report

Geotechnical Analysis of 2014 to 2016 Field Data, Faro Mine Remediation Project

Prepared for

Government of Yukon and the Government of Canada as represented by Indigenous and Northern Affairs Canada

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Acronyms and Abbreviations

BGC BGC Engineering Inc.

CDRM Comprehensive Design Road Map

CDRMR Comprehensive Design Road Map Report

CH2M CH2M HILL Canada Limited

cm/sec centimetre(s) per second

ConeTec ConeTec Investigations Ltd.

CPT cone penetration test

CVD Cross Valley Dam

ETA Emergency Tailings Area

FCD Faro Creek Diversion

FMC Faro Mine Complex

H horizontal

ID Intermediate Dam

km kilometre(s)

m metre(s)

m/s metre per second

m3 cubic metre(s)

mbgs metre(s) below ground surface

mm millimetre(s)

MPa mega Pascal

NFRC North Fork Rose Creek

NWID North Wall Interceptor Ditch

ODEX Overburden Drilling Excentric

PMF probable maximum flood

PPD pore pressure dissipation

ppm part(s) per million

RCD Rose Creek Diversion

RCTA Rose Creek Tailings Area

RU remediation unit

sCPT seismic cone penetration test

SIS Seepage Interception System

SPT Standard Penetration Test

SRK SRK Consulting Canada Inc.

UGC Upper Guardhouse Creek

V vertical

WRD waste rock dump

WVID West Valley Interceptor Ditch

YG Government of Yukon

# Introduction

## Purpose

Between 2012 and 2016, CH2M HILL Canada Limited (CH2M) completed five field seasons at the Faro Mine Complex (FMC), during which subsurface geotechnical investigations were conducted in various areas of the mine where remediation work is planned. The field work has been performed to provide geotechnical criteria and data to support design and selection of various remediation alternatives for the affected mine areas. Work has included geotechnical investigations with borings, test pits, geophysical surveys, and reconnaissance. These field activities are summarized by time, location, and activity in Appendix C of the Comprehensive Design Road Map (CDRM) Report (CDRMR). Data gathered from the 2014 through 2016 field programs were presented in field investigation summary reports, but the data were not evaluated or interpreted. This report summarizes geotechnical evaluations of the data collected from these recent field programs.

## Scope of Work

In 2015 and 2016, a series of data reports were submitted to the Government of Yukon (YG) to (1) describe the field investigation activities that were completed during the 2014 through 2016 field seasons and (2) provide a summary of the geotechnical data collected by CH2M. These data reports are listed below and provide the basis for the geotechnical evaluations summarized in this document.

* Summary of 2014 Field Investigation – North Wall Interceptor Ditch and Upper Guardhouse Creek (CH2M, March 2015j)
* Summary of 2014 Field Investigation – Faro Creek Diversion East Valley and Faro Creek Diversion West Valley Interceptor Ditch (CH2M, March 2015i).
* Summary of 2014 Field Investigation – Lower Guardhouse Creek Interception (CH2M, March 2015k)
* Summary of 2014 Field Investigation – Relocate ETA Tailings to Rose Creek Tailings Area (CH2M, March 2015m)
* Summary of 2014 Field Investigation – Design of a Surface Water Collection Structure for the Emergency Tailings Area (CH2M, March 2015n)
* Summary of 2014 Field Investigation – Dewater and Cover Intermediate Tailings Area (CH2M, March 2015x).
* Summary of 2014 Field Investigation – Construct New Overflow Weir technical memorandum (CH2M, March 2015cc)
* Summary of 2014 Field Investigation – Erosion Dissipation Structure technical memorandum (CH2M, March 2015bb).
* Summary of 2014 Field Investigation – Construct New Side Channel and Side Channel Dike (CH2M, March 2015z)
* Summary of 2014 Field Investigation – Construct Intermediate Dam Spillway technical memorandum (CH2M, March 2015aa)
* Cross Valley Dam Seepage Interception System Test Pit Data Summary (CH2M, January 2015b)
* Summary of 2015 Field Investigation – Faro Valley Seepage Investigation (CH2M, April 2016f)
* Summary of 2016 Field Investigation – Faro Creek Diversion Proposed Realignment (CH2M, August 2016b)
* Summary of FY 2015 and 2016 Field Investigations – CVD and ID Pond Field Data Report (CH2M, August 2016c)

The FMC consists of three main areas, as described in the CDRMR: the Faro Mine Area, the Rose Creek Tailings Area (RCTA), and the Vangorda/Grum Area. To facilitate the analysis of potential remedial alternatives at appropriate spatial scales, the Faro Mine Area is subdivided into smaller remediation units (RUs) based on location and similar characteristics. These RUs are shown on Figure 1‑5 of the CDRMR. The interpretation of data in this report includes data collected from geotechnical investigations performed in the following RUs:

* Perimeter (i.e., freshwater diversions, subdivided into west, east, and south)
* Mill Building Area and Emergency Tailings Area (ETA)
* Rose Creek Tailings Area
* Cross Valley Dam (CVD) and Intermediate Dam (ID) and Associated Ponds (Dams and CVD Pond)

Geotechnical investigations performed in other areas are being, or have already been, reported in separate geotechnical reports, including work performed at the following locations:

* RUs
* Waste dumps (referred to as the Waste Rock Dump [WRD] RU)
* Faro Pit
* North Fork Rose Creek (NFRC), a component of the east Perimeter RU
* Non-RU areas
* Borrow Sources
* Vangorda/Grum Area

# Perimeter Units

## Geotechnical Investigation Activities

### West Perimeter Remediation Unit

CH2M conducted field investigations in the West Perimeter RU in the summer of 2014 and 2015. These field investigations included test pits, geologic reconnaissance activities, and rapid geomorphic assessments of the Upper Guardhouse Creek (UGC) and North Wall Interceptor Ditch (NWID) alignments to evaluate the constructability of proposed improvements to the NWID and UGC. The locations of the field test pits, and the NWID and UGC, are shown in Figure 2-1. The results and details of the field investigations are compiled in the *Summary of 2014 Field Investigation – North Wall Interceptor Ditch and Upper Guardhouse Creek* (CH2M, March 2015j). An analysis of the rapid geomorphic assessments is provided in the hydrology appendix (Appendix E) to the CDRMR.

Five test pits (CH14-102-TP001 through CH14-102-TP005) were excavated adjacent to the NWID in 2014. These test pits were located on the southern side of the NWID to investigate the condition of the embankment and its foundation. Some test pits were advanced into the embankment fill material. Laboratory testing was performed on representative samples of subsurface materials and existing embankment fill collected from the test pits. Testing included gradation, plasticity, and moisture content.

A geologic reconnaissance was also conducted along the NWID in 2014. Geotechnical observations included identification of bedrock outcrops, classification of shallow soil materials where exposed or within hand excavations, and identification of groundwater seeps.

