Groundwater Analysis of 2014 - 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

August 2016

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Contents

Section Page

[Acronyms and Abbreviations v](#_Toc459985715)

[1 Introduction 1-1](#_Toc459985716)

[1.1 Purpose 1-1](#_Toc459985717)

[1.2 Scope of Work 1-1](#_Toc459985718)

[1.3 Application of the Groundwater Flow Model to this Analysis Report 1-2](#_Toc459985719)

[2 Perimeter Remediation Units 2-1](#_Toc459985720)

[2.1 Field Investigation Activities 2-1](#_Toc459985721)

[2.2 Perimeter West – Field Investigation Data Evaluation 2-1](#_Toc459985722)

[2.3 Perimeter East – Field Investigation Data Evaluation 2-2](#_Toc459985723)

[2.3.1 Hydrostratigraphy Summary 2-3](#_Toc459985724)

[2.3.2 Aquifer Properties and Volumetric Discharge 2-4](#_Toc459985725)

[2.3.3 Faro Creek Valley Water Budget 2-5](#_Toc459985726)

[2.3.4 Permafrost 2-5](#_Toc459985727)

[2.3.5 Groundwater and Surface Water Interaction and Water Balance 2-6](#_Toc459985728)

[2.3.6 Summary and Recommendations 2-8](#_Toc459985729)

[2.4 Perimeter South – RCD Field Investigation Data Evaluation 2-9](#_Toc459985730)

[2.4.1 Model Results 2-9](#_Toc459985731)

[3 Waste Rock Dump Remediation Unit (Includes Faro Pit RU) 3-1](#_Toc459985732)

[3.1 Field Investigation Activities 3-1](#_Toc459985733)

[3.2 Field Investigation Data Evaluation 3-1](#_Toc459985734)

[3.2.1 Groundwater Elevation and Faro Pit Lake Elevation 3-2](#_Toc459985735)

[3.2.2 Model Results 3-3](#_Toc459985736)

[3.3 Summary and Recommendations 3-4](#_Toc459985737)

[4 Mill Building Area and Emergency Tailings Area Remediation Unit 4-4](#_Toc459985738)

[4.1 Field Investigation Activities 4-4](#_Toc459985739)

[4.2 Field Investigation Data Evaluation 4-4](#_Toc459985740)

[5 Rose Creek Tailings Area Remediation Unit 5-4](#_Toc459985741)

[5.1 Field Investigation Activities 5-4](#_Toc459985742)

[5.2 Field Investigation Data Evaluation 5-4](#_Toc459985743)

[6 Dams and Cross Valley Dam Pond Remediation Unit 6-4](#_Toc459985744)

[6.1 Field Investigation Activities 6-4](#_Toc459985745)

[6.2 Field Investigation Data Evaluation 6-4](#_Toc459985746)

[7 References 7-4](#_Toc459985747)

Figures

2-1 Perimeter Unit East (FCD) Location Map

2-2 Perimeter RU Flow Budget

2-3 Site-wide Bedrock-Alluvium Exchange

2-4 Site-wide Groundwater Flow Paths Lines

2-5 Perimeter Unit East (FCD) Location Map and Inferred Groundwater Contour

2-6 Stream Flow Measurements – FCO, FCD‑1, FCD‑2

2-7 FY2013 Perimeter South - RCD Investigation Locations

3-1 WRD RU Investigation Location

3-2 Monitoring Well CH12-014-MW007 Groundwater Elevations

3-3 Faro Pit, Zone II Pit and Monitoring Well Water Elevations

3-4 Faro Pit and Waste Rock Dump RU Flow Budget

4-1 ETA Location Map

4-2 Mill/ETA Groundwater Flow Budget

5-1 RCTA Location Map

5-2 RCTA Tailings Flow Budget

5-3 RCTA Alluvial Aquifer Flow Budget

Acronyms and Abbreviations

2D two-dimensional

3D three-dimensional

CDRM Comprehensive Design Road Map

CSM conceptual site model

CVD Cross Valley Dam

ETA Emergency Tailings Area

FCD Faro Creek Diversion

FMC Faro Mine Complex

FY Fiscal Year

GFM groundwater flow model

GW groundwater

ID Intermediate Dam

Kh horizontal hydraulic connectivity

Kv vertical hydraulic conductivity

L/s litre(s) per second

m metre(s)

m/d metre(s) per day

masl metre(s) above sea level

mbgs metre(s) below grade

mm/yr millimetre(s) per year

NFRC North Fork Rose Creek

NWID North Wall Interceptor Ditch

RCD Rose Creek Diversion

RCTA Rose Creek Tailings Area

RU remediation unit

SIS seepage interception system

Ss Specific Storage

Sy Specific Yield

SW surface water

UGC Upper Guardhouse Creek

WRD waste rock dump

WVID West Valley Interceptor Ditch

YG Government of Yukon

# Introduction

## Purpose

Hydrogeologic-related field work completed during Fiscal Year (FY) 2014 through FY2016 at the Faro Mine Complex (FMC) has been documented in field data reports that included limited data evaluation and analyses. This Comprehensive Design Road Map Report (CDRMR) Appendix D provides hydrogeologic analyses not included in those field data reports, ties the analyses to data collected during previous investigations, and summarizes the results of recent hydrogeological modelling conducted for the site.

## Scope of Work

Groundwater (GW) data collected at the FMC since the 1990s have been used to develop and refine a numerical groundwater flow model (GFM) that simulates subsurface flow processes in the FMC. The underlying conceptual site model (CSM) used as a basis for development of the GFM is documented in the *Conceptual Site Model, Faro Mine Remediation Project* (CH2M, August 2012a) and several subsequent reports (CH2M, March 2013o, March 2013f, March 2013n, March 2013m, February 2014q, March 2014i, November 2014k, March 2015gg, RGC, 2015). The *FY2015 Groundwater Flow Model Development Repor*t (CH2M, March 2016e) documents the development and calibration of a refined transient GFM, which was developed to support the design of the NFRC Realignment Project and could be applied site-wide to the Faro Mine Remediation Project.

The GFM has incorporated field data collected through September 2015, including boring logs, geological cross sections, geophysical testing, aquifer testing, as well as regional surficial geological and bedrock geology mapping. This CDRMR Appendix D presents results from GFM simulations to assess GW budgets, GW flow directions, and GW exchange with surface water (SW).

The descriptions of the hydrogeologic system presented in this report represents steady-state conditions based on the spatial and temporal distribution of available hydrogeologic data incorporated into the GFM. It should be noted that the accuracy of the model is highly dependent on the density and accuracy of the field data.

The estimated GW flux values presented in the water budget summary results support the overall understanding of GW movement across the site. These results can be used to assist in decision making for prioritizing remediation efforts as well as to plan additional subsurface investigations in areas where significant data gaps exist. In viewing the results of this modelling, the reader should consider that mathematical models can only approximate physical systems and processes, models are inherently inexact, and the understanding of interrelated physical and chemical processes is incomplete. Furthermore, the collection of additional data will likely lead to revisions in the underlying model assumptions (e.g., material distribution, material properties) and will likely lead to changes in model results. The document *FY2015 Groundwater Flow Model Development Report* (CH2M, March 2016e) provides a more in-depth discussion regarding specific limitations associated with the use of the FMC GFM.

This report is organized in accordance with remediation unit (RU) boundaries proposed for the site. The FMC consists of three main areas, the Faro Mine Area, the Rose Creek Tailings Area (RCTA), and the Vangorda/Grum Area. Each area has been subdivided into RUs based on location, contaminate sources and characteristics, topography, and site-wide remediation objectives*.* The RUs are organized as follows:

* Perimeter (freshwater diversions, subdivided into west, east, and south)
* Waste dumps (as an RU, referred to as the waste rock dump [WRD] RU)
* Faro Pit RU
* Mill Building Area and Emergency Tailings Area (ETA)
* RCTA (including Lower Guardhouse Creek)
* Dams and the Cross Valley Dam (CVD) Pond

Note that the East Perimeter RU includes the Faro Creek Diversion (FCD) and the North Fork of Rose Creek (NFRC). Analysis of hydrogeologic data and modelling related to design of the NFRC Realignment Project is discussed in detail in the *Final North Fork Rose Creek Design Basis Report* (CH2M, August 2016l) and is only discussed in this appendix as pertinent to areas adjacent to NFRC. Also, because of the close proximity and interaction between the WRD RU and Faro Pit RU, for this appendix these RUs are discussed together in Section 3.

