Geochemical Analysis of 2012 – 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

μm micrometre

°C degree(s) Celsius

ABA acid-base accounting

AP acid potential

APHA American Public Health Association

ARD acid rock drainage

BC MOE British Columbia Ministry of the Environment

CaCO3 calcium carbonate

CaCO3 eq/tonne calcium carbonate equivalent per tonne

CDRM Comprehensive Design Road Map

CH2M CH2M HILL Canada Limited

CVD Cross Valley Dam

DI-leach de-ionized leach test

DVIHU Down Valley Interim Hydraulic Upgrades

EQuIS Environmental Quality Information System

ETA Emergency Tailings Area

FCD Faro Creek Diversion

FMC Faro Mine Complex

FY fiscal year

GAI geochemical abundance index

GARD Global Acid Rock Drainage

ID Intermediate Dam

kg kilogram(s)

LGSPC Low-grade Stockpile “C”

m metre(s)

mbgs metre(s) below ground surface

MDE Main Dump East

MDW Main Dump West

MEND Mine Environment Neutral Drainage

mg/kg milligram per kilogram

MGSP Medium Grade Stockpile

mm millimetre(s)

NFRC North Fork Rose Creek

NFRD North Fork Rock Drain

NP neutralization potential

NWID North Wall Interceptor Ditch

NWL Lower Northwest

NWM Middle Northwest

NWU Upper Northwest

OXSP Oxide Fines Stockpile

PMF probable maximum flood

PVC polyvinyl chloride

RCAA Rose Creek Alluvial Aquifer

RCD Rose Creek Diversion

RCTA Rose Creek Tailings Area

RU remediation unit

SIS seepage interception system

SPLP synthetic precipitation leaching procedure

TIC total inorganic carbon

TOC total organic carbon

USCS Unified Soil Classification System

USEPA United States Environmental Protection Agency

WRD waste rock dump

WTP water treatment plant

ZIIE Zone II East

# Introduction

## Purpose

This document provides supporting information to the Comprehensive Design Road Map (CDRM) by presenting the analyses of geochemical data collected at the Faro Mine Complex (FMC) that have either not been previously incorporated into any other geochemical analysis report or have only been presented in data reports without analysis and interpretation. Between 2012 and 2016, CH2M HILL Canada Limited (CH2M) has completed five field seasons at the FMC. Field activities included the collection of water quality and solid samples for geochemical analyses, and monitoring of temperature and pore-gas composition in selected waste dump locations. The results of these geochemical analyses completed between 2012 and 2016 have been validated and are stored in the Environmental Quality Information System (EQuIS) database established by CH2M for the FMC.

Analyses of geochemical data collected during field seasons 2012 and 2013 have been reported previously in the following reports:

* Analysis of 2012 Site-wide Field Data Report (CH2M, March 2013e)
* Geochemical Characterization Report (CH2M, November 2014b)
* 2013 Seep Sampling and Waste Rock Dump Monitoring Data and Analysis Report (CH2M, March 2014c)
* Fiscal Year 2013 Water Quality Modelling Analysis Report (CH2M, March 2014f)
* 2013 Down Valley Interim Hydraulic Upgrades Field Investigation Data and Analysis Report (CH2M, March 2014m).
* 2012 Seepage, Surface Water, and Water Treatment Plant Influent Sampling Report (CH2M, October 2013a)
* Waste Rock Dump Monitoring Report (CH2M, October 2013b).
* Geotechnical Design Report, Water Treatment Plant (CH2M, December 2012).
* Cross Valley Dam Interception System Investigation Data Report (CH2M, March 2013m)
* 2013 Cross Valley Dam Seepage Interception System Field Investigation Data and Analysis Report (CH2M, February 2014q)
* Limited Borrow Material Reconnaissance Faro Mine Remediation Project (CH2M, June 2013f)
* Faro Water Treatment Plant Geotechnical Design Report Addendum, 2013 Borrow Source and Quarry Investigation (CH2M, March 2014b).
* Grum Overburden Dump Fatal Flaw Evaluation Data Report (CH2M, June 2013i).

In fiscal year (FY) 2014 through FY2016, a series of documents were submitted to describe the field investigation activities that were completed and to provide a summary of the geochemical data collected by CH2M during these field seasons, respectively. In addition, a comprehensive dataset of solids data collected between 2012 and 2014 was compiled and described in a data report for later analysis. These data reports provide the basis for the geochemical analysis included in this document. The supporting data reports that contributed to this analysis include the following:

* Input to Analysis of 2012 to 2014 Solids Data (CH2M, March 2015a)
* Summary of 2014 Field Investigation – Site-wide Geochemical Monitoring (CH2M, March 2015b)
* Summary of 2014 Field Investigation – Relocate Oxide Fines to Low-Grade Stockpile “C” (CH2M, March 2015l)
* 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 – Delineate Main and Intermediate Sulphide Cells for Regrading and Capping Design (CH2M, March 2015o)
* Summary of 2014 Field Investigation – Regrade and Reslope Faro Waste Rock Dumps (Upper Surfaces) (CH2M, March 2015p)
* Summary of 2014 Field Investigation – Regrade and Reslope Faro Waste Rock Dumps (Toe of Slope) (CH2M, March 2015q)
* Summary of 2014 Field Investigation – Relocate Contaminated Soil from Faro Lube Shack and Tank Farm Area and Cover (CH2M, March 2015v)
* Borrow Baseline Design Criteria Report (CH2M, March 2015hh)
* Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring (CH2M, April 2016)
* FCD Field Data report (CH2M, April 2016)
* ID PMF Spillway Field Data Report (CH2M, April 2016)

Summaries of geochemical data collected during the 2016 field season have been reported in the following reports:

* Summary of 2016 Field Investigation – Faro Creek Diversion Proposed Realignment (CH2M, August 2016a)
* Summary of Fiscal Year 2015-2016 Field Investigations – CVD and ID Pond Field Data Report (CH2M, August 2016c)
* Summary of 2016 Field Investigation – Faro Creek Diversion Aquifer Testing (CH2M, August 2016h)
* Summary of 2016 Field Investigation – Site-wide Geochemical Monitoring (CH2M, August 2016j)

As geochemical data collected by CH2M before 2014 have been analyzed in one or more of the reports listed above, this *Geochemical Data Analysis Report* focuses on (1) field activities and data collected between 2014 and 2016 and (2) updated trend analysis of key geochemical data (pre-2012 to present). This report intends to further support the understanding of the FMC geochemical conditions as described in previous geochemical analysis reports. The FMC consists of three main areas: 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 has been organized into smaller remediation units (RUs) based on location and similar characteristics. For discussion purposes, this *Geochemistry Data Analysis Report* is organized according to the following RUs:

* Perimeter (i.e., Upper Guard House Creek, Faro Creek Diversion, downstream of North Fork Rose Creek, Rose Creek Diversion, and Downstream of the Cross Valley Dam, sub-divided into West, East, and South)
* Waste dumps (referred to as the waste rock dump [WRD] RU, subdivided into the following groups for the purpose of this report: Faro Valley, Northwest, Stockpiles, Main, Intermediate, S-Wells area, Northeast, and Zone II, which includes the Zone II Outwash Area)
* Mill and Emergency Tailings Area (ETA)
* RCTA
* Intermediate Dam (ID), Cross Valley Dam (CVD), and CVD Pond
* Faro Pit

In addition to the designated RUs, analysis was performed at the following FMC locations:

* North Fork Rose Creek (NFRC)
* Borrow Sources
* Vangorda/Grum Area

## Scope of work

CH2M has previously submitted summaries and analyses of available geochemical data. This documenthas been developed to complete the requested geochemistry data analysis. The scope of this document includes the following:

* Summarize the field investigation and sampling activities completed in the FY2012 through FY2016 field seasons to collect geochemical data.
* Summarize the geochemical analyses performed in laboratories.
* Present available geochemical data stored in the FMC EQuIS database (2012-2015 for solids data and 2014-2015 for the rest) in concise tables.
* Describe the statistical analyses performed on the available geochemical data.
* Describe the understanding of FMC geochemical conditions, including apparent evolution of geochemical characteristics between 2012 and 2016, based on interpretation of the available geochemical data.

CH2M previously produced the *Input to Analysis of 2012 to 2014 Solids Data* report (CH2M, March 2015a), summarizing the geochemical analyses results for the solids samples collected at the FMC between 2012 and 2014. Preliminary observations of the available data at the time were presented in the 2015 report to assist with future analysis and interpretation. The solids data discussion presented herein builds on the information presented in the 2015 report and incorporates additional data collected in 2015. Solids data collected from a Faro Creek Diversion (FCD) drilling program completed in March 2016 are not included in this draft geochemistry analysis report, but will be included in the final version of this report. Data presented include total metals, acid-base accounting (ABA), de-ionized leach tests (DI-leach), synthetic precipitation leaching procedure (SPLP), and modified sequential extraction tests.

Water samples collected from groundwater seepage and monitoring well locations through time have been used to provide input to a comprehensive site-wide geochemical model. A summary of the geochemical modelling activities is provided in Section 2 of the main CDRM report; more detailed discussions on the geochemical model and modelling results are presented in the following reports:

NFRC Geochemical Report (CH2M, March 2016g)

Fiscal Year 2013 Water Quality Modelling Analysis Report (CH2M HILL, March 2014f)

This document presents the current understanding of water chemistry changes at the FMC as a result of ongoing geochemical processes within the mine impacted areas. Statistical analysis completed on the available seepage and groundwater quality data identify trends in water quality data through time. To facilitate a more thorough understanding of water quality conditions, the water quality data discussion presented herein should be read in conjunction with the *Groundwater Analysis Report* (CH2M, April 2016e) and *Hydrology Data Analysis Report* (CH2M, April 2016k). In addition, this report includes vertical profile temperature and pore-gas concentration measurements recorded from the thermistor and pore-gas ports installed at WRD RU monitoring locations.

## Analytical Methods

Geochemical laboratory analyses were conducted on solids and water samples collected during the 2012 through 2016 field investigations. The following sections summarize the analyses performed by the laboratory.

### Solids Samples

Samples were selected from each location based on the data required to support each field investigation, samples available, materials found, and engineering judgment. Approximately 1 kilogram (kg) of material was collected for each solids sample and sent to the laboratory for geochemical analysis. Solids samples collected during the 2012 through 2016 field investigations were analyzed for some or all of the following:

Total metals analysis

ABA parameters:

Paste pH

Total sulphur

Acid-soluble sulphate

Sulphate attributed to barium (using lithium metaborate fusion)

Neutralization potential (NP) (using modified Sobek analysis)

96-hour DI-leach test

Modified SPLP at three pH conditions (pH 3, 4, 5)

Sequential extraction procedure as outlined in the *Quality Assurance Project Plan* (CH2M, September 2015)

General chemical parameters:

Soil pH measurement (1:2 soil:solution ratio)

Total organic carbon (TOC)

Total inorganic carbon (TIC)

The analytical methodologies applied to the solids samples are further described in this section.

#### Total Metals Analysis

ALS Laboratory conducted total metals analyses following the British Columbia *Contaminated Site Regulations* analytical method, Strong Acid Leachable Metals in Soil (BC MOE, 2009) and procedures adapted from the United States Environmental Protection Agency (USEPA) *Method 200.2* (USEPA, 1994). This method uses a mixture of hydrochloric and nitric acids to digest the sample, which was pulverized by the laboratory. This digestion may dissolve metals at concentrations that are unlikely to dissolve at a given time under natural environmental conditions; however, it estimates the total metal content of the sample that could be available for release to the environment as a result of long‐term weathering and diagenesis. The total metal concentrations do not provide insight into the mineralogy of the overburden material and therefore the efficacy for dissolution. However, by determining total metals, a screening tool is gained to identify the potential environmentally available quantity of constituents. These results can be used to identify anomalous geochemical samples and material with relatively elevated total metal concentrations.

Total metal results were compared to the *Global Acid Rock Drainage Guide* (GARD Guide) (INAP, 2013) and Mine Environment Neutral Drainage (MEND) screening criteria to highlight potential sources of constituent loading to key locations at the FMC. Since the material around the FMC contains both crustal material (e.g., primary WRD material) as well as soil (including not only native soil, but also weathered WRD material), the total metals concentrations are compared with elemental crustal abundance concentrations (MEND) and median world soil concentrations to identify relative elevated concentrations (GARD). Concentrations of elemental crustal abundance are sourced from Price (1997) and presented as 10 times the average value in the continental crust, which is the expected range in a meta-volcanic mineralized terrane. The median world soil concentrations are reported in the GARD Guide (INAP, 2013) and are used to calculate a geochemical abundance index (GAI). The GAI is a calculated measure of elemental enrichment relative to a reference material. The GAI compares the actual concentration of an element in a sample with the median abundance for that element in the most relevant media (such as crustal abundance, soils, or a particular rock type). The main purpose of the GAI is to provide an indication of any elemental enrichments that may be of environmental importance. The GAI is calculated by:

GAI = log2(element concentration/1.5 x reference material concentration)

A GAI value of between 3 and 4 represents a concentration 12 to 24 times the reference material content. As such, the GARD Guide considers any GAI value greater than 3 is significant and warrants further examination (INAP, 2013). Because a GAI of 3 is equivalent to 12 times the reference value, the total metals results were compared to 12 times the median world soil concentrations. Some elements tend to be more enriched in the crustal material than in the soil material and vice-a-versa. As such, elements that exceed both criteria in a sample are of greatest interest.

#### Acid Base Accounting

Selected samples collected during the 2012 through 2015 field investigations also underwent ABA analysis. ABA analysis is generally used to predict the tendency of a material to generate or neutralize acid by providing a snapshot (in time) of the balance between the acid production and acid neutralization, based on the sulphur content and presence of neutralizing species, such as carbonate minerals.

Paste pH analysis estimates the readily available acidity or alkalinity in a solid and generally represents in situ weathering conditions of FMC materials. The paste pH methodology followed methods of Canadian Society of Soil Science (Price, 1997) and American Public Health Association (APHA) Method 4500H (1992). In general, a paste pH greater than 7 indicates the presence of a reactive carbonate phase, and a paste pH less than 5 may signify the sample has already gone acidic (i.e., a previously weathered sample) (MEND, March 1991).

Total sulphur was determined using Leco high-temperature induction furnace analysis that followed International Organization for Standardization Method 15178 (2000). The sample was ignited in a combustion analyzer, where sulphur in the reduced sulphur dioxide gas is determined using a thermal conductivity detector.

Acid-soluble sulphur tests are used to determine how much of the total sulphur will react with oxygen to create acid. The test method used by ALS Laboratories follows the procedures outlined in *Field and Laboratory Methods Applicable to Overburdens and Minesoils* (USEPA, 1978). This method involves extractions using hydrochloric acid and then nitric acid, followed by DI-leaching to remove chlorides. The sample is then dried, filtered, and analyzed for total sulphur.

Total barium is obtained by analyzing for lithium metaborate using Method 6020A. This method uses inductively coupled plasma-mass spectrometry. Similar to inductively coupled plasma – atomic emission spectrometry, the sample must be digested in acid before filtration and analysis (USEPA, 2007).

NP values were determined by using the modified Sobek method (MEND, March 1991; Lawrence et al, March 1989). This method involves adding hydrochloric acid to the sample and rating the amount of “fizz” that occurs. This fizz rating is used to determine the strength and molarity of hydrochloric acid required to perform the analysis. The sample is heated in stages, first with hydrochloric acid, then with DI water, and subsequently titrated to obtain the NP (USEPA, 1978). Analyzing NP by the modified Sobek method generally provides a more realistic indication of the readily available carbonate minerals than other NP determination methods, such as the standard Sobek method (MEND, March 1991).

For this evaluation, acid potential (AP) was determined based on the sulphide sulphur content in the material and was converted to units of calcium carbonate equivalent per tonne (CaCO3 eq/tonne). The sulphide content of the FMC samples was determined using the total sulphur content and subtracting the acid-soluble sulphate sulphur, the barium sulphate sulphur, and the amount of theoretical sulphur associated with non-acid generating metal sulphides, such as lead, and zinc. This complex calculation used concentrations of barium, lead, and zinc to estimate the sulphur content not associated with highly reactive iron sulphides. The calculations generally followed the following equation (SRK, June 2004b):

(percent)

Where:

SFFE = sulphide sulphur content

Stotal = total sulphur content

Zn = zinc

Pb = lead

Ba = barium

Ssuplphate = sulphate sulphur content

An important note, at some locations where potentially acid generating material was not anticipated or thought to be very low (e.g., Perimeter RU), solid samples were not submitted for analysis of the complete suite of ABA parameters (i.e., acid-soluble sulphate and Ba were not determined). However, ABA calculations were still determined based solely on total sulphur under the assumption that all sulphur present in the sample was sulphide sulphur. Notably, the calculations of AP based on total sulphur alone may be overly conservative with respect to the acid generation potential of FMC materials.

Although static testing methods provide a fast and cost-effective means of measuring the ABA properties of a material, the interpretations may be limited by the following factors that static tests do not measure: rates of acid generation and NP depletion, actual sample stoichiometries, presence of long-term acid-consuming materials versus highly reactive and readily available acid-consuming materials, and sample variability (MEND, March 1991).

The relative amount of NP and AP is typically assessed through the NP:AP ratio, calculated by dividing the NP by the AP. Various guidance criteria are published and used in decision making. Generally, these criteria are divided into categories of “potentially acid-generating,” “non-acid-generating,” and “intermediate” for the ABA characteristics and provide the following threshold values (USEPA, 1999):

NP:AP values greater than 3:1 suggest non-acid-generating material.

NP:AP values less than 1:1 suggest potentially acid-generating material.

NP:AP values between 1:1 and 3:1 suggest intermediate or “uncertain” material.

These criteria provide the basis for determining the net potential for FMC materials to generate or neutralize acid.

#### De-ionized Water Leach

The objective of the 96-hour DI-leach test (i.e., shake flask test) was to estimate the amount of readily soluble, elemental loading during analyses (e.g., without consideration of weathering reactions or secondary precipitation). The readily soluble elemental load determined by the 96-hour DI-leach test provides insight into the initial chemistry, solubility limits, and geochemical conditions under which contaminants may be released to the environment. DI water is used because it is essentially devoid of dissolved cations or anions that can influence the solubility of the material being tested; therefore, the resulting leachate is solely representative of the material being tested. While the slightly acidic nature of the initial DI water mimics typical precipitation pH, it can also impact elemental solubility from samples with little to no buffering capacity. The 3:1 ratio coupled with the 96-hour leach time was selected to maintain consistency with the SRK leach procedure previously used for FMC materials. However, results from this test do not indicate future drainage chemistry (Price, 2009).

The 96‐hour modified shake flask extractions were performed with DI water and a water‐to‐solids ratio of 3:1. The lab used ultra-pure deionized water (Type 1 Laboratory water) generated from an ELGA water purification system that had an initial pH between 5.5 and 5.8. Following the extraction step, the extract was centrifuged and decanted, filtered through a 0.45‐micrometre (μm) filter, then acidified (ultrapure nitric acid to 2 percent) before being analyzed. This procedure is based on the method outlined by Price (1997) and follows the DI-leach testing procedures historically employed at the FMC (SRK, June 2004b).

#### Modified Synthetic Precipitation Leaching Procedure

Selected samples underwent modified SPLP analysis, based on USEPA Method 1312 (USEPA, September 1994). The SPLP is a static leach test that measures readily soluble constituents of mine and process wastes and provides an initial estimate of a material’s potential to mobilize constituents in the environment. However, SPLP analysis does not provide information related to the reaction rates controlling constituent mobilization. The modified-SPLP analysis was performed on three splits of the same sample, with a water-to-solids ratio of 20:1 for 16 to 20 hours and using three extraction fluids (one for each split), at pH 3, pH 4, and pH 5. In the modified SPLP analysis, pH was adjusted using sulphuric acid (USEPA, September 1994). The extract was filtered through a 0.6- to 0.8-µm glass fibre filter before undergoing analysis for dissolved metals.

In the modified SPLP tests, adjustment of the pH of the extractant from pH 5 through pH 3 demonstrates the effect of different pH waters on the sample (e.g., from slightly acidic precipitation to more acidic mine drainage). The 20:1 ratio for the modified SPLP was selected to remain consistent with the traditional SPLP method. The higher dilution ratio prevents potential solubility limitations from impacting the results, and the high leachate to solid ratio limits the buffering capacity of the solid, thereby allowing a constant pH to be maintained during the extraction.

The SPLP data has not been included in this report as there was no new data from the 2015 field season. All of the SPLP data is presented and discussed in the previous report *Input to Analysis of 2012 to 2014 Solids Data* (CH2M, March 2015a)*.*

#### Sequential Extraction Procedure

Selected samples were subjected to sequential extraction procedures to determine the mobility and mineralogic association of trace metals within the solid material analyzed at the FMC. Solids samples were subjected to extractions using six successively more aggressive dissolution techniques following the protocol described in Thomas (2002). The purpose of the extraction sequence was to determine how trace metals are bound within the solids sample using operational defined extraction steps aimed at selectively releasing trace metals from a particular target phase. In theory, the extraction scheme first releases (1) weakly bound, neutral-salt exchangeable trace metals, followed by (2) acid-soluble material, such as carbonates, acid volatile sulphides, and some aluminum compounds, (3) trace metals associated with amorphous iron and manganese oxides, (4) pyrophosphate extractable materials, such as humic substances or metals complexed with organic matter, (5) trace metals associated with crystalline iron and manganese oxides, and (6) recalcitrant material, such as metal sulphides, resilient metal oxides, and refractory organic material. Silicate minerals are generally not dissolved in this extraction scheme (Thomas, 2002). Results from the sequential extraction procedure, in combination with total metals analysis in a given sample, provide information on the mobility of trace elements during weathering in mine environments.

#### General Chemical Parameters

Following the Soil Science Society of America method (Loeppert and Suarez, 1996), TIC was determined at the laboratory by decomposing the sample with acid in an open system and releasing carbon dioxide. Determined gravimetrically, the release of the carbon dioxide from the sample is proportional to the carbonate content of the sample. The fraction of total organic carbon was determined using CSSS Method 21.2 (Tiessen and Moir, 1993), which uses potassium dichromate and sulphuric acid to oxidize the organic carbon. The organic carbon content of the sample was used to determine the organic matter content using the Van Bemmelon factor.

### Water Samples

Seepage and groundwater samples were collected from accessible seepage locations, groundwater monitoring wells, and streambed piezometers. The following field parameters were measured at all water sampling locations:

Temperature

pH

Specific conductance

Dissolved oxygen

Oxidation-reduction potential

Turbidity (groundwater samples only)

Water samples were filtered and persevered in the field, as appropriate, and sent to the laboratory for a suite of water quality analyses, including the following:

Acidity or hot peroxide acidity

Alkalinity

Ammonia

Anions

Dissolved metals

Dissolved organic carbon

Ferrous iron

Total dissolved solids

Total suspended solids

Select samples were also tested for unfiltered free cyanide.

# Perimeter Remediation Unit

## Field Investigation Activities

Field investigation activities completed within the Perimeter RU during the 2012 to 2015 field seasons were to support the characterization of undisturbed areas bordering defined RUs. The Perimeter RU comprises the West, East, and South portions surrounding the Faro Mine Area and the RCTA. This section focuses on the field investigations between completed in the Perimeter RU West and Perimeter RU South.

Many of the locations where investigation activities were completed between 2012 and 2015 fall within the general geographic extents of the Perimeter RU, but were investigated with the primary purpose of supporting specific design objectives. Locations that were investigated in the Perimeter RU to support the NFRC diversion design are discussed in Section 8. Locations that were investigated in the Perimeter RU to support borrow material investigation are discussed in Section 9. Locations that were investigated in the perimeter RU to support characterization of the Zone II outwash are discussed in Section 3.

### Test Pit Excavation

Five test pits completed in 2014 were located downgradient of the Northeast and Zone II WRDs. Although these test pit locations fall within Perimeter RU East, relevant discussions are presented in Section 3 Waste Rock Dumps RU as the data are relevant to understanding soil quality as a result of geochemical processes in the WRDs. A total of 37 test pits were completed in the NFRC valley and proposed realignment channel as part of the NFRC Realignment Project in 2015. Although these test pits were located within Perimeter RU East, they are discussed separately in Section 8 North Fork Rose Creek. In addition, 31 test pits in potential borrow areas were completed in 2014 and 2015, including 5 in the area east of the RCTA, 13 in the area northwest of the proposed NFRC Seepage Collection Dam, and 13 at the Fresh Water Supply Dam embankment. These potential borrow areas are discussed in Section 9, Borrow Sources.

### Borehole Drilling and Monitoring Well and Thermistor Port Installation

During the 2012 field season, 11 boreholes were drilled down valley from the CVD, and four of these locations (two well clusters) are located in the West Perimeter RU. Wells were installed in clusters of two with one shallow and one deep well screen. These locations were drilled to collect data to support the development of an effective monitoring system to detect breakthrough of mine impacted groundwater from the RCTA to the receiving environment. Further description of the drilling and installation activities, along with the laboratory analyses and discussion are presented in the report titled *Construct Cross Valley Dam Interception System - 2012 Field Sampling Plan* (CH2M, March 2013m).

During the 2015 field season, nine boreholes were drilled adjacent to the FCD in support of the Faro Valley Seepage Investigation. These boreholes were drilled in clusters of three through the overburden with the intent of reaching competent bedrock and installing monitoring wells across the saturated formation within the overburden. The maximum depth of these borings ranged between 5.49 and 29.11 metres below ground surface (mbgs), and the midpoint of well screen ranged between 3.99 and 11.82 mbgs. Description of the drilling and monitoring well installation activities, laboratory analyses, and results discussion are presented in a report titled *Summary of 2015 Field Investigation – Faro Valley Seepage Investigation* (CH2M, April 2016f).

As part of the NFRC Realignment Project investigation in 2015, six boreholes were drilled at the Rose Creek Diversion adjacent to the RCTA. These monitoring wells will be discussed in Section 5 RCTA RU. A further six boreholes were drilled in the proposed borrow area northwest of the proposed NFRC Seepage Collection Dam, which will be discussed in Section 9, Borrow Sources.

During the 2016 field investigation, six boreholes were drilled as part of the FCD proposed realignment investigation (five completed with piezometers and thermistor ports). One of the boreholes was drilled at an angle near the edge of the Faro Pit to a 60-metre (m) depth to help confirm the bedrock material in that area. The other five boreholes were drilled along the proposed realignment of the FCD. A detailed description of the activities, laboratory analyses, and results is presented in the *Summary of 2016 Field Investigation – Faro Creek Diversion Proposed Realignment* technical memorandum (CH2M, July 2016a).

### Seep Sampling

Although some seepage monitoring locations fall along the boundary and ultimately flow into the Perimeter RU, all relevant discussions will be presented in Section 3, WRD RU, as the data are relevant to understanding seep water quality originating from the WRDs.

### Groundwater Sampling

A total of 25 groundwater monitoring wells located within the South and East Perimeter RUs were visited in 2014 and 2015, and 15 locations were sampled. In 2014, one groundwater sampling event took place within the South Perimeter RU and East Perimeter RU between September 10 and 19. In 2015, the sampling event took place between October 3 and 13. Descriptions of groundwater sampling events that took place in 2014 and 2015 are presented in the field summary reports *Summary of 2014 Field Investigation – Site-wide Geochemical Monitoring* (CH2M, March 2015) and *Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring* (CH2M, March 2016d).

## Field Investigation Data Evaluation

### Solids Data

#### Total Metals Analysis

Total metals concentrations in all sampled analyzed from locations CH12-204-MW005B and CH12-204-MW006B were less than both 12 times the median world soil content and 10 times the crustal abundance. These monitoring wells are located in an area that was unaffected by mining activities, along Rose Creek downstream of the diversion channel, which explains the background levels of metals throughout each borehole. Samples collected from locations CH16-102-MW003 through CH16-102-MW007 also contained concentrations below both guidelines. These locations are all in the unaffected mining area above the FCD.

Samples from locations CH15-106-MW003, CH15-106-MW004, CH15-106-MW005, and CH15-106-MW010 contained multiple exceedances. These monitoring wells are located north of the Faro Pit and were drilled into the road along the FCD, where fill material was used to create the road. The samples with exceedances were taken from the road fill material.

Exceedances from these locations include arsenic, cadmium, copper, lead, mercury and zinc. The highest arsenic concentration recorded was in sample CH15-106-MW003\_SOd with a concentration of 862 milligrams per kilogram (mg/kg), almost 12 times more than the higher guideline. Sample CH15-106-MW010\_SOb had the highest recorded lead concentration of 12,900 mg/kg, which is over 30 times the higher of the two guidelines. The highest zinc concentration recorded was 2,100 mg/kg, also in sample CH15-106-MW003\_SOd, almost double the higher of the two guidelines for zinc.

Complete total metals results can be found in Table 2‑1.

#### Acid Base Accounting

ABA characteristics were measured in materials collected from the drilling of CH12-204-MW005B and CH12-204-MW006B. Paste pH was relatively neutral in all samples, ranging from 6.34 to 7.25, and the calculated NP:AP ratios were all greater than 3.0 indicating the material is non-potentially acid generating.