### East Perimeter Remediation Unit

CH2M conducted field investigations in the East Perimeter RU in the summer of 2014 and 2015. Additional investigation work was performed during March 2016. The project features in the East Perimeter RU area are shown in Figure 2-2. The surface water flow upgradient of the Faro Pit is intercepted beginning on the western valley slope of Faro Creek in the West Valley Interceptor Ditch (WVID). The flow from WVID combines with Faro Creek and continues as the Faro Creek Diversion (FCD) along the eastern valley slope to the confluence with NFRC. Investigations have been conducted for two alternative realignments that are proposed to divert flow around a potentially unstable zone in the Faro Pit wall, namely Alternative TA‑01 and Alternative TA-02, as shown in Figure 2-2. Alternative TA-01 intercepts surface flow higher up the slope from the existing diversions on the western and eastern valley slopes, and the reconstructed channel length is approximately 6 kilometres (km). Alternative TA-02 is a shorter realignment section with a reconstructed channel length of approximately 0.5 km.

In 2003, a subsurface investigation was completed by Golder Associates along a proposed full-length FCD realignment (Alternative TA-01), upslope of the existing FCD. On the western side of Faro Valley, 16 test pits were excavated using an excavator along the proposed alignment up to a maximum depth of 5.1 m. On the eastern side of Faro Valley, 15 test pits were excavated on the slope up to a depth of 3.2 m. Two of the test pits were in the vicinity of the proposed Alternative TA-02 localized FCD realignment, but were further than 70 m upslope from the proposed realignment. The results of this investigation are presented in the *Detailed Comparison of Alternatives for the Relocation of the Faro Creek Diversion* (Golder, February 2004).

During the 2014 field season, CH2M conducted bed and bank material characterization along the existing FCD and WVID. This characterization included documentation of observations and pictures of the conditions along diversion channels. CH2M also conducted a geologic reconnaissance along the proposed alternative TA-01 FCD realignment. Geotechnical and geological observations were compiled for these features, which included identification of bedrock outcrops, classification of shallow soil materials where exposed or within shallow test pits excavated by hand, identification of groundwater seeps, and other conditions. The results and details of the 2014 field investigations are compiled in the *Summary of 2014 Field Investigation – Faro Creek Diversion East Valley and Faro Creek Diversion West Valley Interceptor Ditch* (CH2M, March 2015i). A rapid geomorphic assessment of the FCD was also conducted, and is evaluated in the hydrology appendix (Appendix E) to the CDRMR.

Additional work around the FCD was conducted during 2015 and 2016. These investigations included:

* Geophysical surveys along 21 transects crossing perpendicular to the existing WVID and FCD and the proposed realignments, completed in October 2015
* Five exploration boreholes adjacent to the existing FCD and the proposed FCD realignment alternative TA-02, completed in March 2016, and
* A seepage investigation along the existing alignment that included installation of three well clusters on both sides of the Faro Creek valley, and at the confluence of Faro Creek and the existing FCD, completed in November 2015.

Exploration locations are shown in Figure 2-2. The results of the geophysical surveys are included in the *Multi-electrode Resistivity, Seismic Refraction, and Multi-Spectral Analysis of Surface Waves Surveys* report (Frontier, 2016). Details of the investigation and the data collected from the exploration boreholes along the WVID and FCD are summarized in the technical memorandum *Summary of 2015-2016 Field Investigation – Faro Creek Diversion* Proposed Realignment (CH2M, August 2016c). The results of the seepage investigation are compiled in the draft memorandum *Summary of 2015 Field Investigation – Faro Valley Seepage Investigation* (CH2M, April 2016f).

The stability of the northern wall of Faro Pit as it relates to the FCD was evaluated in 2015 by BGC Engineering Inc. (BGC). The findings of this evaluation are presented in the draft report *Faro Open Pit Stability Assessment, Site-Wide Design Basis Report* (BGC, 2016). One of the borings completed in March 2016, CH16-102-BH008, was located near the northeastern Faro Pit slope and was drilled at an inclination of 53 degrees from horizontal to confirm geological interpretation that was assumed by BGC in the Faro Pit stability assessment. The angled borehole confirmed that an intensely sheared and altered zone within the quartz monzonite is confined to the Big Indian Fault Zone, and the rock mass between the fault zone and Faro Pit is of higher quality than encountered in the altered rock zone.

CH2M completed schematic design for the realignment of the NFRC in March 2016. The intent of the NFRC realigned channel project is to relocate the NFRC downstream of the confluence with the FCD to a new alignment located east of the existing NFRC channel. This design included extensive geotechnical and geologic assessments in the NFRC channel realignment and proposed seepage collection dam area. Summaries of geotechnical investigations performed for the NFRC are included in Appendix E of the NFRC Design Basis Report (CH2M, March 2016b).

## Field Investigation Data Evaluation

### West Perimeter RU

The subsurface conditions observed along the NWID alignment generally consisted of glacial till overlying bedrock. The glacial till consisted of silty sand with gravel, sandy silt with gravel, and sandy gravel with silt. The till also contained cobbles and occasional boulders. A boulder as large as 1.5 metres (m) in diameter was encountered in one test pit immediately below the ground surface. The till is therefore highly variable, with a wide range of particle sizes. The soils along the West Perimeter RU are underlain by phyllite bedrock as noted in mapping by Bond (1999b). Bedrock was encountered as shallow as 0.6 m, but was deeper than the maximum depth explored (5 m) in some test pit locations. The upper 0.2 to 0.8 m of bedrock in the test pits were very intensely weathered to decomposed phyllite, transitioning into less weathered phyllite that could not be excavated with the excavator.

The existing embankment for the NWID was observed to be constructed from native glacial till material similar to native soils encountered in the vicinity. The bottom of the embankment fill could generally be identified by the presence of topsoil and organic deposits, ash deposits, roots, and wood. These observations suggest that minimal foundation preparation was performed before embankment construction.

Saturated soils were encountered in three out of the five test pits at depths ranging from 4 to 5 metres below ground surface (mbgs). The observed water could be leakage from the existing NWID because the test pits were located downgradient of the ditch. Hydraulic conductivity tests of the soil were not performed, but the embankment is estimated to have medium hydraulic conductivity typical of silty sand soil. Frozen soil was not encountered at any of the test pit locations.

Signs of embankment instability along the NWID were not observed. The channel slopes were constructed with side slopes of 2 horizontal to 1 vertical (2H:1V) and 3H:1V along the length of the channel.

### East Perimeter RU

#### Faro Creek Diversion – West Valley

Shallow bedrock is prevalent throughout the initial reach, from the start down to geophysical transect CH15-102-GX003, of the existing WVID (southwestern portion); nearly continuous outcropping is found in the channel bed and banks, consisting of granodiorite, biotite muscovite schist, and calc-silicate. The channel is up to approximately 1 m deep. Soil overburden is predominately colluvium. At borehole CH16-102-MW007, bedrock was encountered approximately 4 m below the ground surface, but the borehole location was in the access road embankment and is estimated that at least 1 m of soil overburden consisted of embankment fill material judging from the site topography. The top of bedrock corresponded to a P-wave velocity of approximately 1,000 m per second (m/s) as depicted in the velocity profile developed by Frontier at CH15-102-GX001, which crosses over CH16-102-MW007.

Along the channel reach from transect CH15-102-GX003 to the confluence with the flow from Faro Creek, the top of bedrock in WVID is below the channel, and is estimated to be between depths of 1 to 2 m below the channel bottom as interpreted from the results of the geophysical surveys. The depth to bedrock is highly variable in the boreholes drilled for the seepage investigation. At Well Cluster 1, the depth to bedrock at the three wells was approximately 3, 15, and 4 mbgs, in CH15‑106-MW001, CH15-106-MW002, and CH15-102-MW007, respectively. These boreholes were separated horizontally by approximately 40 m. Bedrock was difficult to verify from the cuttings, which were generated by ODEX (Overburden Drilling eccentric) drilling methods, and was likely encountered shallower than recorded (15 m) at CH15‑102-MW002, as suspected from high blow counts beginning around 8 mbgs. Geophysical survey data suggests that bedrock is likely at a depth of 3 to 4 mbgs in the vicinity of all the wells in Cluster 1, according to P-wave velocity profiles in transect CH15-102-GX007.