In FY2014, FY2015, and FY2016, groundwater-related field work was completed in three of the RUs: the Perimeter, the WRD, and the RCTA. Sections 2 through 6 of this report provide a brief summary of the field work performed, if applicable, and a discussion of the data evaluation and interpretation, including a summary of GW flow paths, flux, and water budgets using results of the steady-state GFM.

## Application of the Groundwater Flow Model to this Analysis Report

The steady-state and transient GFM (CH2M, March 2016e) was developed and calibrated to support the design of the CVD SIS and the NFRC Realigned Channel Project. While the GFM is capable of evaluating changes in GW conditions both spatially and temporally, the results presented in this report pertain to steady-state conditions, representing long term average conditions of the hydrologic system rather than short-term transient conditions. The averaging period used to calibrate the steady-state version of the GFM, water years 2008 through 2015, was selected based on the availability of hydrogeologic data, including precipitation records, GW levels, streamflow measurements, and pond and pit stages.

A numerical model domain is discretized to represent the real world continuous space of a hydrologic system. To maximize the resolution of the numerical solution in areas of interest, while minimizing model run times, the model domain is subdivided into grid blocks of various sizes. Denser, smaller grid blocks are incorporated into the modelling domain where more resolution in the numerical solution is desired, whereas larger grid blocks are used in areas of the modelling domain located away from the main areas of interest. The model grid sizing (horizontal and vertical spacing) is documented in the GFM Development Report (CH2M, March 2016e). The horizontal cells range from 100 metres (m), the uniform value initially assigned throughout the modelling domain, to 12.5 m in the NFRC corridor near the waste dumps, ETA, Rose Creek Diversion (RCD), and CVD area. These subareas were viewed as areas where enhanced cell resolution would facilitate calibrating to local-scale features and allow for enhanced resolution in model output in priority areas around the NFRC and CVD. Cells representing Faro Creek, FCD, waste dumps, Faro Pit, the northern reach of NFRC, and the area between the waste dumps and X14, including the RCTA, have 25-m cell spacings.

All relevant field data collected through September 2015 were used in the GFM to assign material properties. Defined input values include cell-by-cell horizontal and vertical hydraulic conductivity (Kh and Kv respectively), Specific Yield (Sy) and Specific Storage (Ss). Assignment of Kh and Kv values throughout the GFM (CH2M, March 2016e) involves assigning material properties consistent with data resulting from slug tests, packer tests, aquifer tests, professional judgment, and previous calibration efforts (CH2M, 2013o, 2014i, 2016e) and then modified during the calibration process. Only the transient version of the GFM requires Ss and Sy input values. These values were initially assigned for each model layer based on the interpretation of aquifer testing data and supplemented by literature values for similar geologic materials. The GW storage coefficient for a given cell is computed internally based on the layer type (i.e., confined versus convertible and between confined and unconfined) and the simulated GW level within that cell.

Initial and boundary conditions are also informed by the data collected during the completed field investigations and are described in the GFM Development Report (CH2M, March 2016e). The assignment of an initial head value at each active cell within the model domain was informed by the GW elevation data from site wells, however, these only represent a small fraction of the entire GFM domain.

Boundary conditions for GFM are mathematical statements (i.e., rules) that specify head or GW flux at particular locations within the model domain. Boundary conditions include specified head, specified flux, and head-dependent flux. Specified head boundary conditions are specified from observed water elevations in Faro Pit, the Intermediate Dam (ID) Pond, and the CVD Pond. Specified flux boundaries add or remove a specified volumetric flow to or from a model cell. They were used to define water pumped from wells or trenches. Water is currently pumped from three wells and two sumps in the model domain: Well CH12‑Z2‑PW001 in the buried Zone II Pit and Wells SRK08-SPW1 and SRK08-SPW2 in the S-Wells SIS. The extraction from Well SRK08-SPW3 in the S-Wells SIS and the ETA extraction system, represented by flow at FCS-4, are both conceptualized as sumps whose outflow depend on the heads near that boundary. As such, these are head-dependent. Extraction rates were taken from recorded site data and previous studies (CH2M, March 2015gg).

The flow budget figures presented in this report include the potentiometric surface of the water table. The flow budget summarizes the net flux of the first three model layers. In some instances, the direction of flow implied by the net flux arrow does not appear consistent with the direction of GW flow implied by the GW contours. This discrepancy is an artifact of depicting a three-dimensional (3D) flow system on a two-dimensional (2D) figure.

The following is relevant to the discussion on water balances presented for Faro Pit (in Section 3), the ID Pond (in Section 5), and the CVD Pond (in Section 6):

* The pumping associated with Faro Pit and the CVD and ID ponds is not actively simulated in the steady-state model. The water balance is representative of long-term average conditions.
* GW-SW exchange is governed by the difference between the assigned stages in these SW bodies, the modelled heads in the underlying aquifer, and the hydraulic conductivity of the bottom sediments in these SW bodies.

GW and SW exchanges are presented for selected reaches in each RU. Along a stream reach there can be gaining and losing components, however, for the purposes of presentation clarity, only the net flux is shown. GW and SW fluxes within the selected reaches are calculated and indicated by purple lines perpendicular to the channel. These stream reach dividers include a small buffer around the rivers (creeks) to capture GW seepage to the ground surface (which would then briefly flow overland to the nearby surface water body).

The convention used to describe boundary fluxes in this document is aquifer-centric. That is, inflow is flow from a boundary to the aquifer, outflow is flow from the aquifer to a boundary, and the net flow is the inflow minus the outflow.

# Perimeter Remediation Units

## Field Investigation Activities

Field investigations completed within the Perimeter RU in FY2014, FY2015, and FY2016 include the following:

* FY2015 FCD Seepage Investigation (CH2M, March 2016d): To support the understanding of hydrostratigraphy, aquifer properties, soil geotechnical and geochemical properties, and hydraulic gradients within the Faro Creek valley, CH2M completed drilling and monitoring well installation in November 2015.
* FY2016 FCD Seepage Investigation (CH2M, August 2016h): A continuation of the FY2015 work, GW sampling, stream stage monitoring, and aquifer testing was completed in June FY2016.
* FY2015 FCD Realignment Investigation: The remediation design concept for the FCD is to realign the existing diversion upslope from its current alignment to mitigate potential failure of the diversion resulting from pit wall erosion or slope failure into Faro Pit. The purpose of the investigation was to collect data to evaluated short term and long term pit wall stability. The investigation began in early March 2016. Data were collected pertaining to permafrost presence and distribution, soil conditions, depth to bedrock, bedrock conditions, depth to GW, and geotechnical conditions. Data pertaining to permafrost is not currently available. The final version of this CDRMR report will incorporate relevant data from this investigation.
* FY2015 GW-related investigations for the NFRC Realignment Project: The NFRC Groundwater Report, Appendix C to the *North Fork Rose Creek Design Basis Report* (CH2M, March 2016b) provides details on these investigations.
* FY2014 GW-related investigations for Zone II Outwash Area and S-Wells Area (CH2M, March 2015s, March 2015t, March 2015u): Information from these investigations informed the NFRC Realignment Project. It is also detailed in the NFRC Groundwater Report, Appendix C to the *North Fork Rose Creek Design Basis Report*, (CH2M, March 2016b).

Figure 2‑1 presents a map of the completed investigation locations and key features for the FCD in the east subarea of the Perimeter RU.

## Perimeter West – Field Investigation Data Evaluation

Although no specific GW-related field investigations were completed within this RU during FY2014 through FY2016, data are available from earlier investigations that have been incorporated into the GFM and were used to develop the conceptual model for this area. Results from the steady-state GFM, including an assessment of GW flux, GW and SW exchange, and GW flow paths include the following:

* A GW flow budget summary for the west subarea of the Perimeter RU is presented in Figure 2‑2. It includes fluxes summarizing GW and SW vertical exchange.
* Upper Guardhouse Creek (UGC), the natural steep channel draining the uplands above Faro Pit, is losing GW to SW (i.e., gaining stream), estimated as about 1.2 litres per second [L/s]).
* North Wall Interceptor Ditch (NWID), the constructed diversion that conveys UGC away from the Mill Area and the RCTA and discharges downstream of the CVD, is losing SW to GW (i.e., losing stream).

As shown on Figure 2‑2, model results suggest that GW flow from the hillside north of the Perimeter RU convey minimal quantities of water (generally less than 1 L/s).

Vertical GW exchange between the alluvial materials and underlying bedrock are shown on Figure 2-3. Within the west subarea of the Perimeter RU, vertical GW exchange between the alluvium and bedrock is minimal (less than 1 L/s).

