

Preliminary Final Design Basis Report North Fork Rose Creek Project

Prepared for

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

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Note from Government of Yukon:

This report is considered final. Please note that the preliminary final NFRC DBR document was not updated to consider detailed editing prior to finalization. Additionally, although YG and INAC agreed to the concepts during the planning stages and throughout the development of the DBR, it is understood that the evaluation of the DBR may lead to evolution and/or abandonment of the original concepts. The work conducted by CH2M will be considered and built upon in order to advance the NFRC design to completion.

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Acronyms and Abbreviations

<	less than
>	greater than
≤	less than or equal to
°	degree
°C	degree Celsius
%	percent
1D	1-dimensional
2D	2-dimensional
3D	3-dimensional
ACBM	articulated concrete block mat
AAM	Assessment and Abandoned Mines
AANDC	Aboriginal Affairs and Northern Development Canada
AEP	annual exceedance probability
ALT 1	NFRC Seepage Collection Pond Alternative 1
ALT 2	NFRC Seepage Collection Pond Alternative 2
AMP	Adaptive Management Plan
ARD	acid rock drainage
AWG	American Wire Gauge
BGC	BGC Engineering Inc.
C&M	care and maintenance
Canada	Government of Canada
CCME	Canadian Council for Ministers of the Environment
CDA	Canadian Dam Association
CEC	Canadian Electrical Code
CH2M	CH2M HILL Canada Limited
cm/s	centimetre per second
cm/s ²	centimeters per second squared
CMU	concrete masonry unit
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CRREL	Cold Regions Research and Engineering Laboratory
CSA	Canadian Standards Association
CSM	conceptual site model
CSQC	Canadian Sediment Quality Guidelines

ACRONYMS AND ABBREVIATIONS

CVD	Cross Valley Dam
DBR	Design Basis Report
DC	direct current
DDBR	Draft Design Basis Report
DEM	digital elevation model
DES	Denison Environmental Services
DLR	Device Level Ring
DOL	Direct On Line
DQM	Design Quality Manager
DQMP	Design Quality Management Plan
DVIHU	Down Valley Interim Hydraulic Upgrades
EDF	Environmental Design Flood
EDGM	earthquake design ground motion
EDI	Environmental Dynamics Inc.
ELR	Ecological Logistics & Research Ltd.
ERT	electrical resistivity tomography
ETA	Emergency Tailings Area
f'c	Compressive Strength of Concrete
FAA	Fisheries Act Authorization
FCD	Faro Creek Diversion
FGFM	Faro Groundwater Flow Model
FMC	Faro Mine Complex
FMRP	Faro Mine Remediation Project
FPS	frames per second
FWMT	Faro Water Modelling Team
FWSD	Fresh Water Supply Dam
FY	fiscal year
g	gravitational constant
GLL	Gartner Lee Limited
GCR	Geochemical Characterization Report
GPS	global positioning system
GSC	Geological Society of Canada
GW	groundwater
ha	hectare
HDPE	high-density polyurethane

HFB	hydraulic flow barrier
hp	horsepower
HQ	standard drilling tube size
HRMP	Heritage Resource Management Plan
I&C	instrumentation and control
ICP	Instrument Control Panel
ID	Intermediate Dam
IDF	Inflow Design Flood
INAC	Indian and Northern Affairs Canada
IPRP	Independent Peer Review Panel
ISA	International Society of Automation
ITR	Internal Technical Review
IWTS	interim water treatment system
Ka	thousand years ago
KCB	Klohn Crippen Berger Ltd.
KDC	Kaska Dena Council
km	kilometre
km ²	square kilometre
kN	kilonewton
KPa	kilopascal
kV	conductivity value
kVA	kilovolt ampere
kW	kilowatt
L	litre
L/min	litre per minute
L/s	litre per second
LED	light-emitting diode
LFN	Liard First Nation
LOR	LOCAL-OFF-REMOTE
LSA	local study area
m	metre
M	Magnitude
m/d	metre per day
m/s	metre per second
m/m	metre per metre

ACRONYMS AND ABBREVIATIONS

m ²	square metre
m ³	cubic metre
m ³ /day	cubic metre per day
m ³ /sec	cubic metre per second
Ma	million years ago
masl	metre above sea level
MASW	multichannel analysis of surface waves
Max-OL	Maximum Operating Level
mbgs	metres below ground surface
MCE	maximum credible earthquake
mg/L	milligram per litre
M L/d	million litre per day
Min-OL	Minimum Operating Level
mm	millimetre
mm/year	millimetre per year
MODFLOW-USG	
MTP	Medium Term Plan
N	north
N/A	not applicable
N/m ²	Newton per Square Metre
NA	no data available
NBC	National Building Code of Canada
NDHRP	National Earthquake Hazard Reduction Program
NEMA	National Electrical Manufacturers Association
NFRC	North Fork of Rose Creek
NFRC Project	North Fork Rose Creek Realignment Project
NFRD	North Fork Rock Drain
NP	neutralization potential
NRC	National Research Council of Canada
NWID	North Wall Interceptor Ditch
O&M	operations and maintenance
ODEX	Overburden drilling with Eccentric Bit
OSR	Options Selection Report
PGA	peak ground acceleration
PMF	probable maximum flood

PMP	probable maximum precipitation
ppbv	part per billion, volumetric
ppm	part per million
psi	pounds per square inch
PVC	polyvinyl chloride
QC	quality control
QRF	QC Review Form
RCAA	Rose Creek Alluvial Aquifer
RCD	Rose Creek Diversion
RCTA	Rose Creek Tailings Area
RGC	Robertson GeoConsultants
RQD	rock quality designation
RRDC	Ross River Dena Council
RSA	regional study area
RU	Remediation Unit
SAR	Species at Risk
SARA	<i>Species at Risk Act</i>
SEDEX	sedimentary-exhalative
SENES	SENES Consultants Limited
SFN	Selkirk First Nation
SFRC	South Fork of Rose Creek
SIS	seepage interception system
SO ₂	sulphur dioxide
SPD	surge protection device
SPT	standard penetration test
SRK	SRK Consulting Engineers and Scientists
SS	START-STOP
STC	Senior Technical Consultant
TAR	Task Authorization Request
TBD	to be determined
TDS	total dissolved solids
TEES	Tlicho Engineering and Environmental Services Ltd.
tpy	tonne per year
TRB	Technical Review Board
TRC	Technical Review Committee

ACRONYMS AND ABBREVIATIONS

TSFA	terrain stability field assessment
USACE	U.S. Army Corps of Engineers
USgpm	US gallons per minute
V	volt
V-D	variable frequency drive - Direct On Line
VCD	Vangorda Creek Diversion
VE	value engineering
VFD	variable frequency drive
VHG	vertical hydraulic gradient
VWT	Veolia Water Technologies
W	west
WBS	work breakdown structure
WMC	Water Management Consultants Inc.
WMEC	White Mountain Environmental Consulting
WRD	waste rock dump
WSEL	water surface elevation
wt%	percent weight
WTP	water treatment plant
YESAA	Yukon Environmental and Socio-economic Assessment Act
YG	Government of Yukon
YTT	Yukon-Tanana Terrane

Project Description

1.1 Introduction

This Preliminary Final Design Basis Report (DBR) presents the design framework and the Conceptual Design for the North Fork of Rose Creek Realignment Project (NFRC Project). The DBR includes the conceptual drawings, presented in Section 21, and other supporting reports included as appendices.

The purpose of the NFRC Project is to construct a clean water stream diversion to prevent waste rock dump seepage from impacting the creek, and an associated contaminated seepage collection system.

The DBR presents the following:

Basic project information, including site background, a description of the remediation problem and the site conditions and features.

- Description of the design approach, including assumptions and constraints, design objectives, criteria and standards, and alternative designs.
- Results of the field investigations.
- Description of the internal and external design review processes.
- Results of modelling and design analysis, planning and engineering deliverables.
- Conceptual Design Drawings and a Class 4 accuracy cost estimate.,.
- Preliminary construction schedule.

The Preliminary Final DBR is the review document prepared for the Technical Review Committee (TRC). No comments were received from TRC and the Preliminary Final DBR was presented to the Independent Peer Review Panel (IPRP). Following the presentation there were no comments received that resulted in revision to this document. For additional details on the scope of the DBR refer to Section 4.

1.2 Background

The Faro Mine Complex (FMC) is located in Yukon Territory, approximately 200 kilometres (km) north-northeast of Whitehorse (Figure 1-1, figures are appended to this report in Appendix A).). The mine operated from 1969 through 1998; in the 1970s, it was the largest producer of lead and zinc in Canada, with an output of 15 percent of the world's output of these metals. The FMC consists of three main areas: the Faro Mine Area, the Rose Creek Tailings Area (RCTA), and the Vangorda/Grum area (Figure 1-2)

Together, the Faro Mine Area and the Vangorda/ Grum Area contains over 320,000,000 tonnes of waste rock (rock mined to expose the ore or deemed unsuitable for processing) and over 70,000,000 tonnes of tailings (fine-grained materials remaining from ore processing). Of this, about 80 percent of the waste rock and all of the tailings are located in the Faro Mine Area and the RCTA.

The waste rock and tailings are acid-generating, releasing acid rock drainage (ARD) containing dissolved metals into groundwater, seeps, and surface water streams and creeks. This contamination poses a direct threat to benthic and fishery communities that live near the creeks within and downstream of the FMC. Other concerns that need to be addressed include contamination of air and land by lead dust, and direct contact of humans and wildlife with the metal-rich waste materials.

In 2003, the Government of Yukon (YG) and the Indigenous and Northern Affairs Canada (INAC) determined that the FMC mine would not reopen, and initiated a process to develop an overall remediation plan. After an extensive program of consultation, five overarching objectives for the closure of the FMC were identified:

1. Protect human health and safety.
2. Protect and, to the extent practicable, restore the environment, including land, air, water, fish and wildlife.
3. Return the FMC to an acceptable state of use that reflects the pre-mine use where practicable.
4. Maximize local and Yukon socio-economic benefits.
5. Manage long-term site risk in a cost effective manner.

In 2008, the Oversight Committee selected a preferred option that would form the basis for a long-term closure and remediation plan (SRK, 2008). The preferred option selected was to stabilize the WRDs and tailings in place, rather than removing or moving them. Key features of the final remediation plan would include upgrading dams so tailings remain in place, re-sloping waste rock, installing engineered covers over tailings and waste rock, upgrading stream diversions, and installing state-of-the-art water collection and treatment systems that would be required to be operated in perpetuity.

From 2008 through 2010, concepts for overall site closure were developed for YG by SRK Consulting resulting in production of the *Faro Mine Complex Closure and Remediation Plan-Draft 4A* (SRK, 2010). Since development of this closure plan, CH2M has provided technical and engineering assistance to YG that has included the following:

1. Site-wide explorations were conducted from 2012 to 2014 to support development of a Project Proposal for submittal to the Yukon Environmental and Socio-economic Assessment Board (YESAB). This work included collection and compilation of site-wide groundwater, surface water, geochemical, and geotechnical data, and development of detailed, photo-based mapping.
2. An alternatives analysis was completed for the RCTA and presented to the IPRP (CH2M, 2012e). General agreement was reached regarding closure of the RCTA and conveyance of Probable Maximum Flood (PMF) flow around the Intermediate Dam (ID), for protection of the mine tailings.
3. Work was initiated on site-wide groundwater, surface water, and geochemical models. The groundwater and surface water models have been completed; the geochemical modelling was partially complete, before work on the WRD modelling was halted by YG. Limited geochemical modelling has been completed for the NFRC Project to estimate the characteristics of mine-impacted water that will be collected as part of the NFRC Project.
4. Because of safety concerns, the existing Faro Mill Water Treatment Plant was shut down in October 2011. In 2012, CH2M conducted treatability studies and developed the design for a permanent water treatment plant. In 2013, CH2M developed the design for an Interim Water Treatment System (IWTS) and completed the construction in 2014. The IWTS operated in the fall of 2014 and during the spring through fall of 2015. It has a capacity equal to 378 litre/second (L/s).
5. A site-wide water balance model using the GoldSim program has been developed. This model integrates stage-capacity curves for the ID, the Cross Valley Dam (CVD), and the Faro Pit, with operations of the IWTS and pumping from the Emergency Tailings Area (ETA), the Zone II Pit, and the S-Wells. The model provides stochastic estimates, based on precipitation, of projected flow, and treatment rates. The model has been updated to include surface water runoff estimates and operation of the proposed NFRC Seepage Collection Pond.

6. A Medium Term Plan (MTP) was developed in 2012-2013, identifying interim actions that would be implemented within 5 years to protect water, fish and wildlife. From 2013 to 2014, an Interim Works Project Proposal was developed in support of the MTP.
7. In conjunction with the MTP, designs were initiated for the Down Valley Interim Hydraulic Upgrades (DVIHU), the Cross Valley Dam Seepage Interception System (CVD SIS), and the Vangorda Creek Diversion (VCD). The DVIHU was intended to provide additional overflow protection at the ID, until such time that a PMF spillway could be designed and constructed. The CVD SIS will provide interception of mine-impacted groundwater downstream of the CVD, anticipated to be required within 5 to 10 years. The VCD design was intended to replace the existing diversion structure at Vangorda Creek, located adjacent to the Vangorda Pit.
8. During presentation of the DVIHU and CVD SIS designs to the IPRP in 2014, YG determined that a site-wide water management plan and a detailed alternatives analysis needed to be completed for all closure components, including the NFRC, the Waste Rock Dumps (WRDs), and the RCTA. Over a series of meetings with YG, INAC, and the IPRP in 2014, overarching design criteria, with respect to flow capacity of diversion structures, and alternative closure options were developed. The alternatives analyses were presented in the Alternatives Development Status Report (CH2M, 2015a).
9. For the NFRC, alternatives evaluated in conjunction with YG, INAC, and the IPRP, included several alternative options for separation of clean water and mine-impacted water, either presently discharging to the creek or anticipated to be discharged from the WRDs into the creek in the future. These options included construction of extensive cutoff walls and SIS systems for capturing NFRC mine-impacted water, and several NFRC routing options for realigning the creek. Based on these discussions, the following was determined:
 - a. Existing and future mine-impacted water should be separated from clean surface water by diverting NFRC into a newly constructed realigned, lined channel (NFRC Realigned Channel). This channel will be constructed east of the existing NFRC by excavating into the hillslope and providing vertical and horizontal separation from existing and future mine-impacted water.
 - b. Existing and future mine-impacted water should be allowed to flow down the existing NFRC and at the Seepage Collection Pond located downstream from the North Fork Rock Drain (NFRD).
 - c. A culvert should be constructed at the Haul Road and the Haul Road would be reconstructed so that the road can be used for ongoing site operations and to transport materials from the Vangorda/Grum Area to the Faro Mine Area and the RCTA during future site closure activities.
 - d. The Faro Creek Diversion (FCD) will continue to be diverted to the NFRC. Redesign of the FCD will take place separate from design of the NFRC Realigned Channel design.
 - e. The FCD and the NFRC Realigned Channel, and the Haul Road culvert should be designed to convey the 500-year flood event with freeboard or the PMF with no freeboard.
 - f. The initial surface water modelling indicated that a 300,000 cubic-meter-capacity Seepage Collection Pond, located between the Haul Road and the Mine Access Road, would have sufficient capacity to store up to a 500-year flood event from the reduced potentially contaminated catchment area, if combined with adequate pumping capacity and warm-weather operations. This was deemed a reasonable starting point for preparation of the Conceptual Design.
 - g. The NFRC Seepage Collection Pond and the pumping and piping ARD conveyance system should be designed for all-weather operations. To the extent possible, pumping of ARD from the Seepage Collection Pond should take place during warm weather operations. Currently the IWTS operates from middle of April to the end of September.

10. The Draft DBR was submitted to the TRC in August 2015 (CH2M, 2015f). The Draft DBR was presented to the TRC on September 29, 2015 and a presentation on alternatives and design progress was presented to the TRC on January 26 and 27, 2016. These meetings resulted in the following direction from the TRC:
 - a. Because of the extreme environment and uncertainties regarding requirements for collection of contaminated flow during future WRD closure activities, a conservative approach should be used for sizing and designing all components of the NRFC project.
 - b. The culvert or bridge at the Mine Access Road should be designed to pass the 1:500 year storm event with 0.5 metre (m) freeboard or the PMF with no freeboard, whichever is greater.

1.3 Faro Mine Complex Site Description

The FMC is divided into the Faro Mine Area, the RCTA, and the Vangorda/Grum Area. The Faro Mine Area includes the Faro Pit, WRDs, the former ore processing facilities, and a newly-commissioned (September 2014) IWTS for treating ARD. The RCTA consists of three tailings dams, a treatment polishing pond, and the Rose Creek Diversion (RCD), all located south of the Faro Mine Area. The Vangorda/Grum Area, connected to the Faro Mine Area by the Haul Road, lies approximately 13 kilometres (km) east of the Faro Mine Area and includes the Vangorda and Grum pits, WRDs, and an ARD treatment plant.

The FMC is located on the Vangorda Plateau, a northwest-to-southeast-oriented rolling upland located between 1,000 and 1,400 metres above sea level (masl), and is surrounded by the Anvil Range to the north and east, and Rose Mountains to the south. It is located about 15 km north of the Town of Faro (straight line distance) and is connected to the town by the Mine Access Road, which extends approximately 22 km from the Town of Faro to the FMC, gaining over 400 m in elevation.

The Anvil Range rises to a series of peaks over 2,000 masl, including Mount Mye (east of the Vangorda/Grum area) and Mount Aho (north of the Faro Mine Area). Faro Peak and Sheep Mountain are two key features occurring to the south of the FMC. Generally, the FMC Area is typical of a mountainous region that has been influenced by multiple past glaciations, consisting of broad U-shaped valleys, rounded hills, rough mountain peaks, as well as deposits of glacial till and glaciofluvial materials.

The Vangorda Plateau parallels the Tintina Trench, which is a regionally-dominant feature of the Tintina Fault that lies just south of the FMC. This ancient fault contains deposits from at least seven Pleistocene glaciations and numerous wetlands and sloughs (Smith et al., 2004). The Tintina Trench, in the vicinity of the FMC, lies at approximately 600 masl.

The FMC is found primarily on National Topographic System Map 105K/6, with a small portion on 105K/3. The disturbed area of the FMC is generally oriented southeast to northwest, with the following geographic extents:

- 62 degrees (°) 14'30.8" N to 62°21'59.1" N
- 133°10'57.5" W to 133°29'3.8" W

Two local watersheds encompass the FMC: Rose Creek and Vangorda Creek, both of which form part of the Pelly River drainage, which is regionally dominant and flows northwesterly within the Tintina Trench. The Pelly River is a major tributary to the Yukon River and drains more than 49,000 square kilometres (km²) of land.

The Rose Creek watershed encompasses the Faro Mine Area portion of the FMC and drains west to the Pelly River via Anvil Creek. Rose Creek is fed by two tributary forks that join within the FMC: the NFRC and the South Fork of Rose Creek (SFRC). The NFRC drains south from the Anvil Range and is partially fed by Faro Creek and other small tributaries. The SFRC originates further east and drains northwest along the Vangorda Plateau, joining the NFRC just east of the RCTA.

1.3.1 Faro Mine Area

The Faro Mine Area (Figure 1-3) includes the following components:

- The Faro Pit is approximately 1,600 metres (m) long, 975 m wide, and 345 m deep, and contains approximately 15 million tonnes of tailings.
- 30 WRDs contain approximately 260 million tonnes of waste rock, oxide fines and ore piles covering approximately 335 hectares (ha).
- Closed ore processing and handling facilities
- Emergency Tailings Area
- FCD

The area includes contaminated water management facilities, including the S-Wells, NFRD Seepage Interception System (SIS) and ETA SIS, and contaminated water pumping, conveyance, and treatment facilities. A second pit at the Faro Mine Area, the Zone II Pit, was filled with waste rock after mining. Dewatering the Zone II Pit prevents contaminated water from accumulating within the pit and discharging into the NFRC.

Much of the waste material at the FMC is acid-generating, whereby oxidation of sulphide minerals releases sulphuric acid that mobilizes metal contaminants. Waste rock and pit walls at the Faro Mine Area continue to oxidize and release contaminants. Although sulphide cells, low/medium-grade ore stockpiles, and oxide fines stockpiles contain the most consistent highly-mineralized wastes, the waste rock at the Faro Mine Area is generally poorly segregated.

The Faro Pit serves as a contaminated water storage reservoir, providing storage capacity to support seasonal summer water treatment and to reduce site water management risks. The Faro Pit has a storage capacity of approximately 43 million cubic metres (m³) at Elevation 1,153 (BGC, 2006c), which is the approximate elevation of fractured bedrock within the rim of the pit. As of January 2016, the water surface elevation at the Faro Pit equaled 1151.8. The target elevation at the end of each year's treatment season is equal to Elevation 1,141. Based on the current operation of the IWTS, the water surface elevation in Faro Pit is projected to return to its targeted operating level by the fall of 2017. It is anticipated that IWTS will continue to be managed within the target range by the time the NFRC Seepage Collection Pond is scheduled to begin operations.

The FCD diverts Faro Creek around the WRDs and Faro Pit, and directs the flow to the NFRC upstream of the WRDs and mine area. Of the total creek flow within the NFRC at the NFRD, the Faro Creek Diversion contributes about 20 percent of the flow. See Appendix B for a detailed description of the Site hydrology.

Water treatment at the Faro Mine Area consists of a modular lime neutralization system sized to treat up to 32,700 cubic metres per day (m³/day), equivalent to approximately 378 L/s, of mine water. The IWTS is located south of the existing Faro Mill Buildings.

1.3.2 Rose Creek Tailings Area

The RCTA (Figure 1-4) covers an area of over 200 ha in the original valley of Rose Creek, just downstream of the confluence of the NFRC and SFRC. The RCTA is composed of four dams and a creek diversion– the Original, Secondary, ID and CVD, and the RCD. The Original, Secondary, and ID retain a total of 55 million tonnes of tailings in the Rose Creek Valley. The CVD retains a pond that is used at times for final polishing of treated water. The RCD carries Rose Creek around to the southern side of these four dams. Sludge cells on the Original Tailings Area provide storage for water treatment sludge from the Faro Mine Area water treatment system.