The shallow subsurface materials along the proposed Alternative TA-01 realignment of the FCD in the western valley are till and colluvium soil consisting of mixtures of clay, silt, sand, gravel, and cobbles. The ground in undisturbed areas was generally covered by a thin layer (up to 0.3 m thick) of organics consisting of moss and roots.

Frozen soil was encountered in 8 of the 16 test pits excavated along the TA-01 realignment in 2003 at depths from 0.1 to 4.1 mbgs. Frozen ground was not encountered in the shallow hand-dug pits in 2014, but these were only excavated to 0.3 mbgs. The thermistor data at CH16-102-MW007 did not show evidence of frozen ground in June, 2016. According to these observations, frozen ground is intermittently present through the TA-01 realignment in the West Valley.

Groundwater seeps were observed in many locations along the valley slopes. Approximately 15 individual seeps were observed along the west valley slope. Seepage estimates are reported in Appendix D, Groundwater Analysis, of the CDRMR.

The slopes of the existing WVID channel embankment are roughly 3H:1V, and the maximum bank height is 2 m. Signs of embankment instability were not observed.

#### Faro Creek Diversion – East Valley

The subgrade in the area of the proposed FCD realignment alternatives generally consists of glacial till materials that consist of silty or clayey sand and gravel with cobbles and occasional boulders.

At Well Cluster 2 that was installed in the seepage investigation (CH2M, April 2016f), bedrock was not identified in the boreholes that were drilled up to a depth of 29.1 mbgs. It appears that weathered bedrock may have been encountered at approximately 10 m depth based on the very high blow counts and dry cuttings. The P-wave velocity at 10 meters was approximately 1,000 m/s, in agreement with other borehole locations where weathered bedrock was confirmed and correlated with the geophysical data. The depth of soil overburden along the proposed alternative TA-01 FCD realignment varies along the length, up to a maximum depth of approximately 18 m from a study of the geophysical profiles, assuming that a P-wave velocity of 1,000 m/s represents the top of weathered bedrock. A P-wave velocity of 1,000 m/s is typical for a soft shale of stiff clay, indicating that the schist is highly weathered at the top of bedrock.

The flowline of the proposed FCD realignment TA-02 would be in the glacial till material only near where the realigned channel deviates from the existing channel. The flowline will encounter bedrock (weathered) within approximately 20 m away from the existing channel according to interpretation of the geophysical profiles. The bedrock encountered in the field investigations consisted of schist and felsic granite. Both of these rock types tested from the rock cores collected from the boreholes had high durability and good resistance to deterioration under repeated wetting and drying.

One of the 2014 hand-excavated test pits encountered frozen ground at a depth of 0.3 m. All of the test pits excavated by Golder in 2003 met refusal upon frozen ground, except for one that encountered shallow bedrock. The depth to frozen ground varied from 0.2 to 3.2 mbgs.

Frozen ground was not observed in boreholes adjacent to alternative TA-02 FCD realignment, except for the drill pad fill material that was mixed with snow and ice during construction of the pads. These boreholes were advanced through the overburden using ODEX drilling methods and Standard Penetration Test (SPT) sampling to observe frozen ground if present. Thermistor readings in June 2016 revealed frozen ground only in the upper 1 m beneath the ground surface at two (CH16-102-MW005 and CH16-102-MW006) out of the four thermistor installations in the East Valley. Test pits excavated in 2003 by Golder on the uphill side of the existing FCD encountered frozen ground in most of the test pits. Test pit TP03-23 encountered refusal on frozen soil at a depth of 0.75 mbgs, which was located closest to the proposed FCD realignment, approximately 85 m uphill from CH16-102-MW003. However, the frozen soil may be limited to shallow depths according to conditions observed at the 2016 boreholes.

Numerous seeps were observed along the proposed alignment. Golder (February 2004) identified a shallow depth to subsurface seepage in the upper active layer during summer and fall seasons. Investigations to characterize this shallow seepage were undertaken in May/June 2016 and are reported in *Summary of 2015 Field Investigation – Faro Valley Seepage Investigation* (CH2M, April 2016f).

Tension cracks were observed on the slope banks in the existing FCD in two locations during the geologic reconnaissance. The FCD has bank slopes as steep as 1.2H:1V at cross section FCDE-28, where tension cracks were observed. These failures appear to be localized slope instabilities where the channel slope is oversteepened.

## Summary and Recommendations

### West Perimeter – North Wall Interceptor Ditch

The general character of subsurface materials along the NWID was determined at the test pit and boring locations. The depth to bedrock was observed to vary up to 8 mbgs, and appears to vary abrubtly over short distances. Riprap protection will likely be required for many portions of the channel, depending on the depth of the cut required for drainage grade for the TA-01 realignment alternative.

Frozen ground is prevalent along the TA-01 realignment alternative. The depth that the frozen soil extends to is not known. Frozen soils may lose shear strength or settle because of the volumetric reduction when pore ice melts to water. The magnitude of reduction in shear strength and the volumetric strain caused by thaw depends upon the ice content, which is directly related to the density of the soil. High ice-content soils that thaw may have a significant loss in shear strength if the meltwaters do not readily drain, which can create excess pore water pressures. If the meltwaters drain, the soil may have relatively high levels of thaw strain.

Activities such as clearing vegetation cover or constructing an embankment or cut slope can alter the pre-disturbance geothermal regime. The design objective when constructing on permafrost is to minimize thermal disturbance and maintain shear stresses induced by the work within acceptable limits. This is achieved through implementing one or more of the following measures:

* Insulating the permafrost, such as by adding a granular cover of sufficient thickness that seasonal thawing is constrained to this cover
* Using relatively shallow slope angles for embankments or cut slopes
* Minimizing exposure time of frozen excavated faces to above-freezing ambient temperatures

### East Perimeter - Faro Creek Diversion Realignment

The observed depth to bedrock in the boreholes was compared to the P-wave velocity of the subsurface materials measured in the geophysical surveys. A P-wave velocity of 1,000 m/s was estimated to represent the top of weathered bedrock material. The bedrock was estimated by Frontier to have a P-wave velocity of 2,500 m/s, but this higher velocity appears to represent more competent bedrock according to correlations with the borehole data where available. The excavator used by Golder in 2003 appears to have met refusal in rock with an estimated P-wave velocity of approximately 1,000 m/s, extrapolating conditions observed at geophysical transect CH15-102-018 located approximately 20 m from the test pit.

According to the seismic refraction geophysical survey results, the depth to a subsurface layer with a velocity of approximately 1,000 m/s varies between 2 to 5 m along the proposed alternative TA-02 FCD realignment. The design concept for the proposed realignment of the FCD intends that the flowline of the new diversion channel be below the top of bedrock so that seepage along the bedrock surface would “daylight” into the channel, thereby reducing the amount of seepage reaching the Faro Pit. According to the results of the field investigation, the proposed diversion channel will penetrate into bedrock along the length of the diversion, and seepage on top of bedrock will be intercepted by the realigned channel.

