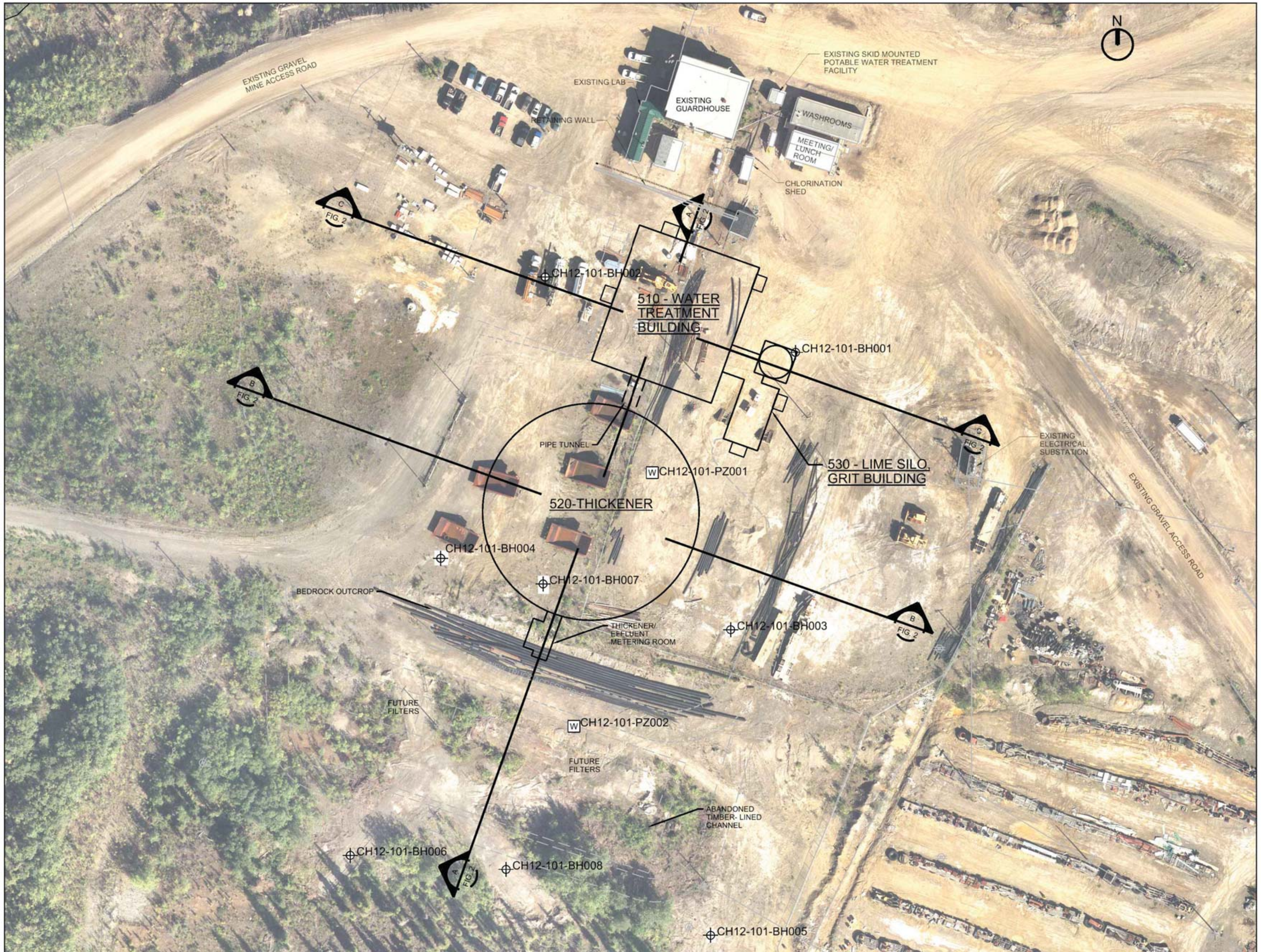
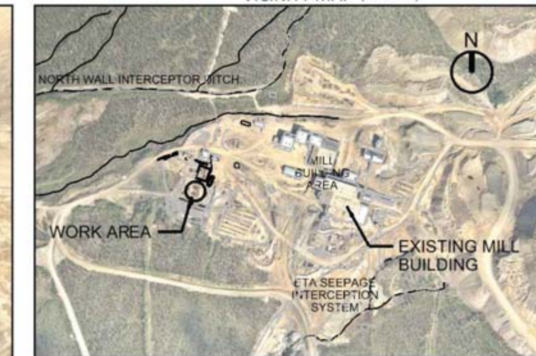
Figures



VICINITY MAP (1:10000)



LEGEND

⌖	BOREHOLE
W	PIEZOMETER

FIGURE 1
Borehole Location Plan

1:500

CH2MHILL.