The calibrated annual average recharge rate is presented in the GFM Development Report (CH2M, March 2016e). For most areas of the model, the calibrated GW recharge rate is approximately 40 millimetres per year (mm/yr) (or about 13 percent of mean annual precipitation rate of 320 mm/yr), with lower values in the RCTA and higher values in areas of deposited waste rock.

Modelled flow paths depicted on Figure 2-4 show GW movement downslope from the northern side of Rose Creek Valley that discharges to SW, such as Lower Guardhouse Creek, or reaches the central portion of the valley. Significant GW does not flow west, continuously down valley beneath NWID.

GW flow paths also indicate that GW originating in the Perimeter RU flows parallel to, or into, the WRD RU. GW that originates in the waste dumps does not discharge into the Perimeter RU, except for, at the toe of the Northwest WRD, where it was deposited into UGC.

## Perimeter East – Field Investigation Data Evaluation

This subsection provides an interpretation of data from the November 2015 and June 2016 FCD seepage investigation (CH2M, August 2016h).

Previous estimates indicate a significant proportion of the water input to Faro Pit via the Faro Valley Waste Dump is leakage from the FCD, GW flow under the FCD, or a combination of both. From a hydrogeology perspective, the primary purpose of the investigation is to:

* Evaluate the proportion of leakage from the FCD in comparison to the quantity of GW flow beneath the diversion channel
* Improve the understanding of the hydrostratigraphy and aquifer properties, including the extent that frozen ground impedes the flow of GW, or limits infiltration, to the active layer above the permafrost

Results from this investigation can be used to assess mitigation options, although remediation alternatives are not addressed in this report. By understanding this, an effective remediation design concept for this project component can be defined. The goal of the remediation design is to keep clean water from entering the Faro Valley Dumps where it becomes impacted. Potential alternatives to capture this source water originating from outside the mine site include lining the upgraded FCD when constructed if a significant portion of the water is sourced from the FCD itself; installing GW cut-off walls, gravity drainage interception trenches, or SISs with active pumping if a significant portion of the water is sourced as GW flow beneath the FCD; or a combination of different measures.

Nine monitoring wells were installed in the following three clusters (Figure 1):

* Cluster 1 - adjacent to the western limb of the FCD (the West Valley Interceptor Ditch [WVID])
* CH15‑106‑MW001, CH15‑106‑MW002, and CH15‑106‑MW007
* Cluster 2 - east side of the Faro Creek valley, adjacent to the FCD
* CH15‑106‑MW003, CH15‑106‑MW004, and CH15‑106‑MW008
* Cluster 3 - near the Faro Creek, WVID, and FCD confluence
* CH15‑106‑MW005, CH15‑106‑MW006, and CH15‑106‑MW010

GW monitoring data were collected in June 2016 at all nine monitoring wells and surface water elevation at FCD-1. The inferred GW contours are presented in Figure 2-5.

### Hydrostratigraphy Summary

A detailed description of the investigation and materials encountered is presented in the field summary reports (CH2M, March 2016d; CH2M, August 2016h). The general hydrostratigraphy at each well cluster is as follows.

#### Cluster 1 - Adjacent to the West Limb of FCD (WVID)

The overburden is comprised mostly of sand and gravel, of varying compositions from grade to approximately 5.7 metres below grade (mbg) in two wells, and 15.5 mbg in CH15‑106‑MW007, where refusal was encountered on bedrock. The maximum depth to bedrock was deeper than anticipated prior to the investigation based on the regional surficial geology mapping [Bond, 1999]).

Static water level elevations in November 2015 for CH15‑106‑MW001 and CH15‑106-MW002, which are the closest to the WVID, were 1,321.5 and 1,319.4 metres above sea level (masl), respectively. MW007, located approximately 10 m lower, had a GW elevation of 1,310.9 masl. Similar elevations were observed during the June 2016 monitoring event at CH15-106-MW001 and CH15-106-MW007, but the groundwater elevation was approximately 2 m lower at CH15-106-MW002 in June 2016. Based on the relative close proximity of these wells to one another, this indicates a very steep localized hydraulic gradient in the area, as depicted on Figure 2-5. Cross sections of the WVID were completed by CH2M in 2014 (CH2M, March 2015i). Based on the cross section WVID‑14, located in the vicinity of Cluster 1, the elevation of the WVID base is approximately 1,319.6 masl. The location of cross section WVID‑14 relative to Cluster 1 is shown on Figure 2-5. Based on these elevations, and the approximate depth of water in the WVID of 0.1 m, the GW table during November 2015 was within 1 m of surface water in the WVID, suggesting that GW may be at an elevation higher than the base of the WVID in this area during seasonally high GW table periods. Additional seasonal GW data are needed to confirm this hypothesis.

#### Cluster 2 - East Side of Faro Creek Valley, Adjacent to the FCD

All three borings in Cluster 2 were terminated before they reached bedrock; the maximum drilling depth was 29.1 mbg (95.5 feet) at CH15‑106‑MW003. Similar to Cluster 1, this depth was significantly deeper than anticipated. Although field observations indicated that the overburden at Cluster 2 was composed of sand, silt, and gravel; differences from Cluster 1 were noted. The lithology at CH15‑106‑MW003 appeared to be very tightly compacted road base fill with a silty matrix from grade to approximately 2.7 mbg. Fat clay was also observed in CH15‑106‑MW003 around 28.5 mbg. Boring CH15‑106‑MW004, from the surface to approximately 2.7 mbg, comprised more coarser-grained material with less fine-grained matrix within the road base fill.

Static water level elevations in the Cluster 2 wells ranged from 1,285.5 to 1,289.4 masl during the November 2015 monitoring event and were similar elevations (less than 1-m change at each well location) during the June 2016 event. Cross-section FCDE‑21 (CH2M, March 2015i), located in the vicinity of Cluster 2, identified the base of the FCD at an approximate elevation of 1,297 masl, and with a stream depth of approximately 0.25 m, indicates a significantly higher surface water elevation than the observed static GW elevations. The location of FCDE‑21 relative to Cluster 2 is shown on Figure 2-5.

GW was noted infiltrating into boring CH15‑106‑MW004, which is located at elevation 1,295.8 masl, at around 2.7 mbg, a thin 0.06-m-thick GW bearing seam was also observed in the boring CH15‑106‑MW003 at elevation 1,294.5 masl. These elevations are at or just below original ground surface. Based on the observed groundwater discharge zones on the upslope side of the FCD and the presence of a surface water drainage channel leading toward the FCD on the eastern slope, this water is interpreted to be water discharging from the upslope areas east of the FCD. However, this interpretation is speculative, and the water entering the borings could have originated from the FCD as well.

#### Cluster 3 - near the Faro Creek, WVID, and FCD Confluence

The results from the Cluster 3 drilling indicated that the localized bedrock profile may slope from south to north, but the general bedrock slope in the investigation area sloped towards the base of the Faro Creek valley and Faro Creek Channel. The overburden is comprised mostly of sand and gravel of varying compositions, from the surface to about 6 mbg in CH15‑106‑MW005 and CH15‑106‑006 and to 17 mbg in CH15‑106‑MW010, where bedrock refusal was encountered.

Static water level elevations for the Cluster 3 wells ranged from 1,310.0 to 1,311.2 masl during both the November 2015 and June 2016 monitoring events. The WVID base elevation near CH15‑106‑MW010 was 1,311.7 masl, compared to the -MW010 GW elevation of 1,311 masl, indicating GW was within 1 m of the base of the FCD in this area. The GW elevation at MW005 was 1,310.0 masl compared to the nearby FCD elevation of about 1,309.65 (1,309.4 masl streambed base and an approximate stream depth of 0.25 m). The GW in this area is at or slightly higher than the FCD, indicating that the FCD is potentially receiving GW discharge in this area, depending on its seasonal stage elevation. November GW elevations may reflect a lower water table period for the area, and as such, the FCD likely behaves as a point of discharge for most of the year, in this area. Additional seasonal monitoring data would be needed to confirm this, although this hypothesis is consistent with the observation that this Cluster location lies in the central portion of the Faro Creek valley in an area where a natural channel resides and which is likely sustained by GW baseflow. Diversions on either side of the valley are more likely perched above the local water table. The estimated depths of the WVID and the FCD in the vicinity of Cluster 3 were obtained from cross sections WVID‑18 and FCDE‑19 (CH2M, March 2015i). Their location relative to Cluster 3 is shown on Figure 2-5.

### Aquifer Properties and Volumetric Discharge

Aquifer testing was performed at the well clusters during May and June 2016. The results are summarized in the following sections, followed by a discussion of water balance for the Faro Creek Valley.