Riprap protection will likely be required for many portions of the alternative TA-01 FCD realigned channel, depending on the depth of cut required to maintain drainage grade, because of the significant depth to bedrock in some areas. Riprap protection of the proposed alternative TA-02 FCD realigned channel will not likely be required except for the portion where the realigned channel ties into the existing channel.

Numerous seeps would present a challenge to maintaining dewatered conditions for construction of fill embankments. These seeps could also lead to areas of instability where channel slopes are saturated. A dewatering or seepage management plan should be prepared and followed to manage the wet conditions during construction.

The frozen ground that is present in some areas along the proposed alternative FCD realignments on the eastern valley slope may present a challenge in design of stable embankments and cuts. The design and construction issues discussed for the frozen soils in West Valley will apply to the East Valley also.

# Mill Building and Emergency Tailings Area RU

The ETA is located between the Mill Building Area and the Mine Access Road and contains mine tailings and mine waste with the potential to negatively affect the local groundwater and surface water. To reduce the potential impact of the ETA, geotechnical investigations were conducted in 2014 to characterize the subsurface conditions for the following evaluations:

* Feasibility of relocating tailings from the ETA to the RCTA or covering the tailings in place
* Feasibility of using the existing Mine Access Road to contain the tailings
* Design of a surface water collection structure for the ETA, to intercept contaminated groundwater and surface water before discharge into the RCTA

## Field Investigation Activities

### Lower Guardhouse Creek Interception

Geological reconnaissance was completed along Lower Guardhouse Creek during 2014, focusing on the upstream portion of the creek. Observations included surficial soil profiles, possible seepage locations, and general terrain. No subsurface geotechnical work was performed. A description of general conditions observed at Lower Guardhouse Creek is presented in the *Summary of 2014 Field Investigation – Lower Guardhouse Creek Interception* technical memorandum (CH2M, March 2015k).

### Emergency Tailings Area

In August 2014, one borehole and six seismic cone penetration test (sCPT) soundings were advanced in the ETA, as shown in Figure 3-1. The sCPT soundings included continuous profiling of the subsurface conditions, and seismic shear wave velocity measurements. Pore pressure dissipation (PPD) testing was also performed in the tailings material at various depths selected by CH2M. The sCPTs were advanced to depths of approximately 4 to 11 mbgs.

Borehole CH14-105-BH003 was advanced to 4.6 m below the ETA surface using a hollow stem auger. Sampling was performed using a split-spoon sampler that was larger (62-millimetre [mm] inside diameter) than the SPT sampler (35 mm inside diameter). The larger split spoon was used to collect a larger volume of tailings material for each sample. It should be noted that the tailings surface was very soft and would not support the drill rig at the originally proposed drill location, which was shifted 10 m west to accommodate rig access. Geotechnical samples were analyzed for gradation and moisture content. The results and details of the recent field investigations are compiled in the *Summary of 2014 Field Investigation – Relocate ETA Tailings to* *Rose Creek Tailings Area* technical memorandum (CH2M, March 2015m).

Prior to the 2014 CH2M investigation, SRK Consulting Canada Inc. (SRK), Inc. advanced 8 boreholes and excavated 1 test pit in the ETA (Figure 3-1). Their investigations were conducted in 2004 and 2005, and provide additional data on the thickness of tailings (SRK, September 2006).

### Mine Access Road Investigation

Two boreholes (CH14-105-BH001 and CH14-105-BH002) were advanced through the Mine Access Road to evaluate the road embankment for suitability as a permanent retention structure if the tailings are covered in place. In general, SPT sample recovery was poor because of the coarse nature of the road fill materials. Soil samples from the boreholes were analyzed in the laboratory for gradation and moisture content. Both boreholes were drilled to a total depth of approximately 13 m using ODEX methods. The results and details of the field investigations are compiled in the *Summary of 2014 Field Investigation – Relocate ETA Tailings to Rose Creek Tailings Area* technical memorandum (CH2M, March 2015m).

### Water Collection Structure Location

The Alternative Development Status report (CH2M, 2015ff) proposed that a low-head concrete cutoff wall be constructed across the original Faro Creek channel, downstream of the Mine Access Road, as shown in Figure 3-1. In July 2014, CH2M supervised two seismic refraction surveys in the ETA downgradient, or southwest, of the Mine Access Road. The purpose of these geophysical surveys was to characterize the subsurface conditions at the proposed water collection structure, including estimating the depth to bedrock and the weathering profile of the rock. The locations of geophysical survey lines CH14-105-GX001 and CH14-105-GX004 are shown on Figure 3-1.

CH2M excavated one test pit in 2014 to a depth of approximately 3 mbgs in the ETA downgradient, or southwest, of the Mine Access Road. Representative soil samples collected from the test pit were tested for gradation, moisture content, Atterberg limits, and moisture-density relationship. The location of test pit CH14-105-TP001 is shown on Figure 3-1.

CH2M conducted a geological reconnaissance in the ETA in June 2014 at the proposed water collection structure location. Geotechnical observations included identification of bedrock outcrops and general terrain assessment.

The details and findings of these field investigations are compiled in the *Summary of 2014 Field Investigation – Design of a Surface Water Collection Structure for the Emergency Tailings Area* technical memorandum (CH2M, March 2015n).

## Field Investigation Data Evaluation

### Lower Guardhouse Creek Interception

Lower Guardhouse Creek flows through a variety of conditions, including a constructed diversion channel, natural marshland, and its native alluvial channel. Bedrock was observed to outcrop adjacent to the creek bank near the Rose Creek Haul Road. Subsurface investigations were not performed at Lower Guardhouse Creek.

### Emergency Tailings

The 2014 CH2M geotechnical investigations within the ETA provided improved data for characterization of the volume and geotechnical properties of the tailings and the underlying materials.

Cross sections of the ETA are shown on Figure 3-2. The tailings thickness was found to be greatest along the original Faro Creek Channel, which generally trends from northeast to southwest across the ETA. The average thickness across the central portion of the tailings is approximately 5 m, and generally thins towards the edges. Immediately upgradient of the Mine Access Road, the tailings thickness was approximately 7 m based on the boreholes advanced by SRK in 2004. At cone penetration test (CPT) location CH14-105-CP001 in the upgradient portion (northeastern area) of the ETA, the thickness of tailings may be as thick as 9.5 m; however, the interpretation between tailings and native alluvial soil in the CPT data is difficult, and the tailings thickness may actually be closer to 5 m as shown on the cross section of Figure 3-2.

The tailings were predominantly silty sand or sandy silt. In some samples, fine gravel was present. The tailings within the ETA were found to contain 12 to 98 percent passing the No. 200 (0.075 mm) sieve.

Blow counts (6-mm inside diameter split spoon) ranged from 7 to 25 blows per 0.3 m (1 foot) in the tailings. The blow counts measured with the larger sampler split spoon are greater than what would be measured with the smaller SPT sampler. The blow counts approximately indicate very loose to medium dense material. Based on the shear wave velocity profiling data from the CPT soundings, the likelihood of liquefaction of the tailings is low at all CPT locations except for CPT CH14-105-CP002, where liquefaction is possible if an earthquake event were large enough to exceed the threshold strains required for liquefaction. This conclusion is based on correlations with normalized shear wave velocity (Youd et al, 2001).