Contaminants from the acid-generating Rose Creek tailings are migrating into the underlying Rose Creek aquifer which flows beneath the tailings. While concentrations of some contaminants are increasing in groundwater down gradient of the RCTA, none have reached levels that are ecologically significant to warrant collection and treatment. Planning and design have been initiated for SIS downstream of the CVD.

RCD runs along the southern end of the RCTA and diverts clean water from the NFRC and SFRC around the RCTA. The RCD is approximately 4,700 m long. It was originally designed to pass a 1-in-50-year flood event of approximately 79 cubic metres per second (m³/sec), with 1 m of freeboard, and carry a 1-in-500-year flood event with no freeboard. Settlement of the RCD dike has reduced the capacity of the RCD from the original design and as discussed in Appendix B (Hydrotechnical Report), inclusion of recent storm event data in the hydrologic analysis has increased the estimated flow rate of the design events. Emergency repairs were conducted in 2004, to raise the elevation of the dike surface and replace riprap (BGC, 2005). In response to additional settlement that has occurred since 2004, additional work to raise the dike is planned to be completed in 2016 as part of the Rose Creek Diversion Upgrades Project (CH2M 2015e). At the time this report was finalized, it is unclear if this work will take place in 2016 or not.

1.4 Remedial Units and Conceptual Site Model

A conceptual site model (CSM) for the RCTA has been developed to convey a summary of the sources of contamination, mechanisms of contaminant release, pathways of contaminant release and transport, and the ways in which ecological resources and humans are exposed to contaminants. To facilitate the analysis of potential remedial alternatives at appropriate spatial scales, the site is subdivided into smaller areas based on location and similar characteristics. These smaller areas are referred to as Remedial Units (RUs).

For the FMC CSM, RUs have been delineated based on local topographic feature, watershed, in-place materials, and the presence, or absence, of mine-impacted water. Figure 1-5 depicts the location of the FMC RUs, listed below:

- Perimeter Units (West, East, and South)
- Faro Pit
- WRDs
- Mill Area and ETA
- RCTA
- CVD and ID and their associated ponds

As shown on Figure 1-5, the NFRC Project is located within the East Perimeter RU.

1.4.1 North Fork of Rose Creek

The NFRC flows through the FMC from north of the Faro Mine Area, approximately 17 km upstream from the Haul Road (Figure 1-6). Generally, the upper reaches of the NFRC are dominated by large cobble and boulder habitats that transition to finer substrates closer to the confluence with the FCD. From the FCD to the Haul Road, the NFRC ranges from 8 m to 12 m wide and has gradients between 0.2 percent and 2.0 percent. The stream morphology within this reach is riffle-pool. An instream pond is located just upstream from the Haul Road; this pond is approximately 250 m by 115 m in spring, but becomes smaller under lower seasonal flows. The depths of the pond fluctuates from about 4 m in the spring to approximately 1 m in late summer.

The NFRC flows beneath the Haul Road through a constructed NFRD that is impassable to fish. The NFRD was designed by Golder Associates (Golder) as described in their design report (Golder, 1986) and contracted by Curragh Resources, Ltd. The NFRD was constructed in 1987 (Ferris, 2009) and has been in service for about 27 years. Downstream from the Haul Road, the NFRC is predominantly confined,

approximately 8.5 m wide, and has gradients ranging from 0.4 percent to 1.6 percent. This section of NFRC is primarily riffle-pool morphology, with an area of cascade-pool.

Downstream from the Mine Access Road (roughly parallel and about 700 m south of the Haul Road), the NFRC splits into two channels. The original channel joins with the SFRC after flowing through five man-made ponds that were constructed to recharge nearby groundwater wells that supplied process water during mine operations. The second channel, the Lower NFRC Diversion, was constructed to allow for diversion of sediment-laden water away from the Pump House Pond during spring freshet.

Metals-contaminated groundwater seepage that flows east from the Northeast WRDs, the former Zone II Pit area (that is, water that is not captured by the pumping well), and the Intermediate Dump (Figure 1-3) combines with groundwater upstream of the NFRD and enters the NFRC in gaining reaches of the creek. Seepage from these areas is contaminated with metals from contact with waste rock and sulfide cells located within the WRD. Water quality sampling and test data, presented in Appendix D (Geochemical Report), shows that zinc concentrations in groundwater and seepage continues to increase. Geochemical modelling, presented in Appendix D, indicates that this contamination is expected to increase significantly as the WRDs mature and the neutralization capacity of the waste rock decreases.

In the autumn of 2013, a new metals load source to the NFRC developed in the area of the NFRD), which resulted in elevated zinc concentrations in the NFRC, measured at the NFRD, and at Monitoring Stations X2 and X14. As discussed in Section 5, sustained zinc concentrations greater than 1.0 mg/L and 0.4 mg/L were measured at Monitoring Stations X2 and X14, respectively. These measured concentrations are over 10 times the zinc concentration of 0.03 mg/L s listed in *Canadian Water Quality Guidelines for the Protection of Aquatic Life* (CCME, 2013).

A detailed monitoring program was implemented to delineate the source of this new load. Drilling of seven wells conducted by Robertson Geotechnical Consultants (RGC) in the fall and winter of 2014/2015 did not identify a source zone or seepage path. RGC concluded that the source likely has a concentrated flow path, originating from a sulfide cell located within the Intermediate Dump.

In response to this increase in zinc concentration, YG and INAC implemented initial remedial responses during the fall and winter of 2014/2015, constructing the NFRD SIS. A localized seepage collection system with all-weather pumps and piping was constructed just downstream of the NFRD to collect contaminated seepage discharging on the western side of the NFRD and convey the seepage to Faro Pit. This system was partially effective in capturing the contaminated seepage, but has limited-flow capacity. Since the installation and the contamination, first observed to be isolated in the discharge on the western side of the NFRD is now elevated over the entire NFRD discharge.

1.4.2 North Fork of Rose Creek Remedial Design Criteria

YG and INAC have determined that the planned remedial actions for the NFRC corridor need to be accelerated to prevent seepage of contaminated groundwater from entering the clean stream flow of the NFRC. While site-specific water quality design criteria needs to be established through an aquatics and fishery assessment, and a regulatory review, the CCME Guidelines (2013), coupled with the projected increases in contaminate discharge and the deterioration of the NFRC, indicates that a significant portion of the present and future seepage and runoff from the WRDs needs to be intercepted and treated.

Based on discussions with the TRC and the IPRP, the following design criteria and design approach has been adopted for development of the DBR and the Conceptual Design:

- The NFRC will be captured and the creek moved away from the current (and future anticipated) WRD seepage flows by constructing a new channel to the east from its current location. The new

NFRC Realigned Channel will be higher in elevation to provide vertical separation from underlying mine-impacted groundwater.

- The NFRC Realigned Channel will be designed to convey the 1-in-500-year return period flood flow, with 0.5 m of freeboard and the PMF without freeboard, whichever is greater.
- The raised creek alignment will isolate mine-impacted groundwater and the WRD surface water runoff from the NFRC stream flows. The mine-impacted water will be conveyed within the existing creek channel and will be captured downstream of the Haul Road in a NFRC Seepage Collection Pond.
- The NFRC Seepage Collection Pond will be sized to capture all surface flow within the NFRC, downstream of the Haul Road up to the estimated 200-year return period annual inflow. This will be achieved through a combination of storage and conveyance of the stored contaminated water during warm weather operations (May through September). To provide maximum flexibility, all systems will be designed for warm and cold weather operations.
- The contaminated water will be conveyed either to the IWTS or to Faro Pit for temporary storage, before treatment.
- Contaminated seepage around the NFRC Seep Collection Pond will be limited to a volume of seepage that will not impact water quality in the SFRC or the RCD. Limited seepage will be acceptable if projected to fully seep into the Rose Creek Alluvial Aquifer (RCAA), where it will be captured at a later date by the planned CVD SIS.

1.4.3 Key Findings and Recommendations

The following key findings and recommendations have been identified through completion of the Preliminary Final DBR, and Conceptual Design:

- The design for conveyance of the 1-in-500-year with 0.5 m freeboard or a PMF with no freeboard, whichever is greater, by a culvert constructed through the Haul Road, and subsequent reconstruction of the Haul Road, appears to be prohibitively expensive. This criteria and the need to re-establish the Haul Road needs to be reviewed.
- The design for conveyance of the 1-in-500 year with 0.5 m freeboard or a PMF with no freeboard, whichever is greater, by a culvert or bridge constructed at the Mine Access Road needs to be reviewed. All other existing culverts along the Mine Access Road are designed for a 1-in-100-year storm event. If the existing culverts are not updated, then the Mine Access Road could be washed out and impassible at other existing locations.
- Because of the very high velocities required to convey the PMF flood flow through a Haul Road culvert, it is uncertain whether a step-pool design downgradient of the Haul Road, incorporated into the DBR and Conceptual Design, would be functional under extreme flow conditions without significant erosion and potential failure. Physical modelling may be required to determine design requirements. The requirement to protect the channel may preclude fish passage.
- Upstream of the Haul Road, a small proportion of stream-flow leakage from the NFRC Realigned Channel results in a significant increase in the size of the NFRC Seepage Collection Pond, for the same level of protection. To avoid this leakage, the Conceptual Design incorporates a double-lined channel upstream of the Haul Road. To protect the channel lining from damage, particularly during ice removal, the Conceptual Design includes an articulated concrete mat for protecting the lining system upstream of the Haul Road. Repair of the lining system will be difficult and, while significantly different in design, CH2M has observed that the VCD structure has been frequently damaged during ice and snow removal.

- Upstream of the Haul Road, the length of the NFRC Realigned Channel has been reduced by about 850 m at the mouth of the valley (identified as Segment 1 in the design) by incorporating a cutoff wall and a seepage collection trench to convey contaminated seepage and runoff downstream away from the realigned channel. Test pits, borings, and geophysical testing indicates that bedrock is shallow in the area of the proposed cutoff wall.
- Elevating the creek just downstream of the confluence with the FCD would require flooding the valley. A cutoff wall at this location, just downstream of the FCD Confluence, potentially required to limit the amount of groundwater bypassing the NFRC Realigned Channel, would be deep and wide in this area because of the extent and highly-permeable characteristics of the alluvial materials. In addition, the hillslope east of Segment 1 appears to have significant local deformation.
- Two NFRC Seepage Collection Pond locations have been identified and Conceptual Designs developed for each location. The NFRC Seepage Collection Pond Alternative 1 (ALT 1) is located between the Haul Road and the Mine Access Road. The NFRC Seepage Collection Pond Alternative 2 (ALT 2), is located between the Mine Access Road and the RCTA. Each of these ponds have advantage and disadvantages, as follows:
 - ALT 1 has as a smaller catchment area. As a result, the ALT 1 pond capacity (300,000 cubic metres) is smaller than the ALT 2 capacity (350,000 m³) to achieve the same level of protection.
 - The foundation conditions at the ALT 1 location are much more challenging than the ALT 2 location. The ALT 1 includes permafrost, ground ice, the NFRC creek channel, and widespread vegetation within the reservoir that would need to be cleared, with the potential for erosion and plugging of the intake structure. The ALT 1 pond will be formed through construction of a retention dam that will need to take into considerations low pH seepage and formation of metal precipitates. Additional field work needs to be conducted to confirm suitability of the ALT 1 dam location.
 - By contrast, the foundation conditions at the ALT 2 location appear to be favorable because of straight forward excavation and construction of the pond embankment. Limited test pits and borings indicate that the foundation materials consist of sand and gravel and that groundwater is sufficiently deep to not be a concern during construction. Additional field work needs to be conducted to evaluate liquefaction potential at the ALT 2 location.
 - We anticipate that seepage through the ALT 1 dam and abutments will be sufficiently low that all seepage would infiltrate into the RCAA and not enter the RCD or the SFRC. By contrast, because of the highly permeable alluvial materials, infiltration through the ALT 2 pond bottom and southern embankment would discharge to the SFRC. The Conceptual Design therefore includes a double liner with a leak detection system for the ALT 2 location.
 - Because the ALT 2 location is off channel, completion of the pond construction and collection of the contaminated flow could take place earlier than the ALT 1 location. Because of the difficult foundation conditions at the ALT 1 location and the potential for elevated flow conditions during freshet, with the potential requirement to pump several hundred L/s, CH2M has assumed that the NFRC Realigned Channel must be operational before completing the core-trench excavation and preparing the foundation.

1.4.4 Key Findings Related to Cost

The following key findings related to cost have been identified through completion of the Preliminary Class 4 cost estimate presented in Section 19. While this cost estimate is considered a Class 4 ROM estimate, development of the estimate has relied on fundamental design criteria that results in significant impacts to the estimated cost. These include the following:

- The Conceptual Design assumes that a PMF capacity culvert will be constructed at the Haul Road and the Haul Road will be reconstructed. Construction and backfill of the culvert accounts for approximately 24 percent of the total estimated cost.
- Completion of the Haul Road culvert extends the construction schedule by one year, increasing overhead and management costs, delays the diversion of NFRC into the realigned channel, and collection of contaminated seepage. To reduce costs, and potentially accelerate collection of contaminate seepage, consideration should be given to not reconstructing the Haul Road. A new Haul Road extension could be constructed from the Haul Road, east of the NFRC, to the Mine Access Road and the NFRC bypassed at the Mine Access Road by construction of a bridge, already included in the Conceptual Design.
- The Conceptual Design is based on the assumption that all contaminated seepage (except for minor amounts of seepage that will be allowed to seep into the RCAA), up to the projected annual inflow associated with a 200-year annual return period, will be collected at a seepage collection pond and conveyed for treatment or temporary storage at the Faro Pit. The determination of pond capacity has not incorporated a risk assessment regarding impact to aquatics or regulatory requirements. Our discussion with Minnow Environmental has indicated that the 200-year return period criteria is reasonable for preparation of the Concept Design. It also conforms to the recommendation from the CDA (see Section 9 of the DBR). The pond sizing, and related costs, could be reduced if the exceedance capacity is reduced through development of a risk assessment, identification of site specific water quality requirements, and regulatory approval.
- Two alternative pond locations have been identified and conceptual designs prepared for each location. The pond sizing assumes that pumping of the collected seepage will take place during warm weather months (May-September) only and that leakage from the NFRC Realigned Channel upstream of the Haul Road into the seepage collection pond is negligible. Leakage from the realigned channel is estimated to highly impact pond sizing: 1 percent leakage from the realigned channel upstream of the Haul road associated with normal annual flow is estimated to result in an additional 50,000 m³ of inflow into the seepage collection pond during the non-pumping period, requiring additional collection, storage conveyance, and treatment. To protect the NFRC Realigned Channel lining from damage during winter ice and snow removal, an articulated concrete mat, with a capital cost of \$9.4 million has been included in the Conceptual Design for Segment 2 of the NFRC Realigned Channel. This cost could be reduced or eliminated by an alternative approach to protecting the lining, or if INAC and YG assumes risk and determines that this lining protection is not necessary.
- Because of the concern related to leakage from the Segment 2 of the NFRC Realigned Channel, described above, the conceptual design includes a double lining system, increasing the estimated capital cost by about \$2.8 million. This cost could be reduced or eliminated if INAC and YG assumes risk and determines that this lining protection is not necessary.
- Because of concerns related to leakage of contaminated seepage into the South Fork of Rose Creek and Rose Creek, the Conceptual Design includes a double lining for Seepage Collection Pond Alternative 2. The secondary lining and leak detection system results in an increase in the estimated capital cost by about \$1.5 million. This cost could be eliminated if INAC and YG assumes risk and determines that this lining protection is not necessary.

Approved Closure Options

2.1 Introduction

This section provides a summary of approved closure options for each of the site areas defined in *Options for Closure of the Faro Mine Complex* (SRK, 2008), subsequent SRK Consulting Engineers and Scientists (SRK) documents, and the *Alternative Development Status Report* (CH2M, 2015a). The purpose of including this summary in this NFRC DBR is to provide a general context of how the NFRC design fits into the overall FMC closure options under consideration.

A formal, approved Options Selection Report (OSR), or similar document that provides official approval of detailed closure options, has not been issued for the Faro Mine Remediation Project (FMRP). The listing provided in this section has been developed based on CH2M's understanding of the closure documents developed to date; our discussions with YG, INAC, the Independent Peer Review Panel (IPRP); and review comments provided by the IPRP pertaining to previous closure reports and submittals. The evaluation of closure options for some site areas is ongoing. The closure options developed for the NFRC Project must consider potential options and the integration with other site areas, in particular, regrading of the waste rock dumps adjacent to the NFRC.

2.2 Faro Mine Area

This area contains approximately 260,000,000 tonnes of waste rock, oxide fines piles, and ore piles located in about 30 waste dumps that surround the Faro Pit. Contaminated seepage collection systems are located at the S-Wells area, the Zone II Pit, the NFRD just south of the Haul Road, and the ETA (Figure 1-3). Contaminated water is pumped from these facilities to either the IWTS or to the Faro Pit for temporary storage before conveyance for treatment. The IWTS is located on the southern side of the Mill Buildings Area. Faro Creek is routed around the Faro Pit via the FCD.

Tentative agreement has been reached by YG, INAC and, IPRP for closure options within the Faro Mine Area, including the following (CH2M 2015a):

- The FCD will be designed and constructed to carry the probable maximum flood (PMF with no freeboard) around the Faro Pit to the NFRC. The existing diversion alignment is being undermined by progressive erosion of the Faro Pit wall. The redesigned alignment of the diversion will be determined based on an evaluation of pit wall stability and a subsurface exploration, completed in the winter of 2015/2016.
- In the short term, the seepage collection systems within and at the base of the WRDs will continue to be operated as currently designed. Requirements for operating the S-Wells and NFRD SIS systems will be reviewed following construction of the NFRC Realignment Project and the NFRC Seepage Collection Pond.
- At the ETA, tailings will be removed from the ETA and placed within the RCTA. Consideration will be given to modifying the ETA collection system to enable collection and conveyance of contaminated seepage during cold weather.

Several options are under consideration for regrading and covering the WRDs. These options are intended to address the following:

- Provide a cover to isolate the contaminated waste rock, oxide fines, and ore piles from human or wildlife contact.

- Provide physical (slope stability and erosion) stability of the WRDs.
- Reduce the amount of infiltration, contaminated surface flow, and corresponding costs for collection and treatment. In select areas, provide a growth medium to enable revegetation.

The selected regrading and cover design must be compatible with the design for realignment of the NFRC and other site-wide closure designs. In October 2015 a covers workshop was conducted with CH2M, YG, INAC, and BGC to discuss cover options.

The selected WRD cover types will be determined based on a cost-benefit analysis and availability of cover and vegetation materials. Some of the highly contaminated waste dumps, including the oxide fine piles, will likely be moved and consolidated so that the seepage from these piles does not continue to seep into the Faro Creek Canyon and the RCTA. Potential for revegetation of the covers will be evaluated during development of the Conceptual Design under the site-wide DBR.

The Faro Pit will continue to be used as a contaminated water storage reservoir, providing storage capacity to support seasonal water treatment, and to reduce site water management risks. Water treatment will continue to be required for the indefinite future. It is likely that as the WRDs mature, additional contaminated seepage will discharge into either the NFRC watershed, the Faro Creek Canyon, or into the Lower Guardhouse Creek. The increase in flow and contaminant concentration, coupled with long-term collection requirements in the RCTA, will likely require expansion of site treatment capacity through construction of a permanent water treatment plant.

2.3 Rose Creek Tailings Area

The RCTA includes four dams: Original, Secondary, Intermediate, and Cross Valley. These first three dams retain an estimated 55 million tonnes of tailings in the Rose Creek Valley. The CVD Polishing Pond has traditionally been used for final polishing of treated water discharged from the Faro Mill treatment plant. Improved water quality from the IWTS has enabled direct discharge to Rose Creek. Discharge from the treatment plant to the CVD pond also enables delivery of high alkali water to the pond, elevating pH within the pond, mitigating acidic underflow from the Intermediate Dam (ID) Pond, and promoting solids settlement. The RCD extends along the southern side of the RCTA and diverts clean water from the NFRC and SFRC around the RCTA.

Tentative agreement has been reached by YG, INAC, and IPRP for closure options within the RCTA, as follows (CH2M 2015a):

- Portions of the RCD will be upgraded such that the channel will be able to carry the 1-in-200-year flood event, with freeboard. Revision of the design and upgrading the capacity to convey a 1-in-500 year flood event needs to be considered in the future.
- An overflow weir will be designed and constructed at the RCD (at the current location of a rip-rap overflow structure) to allow overflow from the RCD into the tailings area for flood events exceeding either the 1-in-200-year or 1-in-500-year flood event (up to PMF capacity), depending on final selection of RCD capacity. A reinforced channel will be designed and constructed within the tailings area to convey flood flow exceeding the 1-in-200- or 1-in-500-year flood event from the overflow weir to the ID Pond.
- The ID and CVD crests and spillways will be redesigned to convey the PMF. Upgrades to the ID Pond to convey the 1-in 500-year flood event are under consideration as an interim measure. At the time of preparation of the NFRC DBR, the decision has not been made whether to implement interim upgrades to the ID Dam.
- Before completing site closure, the ID Pond will continue to be used to collect and store contaminated seepage and runoff from the ETA and the RCTA. This water is currently conveyed to

Faro Pit for interim storage before treatment at the IWTS. In the long term, it is anticipated that dewatering of the ID Pond will be required, along with filling and establishment of a cover system.

- Sludge materials deposited in the CVD Polishing Pond will be removed as needed to improve water quality. The pond will be considered for storage of non-contaminated runoff during regrading and closure of the WRDs and for use as emergency storage of contaminated runoff during long-term operations after site closure.
- An SIS will be designed and constructed downstream of the CVD to capture and convey contaminated groundwater when it emerges from below the RCTA. Its precise location and configuration has not yet been determined.
- Upstream of the ID Pond, the tailings will be covered and revegetated. To the extent practicable, clean surface water will be routed off the tailings area. It is likely that surface water will be collected and conveyed for treatment for some period until proven sufficiently clean for routing directly to Rose Creek.