#### Cluster 1 - Adjacent to the West Limb of FCD (WVID)

Well CH15-106-MW007 did not produce sufficient water for an aquifer test, and CH15-106-MW002 was used as a substitute pumping well. CH15-106-MW002 was pumped at 0.13 L/s for 8 hours with a maximum drawdown of 1.35 m. Drawdown was not observed at monitoring wells CH15-106-MW001 or CH15-106-MW007. Evaluation of the aquifer test data suggested that the hydraulic conductivity of the alluvium ranges from 5 to 10 metres per day (m/d), and that of the weathered bedrock is 0.1 m/d. These properties are not believed to be uniform across the western slope between the WVID and Faro Creek, because of the poor yield at well CH15-106-MW007. Groundwater flow off the western hillsides likely follows preferential flowpaths or localized areas of thicker alluvium, deeper bedrock, or both.

#### Cluster 2 - Eastern Side of Faro Creek Valley, Adjacent to the FCD

There were no successful aquifer tests performed at Well Cluster 2 because of poor production or limited water column in the wells. The bedrock in this area is very deep (greater than 29 m bgs at CH15-106-MW003), while the wells are screened well above this elevation. Water levels at CH15-106-MW004 experienced an approximately 1-m decline following attempted testing (water levels did not return to previous static), suggesting that the well may be screened in a perched zone. Furthermore, the relatively higher groundwater elevations at CH15-106-MW008 suggests that groundwater flow directions here are anomalous, and not toward the Faro Creek valley bottom as with other locations in this area.

#### Well Cluster 3 - near the Faro Creek, WVID, and FCD Confluence

Well CH15-106-MW006 was pumped at 0.25 L/s with a maximum drawdown of 1.84 m. Drawdown was observed at monitoring wells CH15-106-MW005 and CH15-106-MW010. Evaluation of the drawdown data suggests that the hydraulic conductivity of the alluvium in this area is about 3 to 5 m/d, with a zone of very high hydraulic conductivity (300 m/d) in the vicinity of CH15-106-MW006 and CH15-106-MW010. This zone may be associated with the original Faro Creek channel deposits, and may provide a pathway for upgradient groundwater and/or FCD leakage to enter the original Faro Creek valley.

### Faro Creek Valley Water Budget

During June 2016, surface water discharge at FCO (an established flow and monitoring station at the outlet of the original Faro Creek Channel to the pond upstream of the Faro Valley WRDs) was about 7 L/s. The sources of water to Faro Creek at FCO were identified as discharge from the western ditch (the small ditch below the WVID) at 0.5 L/s, water seeping from the FCD roadway (approximately 1 L/s) and a spring located in the central portion of the valley (approximately 6 L/s). These sources all originate as groundwater (as seeps or springs as opposed to surface flow from upgradient areas), although the ultimate origin of this emergent groundwater (either FCD leakage or upgradient groundwater) is undetermined.

### Permafrost

Permafrost in the area of the FCD may impede GW movement or provide a perched aquifer where supra-permafrost resides and interacts with the diversion.

A local empirical-statistical permafrost probability model for the Faro Mine Area was developed by Bonaventura and Lewkowicz (2008 and 2012). This model is based upon a combination of bottom-of-the snowpack temperature measurements in winter and ground truthing of frozen ground in summer. Using this model, the probability of permafrost in the area of the mine ranges from roughly 60 to 82 percent. The probability of permafrost is generally highest on north facing slopes, at the bottom of valleys, and along ridgetops.

The following sections provide a review of the field investigations in the vicinity of the FCD and WVID with respect to observations of permafrost.

#### 2003 Golder Investigation

Permafrost was encountered in June 2003 when test pits were dug in the vicinity of the FCD and WVID (Golder, 2004). These test pits were advanced further upslope along an alternative alignment for the FCD. The following identifies the Golder test pits located in the near vicinity of CH2M’s monitoring well clusters and details refusal on permafrost and seepage observations by Golder:

* Golder test pits TP03‑02, TP03‑03, and TP03-04 were located in the vicinity of CH2M Well Cluster 1. Test pit, TP03-03, observed refusal on permafrost at a depth of 0.8 mbg, and seepage at a depth of 0.5 mbg on top of the permafrost. Further to the northeast, TP03‑04 observed similar conditions at a depth of 0.4 m and seepage at 0.2 mbg, while further southwest along the WVID, TP03‑02 observed refusal on permafrost at a depth of 4.1 mbg.

Given the varied depth of permafrost observation by Golder, it may have a bearing to impeding supra-permafrost and GW flow, given that GW was observed at a depth of 2.7 to 2.8 mbg in November.

* Golder test pits TP03‑18 and TP03‑19 were located in the vicinity of CH2M Well Cluster 2. These test pits, located east of the FCD, observed refusal on permafrost at a depth of 0.6 and 1.8 mbg, respectively. Seepage was observed at depths of 0.2 and 0.4 mbg, respectively, above the permafrost. This range of permafrost depth was generally consistent for all test pits along the FCD area.

Depending on the depth to which permafrost extends in this area, it may not impede GW, which was observed at a depth of 12 to 13 mbg. It would, however, affect the observed leakage from the FCD in this area. Permafrost was not observed during the November investigation. Leakage from the FCD was observed at a depth of 2.8 mbg.

* Golder test pit TP03‑10 was located at the confluence of WVID and Faro Creek, upstream of CH2M Well Cluster 3. Permafrost was observed starting at 0.15 mbg and refusal within the permafrost was at 0.4 mbg. No seepage was observed within this test pit.

GW was observed to be quite shallow (within 1 mbg) in the area of the confluence of WVID, FCD, and Faro Creek in November 2015. As such, permafrost would likely have a bearing on the supra-permafrost and GW flow.

#### 2014 CH2M Field Investigations

During the 2014 geology and terrain preliminary baseline field investigation work (CH2M, March 2015jj), no evidence of permafrost was found along the FCD alignment. However, degraded permafrost was observed almost exclusively on the eastern hillslopes of the Faro Creek valley. A portion of the western side of the Faro Creek Valley was also investigated but till deposits are thicker, and evidence of either bedrock outcrops or degraded permafrost was limited.

#### FY2015 Drilling Investigations

No visible permafrost was observed during the November 2015 drilling at any of the wells; however the drilling method used (ODEX) was not specifically intended to identify permafrost soils or collect preserved ice samples.

The FCD realignment drilling investigation program (March 2016) was completed using specialized drilling equipment for identifying permafrost (e.g., CRREL barrel). Additional data regarding the presence or absence of permafrost and how it affects GW flow will be incorporated into the final report.

### Groundwater and Surface Water Interaction and Water Balance

#### Groundwater

During development of the GFM, limited field data were available for the FCD area. Instead, geology and hydrostratigraphy data used in the model were interpreted for the FCD area based on regional site conditions. Based on the results of investigations completed in FY2015 and FY2016, the model representation in this area could now be refined.

The GW flow budget for the Perimeter RU is presented on Figure 2‑2, including vertical exchange between GW and SW. Results from the steady-state GFM estimates leakage from the FCD at an approximate rate of 1.3 L/s (Figure 2‑2).

Model results suggest the net GW flow from the Perimeter RU into the WRD RU is about 7 L/s; with approximately 5 L/s originating from the eastern side of the valley and about 2 L/s originating from the west of the WVID. Net GW discharge to the creek running through the central portion of the valley is approximately 5 L/s over the reach between the WVID/FCD/Faro Creek confluence and the Faro Valley Dumps.

The GFM does not include the WVID as a water feature. The water elevations in the area of Cluster 1 were simulated at an elevation about 4 m below those observed in November 2015 which creates a larger, drier zone then reflected by observed conditions. This will likely have an effect on the flux estimated by the model on the west side of the Faro Valley. Further refinement of the GW flow model would be required, using the recently collected field data to update model layers, material properties, and model calibration. Based on the hydrostratigraphy information detailed above regarding Cluster 1, if GW partially discharges seasonally to the WVID, then this would decrease the net GW inflow to Faro Creek itself.

Flow measurements were recorded at monitoring station FCO, located within Faro Creek channel downstream of the confluence of Faro Creek and FCD, at the northeast toe of the Faro Valley Dumps. FCO flow data plotted over time is presented in Figure 2-6. As Faro Creek is diverted to the FCD, the contribution to the FCO flow would be both GW and SW runoff generated within the small watershed bounded by the WVID and FCD. The FCD flow data indicates a general base flow of about 2 to 3 L/sec in drier periods. As noted above, incorporating WVID into the GW model, would reduce the net flow to Faro Creek in this reach. A rate of 2 to 3 L/s is on the order of estimated flows that could be expected.