PPD testing in the tailings indicated a fairly rapid dissipation of excess pore pressures. Equilibrium pore pressures were reached generally within 5 minutes after stopping penetration, but in one case took approximately 10 minutes. The PPD results are typical for a sandy silt soil, with some zones of clayey material of lower permeability. The estimated hydraulic conductivity for the tailings was estimated to be between 1x10-5 to 1x10-7 centimetres per second (cm/sec), based on approximate correlations with the dissipation times (Robertson et al, 1992).

The native material underlying the ETA tailings at borehole CH14-105-BH003 consisted of a thin organic layer underlain by silt, sandy silt, and silty sand materials. Field blow counts were generally greater than 50 per 0.3 m, approximately indicating very dense material. The borehole was drilled to refusal at 4.3 mbgs in well graded gravel with sand.

PPD testing provides an indication of the hydrostatic groundwater level at the CPT locations. The groundwater depth in the ETA was found to be between 2 to 3 mbgs upstream (northeast) of the Mine Access Road. At CH14-105-CP001, located on the northwestern boundary of the ETA, the groundwater depth was estimated to be 4.7 mbgs during the investigation. At CH14-105-CP004, on the southwestern edge of the ETA, the depth to groundwater was found to be approximately 0.5 mbgs. The location of these CPT soundings is shown on Figure 3-1.

CH2M assessed the volume of tailings contained within in the ETA as well as remediation alternatives. These assessments are documented in the *Alternative Development Status Report* (CH2M, March 2015ff). The volume of tailings was estimated to be 89,000 cubic metres (m3), and covers an area of 33,000 square metres.

### Mine Access Road

Boreholes (CH14-105-BH001 and CH14-105-BH0020) advanced through the Mine Access Road adjacent to the ETA provided geotechnical data for the road fill, and underlying soil and bedrock.

The road embankment fill generally consisted of well-graded silty gravel and sand with cobbles and boulders. An organic layer was observed beneath the fill embankment. Weathered phyllite schist bedrock was encountered 8 to 9 m beneath the road surface. The degree of weathering was observed to decrease approximately 2 to 3 m below the surface of the rock. Groundwater was observed in the boreholes near the top of the bedrock.

Geotechnical laboratory testing was limited to gradation and moisture content evaluation. Because of the coarse nature of the in situ materials, sieve analysis results are not expected to be entirely representative of the grain size because of the small diameter of the split spoon in relation to the coarse particles. Diamond rock coring was not performed; as such, the bedrock encountered was evaluated from rock fragments observed within the ODEX drill cuttings.

### Water Collection Structure

Results from seismic refraction survey line CH14-105-GX001 indicate that the weathered bedrock surface generally undulates between 1 and 3 mbgs. The interpreted contact with competent bedrock surface undulates between 2.0 and 4.5 mbgs.

The geophysical survey at CH14-105-GX004 indicated that the weathered bedrock surface varies between 1 and 4 mbgs (deepening toward the northern end of the survey line). The interpreted competent bedrock surface roughly paralleled the weathered bedrock surface between 1.5 and 6 mbgs. The seismic refraction survey results from the southern end of CH14-105-GX004 (0- to 10-m stations) were not consistent with the observations made during the geologic reconnaissance. The geologic reconnaissance indicated bedrock outcropping at the surface in this location. The resolution of geophysical data at the ends of seismic refraction lines is generally poor, and the reconnaissance data should instead be relied upon in this area.

The ground surface north of the proposed ETA seepage collection sump appeared to be sand and gravel fill with low-plasticity fines between 19 to 26 percent. South of the proposed collection sump, a 15-m-deep cut as narrow as 4 m was observed, with bedrock outcrops on each side. The bedrock is weathered phyllite.

Test pit CH14-105-TP001 was excavated approximately 8 m west of the seismic refraction survey lines. Laboratory testing on representative samples from the test pit indicated that the soils from 0 to approximately 2 mbgs consisted of clayey to silty gravel with sand, and the soils from 2 to 3 mbgs consisted of silty sand with gravel. Weathered bedrock composed of phyllite was noted from 3 mbgs to the bottom of the test pit at 3.2 mbgs. Groundwater was encountered seeping into the northwestern wall of the test pit at approximately 2.9 mbgs.

## Summary and Recommendations

The geotechnical information collected from the field program was used to compile the *Alternative Development Status Report* (CH2M, March 2015ff), which evaluated the feasibility of relocating tailings from the ETA to the Rose Creek Tailings Area (RCTA) and covering the tailings in place. The recommended mitigation in the *Alternative Development Status Report* was to remove the ETA tailings and enhance the downstream seepage collection through construction of a concrete cutoff wall that is keyed into the shallow bedrock.

The boreholes and CPT soundings provided additional data on the thickness of the tailings, which can be used to get an approximate volume of tailings material in the ETA. However, additional boreholes or CPT soundings are recommended if an improved accuracy of the tailings volume is required.

If the tailing were left in place, some localized saturated zones within the tailings material may be subject to liquefaction in a large earthquake event. The consequences of liquefaction within the ETA are relatively minor, consisting in potential material settlement. Lateral spreading would not be a concern because the tailings are contained behind the road embankment. The Mine Access Road embankment is founded on native coarse-grained soil, and is not subject to liquefaction based on the measured blow counts in the boreholes drilled in the through the access road embankment. If the tailings are covered in place, additional borings with SPT sampling should be performed to evaluate the extents of liquefaction and estimate the amount of settlement.

The water collection concrete structure will mainly retain surface water, and will be founded on bedrock. This structure will have a low bearing pressure, and have a low water head that is not anticipated to pose a hazard of piping through the weathered bedrock. However, considering the discrepancy between the geologic reconnaissance and CH14-105-GX004, the depth and nature of bedrock should be verified at the proposed structure location in order to properly design a cutoff wall. The rock should be cored to evaluate the rock quality, and packer testing should be performed to evaluate the hydraulic conductivity of the rock.

# Rose Creek Tailings Area RU

For the RCTA, alternatives are being considered to route flood flow through the RCTA over a new overflow weir structure into an erosion dissipation structure and armored channel constructed with a side channel dike parallel to the Rose Creek Diversion (RCD). Flood water may then be routed over the tailings surface immediately upstream of the ID embankment to an improved spillway in rock, cut on the right abutment of the ID. The existing ID Pond may be filled, covered, and protected in place; the cover design is currently being evaluated by BGC. Details of the proposed alternatives for the RCTA are presented in the CDRMR. The RCTA Area RU, including the investigation locations and proposed features, is shown in Figures 4-1 and 4-2.

## Geotechnical Investigation Activities

### Intermediate Tailings Area

One borehole (CH14-201-TH001), and three cone penetrometer soundings were advanced in the Intermediate Tailings Area in August 2014 to improve understanding of the impounded tailings for development of alternatives for a RCTA cover. The borehole included SPT, downhole field vane shear testing, and sample collection. Samples were sent to the laboratory for testing of moisture content, gradation, and Atterberg limits. A thermistor port was installed in the borehole after completion, and subsequently monitored. The CPT soundings were advanced to probe refusal, and included shear wave velocity profiling and PPD testing. The details and results of the field investigations are compiled in the *Summary of 2014 Field Investigation – Dewater and Cover Intermediate Tailings Area* technical memorandum (CH2M, March 2015x).