2.4 North Fork of Rose Creek

The NFRC conveys water from the upper NFRC and the FCD past the WRDs, to the Haul Road, through the NFRD, and the Mine Access Road to the SFRC and the RCD. As currently configured, mine-impacted water is collected at the S-Wells, located downstream of the NFRD, and at the NFRD SIS.

In general, agreement has been reached regarding the following general approaches and tentative concepts for the NFRC design by YG and INAC:

- Upstream of the Haul Road, the NFRC will be realigned (that is, moved laterally to the east and typically raised in elevation where feasible), to provide vertical separation of clean surface water from existing and potential contaminated groundwater and surface water discharged from the WRDs. Some portions of the new creek alignment (Segment 2 upstream of the Haul Road) will be lined to prevent infiltration of clean surface water into the underlying groundwater system. For those portions of the realigned creek where raising the creek in elevation is not practicable (Segment 1 upstream of the Haul Road), alternate methods of protecting the creek from inflow of contaminated groundwater consisting of a cutoff wall and drainage trench has been developed during the design process.
- The NFRC Realigned Channel has been designed to convey the peak 1-in-500-year flood event with freeboard or the PMF flood flow without freeboard. Based on the results of the hydraulic analysis completed for the DBR, the very high costs of the Haul Road culvert, and the challenges related to potential scour of the NFRC Realigned Channel downstream of the Haul Road, this criteria needs to be re-evaluated.
- The FCD will be redesigned in the future to convey the PMF flow around the Faro Pit to the confluence with the NFRC. The redesign of the FCD is not included in the NFRC Project.
- A culvert will be designed at the Haul Road to convey the PMF flow through the NFRD. The NFRD will remain in place and the Haul Road will be partially reconstructed if a culvert is used to allow long-term access for site maintenance and closure. The Haul Road reconstruction will be designed and constructed at a lower grade to provide borrow for the NFRC realignment channel construction.
- Downstream of the Haul Road, the realigned NFRC will be constructed to the east of the existing NFRC channel through the drainage area located east of the Haul Road Borrow Area.
- A culvert will be designed at the Mine Access Road to convey elevated storm events. The Mine Access Road falls under the purview of the YG Highway Department. As such, highway design

standards for culverts likely apply. The capacity of the culvert will be equivalent to the Haul Road culvert.

- To the extent practicable, minimal modifications will be constructed downgradient of the Mine Access Road for connecting the realigned NFRC to the SFRC.

Post realignment of the NFRC, the existing NFRC will be used to collect contaminated seepage from the WRDs. A seepage collection pond and dam will be constructed downstream of the NFRD to store contaminated seepage during the winter and during elevated flow conditions, for eventual conveyance and treatment during warm-weather conditions. To provide maximum flexibility, all facilities will be designed for cold weather operations.

Site Planning Areas

3.1 Introduction

This section summarizes the site planning areas for the NFRC design, their locations, general geographical and topographical information, and the logic behind the demarcation of the planning areas. This summary also describes the presence of tailings, waste rock, buildings, infrastructure, and general locations of known contaminated soils and groundwater within the specific-site planning areas.

For the purposes of the NFRC Project, the site planning areas are as follows:

- NFRC Realigned Channel
- WRDs
- Borrow areas
- Seepage Collection Pond
- Seepage Collection Dam

3.2 North Fork Rose Creek Realigned Channel

The NFRC realigned planning area consists of the following sub-areas: (1) the confluence area of the FCD and the NFRC, (2) four segments of the NFRC Realigned Channel, (3) crossings of the Haul Road and Mine Access Road, (4) the confluence area with the SFRC, (5) the RCD area, and (6) new and/or improved access roads within the NFRC Project area.

The NFRC Realigned Channel has been divided into four main channel segments, based on the topography adjacent to the creek, potential alternatives for separation of clean surface water from mine-impacted water (either currently contaminated or with the potential for contamination in the future), and the location of the Haul Road and the Mine Access Road. These areas are shown on Figure 3-1.

Upstream of the Haul Road, the NFRC has been divided into Segments 1 and 2. This is based on the topography of the adjacent slopes, the location with respect to potential contamination from the WRDs, and the potential to elevate and line the creek to separate the realigned creek from potential-contaminated groundwater and surface water. Recent groundwater quality data indicate that sulphate and zinc concentrations are increasing in groundwater at the base of the Northeast WRD, suggesting that this area may represent a conduit for metals loading to the NFRC in the future. The available data is provided in Section 5.

Downstream of the Haul Road, the NFRC has been divided into Segments 3 and 4. Segment 3 is from the Haul Road to the Mine Access Road, and Segment 4 is from the Mine Access Road to the confluence with the SFRC.

Table 3-1 provides a summary of pertinent topographical data pertaining to the NFRC Realigned Channel, Access Road, and the NFRC Seepage Collection Pond, discussed in this section. Stationing provided in Table 3-1 increases from downstream to upstream. The remainder of this section describes each of the NFRC planning areas.

Table 3-1. Summary of Topographic Data
Faro Mine Remediation Project

Location	P3 Stationing	Drainage Sub-Area ^a East (ha)	Drainage Sub-Area West (ha)	Length ^b (m)	Change in Elevation ^c (m)	Slope ^d (%)
Faro Creek Confluence	4+195	1,618	N/A	N/A	N/A	4.5
Segment 1	3+300– 4+195	297	44	885	11	1.2
Segment 2	1+990 – 3+300	495	64	1,360	12	0.9
Segment 3	1+240 – 1+755	35	0	585	34	5.8
Segment 4	1+100 – 1+180	0	0	185	9.5	5.2
Haul Road	1+755 – 1+990	N/A	N/A	140	0.7	0.5
Mine Access Road	1+180 – 1+240	N/A	N/A	24	0.4	1.7
NFRC Seepage Collection Pond	N/A	N/A	N/A	720	15	2.1

Notes:

^a For the Faro Creek Confluence, Drainage Area East equals current drainage area.

^b Length along existing creek, except for Segments 3 and 4, Haul Road, and Mine Access Road length, which are along the NFRC Realigned Channel

^c Change in elevation along existing creek, except for Segments 3 and 4, Haul Road, and Mine Access Road elevation, which are existing ground along the NFRC Realigned Channel

^d Average slope along existing creek, except for Segments 3 and 4, Haul Road, and Mine Access Road slope, which are existing ground along the NFRC Realigned Channel

% = percent

N/A = not applicable

3.2.1 Faro Creek Diversion Confluence

The FCD conveys Faro Creek from upstream of the Faro Pit to the NFRC. The confluence of the FCD and NFRC is immediately upstream of the Faro Mine Area and Segment 1. The watershed contributing to the FCD, just upstream of the Faro Pit, has an area of approximately 1,618 ha. The elevation ranges from 1,860 m at the top of the watershed to about 1,295 m near the Faro Pit. The maximum length of the watershed is about 7,000 m, with a typical width of about 2,400 m. From a location immediately west of the Northeastern WRD (Elevation 1,260 m) to the confluence with the NFRC (Elevation 1,120 m), the diversion has a change in elevation of approximately 140 m over a distance of about 750 m, for an average slope of approximately 5:1 (horizontal to vertical), or about 18.7 percent. It is steeper at the top near the edge of the WRD and flattens near the confluence.

The valley upstream of the confluence with the FCD has a grade of about 1.6 percent and changes in elevation from Elevation 1,120 m to 1,114 m over a distance of about 380 m.

Upstream of the confluence, the FCD has incised downward to expose a granitic intrusive. The sediment load derived from this erosion has created an alluvial fan at the NFRC confluence.

The NFRC watersheds have been previously investigated for evidence of mass-wasting failure based on review of aerial photographs (BGC, 2006a). This work identified relict debris flows, soil slumps, as well as solifluction lobes. These features may present a mobile sediment source in the event of a large flood event in the future.

Water quality monitoring station R7 is located about 60 m upstream of the confluence. The estimates of streamflow flood events and results of water quality testing at R7 are presented in Appendix B. In

general, this testing has indicated some minor elevated zinc concentrations in the streamflow at Station R7, but the quality of this data is uncertain because of questions related to laboratory detection limits at the time of testing.

A preliminary field exploration conducted by SRK (2010a) indicated that alluvial sediments in the area of the confluence consist of sand, gravel, and loose cobbles, range from 7.6 to 12.2 m thick within the centre of the valley, and have measured hydraulic conductivities up to 1×10^{-3} metres per second (m/s).

3.2.2 Segment 1

Segment 1 is located between Stations 3+330 and Station 4+195 (Figure 3-1). It is approximately 865 m long and has a drainage area equal to approximately 297 ha east of the NFRC and approximately 44 ha west of the creek. The creek is at Elevation 1,113 m at the valley entrance and at Elevation 1,102 m at the junction with Segment 2. Within Segment 1, the creek is typically 6 to 9 m wide, with depths ranging from less than 0.5 m to 1 to 2 m in deeper portions of the thalweg. The valley bottom typically ranges in width from 25 to 50 m, broadening to more than 100 m at the junction with Segment 2. The creek has an average slope of about 1.3 percent within Segment 1.

For Segment 1, it does not appear to be feasible to elevate the creek (for clean water and contaminated water separation) without flooding the valley upstream of the confluence with the FCD. The field exploration, consisting of test pits, boreholes, and a geophysical survey (see Section 5), indicates that bedrock may be within a few m of the natural ground surface near the WRDs. The design includes an SIS (for example, cutoff wall and seepage interception drain) between the creek and the WRDs. The timing of the Segment 1 cutoff wall and drain construction will depend on whether monitoring indicates that contaminated groundwater is moving from the WRDs towards the creek in the Segment 1 area.

Within Segment 1, the NFRC typically flows close to the eastern hillslope of the valley. The eastern hillslope has a slope ranging from 15 to 35 percent and is approximately 30 m high before flattening its grade to the east. Significant local deformation resulting from debris flows, soil slumps, and solifluction lobes is visible on the slopes (CH2M, 2015d). On the western side of the creek, the natural hillslope has a slope of approximately 15 percent. The creek is located approximately 360 to 500 m from the base of the WRDs. The Northeast WRD, located within the Segment 1 drainage area, has a height ranging from 60 to 85 m and is sloped between 60 and 75 percent.

Several minor drainages flow from the hillslope east of the NFRC in Segment 2. These will require control during construction and will be addressed for capture during design. Permafrost likely exists in some parts of the eastern slopes.

3.2.3 Segment 2

Segment 2 is located between Stations 1+990 and Station 3+330, as shown on Figure 3-1. It is approximately 1,340 m long and has a drainage area equal to approximately 495 ha east of the NFRC and 64 ha west of the creek (this includes runoff from the WRD slopes). The creek is at Elevation 1,102 m at the junction with Segment 1 and at Elevation 1,090 m near the Haul Road. Within Segment 2, the creek is typically 6 to 9 m wide, increasing in width to over 20 m at locations of meanders created by sand and gravel bar deposition. The creek ranges in depth from less than 0.5 m to 1 to 2 m in deeper portions of the thalweg. The valley bottom ranges in width from about 50 to 70 m for most of Segment 2, broadening to more than 100 m at the Zone II Outwash.

Within Segment 2, the creek is located on the eastern side of the valley, near the base of the hillslope at some locations and meandering away from the hillslope at others. The hillslope to the east has a slope ranging from 12 to 25 percent, and is approximately 30 m high before a change in grade. Similar to Segment 1, local deformation resulting from debris flows, soil slumps, and solifluction lobes are visible on the slopes (CH2M, 2015d).

The most extensively studied area within Segment 2 is the Zone II Outwash area. Numerous wells have been installed to characterize the alluvial thickness, depth to bedrock, groundwater flow patterns, and groundwater quality. Groundwater quality has been substantially impacted because of subsurface migration of mine-affected water from waste dumps in the Zone II Pit area. Recent field explorations (CH2M, 2013b) suggest that the NFRC is a gaining stream along the majority of its length within Segment 2. These conditions suggest that groundwater contamination in the vicinity of the stream represents a viable pathway for contaminants of concern to enter the stream system and degrade surface water quality.

The NFRC is located approximately 100 m from the base of the WRDs in the area of the Zone II Outwash. Just upstream from the NFRD, the toe of the WRDs extends within several m of the instream pond that has formed as a result of partial plugging of the rock drain from debris accumulation. At this location, the WRD is about 115 m high, with an average slope of approximately 65 percent from the toe of slope to the top of the Intermediate Dump.

Groundwater in the waste-rock-filled Zone II Pit is managed (pumped) to mitigate potential seepage from the pit to the Zone II Outwash area. Groundwater contamination in the vicinity of the Zone II area may travel along two potential pathways: groundwater contamination could discharge to NFRC, in which case it would likely bypass the Rose Creek Alluvial Aquifer (RCAA) through the Rose Creek channel, or it may travel as subsurface flow, resulting in continued groundwater contamination loading to the RCAA. Permafrost likely exists in some parts of the eastern slopes.

North of the NFRD is a head pond, which has an approximate area of 1.4 ha and is approximately 1.5 m deep along the NFRD toe slope.

3.2.4 Segment 3

Segment 3 is located between the Haul Road and Mine Access Road. Two alternative alignments are under consideration for this segment (P3 and P4); in all cases, Segment 3 is located between Station 1+240 and Station 1+750, as shown on Figure 3-1. It is approximately 510 m long along the proposed realigned alignments and would have negligible drainage areas contributing to the proposed realigned channel from the west of the realigned channel and approximately 35 ha contributing from the east of the realigned channel. There are no known WRDs or other mine-impacted materials in the vicinity of Segment P3 that could serve as a source for impacted flow to Segment P3. A trapper's cabin is located on the southwestern side of the borrow area near the former P2 alignment. As discussed in Section 11, the P2 alignment has not been selected as the preferred alternative.

The natural ground surface within Segment 3 decreases in elevation from about Elevation 1,105 m near the Haul Road to Elevation 1,080 m near the Mine Access Road, a straight-line distance of about 570 m. This equates to an average slope of 4.4 percent.

The Haul Road Borrow/Granular is a borrow source for clean sand and gravels with rounded cobbles and boulders. Section 11 provides a detailed summary of this borrow area, and detailed borrow information is presented in the Geotechnical Report (Appendix E).

3.2.5 Segment 4

Similar to Segment 3, Segment 4 (located between the Mine Access Road and the confluence with SFRC) also has alternate channel routes that have been considered, presented in Section 11. Of those considered, two alignments remain under consideration: P3 and P4. P4 is located between Stations 0+875 (nearest connection to the SFRC) and 1+110, a distance of about 235 m, while P3 is located between Stations 1+100 (nearest connection to the SFRC) and 1+1+180, a distance of about 80 m.

The ground surface decreases in elevation by about 8 m at the P3 alignment, from Elevation 1,074 m to 1,066 m at P4 and from Elevation 1,076 m to 1,068 m at the P3 alignment. These changes in elevation and distance between the start and end points correspond to slopes equal to about 4.3 percent for the P3 and P4 alignments. There are no known WRDs or other mine-impacted materials in the vicinity of the Segment 4 area that could serve as a source for impacted flow to either alignment and the contributing drainage areas to the alignments are negligible.

3.2.6 Haul Road

The 14-km-long Haul Road connects the Faro Mine Area and Vangorda/Grum Area. It was developed for use by heavy duty off-road trucks hauling ore from the Grum ore transfer pad to the Faro Mill. The road was constructed largely from mine waste rock selected for its non-acid generating characteristics. The road surface is approximately 30 m wide, with a 2-m-high safety berm on each side of the road. The NFRD comprises clean waste rock at the base of the Haul Road structure, where the road crosses the NFRC. The NFRD was designed to convey normal and elevated flows of NFRC through void spaces within the fill. There is some uncertainty regarding the capacity of the NFRD to pass major storm events without impounding significant portions of the flow (CH2M, 2014a).

At the NFRD, the Haul Road is about 60 m high (Elevation 1,148 m to Elevation 1,089 m) from the top of road to the upstream toe, a projected distance of about 88 m. This equates to a slope of about 67 percent. The downstream toe is located at about Elevation 1,095 m, approximately 84 m (projected) from the top of road, with a slope of about 63 percent.

At the P3 and P4 alignment crossings, the Haul Road is about 28 m high (Elevation 1,138 m to Elevation 1,110 m) from the top of the road to both the upstream and downstream toe, a projected distance of about 37 m, which equates to slope of about 77 percent. These elevations and distances correspond to approximate distances between the road surface and the interpreted natural (vegetated) ground surface. Profiles of the alignments and the Haul Road, with mapping updated to include the winter 2014 road construction upstream of the Haul Road, are presented in Section 11.

3.2.7 Mine Access Road Crossing

The Mine Access Road extends approximately 22 km from the Town of Faro to the FMC, gaining over 400 m in elevation. The road is maintained by YG Public Works. Maintenance activities have included localized resurfacing, grading, patching, steaming culverts, and snow clearing. While the two existing culvert crossings located on the Mine Access Road are under the overall management of YG Public Works, they are monitored and maintained by site personnel because of their potential to impact water quality in the SFRC. As discussed in Section 10, YG Public Works' design standards may apply for the sizing of culverts that may be replaced across the Mine Access Road as part of the NFRC Project.

The Mine Access Road has a travelled width of about 10 m. A 450-millimetre (mm) -diameter culvert is located at the intersection of the P4 alignment. This culvert drains an area of about 0.5 ha from the Segment 3 area to the SFRC. In the area of the P3 and P4 alignments, the road slopes about 0.6 percent upslope to the east of P3 and slopes down at about 2 percent.

There are no known mine waste rock materials located in the vicinity of the Mine Access Road crossing.

3.2.8 South Fork Rose Creek

The SFRC originates upstream from Dixon Lake (north of the Vangorda/Grum Area), flows under the Haul Road and Mine Access Road and then flows northwest, south of and generally paralleling the Mine Access Road, eventually joining with the NFRC (Figure 3-2). Habitat has not been well characterized upstream from the Haul Road; however, the stream reach immediately above the Haul Road has a measured bankfull width of 8.6 m, a gradient of approximately 4.8 percent, and morphology that is

predominantly riffle (Minnow, 2009). Further upstream, a gradient of 20 percent has been reported (GLL, 2003).

Between the Haul Road and the confluence with the NFRC (a distance of approximately 10 km), the SFRC is between 5 and 10 m wide with gradients ranging from 0.2 percent to 2.5 percent. The SFRC varies in this reach from a steeper section with boulder and cobble habitat and slightly steeper gradient (2.2 to 2.5 percent) just downstream from the Mine Access Road to a broader valley that includes the former Freshwater Supply Reservoir (Figure 3-2) (Harder, 1991; AECOM, 2009). Here, the channel meanders through gravels and finer particles and has a gradient of 0.2 percent (AECOM, 2009). Downstream from the former reservoir area, the SFRC has primarily riffle habitat, followed by a wetland complex, then another section of riffle habitat that extends to the confluence with the original NFRC (AECOM, 2009).

Downstream from its confluence with the NFRC, the SFRC flows through the 250-m by 40-m Pump House Pond, and then receives flow from the NFRD. From there, the combined NFRC and SFRC become the RCD and flow past the RCTA.

Flow within the SFRC is not impacted by mine-impacted water and is considered a clean water source meeting existing applicable regulatory standards.

3.2.9 Rose Creek Diversion

The RCD routes the flow of the combined NFRC and SFRC around the southern side of the RCTA and the CVD Pond (Figure 3-3). The RCD is approximately 4,700 m long, with a slope ranging from 0.23 to 5.0 percent. Numerous drop structures are present at the downstream portion of the diversion.

The RCD was developed in two stages, the upper section and the lower section, as follows:

- The upper section of the RCD runs adjacent to the eastern limb of the Secondary Dam of the RCTA and was constructed in 1974, in conjunction with the construction of the Secondary Dam. It is a straight channel, approximately 900 m long, and is constrained by the natural slope on the southern side and by a constructed dike on the northern side.
- The lower section of the RCD was constructed in 1980 and 1981, in conjunction with the development of the RCTA's ID Pond. It passes water along the southern valley wall of Rose Creek and returns it into the natural Rose Creek channel, downstream of the CVD. The lower section includes a series of boulder-lined drop structures and a sharp bend at the downstream end. It is constrained by natural slopes on the southern side and by a constructed dike on the northern side, separating the RCD from the tailings, the ID Pond, the ID, the CVD Pond, and the CVD. In 2004, portions of the RCD dike in the lower section were rebuilt to restore freeboard to safely pass the 1-in-500 year design flood. However, recent analysis indicates that the RCD's capacity remains insufficient for the design flood. The RCD has a design capacity of 140 m³/sec, without freeboard, which is less than the 1-in-500-year flood event (CH2M, 2014b). However, hydraulic modelling results predict the existing configuration of the RCD does not provide adequate capacity to convey the 1-in-50-year flood flow of 71 m³/sec before overtopping the overflow structure (fuse plug). Design criteria dictate that the RCD maintain 0.5 m freeboard at the 1-in-500-year flow; however, as part of the RCD Upgrades project and the updated hydrological assumptions, YG and INAC decided to implement an interim measure that will upgrade the RCD to convey the 1-in-200-year flood flow in the summer of 2016. As such, the crest of the RCD dike must be raised to meet freeboard criteria. In addition to raising the crest of the RCD dike, vegetation needs to be removed from the dike and riprap, and slope sloughing needs to be repaired at some locations. The current status of the planned construction is summarized in the *Preliminary Draft Rose Creek Diversion Upgrades – Basis of Design Technical Memorandum* (CH2M, 2015e).

The RCD provides a critical function of diverting the combined NFRC and SFRC flows around the RCTA. There are indications that mine-impacted water from the Secondary Impoundment (see Figure 3-3 for

location) is seeping into the RCD. This conclusion is based on limited staining of the sediments observed within the RCD, as well as elevation differences between the Secondary Impoundment and the RCD water surface. Because of the critical function of the RCD to divert the combined NFRC and SFRC flow around the RCTA, geotechnical explorations are being conducted at the Secondary Dam to evaluate groundwater movement, as well as liquefaction potential of the materials underlying the eastern limb of the Secondary Dam.