Flow measurements were collected by the Care and Maintenance contractor at locations FCD‑1 and FCD‑2, located at the confluence with Faro Creek and approximately 1,000 m downstream in the FCD, respectively. FCD‑1 includes the combined flow from WVID and Faro Creek. The data were collected between 2007 and 2010 and presented on Figure 2-6. The earlier data presented in Figure 2-6 (2007) show very close agreement between discharge at FCD-1 and FCD-2, with values typically within about 20 percent of each other and flow at FCD-1 typically higher than at FCD-2. After 2007, there are very large differences in the measurements between the stations: the flows at FCD-2 are typically reported as higher than at FCD-1, and there are generally odd patterns (such as the very low ratio of flow at FCD-1 to FCD-2 following the later 2008 data, and the reversal of the relationship in flow between the stations between 2009 and 2010). Overall, the evaluation of the FCD-1 and FCD-2 discharge data yield inconsistent trends and extreme differences in discharge between these two nearby stations. Because of these apparently anomalous trends in the FCD flow data, it was not possible to evaluate gaining and losing trends along this reach. The June 2016 discharge measurements found that discharge at the two stations was within computed error ranges as to have no significant difference (flow was about 400 L/s). At the same time, discharge of seeps flowing from the hillside into the FCD between FCD-1 and FCD-2 was about 2 L/s, or 0.5 percent of stream discharge. It is possible that increased hillside discharge during spring snowmelt events of the past may have contributed a much larger percentage of water to the FCD, but increases of 1,000 to 4,000 L/s between FCD-1 and FCD-2 as shown in the historical data seems very unlikely given the incremental increase of catchment size over the 1,000-m stream reach.

To provide a visual aide to present GW discharge to a particular region from source areas (whether mine-impacted or non-mine impacted water), particle tracking was performed for the Faro Mine Area. The components of these flows were assessed using Mod-Path3DU (Muffels, 2011) particle tracking. Mod-Path3DU particles were started on the water table within or beneath the waste dumps and tracked forward to their ultimate discharge location at a hydrologic boundary (e.g., rivers, wells, ponds). The particle’s endpoint boundary type and location data provide the information needed to define the contributing area (e.g., individual WRD subcatchments) that discharges to a particular region. Particle traces generated from this analysis are shown in Figure 2-4. These flowlines suggest that GW in the area flows toward and discharges into the Faro Creek channel deposits and then flows southwest through these deposits prior to discharge into Faro Pit.

#### Groundwater and Surface Water Quality

In June 2016, groundwater samples were collected from the three pumped wells: CH15-106-M002, CH15-106-MW006, and CH15‑106-MW008 (CH2M, August 2016h). Water quality was not uniform between the three well clusters, and the following notable observations were made:

* Total dissolved solids increased an order of magnitude in the downstream direction between each cluster.
* Phosphorous was one order of magnitude higher at CH15-106-MW006 than at the other wells.
* Sulphate increased in the downstream direction between each cluster.
* Dissolved metals cobalt, ferrous iron, and manganese were two orders of magnitude higher at CH15-106-MW006 than at the other wells.
* Dissolved zinc was an order of magnitude higher at CH15-106-MW006 than at CH15-106-MW002, and even higher at CH15-106-MW008, where it exceeded the 0.03 milligram per litre (mg/L) screening level with a value of 0.085 mg/L. The road embankment in this area of the FCD (i.e., Well Cluster 2) is suspected to have been constructed from PAG material.
* Fluoride exceeded the screening level of 0.12 mg/L at CH15-106-MW008, with a value of 0.123 mg/L.

### Summary and Recommendations

Significant depths of permeable sediments were identified underlying the WVID and FCD. Current modeling, based on generic material properties, suggests about 60 percent of the discharge to Faro Pit through the Faro Valley Waste Dump, is sourced from GW flowing underneath the FCD and WVID. The source of the remaining 40 percent is interpreted to be leakage from the FCD (between the Faro Creek confluence and FCD‑1), potential minimal leakage from the WVID, and the minimal amount of run-off generated within the Faro Creek valley (between the WVID and FCD) (Figure 2-1).

Aquifer properties within the Faro Creek valley varied considerably across the valley. At Well Clusters 1 and 3, the alluvial aquifer has hydraulic conductivity values ranging from 3 to 10 m/d, with potential preferential flow zones of much higher permeability at cluster 3 (Table 11). The hydraulic conductivity of the upper bedrock was 0.1 m/d. At Well Cluster 2, hydraulic conductivities were not quantified but are assumed to be very low, because the wells here were not able to sustain continuous pumping even at very low rates.

Stream discharge measurements were inconclusive with respect to identifying whether the reach between FCD-1 and FCD-2 is a gaining or losing reach. Seeps (about 2 L/s) entering the eastern side of the FCD totaled about 0.5 percent of the discharge in the FCD (about 380 to 395 L/s), whereas the error associated with the stream discharge measurements is on the order of 20 to 40 L/s).

Groundwater flow directions were observed to generally follow the pattern of surface topography, with flow toward the original Faro Creek (Figure 2-5). A spring in the center of the valley provided most of the water flowing at FCO. Seeps were observed coming from the roadway on the eastern side of the valley, and were estimated to be about 20 percent of the flow at FCO. A ditch intercepts groundwater along the western side of the valley, with about 10 percent of the flow at FCO. While it is clear that all of these sources are from groundwater, it is not possible to determine if the groundwater originated from upstream groundwater flowing under the FCD and/or the WVID or from stream leakage through the streambed. The presence of the very high hydraulic conductivity zone at Well Cluster 3 suggests that a pathway may exist from upgradient groundwater underneath the FCD, and this may be a significant source of groundwater to discharging springs in the Faro Creek valley.

CH2M recommends the following work be completed to further support the hydrogeological assessment of seepage in the Faro Creek valley area:

* Continue to monitor GW elevations in the monitoring wells in the Faro Creek valley to evaluate seasonal fluctuations.
* Review the original field data provided by the Care and Maintenance contractor for discharge measurements and/or stage rating curves for FCD-1 and FCD-2 to assess the reliability and quality of the data. Update the GFM based on the results of this and other field investigations for improved interpretation and accuracy in predictions.
* Replace destroyed FCD-2.
* Review raw historical stream discharge data at FCD-1 and FCD-2 for accuracy. Rating curves also need to be established at the monitoring station to obtain stage/discharge relationships for accurate calculation of flow rates.
* Collect additional GW samples from the monitoring wells and SW sample from the diversion to assess a SW signal in the shallow GW. A water quality survey of the Faro Creek drainage, including seeps coming from the FCD roadway, springs along the valley bottom, and groundwater intercepted by the western ditch, would assist in determining the relative portion of leaking surface water to upslope groundwater contributing to total flow at FCO.

## Perimeter South – RCD Field Investigation Data Evaluation

### Model Results

This section provides key observations using results from the steady-state GFM including an assessment of GW flux, GW and SW exchange, and GW flow paths. The steady-state GW flow budget for the Perimeter RU is presented on Figure 2‑2. A significant volume of the GW flows into the RCTA RU and the Dams and CVD Pond RU from the south subarea of the Perimeter RU. Model results suggest that approximately 64 L/s of GW flows from the Perimeter RU into the RCTA RU and 26 L/s flows into the Dams and CVD Pond RU from the south. This GW contribution is a combination of the leakage from the RCD and GW originating from upslope areas on the south side of the Rose Creek valley. The majority of the GW inflow from the south is attributed to leakage from the RCD (Figure 2‑2); model results suggest there is about 45.9 L/s of leakage from the RCD in the reach adjacent to Intermediate Impoundment, about 6.7 L/s of leakage from the reach adjacent to the ID Pond, and about 24 L/s of leakage from the reach adjacent to the CVD Pond.

Consistent with observed gradients between the Original Impoundment and the RCD, model results suggest net GW flux is about 2.1 L/s from the southeast corner of the RCTA into the Perimeter RU and the majority of this water discharges from the tailings/GW aquifer to SW in the adjacent reach of the RCD (Figure 2‑2).

Average annual GW flow in the Rose Creek Alluvial Aquifer (RCAA) passing under the CVD into the Perimeter South RU, suggested by the modelling results, is approximately 27 L/s. The model results suggest that GW flow in the RCAA continues to flow west from the Perimeter RU (i.e., approximately marked by X14) at approximately 28 L/s.