### Rose Creek Diversion at Proposed Overflow Weir

Two boreholes (CH14-203-BH001 and CH14-203-BH002) were advanced along the RCD dike using ODEX and diamond core methods in August 2014 to support the design of a proposed overflow weir. The field investigation program consisted of drilling, sampling, and downhole in situ testing. Boreholes included SPT testing in soil and NQ (47.6 mm core diameter) triple-tube diamond coring in bedrock. Laboratory testing of soil samples included gradation testing, and rock samples were submitted for compressive strength analysis. The results and details of the field investigations are compiled in the *Summary of 2014 Field Investigation – Construct New Overflow Weir* technical memorandum (CH2M, March 2015cc)*.*

### Flow Routing over Intermediate Tailings Area

A geological reconnaissance was conducted at the proposed location of an erosion dissipation structure on the south side of the Secondary Dam. The proposed structure includes a layer of riprap placed downstream of the RCD overflow structure to dissipate energy and prevent erosion of the Intermediate Tailings Area. The reconnaissance was completed in the area where the Secondary Dam intersects the RCD. The geologic reconnaissance considered visible surface conditions as they relate to the proposed structure. Observations included bedrock exposures, surficial soils, surface water flows, groundwater seeps, and general site setting and topography. The details and results of the field investigations are compiled in the *Summary of 2014 Field Investigation – Erosion Dissipation Structure* technical memorandum (CH2M, March 2015bb).

Four boreholes (CH14-201-TH002 to CH14-201-TH004 and CH14-201-TH006) were advanced in the Intermediate Tailings Area in August 2014, to support the conceptual design of the proposed Rose Creek Side Channel and associated Side Channel Dike. The boreholes included SPT, downhole field vane shear testing, and sample collection. Soil samples sent to the laboratory were tested for moisture content, gradation, and Atterberg limits. Thermistor ports were installed in the boreholes after completion, and subsequently monitored. Ten CPT soundings were also advanced to probe refusal, and included shear wave velocity profiling and PPD testing. The results and details of the field investigations are compiled in the *Summary of 2014 Field Investigation – Construct New Side Channel and Side Channel Dike* technical memorandum (CH2M, March 2015z).

### Intermediate Dam Spillway

A geotechnical investigation was performed at the ID spillway in August 2014 to support the design of a new ID spillway to pass the probable maximum flood (PMF). The investigation locations are shown in Figure 4-2. Two geotechnical boreholes (CH14-201-BH003 and CH14-201-BH004) were advanced within the existing spillway. The boreholes included SPT sampling and rock coring. In addition, two hydraulic pressure (packer) tests were completed in each borehole. Representative samples of soil were tested for moisture content and gradation, and rock cores were tested for durability and compressive strength. The details and results of the field investigations are compiled in the *Summary of 2014 Field Investigation – Construct Intermediate Dam Spillway* technical memorandum (CH2M, March 2015aa).

Additional field investigation and soil sampling was conducted in November 2015. The investigation consisted of five geotechnical boreholes (CH15-201-MW007 through CH15-201-MW011). Two boreholes were drilled through the overburden and into the bedrock at least 9 m, one was drilled to the top of bedrock, and two others were drilled in overburden only. Drilling included SPTs in soil, and HQ-size (63.5 mm core diameter) core drilling in bedrock. In situ packer testing was completed in bedrock within two of the boreholes to characterize the hydraulic conductivity of the bedrock. Laboratory testing on soil samples included Atterberg limits and gradation, and rock cores were tested for specific gravity, absorption, soundness, and compressive strength.

Geophysical surveys were also completed in this area in October 2015. The survey consisted of one long transect along the length of the spillway, and six lines perpendicular to the spillway. Methods included electric resistivity testing, multi-channel-analysis-of-surface-waves lines, and seismic refraction. The details and results of the additional 2015 field investigations are compiled in the *Summary of 2015 Field Investigation – Construct Intermediate Dam Spillway* technical memorandum(CH2M, May 2016b).

### Cross Valley Dam Seepage Interception System Pipeline

Ten test pits (CH14-204-TP001 through CH14-204-TP010) were completed along the proposed CVD Seepage Interception System (SIS) pipeline alignment in July 2014. The alignment follows a path from the CVD, across the north side of the RCTA RU, ending at the Mill Buildings Area. Test pits were excavated to depths up to 5.5 mbgs. Soil samples sent to the laboratory were tested for moisture content, gradation, and Atterberg limits. Tests were also performed to evaluate soil corrosivity to aid in engineering design of pipeline materials. Corrosivity testing included chloride, oxidation-reduction potential, pH, sulphate, and sulphide content. The results and details of the field investigations are compiled in the *Cross Valley Dam Seepage Interception System Test Pit Data Summary* (CH2M, January 2015b).

## Data Evaluation

### Intermediate Tailings Area

Permafrost conditions were not observed within the Intermediate Tailings Area. Thermistor measurements indicate an active temperature zone (depth to where temperature variation occurred over different seasons of the year) from the ground surface down to a depth of approximately 6 mbgs. For the period of record, frost penetration was observed to depths of approximately 2.5 m in February 2015. Deeper frost penetration is possible later in the winter, or during more severe winters.

The sensitivity of tailings investigated within the Intermediate Tailings Area can be described as insensitive to medium sensitive based on the CPT results. Sensitive soil is defined as soil susceptible to strength loss when subjected to strain.

The tailings are generally consistent in gradation and stiffness at the areas explored. All boreholes encountered a stiffer surface crust approximately 1 to 1.5 m thick where exposed materials are believed to have been over-consolidated by water level fluctuations and repeated wetting and drying cycles. Tailings generally consisted of sandy silt, with sand content varying from 1 to 43 percent. The thickness of the tailings was observed to be as thin as 3 m near the edge, and as thick as 20 m further away from the edge. Native material underlying the tailings consisted of silty sand with gravel, silty gravel with sand, and silt.

In general, two shear vane tests were attempted per hole. However, based on the low plasticity of the silt, results of the shear vane test cannot be relied upon.

Based on observed samples and PPD testing within the CPT soundings, the depth to groundwater within the Intermediate Tailings Area is generally estimated to be between 1 and 1.5 m below the tailings surface, corresponding closely with the water surface adjacent to the ID.

### Rose Creek Diversion at Proposed Overflow Weir

In general, the subsurface materials encountered in the vicinity of the overflow weir consisted of coarse granular fill materials overlying native glacial till and bedrock. The bedrock surface slopes from the south to the north, with depths of 5.2 m to 9.6 mbgs at the two borehole locations. Bedrock is highly laminated and foliated, and the rock core broke easily by hand along the foliations. Frozen soil was not encountered.

Intact rock samples tested for compressive strength were classified as strong to very strong (Hoek, 2007). However, it was noted that cores were difficult to handle without causing additional separations along foliation planes. An evaluation of rock mass strength was performed using the RocData computer analysis program, Version 5.004 (Rocscience, 2015). This evaluation indicates that the rock mass strength may be represented by a cohesion of 2.5 mega Pascals (MPa) and an internal friction angle of 25 degrees.