3.2.10 Access Roads

As part of the NFRC Project, improvements to existing access roads and new access roads will be constructed at the following locations:

- **NFRC Channel Road (new road):** The realigned NFRC channel will include a maintenance access road at the top of the dike for the length of the channel. The road will have a minimum width of 8 m. The grade will follow the grade of the channel: less than 1 percent within the P1 and P2 Segments, 5 to 7 percent within the P3 Segment, and less than 5 percent within the P4 Segment. Turnouts/turnaround areas for 10-wheel trucks will be constructed a maximum distance of 200 m apart. The road will include an all-weather surface, similar to the existing Haul Road Surface at the NFRD. Access will be constructed from the Haul Road to access the NFRC channel road upstream and downstream of the Haul Road.
- **Zone II to FCD Access Road (existing road):** Improved access will be constructed following existing roadways from the Zone II Pit area to the Zone II Outwash and to the confluence of the NFRC with the FCD. This construction will include installation of culverts and surfacing of the roadways to enable all-weather access. A portion of the existing access road will be replaced with a newly-constructed access road along the proposed cutoff wall in Segment 1.
- **NFRC Seepage Collection Pond Access Roads (new roads):** for the Alternate 1 Seepage Collection Pond location, access roads will be constructed to provide access to the following: (1) crest of the NFRC Seepage Collection Pond dam (connection from both abutments), (2) dam spillway, (3) pump station, and (4) interior of the reservoir for maintenance (removal of precipitates and sediment) at intake structures. These roadways will be surfaced similar to the existing Haul Road at the NFRD and will be a minimum of 7 m wide. Turnouts will be provided to enable turnaround of 10-wheel dump trucks. For the Alternate 2 Seepage Collection Pond location, access roads will be constructed to provide access to the following: (1) perimeter of the seepage collection pond, (2) the southern and eastern side of the diversion channel extending to the cutoff wall upstream of the Mine Access Road, and (3) the southern side of the embankment toe (this partially uses existing roads in this vicinity).

3.3 Waste Rock Dumps

Within the Faro Mine Area, waste rock was deposited in a series of dumps surrounding the Faro Pit. There are approximately 260 million tonnes of waste rock in the Faro Valley Waste Dump, covering an area of approximately 335 ha. There are more than 30 separate dumps, each with a unique history and composition.

The Faro Valley Waste Dump's geochemistry has been studied extensively (CH2M, 2014c). The main WRDs at the Faro Mine Area include the Northwest, Faro Valley, Main, Intermediate, Northeast, Zone II, and near pit dumps, and the low-grade and oxide stockpiles. The Faro Mine Area WRDs are shown on Figure 3-4. These dumps do not appear to be separated by natural foundation materials. They may have been separated during initial mine operations, but are now relatively contiguous.

The most mineralized material occurs in a series of low-grade ore and oxide fines stockpiles (Figure 3-4). Although that material represents less than 10 percent of the total volume of waste, it has a high metals

content and is therefore a significant source of contaminants. The next most mineralized material is found in three sulphide cells, in areas within the Main WRD, Intermediate WRD, and Northeast WRD, where some sulphide waste was purposefully segregated. The sulphide cells are not as well-delineated as the low grade ore and oxide fines, so volumes are more difficult to estimate. However, the material's relatively high metals content and acid-generating potential suggest the sulphide cells are large sources of contaminants. The remainder of the WRDs are variable in composition. In general, most dumps contain areas of acidic and metal-leaching waste, and none of the dumps can be considered completely benign. Additional detail about the geochemical characteristics of the mine waste is provided in Section 5.

Seepage that emerges at the toe of the WRDs can affect surface water quality directly. Currently, the majority of poor-quality seepage water is collected through SISs for treatment. Most of the seepage occurs after freshet or large precipitation events. It takes place over a fairly short time frame, based on observations during the CH2M 2012 field program (2013a), as well as the historical seep sampling program (SRK, 2010a). However, several seeps (generally located in pre-mining drainage channels) flow year-round (e.g., X23, FD-05 and FD-06, FD-26, S-Wells). Most notably, seepage observed at the NFRD since the fall of 2013 has resulted in an increase in metal loading and potential impacts to the NFRC and Rose Creek.

3.4 Borrow Areas

Numerous borrow areas have been identified in the Borrow Baseline Design Criteria Report (Borrow Report) (CH2M, 2015b) for potential use during closure of the FMC; site-wide borrow areas have been excerpted from this report and are shown on Figures 3-5 through 3-7. This section briefly describes borrow sources that have potential use on the NFRC Project. Additional details are available in the Geotechnical Report (Appendix E).

1. **Freshwater Supply Dam.** The former Freshwater Supply Dam, which was located on the SFRC, approximately 2.1 km southeast of the NFRC along the Mine Access Road, was breached in 2004. The dam is a zoned earthfill embankment dam with a low-permeability core (Zone 1), a graded sand and gravel shell upstream and downstream of the core (Zone 2), a zone of random fill (Zone 3). A thin (0.6 m) upper phyllite riprap layer (SRK, 2004a) is also present on the upper upstream face. These materials, except for the phyllite shell, have been assessed and found to be suitable for construction of the Seepage Collection Pond Alternative 1 dam and potentially for portions of the realigned channel dike. Note that these borrow materials exist on both sides of the SFRC.
2. **Haul Road Cut.** The Haul Road crosses between Segments 2 and 3 of the proposed realigned NFRC. Select material from the excavated cut through the Haul Road is a recommended source of structural embankment fill material for construction of the realigned channel dike. Because of the nature of this source (unsorted run-of-mine waste), additional geotechnical and geochemical testing will be required to confirm suitability of this material. Considering the large volume of the cut relative to the needed volume of structural embankment fill, it is expected that material can be selectively borrowed from the excavation and segregated for use in dike construction.
3. **Haul Road Borrow/Granular.** The disturbed area directly south of the Haul Road in Segment 3 contains sand, gravel, and a small percentage of cobbles and boulders that may be suitable for several uses, including dike embankment, thermal barrier, and drain rock. This source is also expected to be adequate for production of filter sands and gravels for the Alternate 1 Seepage Collection Pond dam.
4. **Faro Valley Waste Dump.** As shown in Figure 3-5, several areas within the footprint of the Faro Valley Waste Dump have been identified as potential borrow sources of durable and non-acid generating coarse rock fill material that can be processed to riprap and riprap bedding. The areas

shown include, the upper parking lot (Area 1), the lower Northwest WRD (Area 2), the Faro Main Dump (Area 3), and the Faro Northeast WRD (Area 4). Of these areas, the Faro Northeast WRD and the Faro Main Dump have been observed to have the greatest potential for use. Coarse rockfill is needed for riprap and riprap bedding for the NFRC Realigned Channel, and for both NFRC Seepage Collection Pond alternatives.

5. **Granitic Rock Outcrop.** The Granitic Rock Outcrop has been identified as a potential borrow source for coarse rockfill (primarily riprap and riprap bedding). The outcrop is located approximately 8.3 km from the NFRC along the Haul Road and is bounded by the Mine Access Road to the southwest, a stream to the north, and the Grum access road to the southeast (refer to Figure 3-6). The outcrop extends 250 m from the Haul Road to the west.
6. **Tailings Borrow Area East.** The Tailings Borrow Area East is a potential borrow source for low-permeability glacial till, as required, for portions of the NFRC Realigned Channel dike and the Zone 1 core of the Alternative 1 seepage collection pond dam. This borrow source is located east of the NFRC and generally bounded by the Faro Main Dump to the north, the Mine Access Road to the south (Figure 3-5).
7. **Pump House Borrow.** The Pump House Borrow area generally coincides with the proposed location of the NFRC Seepage Collection Pond Alternative 2. This sand and gravel borrow area can be graded and processed to produce the required embankment materials, lining cushion materials, and others for the entirety of the Alternative 2 pond. This area could also be used for various granular borrow associated with the NFRC Realigned Channel dike and/or the NFRC Seepage Collection Pond Alternate 1 dam.
8. **Other Coarse Rock Fill Sources (not presently recommended).** There is an existing riprap quarry at the Grum Sulphide Cell. This area produces quality durable stone from an established source; however, this source requires a long haul if used for the NFRC Project. This could be used for supplemental riprap or riprap bedding if the haul distance is economically preferable to development of a new source at the granitic outcrop.
9. The RCD quarry is an existing quarry site located south of the RCD in the vicinity of the Cross Valley Dam. This calc-silicate source was used to produce riprap and riprap bedding during construction of the lower portion of the RCD. Although a bridge over the RCD would be required, this quarry site could be expanded to produce additional volume. This source has not been evaluated.

Section 11 presents a summary of the borrow areas planned for the NFRC Project including recommendations specific to the NFRC Realigned Channel construction and both of the NFRC Seepage Collection Pond alternatives. The Geotechnical Report (Appendix E) presents detailed information on the evaluation of these borrow areas and recommendations for their use.

3.5 North Fork of Rose Creek Seepage Collection Pond

Contaminated seepage will be collected in a Seepage Collection Trench adjacent to the WRDs and will be conveyed through the NFRD and into the existing NFRC channel downstream of the NFRD. A Seepage Collection Pond will be constructed downstream of the NFRD to collect mine-impacted water for conveyance to the IWTS or to the Faro Pit for temporary storage. To the extent practicable, the NFRC Permanent Seepage Collection Trench will be constructed within the footprint of the existing NFRC stream channel.

Two alternative locations have been identified for construction of the Seepage Collection Pond (Figure 3-1). The Alternative 1 location is located downstream of the NFRD and upstream of the Mine Access Road. The Alternative 2 location is located south of the Mine Access Road and east of the RCTA.

The pond sizing analysis, presented in Appendix B, shows that the combination of 300,000 m³ storage for the Alternative 1 location, and 350,000 m³ storage for the Alternative 2 location, and 126 L/s pumping and conveyance, will store and convey annual precipitation exceeding the annual 200-year return precipitation volume. Contaminated water collected at the storage pond will be pumped from the pond using one or more of three 63 L/s-capacity stainless-steel pumps and conveyed by high-density polyurethane (HDPE) pipeline to either the IWTS or the Faro Pit. To provide redundancy and protection against icing, the pumps will be connected to two non-gated intakes; the primary intake located near the bottom of the pond in a protected enclosure, and a secondary intake located at a higher elevation. The design includes an additional installed 63 L/s pump and a pipeline with a capacity equal 189 L/s. For projected water chemistry of the pond refer to Appendix D.

Storage is assumed take place October through April and conveyance from the pond from May through September. A dead pool will be allowed to remain within the pond over the winter to prevent freezing of the primary intake structure. The actual duration and timing of conveyance out of the pond will depend on the accumulated snow volume, the timing of snow melt, and the freshet volume. The pipelines and pump stations are designed to allow winter operations.

3.5.1 Alternative 1 Location

Alternate 1 consists of a storage pond developed through construction of an earthen dam, approximately 15 m in height from the crest to the downstream toe. The pond will have an active storage volume of 300,000 m³ and will occupy an area equal to about 78,000 m² at maximum storage. The catchment area draining to the Alternate 1 location equals 107 ha.

The hill slope adjacent to the creek on the eastern side has numerous bedrock outcrops consisting of phyllite and schist with varying degrees of weathering foliations, and fractures. In the area of the proposed Alternative 1 Seepage Collection Pond, the bottom of the creek is at approximate Elevation 1073 m. The hillslope rises to a maximum elevation of about 1090 m, a difference of 17 m. Adjacent to the creek, the eastern slope rises from Elevation 1074 m to Elevation 1088 m over a distance of about 21 m, a slope of about 66 percent.

The catchment area west of the NFRC at the Alternative 1 location will be minimized by constructing diversion ditches around the pond to convey runoff around the pond perimeter. The hillslope on the western side of the creek is relatively uniform, with small changes in slope. Bedrock outcrops have not been observed on the hillslope west of the creek. In the area of the proposed Seepage Collection Pond, the bottom of the creek is at approximate Elevation 1,073 m. The hillslope rises to a maximum elevation of about 1,100 m at the S-well Access Road, a difference of about 27 m. Adjacent to the creek, the western slope rises from Elevation 1,074 m to Elevation 1,088 m over a distance of about 100 m, for a slope of about 14 percent.

The distance from the downstream toe of the Haul Road to the Mine Access Road is a straight-line distance of about 722 m. The distance following the creek channel equals about 920 m. The elevation at the toe of the Haul Road equals about 1,085 m, and the elevation at the Mine Access Road equals approximately 1,071 m, which is a 14 m drop. This elevation equates an average creek slope of 1.5 percent.

3.5.2 Alternative 2 Location

Alternative 2 is a lined Seepage Collection Pond located downstream of the Mine Access Road. The proposed pond will have a minimum active storage volume of 350,000 m³ and will occupy an area of about 84,000 m². The catchment area draining to the Alternate 1 location equals 138 ha.

For this alternative, contaminated water from the existing NFRC channel will be directed through a newly constructed and lined diversion channel extending from a groundwater cutoff structure, located upstream of the Mine Access Road, to the lined pond that will be located immediately east of the RCTA.

The alternative consists of three main elements: (1) upstream cutoff, (2) diversion channel, and (3) a lined pond.

The diversion channel begins at a groundwater cutoff structure constructed across the existing NFRC channel upstream of the Mine Access Road. The diversion structure will be constructed upon bedrock and embedded within a weathered bedrock trench. The structure will be backfilled with soil on both sides. The diversion channel consists of a constructed earthen channel with a uniform slope and cross section, double geomembrane liner, and riprap channel lining.

The storage pond will be located upstream of the RCTA, near the junction of the NFRC original channel, the NFRC Temporary Diversion, and the SFRC flood plain. The pond will be developed through construction of an earthen embankment, with a maximum height of approximately 15 m as measured from the crest to the downstream toe of the embankment on the southern side of the pond, nearest the SFRC. The proposed pond will be located within the South Fork flood plain and is underlain by over 40 m of alluvial sand and gravel. A deeper till layer has been identified at depth. Groundwater will be located several metres below the bottom of the pond. The pond will be double lined with LLDPE includes a seepage collection layer and leakage detection system for monitoring for defects in the primary liner and then identifying the leakage locations for repairs, if necessary.

The existing surge ponds will be backfilled, following completion of the NFRC Realigned Channel. The outside berms of the pond adjacent to the SFRC will be designed to pass a PMF flood event without failure.

3.5.3 S-Wells

The S-Wells area is an area of groundwater contamination adjacent to the NFRC. It is located at the southernmost extension of the Intermediate WRD, on the southwestern side of the Haul Road (Figure 3-4). Between 2007 and 2009, groundwater and surface water quality explorations in the S-Wells area indicated high levels of contaminants near the NFRC, with a component of the contaminated groundwater discharging to the creek. By 2008, increasing trends in contaminant concentrations were also evident within the creek, particularly during the winter low-flow period. An SIS was installed in the S-Wells area in 2009.

The S-Wells SIS includes two main components (CH2M, 2012a; SRK, 2010b): (1) two pumping wells within the deep aquifer and (2) a shallow aquifer, and a seepage and surface runoff interception trench. The interceptor trench consists of a 25-m-long trench, installed in February 2009, and a 15.4-m-eastern extension installed in November 2009. Within the trench, a 2.1-m-diameter central sump with a pumping well cross-cuts the shallow aquifer, and a 15-horsepower pump is positioned 0.6 m below the base of the shallow aquifer, at 1,083.3 masl (approximately 7.6 m below ground surface) (SRK, 2010b).

Pumping wells SRK08-PW2 and PW3 are operational. Pumping well SRK08-SPW1 is not currently operational because of excessive precipitate formation in the conveyance systems. The S-Wells SIS collects water year-round. This water is pumped to the Faro Pit, where it is discharged below the pit lake water level. A sea can is installed over the sump, complete with all piping, valves, meters, controls, and discharge pipeline. Data loggers within the sea can record flow rates, cumulative pumped volumes, and water levels. An electrical line from the Faro Pit area provides the S-Wells area with power.

Following completion of the Seepage Collection Pond downstream of the S-Wells, it is anticipated that the S-Wells pumps could be shut off and all contaminated water collected at the newly constructed Seepage Collection Pond would then be pumped to either the Faro Pit for storage or pumped directly to the IWTS for treatment.

3.5.4 NFRD Seepage Interception System

In the autumn of 2013, a new metals load source to the NFRC developed in the area of the NFRD, which resulted in elevated zinc concentrations in the NFRC and at Monitoring Station X14 (located downstream of the FMC). A detailed monitoring program and drilling program conducted in 2014/ 2015 indicated that the source likely originates from a highly-concentrated flow path. Initially, the contamination was observed on flows discharging on the northern side of the rock drain. In response to this contamination, YG and INAC implemented initial remedial responses during the fall and winter of 2014/2015, constructing the Rock Drain SIS. This system consisted of a localized seepage collection system on the northern side downstream of the rock drain, and pumps and piping to convey contaminated seepage discharging to Faro Pit. This system was operated during the winter of 2015 and was partially effective in capturing the contaminated seepage. Recent monitoring has shown that the contamination is no longer isolated to the northern side of the NFRD.

Design Scope Description

4.1 Introduction

This section of the Preliminary Final DBR summarizes the general scope of work conducted for each planning area of the NFRC Project identified in Section 3. Section 3 identifies the site planning areas, their locations, geographical, topographical information, as well as the logic behind the demarcation of the planning areas. Following the discussions of the general design scope of work in this section, Section 5 provides a description of the known existing site conditions and features based on field explorations and data available from the OSR, and other explorations conducted since 2008.

The scope of work for all site planning areas included the following:

Develop scoping documents for preparation of a task authorization request (TAR) to initiate necessary field studies and design work. Prepare additional TARs as required to continue portions of the work based on available funding and schedule constraints.

Subcontract, as necessary, with technical experts in the areas of dam risk analysis, permafrost, and cold weather engineering and construction to guide technical approaches for the NFRC Project, to review documents, assist in development of field exploration plans, and participate as expert reviewers on the Dam Safety Review Board.

Prepare the Draft DBR (DDBR) and Preliminary Final DBR. The DDBR was essentially a planning document. The Preliminary Final DBR is the review document prepared for the Technical Review Committee (TRC). Following receipt of review comments from the TRC, and revision to the Preliminary Final DBR, the Final DBR will be presented to the IPRP. The scope of work for the Preliminary Final DBR includes the following:

- a. Develop preliminary concepts for separating and/or maintaining clean water separate from mine-impacted water in the NFRC, capture the contaminated water, and convey the contaminated water for storage and treatment.
- b. Compile and present data and Information pertaining to the existing site conditions. This includes surface water hydrology, hydrogeology, geological (including seismic), geotechnical (including permafrost), and geochemical data. Identify data gaps and processes to address the data gaps.
- c. Present the following: (1) provide basic project information including site background, a description of the remediation problem and the site conditions and features, (2) provide a description of the design approach including assumptions and constraints, design objectives, criteria and standards, and potential alternative designs, and (3) complete the proposed modelling, (4) provide a description of the internal and external design review processes, and (5) provide planning and engineering deliverables.
- d. Meet with YG and INAC by telephone conference in October 2015 to review the DDBR and in January 2016, review progress in completion of the Preliminary Final DBR. Meet with the Dam Safety Technical Review Board (TRB) in March 2016, to discuss the preliminary final Concept Design and Analysis.
- e. Complete analysis of the 2015 field exploration data and prepare recommendations for additional explorations that will be required to complete the Detailed Design.

Prepare the Final DBR. This will include an update to all sections of the DDBR and add the following sections to the DDBR:

- a. Conceptual Design (equivalent to about a 30% design)
- b. Class 4 level accuracy cost estimate
- c. Preliminary project schedule
- d. Appendices containing engineering analyses and other reports required to support the Conceptual Design

4.2 North Fork of Rose Creek Realigned Channel

The purpose of the NFRC Project is to separate clean surface water within the NFRC watershed from mine-impacted water, which is either currently contaminated or has the potential for contamination in the future. Mine-impacted water originating from the WRDs is entering into the North Fork valley at the Haul Road, at seep locations below the WRDs, and in groundwater. To date, metal loading from the seep discharging in the area of the Haul Road has resulted in a significant impact to water quality within the NFRC and downstream in Rose Creek (detailed in Section 5).

In addition to the work described in Section 4.1, the scope of work for the NFRC Project includes the following:

1. Evaluate the alternative alignments developed and presented in the Alternative Development Status Report (CH2M, 2015a) in consideration of the results of the NFRC Phase 1 field exploration program.
2. Conduct hydrologic modelling to determine requirements for the realigned channel carrying capacity, based on contributing surface area and return flood events. Use both regional and local stream runoff data and runoff estimated from precipitation.
3. Present proposed alignment options for further development based on the results of the Phase 1 and 2 field exploration, other geotechnical data, and the hydrologic analysis. Prepare terrain models of the optimized alignment options, estimate cuts, fills, and excavation requirements. Develop cross sections and profiles.
4. Inform the heritage clearance team of potential alignment changes as soon as possible as preliminary results of the hydrology, geotechnical, and alternative analyses and the field explorations become available. Incorporate pertinent field observations into the design process.
5. Develop a high-level construction sequence to evaluate cost-effective design and construction implementation approaches. For instance, it is recommended that excavation of the Haul Road should, to the extent practical and cost-effective, be conducted so that excavated material can be directly placed rather than stored and re-handled.
6. Develop a water management plan for the construction and post-construction phases. This plan will include collection and conveyance of clean and mine-impacted surface water and groundwater.
7. Provide an initial evaluation of how the eventual closure of the WRDs adjacent to the NFRC valley (e.g., regrading and covering) will be integrated with the realigned channel.
8. Summarize requirements for modifying the Concept Design to accommodate fish passage or habitat.