As may be expected because of its location at the valley bottom and at the toe of the CVD, the area between the CVD and approximately X14 is a significant area of GW discharge to SW. As noted on Figure 2‑2, GW is estimated to discharge to the X13 seepage ditch from the RCAA at about 34 L/s. An additional 26.6 L/s discharges to the seepage ditch at the toe of the CVD upstream of X13. Along Rose Creek, between the confluence of NWID and X14, net GW discharge to the Rose Creek is approximately 27.9 L/s (Figure 2‑2). This is consistent with results from field investigations along lower portions of Rose Creek that indicated that gaining stream conditions are dominant (CH2M, March 2013m). On the southern side of the valley, where RCD continues to be diverted away from the valley bottom, model results suggest that SW from RCD contributes a net 56.1 L/s to the RCAA along the reach downstream from CVD to about X10. In this area, net GW discharge from bedrock to the alluvium is estimated to be about 1.6 L/s (Figure 2-3).

Modelled flowpaths (Figure 4‑5) suggest that most of GW flow originating from the tailings and waste dumps discharge to the SW downstream of the CVD (i.e., X13 seepage ditch or Rose Creek). Surface water leaking from the RCD is interpreted to comprise the majority GW flow in the RCAA that moves downstream beyond X14.

# Waste Rock Dump Remediation Unit (Includes Faro Pit RU)

## Field Investigation Activities

In FY2014 and FY2015, CH2M completed the following field investigations to inform the hydrogeological understanding of the WRD RU:

* Two boreholes were advanced and completed as monitoring wells, CH14‑015‑MW004 in the Northwest WRD and CH14‑015‑MW006 (Northeast WRD) (CH2M, March 2015b). The primary purpose of this investigation, from a hydrogeological perspective, was to gain an improved understanding of acid mine drainage from the waste rock material and to assess and characterize the flow regimes within the lower WRD and the underlying shallow alluvial aquifer beneath the WRD. Seasonal GW elevation data could also be used to characterize infiltration through the waste dumps.
* One borehole was advanced (CH14‑106‑MW009) in the area, which is commonly identified as a sulphide cell in the Main Dump (SRK, March 2010a). This investigation was documented in CH2M March 2015o. From a hydrogeological perspective, the primary purpose of this investigation of the Main Dump was to characterize infiltration, but GW was not encountered and this location was not completed with a well for monitoring GW; gas monitoring and thermistor ports were installed.

Prior to FY2014, the following investigations were completed that have been used to supplement hydrogeological understanding in the WRD RU:

* Monitoring wells were installed through the waste dumps in 2012 on the northern side of the Main Dump (CH12‑014‑MW003), in the Northeast WRD (CH12‑014‑MW005), and on the southern side of the Intermediate Dump (CH12‑014‑MW007) (CH2M, March 2013n). With the exception of CH12‑014‑MW005, which was terminated within the dump, the boreholes were extended through the waste rock, into the underlying alluvium or bedrock, or both.

CH2M has reported annual monitoring of GW elevation and water quality since 2012 (CH2M, March 2013n, March 2014c, March 2015b, and March 2016f). Trends in GW quality are documented in Appendix G to this document, Geochemical Data Analyses.

Figure 3‑1 presents a map of the completed investigation locations described in this Section and key features for the WRD RU.

## Field Investigation Data Evaluation

The FY2014 and FY2015 field investigation data evaluation for investigations within the WRD RU includes consideration of the Faro Pit RU. This section will provide interpretation of data from the investigations described in Section 3.1 to provide the following:

* An evaluation of seasonal variations in GW elevation
* An evaluation of GW elevation in response to the increase in Faro Pit lake elevation as a result of the WTP shutting down before the 2013 treatment season
* An assessment of GW flux, GW and SW exchange, and GW flow paths to summarize understanding of hydrogeologic conditions using results of the steady-state GFM informed by data collected during these and previous field investigations

### Groundwater Elevation and Faro Pit Lake Elevation

Figure 3‑2 presents the GW elevation with time, monitored at CH12‑014‑MW003 and CH12‑014‑MW007, the locations where semi-continuous data are collected. These plots are superimposed with shading to highlight seasonal periods: winter (November through April), spring (May and June), and summer (July through October). The calibrated annual average recharge rate through the waste dumps is approximately 64 percent of mean annual precipitation, or 205 millimetres. These values are within a similar range to estimates at other cold/arid regions (Nichol, 2002; Marcoline, 2008; Janowicz et al., 2008; Momeyer, 2014) and are expected given the high permeability of the waste rock materials, the lack of vegetation on the dumps, and the significant depth to GW beneath the dumps. However, a large variation is anticipated seasonally, annually, and spatially across the waste dumps. At the FMC, the northern-, eastern-, and western-facing slopes experienced the lowest evaporation because of lower energy received at the surfaces. On the southern-facing slope, competing factors of rapid snowmelt infiltration played against increased energy directed at the surface leading to higher seasonal evaporation (Janowicz et al., 2008). The highest evaporation is likely experienced from flat surfaces and southern- and western-facing slopes, and the greatest net percolation is likely experienced across the other aspect slopes.

Seasonal infiltration into the WRD is evident in the GW elevation time series presented for CH12‑014‑MW003 (Figure 3‑2). During the winters (2012, 2013, 2014), GW elevation exhibits small-scale fluctuations of less than several centimetres. A rapid increase in GW elevation is observed in May and June in response to the melting snowpack accumulated on the WRD surface. The recorded increases were approximately 0.3 and 0.2 m in 2012 and 2013, respectively. A more subdued reflection of snowmelt infiltration was recorded in 2014. Over the summer period, the GW elevation continues to increase in response to snowmelt infiltration which is flowing through slower flowpaths or in response to infiltrating rainfall. A direct estimation of snowpack infiltration is complicated because of sublimation, ablation, and redistribution, the importance of aspect, and the effect of the surrounding topography on wind patterns.

Observations of seasonal infiltration in the vicinity of CH12‑014‑MW007 is complicated by a large magnitude increase in GW elevation recorded between March 8 and 19, 2014. This corresponds to the drilling of PW14‑06, completed less than 20 m to the west of CH12‑014‑MW007. Following this large magnitude increase, seasonal changes in groundwater elevation or changes resulting from the increasing water elevation in Faro Pit are indistinguishable, as the GW elevation appears to be slowing and decreasing back to static conditions. Before March 2014, the seasonal response in GW elevation at CH12‑014‑MW007 is similar to that described from CH12‑014‑MW003.

Fluctuations in GW elevation in the three monitoring wells in the WRD area (CH12‑014‑MW003, CH14‑015‑MW006, and CH12‑014‑MW007) were compared to fluctuations in the water elevation in Faro Pit to assess the potential relationship between the two (Figure 3‑3). Since 2013, the elevation of water in the Faro Pit has risen from approximately 1,140.9 masl to 1,153.2 masl; the maximum elevation was reached on April 27, 2015. Between 2013 and April 2015 and, except for less than a month in the Fall of 2014, no WTP capacity was available at the site and Faro Pit was used as the main storage reservoir for water collected from the ID Pond, Zone II Pit, S-Wells, and NFRD SIS. In addition, Faro Pit receives GW seepage through the pit walls, runoff from the waste dumps (directly and as conveyed by ditches adjacent to roadways on the waste dumps), and direct precipitation. In response, the water elevation in Faro Pit (Figure 3‑3) increased at rates of 0.004 to 0.042 m/day. Following the start-up and operation of the interim water treatment system in the spring 2015, the water elevation in Faro Pit decreased to approximately 1,151 masl by November 2015, when the interim water treatment system operation shut-down for the year.

As shown in Figure 3‑3, for certain areas of the waste dumps (e.g., CH12‑014‑MW003), there appears to be a hydraulic connection between Faro Pit and the GW elevation. As the water level in Faro Pit has risen since 2013, so has the water elevation in CH12‑014‑MW003, despite the GW elevation remaining higher than Faro Pit water elevation. This is interpreted to reflect a regional rise of the water table resulting from the additional pressure of greater volume of water stored in Faro Pit (about 6.5 million cubic metres additional water). As shown in Figure 3‑3, the GW elevation in CH12‑014‑MW003 has increased about 0.7 m and has fluctuated from elevations as low as the weathered bedrock to elevations into the native surface in more recent years.