ABA properties were also assessed in samples collected from the Faro Creek Valley Seepage Investigation 2015 drilling program (Table 2‑2). Monitoring locations CH15-106-MW003 and CH15-106-MW004 had acidic paste pH values, however the ratio of NP to AP for all samples was greater than 3.0, indicating the material is not potentially acid generating. Samples collected from the other monitoring locations, CH15-106-MW005 and CH15-106-MW010, had neutral paste pH and net-neutralizing NP:AP ratios (i.e., greater than 3.0), indicating the material is also non-potentially acid generating.

#### De-ionized Water Leach Test

DI-leach testing was conducted on samples collected during 2015 drilling near the FCD at monitoring well locations CH15-106-MW003 (eastern valley), CH15-106-MW005 (western valley), and CH15-106-MW010 (up valley). The DI-leach tests of the borehole materials collected from the upper valley and west side of the Faro Creek valley locations resulted in a final leachate that was near-neutral, but contained elevated concentrations of copper, lead, and zinc, suggesting the potential for increased mobility of these metals. Increased mobility of these constituents in the relatively undisturbed areas of the Faro Creek valley is likely the result of weathering processes of naturally occurring mineralized zones near the land surface. Monitoring location CH15-106-MW003 was drilled through the FCD access road, and samples collected at intermediate depths (approximately 8 mbgs) show potential influences from mine waste materials. Leachate results from this location were acidic and contained readily dissolved sources of cadmium, copper, lead, and zinc. It is estimated that at least a portion of the FCD access road or road bed was constructed using WRD materials, affecting the sediments beneath the roadway. This is supported by total metal analysis of samples collected in this area.

DI-leach testing was also conducted on samples collected from CH12-204-MW005B and CH12-204-MW006B. The final leachate was near neutral for these samples, and the SOb samples from each location contained elevated levels of copper, iron, and lead. This again suggests the potential for increased mobility of these metals, and because of the samples proximity to the surface could also be attributed to natural weathering processes.

All DI-leach results can be found in Table 2‑3.

### Groundwater Data

In 2014 and 2015, most monitoring wells located within the Perimeter RU were sampled only once a year, during the fall. However, monitoring wells P01-01A and P01-01B were also sampled during the summer in 2015. The analytical results and a summary of some key parameters can be found in *Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring* (CH2M, March 2016d). All groundwater analytical data was compared to groundwater quality guidelines established in the Canadian Environmental Quality Guidelines (CCME, 2016).

Groundwater data trends using historical (pre-2012) and current (post-2012) water quality data were also analyzed using the Mann-Kendall trend test, the results of which can be found in Table 2‑4. Statistical analyses were conducted for six key parameters: pH, total alkalinity, sulphate, dissolved magnesium, dissolved iron, and dissolved zinc. These parameters have been identified as geochemically important during previous investigations (CH2M, March 2014c). The level of significance tested is 95 percent, and any non-detectable concentrations were reduced to half of the detection limit.

Monitoring well CH12-204-MW005B showed an increasing trend for total alkalinity and no significant trends for dissolved magnesium, field pH and sulfate. There was not enough data to conduct analysis for dissolved iron or dissolved zinc. CH12-204-MW006B did not have enough data to conduct analysis for dissolved iron. The remaining parameters showed no significant trends. Nine wells installed in either 2012 or 2013 did not have enough data to evaluate statistical trends (Table 2-4). P01-01A showed increasing trends for total alkalinity, dissolved magnesium, and sulphate, and a decreasing trend in field pH. There were no trends in the data evaluated for dissolved iron and dissolved zinc. P01-01B showed increasing trends for total alkalinity, dissolved magnesium, and sulphate. There are no other statistically significant trends in the other analytes evaluated. Monitoring well X16A exhibited significant increasing trends in total alkalinity and dissolved magnesium and significant decreasing trends in dissolved iron and dissolved zinc. Sulphate and field pH did not show any significant trends. Monitoring wells X16B and X17A showed increasing trends for total alkalinity, dissolved magnesium, and sulphate, and decreasing trends for dissolved iron. These two wells did not exhibit significant trends for field pH or dissolved zinc. Monitoring wells X17B and X18A showed increasing trends for total alkalinity, dissolved iron, dissolved magnesium, and sulphate, but no significant trends for either field pH or dissolved zinc. Monitoring well X18B showed increasing trends for total alkalinity, dissolved magnesium, and sulphate, and decreasing trends for dissolved iron, field pH, and dissolved zinc.

### Summary and Recommendations

Results from geochemical testing and analysis of the Perimeter RU materials provides the basis for characterization of key locations within areas bordering the RUs. Results of the solid materials collected are summarized below:

* The fill material used to construct the FCD access road was, at least in part, WRD material with elevated concentrations of zinc, arsenic, cadmium, lead, and copper.
* All the materials evaluated with ABA methods from the borings completed at the FCD are net-neutralizing.
* Material from the FCD leakage investigation subjected to DI-leach testing resulted in near-neutral leachate with significant amounts of copper, lead and zinc in leachate of samples from the northern end of the FCD and western side of Faro Valley.
* DI-leach testing of FCD samples from the eastern side of Faro Valley generated acidic leachate with significant amounts of cadmium, copper, lead, and zinc. This is most likely attributable to the presence of WRD material in the fill used to construct the FCD access road.

Groundwater geochemical testing indicates:

* Water quality in the Rose Creek Valley downstream of the CVD shows significant trends of decreasing pH. Also noted were significant trends of increasing alkalinity and dissolved magnesium, and concentrations of iron and zinc.

# Waste Rock Dump Remediation Unit

The WRD RU encompasses almost all defined WRDs in the Faro Mine Area and some parts of the Perimeter RU, including the Zone II Outwash area, the S-Wells area, and the area to the southwest of the WRDs. Because these parts of the Perimeter RU receive groundwater seepage from the WRDs, the geochemical data obtained in these areas are considered closely representative of that in the WRDs and are discussed in this section. The one exception is the Faro Valley Waste Dump, which drains exclusively to the Faro Pit. The waste dump was not sampled for solids analysis, and only seepage data flowing into the Faro Pit was collected. As such, the Faro Valley Waste Dump is included in the Faro Pit RU.

## Field Investigation Activities

Field investigation activities were completed within the WRD RU from 2012 through 2015 to support the following objectives:

* Locating of suitable material for use in gabion baskets for the Down Valley Interim Hydraulic Upgrades (DVIHU) design (CH2M, March 2014m)
* Understanding of site-wide geochemical properties and WRD pore-gas profiles (CH2M, October 2013b; CH2M, March 2015b; CH2M, April 2016d; CH2M, August 2016h)
* Proposed relocation of material from the Oxide Fines Stockpile (OXSP) to the Low-grade Stockpile “C” (LGSPC) (CH2M, March 2015l)
* Delineation of the sulphide cells in support of the design of regrading, cover, and revegetation of the Main Dump and Intermediate Dump (CH2M, March 2015o)
* The design of regrading and resloping the Faro Mine Area waste dumps (CH2M, March 2015p; CH2M, March 2015q)
* Relocation of Zone II Outwash Material (CH2M, March 2015s)
* Design of a seepage interception system at the Zone II Outwash (CH2M, March 2015t)
* Design of a seepage interception system at the S-Wells (CH2M, March 2015u)
* Proposed excavation and disposal of petroleum contaminated material near the old Faro Lube Shack and Tank Farm Area (CH2M, March 2015v)

### Test Pit Excavation

During the 2013 field season, 11 test pits were excavated in the Lower Northwest (NWL) WRD, and samples were selected from five of these locations to send to the laboratory for geochemical analyses. These test pits were excavated as part of the DVIHU field investigation to evaluate the suitability of the material in the NWL WRD to be used in gabion baskets.

A total of 33 test pits were completed in the WRD RU during the 2014 field season, at locations within the boundaries of WRDs, at the Zone II Outwash area, and along the toes of the WRD slopes. Typically, samples collected from the shallow and bottom-of-pit intervals within each test pit were sent to ALS Laboratory for geochemical analyses; middle interval samples from selected test pits were also submitted for analyses. Two hand samples were also collected from two shallow holes (approximately 0.20 mbgs) hand dug on the northern side of the LGSPC in July 2014. The collected material was logged according to the Unified Soil Classification System (USCS).

Description of the test pit excavation activities, laboratory analyses, and results discussion are presented in the following documents:

* 2013 Down Valley Interim Hydraulic Upgrades Field Investigation Data and Analysis Report (CH2M, March 2014m).
* Summary of 2014 Field Investigation – Relocate Oxide Fines to Low-grade Stockpile “C” (CH2M, March 2015l)
* Summary of 2014 Field Investigation – Delineate Main and Intermediate Sulphide Cells for Regrading and Capping Design (CH2M, March 2015o)
* Summary of 2014 Field Investigation – Regrade and Reslope Faro Waste Rock Dumps (Upper Surfaces) (CH2M, March 2015p)
* Summary of 2014 Field Investigation – Regrade and Reslope Faro Waste Rock Dumps (Toe of Slope) (CH2M, March 2015q)
* Summary of 2014 Field Investigation – Relocate Zone II Outwash Material to Intermediate Sulphide Cell (CH2M, March 2015s)
* Summary of 2014 Field Investigation – Relocate Contaminated Soil from Faro Lube Shack and Tank Farm Area and Cover (CH2M, March 2015v)

### Borehole Drilling and Monitoring Well, Thermistor Port, and Gas Port Installation

During the 2012 field investigation three boreholes were drilled in the WRD RU: CH12-014-MW003 near the Main Dump, CH12-104-MW005 in the Zone II WRD, and CH12-104-MW007 at the toe of the Intermediate Dump. These boreholes were drilled as part of the site-wide WRD monitoring program. All three locations with installed with monitoring wells, thermistor ports, and gas ports.

During the 2014 field season, four boreholes were drilled within the WRD RU: CH14-015-MW004 in the Northwest WRD, CH14-015-MW006 in the Northeast WRD, CH14-104-MW008 in the OXSP, and CH14-106-MW009 in the Main Dump that was designed to go through the sulphide cell. The borings were advanced to native materials underlying the waste rock to a maximum depth of between 32.8 and 65.5 mbgs.

In addition, a total of fourteen boreholes were drilled in areas adjacent to the Faro Mine Area WRDs, including eight borings in the Zone II Outwash area and six borings in the S-Wells area. The maximum depth of boreholes in the Zone II Outwash area ranged between 3.05 mbgs (a shallow monitoring well in a paired cluster, drilled to just below stream level in the NFRC) and 50.5 mbgs (drilled into bedrock to conduct packer testing). The maximum depth of boreholes in the S-Wells area ranged between 6.10 mbgs (a shallow monitoring well in a paired cluster) and 37.20 mbgs (drilled into bedrock to conduct packer testing).

Most borings were completed with monitoring wells; thermistor ports and gas ports were also installed in select locations.

Description of the drilling and instrument installation activities, laboratory analyses, and results discussion are presented in the following documents:

* Waste Rock Dump Monitoring Report (CH2M, October 2013b)
* Summary of 2015 Field Investigation – Faro Valley Seepage Investigation (CH2M, April 2016f)
* Summary of 2014 Field Investigation – Relocate Oxide Fines to Low-grade Stockpile “C” (CH2M, March 2015l)
* Summary of 2014 Field Investigation – Delineate Main and Intermediate Sulphide Cells for Regrading and Capping Design (CH2M, March 2015o)
* Summary of 2014 Field Investigation – Install Zone II Outwash Collection System (CH2M, March 2015t)
* Final North Fork Rose Creek Design Basis Report (CH2M, August 2016m)

### Seep Sampling

Seep sampling was conducted twice per year, in the spring during peak freshet and in the early fall “dry” season, starting in 2012 and continuing through the spring of 2016. Seeps were selected for analytical sampling based on frequency of historical sampling, geochemical modelling needs, and environmental monitoring needs. New sampling locations were established where data gaps were identified or new seeps were discovered. Seeps associated with the ETA, Faro Pit (distinct from the WRDs, with the exception of the Faro Valley Waste Dump), and Vangorda/Grum Area are discussed in Sections 4, 7, and 10, respectively.

Annual seep reports including laboratory analyses and results discussion are presented in the following documents:

* 2012 Seepage, Surface Water, and Water Treatment Plant Influent Sampling Report (CH2M, October 2013a)
* 2013 Seep Sampling and Waste Rock Dump Monitoring Data and Analysis Report (CH2M, March 2014c)
* Summary of 2014 Field Investigation – Site-wide Geochemical Monitoring (CH2M, March 2015b)
* Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring (CH2M, April 2015d)
* Summary of 2016 Field Investigation – Site-wide Geochemical Monitoring (CH2M, August 2016j)

### Groundwater Sampling

Groundwater in the WRDs was sampled multiple times per year, typically once in the winter (February/March), once in the spring (May/June), and once in the fall (September/October). In 2014, the winter event was not completed, and instead two sampling events occurred in the spring: one event before freshet and one event approximately coincident with peak freshet.

Previous groundwater investigations in the WRD area, including laboratory analyses and results discussion are presented in the following documents:

* Waste Rock Dump Monitoring Report (CH2M, October 2013b)
* 2013 Seep Sampling and Waste Rock Dump Monitoring Data and Analysis Report (CH2M, March 2014c)
* Summary of 2014 Field Investigation – Site-wide Geochemical Monitoring (CH2M, March 2015b)
* Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring (CH2M, April 2015d)
* Summary of 2016 Field Investigation – Site-wide Geochemical Monitoring (CH2M, August 2016j)

### Temperature and Pore Gas Monitoring

Temperature and gas concentration data were measured at WRD monitoring locations installed by CH2M during the same sampling events mentioned above in Section 3.1.4, concurrent with the groundwater sampling events. Temperature and gas were also measured during these sampling events at historical monitoring locations (10M3, 10M4, 30M1, 30M4, and 60M1) installed by SRK Consulting starting in the spring of 2013.

## Field Investigation Data Evaluation

### Solids Data

#### North Faro Valley Waste Dump

Although included with the Faro Pit RU and discussed in Section 7, the North Faro Valley Waste Dump is mentioned here for cohesion. The waste dump is located just north of Faro Pit within the former Faro Creek valley. Waste rock material was placed on top of the former Faro Creek channel, which controls seepage in this area. There were no solids collected from the North Faro Valley Waste Dump. Seep data for this area are presented in Section 7.2.1.

#### Northwest Waste Rock Dump

There were three main activities in the Northwest WRD that resulted in solid sample collection for geochemical analysis: a single borehole (CH14-015-MW004) for gas/temperature/monitoring well installation, five test pits to evaluate suitability of the NWL WRD material for gabion baskets as part of the DVIHU field investigations, and two test pits around the crest of the Northwest WRD to evaluate material as part of the WRD slope regrading design. In this section, complete geochemical analysis of materials from the three investigations are discussed separately.

Total metals analyses was performed on selected samples from the single Northwest WRD borehole, CH14-015-MW004 (Table 3‑1). The upper portion (surface to approximately 5.5 mbgs) of the waste rock material from MW004 contains relatively low amounts of sulphide minerals (based on total sulphur content) and as such has a low trace element content (i.e., no trace elements exceeding both screening criteria). Sulphide mineral content increases sharply and is the greatest at approximately 8.23 mbgs based on the spike in total sulphur and iron and parallel increases in the key trace elements arsenic, copper, lead, and zinc (Figures 3-1 and 3-2). Within the sulphide mineral-rich portions of the recovered samples, numerous trace elements exceed, as is to be expected, both the 10 times crustal abundance and 12 times median world soil content screening criteria employed for the FMC solids evaluations. A second sulphide-rich zone occurs near the bottom of the boring at approximately 17.7 mbgs with copper, lead, and zinc exhibiting spikes in concentration mimicking the increase in total sulphur and iron. Near the bottom of the WRD (approximately 28 mbgs), the sulphide content decreases significantly and although trace elements are still elevated, they are generally less than the two screening criteria with the exception of lead which exceeds both criteria. The underlying till, approximately 35 mbgs, is only slightly impacted by arsenic and total sulphur which exceeds the 10 times crustal abundance criteria, while the deeper weathered bedrock material (35.4 mbgs) exhibits no significant impacts at all.

Samples collected from the Northwest WRD were generally composed of phyllite and schist waste rock types, with varying degrees of weathering present. In samples collected from borehole CH14-015-MW004, located in the Middle Northwest (NWM) WRD, a high degree of oxidation and the presence of yellow and or white secondary mineral formation was noted during the investigation. These samples were characterized by acidic paste pH (2.49 – 5.84) and NP:AP ratios of less than 3.0 (Table 3-2). Lenticular zones of highly oxidized minerals were also noted in these samples. Deeper samples within the NWM at CH14-015-MW004 (approximately 35 mbgs), fragments of calc-silicate rock were noted, characterized by near neutral paste pH and a net-neutralizing NP:AP ratio of 201.

DI-leach testing of samples collected from CH14-015-MW004 suggest select trace elements may be highly mobile at specific depth horizons within the Northwest WRD, but not near the surface. Final leachate from samples of CH14-015-MW004 surface materials was near-neutral and did not contain elevated trace elements of concern (Table 3-3). The final leachate of samples collected between 5 and 20 mbgs, where total metal concentrations were found to be elevated, was acidic with elevated concentrations of cadmium, copper, iron, lead, and zinc. Based on borehole logs, WRD materials in this interval exhibited a high degree of oxidation and the presence of yellow and or white secondary mineral formation. These data support the following discussion of sequential extraction test results, which identify readily soluble salts and acid-soluble phases that could mobilize metals when in contact with water.

Sequential extractions were completed on samples collected from borehole CH14-015-MW004 to characterize the mobility and mineralogic association of trace metals within the solid material contained within the Faro Northwest WRD (Table 3-4 and 3-5). Although the sequential extractions analyze for a full suite of trace metal analytes, this section focuses on the key constituents to the FMC area: iron, manganese, zinc, lead, copper, and arsenic. Iron is generally extracted in one of three dominant phases in the Northwest WRD samples (Figure 3-3): amorphous oxides (e.g., ferrihydrite), crystalline oxides (e.g., goethite or schwertmannite), or in the residual fraction (e.g., primary pyrite). Manganese is mainly extracted in the amorphous oxide and residual (e.g., primary mineral phases) fractions, with a notable presence (samples SOf and SOi) of a readily soluble neutral salt exchangeable phase and an acid-soluble fraction. Zinc is predominantly extracted in the residual (i.e., sulphide) or one of the two oxide (amorphous and crystalline) phases; however, in two samples (SOf and SOi), where considerable oxidation and weathering was noted in the boring logs and where increased trace element content was observed in the final DI leachate, a significant portion of the zinc fraction was extracted in the neutral salt exchangeable and acid-soluble phases (Figure 3-3). Lead was largely extracted in either the acid-soluble or residual phases. The acid-soluble lead is most likely lead oxide which can be dissolved under low pH conditions, while the residual phase is most likely lead associated with the sulphide fraction (either the lead sulphide, galena, or as a coprecipitate within pyrite). Copper is extracted mainly in the residual fraction (most likely occurring as a primary sulphide phase) with minor amounts extracted in the amorphous oxide fraction (Figure 3-3). Arsenic is mainly extracted in one of three phases: residual (likely primary arsenic-bearing sulphides), and one of the two oxide fractions (likely as absorbed or coprecipitated arsenic with iron oxides). Considerations should be made when selecting remediation alternatives for the Northwest WRD; although much of the potential contaminant load is tied to primary mineral phases, the presence of zinc and lead in neutral salt exchangeable and acid-soluble phases at certain depths in the WRD suggest the potential for increased mobility of these constituents when in contact with water.

The five samples collected for geochemical analysis from the five test pits to evaluate suitability of the NWL WRD material for gabion baskets as part of the DVIHU field investigations were submitted for total metal analysis. Field observations noted that the waste rock deposited on the lower bench of the NWL WRD contains much less sulphide mineral content that the material encountered during the drilling of CH14-015-MW004. In general, total trace element content was fairly low with a few of the samples (CH13-108-TP006-SOa or CH13-108-TP0015-SOa) exceeding the 10 times crustal abundance screening criteria for arsenic, cadmium, and zinc. All samples with the exception of CH13-108-TP011-SOa exceeded the 10 times crustal abundance criteria for lead. Two samples also exceeded both screening criteria for lead (CH13-108-TP006-SOa and CH13-108-TP0015-SOa) and one of these two samples also exceeded both screening criteria for cadmium (CH13-108-TP006-SOa). However, all of these samples had a near-neutral to slightly alkaline paste pH, very low acid potential (except CH13-108-TP0015-SOa which had only mild acid potential), and very high NP (though CH13-108-TP0015-SOa had about half the NP of the other test pit samples) (Table 3-2). All samples had a very high NP:AP ratio – greater than 250 – with the exception of CH13-108-TP0015-SOa, which was still high, but only 29.8. Unfortunately, no leach testing was performed on these samples. Although a few of the total trace elements exceeded the established screening criteria for the FMC in these samples, the very high NP:AP ratio and the neutral paste pH suggest that the material is still a good candidate for the gabion baskets in the DVIHU design. However, further testing (specifically DI-leach testing) is recommended before selecting the final materials for the gabion baskets.

The final two test pits were excavated around the crest of the Northwest WRD to evaluate material as part of the WRD slope-regrading design. Both test pit samples submitted for geochemical analyses were composite samples of three subsamples collected between the surface and 5 mbgs at the top, middle, and bottom of the respective test pit. Sample CH14-106-TP013-SOCOMP had fairly low total iron (for WRD material) and only exceeded the 10 times crustal abundance criteria for lead. Sample CH14-106-TP014-SOCOMP also had fairly low iron relative to most WRD samples and only exceeded the 10 times crustal abundance for total sulphur and zinc; however, this sample also exceeded both screening criteria for lead.

The ABA analysis (Table 3-2) of samples from the two test pits excavated along the crest of the Upper Northwest (NWU) WRD suggest the upper 5 m of material is near-neutral (paste pH), with fairly low acid potential and very high NP, and is net-neutralizing (NP:AP values between 17 to 28). The DI-leach testing (Table 3-3) also results in near-neutral final pH of the leachates with very low trace element content. Sequential extractions were completed on the composite sample collected from test pit CH14-106-TP013 to characterize the mobility and mineralogic association of trace elements within the outer edge of the WRD that could be impacted by regrading activities (Table 3-4 and 3-5). Sequential extraction data for the CH14-106-TP013 identify two main phases of iron: crystalline oxide and the residual fraction (i.e., pyrite). Most of the manganese was extracted in the amorphous oxide step followed by the residual and the crystalline oxide fractions. Zinc was predominantly found in the residual fraction (most likely associated with sulphides), but a significant amount was also extracted in the crystalline oxide phase. Lead was largely extracted in the acid-soluble and residual phases, which most likely implies lead is present in the WRD material as lead oxides, which are susceptible to leaching under mildly acidic conditions, and as primary sulphide minerals, respectively. Copper is predominantly measured in the residual fraction, which is most likely extracted from primary sulphide mineralization. Finally, greater than 90 percent of the arsenic extracted comes from the residual phase, suggesting most of the arsenic present occurs associated with sulphides. Altogether, the data from these two test pits suggest the WRD material at shallow depths near the crest of the NWU is non-potentially acidic and fairly stable with little potential for mobilization of trace elements during regrading of the slope in this area.

#### Stockpiles

Total metals analyses were performed on samples collected from investigations on the stockpiles (LGSPC and OXSP), which included drilling one borehole (CH14-104-MW008) in the OXSP and excavating three test pits (CH14-104-TP001 through CH14-104-TP003) in the LGSPC. As expected from ore and oxide fines stockpiles in the FMC, almost all of the samples from the upper portion of the boring as well as the test pits exceeded the screening criteria for antimony, arsenic, cadmium, copper, lead, mercury, selenium, silver, sulphur, and zinc (Table 3-1).

The boring log indicates that the upper portion of the OXSP, as represented by sample CH14-104-MW008-SOb (3.7 to 4.0 mbgs), contained significant massive sulphide, specifically pyrite, as supported by the very high total sulphur and iron content in the sample (Figure 3-4) with elevated trace element concentrations (Figure 3-5). Below 4 mbgs, the total sulphur and iron content dropped sharply, but was still elevate down to approximately 13 mbgs, indicative of WRD material. The trace element content was also consistent between 4 and 13 mbgs. However, the trace elemental concentration dropped further below approximately 16.5 mbgs, suggesting a lower sulphide content in the lower WRD material of the OXSP. In the two WRD samples at or below 16.5 mbgs (CH14-104-MW008-SOg and CH14-104-MW008-SOi), the only trace element that exceeds both the 10 times crustal abundance and 12 times median world soil contents screening criteria is total sulphur in sample CH14-104-MW008-SOi. In fact, only arsenic, cadmium, and lead exceed the 10 times crustal abundance criteria in CH14-104-MW008-SOg, while total sulphur is the only exceedance in CH14-104-MW008-SOi. This trend continues into the underlying native organic soil (CH14-104-MW008-SOl), where only lead and total sulphur exceed the 10 times crustal abundance criteria.

ABA data collected from the stockpiles (LGSPC and OXSP) characterize the potential for these sulphide-rich dumps to generate acid over time (Table 3-2). Samples collected from the surface and shallow depths (less than 5 mbgs) within the LGSPC contained high sulphide mineral content and were characterized as potentially acid generating, with acidic paste pH and NP:AP ratios of less than 1.0. Similarly, samples collected in the upper portion of the OXSP were characterized by acidic paste pH and NP:AP ratios less than 1.0. However, the samples from deeper in the OXSP (greater than 16.5 mbgs) and from the underlying native organic soil have a near neutral paste pH, a significantly lower acid potential, and very high NP, such that the material at depth in the OXSP stockpile is net neutral with an NP:AP ratio greater than 10 (Table 3-2). When considering remediation alternatives for these two stockpiles, it is important to note the relative reactive surface area of the sulphides present. In the LGSPC, large, angular sulphide rock fragments are present and highly weathered. In contrast, the OXSP is characterized by fine grained, processed sulphide rocks, and visible oxidation is present in the upper 1 meter of material. Regrading and resloping or even relocation of the upper OXSP material could expose the previously un-weathered sulphide materials, and increase the potential for acidic drainage and metal mobilization.

DI-leach samples collected from the OXSP and LGSPC support the characterization of potential trace element mobility within these stockpiles at the surface and at depth (Table 3-3). Final leachate results from surface materials collected from borehole CH14-104-MW008 (OXSP) and test pits CH14-104-TP001, CH14-104-TP002, and CH14-104-TP003 (LGSPC) was acidic and contained elevated levels of arsenic, cadmium, copper, iron, lead, and zinc. These trace elements are likely tied to readily soluble salts, such as melanterite, that have been observed in surface deposits on the OXSP. The final leachate from samples collected at depth in the OXSP (CH14-104-MW008SOg through SOl) had a near-neutral final pH with very low dissolved trace element content.

Sequential extraction tests were completed on samples collected from borehole CH14-104-MW008, test pit CH14-104-TP03, and two grab samples (CH14-104-SS01 and CH14-104-SS02) to characterize the mobility and mineralogic association of trace metals contained within the OXSP and LGSPC (Tables 3-4 and 3.5; Figure 3-6). Extraction results from the OXSP boring support the field observation of a weathered “zone” or increased weathering at moderate depth (12.5 to 12.8 mbgs) and the presence of soluble salts near the surface (3.7 to 4 mbgs) as well as at moderate depth (12.5 to 12.8 mbgs). Greater than 80 percent of the total iron is extracted in the residual phase in the upper portion of the OXSP stockpile as iron is most likely present as pyrite. Notably, there was no iron extracted in the neutral salt exchangeable fraction in either of the near-surface samples. At moderate depth, iron is predominantly extracted in the residual and crystalline oxide fractions with a lesser amount occurring in the amorphous oxide phase, indicating significant oxidation of primary pyrite to secondary iron oxides in this sample. In the deepest portions of the OXSP stockpile almost 90 percent of the iron is extracted in the residual fraction with a minor amount extracted in the amorphous oxide fraction. Unlike the apparent immobility exhibited by iron in the OXSP samples, greater than 70 percent of the total manganese is extracted in the neutral salt exchangeable fraction in the near surface sample (CH14-104-MW008-SOb) and in the weathered zone at moderate depth (CH14-104-MW008-SOe); the remaining manganese is largely extracted in the residual phase. In the deeper portions of the OXSP stockpile, manganese is extracted in the residual and acid-soluble phases. Similar to manganese, about half of the zinc is extracted in the neutral salt exchangeable fraction in both samples from near the surface as well as the weathered zone at moderate depth; the remaining zinc in these zones is largely extracted in the residual fraction. In the apparently less weathered material (CH14-104-MW008-SOd), greater than 80 percent of the total zinc is extracted in the residual fraction (Figure 3-6) suggesting it is present in primary sulfide material. In the deeper portions of the OXSP stockpile, zinc in the residual fraction gives way to a greater portion of zinc extracted in the amorphous and crystalline oxide phases even though the fraction of iron and manganese oxides extracted at depth is proportionately less. This demonstrates the preferential retention of zinc in the secondary amorphous and crystalline oxides after being mobilized from the primary residual phase. Near surface, lead is predominantly extracted in the acid-soluble fraction with lesser amounts of lead in the residual phase. With depth, the amount of acid-soluble lead decreases while the amount of residual lead increases. The acid-soluble lead is likely associated with secondary lead carbonates, oxides, or even sulfates. In the deepest portions of the OXSP stockpile, the balance between acid-soluble (secondary) and residual (primary) lead is about equal. Copper is dominantly extracted in the residual fraction at all depths of OXSP stockpile. The copper balance is largely extracted in the amorphous oxide fraction with the exception of the weathered zone at moderate depth, where the residual copper phase is balanced by copper extracted in the neutral salt exchangeable fraction. Similarly, arsenic is predominantly extracted in the residual fraction in the upper portion of the OXSP stockpile with a small portion contained in the crystalline oxide phase. In the deeper portion of the OXSP stockpile, arsenic is largely associated with amorphous oxides with the remaining arsenic extracted in the residual phase (Figure 3-6).