4.3 North Fork of Rose Creek Seepage Collection Pond

The Seepage Collection Pond is planned to be located downstream of the NFRD. Three alternative locations have been identified for consideration, but only two alternatives were considered practical and feasible. Conceptual designs were developed for Alternatives 1 and 2. The Seepage Collection Pond

is intended to collect and store the mine-impacted water for conveyance and treatment. The scope of work for the design of the Seepage Collection Pond includes the following:

1. Define the surface water and groundwater catchment areas for the Seepage Collection Pond.
2. Using geologic mapping and topographic mapping, identify potentially suitable locations for location of the storage pond. Compute stage and storage capacity relationships based on this evaluation.
3. Complete a hydrologic analyses to estimate runoff flowrates and volume requirements for the alternative seepage collection ponds.
4. Develop steady state and transient groundwater models for the alternate Seepage Collection Pond locations to estimate the monthly average volume groundwater to surface water discharges.
5. Compare the results of the hydrologic runoff modeling and the groundwater model. Based on these results, select the average monthly flow rate for various annual return periods (such as, 2 year, 10 year, and 50 year). See Appendix B (Hydrotechnical Report) for a detailed presentation of the analysis.
6. Using the results of the hydrologic analyses of runoff and groundwater contributions to surface water, develop a spreadsheet model to compute runoff and storage relationships for different runoff return period events, treatment capacities, treatment durations, and catchment areas. Based on preliminary estimates of mine-impacted water catchment areas, estimate pond storage requirements.
7. Incorporate the stage and storage curves and catchments nodes for the alternative storage ponds into the site-water balance model (GoldSim Model). Use this model to simulate operation of the seepage collection ponds together with operation of the water treatment plant, storage and treatment at the ID Pond and the Faro Pit, and treatment of other sources including the ETA, the S-Wells, NFRD, and the Zone II pit. Simulate both cold weather and warm weather operations. Recognize that long-term operations may include shutting off the S-Wells and the collection of the S-Well seepage with the new NFRC Seepage Collection Pond.
8. Based on the results of the 2015 field program and the hydrologic simulations, determine potential designs suitable for construction in the proposed area downstream of the NFRD. Identify potential challenges to the design and potential materials and equipment for construction, including embankment materials, piping, pumps, pumps stations, and inlet and outlet works.
9. Evaluate expected geochemical conditions projected over the short term (0 to 5 years), medium term (5 to 15 years), and long term (greater than 15 years) for mine-impacted water collected within the Seepage Collection Pond. Use the results of this evaluation to assess requirements relative to pond operations and maintenance (O&M), materials of construction, and pumping and piping.
10. Conduct flood routing through the Seepage Collection Ponds.
11. Provide an initial evaluation of the hazard classification of the dam based on Canadian Dam Association (CDA) requirements for design. Based on the hazard classification of the dam, determine the design flood and earthquake loadings.
12. Perform preliminary engineering analyses sufficient to develop conceptual designs of the dams, including slope stability, filter and drain evaluation, and erosion protection of dam slopes.
13. Develop conceptual designs and evaluate the analysis and detailed design requirements for dam appurtenant structures including: (1) pond outlet works, (2) pond spillway, (3) pump station, and (4) Acid rock drainage (ARD) pipeline to Faro Pit and the IWTS.

4.4 South Fork of Rose Creek

Segment 4 of the realigned NFRC channel will connect with the SFRC. The scope of work related to the SFRC includes the following:

1. Conduct hydrologic analysis and flood routing to determine the flow magnitude and estimated stream channel conditions (width of channel, channel flow velocity, requirements for erosion protection) for various storm events.
2. Determine whether berms or other containment structures need to be constructed within the SFRC area downstream of Segment 4 to protect the Mine Access Road, Seepage Collection Pond, or other features.
3. Evaluate requirements for isolating the existing NFRC from the connection with the SFRC. A portion of the existing diversion may remain in place to collect impacted seepage from the Seepage Collection Pond. The amount of seepage will be a function of the foundation conditions at the dam, potential leakage from the pond area, and the amount of funding required to construct cutoff walls or place linings within the pond.
4. Conduct groundwater modelling to determine:
 - Interaction between the SFRC and potential seepage from the Seepage Collection Ponds.
 - The effect of realigning the NFRC on both the SFRC and the RCTA alluvial aquifers.
 - Location of the water table and potential interaction with the Alternative 2 Seepage Collection Pond.

4.5 Rose Creek Diversion

Two issues have been identified at the RCD for evaluation as part of the NFRC Project:

1. The potential for liquefaction has been evaluated at the eastern limb of the Secondary Dam, adjacent to the RCD. This was accomplished by conducting Standard Penetration Testing and downhole shear wave velocity testing. The results of this field testing and a liquefaction analysis was conducted using the results of the updated seismic hazard assessment completed by Atkinson and Assatourians (2013).
2. Monitoring wells were installed and pump testing conducted to evaluate movement of contaminated seepage from the Secondary Impoundment into the RCD. The evaluation included developing an estimate of hydraulic conductivity (Kv) of the dike and foundation materials and flow rates. Monitoring well data chemistry data will be evaluated when available to estimate metal loading rates, if present, into the diversion.

4.6 Access Roads

As described in Section 3.2.10, construction of new access roads and improvements to some existing roads will be included in the NFRC Project. Road design work is anticipated to include: (1) evaluation of foundation conditions at the proposed access road locations, estimation of traffic and travel requirements (time of year, weather conditions, and loading conditions), (2) design of the road foundation and materials of construction, (3) estimation of drainage areas, runoff for storm events, and culvert design, (4) erosion control requirements, and (5) maintenance requirements.

4.7 Waste Rock Dumps

The Alternative Development Status Report (CH2M, 2015a) presented three options for regrading and covering the WRDs. To the extent that this regrading may impact the NFRC Project, the regrading of the

WRDs needs to be evaluated for all the waste dumps adjacent to the NFRC, both upstream and downstream of the NFRC. As part of the NFRC Project, CH2M has evaluated ways to reduce runoff contributing to the NFRC Permanent Seepage Collection Trench. This could include minor regrading or placing berms at the top of the WRDs. Per YG direction, all CH2M work related to closure of the WRDs has been terminated. Integration of the WRD closure and the NFRC Project will need to be addressed in subsequent designs development. Assumptions regarding WRD regrading and integration with the NFRC-contaminated seepage collection facilities are provided in Section 11.

4.8 Borrow

Potential borrow sources are identified in Section 3.4 and in the 2015 Borrow Report (CH2M, 2015b). As the design concepts for the NFRC Project develop, quantities of required materials will be estimated, and these will be compared with estimated quantities available from the potential borrow sources. More detailed analyses of the available borrow materials has been conducted along with an evaluation of the suitability of the materials based on: (1) geotechnical and seepage requirements, (2) degradation and durability, (3) borrow area development requirements, (4) geochemical stability, and (5) cost for transport.

4.9 Site Operations

A site operations plan specific to the NFRC Project will be prepared. General topics will include the following:

- Water management operations
- Operation, maintenance, repair, and monitoring
- Environmental management and monitoring
- Adaptive management
- Risk management

A description of these plans is provided in Section 22.

Site Conditions and Features

5.1 Introduction

This section details the existing known site conditions and features based on preliminary field explorations and data available in the OSR and other explorations conducted since 2008.

5.2 Existing Infrastructure and Operations

5.2.1 Access Roads

Primary access roads located in the vicinity of the NFRC, the proposed NFRC Realigned Channel, and the Seepage Collection Pond include the following:

1. Haul Road: Connects the Faro Mine Area and the Vangorda/Grum Area (see Section 5.2.4). The road is well maintained and provides all-weather access.
2. Mine Access Road: Primary access from the Town of Faro to the Faro Mine Area.
3. S-Wells Road: Access from the Mine Access Road to the S-Wells are located at the toe of the Haul Road (see Section 5.2.3).
4. NFRD Road: Access from the Haul Road down to the NFRD head pond (constructed in October 2014) can be used for construction access for the NFRC Project.
5. WRD Roads: Access roads are located for access from the Mill Building Area to the Haul Road and to the Northeast WRD and the FCD.
6. Zone II Outwash Road: An access road leads from the WRDs near the Zone II Pit to the Zone II Outwash area. This road is used to access monitoring wells in the Zone II outwash and access NFRC monitoring locations.
7. A spur road off the Zone II Outwash Road provides access to monitoring stations located below the Northeast WRD and to the R7 stream gage station above the confluence with the FCD.
8. In the vicinity of the proposed Seepage Collection Pond, access roads will be constructed to the dam crest, the Outlets Works, and the Pump Station from the Mine Access Road.

5.2.2 Electrical Services

The existing 4.16-kV overhead distribution line is available at the nearby NFRD SIS (see Figure 5-1) but because of the load of the new pump station, it cannot be used to power the new pump station. The load added by the proposed pump station is 600 kilovolt ampere (kVA) and it is not possible to add that at the end of the line located at the NFRD SIS because of voltage drop problems.

A separate 4,160 volt (V) overhead line runs through the main FMC and to the Intermediate Dam Pond. This line has the capacity to feed the new pump station, but would require construction of a relatively long section of line to connect to the pump station location.

The 69-kV powerline that links the Grum with the FMC runs relatively close to the location of the new pump station and is a possible source of power supply for the pump station. However, a 69-kV step down substation is relatively expensive, but remains a viable option. .

YG worked with a separate consultant to evaluate the feasibility of temporarily rerouting the existing 69-kV overhead line during construction of the NFRC Haul Road crossing. The excavation limits for the

NFRC Haul Road crossing will impact approximately four overhead power poles and approximately 230 m of existing overhead electrical line. The analysis indicated that there are two viable options to temporarily relocate the existing line to maintain electrical service at the Vangorda/Grum Area during the NFRC Haul Road Crossing construction, which is anticipated to take two construction seasons to complete. The options are to detour the line around the cut, or to span across the cut with special anchor structures. The two options are equally viable and the estimated costs are the same as well.

Presently, there are two rental generator units onsite. One unit (rated 500 kilowatts [kW]) is able to provide backup power through existing infrastructure to the new pump facility (a maximum of 200 kW). If necessary, because of new pump station loads, a larger rental unit (1 megawatt) could be procured to replace the existing unit.

The requirement and configuration of standby power for the NFRC Seepage Collection Pump Station will be discussed with YG and incorporated, as needed, into the Final DBR.

5.2.3 S-Wells

Contaminated groundwater daylightes both as seeps along the toe of the Intermediate WRD face to the north of the S-Wells area and also flows south toward the NFRC within alluvial, weathered bedrock, and bedrock aquifers. Groundwater contamination in this area discharges to the NFRC and could contribute loading to the RCAA as leakage from the NFRC or RCD. The 2008 S-Cluster groundwater exploration (SRK, 2010c) concluded “the plume of contaminated groundwater [in the S-Wells area] is likely moving underneath the NFRC in permeable materials and discharging to the NFRC at indeterminate locations.” The S-Wells groundwater monitoring locations are shown on Figure 5-2.

In general, groundwater in the S-Wells area is moderately to highly impacted, with some slightly impacted alluvial and overburden locations on the far eastern portion of the site. Figure 5-2 and Section 5.5.3 present information on the level of impact to surface water, groundwater, and seeps based on pH, zinc, and sulphate concentration. The shallow groundwater system generally has the highest contamination, with 11 out of 21 wells classified as highly impacted (and 8 wells classified as moderately impacted). Groundwater contamination does extend into the bedrock as well, with highly impacted groundwater detected in one bedrock well (SRK-08-SPW2) and moderately impacted groundwater detected in the remaining bedrock wells (RGC, 2012a).

An SIS was constructed in 2009 to intercept contaminated groundwater flowing from the Intermediate Waste Dump before it reached NFRC. It consists of three parts (RGC, 2012a):

- A shallow rock-filled interceptor trench located in the shallow aquifer (overburden) with one pumping well (SRK08-PW3).
- Two pumping wells (SRK08-SPW1 and SRK08-SPW2) screened in the deeper bedrock aquifer. Only one well typically operates because the other well contains high iron concentrations.
- Surface water interception via a rock drain at the toe of the Intermediate WRD. Water is diverted to the shallow aquifer interceptor trench.

S-Wells SIS water is pumped to the Faro Pit and currently operates year-round (RGC, 2012a). Zinc and sulphate loads in 2011 captured by the S-Wells SIS were 21.3 tonnes per day (tpy) and 300 tpy, respectively. Between May and December 2012, 17.8 tonnes of zinc and 272.5 tonnes of sulphate were captured at the S-Wells SIS.

Information regarding groundwater quality at the S-Wells is provided in Section 5.5.3.

5.2.4 Haul Road

The 13-km Haul Road connects the Faro Mine Area and Vangorda/Grum Area. The road was constructed as a dumped rockfill structure, largely from mine waste rock selected for its non-acid generating

characteristics. The road surface is approximately 30 m wide, with a 2-m-high safety berm on each side of the road. The NFRD comprises clean waste rock at the base of the Haul Road structure, where the road crosses the NFRC.

At the NFRD, the Haul Road is about 60 m high (Elevation 1148 m to Elevation 1089 m), from the top of road to the upstream toe, a projected distance of about 88 m. At the P2, P3, and P4 crossings, the Haul Road is about 28 m high from the top of the road to the upstream toe.

The Haul Road is used by care and maintenance (C&M) staff as the primary means of access between the two mine areas. For closure planning, the Haul Road is planned to be used to transport materials (fine-grained materials from the Grum Overburden and potentially riprap from the Granitic Outcrop) from the Vangorda/Grum Area to the Faro Mine Area. It is intended that the Haul Road be reconstructed after construction is completed at the realigned channel, to provide access between the two mine areas for maintenance and to haul borrow materials.

The NFRC flows through the Haul Road at the NFRD. A pool forms on the upstream side of the Haul Road embankment as water enters the rock drain. During the freshet, flood events, and other higher flows, the size of the pool increases as flows exceed the flow-through capacity of the rock drain. The NFRD reduces flow velocity, attenuates flows downstream, and collects sediment and debris. To date, the NFRD has performed satisfactorily. The maximum recorded flow through the structure as of 2009 was 22 m³/sec (Ferris, 2009). The following list summarizes the key design information specified by Golder (1986), as summarized by BGC Engineering (BGC, 2006b):

- The drain was to be constructed from calc-silicate rock, whereas the remainder of the Haul Road could be constructed of schistose rock.
- The design flood for this structure was the 1-in-100-year return period flood event (70 m³/sec).
- The width of the calc-silicate rock drain was intended to be 70 m, centered on the pre-existing creek channel.

The construction of the NFRD included rock end-dumped from the final road elevation; the final height was approximately 55 m. This method resulted in a natural sorting of the rock, with the largest rocks at the base of the road and the fine material near the top. There was no observed instability of the Haul Road embankment slopes during construction.

- The assumed slope of the upstream and downstream faces of the drain was 37 degrees, the angle of repose for calc-silicate rock.
- The representative grain size was assumed to be 0.3 m, given the likely maximum particle size and an allowance for particle breakage due to the overlying weight of the rockfill.
- To determine the capacity of the drain, it was assumed no flow occurred in the upper portions of the rock drain (above 3.6 m drain). The routing analysis indicated that the 1-in-100-year flood would produce a 40-m-deep pool on the upstream side of the drain, and that the mean annual flow would result in an 11-m-deep pool.
- The downstream face of the drain (if left at the assumed angle of repose, 37 degrees) was considered to be unstable under high flows, because of seepage forces. The design included the construction of a “fillet” of large diameter rock, to be installed at the downstream toe. The fillet, which was intended to stabilize the toe from seepage forces, was to have a minimum slope of 3H:1V, and extend to 15 m or more above the toe of the drain. This fillet was never constructed.
- The original design included the construction of an emergency overflow spillway and the abandonment of the NFRD; the spillway was never built and the NFRD remains.

- Photos and descriptions indicate that the Haul Road embankment was constructed across an unprepared foundation surface on the valley bottom. Trees, peat, topsoil, and other native materials were not removed before construction of the Haul Road embankment and NFRD. During construction, a bulldozer was used to position large rocks in the channel of the NFRD. Outside the calc-silicate NFRD prism, the Haul Road embankment was constructed of similarly end-dumped schistose (phyllite) rock. This rock is considerably less durable and more prone to breakdown than the calc-silicate comprising the rock drain. In 2014, rock fill material from a borrow area on the Haul Road embankment was used as borrow material for construction of the upstream access road with X-ray fluorescence used to assess chemical nature of material excavated. Trapper's Cabin

A Trapper's Cabin is located in the vicinity of the P3 alignment (Figure 3-1). Additional information is required to determine whether the alignment can pass near this location or whether the location is not acceptable based on the presence of cultural resources.

5.2.5 Interim Water Treatment System

The IWTS consists of two parallel trains of skid-mounted equipment housed in an all-weather insulated and heated fabric building. It is located on the former concentrate load-out concrete pad below the mill. It has a maximum capacity of 380 L/s (6,000 U.S. gallons per minute [USgpm]). Influent water is pumped from the Faro Pit and flows by gravity from the pit rim to a steel break pressure tank located above the IWTS that is used to dissipate energy and provide emergency overflow to the ETA canyon. ID Pond and ETA water can also be pumped to this tank, although this has not yet been done. Effluent from the IWTS is carried via gravity by aboveground high-density polyurethane (HDPE) piping to the CVD Pond or directly to the North Wall Interceptor Ditch (NWID) for discharge at X5. The plant uses lime precipitation to increase pH and precipitate dissolved metals as hydroxides. Aeration is provided to oxidize ferrous iron. Clarification is performed using sand-ballasted clarification augmented with polymer addition. Additional lime slurry can be added to the effluent to increase the pH in the CVD Pond. Sludge is pumped to the edge of the ETA canyon, where it flows by gravity to the tailings-area sludge ponds.

Influent flows by gravity from the break pressure tank into the IWTS building, where it is split between the two trains and flows by gravity through the process. Each flow split first enters a mixed and aerated reactor tank configured into three compartments in series. From there, it flows into a second similar mixed (but not aerated) reactor tank, which in turn discharges into an Actiflo sand-ballasted clarification skid. Polymer is added to adhere the metal precipitates to microsand to facilitate rapid settling in a lamella clarifier. The settled sludge is pumped to a cyclone where the precipitates are separated from the microsand. The microsand is recirculated for reuse and the precipitates (sludge) are discharged to a mixed-sludge holding tank. Make-up microsand is needed periodically, as recovery is not 100 percent. Make-up sand is manually added from bags. A portion of the sludge is pumped as waste sludge to the sludge ponds, and a portion is pumped to a second tank where lime slurry is added. This lime/sludge mixture is pumped to the first and second reaction tanks based on pH feedback control. The wasted sludge is less than 1 percent weight (wt%) solids.

Lime is delivered as pulverized quicklime and is stored in a Pony Express portable silo and then slaked into a slurry of nominally 20 wt% solids using a Porta Batch portable lime-slaking system. It is periodically pumped into a dilution and storage tank in the IWTS from which it is pumped to the lime/sludge mix tank via a recirculation loop. The water used for slaking and slurry makeup is plant effluent, which is also used for polymer makeup. Anionic polymer, which is delivered in 1,000-kilogram bags and made into solution by automated equipment, is then fed to the Actiflos using variable speed pumps.

Monitoring results of IWTS discharge in 2015 has demonstrated that the treatment plant is able to meet or exceed all water quality discharge quality requirements (CH2M, 2015).

5.2.6 Operations

Site operations include the following ongoing site activities:

- Water management operations, including operating, maintaining, repairing, and monitoring water management systems and facilities at the FMC, as follows:
 - Fresh water conveyance diversions at the FCD, the NFRC, and Rose Creek
 - Contaminated water collection, conveyance, and storage facilities at the Faro Pit, the ID, the CVD, the S-Wells, the ETA, the Zone II Pit, and the NFRD
 - Water treatment at the IWTS at the Faro Mine Area, and associated sludge storage facilities
 - Water treatment using mobile, lime-based treatment systems or filtration, as needed to address site-specific adverse water quality conditions (e.g., Down Valley Water Treatment System)
- Operation, maintenance, repair, and monitoring activities required to maintain safety and functionality, and manage the physical and chemical risks to site components, facilities, and equipment:
 - Pits, waste rock storage facilities, ore stockpiles, tailings (e.g., dust suppression), and tailings storage facilities
 - Ditches, culverts, and stream crossings
 - Roads, trails, and access routes
- Environmental management and monitoring, adaptive management, and risk management activities:
 - Adhering to the prescriptions of the *Environmental Management Plan* (YG, 2014a), which was developed so appropriate environmental management practices are carried out.
 - Conducting monitoring programs to ensure environmental compliance
 - Implementing an AMP to assure timely evaluations of site uncertainties, and equally timely responses, as necessary
 - Implementing a risk assessment program to continually re-evaluate and identify risks to health, safety, and the environment

5.3 Geology

5.3.1 Physiography

The Yukon Territory lies within the northern Canadian Cordillera, a north-south-trending mountain system extending from the Beaufort Sea to the U.S. border. Deformation and plate movement, and volcanism along the western edge of the North American craton, created topographic features of steep mountains, plateaus, and valleys within the Cordillera. These features were modified by glaciation, weathering, erosion and deposition to create the modern Yukon landscape.

The FMC is located in the Omineca Belt physiographic region (Figure 5-3) of the northern Yukon Plateau (McKenna and Smith, 2004). The Yukon Plateau is dissected by southwest-trending preglacial valleys and northwest-trending glacial valleys (Jackson, 1994). The Omineca Belt is an area of uplifted sedimentary, metamorphic and granitic rocks within mountain, plateau, and lowland physiographic subunits. The northwest-southeast-trending Tintina Trench bisects the Omineca Belt, and is just south of the FMC. The FMC is located within the MacMillan Highland, an area of small mountain ranges (including the Anvil, South Fork, Wilkinson, and Russell ranges) separated by broad valleys. The Anvil Range is characterized

by uplands dissected by alpine valleys and flanked by intermediate plateau surfaces (Bond, 2001). The FMC is located on the Vangorda Plateau, a northwest-to-southeast-oriented rolling upland located between 1,000 and 1,400 masl.