The GW elevation measured at CH14‑015‑MW006, shown in Figure 3‑3, has been stable at about 1,186.8 masl, in 2014 and 2015. The GW elevation here is higher than the original ground surface and is mounded about 2 m into the WRD material, indicating saturation of the base of waste rock dump in this area. The water quality results from CH14‑015‑MW006 reflect highly impacted GW (defined for the project as sulphate greater than 4,000 mg/L or Zn greater than 5 mg/L. At CH14‑015‑MW006, sulphate has ranged from about 3,000 mg/L to 4,000 mg/l and Zn has been about 100 mg/L). This water either interacts with or receives seepage from the WRD.

As stated in the preceding discussion, the recorded GW elevation at CH12‑014‑MW007 appears to be affected by the drilling of PW14‑06. The drilling activity corresponds to the sharp increase in GW elevation, recorded by the pressure transducer data logger and by subsequent manual water monitoring. The increase in GW elevation recorded between October 2012 and March 2014 appears to reflect seasonal infiltration during the spring and summer and is not related to the increase in water elevation in the Faro Pit. The falling GW elevation after March 2014 may be a reflection of the water elevation returning to a static level or may reflect another process. The water elevation in Faro Pit and GW at CH12‑014‑MW007 appear poorly connected; this could be a response of the large structural control (i.e., “Big Indian” fault) that runs northeast-southwest between this location and Faro Pit; it also may represent low permeability of the material between the Faro Pit and this location. Although this location is interpreted to be installed in an area of concentrated drainage based on pre-mining topography, and hydraulic conductivity of the alluvium was estimated as about 1x10-5 m/s (CH2M, October 2013b), it is noteworthy that the GW elevation response to the disturbance from drilling PW14‑06 appears to slowly return to static conditions (Figure 3‑3). The GW elevation in CH12‑014‑MW007 fluctuates between the native surface and the waste dump material, where up to the bottom 1 m is variably saturated. The water quality results from CH14‑015‑MW006 reflect highly impacted GW ( sulphate has ranged from about 6,000 mg/L to greater than 10,000 mg/L and zinc has ranged from several 100s to 1000s of mg/L), which either interacts with or receives seepage from the WRD.

### Model Results

This section provides key observations using results from the steady-state GFM, including an assessment of GW flux, GW and SW exchange, and GW flow paths. The steady-state GW flow budget for the Faro Pit and WRD RUs is presented on Figure 3‑4.

In general, the Faro Pit is expected to act as a GW sink. With the exception of the period between 2013 and 2015 when no water treatment capacity was available, the water level within the Faro Pit is managed by pumping, creating a local GW sink. This results in flow into the pit from all directions (Figure 2-4). Model results (Figure 3‑4 and 2‑3) suggest that the three main sources of the GW discharge to Faro Pit are as follows:

1. Discharge through pit (rock) face seepage; estimated as approximately 5.5 L/s.
2. Inflow from the Faro Valley Waste Dump, located northeast of the Faro Pit; estimated as approximately 4.7 L/s.
3. Net vertical GW discharge into Faro Pit is estimated as approximately 4.4 L/s.

The net vertical GW discharge shown on Figure 2-3 in this case represents GW flow from bedrock in model layer 4 to bedrock in model layer 3, underlying Faro Pit. It is part of the Faro Pit RU GW balance, but this value represents deeper GW flow into shallower bedrock and is not a separate input to Faro Pit. Eventually this GW discharges to the pit, and the flux is represented by the vertical GW discharge to Faro Pit when it discharges from model layer 1 to Faro Pit.

Much less GW is estimated to discharge into the Faro Pit from the more topographically elevated areas to the west and east of the pit that are covered by the Northwest and Northeast WRDs; the estimates for these are about 0.6 and 0.3 L/s, respectively. GW flows into the pit (through overburden) from other areas around the Faro Pit, are estimated to have minimal contribution (less than 1 L/s).

Operation of the GW extraction well in the Zone II Pit may result in limited outflow from the southeast portion of the Faro Pit. This outflow is likely captured by the extraction well and treated. During the period in which no water was removed from Faro Pit, hydraulic gradients may have been increased between Faro Pit and Zone II Pit area or south of this area; however as shown on Figure 3‑2 and 3‑3 (described in Section 3.1.1), the gradient is towards the pit in areas to the east of Faro Pit (and likely to the North).

The GW flow budget summary for the WRD RU is also presented in Figure 3‑4. Key observations from these results of average annual discharge of mine-impacted GW from the FMC waste rock dumps, are as follows:

1. The greatest net GW flux from the WRD RU occurs in the area of the Main Dump and various ore stockpiles towards the ETA; modelling results suggest the discharge is approximately 7.4 L/s. This is also the area discharging the greatest load (see CDRM Section 7, Mill Building Area and ETA RU).
2. Net GW flux from the area of the Intermediate Dump to the areas of the S-Wells is estimated to flow at approximately 2.3 L/s.
3. GW flux, into the NFRC area upstream of the Haul Road, from the adjacent waste dumps, is estimated to flow at approximately 1.7 to 0.4 L/s from each dump (a total of 3.5 L/s) as shown on Figure 3‑4.
4. Leakage from the FCD adjacent to the Northeast WRD is estimated as 0.7 L/s (Figure 2‑2). All of this flow is suggested to flow as GW into the area of the Northeast WRD (Figure 3‑4).
5. GW flux from the area of the Main and Intermediate dumps to the forested area between the ETA and S-Wells is estimated at approximately 0.7 L/s.
6. Less than 0.5 L/s of GW is estimated to discharge from the Northwest WRD to the Perimeter RU, towards the RCTA in vicinity of Lower Guardhouse Creek, or to the mill area (Figure 3‑4).

In the WRD RU, net GW flow suggested by the model results is from the alluvium into the underlying bedrock. Model results suggests the net result is approximately 6.2 L/s of deep GW discharge (Figure 2‑3).

GW recharge on the waste dumps flows vertically downward until it reaches the pre‑mining ground surface. Upon reaching the pre‑mining ground surface, it flows south and east, depending on the pre‑mining topography. Modelled flowpaths are shown on Figure 2-4; the individual WRD subcatchments are largely identifiable in this figure, including the Faro Pit GW catchment. Mine-impacted GW discharges to SW in the Faro Pit and along the base of the southern and eastern sides of the waste dumps, through seeps and into channels, including NFRC. A portion of the GW also takes a deeper path and flows beneath the NFRC to the RCAA where it eventually daylights at the series of Rose Creek Valley dams or continues downstream in the RCAA. GW leaving the waste dumps seeps out around the base of the waste dumps and discharges to the NFRC and ephemeral streams in the ETA. These results suggest that although there may be specific areas where GW discharge may coalesce, GW flows from the WRD RU into the surrounding Perimeter RU, the Mill Building Area, and ETA RU to the east and south. There is limited discharge towards the west.

## Summary and Recommendations

As a result of strong seasonal variation in net deep percolation and evaporation, we recommend consideration of seasonality, at a monthly or finer scale, when determining and applying evaporation estimates to the waste dumps. Previous work has shown that annual net percolation and evaporation estimates as a percentage of annual rainfall, can vary significantly with variation in annual rainfall.

To better evaluate the connection between Faro Pit and regional GW, additional modelling runs should be completed with transient water elevations in Faro Pit, reflecting the observed change between 2013 and 2015.

# Mill Building Area and Emergency Tailings Area Remediation Unit

## Field Investigation Activities

No specific GW-related investigations were completed in the Mill Building Area and ETA RU during FY2014 or FY2015. However, other investigation in the ETA area consisted of advancing three boreholes and five CPTs to determine the thickness of tailings, assess the extent of contamination in the underlying soils and within the tailings, and assess the geotechnical characteristics of the tailings and mine Access Road fill (CH2M, March 2015m).

In support of the design of a SW collection structure at the ETA, 2014 field investigation also included geophysical surveys, a test pit investigation program, and geological reconnaissance (CH2M, March 2015n). Stream stage recorders were installed at FCS-4 and X-23 by instrumenting the existing 90‑degree V-notch weirs at these locations with stilling wells and water level transducers (CH2M, March 2015n).

Figure 4‑1 presents a map showing these investigation locations and the key features within the ETA.

## Field Investigation Data Evaluation

Although no specific GW-related field investigations were completed in this RU during FY2014 and FY2015, data are available from previous investigations that has been incorporated into the GFM to improve understanding of hydrogeologic conditions. This section provides interpretation of results from the GFM, including an assessment of GW flow paths and flux, summary water budgets using results of the steady-state GFM informed by data collected during these field investigations.