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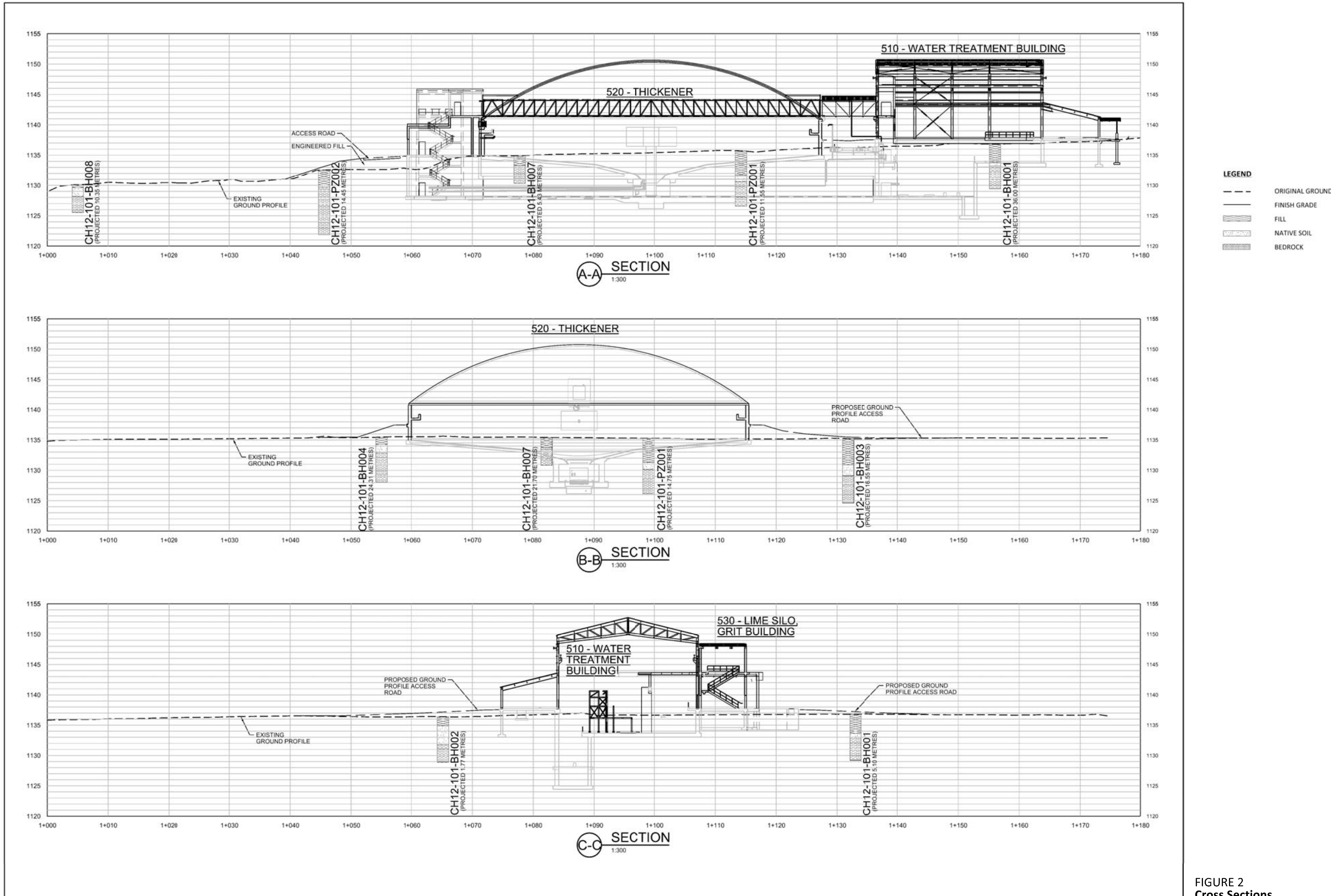
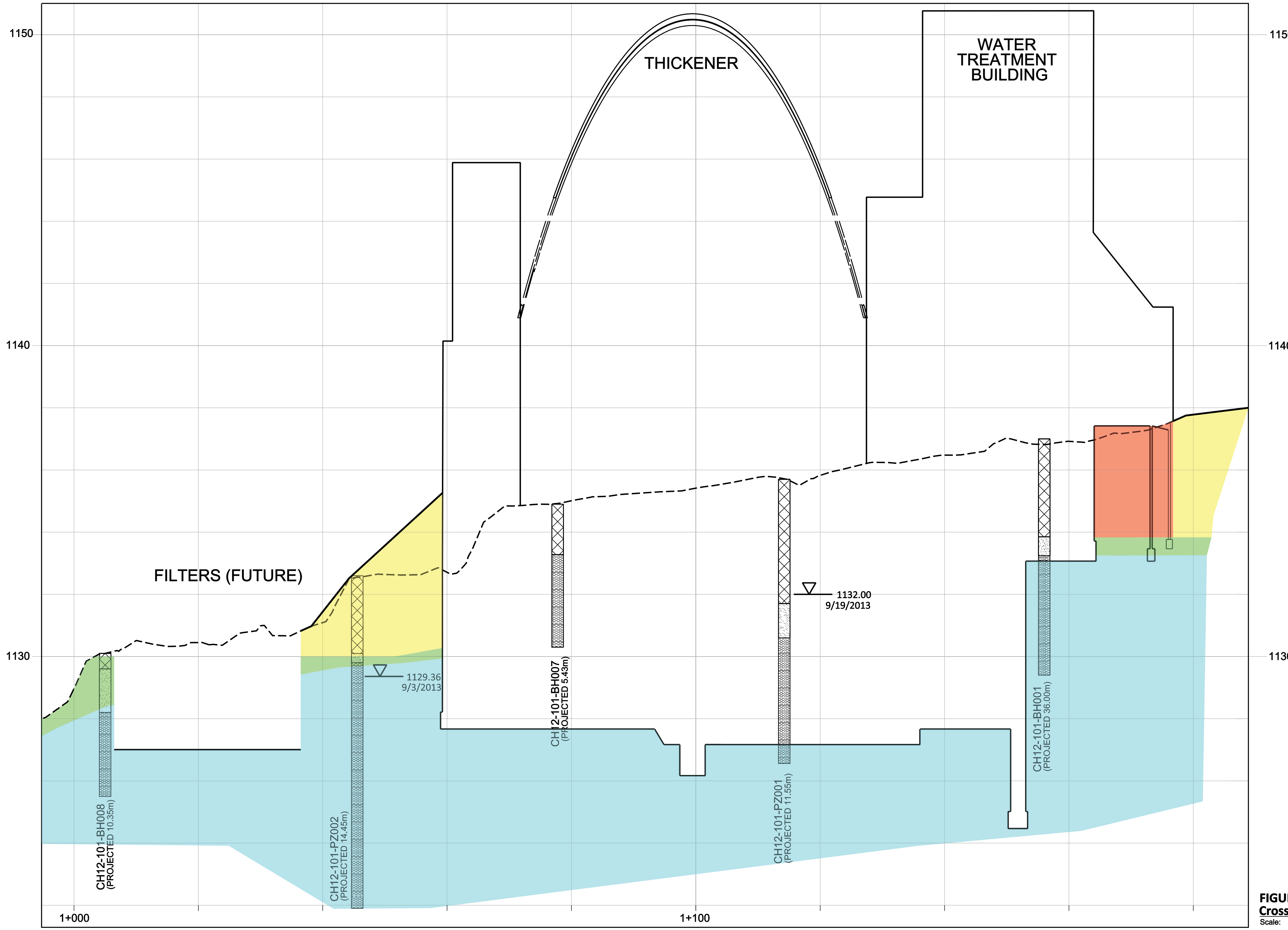


FIGURE 2
Cross Sections



LEGEND

- ORIGINAL GROUND
- FINISH GRADE
- FILL
- NATIVE SOIL
- BEDROCK
- STRUCTURAL FILL
- GENERAL FILL
- (LEVEL) (DATE) MAXIMUM WATER ELEVATION & DATE

Notes:

1- Fill placed in ground sloping steeper than 5H:1V should be benched into slope.

2- Limits of overexcavation and structural fill will vary depending on foundation design, site infrastructure needs and features, and actual subsurface conditions encountered.

FIGURE 3
Cross Section A-A
Scale: Horiz 1:600; Vert 1:120