5.3.2 Bedrock Geology

The FMC is located along the miogeocline (ancient continental margin), just north of the Tintina Trench. The Tintina Trench is a valley that contains the Tintina Fault (Figure 5-4), a right lateral strike-slip fault separating the miogeocline to the north and a mosaic of accreted terranes to the south. In post-Cretaceous time, the Tintina Fault offset the two different geologic areas by roughly 420 km (Murphy and Mortensen, 2003). The north region is composed of a thick, older sequence of sedimentary rocks that were deposited on the western margin of the stable paleo-North American continental margin from the Mid-Proterozoic Era until the Early Jurassic Era (Lowe et al., 1994; Wheeler et al., 1991). The region south of the Tintina Fault comprises several younger, litho-tectonic terranes of varying rock types that amalgamated and accreted to the stable sedimentary package.

The miogeoclinal assemblage to the north was deposited from the Mid-Proterozoic through the early Jurassic Eras (ca. 1250-190 million years ago [Ma]) and is dominantly limestone and sandstone formed on the stable submerged continental shelf off the western edge of the ancient North American continent. Shale, sandstone, and chert accumulated in adjacent basins (e.g., Selwyn Basin deposits). Total interpreted present thickness of the metasedimentary rocks of North American miogeocline, from the Mount Mye Formation through Earn Group, are documented to be greater than 7,400 m (Pigage, 2004). To the south of the Tintina Fault, the geology consists of a mosaic of accreted and fault-separated amalgamated terranes that are different from one another, as well as the rocks of ancient North America. Geological evidence further suggests that several of these terranes may have amalgamated with each other before their accretion to ancient North America. Major geological terranes south of the Tintina Fault include the late Devonian to mid-Permian (ca. 365-270 Ma) Yukon-Tanana Terrane (YTT), which comprises a metamorphosed continental arc assemblage, the Stikinia Terrane (a Late Triassic to Mid-Jurassic magmatic arc assemblage), and the Mississippian to late Triassic Cache Creek oceanic assemblage (Lowe et al., 1994). These Intermontane terranes are thought to represent one interrelated set of arcs, marginal seas, and continental fragments that once formed a Paleozoic to early Mesozoic fringe to North America (Colpron et al., 2007).

The Selwyn Basin is a large depositional basin of central Yukon in which deep water clastic rocks, chert, and minor carbonate accumulated along the ancient North American continental margin during Neoproterozoic and early Paleozoic time. The basin is bounded by platform carbonates to the northeast that underlie an area of approximately 700 by 200 km across the central Yukon Territory. The Tintina Fault truncates the basin on the southwest. In a Cordilleran framework, Selwyn Basin strata form a strongly deformed and thrust-faulted package located between the Mackenzie foreland fold-and-thrust belt, and accreted terranes and displaced elements of the ancient North American continental margin. The area is well-known for lead-zinc-silver sedimentary-exhalative (SEDEX) massive sulphide deposits, which have been discovered in Cambrian (Faro or Anvil Mining District), Silurian (Howards Pass), and Devonian (Macmillan Pass) shales.

The FMC is located in the Anvil District, which contains the most westerly exposures of the Selwyn Basin. The bedrock stratigraphy of the Anvil District consists of a structurally thickened sequence of late Precambrian to upper Paleozoic poly-deformed, poly-metamorphosed, metasedimentary and metavolcanic schists and phyllites of the miogeoclinal assemblage (Jennings and Jilson, 1986). The stratigraphic sequence comprising the Anvil District range from late Precambrian to Ordovician and can be divided into three formations: Mount Mye (oldest), Vangorda, and Menzie Creek (youngest) (Jennings and Jilson, 1986).

The metasedimentary rock sequences were intruded by felsic magmas during Cretaceous and Eocene time in response to collision of Yukon-Tanana suspect terrane with the North American craton (Jennings and Jilson, 1986). The oldest felsic intrusive rocks are of the Anvil plutonic suite (109 Ma), consisting of biotite-muscovite granite. The Anvil Batholith, a major northwest trending granitic pluton, is the central feature of the district and forms the core of the domal regional structural feature referred to as the Anvil Arch (Templeman-Kluit, 1972). The intrusion of the batholith caused metamorphism within sedimentary and volcanic strata ranging from moderate (schist) to low (phyllite). A higher degree of metamorphism is generally observed near the Anvil Batholith contact. The strata of the metamorphic sequence dip northeast and southwest, away from the Anvil Batholith.

The NFRC alignment is largely underlain by the phyllite member of the Mount Mye Formation, and surrounded by the younger Vangorda Formation (Figure 5-5). Some portions of the project site are also underlain by graphitic phyllite and schist members and calc-silicate members of the Mount Mye Formation. One area crosses an intrusion of the Tay River plutonic suite. The Anvil plutonic suite is cross-cut by the Tay River plutonic suite (97 Ma), which consists of unfoliated plutons, dikes, and sills of biotite-hornblende granodiorite to granite composition (Pigage, 2004). The Cambrian-aged Mount Mye Formation (Jennings and Jilson, 1986) is the oldest unit exposed in Anvil District. The Mount Mye Formation is a deep marine sequence dominated by noncalcareous phyllite and schist with lesser marble and calc-silicate lenses and carbonaceous schist. Typical Mount Mye phyllite is a medium to dark grey, noncalcareous, moderately soft to soft, fine-grained, micaceous phyllite.

The Cambrian- and Ordovician-aged Vangorda Formation is also a deep marine sequence widespread in the Anvil District, and overlies the Mount Mye Formation. It is characterized as a pale silvery grey, calcareous, recessive phyllite (Jennings and Jilson, 1986). Lesser interbedded rock types include limestone/marble, carbonaceous phyllite/schist, dolomitic siltstone, and chloritic phyllite/amphibolite. At higher metamorphic grade, the Vangorda Formation consists of thinly banded, resistant, pale cream and dark brown calc-silicate rock.

Geologic mapping (Pigage, 2004) indicates that part of the area under the proposed Seepage Collection Pond is underlain by a gabbro member of the Menzie Creek Formation. The Ordovician-aged Menzie Creek Formation is a 1-km-thick sequence of metavolcanic rocks deposited during episodic extension on the continental margin. The Menzie Creek Formation appears as a thick, resistant, grey-weathering, basaltic volcanic unit (Jennings and Jilson, 1986) that conformably overlies the Vangorda Formation. South of the Anvil Batholith, the Menzie Creek Formation consists of a medium green, pervasively foliated, noncalcareous to slightly calcareous chloritic phyllite (Pigage, 2004).

5.3.3 Structure

Numerous strike-slip and normal slip faults have been documented by Pigage (2004) in the Anvil District. In most cases, the faults are steep with small displacements. Two approximate fault orientations predominate: north and northeast. Jennings and Jilson (1986) documented five deformation phases within the Anvil District. The first two deformation phases (D1 and D2) are generally considered the most important in that they are regionally developed and accompanied by regional structural fabrics. These two deformation periods trend southeast. The D1 deformation marks the general convergence of YTT and Slide Mountain Terrane with the ancestral North American craton and represent the major period of active low angle (thrust) faulting. In the vicinity of the FMC, rocks from amalgamated terranes (e.g., YTT and Slide Mountain Terrane) were thrust over North American rocks in the Anvil District along the northwest extension of the Inconnu thrust.

D2 deformation is linked to buoyant intrusion of the Anvil plutonic suite (Pigage and Jilson, 1985). The stratigraphic units in the Anvil District are domed by plutonic intrusions to form a northwest-trending structural culmination called the Anvil Arch (Templeman-Kluit, 1972). The Anvil Arch is cored by the

Anvil and Tay River plutonic suites. Metamorphic grade decreases radially away from the granites in the core of the Arch.

The intrusion of the mid-Cretaceous Anvil plutonic suites were likely related to local extension and relaxation following intrusion of the Anvil batholith to the northeast and consist of extensional faults locally developed along the southwest margin of Anvil Batholith and overlying metasedimentary rocks.

The NFRC Seepage Collection Pond is located near a mapped normal fault (Figure 5-5) that separates the Mount Mye Formation on the eastern side from the Vangorda Formation on the western side. The Vangorda Formation is down-dropped relative to the Mount Mye Formation. The project site is surrounded by multiple northwest-trending unnamed faults. These faults may be related to the Tintina Fault to the south, or tectonic extension.

5.3.4 Surficial Geology

The surficial geology of the Anvil District is influenced by its glacial history, physiography, and past and current fluvial regime. The Anvil district is overlain by sediments originating from the McConnell glacial period, which began approximately 25 to 15 thousand years ago (Ka) (Bond, 2001).

Glacial ice advanced into the Tintina Trench and followed the topographic lineament northwest into central Yukon. McConnell ice originated from regional accumulation zones in the Selwyn, Pelly, and St. Elias mountains (Bond, 1999). Ice generally flowed from east to west, becoming more northwesterly where it intersected the Vangorda Plateau. With the exception of a few unglaciated summits (nunataks), the entire area was covered by the Selwyn Lobe of the Cordilleran ice sheet (Jackson, 1986). The upper limit of erratics mapped on Mount Mye (summit elevation 2061 m) is 1,951 m, suggesting that this may have been the height of the last glaciation (Bond, 2001).

Deglaciation of the region likely began by a rapid rise in the equilibrium-line altitude causing thinner ice in high mountains and cirques to stagnate and melt before the thick accumulations in adjacent valleys (Jackson, 1994). Deglaciation in this map area was characterized by large stagnant ice blocks, a complex system of glaciofluvial deposition, and glacial lake ponding in the Tintina Trench and area. This pattern of downwasting and stagnation is common in much of the Cordillera and is responsible for blockages to down-valley drainage and extensive ice-stagnation landforms in cirques and valley bottoms (Fulton, 1991). Deglaciation of the region was likely complete by around 10 Ka (Jackson, 1994).

A veneer of glacial till and glacio-fluvial deposits, intermixed with slope-derived colluvium, originally overlaid the Faro Pit and the surrounding southern-facing hill slope (RGC, 1996). Faro Valley to the northeast of the pit and the former Faro Creek Channel southwest of the pit contain thicker deposits of colluvium and fluvial deposits, indicated to be up to 100 m thick northwest of the pit and thinning to about 10 m south of the pit (RGC, 1996). Surficial geology of the Faro Mine Area is shown on Figure 3-5 based on surficial mapping (Bond, 2001 and 1999).

Surficial deposition within the Rose Creek Valley is a classic fluvial depositional system deposited by Rose Creek and its tributary, the NFRC. The alluvial unit is composed of a heterogeneous mixture of silt, sand, gravel, and cobbles. The alluvial deposits are thickest near the centre of the valley, aligned with the ancestral thalweg of Rose Creek, with the thickest deposits on the order of 50 m. Before tailings deposition, Rose Creek was flowing in a meandering stream channel crossing the valley floor and was fed by several smaller streams that drained the hillsides of Rose Creek Valley.

Outcrops are abundant at higher elevation along the ridges on both sides of the Rose Creek Valley, but the flanks of the valley are dominated by an extensive mantle of colluvium and soil with local patches of thin glacial till.

Drilling results from past studies indicate that bedrock in the Rose Creek Valley bottom is overlain in most places by very dense glacial till, apparently continuous with the till deposits found over bedrock on the valley slopes. In the valley bottom, the till is overlain by a complex of fluvial and glaciofluvial sands

and gravels. Within the sand and gravel are irregular deposits of silts, sands, and gravels. These silty deposits appear to be discontinuous, which may be a result of post deposition glacial or fluvial action. Maximum thicknesses of the sand and gravel are 35 to 40 m. Before mine development, Rose Creek had incised this deposit by up to 10 m in the region of the tailings impoundments (RGC, 1996).

Review of the surficial geology maps for the area (Bond, 2001; Bond, 1999; GLL, 2008a; RGC, 1996) suggests the following:

- Upland areas such as Mount Aho, Mount Mye, and the Rose Mountains are generally covered by colluvium with exposed rock and felsenmeer above 1,770 m, and at lower elevations on northern- and western-facing slopes where nivation processes are common.
- Till in the alpine valleys of Mount Mye is composed of sediments derived from local ice sources and the Cordilleran ice sheet.
- Till flanks the alpine valleys to an elevation of approximately 1,550 m and is commonly colluviated, draped by colluvium, or buried by talus.
- In valleys separating the uplands in the Anvil Range, till is thick and commonly underlies glaciofluvial deposits in areas of former meltwater drainage
- Broad side hills and areas adjacent to river valleys are frequently composed of blanket or veneer glacial deposits.
- Valley bottoms, including SFRC, NFRC, and Faro Creek, comprise fluvial materials and glaciofluvial materials.
- Till veneers and colluviated till veneers are common on south- and southeast-facing slopes that were once exposed to glacial erosion by the northwesterly flowing ice sheet
- Till materials are predominantly identified surrounding the Faro open pit.
- Glaciofluvial deposits are identified in isolated pockets throughout the project area.
- Few organics are identified in the vicinity of the FMC.

5.3.5 Permafrost

The FMC is located close to the boundary between the extensive and sporadic discontinuous permafrost zone (Heginbottom et al., 1995). Permafrost distribution varies with the degree of continentality. Maritime locales with negative surface lapse rates (temperature decreases with elevation) regardless of treeline, result in probability of permafrost increasing with elevation. However, continental sites have more complex patterns of surface lapse rates. The surface lapse rate in forested areas can be inverted resulting in lower temperatures in valley bottoms and greater degree of permafrost presence, but less likelihood of permafrost as elevation increases toward treeline. At continental sites, permafrost presence is correlated with both elevation and incoming solar radiation above treeline (Bonaventure et al., 2012). Valley bottom sediments may also have a higher ice content, including large ice inclusions such as ice wedges, ice veins, and tabular ice bodies, especially in the fine-grained sediments. Permafrost distribution is also influenced by vegetation cover, surface sediments, soil moisture, slope aspect, snow depth and water flow (surface and ground water).

In the Boreal Forest Zone, permafrost is located where soil moisture levels are higher, such as in till and colluviated till deposits. Within areas mantled by till, permafrost is more common on north-facing slopes and in old growth forests; these sites typically receive reduced solar radiation. Discontinuous zones of permafrost have been noted from drilling records from the NFRC area (e.g., BGC, 2015) and in the shallow subsurface from drilling/test pitting for the FCD realignment. Patterned ground, palsas, thermokarst, and frost boils are commonly associated with the glaciolacustrine deposits in the alpine

valleys of Mount Mye. Thermokarst is also present on alluvial plains where streams are eroding fine-grained surficial deposits. Similarly, the removal of the organic blanket will often result in the melting of the permafrost, with the resultant meltwaters flowing to and saturating the surface, especially in poorly-drained areas (Doherty et al., 2002). Other evidence of permafrost activity occurs in the alpine and subalpine zones and includes frost shattering, stone stripes, and solifluction (Bond, 2001).

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. Logistic regression was used to relate bottom of the snowpack temperatures to the presence or absence of permafrost. This local model was combined with a 30-m grid-cell digital elevation model (DEM), potential incoming solar radiation model, and equivalent elevation grid to predict the probability of permafrost over the entire area. The equivalent elevation grid adjusts the elevation at a location for surface lapse rates above and below the treeline. Using this model, the probability of permafrost at the FMC ranges from roughly 60 to 82 percent (Figure 5-6). The probability of permafrost is generally highest at the bottom of valleys and along ridgetops.

Permafrost degradation is triggered by disturbances that cause the active layer to become saturated or the ground ice to thaw (Lipovsky and Huscroft, 2007). Forest fires, river erosion, high pore pressure, or increased groundwater table or surface water runoff can all trigger permafrost slope failure. While the permafrost probability model does not account for these factors, they can be mapped at the Faro Mine Area. For example, runoff flow paths can be overlaid on the permafrost probability map to evaluate areas where probability of permafrost may be impacted. For more detail on permafrost conditions refer to Appendix E

Although there is permafrost at the site, permafrost temperatures are generally warmer than -1°C . In January 2016, a test cut was excavated from the permafrost hill slope in Segment 2, adjacent to the access road between the Haul Road and the head pond adjacent to NFRD. Construction of this test cut, summarized in BGC (2016), provided the following findings:

- Clearing and grubbing vegetation cover and snow enhances frost penetration into the ground, if subsequently exposed to cold ambient temperatures for a period of several weeks to months, but also enhances the formation of a hard-frozen crust.
- Exposed surfaces were hard frozen to depths ranging from 0.3 m to 1.2 m
- Excavation of the hard-frozen crust required first breaking it up with multiple passes of a CAT D9 ripper
- Hard frozen materials broke into boulder-sized chunks.
- Marginally-frozen materials were rippable with one pass of a CAT D9 ripper.

5.3.6 Seismic History and Hazard

Earth-shaking events can trigger a variety of natural hazards, including ground vibrations, large landslides and avalanches, liquefaction of saturated sediments, and surface rupture. In May 2004, a limited site-specific seismic hazard assessment was conducted by Dr. Gail Atkinson that identified the possibility of post-glacial movements in the region along the nearby Tintina Valley Fault System (Tintina Fault Zone) which may increase the site-specific seismic hazard within the FMC beyond that given by the 2005 National Building Code of Canada (NBC) Seismic Hazard Maps (Adams and Halchuck, 2003). More recently, CH2M evaluated current seismic/tectonic studies of the area and the updated Seismic Hazard Maps prepared by the Geological Survey of Canada (GSC) with the intent to perform an updated site-specific seismic hazard evaluation of the FMC and, in particular, the Tintina Fault Zone directly adjacent to the FMC (CH2M, 2013a; GSC, 2012).

Findings from the 2013 CH2M seismic hazard assessment summary showed that there is little documented evidence of recent displacements along the Tintina Fault Zone in this region of Yukon. There appears to be a small concentration of epicentres aligned along the Tintina Fault; however, these were minor earthquakes (less than Magnitude [M] 5), and most of the activity is at the northern end, close to the Alaskan border, which suggests that this geological fault structure remains a zone of weakness (Cassidy et al., 2005).

A 2008 global positioning system (GPS) -based deformation study by Leonard et al. associated the Tintina Fault Zone with low-level seismicity (up to M5) and calculated a maximum right-lateral strike-slip rate of only 0.5 millimeters per year (mm/year), suggesting that the fault no longer accommodates significant seismic deformation (Leonard et al., 2008). In contrast, the zones with the highest deformation rates are those that most directly represent the North America plate boundaries with the Pacific plate, Yakutat block, or both: the Fairweather Fault Zone (27.3 mm/year) and the southern St. Elias zones (3.6 to 18.3 mm/year), located more than 400 km southwest of the FMC (Leonard et al., 2008). Through the interior of Yukon, there are only three focal mechanisms from recent moderate (less than M5) earthquakes in the vicinity of the Tintina Fault system (Cassidy et al., 2005; Leonard et al., 2008).

They are a mixture of right lateral strike slip and thrust earthquakes and do not align with the orientation of the Tintina Fault system. Furthermore, there has been no evidence found for active faulting along the Canadian segments of the Tintina Fault Zone or the Denali Fault system (Cassidy et al., 2005). Data on recent earthquakes that occurred within about 250 km of the FMC site (62.2° N and 133.2° W) from September 1985 to November 2012 were extracted from the Earthquakes Canada/GSC database. No earthquakes of greater than M5 have occurred within approximately 220 km of the site. Within a 50-km radius of the FMC, approximately 38 earthquakes have been recorded since 1985. Only one event, an M4.6 event occurring in November 2002 in the Pelly Mountains, exceeded M4. The closest documented event, an M2.2, occurred about 15 km northwest of the FMC on Christmas Day, 1986.

Typical native soils at the FMC consist of thin discontinuous deposits of glacial till and glaciofluvial deposits overlying phyllitic and schistose bedrock. A geotechnical exploration conducted by CH2M in 2012 at the site of the proposed water treatment plant classified the FMC as a Class C site (very dense soil and soft rock) (CH2M, 2012b, 2012c, and 2013e).

The most relevant conclusion from the 2013 CH2M study is that evidence for contemporary activity along the Tintina Fault appears weak. The Tintina is a 30-km-wide fault zone that is characterized by a low current slip rate and low activity rates, with the most recent interpretation suggesting that the fault no longer accommodates significant seismic deformation (Leonard et al., 2008), although the evidence for this is not entirely conclusive. Moreover, it exhibits a “flower structure” with the fault zone being wide at the surface and appearing to narrow with depth (Snyder et al., 2005). Based on these findings, it now appears that the Tintina Fault may be better treated as an aerial source zone that may contain fault structures, as opposed to a distinct linear active fault.

A probabilistic seismic hazard assessment was completed for the FMC (CH2M, 2013c) using the seismic source zonal models developed by the GSC for the National Building Code of Canada 2010 (GSC, 2012). These results show the peak ground acceleration hazard for a 2 percent in 50 years (0.000404 per annum) probability of exceedance event, or a 1-in-2,475-year return period event, to be 0.110 g (108 centimeters per second squared [cm/s^2]).

In contrast, the 2004 study by Atkinson found that for an annual probability of exceedance of 0.0001, corresponding to a 10,000-year return-period ground motion, the mean value of peak ground acceleration (PGA) at the Faro site is 0.557g (546 cm/s^2) for National Earthquake Hazard Reduction Program (NEHRP) D soil conditions. The median PGA on NEHRP D for Faro, at the 0.0001 per annum

probability, is 0.350g (343 cm/s²). These ground motions correspond to an earthquake of approximately M7, at a distance of 10 to 20 km from the FMC.

An updated seismic hazard analysis was performed for the FMC by Atkinson and Assatourians (2013) considering the updated regional seismotectonic data setting and regional geologic interpretation by CH2M (CH2M, 2013c). This seismic hazard analysis was conducted using EqHaz software and considered two options for the Tintina Fault: one in which it is an aerial source zone, and one in which it is a linear fault source. This treatment is in concurrence with the findings of the CH2M study (2013c). This study found that for an annual probability of exceedance of 0.0004, corresponding to approximately a 2,475-year return-period ground motion, the mean-hazard value of PGA at Faro is approximately 0.118 g (116 cm/s²) for NEHRP B/C soil conditions. For an annual probability of exceedance of 0.0001, corresponding to a 10,000-year return-period ground motion, the mean-hazard value of PGA at Faro is approximately 0.24g (240 cm/s²) for the NEHRP B/C soil conditions (average shear-wave velocity of 760 m/s in upper 30 m).