Modelling results suggest that average annual discharge of mine-impacted GW to the ETA from the FMC waste dumps located northeast of the ETA (including the Main Dump and various ore stockpiles) is approximately 7.4 L/s (Figure 4‑2). The GW flow suggested by the model from the Mill Building Area, which also contributes load to the ETA, is about 1.3 L/s. There is a net gain of GW to the alluvium from underlying bedrock (Figure 2-3) and the majority of the GW that flows into the ETA area discharges as SW in the Faro Creek Canyon (estimated at about 9.3 L/s) (Figure 4‑2). This result is consistent with a thinning of the overburden through Faro Creek Canyon and the lower‐permeability competent bedrock (calcareous phyllite of the Vangorda Formation) providing the foundation (AECOM, March 2009). Less than 1 L/s discharges from the ETA RU to the RCTA RU as GW (Figure 4‑2).

# Rose Creek Tailings Area Remediation Unit

## Field Investigation Activities

In FY2014 and FY2015, CH2M completed the following field investigations, in part, to inform hydrogeological understanding in the RCTA RU:

* In FY2014, CH2M drilled and installed three monitoring wells (CH14‑015‑MW01A, CH14‑015‑MW01C, and CH14‑015‑MW02A) in the original impoundment of the RCTA (CH2M, March 2015b). From a hydrogeology perspective, the primary purpose of this investigation was to assess the recent deterioration of GW quality at P03‑06 and to evaluate if the primary source contribution was bypass loading from the ETA SIS or tailings porewater from the coarse tailings beaches in the Original Impoundment. Results of this investigation were used to inform the GFM; Appendix G to this document provides additional information on the GW quality results.
* During a FY2015 investigation of the eastern limb of the Secondary Dam between the RCTA and RCD, monitoring wells CH15‑201‑MW001 through MW006 and stream stage gauges (CH15‑201‑SG002 to CH15‑201‑SG004) were installed. Appendix C to the *North Fork Rose Creek Design Basis Report* (CH2M, March 2016b) provides further detail. From a hydrogeology perspective, this investigation was intended to perform aquifer testing to better define the hydraulic properties of aquifers between the Second Impoundment and the RCD. This information was necessary to evaluate leakage from the Second Impoundment into the RCD.

Figure 5‑1 presents a map showing these investigation locations and the key features within the RCTA RU.

## Field Investigation Data Evaluation

Data from the field investigations completed in this RU during FY2014 and FY2015 have been incorporated into the GFM to improve understanding of hydrogeologic conditions. This section provides interpretation of results from the GFM that includes an assessment of GW flow paths and flux, including summary water budgets, using results of the steady-state GFM informed by data collected during these field investigations.

The calibrated annual average recharge rates are presented in CH2M (March 2016e). Based on the depositional history, the tailings are classified as coarse or fine (RGC, September 2005). The annual average recharge rates are estimated as 34 mm/yr (for the coarse tailings) and 16 mm/yr (for fine tailings).

Figure 5‑2 presents flow budget for model layer 1, which in the RCTA RU generally represents tailings (except in the areas where there are no tailings, such as to the north of the RCTA and south of NWID). As is expected in this fine-grained material, GW flux is small. Net GW flux into the tailings area is from both the northern and southern sides of the valley, including in the area adjacent to the Secondary Dam; however, the magnitude in this area is small (about 0.2 L/s). The largest contribution to the RCTA (an estimated 2.8 L/s) is from the north into the Second and Intermediate impoundments. It is interpreted to be shallow GW originating from the ditch that conveys water from Faro Creek Canyon to RCTA. In the southeastern portion of the RCTA, two additional observations on the net GW flux are suggested by the model results. These are as follows:

* GW flows to the east from the tailings into the Perimeter RU at the upstream end of the RCTA
* GW flows to the north from the Perimeter RU into the RCTA in the southeast corner

In both of these areas, the magnitude is negligible (Figure 5-2). As described in Section 4.2, there is minor GW contribution into the tailings from the ETA, as most of the GW discharges to SW before flowing from the ETA RU.

Model results of vertical flux between the tailings and RCAA suggest there are areas of upwelling and downward flow (Figure 5-4). For the majority of the RCTA, flux in either direction is estimated to vary from between 0 and 1x10-2 cubic metres per day per square metre.

Figure 5‑3 presents the GW flow budget for the alluvial aquifer within the RCTA. Key observations from these results of average annual discharge of GW in the RCTA area are as follows:

1. The greatest net GW flux into the RCTA RU occurs from the RCD on the southern side of Rose Creek Valley; modelling results suggest the GW flow into the RCAA is approximately 55.2 L/s. This non-mine-impacted GW is sourced from leakage from RCD and GW originating from upslope areas to the south. Model results of GW and SW exchange (Figure 2‑2) suggest that the net leakage from the RCD between the area known as the Fuse Plug and roughly where the tailings beach enters the ID Pond, is 44.8 L/s. Net leakage from the RCD adjacent to the ID Pond is losing 6.5 L/s to GW. This discharges to RCAA along with about 2.4 L/s of GW originating from uplands located to the south.
2. The net GW flux passing under the eastern edge of the RCTA in the RCAA, from the NFRC and SFRC valley, is estimated at approximately 13.6 L/s.
3. The contribution of GW into the RCAA from the northern side of the valley is negligible (less than 0.2 L/s) in comparison to the flows from the south and east. This includes flow from the ETA area, as reported in Section 4.2.
4. GW flux passing under the ID in the Dams and CVD Pond RU is approximately 68.6 L/s.

In the RCTA, net GW flow suggested by the model results, is from the underlying bedrock into the RCAA, as is typical in mountainous environments, where the upland mountain areas act as GW recharge areas and the valley bottoms as GW discharge areas. Model results suggests this occurs at approximately 7 L/s (Figure 2-3). In the area just north of the RCTA and bounded by NWID, net GW flow suggested by the model results, is from the alluvium into bedrock at rate of approximately 1 L/s.

Originating north of the Mill Building Area, Lower Guardhouse Creek conveys FMC WRD seepage and run-off to the RCTA. Model results of the GW and SW exchange reported on Figure 5‑2 suggest that Lower Guardhouse Creek is a net gaining stream, estimated to receive approximately 1.8 L/s of GW discharge.

The RCD, adjacent to secondary dam, is gaining a net of 2 L/s from GW (Figure 2‑2).

Modelled flowpaths are shown on Figure 2-4. Non-impacted and mine-impacted GW that does not discharge to SW originating in most areas of the site, flows through the RCAA. Model results suggest flow coalesces on the northern side of the northern half of Rose Creek Valley. This is consistent with evolving water quality which shows elevated concentrations of sulphate and metals in water measured in the northern portions of the RCTA. Non-impacted mine water sourced from RCD is expected to comprise the majority of flow in the south half of the RCAA. The RCAA is a fluvial depositional system deposited by Rose Creek and its tributary, the NFRC. The alluvial deposits are thickest near the centre of the valley, aligned with the ancestral thalweg of Rose Creek, with the thickest deposits around 50 m thick.

# Dams and Cross Valley Dam Pond Remediation Unit

## Field Investigation Activities

No GW-related investigations were completed in the Dams and CVD Pond RU during FY2014 or FY2015.

## Field Investigation Data Evaluation

Although no specific GW-related field investigations were completed in this RU during FY2014 and FY2015, data are available from previous investigations (CH2M, March 2013m) that have been incorporated into the GFM and are used to summarize the GW budget and conceptual model of this area. This section provides key observations using results from the steady-state GFM, including an assessment of GW flux, GW and SW exchange, and GW flow paths.

Average annual GW flow in the RCAA passing under the ID suggested by the modelling results, is approximately 68.6 L/s (Figure 4‑2). A significant volume of the GW flows into the Dams and CVD Pond RU from the south subarea of the Perimeter RU. This GW contribution is a combination of the leakage from the RCD and GW originating from upslope areas on the southern side of Rose Creek Valley. As shown on Figure 4‑2, approximately 26 L/s are estimated to discharge from the Perimeter RU into the Dams and CVD Pond RU from the south; less than 1 L/s enters from the northern slopes of the Perimeter RU. The majority of the GW inflow from the south is attributed to leakage from the RCD (Figure 2‑2); model results suggest there is about 24 L/s of leakage in the reach adjacent to the CVD Pond.

As is typical in mountainous environments, the upland mountain areas are expected to act as GW recharge areas and the valley bottoms as GW discharge areas. As noted on Figure 4‑2, GW is estimated to discharge to CVD Pond from the RCAA at about 43 L/s. GW discharge from bedrock to the alluvium is estimated to be about 2.5 L/s (Figure 2-3).

The model results suggest that the GW flow in the RCAA that continues under the CVD into the south subarea of the Perimeter RU is 27.3 L/s.

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