### Intermediate Tailings Area at Proposed Erosion Dissipation Structure

The southeastern area of the Intermediate Tailings Area contains a wide variety of fill materials (i.e., sand, gravel, cobbles, and boulders) used to construct the adjacent embankments, the RCD dike, and the Secondary Dam. The channel flows through these fill materials into the Intermediate Tailings Area, where the bottom of the channel becomes very soft silt tailings. Soft tailings were noted to liquefy upon disturbance. Signs of embankment instability were not observed. The channel slopes were estimated to vary between 1.5H:1V and 2H:1V.

### Intermediate Dam Spillway

In general, the materials encountered beneath the proposed ID spillway were found to consist of silty sand and gravel alluvium overlying native till and bedrock. The soil was stratified, with some layers of clean sand and gravel, with occasional cobbles and boulders noted.

The depth of bedrock varied from about 0 to 11 mbgs at the exploration locations. In the vicinity of the proposed spillway, a weathered bedrock outcrop is present, along the northern side of the road, proximal to CH14-201-BH003. The bedrock is a dark grey to blue-grey, intensely foliated, medium-strong schist with quartz veins. Rock cores retrieved during the drilling program were noted to readily separate along the foliation planes. Review of borehole data indicates that the bedrock surface slopes downward generally from east to west. An evaluation of rock mass strength was performed using the RocData computer analysis program (Rocscience, 2015). This evaluation indicates that the rock mass strength may be represented by a cohesion of 6 MPa and an internal friction angle of 32 degrees.

Frontier Geoscience, Inc., under subcontract to CH2M, prepared a geophysical report (Frontier, 2015) summarizing the results of the geophysical data collection. The analysis was completed in conjunction with review of nearby borehole logs. In general, the results of the geophysical survey are consistent with the materials observed at the surface and encountered within the boreholes. Seismic refraction results indicate that the survey area is underlain by up to four distinct shear wave velocity layers. Underlying the shallow surficial layer (maximum thickness of 9 m) is an upper intermediate layer with velocities consistent with denser overburden of unsaturated sands, gravels, clays, and silts. The thickness of this layer varies between approximately 1 m at the northeastern end of line SL-201-6 (east of the ID), up to approximately 11 m on line SL-201-4 (aligned with the ID). Below the upper intermediate velocity layer, a second, higher velocity layer is interpreted in most of the survey area. These velocities are generally indicative of dense, saturated sands, gravels, and till. Boreholes and testpits in relatively close proximity to survey lines intersected weathered bedrock at the top of this velocity layer. This layer is highly variable in thickness. The bedrock surface rises in elevation to the northeast.

Results of packer testing at two monitoring wells completed in 2015 indicate that the deeper bedrock has lower hydraulic conductivity than the upper more weathered bedrock.

### Cross Valley Dam Seepage Interception System Pipeline

Data evaluation and geotechnical design criteria for the pipeline are provided in the *Cross Valley Dam Seepage Interception System Test Pit Data Summary* (CH2M, January 2015b). Overall characterizations are summarized below.

The particle sizes of subsurface materials varied widely from clay up to large boulders, but in general consisted of silty or clayey sand and gravel. The fines content ranged from less than 5 percent up to 45 percent. Large boulders up to a diameter of 1 m were observed.

Bedrock was encountered in five out of the ten test pits, and consisted of phyllite, schist, or granodiorite. The depth to bedrock varied from the ground surface to depths greater than 5.5 mbgs.

Frozen ground was not observed at the time of test pit excavation. However, the temperature was measured as low as 0 degrees Celsius at the bottom of some test pits.

Only one of the soil samples had properties that would classify as corrosive, from test pit CH14-204-TP010. This sample was in artificial fill material near the Mill Building Area that contained mine debris or mine waste rock materials with corrosive properties. All of the native soil samples had properties indicating non‐corrosive soil.

## Summary and Recommendations

### Overflow Weir

Depending on the depth to which the base of the RCD overflow weir will be constructed, piping of fines may occur if it is constructed directly on top of the silty sand materials. A filtration layer beneath the riprap will likely be required. Additional erosion control measures along the downstream slope of the weir, such as concrete blocks or grouted riprap should be considered and evaluated. It is recommended that packer testing is completed within the vicinity of the proposed overflow weir, in order to further characterize hydraulic properties of the bedrock. This will allow evaluation of potential percolation issues that could decrease stability along the base of the weir.

### Tailings Cover

It is recommended that studies be performed to assess the performance of the tailings, especially in the areas where significant grading will be performed, such as the ID Pond, where fill placement of between 7 and 9 m may occur. Design issues include the performance of the tailings cover as the tailings consolidate. Construction issues include trafficability and dewatering.

### Side Channel and Side Channel Dike

Refer to Section 9 of the CDRMR for a discussion of the proposed design of the side channel. It is proposed that the side channel dike be founded on suitable natural ground. Tailings under the footprint of the dike should be removed.

Alternatively, ground improvement techniques for tailings in the foundation vicinity may be evaluated. Approaches such as incremental loading with and without wick drains and soil improvements using compacted sand and stone columns may achieve necessary ground strengths at relatively low costs. Consolidation testing should be completed, if incremental loading is considered for ground improvement.

### Intermediate Dam Spillway

The proposed ID spillway concept requires approximately 4 m of excavation along the centerline of the spillway channel, up to approximately 10 m in the basin immediately downstream of the control structure, and up to 15 m in the plunge basin (energy dissipater). Based on available data, it is anticipated that scouring may occur into the right abutment of the ID. Therefore, it is proposed that a reinforced concrete wall on the southern side of the channel be used to separate the spillway channel from the ID embankment. In addition, it is anticipated that dental concrete, rock bolting, or equivalent measures will be necessary on the base and sides of the spillway to protect against scour. It is recommended that an additional study on these erosion protection measures is completed to provide necessary design criteria.

### Erosion Dissipation Structure

Based on available geotechnical information, filter layers beneath riprap should be included in the design to mitigate issues related to loss of fines by piping and erosion beneath the riprap. In consideration of designing the erosion dissipation layering, it is recommended that samples be collected along the length of the channel for grain size analysis. Gradation of the channel base can be used to determine the required layers and gradation of the erosion dissipation structure. The erosion dissipation structure should be designed with consideration of suitable borrow sources onsite.

### Cross Valley Dam Seepage Interception System Pipeline

The characterization of subsurface material along the proposed CVD SIS pipeline was completed based on the conditions encountered at the test pits. The subsurface investigation provided data necessary for the pipeline design.

The proposed pipeline trench excavation will encounter phyllite or schist bedrock over some portion of the proposed pipeline alignment, anticipated along at least 1500 m of the pipeline length.

The pipeline will be installed in what appears to be the active zone for frost penetration and temperature variation with seasons. The pipe should be protected by insulation to prevent freezing.

# Dams and Cross Valley Dam Pond

As described in the CDRMR, one alternative for remediation includes using the CVD Pond as temporary storage during construction and then emergency storage for long-term care and maintenance. Field investigations were conducted in the CVD Pond to develop a higher resolution stage-storage curve in support of current water management and closure alternatives being considered for the CVD Pond, and to characterize sludge material properties and presence within the pond.

Field investigations in the ID Pond were conducted to develop a higher resolution stage-storage curve in support of water management and possible backfilling of the ID Pond, and to characterize the tailings and sediment deposited in the pond.

## Field Investigation Activities

Under subcontract to CH2M, Aurora Geosciences Ltd. performed bathymetric and sub-bottom profile surveys of the CVD Pond in October 2015 and of the ID Pond in June 2016 . Multi-beam sonar, single-beam sonar, acoustic sub-bottom profiling, and real-time kinematic global positioning surveying methods were used to define the pond perimeter, bottom material deposits, and layers beneath the pond.