The remaining sequential extraction data are from samples collected in test pits excavated in the upper portion of the LGSPC. As such, the samples exhibit signs of partial weathering in the sequential extraction data. While iron is predominantly extracted in the residual fraction (i.e., present as sulphide), there is also significant iron extracted in the crystalline iron phase and to a lesser extent some neutral salt exchangeable iron as well (Figure 3-6). Manganese, on the other hand, is dominantly extracted in the neutral salt exchangeable fraction with the balance largely in the residual fraction and minor amounts in crystalline and amorphous oxide phases and the acid-soluble phase. Similar to manganese, zinc is largely extracted in the neutral salt exchangeable fraction with the balance in the residual phase. In most samples, copper is predominantly (40 to 90 percent) extracted in the residual phase with the balance largely occurring in the neutral salt exchangeable fraction. The elevated concentration of manganese, zinc, and copper in the neutral salt exchangeable fraction suggests that these trace metals could be readily mobilized from the upper portion of the LGSPC during regrading/resloping or relocating activities. Lead and arsenic are also largely present in the residual extraction step, but are also found in secondary mineral phases: lead in the acid-soluble phase, likely as secondary oxides, carbonates, or sulfates, and arsenic associated with the oxide fractions (mainly crystalline oxide). The arsenic extracted in the pyrophosphate step at pH 10 is likely because of arsenic desorption from crystalline iron oxides at high pH.

This sharp decrease in total elemental content of the OXSP stockpile below approximately 16.5 mbgs coupled with the net neutral and relatively stable mineralogy has significant implications for potential relocation of the material as part of the final WRD closure design. If the OXSP is relocated, the upper 12 to 15 m may have to be moved, though the highest trace metal content is concentrated in the upper 5 m. Investigations at the LGSPC indicate that the upper portion of the pile is highly impacted and there is high potential for mobility of manganese, copper, and zinc if the material is disturbed and exposed to flushing because of precipitation.

#### Main Dump

Investigations in the Main Dump included two borings, CH12-014-MW003 and CH14-106-MW009, drilled to install monitoring wells and gas/temperature ports for long-term monitoring of the WRD and support the site-wide geochemical modeling effort. In addition, eight test pits were excavated around the top of the Main Dump to help delineate the upper portion of the sulphide cell and evaluate the upper portion of the WRD material. One test pit, CH14-106-TP015, was also excavated along the outer edge of Main Dump to support the WRD regrading and resloping design efforts.

Boring CH12-014-MW003 was drilled on the northernmost side of the Main Dump directly above the former Faro Creek channel. This location was selected to provide a monitoring point on the upgradient edge of the Main Dump to compliment the long-term monitoring point, X23, downgradient of the Main Dump within the former Faro Creek channel. Total metals analysis was conducted on all samples except CH12-014-MW003-SOj, SOk, SOl, which were submitted for additional ABA analysis after the initial samples were analyzed. As such, the sample identification for these three late samples is alphabetically after the originally submitted samples, even though they are taken from 2.4, 14.0, and 14.9 mbgs, respectively. The highest trace element concentration measured comes from near surface samples (Table 3-1, Figures 3-7 and 3-8). Arsenic, cadmium, lead, zinc, and total sulphur exceed both screening criteria for the FMC in sample CH12-014-MW003-SOa, collected at the surface (Table 3-1). The trace element concentration generally decreases with depth in the CH12-014-MW003 boring (Figure 3-8) with the exception of a small spike in values at approximately 20 mbgs (sample CH12-014-MW003-SOe) and again near the bottom of the boring at approximately 29 mbgs (sample CH12-014-MW003-SOh). A large increase in total sulphur is observed at approximately 2.4 mbgs (CH12-014-MW003-SOj); however, no total elemental data is available from this horizon.

The paste pH of samples from the upper 2.4 m of boring CH12-014-MW003 is mildly acidic, whereas the deeper samples are all near-neutral (pH 6.5 to 7.5) to slightly alkaline. The acid potential is moderate down to approximately 14 mbgs with the exception of CH12-014-MW003-SOj at 2.4 mbgs, which has a high acid potential (622 kg CaCO3 eq/tonne). Below approximately 14 mbgs, the acid potential is relatively mild. In contrast, the NP is generally relatively high for the entire boring, ranging from 340 to 730 kg CaCO3 eq/tonne, with the highest values occurring in the upper 2.4 m of the boring. Consequently, the NP:AP ratio is greater than 3.0 and generally higher than 10.0 with the exception of CH12-014-MW003-SOj at 2.4 mbgs, where the NP:AP is 1.1. As such, the majority of the samples at this location are net-neutral and the only potential for acid generation occurs at 2.4 mbgs. DI-leach testing suggests that this acid potential is not immediate, as the final pH of the leachate from all CH12-014-MW003 boring samples was near-neutral to slightly alkaline. However, the specific conductance of the final leachate from the upper 5 m is elevated ranging from a high (2,880 micro-Siemens per centimetre) at 2.4 mbgs, decreasing to 1,580 microSiemens per centimetre at 5.2 mbgs. The elevated specific conductance in these near surface samples is reflected in the high sulfate concentration (1,840 to 883 mg/L) in the final leachate from the upper 5 m of the boring. The total elemental concentrations, however, are generally low in the leachate from all samples with the exception of CH12-014-MW003-SOj, which has slightly elevated concentrations of lead and zinc.

Sequential extractions were performed on two samples from the boring: one in the WRD material near the surface (CH12-014-MW003-SOa) and one in the underlying alluvium (CH12-014-MW003-SOf). A duplicate from the alluvium (SOf) was also subjected to sequential extractions (Table 3-4 and 3-5). In both material types, between 70 and 80 percent of the iron was extracted in the residual phase (likely as sulphide minerals), while the remaining 20 to 30 percent was extracted in either the amorphous or crystalline oxide fraction (Figure 3-9). Manganese was largely extracted in either the residual or amorphous oxide fraction with minor amount in an acid-soluble phase near the WRD surface in CH12-014-MW003-SOa. The deeper alluvium sample had greater residual manganese with the balance split between amorphous oxide and an acid-soluble phase. Zinc was extracted in the residual (i.e., primary sulphide), amorphous oxide, and acid-soluble fractions with lesser amounts of neutral salt exchangeable and crystalline oxide fractions in the near surface WRD sample (Figure 3-9). The acid-soluble zinc may be the result of zinc desorption from oxide surfaces, while the neutral salt exchangeable is likely related to secondary sulfate salts typically found in shallow WRD samples at the FMC. In the alluvium sample, a larger portion of zinc was extracted in the residual fraction with most of the balance in either the crystalline or amorphous oxide fractions. The minor amount of acid-soluble zinc in this sample could be related to sorption of zinc to an oxide surface. The majority of the lead in the near surface WRD material was extracted in either the acid-soluble or the alkaline pyrophosphate step (Figure 3-9). These extraction phases likely represent secondary lead minerals such as oxides, sulfate, or carbonates which can be dissolved under these conditions. A minor amount of primary lead sulphide is extracted in the residual fraction. In the alluvium, most of the lead is found in the residual phase with lesser amounts associated with secondary mineralization (i.e., amorphous oxides, acid-soluble, alkaline pyrophosphate extractable lead). Greater than 70 percent of the total copper resides in the residual fraction in the WRD material with the remaining associated with amorphous oxides or acid-soluble phases. In the underlying alluvium, greater than 80 percent of the total copper is residual (i.e., sulphide) with the balance largely occurring in amorphous oxide phases. The distribution of arsenic is similar in both the WRD material and the underlying alluvium with most of the arsenic extracted in the residual fraction and the remaining mostly occurring in either the amorphous or crystalline oxide fraction (Figure 3-9).

Boring CH14-106-MW009 was drilled near the center of the estimated boundaries of the Main Dump Sulphide Cell. However, the total metal and sulphur analyses suggest the boring encountered very little sulphide-rich material (Table 3-1). Total iron was significantly greater than total sulphur indicating most of the iron present was not associated with sulphide minerals and the only samples where total sulphur exceeded both screening criteria was CH14-106-MW009-SOa near the surface and CH14-106-MW009-SOp near the bottom (48.5 to 48.8 mbgs) of the boring (Figure 3-10). In the rest of boring total sulphur exceeded the crustal abundance criteria with the exception of one sample near the bottom of the WRD and the sample of native material underlying the WRD (Table 3-1). The trace element trends largely mimicked total iron and sulphur though the shifts between the highest and lowest concentrations were slightly more exaggerated than iron and sulphur trends at the same depth intervals (Figure 3-11). Notably, sample CH14-106-MW009-SOp, where total sulphur is elevated, is the only depth where any trace elements (i.e., lead and zinc) exceed both screening criteria (Table 3-1). Even in the near surface sample (CH14-106-MW009-SOa), where total sulphur is also elevated, the only trace element of concern that exceeds the screening criteria is lead and it only exceeds the 10 times crustal abundance criteria. Of the main trace elements of concern at the FMC, only arsenic (in three samples) exceeded the 10 times crustal abundance in the remaining boring samples; the majority of the trace elements in the rest of the boring samples fall below the screening criteria. With the exception of one sample, CH14-106-MW009-SOp, the paste pH at this location was neutral to slightly alkaline. CH14-106-MW009-SOp had a mildly acidic paste pH (5.17) and is one of the two samples with total sulphur that exceeded both screening criteria. The acid potential, was fairly low for all samples with the exception of the two samples (CH14-106-MW009-SOa and CH14-106-MW009-SOp) where total sulphur exceeded both screening criteria and even the acid potential in these two samples was only moderate (Table 3-2). The NP for all samples is relatively high and as such the NP:AP ratio for all samples is greater than 3.0 and the samples are all considered net-neutral. Similar to the paste pH results, DI-leach testing performed on the boring samples resulted in near-neutral to slightly alkaline pH of the final leachate with the exception of CH14-106-MW009-SOp, which was slightly acidic (pH 6.5). The final leachate from CH14-106-MW009-SOp also had the highest sulfate (979 mg/L) and slightly elevated concentrations of lead and zinc (Table 3-3), but generally did not exhibit elevated trace elements. All of the other samples from boring CH14-106-MW009 did not contain any elevated trace element concentrations.

Sequential extractions were performed on seven samples from the boring (Table 3-4 and 3-5): six in the WRD material (CH14-106-MW009-SOa, CH14-106-MW009-SOd, CH14-106-MW009-SOi, CH14-106-MW009-SOk, CH14-106-MW009-SOm, CH14-106-MW009-SOp) and one in the underlying alluvium (CH14-106-MW009-SOt). With the exception of one sample (CH14-106-MW009-SOp), approximately 90 percent of the total iron was extracted in the residual fraction in both the WRD and underlying alluvium samples (Figure 3-9). The balance was extracted as amorphous and crystalline oxide phases. In sample CH14-106-MW009-SOp, a little over 70 percent of the total iron was extracted in the residual fraction with the remaining largely extracted as crystalline oxide and minor amorphous oxide. While the residual fraction is typically assumed to represent iron sulphides, the disparity in total iron being significantly greater than total sulphur indicates that the iron was extracted from another residual source, potentially silicate minerals susceptible to the residual extraction step. Manganese was also largely extracted in the residual fraction, but to a slightly lesser extent (65 to 85 percent). Near the surface, the balance was largely acid-soluble manganese, which could represent secondary carbonates, adsorbed manganese, or manganese oxides susceptible to acid solubilisation. At depth, amorphous and crystalline oxide phases of manganese largely made up the balance. In the alluvial sample, the residual manganese was largely balanced by the acid-soluble fraction. Zinc was largely extracted in the residual fraction (most likely as a primary sulphide) and balanced by amorphous and crystalline oxide phases (Figure 3-9). The lead extracted from the CH14-106-MW009 samples was predominantly either in a residual phase (i.e., primary sulphide) or an acid-soluble phase (i.e., secondary mineral). Copper was mostly extracted in the residual phase (i.e., primary sulphide) with amorphous oxides making up the majority of the balance. Arsenic is also largely extracted in the residual fraction with the exception of sample CH14-106-MW009-SOm and CH14-106-MW009-SOt (alluvium sample), which both had very low total arsenic concentrations. As such, accurate interpretation of sequential extraction data is hampered by non-detects in many of the extraction steps.

A total of nine test pits were excavated within the Main Dump. Eight test pits were dug to help delineate the upper portion of the sulphide cell and evaluate the upper portion of the WRD material. Material from these eight test pits was collected from either the top (SOa), middle (SOb), or bottom (SOc) of the test pit with several depth samples from each test pit submitted for geochemical analysis. Alternatively, the one test pit, CH14-106-TP015, which was also dug along the outer edge of Main Dump to support the WRD regrading and resloping design efforts, only had one composite sample covering all three depth intervals submitted for analysis. Unlike the two borings drilled in the Main Dump, the test pits tended to have total elemental concentrations that exceeded at least one of the two screening criteria established for the FMC (Table 3-1). Arsenic exceeded at least one of the two criteria in every sample except CH14-106-TP001-SOc and was exceedingly elevated in samples CH14-106-TP003-SOa, CH14-106-TP004-SOa and CH14-106-TP004-SOc, and CH14-106-TP006-SOa and CH14-106-TP006-SOc. Copper on the other hand was generally below the two screening criteria in every sample except CH14-106-TP004-SOa and CH14-106-TP006-SOa and CH14-106-TP006-SOc, where the copper values were greater than both criteria. Lead exceeded one of the two criteria in all samples except CH14-106-TP005-SOa and CH14-106-TP008-SOc, but significantly exceeded both criteria in samples CH14-106-TP001-SOa; CH14-106-TP002-SOa and CH14-106-TP002-SOc; CH14-106-TP003-SOa, CH14-106-TP003-SOb, and CH14-106-TP003-SOc; CH14-106-TP004-SOa and CH14-106-TP004-SOc; and CH14-106-TP006-SOa and CH14-106-TP006-SOc. Zinc exceeded both criteria in all samples except CH14-106-TP002-SOc, CH14-106-TP005-SOa and CH14-106-TP005-SOc, and CH14-106-TP008-SOa, CH14-106-TP008-SOb, and CH14-106-TP008-SOc. Also with the exception of CH14-106-TP002, zinc concentrations increased with depth at each of the test pit locations near the center of the Main Dump. Near the edge of the Main Dump, arsenic and lead exceeded 10 times crustal abundance in CH14-106-TP015-SOCOMP, but only zinc exceeded both criteria at this location. Total sulphur exceeds at least the 10 times crustal abundance screening criteria in all test pit samples except for CH14-106-TP015-SOCOMP. However, there are few distinct trends in the individual test pits. For example, at test pit location CH14-106-TP001, the total sulphur is very high near the surface (53,300 mg/kg in sample CH14-106-TP001-SOa), but an order of magnitude lower at depth (5,500 mg/kg in sample CH14-106-TP001-SOc). Other than location CH14-106-TP001, most total sulphur values appear to be within natural variation between the depths at a particular location. The locations that have the highest total sulphur concentrations across all depths are: CH14-106-TP003, CH14-106-TP004, and CH14-106-TP006.

ABA properties were characterized in samples collected from the Main Dump East (MDE) and Main Dump West (MDW) waste dumps (Table 3-2); however, not all of the samples collected were submitted for ABA analysis (i.e., did not have NP analyzed at a minimum to permit ABA calculations). Lithologic logs from the test pits in the MDE and MDW indicate highly variably lithology within these WRDs, and therefore ABA properties were also widely variable, dependent on lithology. Where abundant pyrite or massive sulphide waste rock noted, as observed in CH14-106-TP001, CH14-106-TP004, and CH14-106-TP006, acidic paste pH and NP:AP ratios of less than 1:0 were measured (Table 3-2). Many samples contained mixed lithology rock fragments, including weathered phyllite, massive sulphide, quartzite, and calc-silicate rock. In these samples, the presence of massive sulphide rock and it’s acid generating properties were buffered by the presence of calc-silicate rock, represented by near-neutral to slightly acidic paste pH and NP:AP ratios of greater than 3 (Table 3-2). Overall, the material contained within the MDE and MDW have net-neutralizing properties. However, localized zones of acid generating material exist and can contribute to increased acid production and metal mobilization into the environment. Factors that would influence potential acid generation include WRD infiltration flowpaths and regrading/resloping activities.

DI-leach samples collected from the Main Dump were used to characterize the mobility of constituents near the surface and edges of the Main Dump. Sample results from surface materials collected from test pits located near the northern edge of the Main Dump (CH14-106-TP004 and CH14-106-TP006) had acidic leachate (pH 2.03 within 2 mbgs at both locations) that contained greater concentrations of arsenic, cadmium, copper, iron, lead, and zinc (Table 3-3). Mobility of trace metals in these samples may be because of the presence of readily dissolved secondary salts, such as melanterite. In contrast, the composite sample taken from the test pit on the southern edge of the Main Dump (CH14-106-TP015-SOCOMP) generated a slightly alkaline leachate with low final sulphate and trace elemental content. Other surface samples collected from excavated test pits showed greater variability in material composition, however a trend of generally increased mobility of trace metals across the surface materials of the Main Dump was observed (Table 3-3).

Sequential extraction tests were completed on samples collected from test pits (CH14-106-TP001, CH14-106-TP002, CH14-106-TP003, CH14-106-TP004, CH14-106-TP005, CH14-106-TP006, CH14-106-TP008, and CH14-106-TP015) to characterize the mobility and mineralogic association of trace metals within the solid material contained within the Main Dump (Tables 3-4 and 3-5). Iron is predominantly extracted in the residual phase (presumably as a sulphide) with crystalline oxide making up the majority of the remaining iron extracted (Figure 3-12). Iron is also extracted to a lesser extent in the amorphous oxide fraction. In the two samples (CH14-106-TP004-SOa and CH14-106-TP006-SOa) where the final DI leachate was highly acidic (pH 2.03), there is a small amount of iron extracted in the neutral salt exchangeable fraction which is most likely attributable to highly soluble and highly acidic secondary iron sulfates, such as melanterite. Manganese distribution is highly variable and somewhat dependent on the total manganese concentration in the sample. In samples where the manganese is very high, manganese is recovered mainly in the amorphous oxide fraction with the remaining extracted in the residual fraction. In samples where the total manganese concentration is considerably lower and possibly depleted, a large portion of manganese is extracted in the neutral salt exchangeable fraction with an increase in manganese in the crystalline oxide phase and the balance in the residual fraction. For other samples with more median manganese concentrations, the acid-soluble and residual phase are the main steps where manganese is extracted with amorphous oxides playing a lesser role. The presence of manganese in the acid-soluble phase in sample locations where the paste pH was near-neutral and the shift to manganese in the neutral salt exchangeable fraction at sample locations where the paste pH was highly acidic, suggests that much of the manganese in the surface samples of the Main Dump may be susceptible to mobilization should the soil pH decrease. The distribution of zinc within the sequential extraction steps is tied to the soil pH of the sample. In samples where either the paste pH or final DI-leach pH was moderately to highly acidic (CH14-106-TP001-SOa, CH14-106-TP004-SOa, and CH14-106-TP006-SOa and SOc), a significant portion of the total zinc is extracted in the neutral salt exchangeable fraction, suggesting zinc is associated with highly soluble secondary sulfate salts. The remaining zinc is extracted in the crystalline oxide and residual fractions in these samples (Figure 3-12). In the more neutral samples (with the exception of CH14-106-TP001-SOc, CH14-106-TP003-SOc, and CH14-106-TP004-SOc), zinc is largely extracted in the residual or amorphous and crystalline oxide phases, indicating zinc associated with either primary sulphides or secondary (e.g., iron) oxides, respectively. In samples CH14-106-TP001-SOc, CH14-106-TP003-SOc, and CH14-106-TP004-SOc, a significant portion of the total zinc is extracted in the acid-soluble fraction, which could be the result of desorption of surface bound zinc from oxide minerals under mildly acidic conditions as the drop in pH changes the surface charge of the secondary oxides causing the weakly-bound zinc to desorb. As such, the acid-soluble zinc fraction is considered susceptible to mobilization. With the exception of sample CH14-106-TP003-SOa, lead is largely extracted in either the residual or acid-soluble fraction (Figure 3-12). The residual lead is likely present as primary lead sulphides whereas the acid-soluble lead is likely present as secondary lead-bearing minerals such secondary lead-oxides, -sulphates, or possibly –carbonates. The presence of the secondary acid-soluble fraction indicates that lead may be susceptible to mobilization under changing site conditions (i.e., acidification). Sample CH14-106-TP003-SOA also contains lead in the residual and acid-soluble fractions, but lead is predominantly extracted in the amorphous oxide phase, which is a more stable secondary lead-bearing fraction. Copper is largely extracted in the residual and amorphous oxide fractions with minor amounts of acid-soluble phases present (Figure 3-12). In the samples with the acidic soil pH, copper is also extracted in the neutral salt exchangeable fraction and no acid-soluble phase is detected. This indicates that copper can become highly mobile if the WRD material becomes acidic and suggest at least a portion of the total copper is readily mobile in the samples that already have a low soil pH. Arsenic is largely associated with primary minerals (residual phase) or oxide minerals (predominantly crystalline oxides, but to a lesser extent amorphous oxides). Since arsenic forms oxyanions that can be negatively charged and absorb to mineral surfaces (e.g., oxides) at neutral to alkaline soil pH, the high pH pyrophosphate extraction step is likely targeting arsenic oxyanions and causing desorption by generating negative charged surfaces on the secondary oxides. Under acidifying conditions, these oxyanions would become more tightly bound to the more positively charged surface of the secondary oxide mineral.

#### Intermediate Dump

Investigations in the Intermediate Dump included a single boring, CH12-014-MW007, drilled to install monitoring wells and gas/temperature ports for long-term monitoring of the WRD and support the site-wide geochemical modeling effort. In addition, five test pits were excavated around the top of the Intermediate Dump to help delineate the upper portion of the sulphide cell and evaluate the upper portion of the WRD material. Two additional test pits, CH14-106-TP016 and CH14-106-TP017, were also excavated along the outer edge of Intermediate Dump to support the WRD regrading and resloping design efforts.

CH12-014-MW007 was drilled on the Haul Road below the upper bench of the main portion of the Intermediate Dump and within a pre-mining drainage pattern that drained from the center of the Intermediate Dump towards the S-Wells area. The CH12-014-MW007 monitoring well and temperature/gas ports were installed in this location in an attempt to collect data from the Intermediate Dump in a location upgradient of the S-Wells. The boring drilled through approximately 47 m of WRD material, approximately 7.5 m of native soil (alluvium), a little less than 3 m of weathered bedrock, and 7 m of bedrock material, for a total depth of 212 m. Two samples of the underlying alluvium and one sample of the weathered bedrock were submitted for geochemical analysis to evaluate the impacts of the WRDs on the underlying native geologic material.

Total metals analyses were performed on WRD samples collected from CH12-014-MW007 (Table 3-1). In general, the total iron concentrations are fairly consistent within the WRD material ranging from 52,600 mg/kg near the surface to a high of 75,400 mg/kg at the bottom of the WRD material (Figure 3‑13). The WRD material is slightly depleted in total sulphur near the surface (less than 2 m), but steadily increases down to approximately 16 mbgs. Below 16 mbgs, the total sulphur fluctuates likely reflecting the variability in sulphide content of the WRD material. At the bottom of the WRD material, there is a spike in total sulphur content implying a sharp increase in sulphide content of the WRD (Figure 3-13).

Similar to total sulphur and iron, the total trace element concentrations are slightly depleted near the surface, but increase below 2 m and maintain a fairly consistent concentration down to approximately 28 mbgs (Figure 3-14). Copper, lead, and zinc increase steadily between 28 and 44.5 mbgs before the concentrations drop sharply in the underlying alluvium and weathered bedrock. In contrast, arsenic tends to maintain a fairly constant concentration with depth. In all samples, measured arsenic is above the 10 times crustal abundance screening criteria, but only exceeds both criteria in a few samples (Table 3-1). There are no arsenic exceedances in the underlying native material. Despite the steady increase in copper concentration, there are no screening criteria exceedances for copper in the CH12-014-MW007 boring. Every WRD sample has lead greater than both screening criteria with the exception of a few samples where only the 10 times crustal abundance criteria is exceeded. The underlying alluvium also has elevated lead above 10 times crustal abundance, whereas the weathered bedrock does not (Table 3-1). There are two depth intervals where zinc exceeds both screening criteria (10 to 14 mbgs and at the bottom of the boring, 40 to 44.5 mbgs), but at most other depths, the zinc concentration is relatively low. Interestingly, the total zinc concentration in the underlying alluvium exceeds both screening criteria, suggesting that the underlying alluvium is impacted by the overlying WRD material.

The WRD material in CH12-014-MW007 is near-neutral (pH 6.5 to 7.5) down to a depth of approximately 37 mbgs. Below this depth, the paste pH of WRD material is slightly acidic (i.e., below pH 6.5) becoming mildly acidic (i.e., below pH 6.0) near the bottom of the WRD (44.5 mbgs). The underlying alluvium is also mildly acidic (pH 5.6) immediately below the WRD, but is only slightly acidic near the bottom of the alluvium and in the weathered bedrock. The alluvium and weathered bedrock have fairly low buffering capacity (i.e., NP 40 to 60 kg CaCO3 eq/tonne) and as such, the slightly to mildly acidic pH is likely because of impacts from the overlying WRD material. In fact, at the very bottom of the WRD (44.5 mbgs), the highest AP and the lowest NP in the boring is encountered. This sample, CH12-014-MW007-SOi, is the only sample from the boring that was definitively net acidic (NP:AP = 0.3). There are two more samples, CH12-014-MW007-SOb and CH12-014-MW007-SOp, at depths of 10.4 mbgs and 15.8 mbgs, respectively, where the NP:AP ratio is less than 3.0 (indicating material at these depths may be net acidic). The rest of the WRD and the underlying native material from the boring is net neutral and not expected to generate acidity over time. As such, with the exception of a few mineralized zones, the WRD material at CH12-014-MW007 is not expected to contribute to acid generation from the Intermediate Dump.

Random samples based on observations made during drilling the CH12-014-MW007 boring were submitted for DI-leach analysis (Table 3-3). Unfortunately, the most sulphur-rich samples (CH12-014-MW007-SOi) were not submitted. In general, the DI leaching generated a near neutral final leachate with low trace element content, indicating that, of the samples submitted, the trace elements were relatively stable and not immediately mobile from the WRD material. Two samples from boring CH12-014-MW007 were submitted for sequential extraction analysis: CH12-014-MW007-SOi, from the mineralized zone at the very bottom of the WRD, and CH12-014-MW007-SOj, from the very top of the underlying alluvium (Figure 3-15). These samples were selected to characterize the mobility and mineralogic association of trace metals across the contact of the WRD with the underlying native soil. Despite the significant different in total elemental content between the two samples, in general, the sequential extraction results are very similar between the two distinctly different sample types. This might be because of some of the WRD material washing down into the alluvium when it was initially deposited. In other words, the elemental content of the underlying alluvium may be caused, in large part, by contamination by WRD material, though there are some slight differences. In both samples, iron is predominantly extracted in the residual fraction and is likely present in sulphide and recalcitrant silicate minerals (Figure 3-15). At the bottom of the WRD, about 10 percent of the iron is extracted in the amorphous oxide phase while the remaining 5 percent is extracted as crystalline oxide. In contrast, the underlying alluvium has approximately 15 percent of the iron present as crystalline oxide and a little less than 5 percent as amorphous iron. A little more than 70 percent of the total manganese is extracted in the residual phase in both material types, with a little more than 10 percent as amorphous oxide in the WRD and a little less than 5 percent as amorphous oxide in the underlying alluvium. Both materials have about 10 percent of the manganese extracted in the highly mobile neutral salt exchangeable fraction with a small amount of manganese also occurring in an acid-soluble phase within the alluvium. In general, manganese in the underlying alluvium appears to be slightly more mobile than in the overlying WRD material. Greater than 95 percent of the total zinc in the WRD material is extracted in the residual fraction (i.e., sulphide phase), whereas only 65 percent of the total zinc in the alluvium is residual (Figure 3-15). In fact, the alluvium has about 5 percent neutral salt exchangeable zinc and a little more than 15 percent acid-soluble zinc. The neutral salt exchangeable zinc is likely present in secondary sulfate salts that have formed in the alluvium and are highly mobile under saturated (i.e., freshet) conditions. The acid-soluble zinc may be zinc adsorbed to oxide mineral surfaces that would be mobilized under acidic conditions. The remaining zinc in the alluvium is associated with amorphous and crystalline oxides (likely iron or manganese). Lead is predominantly extracted in the residual fraction (i.e., sulphide) in both material types, but the balance of each extraction sequence is largely in more potentially mobile fractions. Both samples have significant acid-soluble lead and the WRD sample also has significant neutral salt exchangeable lead. The neutral salt exchangeable lead is likely associated with secondary sulfate salts that form within the WRD material, while the acid-soluble phase is likely a secondary lead mineral that is susceptible to dissolution under mildly acidic conditions. Copper is almost solely (greater than 95 percent) extracted in the residual phase (i.e., primary sulphide minerals) in the WRD sample and predominantly (greater than 85 percent) in the residual fraction in the sample of the alluvium. The bulk of the extraction balance for copper occurs in the amorphous oxide fraction of both samples. Arsenic is largely extracted in the residual fraction (85 to 90 percent) in both samples with most of the remaining total arsenic recovered in the amorphous oxide fraction, though some arsenic is recovered in the crystalline oxide step of the alluvium sequential extraction sequence (Figure 3-15). In general, the sequential extractions suggest that the trace elements content of both of these samples is fairly stable and resistant to mobilization under current conditions as most of the trace elements were recovered in the residual step.