A preliminary liquefaction assessment was performed for the NFRC Seepage Collection Dam sites, and the NFRC Realigned Channel embankment. This assessment based on the initial phases of subsurface data collection indicates that the risk of liquefaction from a 2,476 year event is low. A more detailed assessment of liquefaction risk and seismic hazards should be performed for final design evaluations following subsequent phases of geotechnical subsurface exploration programs.

5.4 Surface Water Hydrology

A detailed discussion of surface water hydrology is presented in Appendix B.

Two local watersheds encompass the FMC: Rose Creek and Vangorda Creek, both of which form part of the Pelly River drainage. The Pelly River is regionally dominant and flows northwesterly within the Tintina Trench. The Pelly River is a major tributary to the Yukon River and drains more than 49,000 km² of land.

The Rose Creek watershed encompasses the Faro Mine Area and RCTA portions of the FMC and drains west to the Pelly River via Anvil Creek. Rose Creek is fed by two tributary forks that join within the FMC: the NFRC and the SFRC. The NFRC drains south from the Anvil Range and is partially fed by Faro Creek and other small tributaries. The SFRC originates further east and drains northwest along the Vangorda Plateau, joining the NFRC just east of the RCTA. Downstream from the confluence of the NFRC and SFRC, the main stem of Rose Creek is diverted around the tailings in the RCD, which terminates downstream of the RCTA, where the creek rejoins its original channel just northwest of the CVD. Rose Creek flows into Anvil Creek approximately 13 km northwest of the FMC; Anvil Creek then flows into the Pelly River, approximately 33 km west of the Faro Mine Area.

Runoff to the NFRC upstream of the FMC arises from two main catchment areas as shown in Figure 5-7. The FCD receives runoff from a catchment area of approximately 16.2 km², which subsequently outlets to the NFRC northeast of the WRD. The remaining runoff arises from a 98.6 km² catchment upstream of the confluence of the NFRC and FCD.

The proposed NFRC Realigned Channel will convey runoff from the 114.8 km² catchment area downstream of the confluence of the NFRC and FCD, as well as runoff from an additional approximately 8 km² catchment area east of the channel (Figure 5-1). New culvert crossings will be constructed at the NFRD and at the Mine Access Road. Downstream of the Mine Access Road, the NFRC Realigned Channel will converge with the SFRC and continue west towards the RCD.

Under the proposed condition, surface runoff from the catchment west of the NFRC Realigned Channel, including the eastern slope of the WRD, will be collected by the NFRC Permanent Seepage Collection Trench for conveyance to the proposed NFRC Seepage Collection Pond. The surface water from two existing drainage ditches within Segment 2 along the east slope will be conveyed into the NFRC

Realigned Channel via lined ditches. Runoff from this catchment will be conveyed across the NFRD via the existing NFRC crossing. Runoff arising from the adjacent catchment area west and north of the proposed NFRC Seepage Collection Pond will be conveyed around the pond via constructed ditches and berms and conveyed downstream to the NFRC.

In order to support design of the NFRC Realigned Channel, a review of existing meteorological and flow data was completed. In addition, raw data collected from 2014 and 2015 was processed for inclusion in the meteorological and flow records data sets. A detailed description of data collection, processing, and analysis is included in the Hydrotechnical Report (Appendix B).

5.5 Groundwater

5.5.1 Hydrogeologic Setting

A detailed discussion of site groundwater data, analyses, and modelling is provided in Appendix C.

Pre-mining regional groundwater flow within the Faro Mine Area likely mirrored the topographic gradient with flow oriented from the highlands towards the valley bottoms. This suggests the pre-mining groundwater moved south/southwest from Mount Aho and adjacent mountains in the north towards the Rose Creek Valley; and on the opposite side of the valley, north-to-northwest flow would be expected from the Rose Mountains towards Rose Creek. Between the Faro Mine Area and Vangorda/Grum Area, there is a surface drainage divide, which is assumed to be coincident with a groundwater flow divide. From this local topographic high, groundwater flow is expected to follow the gradient of Rose Creek and travel northwest to west toward the RCTA.

Mining activities have changed the landscape (for example, generating new surface topography with open pits and waste rock piles, fracturing rock faces, and ponding water behind dams), altered the premining site-wide permafrost distribution, and are actively controlling groundwater (that is, depressurization of pit walls, groundwater capture via pumping wells, and altering recharge patterns with diversion channels), which influences the direction and quantity of groundwater flow. Factors controlling the pre-mining groundwater flow regime are expected to be regionally similar post-mining, but in local areas, groundwater flow would be altered, especially in areas with permafrost existence and on-going degradation. A more detailed description of lithology and groundwater conditions in specific areas of the FMC is provided in Appendix C.

5.5.2 Faro Mine Area Hydrogeology

The NFRC area includes the Zone II Outwash, S-Wells areas, and the NFRD SIS, which are located between the Faro Valley Waste Dump and the NFRC. The stratigraphy within the Zone II Outwash and S-Wells areas consists of alluvial and outwash materials overlying bedrock. In the area of the S-Wells, a shallow aquifer unit of sand and gravel is underlain by low-permeability till with an underlying deeper aquifer of sand and gravel overlying weathered bedrock. The bedrock in the S-cluster area consists of schist of the Mount Mye Formation and is defined as calcareous schist to calcareous silicate (AECOM, 2009). Groundwater flow in the NFRC valley is towards the southwest, with a gradient of approximately 0.02 metres per metre (m/m), consistent with the gradient of the NFRC (SRK, 2010b).

In general, the Faro Pit is expected to act as a groundwater sink. The water level within the Faro Pit is actively managed by pumping, creating a local groundwater sink, potentially resulting in flow into the pit from most directions. Zone II Pit water elevations are managed by pumping to maintain below approximately 1,096 m. Maintaining Zone II Pit water levels below the NFRC stage ensures that seepage from the Zone II Pit will not flow toward and subsequently discharge into the NFRC. The ETA is located in the former Faro Creek Channel, downstream from the Faro Pit. A significant groundwater and surface

water source to the ETA is the upgradient waste dumps and associated seeps (including seep location X23, which is surface expression of the groundwater flow traveling along the Faro Creek Channel).

The RCAA system is a fluvial depositional system deposited by Rose Creek and its tributary, the NFRC. The alluvial aquifer is composed of a heterogeneous mixture of silt, sand, gravel, and cobbles. 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. Before tailings deposition, Rose Creek was flowing in a meandering stream channel that crossed the valley floor and was fed by several smaller streams that drained the hillsides of Rose Creek Valley. The water table of the underlying valley-fill aquifer was very close to the stream level, indicating a good hydraulic connection between the stream and the groundwater that flowed in the permeable valley sediments (RGC, 1996). Following the onset of mining operations, tailings were deposited over the alluvial valley-fill deposits to a maximum thickness of about 25 m. The greatest thicknesses of tailings were deposited in the Original and Secondary Impoundments, with thickness diminishing toward the edges of the valley (RGC, 1996).

5.5.3 Groundwater and Surface Water Interaction

Knowledge of surface water and groundwater interaction is somewhat limited because of the limited number of data available to support the characterization of stream-aquifer interaction at the site. Three individual studies were conducted between 2012 and 2014, consisting of the installation of streambed piezometers and associated stream stage gauges, to further quantify the nature of surface water/groundwater interaction within the Rose Creek drainage. Studies along the lower reach of Rose Creek below the CVD were conducted in 2012, followed by studies along the upper and lower reaches of the NFRC in 2013 and 2014, respectively. The results of the lower Rose Creek study indicated that gaining stream conditions are dominant throughout the lower portions of Rose Creek between the CVD and just downstream of X14. The results of the NFRC studies indicated that gaining stream conditions also dominate the NFRC from its confluence with the FCD through the haul road and extending to the Mine Access Road. Very limited lengths of losing stream conditions were indicated in the vicinity of the S-Wells SIS. Groundwater samples collected during the NFRC studies indicated modest levels of zinc in groundwater ranging from between 2 and 5 mg/L in the vicinity of the Zone II Outwash, NFRD and S-Wells SIS. A more detailed description of surface water and groundwater studies is provided in Appendix C.

5.5.4 Groundwater Quality

Groundwater quality at the site is changing as a result of the ongoing geochemical processes within mine-impacted areas. The three main contributors of contaminant load to groundwater are as follows:

- **The WRDs:** the Northeast WRD, Northwest WRD, Main Dump, and Intermediate WRD (including the infilled Zone II Pit)
- **The Faro Pit** (including discrete inputs into the pits--that is, pit walls, SIS, and surface runoff)
- **Tailings:** ETA and RCTA

For the purposes of this discussion, the relative levels of contamination are categorized according to the concentrations listed herein for use in illustrating figures and differentiating areas of impact within the text. These categories are based on zinc and sulphate concentrations (and further described in the conceptual site model [CH2M, 2012a]):

- **Not impacted or minimally impacted:** sulphate less than or equal to ($\leq$) 40 mg/L and zinc ≤ 0.05 mg/L.
- **Slightly impacted:** sulphate greater than ($>$) 40 mg/L and ≤ 400 mg/L or zinc > 0.05 mg/L and ≤ 0.5 mg/L.

- **Moderately impacted:** sulphate >400 mg/L and $\leq 4,000$ mg/L or zinc >0.5 mg/L and ≤ 5 mg/L. This corresponds to sulphate and zinc concentrations one order of magnitude greater than the “slightly impacted” range.
- **Highly impacted:** sulphate >4,000 mg/L or zinc >5 mg/L. This corresponds to sulphate and zinc concentrations one order of magnitude greater than the “moderately impacted” range.
- In general, spring samples collected during the influence of freshet tend to show lower concentrations, except in years when the freshet comes too late or too early relative to the sampling event. By contrast, samples collected in summer and fall tend to show the highest concentrations.

A brief summary of the groundwater quality within the Faro Mine Area is described herein. Figures 5-8 and 5-15 show the overall water quality effects at the Faro Mine Area for alluvial wells and bedrock wells, respectively.

5.5.4.1 North Fork of Rose Creek Groundwater Quality

Groundwater flows towards NFRC from the WRDs located to the west of the Zone II Outwash area. Groundwater in the waste-rock-filled Zone II Pit is managed (pumped) to mitigate potential seepage from the former pit to the Zone II Outwash area.

In the NFRC area, the two most extensively studied areas within the NFRC Valley, before the emergence of contamination at the Haul Road in 2014, are the Zone II Outwash area and the S-Wells area. Groundwater quality has been impacted in both the Zone II Outwash and S-Wells areas because of subsurface migration of mine-affected water from WRDs in the Zone II Pit area and from the Intermediate WRD, respectively.

Field explorations conducted in 2013 and 2014 indicate that the NFRC is a gaining stream along the majority of its length between its confluence with the FCD and the Mine Access Road. These conditions indicate that groundwater contamination in the vicinity of the stream represents the most likely pathway for contaminants of concern to enter the stream system and degrade surface water quality.

To mitigate this concern, a SIS was installed at the S-Wells site that consists of a shallow permeable trench and a series of deeper weathered bedrock extraction wells. Recent groundwater quality data also indicate that sulphate and zinc concentrations are increasing in groundwater at the base of the Northeast WRD, suggesting that this area may also represent a conduit for metals loading to the NFRC.

In the Zone II Outwash area, groundwater in the alluvial aquifer ranges from highly impacted to not impacted, with most wells showing moderate impacts. In the bedrock aquifer, groundwater is also moderately impacted, with one well considered highly impacted. Concentrations have generally remained stable or show gradual increasing trends in Zone II Outwash wells over the monitoring period.

Groundwater quality in the S-Wells area is classified as slightly-to-moderately impacted and have relatively stable concentration trends. Groundwater quality in the bedrock aquifer is improving somewhat overall as a result of pumping the S-Wells SIS bedrock wells. However, operation of the shallow aquifer interceptor trench of the S-Wells SIS has not made a noticeable impact on shallow groundwater quality downstream of the SIS (RGC, 2012a).

5.5.4.2 Ground Quality in Other Areas of the Faro Pit

Faro Pit water quality is highly impacted with moderate sulphate concentrations (less than 1,000 mg/L) and high zinc concentrations (above 5 mg/L) for data reviewed between 1998 and 2012 (DES, 2012a). Contaminated water from the S-Wells SIS and from the Zone II Pit are currently pumped to Faro Pit. Seep water flowing to Faro Pit (discharging from the Faro Valley Waste Dump) ranges in water quality from not impacted to highly impacted.

Water in the Zone II Pit (well X26) is highly impacted. Sulphate concentrations have been more variable than zinc concentrations since 2008, however, both sulphate and zinc concentrations within the pit continue to increase.

The Northeast WRD is located to the north to northeast of the Zone II Pit and east to northeast of the Faro Pit. Groundwater quality at areas in the vicinity of the Northeast WRD can be summarized as follows:

- Areas downgradient from the Northeast WRD: Groundwater in weathered bedrock and deeper bedrock adjacent to the Northeast WRD have worsened substantially over the last 10 years, and zinc concentrations up to about 10 mg/L have been detected at the well pair closest to Zone II. The well pairs located farther northeast have moderate groundwater effects.
- NFRC upgradient from Northeast WRD: Groundwater upgradient from the Northeast WRD are characterized by sulphate concentrations less than 200 mg/L and zinc concentrations up to 1 mg/L. (RGC, 2012b).

The ETA has some of the highest-contaminated groundwater and surface water in the Faro Mine Area and represents a major source of contaminant loading to the RCAA. Groundwater quality in the ETA has shown increasing trends for acidity, sulphate, and zinc, and this trend is expected to continue. Seepage from the Main Dump has become noticeably more acidic over the last several years, suggesting ongoing “breakthrough” of ARD products and a decline in the buffering capacity of the Main Dump waste rock and ETA alluvial soils (RGC, 2012b).

In the RCTA, low-metals-bearing groundwater from the south and southeast flows to the RCTA, and Faro-Mine-contaminated groundwater flows to the RCTA from the north, with a significant portion of contamination associated with the Faro Creek Canyon. Locally, the tailings contribute to groundwater contamination in the RCTA as well. The extensive leakage of clean water from the RCD (south of the RCTA) has a major influence on the spatial water quality trends in the RCAA, especially further downgradient near the CVD. There is a significant spatial trend from south to north of not impacted groundwater transitioning to moderately impacted groundwater in the western half of the RCTA.

5.5.5 Recommendations

The following additional data collection is recommended to improve characterization of the hydrogeologic system to support further design of the NFRC Temporary Diversion design:

- Drill additional borings and perform aquifer testing/packer testing at the locations of the seepage collection pond dams to improve characterization of the stratigraphy, bedrock properties, and alluvial properties at the dam sites. This is a higher priority for Alternative 1, as the NFRC Seepage Collection Pond is unlined and there is remaining uncertainty as to the competent bedrock topography in the area.
- Drill additional borings and perform aquifer testing at the locations of the groundwater cutoff walls proposed between Segments 1 and 2, as well as the cutoff wall upstream of the Mine Access Road in Alternative 2. This information will improve characterization of aquifer properties and competent bedrock topography in these areas, which is critical to design of effective groundwater cutoff structures.

5.6 Geochemistry

A detailed presentation of geochemical data and analysis is provided in Appendix D.

Sediment quality has been monitored relative to the FMC since as early as 1973 (Rose and Anvil Creeks) and 1991 (Vangorda Creek). The most recent sediment data collections for the FMC took place in 2007 Stream Sediment Quality

5.6.1.1 Historical Studies

Sediment quality has been monitored relative to the FMC since as early as 1973 (Rose and Anvil creeks) and 1991 (Vangorda Creek). The most recent sediment data collections for the FMC took place in 2007 and 2008, *Aquatic Baseline Characterization* [Minnow, 2014a]). Detailed data and the location of sampling stations are shown in Appendix 6E, *Aquatic Baseline Characterization* (Minnow, 2014a). In general, the sediments from the FMC area are composed of sand, gravel, or larger rocks, consistent with the fast-flowing characteristics of most streams in the area. Of samples collected in the NFRC, Rose Creek, and Vangorda Creek, silt and clay fractions represented less than 5 percent combined, except at NFRC upstream from the Access Road, where the proportion of silt plus clay was 30 percent. All samples had less than 4 percent of total organic carbon.

Sediment metal concentrations collected from reference areas of Rose and Vangorda Creeks did not exceed the Canadian Sediment Quality Guidelines (CSQC) for the Protection of Aquatic Life Probable Effect Level (CCME, 2013) in either whole sediment samples or the fraction containing fine sand and smaller particles (Minnow, 2007). Sediment arsenic, lead, manganese, and zinc concentrations in mine-exposed areas were elevated relative to reference levels and guidelines, and were roughly three times higher in the fine fraction versus whole sediment samples (Minnow, 2007). However, sediment samples from the same areas resulted in no observable toxic effects to the amphipod *Hyallela azteca* in laboratory tests (Minnow, 2009).

This most recent sediment data also shows elevated metal concentrations in samples collected downstream from the FMC based primarily on analysis of the ≤ 0.15 -mm fraction of the sediment samples. In particular, levels of arsenic, lead, and zinc were higher than the CSQC for the Protection of Aquatic Life Probable Effect Level (CCME, 2013; Minnow, 2007). However, as noted above, the fine fraction generally represents less than 5 percent of the total and therefore, these data may not be wholly representative of the downstream sediment.

Time series plots for pH, alkalinity, sulphate, iron, zinc, and magnesium were generated for key locations at the FMC and evaluated for changes in chemistry over time. Locations examined for the Faro Mine Area are presented on Figure 5-10.

5.6.2 Waste Rock Dumps

Geochemical loading from the FMC dumps is controlled largely by the waste rock material composition, as well as how it was placed, relative to the pre-mining topography. The Faro ore body existed in a topographic low-lying area. Before the Faro Pit was mined, Faro Creek flowed across the planned open pit. Faro creek generally flowed north to south across the ore body. In general, background conditions prevail upgradient of the FMC. However, the flow direction of seepage water related to the various waste dumps is highly variable due to localized flow conditions. Faro Mine Area waste dump seepage generally flows to the south/southwest. The NFRC Project scope includes capturing the mine-impacted water emerging from the eastern waste rock dumps towards the NFRC corridor. Seepage from the Main Rock Dump towards the south was evaluated as part of the NFRC Project. In general seepage from the Main Rock Dump, flows towards the ETA, some deeper flow paths make to the RCAA, and some shallow flow toward the S-wells. Generally along the south/southwest toe of the WRDs the seepage does not discharge to the land surface.

Previous borehole data and historical geological information indicate the FMC dumps are underlain by discontinuous, generally thin (less than 10-m-thick) deposits of glacial till, glaciofluvial sediments, and low-permeability bedrock (RGC, 1996; Bond, 2001). When the FMC dumps were established, the relatively coarse waste rock material (which has a fairly high hydraulic conductivity) was placed over the native soil, which is less permeable. As a result, water infiltrating the waste rock pile will either continue to infiltrate the native soil or will travel along the paleosurface at the base of the WRD until it daylight at the toe of the waste rock. The water infiltrating the native soil impacts local groundwater below the

WRD, and could degrade groundwater in downgradient locations. As mine-influenced water migrates through the aquifer system, some constituents move quicker than others. Sulphate, released through oxidation of sulphide rock, tends to move at the velocity of groundwater because it does not readily react with or adsorb to aquifer materials. Dissolved metals, however, can react with and adsorb to the subsurface matrix, and these geochemical interactions influence the rate of migration. Elevated sulphate concentrations and decreasing pH are early signs that upgradient ARD reactions are impacting groundwater quality (CH2M, 2013d).

Seepage water from WRDs can impact surface water quality directly. For most surface seepage locations, flow rates increase after freshet or large precipitation events and much of the flow takes place over a fairly short timeframe, based on observations during the CH2M 2012 field program (CH2M, 2013d) and based on the historical seep sampling program (SRK, 2010). However, several seeps (generally located in pre-mining drainage channels) flow year-round (e.g., X23, FD-05 and FD-06, FD-26, S-Wells). In the NFRC watershed, the main perennial seep, located at the S-Wells, is currently collected using an SIS to collect the seepage and pump it year-round back to Faro Pit for eventual treatment at the water treatment plant (WTP).

The main source of contaminants in the Faro Mine Area is sulphide-containing waste rock stored in the waste dumps. The main sulphide minerals in the waste dumps are the ore minerals sphalerite (ZnS) and galena (PbS), and the gangue mineral, pyrite (FeS₂). Minor amounts of chalcopyrite (CuFeS₂) and arsenopyrite (FeAsS) are also present in a matrix of gangue minerals that include quartz (SiO₂), magnetite (Fe₃O₄), carbonate minerals, and barite (SRK, 2004). FeS₂ is the most abundant sulphide mineral at the FMC. The main source of acidity and metals at the FMC is the oxidation of these sulphide minerals in the waste dumps.

5.6.3 Faro Pit

The Faro Pit has unique geochemical properties that contribute to the water quality of the pit lake water therein. Constituents primarily load to the pit lake through seepage from pit walls and WRDs.

The Faro Pit provides storage for water pumped by various water interception systems year-round, so it is possible to operate the WTP seasonally. Therefore, groundwater inputs from surrounding WRDs (e.g., those associated with the S-Wells SIS, the ETA, and the Zone II Pit) are contributing to the load within the pit.

The Faro Pit received tailings from milling operations from 1992 to 1998. The presence of net acidic, yet alkaline-bearing, tailings complicates the geochemistry of the pit lake. In the short-term, these tailings are contributing alkalinity to the water column. The tailings at the bottom of the pit are not expected to become acid-generating or a significant source of metals, because the subaqueous disposal limits contact with oxygen. Disposing oxidized, alkaline WTP sludge to the pit would further mitigate potential metal loading from the tailings to the pit water through burial under potentially-neutralizing material. The Faro Pit is used as a reservoir to store contaminated water for treatment. The Faro Mine Area is typically characterized by a regional groundwater sink (the Faro Pit) because the pit is pumped to lower than the regional groundwater level. However, the old WTP was decommissioned in October 2012 and the new IWTS was not installed until October 2014, with limited operations in October 2014. As such, Faro Pit was not pumped from October 2012 through May 2015 (except for a limited time in October 2014), which resulted in the Faro Pit lake water level rising above normal operating levels. During that time, downstream monitoring wells indicated a rise in groundwater level that generally tracked the pit lake level. Recent data collected following the start-up of the IWTS suggest it will take several (3 to 4) years to pump the Faro Pit lake water levels down to targeted operating levels.