In March 2016 under supervision by CH2M, additional field exploration was performed including 8 CPT soundings in the ID Pond, 3 CPT soundings in the CVD Pond, and 14 boreholes in the CVD Pond. The CPT soundings were advanced from the frozen pond surface by ConeTec Investigations Ltd. (ConeTec) of British Columbia. Drilling within the CVD Pond was performed by ConeTec using a track-mounted sonic drill rig set upon the frozen surface of the pond. Sampling of the pond bottom soil, sludge, and tailings was performed using an Aqualock piston sampler in the sonic boreholes. The sampling and borehole locations are shown in Figure 5-1.

The details and results of these field investigation activities are compiled in the *Summary of Fiscal Year 2015 and 2016 Field Investigations – Cross Valley Dam and Intermediate Dam Ponds Field Data* (CH2M, August 2016c).

## Field Investigation Data Evaluation

### CVD Pond Volume

The CVD Pond has a maximum depth of 14.25 m below the water level elevation 1,028.68 m at the time of the bathymetry survey. The total volume of water in the CVD Pond was estimated to be 1,414,765 m3, not including a minor amount of volume around the perimeter of the pond where the water becomes too shallow for the survey methods. A new stage-storage curve for the pond was prepared based upon the results of the bathymetric survey. Using the bathymetry data, the stage-storage curve was developed up to water surface elevation 1,027 m, above which the bathymetric survey becomes unreliable for volume estimates in the shallow water that existed during the survey. Above elevation 1,027 m, the data from the 2011 LIDAR survey of the entire project area were used (CH2M, October 2013i). The LIDAR survey was performed when the water level was below 1,027 m. The updated stage-storage curve is presented in the *Summary of the 2015-2016 Bathymetry and Sub-Bottom Data Review and Stage Storage Curve Development for the Faro Mine Remediation Project* (CH2M, August 2016k).

### ID Pond Volume

The maximum depth of the ID pond is 7.8 m in the most western part of the pond. The pond bottom is mostly featureless and becomes shallower to the east. The volume of the ID Pond was estimated at the time of the survey to be 1,473,145 m3, not including a minor amount of volume around the perimeter of the pond where the water becomes too shallow for the survey methods. The water level at the time of the survey was 1,045.98 m. A new stage-storage curve for the pond was prepared based upon the results of the bathymetric survey below elevation 1,043.6 m, and the 2011 LIDAR survey (CH2M, October 2013i) above elevation 1,043.6 m. The updated stage-storage curve is presented in the *Summary of the 2015-2016 Bathymetry and Sub-Bottom Data Review and Stage Storage Curve Development for the Faro Mine Remediation Project* (CH2M, August 2016k).

### CVD Pond Sludge Characterization

Total suspended solids in the CVD pond suspected to be formed from ferrous iron sludge oxidation has resulted in operational changes to the CVD pond discharge protocols. As described in the *Summary of Fiscal Year 2015 and 2016 Field Investigations – Cross Valley Dam and Intermediate Dam Ponds Field Data* (CH2M, August 2016c), an investigation to characterize sludge material properties and presence within the pond was performed to support current water management issues and closure alternative considerations. Sludge was only observed in three of the boreholes (CH16-201-BH008, CH16-201-BH011, and CH16-201-BH011A) completed in the CVD Pond, and the CPT results were inconclusive because the sludge was too soft. The sludge was observed towards the northern end of the pond with an estimated sludge thickness of up to 1.7 m at the borehole locations. Where encountered, the apparent sludge consisted of primarily silt and clay-sized material that had a consistency that appeared to range from that of an extremely soft soil to a viscous fluid. The color was generally bluish-green, and began to change to orange when exposed to air, likely due to iron oxidation.

The sub-bottom survey resulted in a profile of layers beneath the ponds with different reflective properties. For the CVD Pond, the layers were segregated into Feature B through G (Feature A is the mudline). For the ID Pond, the layers were segregated into Feature 1 and 2.

Comparison of the borehole and CPT-sounding data in the CVD Pond with results of the sub-bottom profiling analysis, performed by Aurora, suggests that the possible sludge deposits approximately correlate to the Feature B reflective layer identified by the sub-bottom survey. The estimated top and bottom elevation of sludge material is summarized in Table 5-1 according to observations in the soil borings and sub-bottom profiling results. As can be seen in Table 5-1, the bottom of Feature B, or sludge, measured using the two separate methods was generally within one-half meter of each other, but in some cases almost one meter in difference. However, there are limited locations with data to draw conclusions from. The borehole thickness or depth observations were not consistently greater or less than the sub-bottom profiling measurements, leading to a conclusion that the methods are approximate as a result of the extremely soft soil to viscous-fluid characteristics.

As shown in Figure 5-2, the Feature B layer is found primarily in relatively shallow water at the northern end of the pond, where the Feature B thickness ranges from about 1 to 5 m. Interpreted sludge deposits are also identifiable as Feature B along the southern shore of the CVD Pond. This finding of sludge thickness and spatial distribution is consistent with the historical water treatment activities as described by D. Duivenvoorden, a long-time FMC employee (Duivenvoorden, pers. Comm, 2016). According to Duivenvoorden, from approximately 1997 to 1999, lime was added at the southern shore of the CVD Pond via a slurry tank. The lime-rich water was then pumped into the ID Pond, which at that time was operated with a much higher water level in the pond. As a result, the high pH water would migrate towards the spillway and flow down it, back into the CVD Pond. The majority of deposited sludge is expected to have originated from the Down Valley Treatment System, constructed in 2002 to treat siphoned ID Pond water through agitation with a lime slurry. Treated effluent water was then discharged into the CVD Pond from the peninsula on the northern shore where water was retained to allow for treatment solids to settle out of suspension. The spatial distribution of Feature B correlates with the bulk of the sludge deposits along the northern edge near the ID Pond spillway and the peninsula on the northern shore.

### Pond Bottom Deposits in the ID Pond

The sub-bottom survey resulted in a profile of two principal layers beneath the ID Pond, Feature 1 and 2. Feature 1 was interpreted by Aurora to be possible tailings deposits. These tailings would be intermixed with soil sediment settling out of the ponds over the years. The thickest pond bottom deposits were in the deepest part of the ID Pond along the dam. A thickness of up to 12 m was estimated from the results of the sub-bottom survey.

Feature 2 was interpreted by Aurora to possibly be bedrock; however, based on borings advanced prior to construction of the ID pond by Golder Associates (Golder 1980), the depth to bedrock beneath the ID Pond is on the order of 40 meters beneath the original ground surface. Feature 2 is more likely a dense alluvial material.

## Summary and Recommendations

Based on results of the field investigation it appears that approximately 1 to 5 m of sludge deposits are located at the north end of the pond in the vicinity of the peninsula on the north shore of the CVD Pond. The sludge consists primarily of silt and clay-sized material that had a consistency that appeared to range from that of an extremely soft soil to a viscous fluid. According to sub-bottom profiling, less than 0.3 m of sludge is interpreted across the majority of the pond bottom. Near the southern shore, about 1 to 2.5 m of sludge is interpreted to be loosely settled on the pond bottom.

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Table

Figures