A total of seven test pits were excavated within the Intermediate Dump. Five test pits were dug to help delineate the upper portion of the sulphide cell and evaluate the upper portion of the WRD material. Material from these five test pits was collected from either the top (SOa), middle (SOb), or bottom (SOc) of the test pit with several depth samples from each test pit submitted for geochemical analysis. Alternatively, the two test pits, CH14-106-TP016 and TP017, which were dug along the outer edge of Intermediate Dump to support the WRD regrading and resloping design efforts, only had composite samples covering all three depth intervals submitted for analysis. Compared to CH12-014-MW007, the test pits tended to have much higher total elemental concentrations, especially the test pits excavated to delineate the sulphide cell (Table 3-1). Every sample submitted for total elemental analysis exceeded both screening criteria for the FMC except for samples CH14-106-TP007-SOc, CH14-106-TP009-SOa and SOc, and CH14-106-TP012-SOa, which only exceeded the 10 times crustal abundance criteria. Cadmium exceeded at least the 10 times crustal abundance screening criteria in every samples except CH14-106-TP010-SOa and both criteria in half of the samples submitted. Copper exceeded at least the 12 times median world soil content screening criteria in 7 out of 12 samples and exceeded both criteria in 3 out of those 7 samples. With the exception of test pit CH14-106-TP012, copper was always more concentrated in the near surface (SOa) sample. Every samples submitted for total lead exceeds both screening criteria with the exception of CH14-106-TP010-SOc, which only exceeds the 10 times crustal abundance criteria and CH14-106-TP009-SOc which was lower than both screening criteria. Likewise, every sample submitted for total zinc analysis exceeds both screening criteria with the exception of CH14-106-TP012-SOa, which only exceeds the 10 times crustal abundance criteria, and CH14-106-TP009-SOc, which was lower than both screening criteria. In general, location CH14-106-TP009 has the lowest total elemental concentrations in the central Intermediate, while locations CH14-106-TP007 and CH14-106-TP010 have some of the highest total elemental concentrations (Table 3-1).

Similar to the test pits excavated within the interior of the Intermediate Dump, the two test pits (CH14-106-TP016 and TP-017) excavated along the outer margin had very high total elemental concentrations. In all three composite samples from the two locations, arsenic, cadmium, lead, and zinc concentrations exceeded both screening criteria. Copper exceeded the 12 times median world soil content screening criteria in CH14-106-TP017-SOCOMPA and CH14-106-TP017-SOCOMPB, but was not significantly elevated in CH14-106-TP0016-SOCOMP. While both locations had elevated total elemental concentrations that generally exceeded the FMC screening criteria, CH14-106-TP017 had significantly greater total elemental concentrations

Similar to the Main Dump, ABA characteristics of samples collected from the Intermediate Dump represent a wide range of waste rock lithologies, including massive sulphides, phyllite, calc-silicate, and igneous rock types. However, samples collected from the Intermediate Dump generally contained greater abundance of sulphide minerals and therefore had increased potential to generate acid. In samples where massive sulphides were noted on the log, paste pH values were acidic and very little, if any, NP was measured (Table 3-2). In fact, with the exception of test pit location CH14-106-TP009 and samples CH14-106-TP007-SOc, CH14-106-TP012-SOa, and CH14-106-TP016-SOCOMP, all samples had a moderately to highly acidic paste pH and every samples with an acidic paste pH, with the exception of CH14-106-TP010-SOc and CH14-106-TP011-SOc, had an NP:AP ratio less than 1.0. CH14-106-TP011-SOc had a paste pH of 4.5 and an NP:AP ratio of 1.8, while CH14-106-TP010-SOc had a paste pH of 3.8, but a very high NP (1,030 kg CaCO3 eq/tonne), resulting in an NP:AP of 19.1 (Table 3-2). In samples, where an absence of massive sulphide waste rock was noted on the lithologic logs (i.e., CH14-106-TP009-SOa and SOc, CH14-106-TP007-SOc, CH14-106-TP012-SOa, and CH14-106-TP016-SOCOMP), the paste pH was near-neutral and the NP:AP ratio was greater than at least 7.0 (Table 3-2). Overall, the Intermediate Dump contains material that has greater potential for acid generation and metal mobilization than materials contained within the MDE or MDW.

DI-leach testing conducted on near-surface samples collected from test pits excavated into the upper 5 m of the Intermediate Dump surface were used to characterize the mobility of constituents at different locations within the Intermediate Dump. The final leachate of samples from CH14-106-TP007, CH14-106-TP010, CH14-106-TP011, CH14-106-TP012, and CH14-106-TP017 was mildly to highly acidic and contained substantial levels of arsenic, cadmium, copper, iron, lead, and zinc (Table 3-3). Mobility of trace metals in these samples may be because of the acidic conditions generated by the increased abundance of sulphide minerals contained within the Intermediate Dump. While some of the increased sulphide materials can be linked to the Intermediate Dump Sulphide Cell, the presence of acid and metals leaching in nearly all of the surface samples indicates a more widespread concern for metal mobility in the Intermediate Dump.

Select samples from test pits CH14-106-TP007, CH14-106-TP009, CH14-106-TP010, CH14-106-TP011, CH14-106-TP012, and CH14-106-TP017 were subjected to a sequential extraction procedure to characterize the mobility and mineralogic association of trace metals within the solid material contained within the Intermediate Dump (Table 3-4 and 3-5). Iron is predominantly extracted in the residual fraction (30 to 85 percent of the total) and is most likely present as primary iron-bearing sulphides and silicates (Figure 3-16). The remainder of the iron is largely extracted in the crystalline oxide step with lesser amounts of amorphous oxide also present. The phase of iron in these samples does not appear to be affected by the soil pH of the sample. In contrast both manganese and zinc phases are highly impacted by the soil pH. In all of the samples, approximately 25 to 50 percent of the total manganese is extracted in the residual step. In the near-neutral samples, a significant portion of the remaining manganese is extracted in the acid-soluble fraction with the remaining occurring in either the crystalline or amorphous oxide phase. In contrast, the samples with an acid paste pH, exhibit a significant reduction in the acid-soluble phase coupled to a significant increase neutral salt exchangeable manganese, suggesting a large portion of the total manganese in these samples is likely present in secondary salt that are susceptible to mobilization. Similar to manganese, the distribution of zinc in the extraction fractions is dependent upon the paste pH of the sample. For most samples, residual zinc is the dominant fraction. However, for near neutral or mildly acidic samples, the remaining zinc is extracted in acid-soluble and amorphous and crystalline oxide fractions. In contrast, the remaining zinc in samples with an acidic paste pH occurs in the highly soluble neutral salt exchangeable fraction with a significant to complete diminish in the acid-soluble phase (Figure 3-16). One exception is in sample CH14-106-TP010-SOc, which has a paste pH of 3.8, but zinc is still dominantly extracted in the acid-soluble phase with a lower percentage in the neutral salt exchangeable fraction. This may be because of the fact that CH14-106-TP010-SOc has a very high NP that acts to buffer the dissolution of the acid-soluble zinc phase and formation of the neutral salt exchangeable secondary salt phase. Lead does not appear to be significantly impacted by the paste pH of the sample with most of the extracted lead occurring in either the residual or acid-soluble fraction. Similarly, copper is not distinctly impacted by the paste pH of the sample. The majority of the total copper is extracted in the residual fraction. In samples with an acidic paste pH, copper is extracted in the neutral salt exchangeable fraction and in most samples, there is no copper in the acid-soluble fraction. In contrast, acid-soluble copper is more significant in samples with a near neutral paste pH. Arsenic is extracted in one of three of the sequential extraction steps in almost all samples with little discernible impact to paste pH of the sample. The majority of the arsenic is recovered in the residual fraction which likely represents arsenic associated with primary sulphides (Figure 3-16). The remaining arsenic was recovered in either the crystalline oxide or the alkaline pyrophosphate step. The arsenic liberated during the alkaline pyrophosphate likely occurs as arsenic oxyanions that have a negative charge and are bound to positive (typically oxide) surfaces. The increased pH of the extraction step, changes the surface charge of oxyhydroxides to more negative, which, in turn, causes surface bound arsenic to be released to the extractant. As such, most of the arsenic in these samples is either present in primary sulfides, or coprecipitated in or adsorbed to secondary oxides.

#### S-Wells Area

Total metals analyseswere performed on selected samples from the S-Wells investigations, which includes three boreholes (CH14-107-MW007B, CH14-107-MW008B, and CH14-107-MW010). Overall there were very few samples with reported concentrations exceeding the standards for metals (Table 3‑1). One sample from CH14-107-MW010 exceeded both standards for arsenic, with a concentration of 153 mg/kg; this was the only arsenic exceedance. Two samples from the same location, CH14-107-MW010, exceeded one or both of the zinc standards. These samples had concentrations of 915 and 1,220 mg/kg. A few exceedances were noted for selenium and silver, and the remaining samples fell under the metal standards.

Results from ABA testing on S-Wells material were characterized as acidic paste pH; however NP:AP ratios for all samples were greater than 3.0, indicative of net-neutralizing material (Table 3‑2).

DI-leach samples were collected from the S-Wells area and were used to characterize the mobility of constituents near the land surface and at depth. Sample results from boreholes CH14-107-MW008B and CH14-107-MW010 had acidic leachate near the surface that had greater potential to mobilize arsenic, iron, lead, and zinc (Table 3-3). At depth, leachate from these locations was neutral, with potential mobility of zinc.

Sequential extraction tests were completed on samples collected from borehole CH14-107-MW010 to characterize the mobility and mineralogic association of trace metals within the solid material contained within the S-Wells area (Table 3‑4 and 3-5). Iron is predominantly present in the S-Wells area as primary iron sulphide (i.e., pyrite) as well as crystalline iron oxide phases (Figure 3-15). Manganese is generally present in amorphous iron oxide, crystalline iron oxides, and primary mineral phases. Greater than 50 percent of the zinc present in the S-Wells material is contained within more readily dissolved salts, acid-soluble, and amorphous iron oxide phases. Lead is associated with amorphous iron oxide and primary mineral phases in samples collected in the S-Wells area downgradient of the intermediate dump. Copper is mainly found in either amorphous iron oxides or primary mineral phases. Arsenic in the borehole samples is associated with amorphous iron oxide phases, crystalline iron oxides, and primary sulphide minerals.

#### Northeast Waste Rock Dump

Total metals analyses were performed on selected samples collected from the Northeast WRD investigations, which include one borehole (CH14-015-MW006) and eight test pits (CH14-106-TP018 through to CH14-106-TP026). In general, the samples analyzed fell under the two standards for metals, excluding arsenic and lead (Table 3-1). Arsenic concentrations exceeded one or both of the standards in samples from two of the three locations (CH14-015-MW006 and CH14-106-TP019). The highest concentration of arsenic reported was 183 mg/kg in a sample collected from CH14-015-MW006, which exceeds both of the standards for arsenic. Samples from all three locations exceeded one or both of the standards for lead, with the highest concentration reported also in a sample from CH14-015-MW006, at 1560 mg/kg. Elemental concentrations with depth in CH14-015-MW006 show no distinct trend; however, total sulfur concentrations are very constant with depth (Figure 3-17, 3-18).

ABA samples were collected during the borehole drilling and test pit excavation in the Northeast Lower WRD. Samples of waste rock were collected from various lithologies, including calc-silicate, phyllite, schist, and granite. Although paste pH was acidic in some samples, the NP:AP in all samples was greater than 3.0, indicating net-neutralizing properties (Table 3-2). One sample collected from CH14-015-MW006 (27 mbgs) contained secondary sulphur salts formed on rock fracture surfaces. However, the presence of calc-silicate rock provides a buffer to any acid generated from these secondary salt deposits.

DI-leachate samples collected from the surface and deeper materials of the Northeast WRD were used to characterize the mobility of constituents within the WRD. One test pit excavated into the upper 5 m of the Northeast Upper WRD surface (CH14-106-TP019) show potential for acidic leachate, with increased mobility of trace metals copper, lead, and zinc (Table 3-3). In contrast, samples collected from borehole CH14-015-MW006, located in the Northeast Lower WRD were characterized by neutral to alkaline leachate with trace metals generally immobile. One exception is the presence of arsenic at depth, approximately 27 mbgs (Table 3-3). Secondary sulfur salts were noted in the borehole log and likely are the source of the readily dissolved arsenic. Test pits excavated within the access road to the base of the NE WRDs were characterized by near-neutral leachate containing slightly elevated concentrations of copper, iron, lead, and zinc (CH15-107-MW030, CH15-107-MW032, CH15-107-MW034, CH14-106-TP020, CH14-106-TP025, and CH14-106-TP026) near the surface, and at depth.

Sequential extraction tests were completed on samples collected from borehole CH14-015-MW006 and test pit CH14-106-TP019 to characterize the mobility and mineralogic association of trace metals within the solid material contained within the Northeast WRD (Tables 3-4 and 3-5). Iron is generally present in the Northeast WRD as one of three dominant phases (Figure 3-19): amorphous iron oxide, crystalline iron oxides (e.g., Schwertmannite), or as primary pyrite (residual). Manganese in borehole and test pit samples generally is present in the acid-soluble phase, possibly associated with carbonate minerals, crystalline iron oxides, and primary manganese mineral phases. Zinc mobility generally follows iron in these samples, with additional presence of readily soluble neutral salt exchangeable and acid-soluble phases. As noted in the ABA data and borehole logs, secondary sulfosalts were observed in CH14-015-MW006, which may be the readily soluble source of zinc. Acid-soluble lead and primary lead sulphide (i.e., galena) are the main phases of lead in northeast WRD samples. Three copper phases are dominant in the Northeast WRD samples: acid-soluble copper, copper associated with amorphous iron oxide, and copper associated with primary sulphide minerals. In the Northeast WRD, arsenic is generally associated with amorphous oxide phases, crystalline iron oxides, and primary mineral phases. In CH14-015-MW006, the relative percentage of arsenic tied to amorphous oxide phases increases with depth. Readily mobile zinc and lead in the form of secondary sulfate salts and acid-soluble phases could potentially contribute to increased metal loading to drainage areas during reclamation activities and contact with water.

#### Zone II Pit and Outwash Area

Total metals analyses were performed on selected samples from the Zone II Pit and Outwash Area investigations (Table 3‑1). Overall, very few exceedances were reported for samples collected from CH14-107-MW001 to CH14-107-MW004, and the remaining 13 locations contained a significant amount of exceedances. CH12-014-MW005, was drilled in the Zone II WRD, contained the most exceedances. Elemental concentrations in CH12-014-MW005 had two spikes with depth; concentrations spiked around 10.5 and 37.5 mbgs (Figure 3-20, 3-21). The deeper of the two spikes is especially noticeable in total iron and sulfur concentrations with depth.

Samples collected from 11 different locations contained exceedances for arsenic, including almost all of the samples analyzed from CH12-014-MW005, located on the Zone II WRD. The highest concentration of arsenic was 2,370 mg/kg, which came from a sample collected during the drilling of CH12-014-MW005 and exceeds both of the standards for arsenic. The highest concentration of arsenic recorded from the Zone II Outwash was 77.8 mg/kg in a sample from CH14-107-MW005B, which is significantly less than the Zone II Pit. However, the concentration still exceeds both of the standards.

Cadmium concentrations exceeded the standards in samples from four different investigation locations. The highest cadmium concentration reported was 35.4 mg/kg, in a sample collected from CH14-107-TP001 in the Zone II Outwash.

Only two different locations contained samples that exceeded the copper standards: CH12-014-MW005 and CH14-107-TP001. The highest concentration came from CH12-014-MW005, with a sample reaching a concentration of 1,270 mg/kg copper, more than double the higher of the two standards.

Samples from ten locations contained concentrations of lead exceeding one or both of the standards. The highest concentration of lead recorded was 6,430 mg/kg, also in a sample collected from CH12-014-MW005 in the Zone II WRD. The higher of the two standards for lead is the Median Soil Content, with a value of 420 mg/kg. The average concentration in samples collected from CH12-014-MW005 exceeded that, at 1,305 mg/kg. In the Zone II outwash, the highest concentration of lead was 4,990 mg/kg, reported for a sample collected from CH14-107-MW005B.

Sulphur concentrations were quite high in CH12-014-MW005 with an average of 23,758 mg/kg, almost three times the higher of the two standards. The remaining locations in the area generally fell under the standards.

Seven locations contained samples that exceeded the standards for zinc. The highest recorded concentration of zinc once again came from CH12-014-MW005, with the concentration in one sample as high as 12,200 mg/kg.

ABA characteristics of materials collected near the land surface in the Zone II Outwash area included acidic paste pH and NP:AP ratios of less than 3.0 (Table 3-2). At depth, paste pH was neutral in most samples with NP:AP ratios of greater than 3. In the Zone II WRD (location CH12-104-MW005) the NP:AP ratios were generally greater than 3, indicating net-neutralizing material.

DI-leach samples collected from the surface and deeper materials of the Zone II Pit were used to characterize the mobility of constituents in the Zone II East (ZIIE) WRD. One test pit excavated into the upper 5 m of the ZIIE WRD surface (CH14-107-TP001) show potential for neutral to alkaline leachate, with increased mobility of lead and zinc in the upper 3 m of the WRD (Table 3-3). Samples collected from borehole CH12-014-MW005, located near the Zone II Pit, were generally characterized by neutral leachate with limited metal mobility (Table 3-3). However, discrete intervals at approximately 10 mbgs and from 35 to 40 mbgs were characterized by acidic leachate and the presence of mobile trace metals arsenic, cadmium, iron, lead, and zinc.

In the Zone II Outwash area, DI-leach results show increased potential for mobility of copper, lead, and zinc (Table 3-3) in shallow test pits excavated (CH14-107-TP002, CH14-107-TP003, and CH14-107-TP004). Samples collected from boreholes showed increased mobility of zinc in nearly all sample depths, likely associated with secondary salt formation. Local variations in material types were observed in the leachate results, with potentially increased mobility in arsenic (CH14-107-MW002 and deeper samples in CH14-107-MW003), copper (CH14-107-MW002), and lead (CH14-107-MW002, CH14-107-MW005B, and CH14-107-MW006B).

Sequential extraction tests were completed on samples collected from borehole CH12-014-MW005 and test pit CH14-107-TP001 to characterize the mobility and mineralogic association of trace metals within the solid material contained within the Zone II Pit area (Table 3-4 and 3-5). Iron is generally present in the Zone II Pit area as one of three dominant phases (Figure 3-22): amorphous iron oxide, crystalline iron oxides (e.g., Schwertmannite), or as primary pyrite (residual). Manganese and zinc in Zone II Pit area borehole and test pit samples generally is present in readily soluble salts, acid-soluble phases, crystalline iron oxides, and primary manganese mineral phases. Secondary salts containing lead, acid-soluble phases, and primary lead sulphide (i.e., galena) are the main phases of lead in zone II pit area. Copper and arsenic are predominantly present in primary sulphide minerals, and to a lesser extent, amorphous iron oxides. In addition to these two phases, arsenic also has a minor presence in crystalline iron oxides.

Sequential extractions were completed on selected samples collected from boreholes (CH14-107-MW003, CH14-107-MW004, CH14-107-MW005B, and CH14-107-MW006B) and test pits (CH14-107-TP002, CH14-107-TP003, and CH14-107-TP004) to characterize the mobility of iron, manganese, zinc, lead, copper, and arsenic in the Zone II Outwash area (Table 3-4 and 3-5; Figure 3-23, 3-24). Shallow borehole and test pit sample data show the partitioning of iron into two main phases: crystalline iron oxides and primary pyrite. At depth, iron is also present in the amorphous phase, as exhibited in CH14-107-MW004 (SOi sample). Manganese in the Zone II Outwash samples generally occurs in the primary mineral, crystalline iron oxide, and amorphous iron phases, with a minor fraction of the manganese contained in secondary salts and acid-soluble phases. The presence of zinc in shallow borehole and test pit samples is widely distributed across the following phases: neutral exchangeable salts, acid-soluble, amorphous iron, crystalline iron oxide, and primary minerals. Zinc at depth, in sample CH14-107-MW004 (SOi sample), is less associated with primary mineral phases and more abundant in amorphous iron oxide phases. Secondary salts containing lead, acid-soluble, amorphous iron oxides, and primary lead sulphide minerals are the main phases of lead in the Zone II Outwash area. Copper is mainly present in primary mineral phases in the Zone II Outwash material; however, there is a minor readily mobile copper in secondary salts and acid-soluble phases. In shallow borehole and test pit samples, arsenic is generally associated with crystalline iron oxides and primary mineral phases. In deeper samples, arsenic can be mobilized from water interacting with secondary salts, acid-soluble phases, and amorphous iron phases.

### Seepage Data

There are 70 seeps that are associated with the WRD RU. Seeps are sampled twice a year, once during the spring, close to freshet, and once during the fall. The analytical data, field parameter results, and a summary of some key parameters can be found in *Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring* (CH2M, April 2016d).

Historical seepage data trends were also analyzed using the Mann-Kendall trend test, which statistically determines whether a data set consistently increases or decreases over time. The test requires at least five data points above the detection limit to produce an accurate result. Statistical analyses were conducted for six key parameters: pH, total alkalinity, sulphate, dissolved magnesium, dissolved iron, and dissolved zinc. These parameters have been identified as geochemically important during previous investigations. The level of significance tested is 95 percent, and any non-detectable concentrations were reduced to half of the detection limit. Table 3‑6 presents the results from the Mann-Kendall analyses. Figures 3-25 through 3-28 provides time-trend graphs of all the seep data to complement the Mann-Kendall analysis.

#### Northwest Waste Rock Dump

There are five seep locations associated with the Northwest WRD. Out of these five locations, significant trends were only observed in two seeps. SRK-FD18 exhibited a decreasing trend in dissolved zinc and no trend in the other parameters analyzed. SRK-FD19 has a significant increasing trend in dissolved iron, dissolved magnesium, dissolved zinc, and sulphate, while the field pH exhibited a significant decreasing trend.

#### Stockpiles

The stockpile areas include the OXSP, the LGSPC, and the Medium Grade Stockpile (MGSP). There are six seeps total associated with these locations, two at each stockpile.

Out of the parameters at each location that could be tested, none at the MGSP or OXSP showed any significant statistical trends. At the LGSPC, SRK-FD38 shows significant increasing trends for dissolved iron, sulphate and dissolved zinc. The remaining parameters showed no significant trends. Two of the LGSPC seeps (CH-FD-66 and SRK-FD38) and one of the MGSP seeps (SRK-FD37) were also plotted on time-series plots to help confirm the Mann-Kendall results (Figure 3-26). Along with confirming the Mann-Kendall results for SRK-FD38, Figure 3-26 also shows increasing trends of sulphate, dissolved iron, dissolved magnesium, and dissolved zinc concentrations at SRK-FD37.

#### Main Dump

Eight locations are associated with seepage from the Main Dump.

Mann-Kendall statistical analyses were performed on data collected from the Main Dump area seeps. Because of minimum data requirements, analysis could only be performed on seven of the eight locations for field pH, and only on five of the seven for the remaining key parameters. Only three of these five seeps exhibited any significant trends. SRK-FD12, SRK-FD31, and X23 all exhibited decreasing trends in total alkalinity and field pH and increasing trends in dissolved iron, dissolved magnesium, and dissolved zinc. SRK-FD12 and SRK-FD31 also exhibited an increasing trend in sulphate; there was no sulphate trend evident in the Mann-Kendall analysis for X23. The same six key parameters were plotted over time for four of the seeps in the Main Dump area, SRK-FD09, SRK-FD30, SRK-FD31, and X23 (Figure 3-26). These time-series plots also show decreasing total alkalinity trends at SRK-FD31 and X23, and increasing dissolved magnesium, zinc, and iron concentrations at the same two locations. Sulphate concentrations at SRK-FD31 are also increasing over time.

#### Intermediate Dump

There are 12 locations associated with seepage from the Intermediate Dump. Because of the minimum data requirements for Mann-Kendall analysis, nine of the locations around the Intermediate Dump did not have enough data points for any of the parameters to be tested. Three of those nine locations (SRK-FD49, SRK-FD52, and SRK-FD55) had enough data for field pH to be tested, but no significant trend was found at any of the three locations. Three locations (CH-FD56, SRK-FD13, and SRK-FD54) had enough data points for trend analysis to be completed; no trends were observed at CH-FD56. At SRK-FD13, dissolved iron and sulphate have increasing trends over time, while the remaining parameters showed no significant trends. SRK-FD54 has decreasing trends for total alkalinity and field pH, and an increasing trend for dissolved iron. There were no significant trends for the other parameters at SRK-FD54. Data from the same six key parameters for SRK-FD13 and SRK-FD54 was plotted on time-series charts (Figure 3-27). These charts confirm the Mann-Kendall results, and also suggest that sulphate, dissolved magnesium, and dissolved zinc also have increasing concentrations over time.

#### Northeast Waste Rock Dump

The Northeast WRD has 23 seepage locations. Seven of the Northeast WRD seepage locations did not have enough geochemical data to calculate any of the statistical trends. An additional eight locations only had enough field pH data to calculate statistical trends. Of the eight locations analyzed for trends in field pH, only two locations, CH-FD-62 and CH-FD-68, exhibited trends; CH-FD-62 had a decreasing trend in pH, while CH-FD-68 had an increasing trend in pH.

Of the remaining eight locations, only five locations exhibited significant trends. NE1 had decreasing field pH and dissolved zinc with no other significant trends, while NE2 exhibited an increasing trend in dissolved magnesium and dissolved zinc with no other significant trends. At SRK-FD05, dissolved magnesium, dissolved zinc, and sulphate increased over time with no other trends observed. At SRK-FD24, total alkalinity and field pH trended down over time, while dissolved iron, dissolved magnesium, dissolved zinc, and sulphate all increased over time. At SRK-FD26, dissolved magnesium and sulphate decreased over time with no other trends observed at that location. The same six key parameters were plotted with time for four of the Northeast WRD seeps to assist with analyzing trends (Figure 3-28). The only evident visual trend from these charts is increasing concentrations of dissolved iron at SRK-FD24.

#### Other Locations

Other locations contained in the WRD RU are the Zone II WRD, Ramp Zone WRD, Parking Lot WRD, and one location associated with the FCD (eight seep locations altogether).

None of the three Zone II WRD seep locations (SRK-FD07, SRK-FD50, and CH-FD-74) had enough data points to do a statistical analysis. The FCD location (SRK-FD20) only had enough results for field pH to calculate the trend, and no significant trend was found. Out of the three Parking Lot WRD seep locations, CH-FD-65 only had enough results for field pH to evaluate the trends and no significant trend was found; while SRK-FD01 had no significant trend for total alkalinity and dissolved iron, increasing trends for dissolved magnesium, dissolved zinc, and sulphate, and decreasing trend of field pH; SRK-FD02 did not have enough data to perform the trend analysis. The time-series trend plots (Figure 3-25) also visually confirms the Mann-Kendall trends for SRK-FD01. For the Ramp Zone WRD location, SRK-FD14, there was not enough data to perform trend analysis on dissolved iron, but dissolved magnesium was found to exhibit an increasing trend, while there was no significant trend found in any of the remaining analytes evaluated.

### Groundwater Data

There are 6 groundwater monitoring wells associated with the WRD RU. Monitoring wells are sampled and monitored three times a year: once during the winter or spring, once in the summer, and once during the fall. The analytical data and field parameter results can be found in Tables 3-7 to 3-9, and a summary of some key parameters can be found in *Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring* (CH2M, April 2016d) and *Summary of 2016 Field Investigation – Site-wide Geochemical Monitoring* (CH2M, August 2016j). All groundwater analytical data was compared to groundwater quality guidelines established in the Canadian Environmental Quality Guidelines (CCME, 2016).

Historical groundwater data trends were also analyzed using the Mann-Kendall trend test (Table 3‑11). Statistical analyses were conducted for six key parameters: pH, total alkalinity, sulphate, dissolved magnesium, dissolved iron, and dissolved zinc. These parameters have been identified as geochemically important during previous investigations. The level of significance tested is 95 percent, and any non-detectable concentrations were reduced to half of the detection limit.

#### Main Dump

CH12-014-MW003 showed a significant decreasing trend for sulphate and no significant trend for any other parameter analyzed.

#### Intermediate Dump

CH12-014-MW007 showed decreasing trend in magnesium and no significant trends in any other analyte evaluated.

#### Northeast Waste Rock Dump

CH14-015-MW006 exhibited a significant decreasing trend in dissolved zinc, but no other significant trends in the remaining parameters.

### Temperature and Pore Gas Data

There are 15 WRD monitoring locations across the FMC: 9 locations associated with the Faro WRDs and 6 locations associated with the Vangorda/Grum Waste Dumps. Monitoring was completed at these locations from 2003 to 2016 and a discussion of the general trends observed at the Faro WRD locations are presented herein. WRD profile graphs showing the relationships between depth, temperature, oxygen concentrations, and carbon dioxide concentrations (where available) are provided on Figures 3‑31 through 3-39. Discussions of the Vangorda/Grum locations are presented in Section 10.

##### 30M1

Temperature generally decreased with depth, starting from the shallowest measurement depth of 0.7  to 20 mbgs, and ranged from 0.7 degrees Celsius (°C) to 37°C. Temperatures were relatively constant with respect to depth from 20 to 30 mbgs, ranging from 33 to 38°C.

Oxygen concentration remained fairly consistent from 0.7 to 20 mbgs at approximately 17 percent, but decreased to almost 0 percent at 30 mbgs during some of the monitoring events.

##### 60M1

Temperature generally decreased from 0.7 to 20 mbgs and ranged from 1.4 to 48.8°C. Below 20 mbgs, the temperature steadily decreased to approximately 10°C at 60 mbgs. Oxygen concentration fluctuated throughout the depth of the measurements, but generally appeared to decrease from 15 percent near the surface to 5 percent at 20 mbgs, increasing back to 15 percent at 60 mbgs.

##### CH14-106-MW009

Temperature consistently decreased from near the surface to 36 mbgs and ranged from -1.27 to 19°C. Below 36 mbgs, the temperature appeared to decrease slightly to the maximum measurement depth of 41 mbgs.

The oxygen concentration varied throughout the depth of the measurements, but generally decreased to a depth of 50 mbgs and increased slightly below 50 mbgs. The oxygen concentration ranged from 0 to 20 percent.

##### CH14-104-MW008

The temperature varied from 0.91 mbgs (the shallowest measurement depth) to 10.91 mbgs and ranged from -0.45 to 8.66°C. The temperature below 10.91 mbgs was approximately 6.5°C. The oxygen concentration generally increased from 4 percent at 0.91 mbgs to 16 percent at 16.9 mbgs, decreased to 10 percent at 13.64 mbgs, then increased to 19 percent at the deepest measurement depth, at 22.78 mbgs.

##### CH14-015-MW006

Temperature varied the most in the top 10 mbgs, with the most variation observed at the surface. The temperature at the surface ranged from 0.28 to 13.31°C and reached a temperature of 4°C below 10 mbgs. Oxygen concentration increased from approximately 16.5 percent at 4.50 mbgs (the shallowest measurement depth) to 20.5 percent at 18.2 mbgs (the deepest measurement depth).

##### CH14-015-MW004

Temperature varied the most in the top 10 mbgs, with the most variation observed at the surface. The temperature at the surface ranged from -1.42 to 9.54°C. Below a depth of 10 mbgs, the temperature decreased gradually to approximately 5°C at 41 mbgs (the deepest measurement depth). Oxygen concentration decreased from approximately 15 percent at 1.448 mbgs (the shallowest measurement depth) to approximately 0 percent at 8.458 mbgs and increased to approximately 20 percent at 23.698 mbgs. The concentrations remained about the same below 23.698 mbgs to 30 mgs (the deepest measurement depth).

##### CH12-014-MW007

Temperature varied the most in the top 10 mbgs, but generally increased with depth and ranged from ‑4 to 20°C at 40 mbgs (the deepest measurement depth). Oxygen concentration generally decreased from 20 percent at 5 mbgs to 5 percent at 12.71 mbgs, increased to 20 percent at 30.21 mbgs, and then decreased to approximately 5 percent at 40 mbgs.

##### CH12-014-MW005

Temperature varied the most in the top 10 mbgs, with the most variation observed at the surface. The temperature at the surface ranged from -0.1 to 9.82°C. Below a depth of 10 mbgs, the temperature remained fairly constant at approximately 7°C to 25 mbgs (the deepest measurement depth). Oxygen concentration generally decreased from 20 percent at 8.956 mbgs to 15 percent at 13.956 mbgs, increased to 20 percent at 18.956 mbgs, and then decreased to approximately 5 percent at 23.956 mbgs (the deepest measurement depth for oxygen concentration).

##### CH12-014-MW003

Temperature varied the most in the top 10.27 mbgs, with the most variation observed at the surface. The temperature at the surface ranged from -2.91 to 9.33°C. Below a depth of 10.27 mbgs, the temperature decreased gradually to approximately 7°C at 15.27 mbgs and remained near this temperature to 25.27 mbgs (the deepest measurement depth). Oxygen concentrations generally increased from 10 percent at 5.27 mbgs to 15 percent at 10.27 mbgs, then decreased to 5 percent from 15.27 mbgs to 20.27 mbgs (the deepest measurement depth for oxygen).

### Summary and Recommendations

The WRD RU contains highly variable geochemical properties, which are dependent on the lithologies present in each WRD. Data collection and analysis included in the FMC characterization investigations was integral to the improvements made to the geochemical models that support the site-wide water quality model. The associations of geochemical properties with specific mineral assemblages used in the modelling effort were supported by the data presented in this document, with particular emphasis on WRD composition. The following sections provide a summary of key findings for each WRD area.

#### Northwest Waste Rock Dump

* Increased abundance of trace elements arsenic, copper, lead and zinc were determined in the high sulphide content material encountered at intermediate depths within the Northwest WRDs.
* In general, the Northwest WRD contains near-neutral, net-neutralizing material, with localized mid-depth zones of acidic and potentially acid-generating material. The acidic zones coincide with oxidized sulphide material and the formation of secondary sulphate salts, as noted in borehole logs.
* The final leachate from surface materials in the Northwest WRD was near-neutral and did not contain significant trace element concentrations, indicating trace elements are not likely to be mobilized during short-term disturbance of the WRD surface. At intermediate and deeper depths within the Northwest WRD, the final leachate tended to be acidic (low pH) and contained elevated concentrations of the trace metals cadmium, copper, iron, lead, and zinc, which is consistent with the borehole log identification of increased oxidative weathering and the presence of highly soluble secondary sulphate salts.
* Although much of the potential contaminant load in the Northwest WRD is tied to primary sulphide mineral phases, the presence of zinc and lead in neutral salt exchangeable and acid-soluble phases suggest increased mobility of these constituents when in contact with water or during storm events.
* Analysis of seepage water quality identified localised trends of increasing magnesium concentration (SRK-FD19) and decreasing pH (SRK-FD16) were noted in the Northwest WRD, which drain toward Upper Guardhouse Creek and the Upper Parking Lot WRD.
* Monitoring results from CH14-015-MW004, installed in the Northwest WRD, indicate pyrite oxidation is moderately active. Temperatures ranged up to 10°C at 10-m depth. No long-term changes in temperatures were observed. Oxygen concentrations are strongly depleted at 8-m depth and range to near-atmospheric at 0.5- and 25- to 30-m depths. The temperature and oxygen suggest oxygen transfer is driven primarily by vertical convective air flow.

#### Stockpiles

* The upper, weathered portion of the OXSP and LGSPC contained greater content of antimony, arsenic, cadmium, copper, lead, mercury, selenium, silver, sulphur, and zinc.
* The Faro stockpiles (LGSPC and OXSP) contain high abundance of sulphide minerals and increased potential to generate acid, especially in the unweathered fine-grained material of the OXSP, at depths of greater than 1 mbgs.
* Final leachate results from surface materials collected from the OXSP and LGSPC were acidic, with elevated arsenic, cadmium, copper, iron, lead, and zinc. These elements are likely tied to readily soluble secondary sulphate salts, such as melanterite, that have been observed in surface deposits in the OXSP.
* The presence of readily dissolved neutral salt exchangeable phases such as melanterite in the OXSP and LGSPC are key considerations for the mobilization of metals during reclamation activities.
* Trends of increasing concentrations of sulphate, dissolved iron, and dissolved zinc were identified at seepage monitoring locations SRK-FD37 and SRK-FD38.
* Measured increased temperature at intermediate depths within the OXSP, combined with increased carbon dioxide production from the consumption of available NP and depleted oxygen, signifies ongoing pyrite oxidation reactions occurring within the stockpile.

#### Main Dump

* Near surface samples collected from the Main Dump were associated with increased sulphur content and associated trace metals. Increased abundance of sulphide rock types and metals content was more widespread than previously identified sulphide cell boundaries.
* ABA properties in the Main Dump exhibited a wide range in values, because of the wide range in lithologies of waste rock deposited. Overall, the Main Dump contains net-neutralizing material with localized zones of massive sulphide rock where acid generation is expected.
* Final leachates extracted from Main Dump surface materials had variable composition. However, in general, the final leachate was acidic and contained elevated concentrations of arsenic, cadmium, copper, iron, lead, and zinc, implying increased mobility of these elements during flushing events (i.e., freshet or summer rain). The mobility of trace elements in the Main Dump surface materials may be because of the presence of readily dissolved secondary sulphate salts, such as melanterite.
* Shallow samples collected from the Main Dump indicate a greater presence of zinc in neutral exchangeable salts such as melanterite and acid-soluble phases. Lead mainly occurs as primary lead minerals and acid-soluble lead phases. The presence of copper in the main dump is generally incorporated into primary mineral phases or associated with amorphous iron oxide. Similar to trends observed in iron and zinc, copper is also tied to neutral exchangeable salts in CH14-106-TP004 and CH14-106-TP006, and acid-soluble phases in shallow test pit samples. Arsenic is associated mainly with crystalline iron oxides and primary mineral phases, with some shallow samples also tied to amorphous phases.
* Significant trends of increasing alkalinity, pH, and concentrations of dissolved iron, magnesium, sulphate, and zinc were noted at X23 (northwestern edge of the Main Dump). This steady increase in ions and metals of interest is likely associated with the breakthrough of other highly-impacted seeps draining toward X23, along flow paths.
* Monitoring results from installations in the Main Dump indicate acid rock drainage (ARD) activity ranges from strongly active near the middle of the dump (location CH14-106-MW009) to only slightly active at the northern edge of the dump (CH12-014-MW003). Temperatures ranged up to 19°C at 36-m depth at CH14-106-MW009, and up to 8°C at CH12-014-MW003. Oxygen concentrations are depleted throughout the monitored depths. The temperature and oxygen profiles from CH14-106-MW009 suggest oxygen transfer at the middle of the dump is driven primarily by convective air flow, both vertical and lateral. The profiles from CH12-014-MW003 suggest pyrite oxidation is limited by oxygen supply, which may be primarily through diffusion.

#### Intermediate Dump

* The Intermediate Dump Sulphide Cell is not as well defined as previously thought, with massive sulphide rock types present at near surface and at depth, widely distributed within the Intermediate Dump.
* Near surface samples collected from the Intermediate Dump were associated with increased sulphur content and associated trace metals. Increased abundance of sulphide rock types and metals content was more widespread than previously identified sulphide cell boundaries.
* ABA properties in the Intermediate Dump were highly variable, as observed in the Main Dump. However, the abundance of massive sulphide rock was much greater in the Intermediate Dump than in the Main Dump, and overall has substantial potential to generate acid.
* The final leachate from DI-leach testing of waste rock material collected from test pits excavated into the upper 5 m of the Intermediate Dump surface was acidic in nearly every sample test, indicating the entire near-surface material of the Intermediate Dump has the potential to generate low pH runoff and contribute metal loading during disturbance and follow-on flushing.
* Mobility of manganese and zinc in the Intermediate Dump is generally pH dependent, and highly mobile in acidic samples in the neutral salt exchangeable phase. This suggests these constituents are present in secondary salt deposits within the waste dump.
* Seepage emanating from the Intermediate Dump (at SRK-FD54) is characterized by decreasing trends in alkalinity and pH, and increasing concentrations of magnesium and sulphate. These trends indicate the onset of ARD generation at this location.

#### S-Wells

* Although groundwater and seepage within the S-Wells area contains increased contaminant loads, total metals analysis from the S-Wells area samples showed very few exceedances of screening criteria.
* S-Wells area materials exhibited acidic paste pH, however, NP:AP ratios were indicative of net-neutralizing sediment. Areas where acidic paste pH exist but net-neutralizing NP:AP ratios persist likely highlight the presence of buffering rock types such as calc-silicate rock to neutralize acid generated by sulphides.
* Final leachate from DI-leach testing of materials from the S-Wells area was acidic, with elevated concentrations of arsenic, iron, lead, and zinc in near-surface samples. Potential mobility of trace elements at depth was not as pronounced.
* Greater than 50 percent of the zinc present in the S-Wells material is contained within more readily dissolved salts, acid-soluble, and amorphous minerals.

#### Northeast Waste Rock Dump

* Arsenic and lead exceeded one or both of the screening criteria in samples collected from the Northeast WRD.
* Although paste pH was acidic in some samples, the NP:AP in all samples was greater than 3.0, indicating net-neutralizing properties. Acid generated from secondary sulphur salts formed on rock fracture surfaces is expected to be buffered by the presence of calc-silicate rock.
* Final DI-leach testing leachate of surface materials from the Northeast WRD was acidic, with elevated levels of copper, lead, and zinc. In contrast, DI-leach testing of Northeast WRD samples collected at depth were generally characterized by neutral to alkaline leachate with very low trace element concentrations in the final leachate, with exceptions noted where sulphate salts noted on the borehole log.
* In the Northeast WRD, zinc is present in readily soluble neutral salt exchangeable and acid-soluble phases. Evidence of sulphate salts present in the borehole materials was noted on the lithologic logs from this area. Lead occurs as acid-soluble and primary lead sulphide minerals.
* Increasing zinc concentrations have been noted along the eastern edge of the Northeast WRD (SRK-FD05), which has potential to directly impact water quality in upstream NFRC reaches.
* Monitoring results from CH14-015-MW006, installed in the Northeast WRD, indicate pyrite oxidation is only slightly active. Temperatures ranged up to 4°C from 10 to 19 mbgs. Oxygen concentrations were near-atmospheric at all monitored depths. The temperature and oxygen profiles suggest minimal pyrite oxidation is occurring, and oxygen transfer within the pile is likely dominated by diffusion.

#### Zone II Waste Rock Dump and Outwash

* Trace elements arsenic, cadmium, copper, lead, and zinc were abundant in the Zone II Outwash surface and intermediate depth materials.
* ABA characteristics of materials collected near the land surface in the Zone II Outwash area included acidic paste pH and NP:AP ratios of less than 3.0. At depth, paste pH was neutral in most samples with NP:AP ratios of greater than 3.0.
* DI-leach test results from the Zone II Pit area exhibited neutral to alkaline conditions, with increased concentrations of lead and zinc in the upper 3 m of the WRD material, and in discrete intervals at depth (approximately 35 to 40 mbgs). In the Zone II Outwash area, DI-leach results showed increased concentrations of copper, lead, and zinc in shallow test pits excavated, and zinc in nearly all sample depths. Secondary sulphate salt formation was noted in the borehole logs, and likely the source of the soluble trace metals identified.
* The presence of zinc the Zone II Outwash area is widely distributed across the following phases: neutral exchangeable salts, acid-soluble, amorphous iron, crystalline oxide, and primary minerals. Secondary salt formation in the Zone II Outwash sediments may also contribute mobile forms of lead, copper, and arsenic.
* Monitoring results from CH12-014-MW005, installed in the Zone II WRD, indicate pyrite oxidation is moderately active. Temperatures ranged up to 8°C from 15 to 30 mbgs. Temperature and oxygen profiles are suggest only moderate pyrite oxidation is occurring, and oxygen transfer within the pile is likely limited by diffusion.

# Mill Building and Emergency Tailings Area Remediation Unit

The Mill Building Area and ETA RU encompasses the area around the main FMC mine processing, maintenance, and support facilities, as well as the ETA tailings discharge deposits contained within the lower Faro Creek valley, south of the Mill Building area.

## Field Investigation Activities

The ETA has been identified as a contaminant source to groundwater and surface water, and the tailings material in this area are planned to be either relocated or covered in place. Field investigation activities completed within the Mill Building Area and ETA RU during the 2014 field season were to support the determination of ETA thickness and extent of contamination in the underlying soils and within the tailings.

In addition, a pipeline that will convey contaminated groundwater from the toe of the CVD to the proposed water treatment plant (WTP) was being designed. The proposed pipeline alignment goes through the Mill Building Area and ETA RU; therefore, some investigations completed within this area were to support to design of this pipeline.

Limited test pit excavation and borehole drilling activities were conducted within the Mill Building Area and ETA RU in the 2014 field season. Although these activities were mainly for the purpose of geotechnical investigations, select samples were sent to the laboratory for geochemical analyses to support the overall understanding of geochemical conditions at the FMC. No monitoring wells were installed within the Mill Building Area and ETA RU.

### Test Pit Excavation

During the 2014 field season, a total of ten test pits were completed along the proposed CVD SIS pipeline alignment between the CVD and the proposed WTP. Two of these test pits were located within the Mill Building Area and ETA RU, whereas the other eight were located within either the RCTA RU (discussed in Section 5) or the Dams and CVD Pond RU (discussed in Section 6). Test pits were excavated to approximately 5 mbgs, with soil samples collected in approximately 1.5 m depth intervals. The main purpose of these soil samples was for geotechnical analyses; however, limited geochemical (i.e., corrosivity) data was also obtained, including chloride, oxygenation reduction potential, pH, sulphate, and sulphide.

Additional test pit excavation was completed within the Mill Building and ETA RU in 2014; however, the principle purpose of those activities were geotechnical investigation and as such, no geochemical data was obtained.

### Borehole Drilling

During the 2012 field season, two piezometers (CH12-101-PZ001 and PZ002) were installed and eight borings (CH12-101-BH001 through BH008) were drilled in the Mill Building Area at the proposed location of the replacement WTP. While these piezometer installations and borings were mainly conducted for geotechnical purposes, geochemical data was also collected to assess any potential impacts to the proposed area. Further discussion on the drilling and sample collection is present in the report titled *Geotechnical Data Water Treatment Plant* (CH2M, December 2012).

During the 2014 field season, three boreholes were drilled in the ETA and on the Mine Access Road downstream (west) of the ETA. The ETA has been identified as a contaminant source to groundwater and surface water, and the tailings are planned to be either relocated or covered in place.

Geochemical analyses were conducted on samples from the one boring drilled through the tailings and into the underlying alluvium within the ETA. In addition, one grab sample and a duplicate sample were collected from one of the borings on the Mine Access Road at approximately 10.7 mbgs because of strong petroleum hydrocarbon odour detected during the investigation. Laboratory analyses for VOCs and hydrocarbons were completed on these samples. There were no detections of VOCs in this material; however, hydrocarbons F2 (C10-C16) and F3 (C16-C34) were detected in the parent sample at 501 and 209 mg/kg, respectively. The duplicate sample reported similar concentrations.

Description of the drilling activities, laboratory analyses, and results discussion are presented in a report titled *Summary of 2014 Field Investigation – Relocate ETA Tailings to Rose Creek Tailings Area* (CH2M, 2015m).

### Seepage Investigation

Seepage investigation in the Mill Building Area and ETA RU was completed as part of the side-wide seep sampling program in 2014 and 2016. There are 12 seeps that are associated with the Mill Area and six seeps associated with the ETA. Discussions of seep sampling activities and data analyses are summarized in Section 3.1.3, and the detailed descriptions are presented in the following reports:

* 2012 Seepage, Surface Water, and Water Treatment Plant Influent Sampling Report (CH2M, October 2013a)
* 2013 Seep Sampling and Waste Rock Dump Monitoring Data and Analysis Report (CH2M, March 2014c)
* Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring (CH2M, April 2016d)
* Summary of 2014 Field Investigation – Site-wide Geochemical Monitoring (CH2M, March 2015b)
* Summary of 2016 Field Investigation – Site-wide Geochemical Monitoring (CH2M, August 2016j)

## Field Investigation Data Evaluation

### Solids Data

#### Total Metals

From the 8 borings and 2 piezometers completed in the Mill Area at the proposed site of the replacement WTP in 2012, 27 samples plus 4 duplicate samples were submitted for total metals analysis; full results from the analysis can be found in Table 4-1. In general these samples were only mildly impacted to not impacted at all; most exceedances were greater than 10 times the average crustal abundance, but less than 12 times the mean world soil content. Lead, mercury, and zinc were the only elements measured that exceeded both criteria in any sample measured. Lead and zinc exceeded both criteria in samples CH12-101-BH004-SOa and CH12-101-PZ002-SOa; mercury also exceeded both criteria in sample CH12-101-BH004-SOa. Lead also exceeded both criteria in samples CH12-101-BH001-SOa and CH12-101-BH003-SOa. Arsenic and cadmium, among a handful of other elements, were measured greater than 10 times the crustal abundance at a few other sample locations, but were always less than 12 times mean world soil content. Strikingly, almost all of the exceedances were measured in fairly shallow or even surficial soil samples suggesting that the impacts may be related to historic dust deposits related to ore process and handling at the mill and are not naturally occurring. This trend can be seen in Figures 4-1 to 4-14, which show elemental concentrations with depth in CH12-101-BH001 to CH12-101-BH005 and both piezometers. A surficial soil – dust study may be warranted before construction of the WTP in this area to evaluate the hazards and risk created by construction activities and to evaluate the risk to human health during construction. Since this area is not believed to contain mineralized soil and rock, the metals measured in these samples do not present any long-term issue or concern to the proposed WTP structure.

The single boring drilled in the ETA, CH14-105-BH003, was intended to determine the depth of the tailings and to collect samples from the tailings and the underlying alluvium to determine the extent of contamination. Five samples and one duplicate from this boring were submitted for geochemical analysis: two samples in the upper and lower tailings (CH14-105-BH003-SOa and CH14-105-BH003-SOd), one sample in the alluvium at the upper contact with the tailings (CH14-105-BH003-SOd-B), and two samples distinctly in the underlying alluvium (CH14-105-BH003-SOe and CH14-105-BH003-SOg). As expected, the tailings samples contain very high elemental concentrations that generally exceeded either the 10 times crustal abundance and/or the 12 times median world soil content standards, while elemental concentrations are decreased in the underlying alluvium samples (Figures 4-15 and 4-16). However, the surficial tailings sample (CH14-105-BH003-SOa and duplicate CH14-105-BH903-SOa), which was collected between 0 and 0.5 mbgs, was depleted in more acid-mobile metals such as cadmium, copper, lead, magnesium, and zinc relative to the concentrations of the same metals observed in the tailings between 2.3 and 2.7 mbgs (CH14-105-BH003-SOd). Meanwhile, less acid-mobile elements, such as arsenic, were only slightly depleted. For example, cadmium and zinc were at or below both screening criteria in the surficial sample, but were more than six and twenty times, respectively, greater than the higher of the two screening criteria (i.e., 12 times mean world soil content) in the deeper tailings material. In contrast, arsenic was almost four times the mean world soil content criteria at the surface and only slightly higher (five times mean world soil content) at depth. It is notable that magnesium, which is commonly the first element coupled to sulphate that indicates impacted waters at the FMC, is highly depleted in the upper tailings material and is even enriched in the underlying alluvial material.

The total elemental concentrations of the underlying alluvium exhibits a sharp drop with depth. However, there is evidence of vertical migration of trace elements just below the tailings contact. Sample CH14-105-BH003-SOd-B of the alluvium immediately beneath the tailings has almost identical elemental concentrations to the tailings material overlying it, however, the total sulphur content of CH14-105-BH003-SOd-B is an order of magnitude lower than the tailings material. Given that (1) the tailings in the ETA were deposited as a slurry, (2) this upper alluvial layer is fine to coarse gravel, and (3) the similarity in elemental composition with the overlying tailings, suggests this upper alluvial horizon contains a significant amount of primary tailings material, but the order of magnitude lower sulphur content also indicates that at least some of the elemental content in this horizon may be because of vertical migration of elements leached from the overlying tailings material and retained in the alluvium.

Below the tailings-alluvium contact zone (2.3 to 2.7 mbgs), the alluvium still exhibits elemental concentrations indicative of impact from the overlying tailings down to the deepest sample (CH14-105-BH003-SOg) at 4.3 to 4.7 mbgs. However, starting at 3.2 to 3.5 mbgs, there are fewer elemental exceedances of either screening criteria and the elemental concentrations are generally an order of magnitude lower than the tailings material. Still arsenic, cadmium, lead, and zinc remain significant concerns even at depth and zinc, which has been demonstrated to be one of the more mobile trace elements at the FMC exhibits a potentially increasing trend with depth.

Based on the results from this single core through the ETA tailings material, it appears that trace elements in the upper surface of the tailings have been disproportionately leached or otherwise mobilized – most likely because of acid-generation and related weathering reactions – relative to the elemental concentrations observed deeper in the tailings material. The underlying alluvium exhibits impacts from the tailings up to 2 m below the tailings-alluvium interface, which may be the result of vertical migration of trace elements leached from the tailings, though impacts from original deposition of the slurried tailings material cannot be completely ruled out. Further investigations with additional samples across the tailings-alluvium interface and deeper into the alluvium are warranted to establish trends across the ETA. Mineralogical evaluation of the trace element mineralization within the alluvium may also help to determine the nature of the elemental impacts (i.e., primary deposition or secondary mineralization because of leaching of the overlying tailings).

#### Acid Base Accounting

ABA data collected from the tailings material from boring CH14-105-BH003 indicate general acid-generating materials, with paste pH between 1.7 and 4.7 and the most acidic samples occurring at the surface where the NP has been depleted (i.e., NP not detected in this sample). The lack of NP and exposure to weathering has accelerated the oxidation of sulphides, the generation of acid, and the leaching of trace elements at the surface. In contrast, the moderately acidic sample (CH14-105-BH003-SOd) 2.3 to 2.7 mbgs is buffered from rapid oxidation and accelerated acid generation because it still contains a significant amount of the original NP (350 kg CaCO3 eq/tonne) from mill process that generates the tailings under alkaline conditions. The lack of NP in the upper alluvium sample (CH14-105-BH003-SOd-B; NP below detected) further supports the assumption that trace elements present in this sample are not associated with primary deposition of tailings as primary tailings typically contain some NP (or are highly acidic and trace element depleted). The trace elements in CH14-105-BH003-SOd-B are more likely because of secondary mineralization resulting from vertical migration of tailings leachate. Regardless, the NP:AP ratios both tailings samples and the upper alluvium was less than 1.0, indicating the materials will ultimately become acid generating. This is not unexpected for the tailings material which is predominantly fine-grained sulphide material. Full ABA data and results are presented in Table 4-2.

#### DI Leach

DI-leach tests were carried out on samples collected from shallow borehole CH14-105-BH003, completed in the ETA materials. Leachate from this area is characterized by acidic conditions and highly mobile constituents: arsenic, cadmium, copper, iron, lead, and zinc. With the high metal content in this material and lack of NP, this area continues to be an area of high impact from mining activities. DI-leach results are found in Table 4-3.

### Seepage Data

There is a total of eighteen seep sample locations within the Mill Building Area and ETA RU. A summary of some key parameters can be found in the four reports mentioned in section 4.1.3.

#### Mill Area

Historical seepage data trends were analyzed using the Mann-Kendall trend test, which statistically determines whether a data set consistently increases or decreases over time. The test requires at least five data points above the detection limit to produce an accurate result. Statistical analyses were calculated for six key parameters: pH, total alkalinity, sulphate, dissolved magnesium, dissolved iron, and dissolved zinc. These parameters have been identified as geochemically important during previous investigations. The level of significance tested is 95 percent, and any non-detectable concentrations were reduced to half of the non-detectable limit.

Out of the 11 locations in the Mill Area, six locations did not have enough data to evaluate with the Mann-Kendall trend test. Three locations (CH-MILL-01, CH-MILL-02, CH-MILL-04) only had enough field pH data to complete statistical trend analyses and there were no trends observed. Location SRK-FD33 showed significant decrease over time for field pH, but no significant trend for the other key parameters. CH-MILL-03 showed no significant trend for any of the key parameters. These results can be found in Table 4-4a.

#### Emergency Tailings Area

Seep sampling location CH-ETA-03 is the only location in the ETA that did not have enough data points to perform statistical analysis on any analytes. With the exception of FCS-4, the remaining seep sampling locations only had enough field pH data for Mann-Kendall analysis. CH-ETA-01 exhibited a significant decreasing trend in field pH, while CH-ETA-02, FCS-2, and FCS-3 did not show any significant trends in field pH. The FCS-4 sampling location exhibited a significant increasing trend in dissolved magnesium and dissolved zinc, but no significant trend in total alkalinity, dissolved iron, or sulphate. The field pH at FCS-4 showed a significant decreasing trend over time. These trend results can be found in Table 4-4b.

### Summary and Recommendations

Results from the Mill Area and ETA are summarized below:

* Lead, mercury, and zinc were the only elements measured that exceeded both 10 times the average crustal abundance and 12 times the mean world soil content in a few of the samples analyzed from the Mill Area. However, almost all of the exceedances were measured in surficial soil samples suggesting that the impacts may be related to historic dust deposits from historical ore processing and handling at the mill and are not naturally occurring.
* Trend analysis completed on water quality parameters in seepage locations near the Mill Area showed decreasing pH in one location (SRK-FD33), and no other significant trends for other key parameters. Trend analysis in the ETA found that dissolved magnesium and dissolved zinc are increasing concomitant with a decreasing trend in pH at FCS-4, suggesting the drainage may be in the early stages of evolving towards more acidic conditions. Continued monitoring is recommended at this location.
* Surficial ETA materials have been depleted in acid-mobile trace metals because of weathering processes. At depth, the total metal content in the tailings material deposited in the ETA has greater content of constituents of concern. The underlying alluvium exhibits impacts from the tailings up to 2 m below the tailings-alluvium interface, which may be the result of vertical migration of trace elements leached from the tailings.
* ABA properties measured in the ETA tailings and upper alluvial material indicate acid generating materials, with limited NP available. Leachate from this area is characterized by acidic conditions and highly mobile constituents: arsenic, cadmium, copper, iron, lead, and zinc. Water quality trends in the ETA show increasing concentrations of sulphate, iron, magnesium and zinc. Associated decreases in pH have been observed at key locations within the ETA.
* The Mill Area and ETA continue to be areas of high impact from historical mining activities.

Recommendations for further work include:

* A surficial soil-dust study may be warranted before construction of the WTP in the Mill Area to evaluate the hazards and risk created by construction activities and to evaluate the risk to human health during construction.
* Further investigations with additional samples across the tailings-alluvium interface and deeper into the alluvium are warranted to evaluate the migration of trace metals into the underlying alluvium in the ETA. Mineralogical evaluation of the trace element mineralization within the alluvium may also help to determine the nature of the elemental impacts (i.e., primary deposition or secondary mineralization because of leaching of the overlying tailings).

# Rose Creek Tailings Area Remediation Unit

The RCTA RU encompasses the Original Impoundment, Secondary Impoundment, Intermediate Impoundment, the ID Pond (ID Pond), and the area east of Faro Canyon and north of the RCTA up to the North Wall Interceptor Ditch (NWID). This RU does not include the Rose Creek Diversion (RCD), ID, CVD or CVD Pond.

## Field Investigation Activities

Field investigation activities completed within the RCTA RU during the 2013 to 2015 field seasons were to support the following objectives:

* Further quantify groundwater flow components in the RCTA to support design of the CVD Seepage Interception System (SIS) and site-wide geochemical and water quality modelling efforts at the site
* Improvements to the understanding of site-wide geochemical properties and the site-wide water quality model
* Improvements to the understanding of the impounded tailing characteristics for planned cover-in-place reclamation activities

### Borehole Drilling and Monitoring Well and Thermistor Port Installation

During the 2013 field season, one well cluster was drilled in the Intermediate Impoundment of the RCTA. The CH13‐204‐MW016 well cluster consisted of four monitoring wells installed in three boreholes: one deep alluvium well (CH13‐204‐MW016E), one shallow alluvium well (CH13‐204‐MW016C) and two wells (CH13‐204‐MW016A/B) completed as a nested installation screened within the middle and deep tailings material. Soil samples were collected during the drilling of these monitoring wells and selected samples were submitted for geochemical analyses.

During the 2014 field season, three boreholes were drilled in the Original Impoundment within the RCTA RU, to investigate groundwater quality beneath the tailings in the Rose Creek Alluvial Aquifer (RCAA) just downgradient of monitoring location FCS-4 within the lower portion of Faro Canyon of the ETA. Boreholes were advanced into the tailings material and the underlying alluvium, with maximum depths ranging from 16.76 mbgs (into gravel below the tailings) to 47.24 mbgs (into bedrock). Selected samples were submitted for geochemical analyses. Monitoring wells were installed in each of these borings.

Five boreholes were also drilled in the Intermediate Impoundment during the 2014 field season. Four of these boreholes were drilled to collect subsurface data to support design efforts for the proposed new side channel dike structure, and the remaining borehole was drilled to help improve understanding of the impounded tailing characteristics for planned cover-in-place reclamation activities. Borings were advanced into the native materials beneath the tailings, to maximum depths ranging from 3.50 mbgs to 20.42 mbgs. Samples were collected for geochemical analyses. One 25.4-millimetre (mm) (1‑inch) ‑diameter thermistor port was installed in each of these borings.

Description of the drilling and monitoring well and thermistor port installation activities, laboratory analyses, and results discussion are presented in the following documents:

* 2013 Cross Valley Dam Seepage Interception System Field Investigation Data and Analysis Report, Faro Mine Remediation Project (CH2M, February 2014q)
* Summary of 2014 Field Investigation – Site-wide Geochemical Monitoring (CH2M, March 2015b)
* Summary of 2014 Field Investigation – Dewater and Cover Intermediate Tailings Area (CH2M, March 2015x)
* Summary of 2014 Field Investigation – Construct New Side Chanel and Side Channel Dike (CH2M, March 2015z)

### Seep Sampling

The RCTA seep sampling is part of the site-wide seep sampling program, which was discussed previously in in Section 3.1.3. There are 11 seeps that are associated with the RCTA and surrounding area. Four seeps are monitored at the base of the Secondary Impoundment dam (CH-RCTA-03, CH-RCTA-07, CH‑RCTA-08 and CH-RCTA-09). Two of these seeps (CH-RCTA-03 and CH-RCTA-07) are collected where water emanates directly from the Secondary Impoundment dam. One of these seeps, CH-RCTA-09, is monitored where water seeps from the lower western face of the RCD dam that diverts water from the original (pre-1981) RCD channel.  The fourth seep, CH-RCTA-08, is monitored directly from the water that flows west through the original (pre 1981) RCD channel to the Intermediate Impoundment. Water sampled at CH-RCTA-08 represents aggregate flow from the seeping lower face of the Secondary Impoundment dam and RCD dam.

CH-RCTA-04 is monitored downstream of CH-RCTA-08 along the same flowpath, on the surface of the Intermediate Impoundment. CH-RCTA-06 is monitored at a pool of water on the Intermediate Impoundment surface approximately 650 m west of CH-RCTA-04.  CH-RCTA-05 is monitored where seepage from the RCD drains toward the Intermediate Impoundment. FCS-5 is monitored near the Secondary Impoundment dam within the ditch that conveys water from the ETA (i.e., FCS-4) to the ID Pond. GDHSCK, CH-RCTA-01, and CH-RCTA-02 are monitored on the northern side of the RCTA, downstream from the Secondary Impoundment dam.

### Groundwater Sampling

Groundwater was sampled in the RCTA annually in the late summer to early fall. In 2014, one groundwater sampling event took place within the RCTA RU between September 10 and September 20. In 2015, sampling events took place between October 4 and 11.

## Field Investigation Data Evaluation

### Solids - Total Metals

The CH13-204-MW016 well cluster was installed in the northern portion of the Intermediate Tailings Impoundment to address a data gap in groundwater chemistry in the tailings and underlying RCAA in support of development of the RCTA PHAST model. Samples of the tailings and underlying aquifer material were submitted for geochemistry including total metals. The tailings are approximately 8.7 metres (m) thick in this location and three samples with one duplicate were submitted for total metals analysis including a surface sample, a bottom sample, and a middle depth sample. As expected, the total metal concentrations in the tailings are elevated and numerous elements exceed both the median world soil content and the crustal abundance standards (Table 5‑1). There is no discernible trend in elemental concentrations with depth in the tailings material (Figures 5-1 and 5-2); the variation in samples from different depths is not significantly different relative to the natural variation of duplicate samples taken from the same depth. Although the deepest tailings sample is geochemically similar to the overlying tailings samples, the boring log from this depth horizon indicates there is native organic material (i.e., decomposing roots and sticks) suggesting that there is a transition zone between the upper RCAA and the deposited tailings material. Given that thick, peaty organic material is observed in the floodplains adjacent to undisturbed streams in the FMC, it is likely that the tailings were simply pumped as a slurry over this organic material resulting in a zone that contains native organic material but is geochemically similar to overlying tailings material. Within a half meter, the elemental concentrations drop sharply indicative RCAA material (Figures 5-1 and 5-2), but trace element concentrations are still elevated, but with only a few exceedances, indicating there is some impact from the overlying tailings material. With depth into the RCAA, the elemental concentrations are more indicative of background levels found at the FMC with only a few exceptions.

The CH14-015-MW001 and CH14-015-MW002 boring clusters were drilled in the Original Tailings Impoundment at the base of Faro Canyon, just downstream of the ETA and sampling location FCS-4. These clusters were drilled to install wells in the tailings and RCAA material in an effort to fill data gaps in the groundwater chemistry in this area. The main objective was to determine how much seepage from the WRDs moving through the ETA via Faro Canyon was seeping into the upper RCAA below the tailings and to establish groundwater chemistry in this area for improvements in the RCTA PHAST model. As expected, the total metal concentrations in the tailings are elevated and numerous elements exceed both the crustal abundance standards and the median world soil content (Table 5‑1). There is no discernible trend in elemental concentrations with depth in the tailings material (Figures 5-3 and 5-4). There is a sharp decrease in elemental concentrations between the bottom of the tailings at 16.8 mbgs and the top of the alluvium at 19.2 mbgs. With the exception of total S in the upper 1 to 2 m of the alluvium, there are no elemental exceedances relative to the mean world soil content and crustal abundance screening criteria. Total S steadily decreases more than an order of magnitude from the top of the RCAA at 19.2 mbgs and the deepest alluvium sample at 25.9 mbgs. Over the same interval, iron values barely decrease, perhaps suggesting a shift from more iron sulphide in the upper portions of the RCAA to more iron oxyhydroxides deeper in the RCAA. The trace elements all conform to a similar trend with depth below the tailings in the RCAA sediments, suggesting a similar mechanism is controlling the fate and transport of trace elements within the alluvium.

During the 2014 field season, a series of borings were conducted in the southern portion of the Intermediate Tailings Impoundment along the path of the proposed probable maximum flood (PMF) spillway side-channel dike to mainly conduct geotechnical investigations. A total of 15 samples of mostly tailings material from a total of 5 boreholes were also submitted for geochemical analysis. As expected, the total metal concentrations in the tailings are elevated and numerous elements exceed both the crustal abundance standards and the median world soil content (Table 5‑1). A few holes were drilled deep enough to penetrate the underlying native material. At boring CH14-201-TH002, two samples (SOp and SOp-B) were collected at the tailings-RCAA contact at depth of 19.8 to 20.3 mbgs. Sample CH14-201-TH002-SOp is identified as organic material and likely represents the original peaty growth that existed before tailings deposition, while sample CH14-201-TH002-SOp-B is identified as silt, but based on geochemical composition is likely some of the initial tailings material deposited on top of the native peaty substrate and occurs interbedded with the organic substrate. The only elements that exceed both the crustal abundance and the mean world soil content criteria in the organic material (CH14-201-TH002-SOp) are lead, total sulphur, and zinc; iron is also an order of magnitude lower in this sample than the overlying tailings material. Boring CH14-201-TH004, which is close to the southern margin of the Intermediate Tailings, encountered till material at a depth of 3 to 3.5 mbgs. A single sample, TH003-SOd-B, was submitted for geochemical analysis of this till material. The sample does exhibit slight impacts from the tailings material, but only exceeds both criteria for total sulphur and zinc. Given the disproportionately high levels of total sulphur and zinc relative to other elements typically elevated in the tailings source material, it is likely the sulphur and zinc represent secondary deposition or migration of these elements from the tailings source material deeper into the underlying RCAA. The mobilization of zinc and sulphur from the tailings material, followed by secondary deposition of these elements in the RCAA has implications for the fate and transport within the RCTA. Further illustrating the potential impacts of the tailings material on the underlying RCAA, a sample of weathered bedrock, CH14-201-TH004-SOf, was collected from a fairly shallow depth (6.1 to 6.6 mbgs). This weathered bedrock at this depth exhibited elevated trace elements with arsenic, lead, mercury, total sulphur, and zinc exceeding both the crustal abundance and the mean world soil content criteria. The final non-tailings sample, CH14-201-TH006-SOe, submitted for geochemical analyses was collected in alluvium below the tailings at a depth of 5.2 to 5.6 mbgs. Surprisingly, this sample was only moderately impacted with only arsenic and total sulphur exceeding both criteria.

### Acid Base Accounting

Results from ABA testing on samples collected in the RCTA RU characterize the tailings material as well as the native soils, alluvial sediments, and weathered bedrock underlying the RCTA (Table 5‑2). Paste pH was generally acidic in the fine grained tailings material with NP:AP ratios of less than 1.0. Organic soils were observed underlying the fine-grained, pyrite-rich tailings material (CH14-201-TH002-SOp). Although the organic soils had near-neutral paste pH, the elevated total sulphur resulted in a very high calculated acid potential (178 kg CaCO3 eq/tonne). Because the non-sulphide fractions, acid-soluble sulphate and barium sulphate, were not determined, the AP was calculated conservatively assuming all of the total sulphur is attributable to sulphide. As such, the NP:AP ratio were less than 1, suggesting potentially acid generating material, however, as noted above, the total sulphur in this sample may be secondary, which would not contribute to acid potential. Thus, while the organic material is certainly impacted from the overlying tailings, the potential to generate acid from this horizon is dubious given the neutral pH of the sample and the lack of complete data for the ABA calculation. Lithologic logs from RCTA field investigation locations identify unconsolidated alluvial sediments (silts, sands, and gravels) underlying the organic soils beneath the tailings deposits. ABA parameters measured in samples collected from these sediments seemed to be related to overall pyrite content in the sediments. Where clasts of diorite, quartz, and phyllite were noted, paste pH was generally near neutral and NP:AP ratios were greater than 3.0. Where abundant pyrite grains were noted on the lithologic logs, paste pH was more acidic and NP:AP ratios were generally less than 3.0, and often less than 1.0. Samples collected from weathered phyllite bedrock in the RCTA were characterized as near neutral (paste pH) and NP:AP of greater than 3.0. In summary, the ABA data in the RCTA generally indicate potentially acid generating tailings material overlie heterogeneous alluvial materials, ranging from non acid-generating to potentially acid generating, depending on the pyrite content.

### DI Leach

DI-leach extractions were carried out on selected samples collected from boreholes (CH14 -015-MW001A, CH14-015-MW001C, CH14-015-MW002A, CH13-204-MW016C, and CH13-204-MW016E) and test holes (CH14-201-TH001) completed in the RCTA and underlying materials (Table 5‑3). DI-leach testing on samples from the original tailings material generated a leachate with a final pH that was acidic and contained elevated concentrations of cadmium, copper, lead, and zinc, indicating these elements are readily mobile. The final leachate from the Intermediate Tailings Area samples is characterized by acidic leachate with elevated concentrations of copper, iron, lead, and zinc. DI-leach test results from the alluvial material underlying the Intermediate Tailings Area resulted in a neutral to alkaline final leachate without any of the trace elements significantly elevated in the solution, indicating that the trace elements detected in the total metal analysis are associated with relatively stable mineral phases that do not readily dissolve.

### Sequential Extraction

Sequential extraction tests were completed on samples collected from the RCTA to characterize the relative mobility and mineralogic association of trace elements within the tailings and underlying alluvial material. Sequential extractions were carried out on samples collected from the following locations: CH13-204-MW016C, CH13-204-MW016E, and CH14-015-MW001C. Although the sequential extractions analyze for a full suite of trace element analytes (Tables 5‑4 and 5-5), this section focuses on the key constituents to the FMC area: iron, manganese, zinc, lead, copper, and arsenic. Iron is generally present in the RCTA tailings, fill, and underlying alluvium in one of three of the extraction steps (Figures 5-5 and 5-6): amorphous iron oxides (e.g., ferrihydrite,), crystalline iron oxides (e.g., goethite, schwertmannite), or in the residual fraction (e.g., the iron sulphide, pyrite). Manganese in the tailings is mainly extracted in the residual fraction (likely as a coprecipitate in primary sulphide phases) followed by the neutral-salt exchangeable fraction (e.g., highly soluble secondary sulphate salts). Manganese in the tailings is also extracted, to a lesser extent, in the amorphous and crystalline oxide phases. Manganese in the underlying alluvial sediments is also predominantly extracted in the residual phase with the remaining manganese balance distributed in the acid-soluble and amorphous oxide phases and to a lesser extent, the neutral-salt exchangeable and crystalline oxide phases. In a few samples (CH13-204-MW016E-SOd, SOe, and SOi), a significant portion (greater than 10 percent) of the total manganese is extracted in the neutral-salt exchangeable fraction indicating manganese at these depths is readily mobile. In boring CH14-015-MW001C, zinc exhibits a bimodal distribution from the surface down to 16.8 mbgs, extracted in either the residual phase (e.g., zinc-bearing sulphide) or in the neutral-salt exchangeable fraction (e.g., highly soluble, secondary sulphate salts); the total zinc content is also higher in these samples. Below approximately 16.8 mbgs, zinc is still predominantly extracted in the residual fraction, but is fairly equally distributed between the amorphous and crystalline oxide phases and the neutral-salt exchangeable phase, suggesting a higher partitioning of zinc into secondary oxide phases with depth in the tailings material, although the total zinc content is significantly lower with depth. Within the alluvium underlying the tailings, zinc distribution is largely bimodal occurring predominantly in the residual phase (i.e., zinc-bearing sulphides), but also significant distribution in the crystalline oxide phase (i.e., iron and/or manganese oxides). Minor amounts of zinc are also extracted in the amorphous oxide fraction. This suggests that the majority of the zinc measured in the RCAA is likely primary in nature, though secondary zinc may be associated with crystalline oxides through adsorption. In boring CH14-015-MW001C, lead is almost completely extracted in the residual (i.e., sulphide) fraction near the surface (i.e., 2.2 mbgs in sample CH14-015-MW001C-SOa). At approximately 16.8 mbgs, very little lead is recovered in the residual fraction (approximately 20 percent) with most of the lead recovered in the neutral-salt exchangeable (i.e., secondary sulfo-salts) and acid-soluble (i.e., lead carbonates and some lead oxide) fractions. At greater depths in the tailings at CH14-015-MW001C, the total lead concentration is very low making sequential interpretation of sequential extraction data dubious, however, lead is largely distributed between the residual, acid-soluble, and amorphous oxide fractions. In boring cluster CH13-204-MW016, lead is largely extracted in the acid-soluble and neutral-salt exchangeable fractions in the tailings and upper RCAA where total lead is elevated. There is a significant amount of lead extracted in the alkaline (pH 10) pyrophosphate phase, though the reasoning for this is not immediately apparent, but it could be a carryover from the amorphous oxide extraction step. As the lead concentration drops below the tailings in the RCAA, the lead distribution shifts to more in the residual and amorphous oxide fractions. There is still significant lead extracted in the pyrophosphate fraction. In both CH13-204-MW016 and CH14-015-MW001 boring clusters, copper was largely extracted in the residual (i.e., sulphide) and amorphous oxide fractions, while arsenic was largely extracted in three main phases: amorphous oxides, crystalline oxides, and the residual fraction.

### Seepage Data

There were 11 seep locations monitored within the RCTA to provide additional water chemistry estimates of the RCTA pore water in support of the PHAST model for the RCTA. These data have been reported in *Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring* (CH2M, 2015).

Seepage data trends were analyzed using the Mann-Kendall trend test, which statistically determines whether a data set consistently increases or decreases over time. The test requires at least five data points above the detection limit to produce an accurate result. Statistical analyses were calculated for six key parameters: pH, total alkalinity, sulphate, dissolved magnesium, dissolved iron, and dissolved zinc. These parameters have been identified as geochemically important during previous investigations. The level of significance tested is 95 percent, and any non-detectable concentrations were reduced to half of the non-detectable limit.

Three seep sampling locations, CH-RCTA-01, CH-RCTA-02, and CH-RCTA-09, did not have enough data to perform Mann-Kendall analyses. Given the general low pH of seep, CH-RCTA-03, total alkalinity was not generally measured at this location and therefore no trend analysis was conducted (Table 5-6). CH‑RCTA-03 did exhibit a significant decreasing trend in dissolved iron, but no other trends were observed in the remaining data set. CH-RCTA-07 showed a significant decreasing trend for iron, sulphate, and dissolved zinc, but no significant trends for total alkalinity, dissolved magnesium, or field pH. CH-RCTA-08 only had enough field pH data to perform Mann-Kendall analysis; there was no significant trend in the field pH data. Four seeps, CH-RCTA-04, CH-RCTA-05, CH-RCTA-06, and GDHSCK, only have enough field pH data to conduct the Mann-Kendall trend analysis. All four locations had no significant trend in field pH. The final seep sampling location in the RCTA is FCS-5. Mann-Kendall analysis found a significant increasing trend in field pH, but no trends in the other parameters tested; there was not enough data to test total alkalinity.

### Groundwater Data

There are 41 groundwater monitoring wells associated with the RCTA RU that are sampled as part of the yearly fall sampling program. In 2014 and 2015, most monitoring wells were sampled only once a year, during the fall. However, in 2015 monitoring wells P03-06-01, P03-06-03, and P03-06-06 were also sampled during the summer. The analytical data and field parameter results can be found in *Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring* (CH2M, April 20156d.

Groundwater data trends employing current and historical data sets were analyzed using the Mann-Kendall trend test. Statistical analyses were conducted for six key parameters: pH, total alkalinity, sulphate, dissolved magnesium, dissolved iron, and dissolved zinc. These parameters have been identified as geochemically important during previous investigations. The level of significance tested is 95 percent, and any non-detectable concentrations were reduced to half of the detection limit.

A subset of groundwater wells in the tailings area were chosen for the Mann-Kendall analysis. The majority of the wells on the tailings are nested wells with 8-9 different depths, labelled in numerical order with 01 being the deepest. A summary of the results of the Mann-Kendall analysis are presented in Table 5‑7.

For well P03-01, nested wells P03-01-02, P03-01-04, P03-01-06, P03-01-08, and P03-01-09 were chosen for Mann-Kendall analyses. Total alkalinity showed a significant increase in P03-01-02, and significant decrease in P03-01-04, with no significant trends in the other three nested locations. Dissolved iron showed a significant increase in P03-01-02, P03-01-06, and P03-01-09, with no significant trends in the other two nested locations. Dissolved magnesium showed a significant decrease in P03-01-04, but significant increases in P03-01-06 and P03-01-09, with no significant trends in the other three nested locations. Dissolved zinc showed significant increases in the deepest three nested locations analyzed (P03-01-02, P03-01-04, and P03-01-06), with no significant trends in the two shallow nested locations. Field pH showed significant decreases in P03-01-04 and P03-01-06, with no significant trends in the other three nested locations. Sulphate decreased at P03-01-02 and increased at P03-01-06, with no significant trends at the remaining nested locations.

Mann-Kendall analyses were performed on P03-03 at sampling depths P03-03-02, P03-03-04, P03-03-06, P03-03-08, and P03-03-09. Results showed a significant decrease in total alkalinity at P03-03-04 and P03-03-06 with no significant trend at any other depth. Dissolved iron exhibited a significant increase in all of the analyzed depths except P03-03-08. Dissolved magnesium increased significantly at P03-03-04 and P03-03-06 depths, but no trends were observed at the other depths. Dissolved zinc only exhibited a significant increasing trend at the P03-03-04 depth interval and no trends at any other depth interval. . P03-03-06 and P03-03-08 are the only depths that show a significant trend (decreasing) for pH. Sulphate significantly increased at every depth except P03-03-08, which exhibited no significant trend over time.

Wells P03-04-02, P03-04-04, P03-04-06 and P03-04-08 were chosen for P03-04 nested cluster. Analyses showed that total alkalinity significantly increased at P03-04-02 and P03-04-04, but significantly decreasing at P03-04-06 and P03-04-08. Dissolved iron significantly increased at P03-04-04 and significantly decreased at P03-04-06; there was no significant trend in dissolved iron at either the P03-04-02 or P03-04-08 depth interval. Dissolved magnesium shows a significant increase at every depth interval except P03-04-06, which does not exhibit a significant trend. Dissolved zinc showed a significant decrease at the P03-04-04 and P03-04-06 depth intervals and no trend at the P03-04-02 and P03-04-08 depths. Sulphate exhibited an increasing trend in the two deepest depth horizons (P03-04-02 and P03-04-04), a significant decrease at P03-04-06, and no trend at the shallowest interval, P03-04-08. No significant trends were found for the field pH.

Wells P03-05-02, P03-05-04, P03-05-05, P03-05-06, and P03-05-08 were chosen for P03-05. All of these locations showed a significant decrease in total alkalinity with the exception of P03-05-05 which does not exhibit a significant trend. Dissolved iron and dissolved magnesium all showed significant increasing trends for all five depth intervals. All depths exhibit a significant increasing trend in sulphate with the exception of P03-05-05, which does not exhibit a significant trend. Dissolved zinc showed a significant increasing trend in the two deepest depth intervals (P03-05-02 and P03-05-04), but no discernible trend in the three shallowest intervals. The field pH showed a significant decreasing trend for locations P03-05-02, P03-05-04, and P03-05-06.

For well P03-06, nested wells P03-06-01, P03-06-02, P03-06-03, P03-06-04, P03-06-05, and P03-06-06 were chosen. In the deepest four depth intervals (P03-06-01, P03-06-02, P03-06-03, and P03-06-04), dissolved iron, dissolved magnesium, dissolved zinc, and sulphate all exhibited significant increasing trends, while total alkalinity and field pH showed significant decreasing trends. The shallowest two depth intervals (P03-06-05 and P03-06-06) were more variable, with no trend for total alkalinity at either depth; increasing dissolved magnesium, dissolved zinc, and sulphate at the P03-06-05 depth; and increasing dissolved iron and decreasing field pH at the P03-06-06 depth. All other parameters at these two depth intervals did not exhibit any significant trends.

Well P03-08 had statistical trend analyses performed on P03-08-02, P03-08-04, P03-08-06 and P03-08-07 locations. Total alkalinity showed a significant increasing trend for locations P03-08-02, P03-08-06, and P03-08-07 and no discernible trend at the other two depths. Dissolved iron showed a significantly increasing trend at P03-08-04 and no trends at any other depth interval. Dissolved magnesium showed a significantly increasing trend at P03-08-02, but significant decreasing trends at the remaining three depth intervals. Dissolved zinc showed significantly decreasing trends at P03-08-02 and P03-08-07 and no trends at the other three depth intervals. The only significant trend for pH was observed at the P03-08-06 depth interval, which showed a significant increasing trend. Sulphate exhibited no trend in the deepest two depth intervals, and a significantly decreasing trend at the upper three depth locations (P03-08-06, P03-08-07, and P03-08-08).

X21-96A and X21-96B is a nested well pair. Both of these showed significant decreasing trends for total alkalinity and field pH and significant increasing trends for dissolved iron, dissolved zinc, and sulphate. Dissolved magnesium showed a significantly decreasing trend for X21-96A, but a significantly increasing trend for X21-96B.

### Summary and Recommendations

Investigations carried out to characterize the materials contained within the RCTA RU include the following key observations:

* Total metals concentrations in the tailings material are greater than both the median world soil content and crustal abundance criteria.
* Total metals concentrations in the underlying RCAA material were much less than the observed concentrations in the tailings material, and indicative of background levels at the FMC.
* Some exceedances of total metals lead and zinc were measured in the organic soil layer immediately underlying the tailings material.
* The tailings material is generally acidic with NP:AP ratios of less than 1.0. Although the organic soils immediately underlying the tailings had near-neutral paste pH, the elevated total sulphur content resulted in a very high calculated acid potential, resulting in net acid generating properties. Thus, while the organic material is certainly impacted from the overlying tailings, the potential to generate acid from this horizon is dubious given the neutral pH of the sample and the lack of complete data for the ABA calculation
* ABA data in the RCTA generally indicate potentially acid generating tailings material overlie heterogeneous alluvial materials, ranging from non acid-generating to potentially acid generating, depending on the pyrite content.
* DI-leach testing on samples from the original tailings material generated a leachate with a final pH that was acidic and contained elevated concentrations of cadmium, copper, lead, and zinc. The final leachate from the Intermediate Tailings Area samples is characterized by acidic leachate with elevated concentrations of copper, iron, lead, and zinc.
* DI-leach test results from the alluvial material underlying the Intermediate Tailings Area resulted in a neutral to alkaline final leachate without any of the trace elements significantly elevated in the solution, indicating that the trace elements detected in the total metal analysis are associated with relatively stable mineral phases that do not readily dissolve.
* Results from sequential extraction analysis identify highly soluble phases of manganese, zinc, and lead in the tailings material and underlying RCAA materials (where total metal content is also elevated).
* Overall the groundwater trends in the RCTA show increasing concentrations of sulphate, dissolved iron, dissolved magnesium, and dissolved zinc.

# Intermediate Dam, Cross Valley Dam, and Cross Valley Dam Pond Remediation Unit

## Field Investigation Activities

Field investigation activities completed in the area that includes the Dams and CVD Pond RU during the 2012 and 2016 field seasons were to support the following objectives:

* Design of a seepage interception system (SIS) to collect groundwater moving through the RCAA, downstream of the ID (CH2M, March 2013m)
* Design of the ID PMF Spillway as part of long-term routing of water around the RCTA (CH2M, April 2016f)

### Borehole Drilling and Monitoring Well Installation

During the 2012 field investigations seven boreholes were drilled in the Dams and CVD Pond area along the proposed CVD SIS alignment. Samples were collected from these borings and selected samples sent to the laboratory for geochemical analyses. The boreholes were completed with 203-mm monitoring wells constructed with schedule 40 polyvinyl chloride (PVC) well casing equipped with 0.04‐inch slot PVC screened section from 6.1 to 18.3 m long; in some cases, they included a sump (up to 6.1 m long), constructed of a section of solid PVC. These wells were intended for use in aquifer testing.

Two boreholes were drilled on the existing ID Spillway during the 2014 field season. Both borings were advanced through the overburden and at least 4.6 m into the bedrock, terminating at a maximum depth of 8.15 mbgs and 16.92 mbgs, respectively. Although these borings were drilled primarily for geotechnical investigation, samples collected in the overburden were selected for geochemical analyses including past pH and total metals.

As additional foundation information was required to support the concept design of the ID PMF Spillway, five boreholes located within, and near, the existing ID Spillway were drilled during the 2015 field season. One of these boreholes is located near the approximate boundary between the RCTA RU and the Dams and CVD Pond RU; however, as these boring were completed at the same time for the ID PMF Spillway design, they are all covered in this section. Two borings were terminated at 27.1 and 24.1 mbgs, respectively, without encountering bedrock, because of the extent of overburden being greater than anticipated. One boring terminated at the top of bedrock at 10.82 mbgs. The remaining two borings were drilled through the overburden and cored into the bed rock at 24.08 mbgs. One monitoring well was installed in each of these borings to allow for future pump testing.

During the 2016 field investigation, sonic borehole drilling occurred on the CVD Pond while it was frozen to collect samples of the sludge on the bottom of the pond. Six sample locations were originally planned; however, recovery was very poor for some samples, so ten in total were collected.

Description of the drilling and monitoring well installation activities, laboratory analyses, and results discussion are presented in the following documents:

* Cross Valley Dam Interception System Investigation Data Report (CH2M, March 2013m)
* Summary of 2014 Field Investigation – Construct Intermediate Dam Spillway (CH2M, March 2015aa)
* Summary of 2015 Field Investigation – Construct Intermediate Dam Spillway (CH2M, April 2016f)
* Summary of 2016 Field Investigation – CVD and ID Pond Field Data Report (CH2M, August 2016c)

### Cone Penetrometer Testing and Sonic Aqualock Sampling

Cone penetrometer testing was performed on both the CVD and ID ponds during the 2016 field investigation. A total of eight gamma seismic cone penetration tests and three gamma flow (ball) penetration tests were performed on the frozen ponds during the winter season. Ball penetration tests were used when the material was too soft for a seismic cone penetration test. Further description of these investigations, the laboratory analyses results, and discussion are presented in the document titled *Summary of Fiscal Year 2015-2016 Field Investigations – CVD and ID Pond Field Data Report* (CH2M, August 2016c).

### Groundwater Sampling

Groundwater sampling events within the Dams and CVD Pond RU were conducted in the summer in 2012, and in early fall in 2013 to 2015 field investigations.

Description of the groundwater monitoring activities, laboratory analyses, and results discussed are presented in the following documents:

* Cross Valley Dam Interception System Investigation Data Report (CH2M, March 2013m)
* 2013 Cross Valley Dam Seepage Interception System Field Investigation Data and Analysis Report (CH2M, February 2014q)
* Summary of 2014 Field Investigation – Site-wide Geochemical Monitoring (CH2M, March 2015b)
* Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring (CH2M, April 2016d)

## Field Investigation Data Evaluation

### Total Metals

Total metal results were compared relative to the 10 times crustal abundance and 12 times median world soil content criteria (Table 6‑1). Very few exceedances were noted in the Dams and CVD Pond area, excluding the samples collected during the 2016 sampling of the tailings beneath the ID Pond (these samples had exceedances for ten different metals, which is expected in tailings materials and therefore not discussed here). Arsenic had the most exceedances, with concentrations exceeding the crustal abundance value of 18 mg/kg in 17 samples from 8 different locations. The highest arsenic concentration recorded was 268 mg/kg, from a sample collected during the drilling of CH12-204-MW002B. No exceedances were noted for any of the key elements of concern for the FMC: cadmium, copper, iron, lead, or zinc. A few exceedances were noted for sulphur and selenium (relative to 12 times crustal abundance only), but generally all samples fell below the two screening criteria.

Boring CH15-201-MW010 was drilled as part of geotechnical investigations to support design for the proposed spillway at the ID Pond Dam. Three samples and one duplicate were submitted for geochemical analyses in addition to the geotechnical investigations. These samples were typical of background soil samples from the FMC and exhibited no exceedances of concern. In addition, two samples had slightly elevated selenium values that exceeded 12 times the average crustal abundance, but were well 10 times mean world soil content. The samples from analyzed from this boring, indicate that location is un-impacted by activities at the FMC.

### Acid Base Accounting

This section describes ABA results from samples collected from six borehole locations to the north of the RCTA near the proposed ID spillway and six borehole locations downgradient of the CVD. Collected in thick unconsolidated sediments overlying bedrock to the north of the RCTA, ABA parameters from this area are characterized by neutral to alkaline paste pH, and NP:AP ratios much greater than 3.0. These sediments are considered net-neutralizing, and are not expected to generate acidic conditions over time. Sediments collected from boreholes located downgradient of the CVD also exhibited net-neutralizing potential, with NP:AP greater than 3.0 and near neutral paste pH. ABA results are presented in Table 6‑2.

### DI Leach

DI-leach testing was conducted on samples collected from the CVD area in an effort to characterize the potential mobility of constituents within the areas immediately downgradient of the CVD Pond. Final leachates from CVD investigation locations (CH12-204-MW001B, CH12-204-MW003B, CH12-204-MW005B, and CH12-204-PZ001) were generally near-neutral with very low dissolved trace element content. However, samples from just below the surface (CH12-204-MW004B\_SOb) and at greater depths (CH12-204-MW002\_SOf) that were subjected to DI-leach testing exhibited acidic leachate and increased concentrations of copper, iron, lead, and zinc. These readily mobile metals may be associated with secondary salt formation beneath the ground surface. The following discussion of sequential extraction results provides additional insight into the partitioning of metals within the solid material collected from the CVD investigation locations. All DI-leach analytical results are presented in Table 6‑3.

### Sequential Extraction

Sequential extractions were conducted on samples collected from boreholes (CH12-204-MW001B, CH12-204-MW002B, CH12-204-MW003B, CH12-204-MW004B, CH12-204-MW005B, and CH12-204-PZ001) downgradient of the CVD. Although the sequential extractions analyze for a full suite of trace metal analytes (Tables 6-4 and 6-5), this section focuses on the key constituents to the FMC area: iron, manganese, zinc, lead, copper, and arsenic. Iron is generally present in the CVD area as one of three dominant phases (Figure 6-1): amorphous oxides (e.g., ferrihydrite), crystalline oxides (e.g., goethite or possibly schwertmannite), or as in the residual fraction (i.e., primary pyrite). However, in two locations (CH12-204-MW002B and CH12-204-MW004B) iron is extracted in the neutral salt exchangeable fraction in substantial proportions (greater than 70 percent in CH12-204-MW004B). Manganese is mainly extracted in the acid-soluble, crystalline oxide, residual fractions, with a notable presence in the neutral salt exchangeable fraction in CH12-204-MW002B. Zinc is generally present in two main phases: crystalline oxide and residual (i.e., primary zinc-bearing sulphides). To a lesser extent, zinc is also associated with the amorphous oxide and acid-soluble fractions. In CH12-204-MW002B, zinc is largely extracted in the neutral salt exchangeable phase, which could suggest association with secondary iron sulfate salt deposits, such as melanterite. Lead is mainly extracted in the acid-soluble, amorphous oxide, and residual fractions. Copper is mainly extracted in the residual and amorphous oxide phases, with a minor component extracted in the neutral salt exchangeable and acid-soluble phases. Arsenic in the CVD area samples is extracted within the residual (i.e., primary minerals) phase, or associated with the crystalline and amorphous oxide fractions. Arsenic is also extracted in the neutral salt exchangeable fraction of CH12-204-MW002B.

### Groundwater Data

There are 36 groundwater monitoring wells associated with the CVD RU that are sampled as part of the yearly fall sampling program. In 2014 and 2015, most monitoring wells were sampled only once a year, during the fall. However, in 2014, monitoring well P09-C2 was sampled in the summer. And, in 2015 monitoring wells P01-11, P05-01-03, P05-01-05, P09-C2, and P09-C3 were also sampled during the summer. A summary of the groundwater sampling data including key parameters can be found in *Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring* (CH2M, April 2016d).

Recent (2012 to present) and historical (pre-2012) groundwater data trends were analyzed using the Mann-Kendall trend test. Statistical analyses were conducted for six key parameters: pH, total alkalinity, sulphate, dissolved magnesium, dissolved iron, and dissolved zinc. These parameters have been identified as geochemically important during previous investigations. The level of significance tested is 95 percent, and any non-detectable concentrations were reduced to half of the detection limit. Mann-Kendall results are summarized in Table 6‑6.

A subset of groundwater wells in the CVD area were chosen for the Mann-Kendall analysis. Several of the wells at the CVD are nested wells with 2 or more different depths, labelled in numerical order with B or -01 being the deepest.

For well P03-09, nested wells P03-09-01 to P03-09-09 were analyzed using Mann-Kendall statistics. Total alkalinity showed a significant decrease in P03-09-01, no significant trend in P03-09-02, and significant increases in the remaining seven nested locations. Dissolved iron showed a significant increase in P03-09-02 and significant decreases in P03-09-08 and P03-09-09; no significant trend in dissolved iron was observed in the remaining five nested wells. Dissolved magnesium showed significant increases at every depth except P03-09-01 and P03-09-05, which did not have significant trends. There are no significant trends in the field pH data except for P03-09-08, which exhibited a significant decreasing trend. Sulphate was shown to be increasing at every depth interval except P03-09-01, which did not exhibit a significant trend. Dissolved zinc shows significant decreases in P03-09-02, P03-09-04, and P03-09-06 and no significant trends at any other depth.

Mann-Kendall analyses were performed on P05-01 locations P05-01-01 to P05-01-06. Results showed a significant increase in total alkalinity at all nested wells except P05-01-01. Dissolved iron, dissolved magnesium, and sulphate all exhibited significantly increasing trends at all depths. Dissolved zinc decreased significantly over time in the deepest sampling intervals (P05-01-01 to P05-01-03), with no significant trends at the remaining depths. The field pH showed significant decreasing trends at every well cluster depth except P05-01-01, which did not have a significant trend.

Mann-Kendall statistics were performed on depths A and B at well CH12-204-MW001. No significant trends were found for any parameters at depth B, while total alkalinity was found to be significantly increasing at depth A.

At well CH12-204-MW002B, dissolved iron, dissolved magnesium, and sulphate were significantly increasing. Well CH12-204-MW003B showed a significantly increasing trend for dissolved iron.

Mann-Kendall statistics were performed on depths A and B at well CH12-204-MW004, but no significant trends were found at either depth.

For well P01-02, nested wells P01-02A and P01-02B were analyzed using Mann-Kendall statistics. Total alkalinity was significantly increasing at both depths. Dissolved magnesium was significantly increasing at P01-02A, while dissolved iron was increasing at P01-02B. There were no additional discernible trends in P01-02A, but field pH and sulphate were both found to have significant decreasing trends in P01-02B.

Well P01-11 showed significantly increasing trends for total alkalinity, sulphate, dissolved iron, dissolved magnesium, and dissolved zinc and significantly decreasing trends for field pH.

At well P05-02, significantly increasing trends were found for total alkalinity, dissolved iron, dissolved magnesium, dissolved zinc, and sulphate. Field pH showed a significantly decreasing trend.

Well P05-03 showed significantly increasing trends for total alkalinity, sulphate, dissolved iron, and dissolved magnesium and significantly decreasing trends for field pH and dissolved zinc.

At well P09-C1, total alkalinity, sulphate, and dissolved iron showed significantly increasing trends, but no trends dissolved magnesium, dissolved zinc, and field pH.

Well P09-C2 showed significantly decreasing trends for dissolved iron, dissolved magnesium, dissolved zinc, and sulphate. Field pH showed an increasing trend.

P09-C3 showed significantly increasing trends for dissolved magnesium and sulphate and a significantly decreasing trend in dissolved zinc. The remaining parameters did not exhibit any significant trends.

Wells MW1, MW2, RGC-PW1, and RGC-PW2 did not have enough data points for any parameters to allow statistical analysis using Mann-Kendall.

### Summary and Recommendations

Results from the Dams and CVD Pond area provide key information on the geochemical properties of the materials in these areas, and provide the following findings:

* With the exception of arsenic, there were very few total metals exceedances noted in the Dams and CVD Pond area.
* The unconsolidated sediments overlying bedrock in the areas directly north of the RCTA, as well as downgradient of the ID and CVD ponds, were net-neutralizing and not expected to generate acidic drainage through time.
* Final leachates from CVD investigation locations were generally near-neutral with very low dissolved trace element content. However, two samples (CH12-204-MW004B\_SOb and CH12-204-MW002\_SOf) exhibited acidic leachate and increased concentrations of copper, iron, lead, and zinc, indicating the possible presence of secondary salt formation beneath the ground surface.
* Sequential extractions were conducted on samples collected from locations downgradient of the CVD. Trace metals present in readily soluble phases (neutral salt exchangeable and acid-soluble) in these samples could be indicative of trace metal association (particularly zinc) with secondary iron sulfate deposits
* The overall groundwater trend in the CVD area indicates increasing total alkalinity, dissolved iron, dissolved magnesium, and sulphate concentrations. There is also a general decreasing trend of pH values.

# Faro Pit Reclamation Unit

The Faro Pit RU encompasses the pit walls and draining areas to the Faro Pit. Because all of the seeps sampled in the Faro Valley Waste Dump flow to the south into Faro Pit and there was no solids investigation of this waste dump, the Faro Valley Waste Dump is included in this RU. Geochemical field investigation activities assigned to the Faro Pit RU are described in this section.

## Field Investigation Activities

Field investigation activities completed within the Faro Pit RU were limited to seep sampling within and around the Faro Pit, which was conducted semi-annually as part of the side-wide seep sampling program, and water quality profiling and depth-specific sampling in the Faro Pit lake that was conducted annually under subcontract by Laberge Environmental Services (Laberge).

There is a total of 42 seepage locations within the Faro Pit RU. Some of these locations have not been sampled since 2012 or earlier because of access restrictions, seepage drying up, or seepage taking a new path and being given a new name. Data collected from some of these accessible seep locations within the Faro Pit RU are in fact used to describe geochemistry in the Faro Mine Area waste dumps; therefore, they are not covered in this section.

Description of the site-wide seep sampling activities, laboratory analyses, and data discussions are summarized in section 3.1.3 and documented in the following reports:

* Activity Code SW-015, Field Sampling Plan for 2012 Seep and Surface Water Monitoring (CH2M HILL, May 2012d)
* 2013 Seep Sampling and Waste Rock Dump Monitoring Data and Analysis Report (CH2M HILL, March 2014c)
* Summary of 2014 Field Investigation – Site-wide Geochemical Monitoring (CH2M, March 2015b)
* Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring (CH2M, April 2016d)
* Summary of 2016 Field Investigation – Site-wide Geochemical Monitoring (CH2M, August 2016j)

Summary reports provided by Laberge on the annual water quality profiling and depth-specific sampling have been included in the afore-mentioned reports as an appendix.

## Field Investigation Data Evaluation

### Seep Sampling

A total of 24 seep locations within Faro Pit were accessed during the fall 2015 seep sampling event, including 16 field parameter-only locations and 8 sample collection locations. Some of these locations were found to be dry or underwater because of rise in the Faro Pit lake level; therefore, only 6 samples and 8 additional sets of field parameters were obtained. The Faro Pit seep analytical data and field parameter results for the 2015 field season can be found in *Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring* (CH2M, April 2016d).

In addition to the seep locations sampled and monitored by CH2M, Laberge has supported the fall sampling event since 2013 and sampled a total of 11 seep locations on the edge of the Faro Pit that are accessible by boat only. Seep sampling activities and observations noted during each sampling event are presented in a summary report, attached to CH2M’s annual seep reports (March 2014c; March 2015b; April 2016d).

Historical seepage data trends were analyzed using the Mann-Kendall trend test, which statistically determines whether a dataset consistently increases or decreases over time. The test requires at least five data points above the detection limit to produce an accurate result. Statistical analyses were conducted for six key parameters: pH, total alkalinity, sulphate, dissolved magnesium, dissolved iron, and dissolved zinc. These parameters have been identified as geochemically important during previous investigations. The level of significance tested is 95 percent, and any non-detectable concentrations were reduced to half of the detection limit. Unless otherwise stated in the summary below, the Mann-Kendall analyses results exhibited no significant trends. Mann-Kendall results tables are found in Table 7‑1.

Historical and current data from a total of 28 seep locations within or around Faro Pit was evaluated for the Mann-Kendall test. Of these 28 seep locations, 12 did not have enough data to perform any statistical analysis. Of the remaining 16 seep locations, 6 (CH-FP-25, CH-FP-37, CH-FP-39, FP07, FP10, and FP18) only had enough data to analyze field pH. With the exception of FP18, all of these locations did not exhibit a significant trend in field pH; FP18 showed a significant decreasing trend, where the field pH value reduced from 8.30 in fall 2009 to 7.72 in fall 2015. The remaining 10 seep locations had enough laboratory analytical data to perform Mann-Kendall analysis on at least a portion of the data set. Mann-Kendall results for location A25 exhibited a significant decreasing trend in total alkalinity, but no trends in any other parameter tested. FP01 showed significant increase in dissolved magnesium and dissolved zinc, but no other trends were observed. FP02 showed a significant decrease in sulphate, but no trends in total alkalinity, dissolved magnesium, or dissolved zinc. There were not enough data points to evaluate dissolved iron or field pH. FP05 showed a significant increasing trend for pH, and a significant decreasing trend for total alkalinity, but no trends in the remaining analytical data. FP06 exhibited significant increasing trends in total alkalinity and dissolved magnesium, but no trends in field pH, sulphate, or dissolved zinc. There was not enough data to evaluate dissolved iron. FP09 showed a significant decrease in total alkalinity and field pH and a significant increase in dissolved magnesium and sulphate. No trend was observed in the dissolved zinc data and there was not enough dissolved iron data to evaluate. There were no trends in seepage data from FP11 or FP12. FP13 showed a significant decrease in dissolved magnesium, sulphate and dissolved zinc, while FP14 exhibited a significant increase in dissolved iron, dissolved magnesium, and sulphate.

Fourteen seep locations flowing into Faro Pit from the Faro Valley Waste Dump were considered for Mann-Kendall evaluation. Of the 14 locations, 3 (CH-FP-22, CH-FP-26, CH-FP-40) did not have enough data to conduct the analysis and another 3 (CH-FP-29, CH-FP-39, CH-FP-42) only had enough field pH to evaluate; there was no trend observed in the 3 locations where only field pH was evaluated. Seep sampling location A30 is one of two major seep locations with the Faro Valley Waste Dump. Total alkalinity and field pH both exhibited significant decreasing trends, while dissolved iron, dissolved magnesium, and dissolved zinc all had significant increases. There was no significant trend in sulphate at seep A30. Location CH-FP-30 exhibited a significant increasing trend for total alkalinity, but no significant trends in the remaining parameters evaluated. Seeps CH-FP-31 and CH-FP-33 did not have any significant trends in any of the parameters evaluated. CH-FP-34 exhibited a significant decrease in dissolved zinc, whereas CH-FP-35 showed a significant decrease in dissolved magnesium and sulphate; other parameters evaluated at these locations did not exhibit any significant trends. CH-FP-36 showed an increase in field pH, but no other trends were observed. Location SRK-FD40 has significant decreasing trends for dissolved iron, dissolved magnesium, dissolved zinc, and sulphate. The remaining trend analyses showed no significant trends. Mann-Kendall analysis results tables for the Faro Valley Waste Dump seeps are found in Table 7-1.

Time-series charts were also plotted for the same six key parameters at 12 locations in the Faro Pit area (Figure 7-1). These confirm the Mann-Kendall results for FP05, and also show increasing trends for sulphate and dissolved magnesium at this location. CH-FP-30 and FP18 were not graphed, however the time-series charts for SRK-FD40 do not show obvious increasing trends for dissolved iron, dissolved magnesium, dissolved zinc, or sulphate as the Mann-Kendall results identify. No other major trends are discernible in the time-series charts.

### Faro Pit Lake Profiling

As reported by Laberge, the most striking change in the Faro Pit lake water quality profile between 2013 and 2015 is the reduction in the fresh water cap at the surface. This observation was particularly apparent in October 2015, when the contrast in conductivity between the surface and deep water was gone, and the conductivity was almost uniform from top to bottom. The temperature of the Faro Pit lake was also quite uniform and was close to the temperature of maximum density adjusted for salinity, (3.7°C). These observations are indicative of the Faro Pit lake being no longer meromictic, and now being mixed from top to bottom.

Water quality profiling and depth-specific sampling activities and observations noted during each sampling event are presented in a summary report, attached to CH2M’s annual seep reports (March 2014c; March 2015b; April 2016d).

### Summary and Recommendations

Long-term seepage and Faro Pit lake monitoring programs have provided the following key findings for the Faro Pit RU:

* Statistically significant increasing pH and decreasing alkalinity observed in seepage location FP05. Other locations have indicated significant decreases in pH. These variations in seepage water quality highlight the variability of mine materials that seepage water encounters along flow paths toward the Faro Pit. These transitions in chemistry are important to the continued understanding of the site, and incorporation into the site wide water quality model.
* Faro Pit lake chemistry has been evolving through time, with recent observations highlighting the reduction of the fresh water cap, and a more uniform, well mixed lake chemistry is observed throughout.

# North Fork Rose Creek

In the winter of 2013, water quality monitoring in the NFRC indicated that seepage of high concentration zinc-contaminated water was impacting the NFRC in the area of the North Fork Rock Drain (NFRD). Following completion of an initial field investigation and preliminary remedial measures to collect the contaminated seepage, it was determined that the NFRC Realignment Project was required to provide necessary protection for the NFRC and Rose Creek, downstream from the FMC. The project consists of realignment of the NFRC, separation of clean and contaminated mine water, and the collection and treatment of mine-impacted water.

This section covers the area of the Faro Mine Area that was investigated for the NFRC Realignment Project. Although most of the area discussed herein falls within the Perimeter RU for the purpose of site-wide remediation, geochemistry data collected in the NFRC area have been presented separately in a report titled *North Fork Rose Creek Geochemical Report* (CH2M, March 2016g) and will be used to support the realignment design of the NFRC. As such, the analyses of this geochemistry data are being presented separately from the rest of the Perimeter RU.

## Field Investigation Activities

Field investigations completed in 2015 for the NFRC Realignment Project were mostly for geotechnical purposes; however, select samples were submitted to the laboratory for geochemical analyses in order to support the overall understanding of geochemical conditions at the FMC.

### Test Pit Excavation

During the 2015 field season, a total of 37 test pits were excavated in the NFRC valley and proposed realigned channel area as part of the NFRC Realignment Project. Selected samples were submitted to ALS Laboratories for geochemical analyses.

Description of the test pit excavation activities, laboratory analyses, and results discussion are presented in the *North Fork Rose Creek Geotechnical Report* (CH2M, March 2016i).

### Borehole Drilling and Monitoring Well and Thermistor Port Installation

A total of 39 boreholes were drilled in the NFRC area during the 2015 field season, including 12 boreholes at the proposed Seepage Collection Pond, and 27 boreholes along the proposed realigned channel. Many of the boreholes were advanced through the soil overburden and into the bedrock for the purpose of geotechnical investigation. Monitoring wells or piezometers were installed in these 37 boreholes. In addition, some of these locations were completed with a nested thermistor monitoring port.

Description of the drilling and monitoring well and thermistor port installation activities, laboratory analyses, and results discussion are presented in the *North Fork Rose Creek Geotechnical Report* (CH2M, March 2016i).

### Groundwater Sampling

Samples were collected from a subset of the NFRC groundwater wells and streambed piezometers and the results and discussion of this groundwater sampling program can be found in Appendix C, North Fork Rose Creek Groundwater Report, to the *North Fork Rose Creek Design Basis Report* (CH2M, August 2016m).

## Field Investigation Data Evaluation

### Solids Data

Total metals analyses were performed on samples collected from the 2015 field season NFRC investigations. In general, the elemental concentrations in samples from the NFRC area fell under the 10 times crustal abundance and 12 times median world soil content criteria established as a screening tool for the FMC. A few localized areas did have elemental concentrations above the two screening criteria. The area with the highest amount of samples exceeding the criteria was near the toe of the NE WRD, in the northern portion of NFRC area.

Eight locations with a total of 13 samples yielded arsenic concentrations that exceeded at least one of the two criteria. The highest concentration of arsenic reported in the NFRC area (98.1 mg/kg), which exceeded both screening criteria, came from a sample collected during the drilling of CH15-107-MW035. This is the only sample that exceeded the 12 times median world soil content criteria while a duplicate of the same sample only exceeded the 10 times crustal abundance criteria. The remaining arsenic exceedances are concentrations which only exceed the 10 times crustal abundance value of 18 mg/kg; the lower of the two standards for arsenic.

One sample from the NFRC area, collected from CH15-107-MW032, exceeded both criteria for cadmium. The concentration of cadmium in this sample was 9.52 mg/kg. Total cadmium in all the remaining samples was lower than both screening criteria (10 times crustal abundance was the lower of the two at 1.5 mg/kg).

One sample from CH15-107-MW034 had an elevated copper concentration, with a reported value of 589 mg/kg, exceeding the 12 times median world soil content criteria of 360 mg/kg; the higher of the two criteria. All remaining samples were lower than both of the criteria for copper. All samples except one also met both the screening criteria for zinc. One sample from CH15-107-MW032 had a zinc concentration of 1,070 mg/kg, which exceeds the crustal abundance criteria of 700 mg/kg.

Select samples also exhibited total concentrations of molybdenum, selenium, silver and sulphur which exceed the lower of the two standards. All total metals results are presented in Table 8‑1.

ABA analysis was completed on 2015 drilling materials collected near the RCD. The upper 5 m of material in two monitoring locations, CH15-201-MW001 and CH15-201-MW003, had acidic paste pH (Table 8-2). Samples collected at depth in all monitoring stations were characterized by near neutral to alkaline paste pH. All samples in the NFRC area analyzed with ABA had very low sulphur (i.e., AP) and generally high NP. As such, every sample analyzed was net-neutral by a significant amount and no acid generation is anticipated from any location sampled.

Leachate tests were completed on selected samples collected during the NFRC borehole drilling and test pit investigations. Monitoring stations installed near the base of the northeast WRDs were characterized by near-neutral leachate containing slightly elevated concentrations of copper, iron, lead, and zinc (CH15-107-MW030, CH15-107-MW032, and CH15-107-MW034) near the surface, and at depth. Two monitoring locations did not show contain readily leachable metals: CH15-107-MW029 (at depth) and CH15-107-MW031.

DI-leach testing was also conducted on samples collected during 2015 drilling near the RCD at monitoring well locations CH15-201-MW002, CH15-201-MW003, and CH15-201-MW005 (Table 8-3). Results from the DI-leach testing from borehole materials collected from CH15-201-MW002 generated an iron-bearing, yet alkaline leachate. At monitoring locations CH15-201-MW003 and CH15-201-MW005, leachate from samples collected between 3.0 and 9.0 mbgs was slightly acidic and contained elevated concentrations of zinc.

### Groundwater Data

Groundwater analytical results from the NFRC study investigation and discussion of these results is presented in Appendix C, North Fork Rose Creek Groundwater Report, to the *North Fork Rose Creek Design Basis Report* (CH2M, August 2016m).

### Summary and Recommendations

A detailed description of the geochemical field investigations in the NFRC area is provided in the North Fork Rose Creek Geochemical Report (CH2M, March 2016k). However, analysis of solids data collected as part of the North Fork Geochemical Report was not previously reported, and is included in this report. Key findings of the data are provided below:

* Increased abundance of total metals arsenic, cadmium, and copper were measured in samples collected from the toe of the Northeast WRD.
* All samples in the NFRC area analyzed contained very low sulphur (i.e., AP) and generally high NP, suggesting net-neutralizing conditions in these materials.
* Monitoring stations installed near the toe of the northeast WRDs were characterized by near-neutral leachate containing elevated concentrations of copper, iron, lead, and zinc near the surface, and at depth. Leachate from samples collected between 3.0 and 9.0 mbgs at monitoring locations CH15-201-MW003 and CH15-201-MW005 was slightly acidic and contained elevated concentrations of zinc.

# Borrow Sources

## Field Investigation Activities

Field activities have been completed across the FMC in search for suitable borrow material that are required for the proposed FMC closure activities. Existing onsite borrow areas and potential future borrow areas have been investigated by means of test pit excavation and borehole drilling. Detailed description of each borrow area and investigation activities completed through the 2014 field season are presented in a report titled *Borrow Baseline Design Criteria Report* (CH2M, March 2015hh).

### Test Pit Excavation

During the 2012 field investigation, shallow test pits were excavated using hand tools in 15 different locations across the site to investigate potential borrow materials. Only limited samples from these test pits were sent for geochemical analyses. Further discussion on the excavation and sampling of these test pits, including geochemical results and discussion, can be found in the report titled *Limited Borrow Material Reconnaissance Faro Mine Remediation Project* (CH2M, June 2013f).

During the 2013 field investigation, 26 test pits were excavated at locations throughout the Haul Road, Rose Creek Haul Road, and Rose Creek borrows to depths of 0.6 to 6.0 mbgs, and samples were taken at selected depths during excavation. Five manual test pits were also excavated in the Rose Creek Borrow using a shovel and grab sampling methods. Selected samples from these excavations were sent to the laboratory for paste pH, total metals, and ABA analyses.

During the 2015 field season, a total of 26 test pits were completed in potential borrow source areas at the FMC, including 13 in the area northwest of the proposed NFRC Seepage Collection Dam, and 13 at the Freshwater Supply Dam. Although these investigations were mainly for the geotechnical purposes, selected samples were submitted to ALS Laboratories for geochemical analyses. Description of the 2015 test pit excavation activities including sampling methodology, laboratory analyses, and results discussion are presented in the *North Fork Rose Creek Geotechnical Report* (CH2M, March 2016i).

### Borehole Drilling

Four boreholes were completed in the Rose Creek Haul Road and Rose Creek Borrows during the 2013 field investigation using a Pionjar drill rig down to a depth of 2.0 mbgs, or refusal, whichever was reached first. Further discussions of the 2013 borrow investigations are presented in the report titled *Faro Water Treatment Plant Geotechnical Design Report Addendum, 2013 Borrow Source and Quarry Investigation* (CH2M, March 2014b).

During the 2015 field season, six boreholes were drilled in the potential borrow area northwest of the proposed NFRC Seepage Collection Dam. Many of the boreholes were advanced through the soil overburden and into the bedrock for the purpose of geotechnical investigation. Description of the 2015 drilling activities, laboratory analyses, and results discussion are presented in the *North Fork Rose Creek Geotechnical Report* (CH2M, March 2016i).

## Field Investigation Data Evaluation

### Solids Data

Total metals analyses were performed on samples collected from the borrow investigations completed in the 2012 to 2015 field seasons. All samples submitted for total metal analysis were below the 10 times crustal abundance and 12 times median world soil content screening criteria used at the FMC for all elements except for samples from test pits in both the Rose Creek Borrow Area and the Fresh Water Supply Dam Area, which had arsenic concentrations exceeding the 10 times crustal abundance criteria of 18 mg/kg, but still lower than the 12 times median world soil content criteria of 72 mg/kg. The concentration of arsenic in these samples was still relatively close to the crustal abundance criteria, with 62.5 mg/kg the highest concentration recorded in the Rose Creek Borrow Area and only 27.4 mg/kg the highest concentration in the Fresh Water Supply Dam Area. All of the samples with arsenic exceedances came from near the surface. All total metals analytical results are presented in Table 9‑1.

Samples collected from the borrow areas were submitted for ABA analysis between 2012 and 2016 to evaluate the potential for proposed borrow source material to generate acidic drainage. With the exception of a few acidic paste pH values measured in samples collected from the pump house ponds area (CH14-403-TP001, CH14-403-TP002, and CH14-403-TP004), the material collected from the various borrow source areas had near neutral to alkaline paste pH and low calculated AP. Ratios of NP to AP in these samples ranged up to about 4,200, indicating net-neutralizing properties (Table 9‑2).

In 2015, shallow samples were collected in the vicinity of the Freshwater Dam and selected samples were sent for ABA analysis. The unconsolidated freshwater dam materials are characterized as non acid generating, with neutral to alkaline paste pH and NP:AP ratios much greater than 3.0 (Table 9‑2).

DI-leach tests were also carried out on selected sample intervals from the general NFRC area borrow source areas. All of the borrow source samples generated neutral to alkaline leachate with very low trace element concentrations. However, a few surface samples at the following locations did generate leachate with elevated arsenic, copper, iron, lead, and zinc: CH15-403-TP008, CH15-403-TP010, and CH15-403-TP014. At all three of these locations, permafrost or cold soils were noted in the test pit logs. These locations are also adjacent to and just below the Haul Road between the Intermediate and Main Dumps. Although the total elemental concentration of these samples is low, the combination of dust or runoff from the Haul Road and the limited penetration and flushing of runoff in these locations because of frozen soil at depth, could explain the presence of secondary sulfate salts in the samples that build-up overtime in the soil. As such, the total metal content is low, but there is enough secondary salt in the soil that it would show up in the first flush (i.e., DI-leach testing). Given that the concentrations in the DI-leach test is not exceedingly high and the total metals are low, these locations are still deemed suitable for borrow material from a geochemical perspective. DI-leach analytical results are presented in Table 9‑1.

## Summary and Recommendations

Geochemical results from the borrow investigations provide supporting documentation for the composition of materials potentially used in construction or remediation. The key characteristics of the borrow materials sampled are listed below.

* Total metals analysis results characterize the borrow material as having total metal concentrations of less than both the 10 times crustal abundance and 12 times median world soil content screening criteria. Arsenic was an exception in shallow test pit samples, however, concentrations were not elevated at significant levels.
* Borrow investigation materials generally were characterized as neutral to alkaline paste pH, low AP, and net-neutralizing NP:AP ratios.
* Leachate generated from the borrow material generally was neutral to alkaline with low trace element concentrations. Potential impacts from the Haul Road and adjacent Intermediate Dump was noted in a few samples where frozen ground limited infiltration and mobility of constituents, and allowed for the buildup of secondary sulfosalts. Further investigation into the role of frozen ground on shallow soil chemistry is warranted to characterize the geochemical processes occurring in these zones.

# Vangorda/ Grum Area

This section discusses the investigations completed in the Vangorda/ Grum Area, which are within the FMC but not encompassed in defined RUs as presented in previous sections. Geochemical data collected in the Vangorda/Grum Area were analyzed to further characterize the FMC materials. Areas discussed in this section include the following:

* Vangorda Pit and Vangorda Waste Dump
* Grum Pit and Grum Waste Dump
* Grum Overburden Dump

## Field Investigation Activities

Previous investigations in the Vangorda/Grum Area reported that till overburden material was excavated from the Grum Pit and placed to the east of the pit into the Grum Overburden Dump. The majority of the Vangorda/Grum field investigations in 2012 and 2013 field seasons were to help confirm this information. Other field investigations included a WRD investigation. As with the Faro Mine WRDs, borehole investigations in the Grum and Vangorda Waste Dumps were conducted in 2012 and 2013. The purpose of these investigations was to increase understanding of geochemical properties and WRD pore-gas profiles.

### Test Pit Excavation

Seven test pits were drilled in the Grum Overburden Dump during the 2012 field investigation. Test pits were advanced to depths of between 4.5 and 6.1 mbgs, and composite soil samples were collected from each test pit. Composite samples were submitted to the laboratory for geochemical analyses. Further discussion can be found in the report titled *Grum Overburden Dump Fatal Flaw Evaluation Data Report* (CH2M, June 2013i).

During the 2013 field investigation, 14 test pits were excavated and 14 surface samples were collected in the Grum Area. Test pits were excavated to a maximum depth of 5.79 mbgs with soil samples collected at various depths during excavation. Surface samples were collected using a shovel from pits dug to a maximum depth of 1 mbgs. All samples from the surface locations and selected samples from the test pits were sent to the laboratory for geochemical analyses. Further discussion of the field investigation including data reporting and analysis can be found in the report titled *Phase II Borrow Reconnaissance* (CH2M, March 2014n).

### Borehole Drilling and Monitoring Well Installation

During the 2012 field investigation, three boreholes were drilled in the Vangorda and Grum areas: CH12-014-MW011 and CH12-014-MW012 in the Grum Waste Dump, and CH12-014-MW013 in the Vangorda Waste Dump. There boreholes were drilled to investigate the geochemical and hydraulic properties of the waste rock, and to monitor soil-gas and temperature profiles in the WRDs. All boreholes were completed with monitoring wells, thermistor ports, and soil-gas ports. Soil samples were collected during drilling and select samples were submitted to the laboratory for geochemical analyses.

Six boreholes were drilled in the Grum Overburden Dump during the 2012 field investigation. The depths of the boreholes ranged from 41.15 to 44.20 mbgs. Composite grab soil samples were collected during drilling of the boreholes at approximately 5-m intervals, and selected samples were submitted to the laboratory for geochemical analyses. The boreholes were backfilled with bentonite chips after reaching the target depth. Further discussion of the 2012 drilling activities including sample analyses results and discussion can be found in the Technical Memorandum *Waste Rock Dump Monitoring Report* (CH2M, October 2013b).

During the 2013 field investigation, 16 boreholes were drilled in the Grum Mine Area. Five of these boreholes were drilled using a sonic rig in the Grum Overburden dump to depths of 50.29 mbgs, ten boreholes were drilled using a Pionjar north of the Grum Pit to a maximum depth of 3.79 mbgs, and one borehole was drilled using the sonic rig drill rig north of the Grum Pit to a depth of 17.7 mbgs. Some of the Pionjar locations did not recover enough material to submit to the laboratory for testing, so in this case hand samples were dug adjacent to the boreholes to supplement the material. Composite soil samples of approximately 1-m-long sections were collected from the sonic boring locations. Selected samples from the locations were submitted to the laboratory for analyses.

### Seep Sampling

Seepage investigation in the Vangorda/Grum Area is part of the side-wide seep sampling program, which was discussed previously in Section 3.1.3. There are 20 seeps associated with the Vangorda Pit and WRD, and 48 seeps associated with the Grum Pit and WRDs (including 3 seeps at the toe of the southern edge of the Grum Waste Dump, along Vangorda Creek).

Description of the seep sampling activities is presented in the following documents:

* Summary of 2014 Field Investigation – Site-wide Geochemical Monitoring (CH2M, March 2015b)
* Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring (CH2M, April 2016d)
* Summary of 2016 Field Investigation – Site-wide Geochemical Monitoring (CH2M, August 2016j)

### Groundwater Sampling

Groundwater samples were collected from the Vangorda/ Grum Area as part of the site-wide groundwater sampling program. A total of five groundwater sampling events were completed in 2014 and two completed in 2015. Description of the groundwater sampling activities is presented in the following documents:

* Summary of 2014 Field Investigation – Site-wide Geochemical Monitoring (CH2M, March 2015b)
* Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring (CH2M, April 2016d)

### Pore Gas and Soil Temperature Monitoring

Pore gas and soil temperature data were collected from all locations within waste dumps where gas ports and thermistor ports (or permanent thermistor strings) were installed. During the 2014 and 2015 field seasons, pore gas and temperature in the Vangorda Waste Dump was monitored at locations 10M4, 30M4, and CH12‑014‑MW013; pore gas and temperature in the Grum Waste Dump was monitored at locations 10M3, CH12-014-MW011, and CH12‑014-MW012.

Description of the pore gas and soil temperature monitoring activities is presented in the following documents:

* Summary of 2014 Field Investigation – Site-wide Geochemical Monitoring (CH2M, March 2015b)
* Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring (CH2M, April 2016d)
* Summary of 2016 Field Investigation – Site-wide Geochemical Monitoring (CH2M, August 2016j)

## Field Investigation Data Evaluation

### Solids Data

#### Total Metals

All the samples analyzed in the Vangorda area came from drilling one borehole, CH12-014-MW013. The majority of samples analyzed from the borehole exceeded the lower of the two standards for, selenium, and silver, and exceeded both the standards for arsenic, cadmium, copper, lead, mercury, sulphur, and zinc (Table 10‑1). Trace element concentrations generally decrease with depth at CH12-014-MW013, however total iron and sulphur concentrations varied significantly with depth (Figure 10-1 and 10-2).

Arsenic concentrations in the Vangorda area averaged 447 mg/kg, and the highest concentration recorded was 728 mg/kg. Cadmium had an average concentration of 23.9 mg/kg, and the highest recorded concentration was 44.8 mg/kg. Average copper concentration in the Vangorda samples was 1,098 mg/kg, and the highest concentration recorded at this location was 2,280 mg/kg. The highest lead value recorded was 14,200 mg/kg, and the average across all samples was 7,102 mg/kg. Average mercury concentration in the samples was 7.71 mg/kg, with a highest concentration recorded of 17.1 mg/kg. Sulphur concentrations had a highest recorded concentration of 252,000 mg/kg with an average of 138,788 mg/kg over all samples. The average zinc concentration was 13,631 mg/kg with a highest recorded concentration 33,000 mg/kg.

The Grum Overburden Dump area had slightly more exceedances, but overall was still below the standards. 16 investigation locations in this area had samples that exceeded one or both of the standards for arsenic. The highest recorded concentration of arsenic was 260 mg/kg and came from a sample collected during the drilling of CH13-311-BH015.

Concentrations of cadmium exceeded the standards in four locations from the Grum Overburden Dump. The highest recorded concentration was also in a sample collected from CH13-311-BH015, with a concentration of 8.43 mg/kg, exceeding both standards.

Nine locations in the Grum Overburden Dump contained samples that exceeded the standards, and the majority of these samples exceeded both of the standards. The highest concentration came from a sample collected during the drilling of CH13-311-BH014, with a lead concentration of 2,000 mg/kg.

Zinc concentrations exceeded the standards in samples from five investigation locations. The highest concentration recorded was 6,490 mg/kg in a sample collected from CH13-311-BH014, which exceeds both of the standards.

The locations in this area which contained the most exceedances are CH12-311-BH004, CH13-311-BH013, CH13-311-BH014, CH13-311-BH015, and CH13-311-TP004. Excluding CH13-311-TP004, these investigation locations are all in the same area of the Grum Overburden Dump.

In the Grum Waste Dump area, samples were collected from two boring locations. Elemental concentrations in these two locations were generally consistent with depth, excluding total lead which increased with depth at both locations (Figures 10-3 through 10-6). The majority of these samples fell under both standards. Select samples from both locations exceeded the lower of the two standards for arsenic, and the highest recorded concentration was 38.1 mg/kg. The only exceedance for lead was in a sample from CH12-014-MW011, and exceeded both standards with a concentration of 467 mg/kg. Selenium, antimony, silver, and sulphur each had at least one sample exceeding the lower standard.

Similar to the Grum Waste Dump, the Grum Pit area and remaining area surrounding the Grum site also had very few exceedances. One arsenic exceedance was recorded in the sample collected at CH13-311-SS031 near the Grum Pit with a value of 19.3 mg/kg, exceeding crustal abundance standard of 18 mg/kg, which is the lower of the two standards for this metal. Arsenic exceedances were also recorded in four locations in the surrounding Grum area. Three locations contained exceedances for selenium, CH13-311-SS028, CH13-311-SS029, and CH13-311-BH010. These were the only reported exceedances in the Grum Pit and surrounding Grum area.

#### Acid-base Accounting

ABA parameters measured in the general area of the Grum mine, including the Grum Pit, waste dump, and overburden dumps highlight the near neutral paste pH and net acid neutralizing NP:AP greater than 3.0) characteristics of the Grum mine materials. ABA analyses were not carried out on materials collected from the Grum Sulphide Cell.

In contrast, the Vangorda mine materials are characterized by acidic paste pH and NP:AP ratios of less than 1.0. Only one weathered bedrock sample (CH12-014-MW013\_SOh) was analyzed for ABA parameters and was characterized as potentially net acid neutralizing with a slightly acidic paste pH and NP:AP ratio greater than 3.0.

All ABA results are presented in Table 10‑2.

#### DI Leach

DI-leach tests were completed on material sampled from boreholes drilled in the Grum Overburden Dump area. With the exception of mobile forms of arsenic in a few discrete samples collected from boreholes, leachate results show neutral to alkaline conditions and limited mobility of trace metals in the subsurface materials. Similar results were exhibited in surface samples collected from the Grum Overburden Dump test pit excavations, with isolated occurrences of mobilized arsenic, lead and zinc, measured in the neutral to alkaline leachate.

In contrast, results from DI-leach testing on materials collected from borehole CH14-014-MW013 indicate acidic leachate, with mobile trace metals cadmium, iron, lead, and zinc at depths greater than 9 mbgs. Surficial samples collected in shallow boreholes near the Vangorda Waste Dump showed increased potential for arsenic, copper, lead, and zinc to mobilize.

All DI-leach analytical results can be found in Table 10‑3.

#### Sequential Extraction

Sequential extraction tests were completed on samples collected from boreholes CH14-014-MW011, CH14-014-MW012, and CH14-014-MW013 to characterize the mobility and mineralogic association of trace metals within the solid material contained within the Grum and Vangorda waste dumps (Tables 10‑4 and 10-5). Although the sequential extractions analyze for a full suite of trace metal analytes, this section focuses on the key constituents to the FMC area: iron, manganese, zinc, lead, copper, and arsenic. Iron is generally present in the Grum and Vangorda waste dumps as one of three dominant phases (Figure 10-7): amorphous iron, crystalline iron oxides (e.g., schwertmannite), or as primary pyrite (residual). Manganese mainly occurs as readily dissolved acid-soluble phases (such as carbonate minerals), amorphous, and primary mineral phases. The presence of zinc in the Grum Waste Dumps is associated with amorphous iron, crystalline oxides, and primary zinc sulphide (sphalerite). In the Vangorda Waste Dump, greater than 80 percent of the zinc occurs as primary sulphide minerals. Lead occurs in both Grum and Vangorda waste dumps as acid-soluble phases, primary minerals (galena), and in some samples collected from the Grum Waste Dump, lead is associated with amorphous iron mineral deposits. Grum Waste Dump samples contain copper associated with primary sulphide minerals and amorphous iron, and a minor presence of copper present in neutral salt exchangeable and acid-soluble phases. Copper is mainly present in primary sulphide minerals at the Vangorda Waste Dump, with a minor fraction associated with amorphous iron and acid-soluble phases. Arsenic in the Grum and Vangorda samples is not contained in readily soluble salts. Instead, arsenic is predominantly found in amorphous, crystalline oxide, and primary mineral phases.

### Seepage Data

There are 82 seeps that are associated with the Vangorda/Grum Area. Seeps are sampled twice a year, once during the spring close to freshet, and once during the fall. The analytical data and field parameter results along with a summary of some key parameters can be found in *Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring* (CH2M, April 2016d). All seep analytical data was compared to freshwater quality guidelines established in the Canadian Environmental Quality Guidelines (CCME, 2016).

Historical seepage data trends were also analyzed using the Mann-Kendall trend test, which statistically determines whether a data set consistently increases or decreases over time. The test requires at least five data points above the detection limit to produce an accurate result. Statistical analyses were conducted for six key parameters: pH, total alkalinity, sulphate, dissolved magnesium, dissolved iron, and dissolved zinc. These parameters have been identified as geochemically important during previous investigations. The level of significance tested is 95 percent, and any non-detectable concentrations were reduced to half of the detection limit. A summary of the Mann-Kendall results is presented in Table 10‑6.

#### Grum Waste Rock Dump

There are 26 seep locations associated with the Grum Waste Dump. Of the 26 seep locations, 6 locations did not have enough data for any statistical evaluation and 5 locations (SRK-GD08, SRK-GD10, SRK-GD12, SRK-GD20, SRK-GD23) only had enough field pH data to evaluate; no trends in the field pH data from these five locations was observed. Five of the remaining seep locations (GD05 d/s, SRK-GD16, SRK-GD24, Sweet Creek, and WTA02) had enough data to evaluate with Mann-Kendall, but no significant trends were observed in any of the parameters evaluated. Mann-Kendall results from the remaining 10 seeps indicate very few statistical trends. Sheep Creek exhibited a significant increase in dissolved zinc, but no other trends. SRK-GD01 showed a significant increase in dissolved magnesium and sulphate and a significant decrease in dissolved zinc. SRK-GD02 exhibited a significant increase in dissolved magnesium, but not other significant trends. SRK-GD05 showed a significant increase in total alkalinity, dissolved magnesium, and sulphate with a significant decrease in dissolved zinc. SRK-GD06 exhibited an increase in dissolved magnesium and sulphate. SRK-GD07 showed an increase in total alkalinity, but did not exhibit any other significant trends. SRK-GD11 and SRK-GD13 exhibited a significant increase in total alkalinity, dissolved magnesium, and sulphate, but no other significant trends. Mann-Kendall analysis on concentrations at location V15 show statistically increasing total alkalinity, dissolved magnesium, and dissolved zinc, and decreasing values of field pH. WGD01 showed a significant increase in dissolved magnesium, but no other trends were observed. Figure 10-8 shows time trend graphs for the same key parameters for locations SRK-GD01, SRK-GD05, SRK-GD15, and V15. This contradicts the Mann-Kendall results for V15, as the charts show almost stable dissolved zinc. Other noticeable trends in Figure 10-8 are increasing sulphate over time at SRK-GD05 and SRK-GD13, and increasing dissolved zinc at SRK‑GD13.

#### Vangorda Waste Dump

There are ten seep locations in the Vangorda Waste Dump area. Two seep locations (SRK-VD01 and SRK‑VD12) did not exhibit any significant trends in the Mann-Kendall analysis. SRK-VD05, SRK-VD06, and SRK-VD07 have a significant decrease in field pH, but no other significant trends. SRK-VD02 showed a significant decrease in total alkalinity and a significant increase in dissolved iron and dissolved zinc, with no other trends observed. SRK-VD003 exhibited an increase in dissolved iron, dissolved magnesium, sulphate, and dissolved zinc and a decrease in field pH. SRK-VD04 showed an increase in dissolved iron and field pH. SRK-VD09 also exhibited an increase in dissolved iron, but had a decrease in field pH. SRK-VD10 exhibited a significant increase in dissolved iron, dissolved magnesium, and sulphate, but no trends in dissolved zinc or field pH. Figure 10-9 shows time-series plots for all six parameters for seep locations SRK-VD01, SRK-VD02, SRK-VD03, SRK-VD04, and SRK-VD05. These charts help to confirm the results of the Mann-Kendall analyses. From the time-series charts it is also evident that SRK-VD04 and SRK-VD05 have increasing concentrations of sulphate, dissolved iron, and dissolved magnesium.

#### Grum Pit

The Grum Pit area has 28 seepage locations (Table 10-6). Of the 28 seep locations, 8 did not have enough data to perform the Mann-Kendall test. Of the 20 seep sampling locations with data, 11 only had enough field pH data to evaluate, and no significant trends were found at any of these locations. Of the remaining 9 seep sampling locations, four locations (CH-GP-19, GP04, GP08, and GP12) did not have a significant trend in any parameter evaluated. GP02 exhibited a significant increase in dissolved iron and decrease in field pH. GP03 showed a significant increase in dissolved magnesium. GP07 had a significant decrease in field pH, but all other parameters evaluated did not exhibit a significant trend. GP09 showed a significant increase in total alkalinity, while GP10 had a significant increase in dissolved iron. Four seep locations (GP02, GP09, GP12, and V23) were plotted over time for the same six key parameters, and help to confirm the Mann-Kendall results (Figure 10-10). They also show decreasing concentrations of sulphate at GP12.

#### Vangorda Pit and In-pit Dumps

The Vangorda Pit area has 16 seepage locations. The only statistical trend calculated in this area was for pH values at VP10, which are significantly decreasing over time. The remaining locations and parameters either did not have enough data points to perform the analysis, or no significant trends were found. Four of the seepage locations (CH-VP-17, CH-VP-18, CH-VP-20, and VP09) were plotted on time-series charts for the same six key parameters (Figure 10-11). These charts show increasing trends of sulphate, dissolved magnesium, and dissolved iron at location VP09.

### Groundwater Data

In 2012, CH2M installed two groundwater monitoring wells in the Grum Waste Dump (CH12-014-MW011 and CH12-014-MW012) and one groundwater monitoring well in the Vangorda Waste Dump (CH12-014-MW013). The monitoring wells are sampled and monitored three times a year: once during the winter or spring, once in the summer, and once during the fall. The analytical data and field parameter results can be found in Table 10‑7, and a summary of some key parameters can be found in *Summary of 2015 Field Investigation – Site-wide Geochemical Monitoring* (CH2M, April 2016d). All groundwater analytical data was compared to groundwater quality guidelines established in the Canadian Environmental Quality Guidelines (CCME, 2016).

Historical groundwater data trends were also analyzed using the Mann-Kendall trend test. Statistical analyses were conducted for six key parameters: pH, total alkalinity, sulphate, dissolved magnesium, dissolved iron, and dissolved zinc. These parameters have been identified as geochemically important during previous investigations. The level of significance tested is 95 percent, and any non-detectable concentrations were reduced to half of the detection limit. A summary of the Mann-Kendall results for the groundwater locations is presented in Table 10‑8.

#### Vangorda Waste Rock Dump

CH12-014-MW013 showed increasing trends for total alkalinity, dissolved magnesium, and sulphate with no significant trends for the remaining parameters.

#### Grum Waste Rock Dump

CH12-014-MW011 and CH12-014-MW012 both exhibited increasing trends for total alkalinity and no significant trends for any other parameter tested.

### Temperature and Pore Gas Data

There are six waste dump pore gas and temperature monitoring locations associated with the Vangorda Grum mine area, including three locations in the Grum Waste Dump and three locations in the Vangorda Waste Dump. Monitoring was completed at these locations from 2003 to 2016. A discussion of the general trends are presented in the following sections. The soil temperature profiles and graphs showing the relationships between depth and oxygen concentrations are provided on Figures 10-12 through 10‑17.

#### Vangorda and Grum Waste Rock Dumps

##### CH12-014-MW011

Temperature varied the most in the top 10 mbgs during the observed years, with the most variation observed at the surface. The temperature at the surface generally ranged from -3 to 15°C and reached a temperature of 3°C below 10 mbgs. Oxygen concentrations remained fairly consistently between 19  and 21 percent throughout the measure depths and seasons.

##### CH12-014-MW012

Temperature varied the most in the top 8 mbgs during the observed years, with the most variation observed at the surface. The temperature at the surface generally ranged from -3 to 14°C and reached a temperature of 4.5°C below 8 mbgs. Oxygen concentration measurements were fairly steady between the different seasons: typically around 12 percent at 5 mbgs (the shallowest measurement depth), decreasing to about 2 percent at a depth of 10 mbgs, then continuing to increase to 21 percent at a depth of 18 mbgs.

##### CH12-014-MW013

Temperature generally climbed from between the depth of 2.45 mbgs (the shallowest measurement depth) to 12.45 mbgs and slowly decreased to a depth of 25 mbgs. The temperature ranged from -2 to 21°C from 2.45 to 12.45 mbgs and from 21 to 15°C from 12.45 to 25 mbgs. Oxygen concentration was approximately 20 percent from 5 to 20 mbgs and dropped to nearly 0 percent at 25 mbgs.

##### 10M3

The temperature varied between -5 and 10°C above the depth of 10 mbgs and typically reached a temperature of 5°C at a depth of 10 mbgs (the deepest measurement depth). Oxygen concentrations generally dropped from 20.5 percent at 0.7 mbgs (shallowest measurement depth) to approximately 15 percent at 3 mbgs, and increased to approximately 17 percent below 5.6 mbgs.

##### 10M4

The temperature generally decreased through the measured depths and ranged from -4 to 15°C. The temperatures measured in 2003 were significantly higher than in the subsequent years. Oxygen concentrations appeared to increase to a depth of 1.4 mbgs from as low as 14.3 percent and remained fairly consistent with depth at approximately 20 percent below 1.4 mbgs.

##### 30M4

Temperature varied the most in the top 5 mbgs during the observed years, ranging from -5 to 15°C. The temperature continued to increase from near surface to 20 mbgs. At 20 mbgs, the temperature was typically 20°C and the temperature decreased slightly to the deepest measured depth at 30 mbgs. Oxygen concentrations decreased quickly from saturation near the surface to near depletion at 2.8 mbgs. Below 2.8 mbgs the oxygen concentration increases to a maximum of 3 to 8 percent at 10 mbgs before decreasing to near depletion at 20 mbgs. At the bottom of the hole, the oxygen concentrations range from near depletion to approximately 15 percent with most measurements falling below approximately 5 percent.

## Summary and Recommendations

Results from data collected as part of the various field investigations in the Vangorda and Grum areas are summarized below:

* Representative samples collected from the Vangorda Waste Dump contained greater content of arsenic, cadmium, copper, lead, mercury, sulphur, and zinc than both of the reference criteria, with greater concentrations in the waste rock near the ground surface.
* The Vangorda Waste Dump area contains net acid generating properties, based on ABA data.
* Materials from the Vangorda Waste Dump have the potential to generate acidic leachate, with mobile trace metals arsenic, copper, lead, and zinc in the shallow WRD, and cadmium, iron, lead, and zinc at depths greater than 9 mbgs.
* Selected samples collected from the Grum Overburden Dump, Grum Waste Dump, and Grum Pit area contained greater abundance of arsenic, cadmium, zinc, and lead.
* The material contained within the Grum Waste Dump is characterized by near-neutral paste pH and net acid neutralizing materials.
* Materials from the Grum Overburden Dump area are expected to generate neutral to alkaline leachate conditions, and limited mobility of trace metals. However, shallow samples collected from test pits showed increased potential for trace metal mobility, specifically arsenic, lead, and zinc.
* Sequential extraction results from both Vangorda and Grum materials identify potential mobile fractions of copper, manganese, and lead. Greater than 80 percent of the zinc present in the Vangorda Waste Dump materials is in the residual (sulphide mineral) phase.
* In general, seepage water quality in the Vangorda Waste Dump and Vangorda Pit show trends of increasing sulphate, magnesium, dissolved iron, and dissolved zinc, and decreasing pH. Similar trends have also been observed in Vangorda Waste Dump groundwater.
* Seepage water quality of the Grum Waste Dump through time shows increasing concentrations of magnesium and stable values of dissolved zinc. Increases in alkalinity and magnesium concentrations have also been noted in Grum Waste Dump area groundwater. Observed increases in sulphate concentration have been noted at SRK-GD01, SRK-GD05, SRK-GD06, SRK-GD11, and SRK-GD013. Increases in dissolved zinc were observed at Sheep Creek and V15. In the Grum Pit, observed decreasing pH has been noted at GP02 and GP07.

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Tables

Figures