WRDs in the Faro Mine Area are unsaturated and of variable composition. When precipitation (snowmelt or rainfall) infiltrates through the waste dumps, it collects at their bases, near pre-mining topographic lows (CH2M, 2014d). Depending on the subcatchment area a WRD is located in, seepage

from the waste rock dumps near the Faro Pit may flow to the Faro Pit, Zone II Pit, NFRC, old Faro Creek, Guardhouse Creek, or Rose Creek Valley (Figure 5-9) (RGC, 1996). Data compiled from samples collected at seepage, surface water monitoring stations, and monitoring wells provide the foundation for the characterization of water quality conditions in the Faro Mine Area (Figure 5-9).

5.6.4 Faro Background Water Quality

Except for seepage collected at the ETA, the S-Wells, or behind the ID, water from the FMC WRDs ultimately flows into Rose Creek, which contributes to Anvil Creek, before flowing into the Pelly River. Faro Creek flows from the north and is diverted around the Faro Pit via the FCD (Figure 5-9). Water in the FCD flows into the NFRC, northeast of the Faro Northeast WRD. Two main surface water locations have historically been sampled for background conditions in the Faro Mine Area: (1) Faro Creek, upstream from the FCD (Stations FC and FDU), and (2) the NFRC, upstream from the confluence with the FCD (Station R7) (Figure 5-9).

5.6.5 Constituent Loading to the Faro Pit

The Faro Pit lake water quality is monitored at X22B (located on the lake surface at the southwestern end of Faro Pit lake, near the pumping barge) and can be described as buffered ARD (Figure 5-9). It has a neutral pH and is highly impacted based on concentrations of zinc. The dissolved sulphate concentrations have been consistent in recent years, and the zinc concentration has been increasing over time (CH2M, 2013d). As the alkalinity is consumed, the pH will decrease, resulting in an increase in dissolved acid mine drainage products. The following sources contribute influent waters that affect water quality in the Faro Pit:

- Seepage and runoff from the north Faro WRDs (FVN and FVS)
- Seepage and runoff from the Northeast WRD (NEU, NEL, NELS, and NEO)
- Pumping from the Zone II Pit (CH12-Z2-PW01, replaced old well X26)
- Pumping from the S-wells (Figure 5-9)
- Pumping from the ETA (intermittent, based on water management needs [Figure 5-11])
- Pumping from the Intermediate Pond (intermittent, based on water management needs [Figure 5-11])

Figure 5-10 shows a summary of the water quality and level of impact at seepage monitoring stations in the Faro Pit area. Water that is not captured by the FCD (including potential leakage from the FCD) flows through the Faro Valley Waste Dump (FVN and FVS) and seeps into the Faro Pit along the north pit wall (Figure 5-9). Location A30 is on the north pit wall of Faro Pit and is on the flow path of the historical Faro Creek (Figure 5-9). The flow in this area is high, and the high flux of oxygenated water through the Faro Valley Waste Dump (FVN and FVS) may be causing relatively acidic conditions in this area, relative to other seepage areas. The water is highly impacted with a low pH and moderate concentrations of sulphate (545 mg/L) and high concentrations of zinc (47.3 mg/L), (Figure 5-12). Characteristics of acid mine drainage (i.e., increased sulphate and zinc) have been present and have shown variability since 2002, with concentrations of iron (2.1 mg/L) generally increasing over time (Figure 5-12). The observed general decrease in alkalinity over time and increased sulphate concentrations indicate much of the available NP in this area has been consumed, and there is a net acid generation effect on seepage from A30 reporting to the Faro Pit lake (Figure 5-12).

Seepage from the Northeast WRD flows either to the Faro Pit or to the NFRC along a pre-mine surface drainage divide (Figure 5-9). A geochemical characterization of the Northeast WRD's waste rock materials indicates substantial potential for long-term acid generation (CH2M, 2013e). Water quality results from samples collected from the Northeast WRD indicate widely variable composition and highly impacted waters. The most highly impacted waters are generally downgradient from the Lower East Sulphide Cell. The two main flows from the Northeast WRD report to the Faro Pit lake: (1) SRK -FD24 and (2) SRK-FD26 (Figure 5-9). SRK-FD24, which is west of and topographically lower than the Northeast

Sulphide Cell, is characterized as highly impacted water with high concentrations of iron (10.8 mg/L), zinc (40 mg/L), and sulphate (1,060 mg/L) (Figure 5-13). A review of the data at SRK-FD24 highlights the transition from neutral to acidic conditions over time, marking a distinct stage in the evolution of the Northeast WRD seepage chemistry (Figure 5-13). SRK-FD26 is a moderately impacted, high-flow monitoring location that follows a pre-mine drainage just north of the former Zone II Pit (Figure 5-13). Concentrations of sulphate and zinc were 806 mg/L and 5.7 mg/L, respectively, and iron was less than the detection level in samples collected at SRK-FD26 (Figure 5-13).

In general, very little seepage flows from the south and west pit walls into the Faro Pit. The only other important inputs into the Faro Pit are from the CH12-Z2-PW01 (replaced old well X26) and the S-Wells SIS area (Figure 5-9). The X26 well maintains groundwater levels through pumping in the former Zone II Pit and contributes water and constituent loading to the Faro Pit lake. Groundwater pumped from the Zone II Pit is considered highly impacted, with high sulphate content (3,320 mg/L) and concentrations of zinc that are greater than 20 mg/L (Figure 5-14). Through time, X26 has maintained one of the highest average zinc (79 mg/L), iron (53 mg/L) and sulphate (2657 mg/L) concentrations of all the inputs into Faro Pit (Figure 5C-8) (DES, 2012).

The S-Wells SIS area is another source of water and constituent loading to the Faro Pit lake (Figure 5-9). The numerous contaminant sources that contribute to the S-Wells area are attributed to the pre-mine topography. The current conceptual site model indicates pre-mining drainage patterns are focusing seepage water from the Intermediate and Main dumps, towards the S-Wells SIS area and ETA, respectively. Monitoring wells (MW-007 and MW-003) have recently been installed through the WRD into the underlying alluvium upstream of these seepage areas, to evaluate the evolution of seepage chemistry along the flow path of these historical drainages (CH2M, 2012a).

Seepage water collected by the S-Wells SIS, represented by the water quality observed in SRK08-SPW3, is considered highly impacted. The S-Wells area is expected to be a large contributor to increased contaminant loads through time, with sulphate and zinc concentrations greater than 5,000 mg/L and 300 mg/L, respectively, in SRK08-SPW3 (Figures 5-23 and 5-14). Alkalinity in SRK08-SPW3 has decreased over time, from 587 mg/L to 401 mg/L, but has remained present to neutralize ARD (Figure 5-14). Although groundwater quality in the S-Wells area was expected to improve with the installation of the SIS, no notable change in water quality (better or worse) has been observed. Contaminant concentrations have neither been shown to increase, nor to decrease, in groundwater downgradient of the S-Wells SIS. Increased concentrations of sulphate and zinc in groundwater monitored by wells southeast of the S-Wells SIS (i.e., SRK05-SP3A/B, SRK05-SP1A/B, and SRK05-SP2) indicate the SIS may not be capturing at least a portion of the waste dump seepage.

5.6.6 Constituent Loading to the North Fork Rose Creek

Seepage water that flows east from the Northeast WRDs and from the former Zone II Pit area (i.e., water that is not captured by the X26 well) contributes to the NFRC, upstream of the North Fork Rock Drain (NFRD) and is represented by the water quality measured at monitoring stations SRK-FD21, SRK-FD05, SRK-FD06, NE1, NE2, and NE3 (Figure 5-9). Although SRK-FD21 is within the catchment boundary for NFRC, seepage likely also flows to the Faro Pit (Figure 5-9). Seepage from SRK-FD21 is highly impacted, with concentrations of sulphate and zinc at 3,200 mg/L and 36.7, respectively (Figure 5-15). Highly impacted seepage water has been observed emanating from the east side of the Northeast WRD at SRK-FD05 (Figure 5-15). SRK-FD05 and SRK-FD06 are two sampling points that represent a broad perennial seep located near the base of the east face of the Northeast WRD (Figure 5-9), with each seep sampling station located approximately 20 m apart at the northern and southern ends of the overall seepage area, respectively. Observed water quality at SRK-FD05 indicates seasonal fluctuations in concentrations of sulphate (692 mg/L [September 2012] to 904 mg/L [June 2013]) and zinc (5.9 mg/L [September 2012] to 8.3 mg/L [June 2013]), with greater concentrations observed in the spring than in the fall, and an overall trend of increasing concentrations through time (Figure 5-15) (SRK, 2010). The

highly impacted seepage waters emanating from the Northeast WRD support the need for continued monitoring at these locations. Monitoring stations BH 14, A/B, located to the south of SRK-FD05 (Figure 5-16), indicate groundwater is highly impacted with sulphate (about 2,500 mg/L) and zinc (about 10 mg/L) (Figure 5-17).

Seepage water in the WRDs adjacent to the Zone II Pit that is not captured by the X26 well continues along a general flowpath toward the Zone II Outwash and is further influenced by WRD seepage (RGC, 2012b). Wells near the base of the WRD (i.e., BH8) (Figure 5-18) indicate groundwater is highly impacted with sulphate (about 3,000 mg/L) and zinc (greater than 100 mg/L), flowing toward the NFRC (Figure 5-18). Increased concentrations of zinc (greater than 5 mg/L) have also been observed in wells closer to the NFRC (i.e., BH6) (Figure 5-19). SRK-FD08 is the only seepage water monitoring station located within the Zone II Outwash area, and it has been dry during the 2012 and 2013 sampling events (Figure 5-9). Well P96-6, located downstream of the Zone II Outwash area and upstream of the NFRD, indicates groundwater moderately impacted with sulphate (518 mg/L) and zinc (0.73 mg/L) and seasonal fluctuations where water quality improves (through dilution) during freshet conditions (RGC, 2013).

Downstream from the Zone II Outwash, the NFRC flows southwest at the base of the Intermediate WRD, underneath the Haul Road through the NFRD, and past the S-Wells area. The S-Wells area is characterized by highly impacted groundwater that is collected and pumped to the Faro Pit. However, groundwater that is not captured by the S-Wells SIS continues to flow toward NFRC and its confluence with the SFRC (Figure 5-20).

In the autumn of 2013, a new metals load source to the NFRC developed in the NFRD area). A detailed monitoring program was implemented to delineate the source of this new load. The RGC drilling of seven wells in the fall and winter of 2014/2015 did not identify a source zone or seepage path. RGC concluded that the source likely has a concentrated flow path, originating from a sulfide cell located within the Intermediate Dump.

Sustained zinc concentrations greater than 1.0 mg/L and 0.4 mg/L were measured at Monitoring Stations X2 and X14, respectively, during the fall, winter, and spring of 2014/2015, decreasing with increasing stream flow during the summer (Figure 5-24). These measured concentrations are over 10 times the zinc concentration of 0.03 mg/L s listed in *Canadian Water Quality Guidelines for the Protection of Aquatic Life* (CCME, 2013). New guidelines have recently been proposed (available for public comment through March 2016) that defines the recommended guideline of zinc concentration on the basis of pH and hardness. The proposed long-term guideline is an equation based on hardness and pH. Review of the proposed guidelines and a plot of the hardness measured at X14 (Figure 5-25), and pH measured at X14 indicates that the proposed CCME guideline for zinc ranges from approximately 0.19 to 0.69 mg/L, varying seasonally with changes in pH and harness.

5.6.7 Constituent Loading to Area between S-Wells and X23

While the S-Wells area and the X23 seepage area are considered hot spot seepage areas south of the Intermediate WRD and Main Dump, respectively, reduced monitoring takes place between the two locations because significant surface seepage locations have not been identified in this area. However, one well (SRK08-P9) makes it possible to assess the groundwater conditions flowing from the Faro WRD towards the RCAA in this region (Figure 5-19). Groundwater samples collected in 2012 suggest this area is moderately impacted with sulphate (1,160 mg/L), but not impacted with zinc (0.01 mg/L). Additional monitoring is required to determine whether this area reflects localized impacts from specific waste dumps or represents regional constituent loading because of pre-mining topography and contributions from the waste dumps.

5.7 Geotechnical Conditions within North Fork of Rose Creek Project Area

5.7.1 Geotechnical Explorations

This section summarizes site explorations and data gathering conducted for design of the NFRC Project. Applicable data from prior site explorations are also discussed in this section.

5.7.1.1 North Fork of Rose Creek Phase 1 Site Exploration

In April 2015, an initial phase of geotechnical site exploration was conducted along the hill slope east and south of the NFRC within Segments 1 and 2. The geotechnical exploration program included drilling eight boreholes to depths between 7.6 and 19.8 m below ground surface (mbgs) at the locations shown in Figure 5-21.

Standpipe piezometers were installed in the boreholes for measurement of groundwater levels. Solid polyvinyl chloride (PVC) casings, into which thermistor strings could be inserted at a later time, were also installed for measurement of ground temperatures. Geotechnical drilling and soil sampling was performed with a variety of tools (solid and hollow stem auger, Cold Regions Research and Engineering Laboratory [CRREL] core barrels, ODEX [Overburden Drilling Excentric], and standard penetration test [SPT] split spoons).

5.7.1.2 North Fork of Rose Creek Phase 2 Site Exploration

In July and August of 2015, Phase 2 site explorations were conducted to gather additional geotechnical and groundwater design data. Geotechnical drilling was performed using direct push, ODEX, CRREL, and rock coring (HQ or 63.5-mm core-diameter) methods. Samples have been retrieved from SPT, CRREL, direct push, HQ coring (in rock) and Shelby tube. The Phase 2 exploration consisted of the following explorations (refer to Section 12 for more detail on Phase 2 explorations and location map:

- Segment 1: 3 test pits on the west side of NFRC and borings to install 5 new monitoring wells at the toe of the Northeast WRD for contamination monitoring and to evaluate potential groundwater interception approaches within Segment 1 (e.g., cutoff wall and seepage interception trench).
- Segment 2: 19 test pits on both sides of NFRC, and 10 exploratory borings on the eastern side of the NFRC.
- Segment 3: 10 test pits and 4 borings.
- Segment 4: 2 test pits and 1 boring.
- Seepage Collection Pond Dam Foundation: 3 test pits and 6 borings. (Note additional exploratory test pits were dug to locate bedrock in the foundation area of the dam before drilling borings.
- Borrow Area for Seepage Collection Dam: 6 borings and 14 test pits.
- Riprap Borrow area for NFRC Temporary Diversion and NFRC Seepage Collection Dam: 6 borings and 3 test pits.
- RCD: 6 borings.
- Breached Fresh Water Supply Dam: 13 test pits.

The large portion of exploratory borings included installation of groundwater monitoring wells and thermistor strings. At the time of this Preliminary Final DBR, the borings for the riprap borrow area, WRD seepage, and Segment 2 borings and test pits have been completed. Field logs are currently being

reviewed and laboratory tests are being assigned for subsequent submission to laboratory testing companies.

Additional geotechnical data collection for Phase 2 will consist of a geophysical survey program in Segments 1, 2, 3, and 4; the Seepage Collection Dam and borrow areas; and the RCD.

5.7.1.3 Prior Explorations

Subsurface explorations carried out before 2015 were generally performed for site-wide exploration data gaps or other specific data collection requirements. Although these may not have been performed specifically for the NFRC Temporary Diversion, some do provide data useful for understanding subsurface conditions in the NFRC area. A preliminary assessment of previous explorations that may have applicable data includes the following:

- Eight monitoring wells installed on the western side of the NFRC in Segment 2 in 2014
- Eight test pits excavated on the western side of NFRC in Segment 1 and Segment 2 in 2014
- Approximately 19 streambed piezometers and 10 groundwater monitoring wells in Segments 1 and 2 in 2013

5.7.2 Interpretation of Subsurface Conditions

5.7.2.1 Hill Slope Area East and South of North Fork of Rose Creek

Based on the findings of the Phase 1 site exploration, and supplemented with the preliminary findings of the Phase 2 site exploration (in progress), ground conditions along the hill slope to the east and south of the NFRC show a complex erosional and depositional history, with terrain units ranging from colluvium, alluvium, till, glaciofluvial, and glaciolacustrine deposits. Subsurface conditions consist of a mixture of sand, silt, clay, and gravel of varying proportion, with occasional buried layers of peat and organics, and occasional cobbles and boulders in the till deposits, with a corresponding range in geotechnical properties such as permeability and plasticity. Preliminary findings from the Segment 2, Phase 2 borings indicate the presence of bedrock at varying depths below the soil deposits, with rock somewhat more shallow closer to the creek. In addition, permafrost of varying thickness and ice contents were encountered in most of the borings.

In unfrozen soils, SPT “N” blow counts typically ranged between 10 and 50, indicative of compact to dense conditions for coarse-grained soils, although lower SPT “N” blow counts of 5 to 8, indicative of loose density, have also been reported though these are only isolated cases and do not appear to be widespread, based on the data collected to date. In addition, some higher blow counts may not represent actual in situ density or consistency of the material because of the presence of oversized gravel, cobbles, or boulders during testing. Bedrock (phyllite and granodiorite) was encountered in two of the Phase 1 boreholes, at depths ranging from 5.6 to 19.8 mbgs. Between May 6 and 9, 2015, groundwater was observed in six of the eight Phase 1 boreholes, with the two remaining boreholes dry to the maximum piezometer depth of approximately 15 mbgs. Groundwater levels are expected to fluctuate, depending on seasonal or weather changes, but may correlate somewhat with the water level in NFRC at locations closer to the creek. Although a preliminary assessment of liquefaction of foundation soils for the NFRC Seepage Collection Dam and NFRC channel embankment indicate the risk is low, additional subsurface data and analysis should be performed for final design to better determine seismic hazard potential for all constructed foundations and embankments.

Permafrost is discontinuous, with mean ground temperatures in the NFRC area are close to 0 degrees Celsius (°C) (+/- 2°C). Where present, the permafrost thickness ranges from approximately 3 m to greater than 20 m. Permafrost in the area of the NFRC located was more prevalent within approximately 500 m east of the haul road. High-ice-content (greater than 15 percent by volume) frozen soil layers have been observed, both at shallow and deep depths. For the majority of frozen soils, visible ice

contents were generally less than 5 percent. In addition, some samples indicated the presence of higher water content seasonal ground ice (active zone) that was also close to melting point (0°C).

The findings of the Phase 1A and preliminary information from the Phase 2 site explorations did not correlate well with the desktop surficial geology mapping carried out for the area (Bond, 1999). Furthermore, the one borehole that was drilled along one of the former geophysical survey lines conducted in the area did not correlate strongly with the geophysical interpretation (Aurora, 2013) for this section. Geophysical surveys will be performed in 2015 with specific application for the design of the NFRC Temporary Diversion to ensure consistent interpretation of all collected data.

The strength, density, and consistency of soils in the area will largely depend on its thermal state (i.e., frozen or unfrozen) and on its water (ice) content. When frozen and ice-bonded, the soil can be relatively hard and strong. In the thawed state, the same material can become wet and soft or loose if the ice content is high (i.e., greater than approximately 15 percent visible or non-visible ice). If the ice content is relatively low (i.e., less than approximately 5 percent), the soil may not soften or weaken substantially compared to in its frozen state. The presence and distribution of permafrost also impacts the local groundwater regime. Frozen soil may act as an impervious barrier such that a perched water table exists near the base of the active layer (seasonal thaw depth). If poorly drained, this may have the effect of saturating materials within the active layer during the summer months from either water expelled during melting of the permafrost or from rainfall infiltration and groundwater flow within the active layer. Below the base of the permafrost, a deeper hydrogeological regime may exist. Given that the permafrost is at a temperature close to its melting point, the permafrost is sensitive to warming, whether from climate warming or from surface disturbance, such as the removal of vegetation cover or earthwork construction. Settlement may occur with permafrost thaw, with the magnitude of settlement depending on the depth of thaw and the ice content of the thawed material. Permafrost thaw may also cause slope instability because of increased saturation levels of materials within the active layer or from excess pore water pressures generated, particularly in materials with high ground ice content that thaw but do not drain rapidly. Finally, permafrost thaw may alter the local surface and ground water hydrology.

5.7.2.2 Seepage Collection Pond Dam Area

In the vicinity of the NFRC and the proposed NFRC Seepage Collection Dam area, bedrock generally consists of schists and phyllites with occasional granodiorites and gabbro. The bedrock tends to be moderately to highly weathered near the bedrock surface, with the weathering decreasing with increasing depth. Schists and phyllites tend to be strongly foliated, with fractures frequently occurring along the foliation planes.

Existing access roads were generally constructed with sands and gravels with trace to some silt obtained from local borrow deposits. The Haul Road, which includes a rock drain composed of clean cobbles and boulders, was constructed with run-of-mine rockfill and consists of well-graded sand and gravel with some cobbles and boulders.

Preliminary findings of the Phase 2 site exploration indicate that foundation conditions in the vicinity of the proposed Seepage Collection Dam alignment consist of sand till with some cobbles and boulders overlying bedrock (phyllite or schist). The depth to bedrock is generally shallow (less than 6 m depth) south of the existing creek, and deeper (from 6 m to over 30 m depth) north of the creek. The bedrock is generally moderately to highly weathered within approximately 3 m of the bedrock surface, and less-weathered, but still heavily fractured [rock quality designations (RQD) of 0] below. Permafrost is discontinuous within the Seepage Collection Pond footprint and apparently absent south of the creek, but present in the lower portion of the valley north of the creek, to a distance of approximately 7 to 10 m from the edge of the creek. Between this approximate distance to the creek is a through talik, (i.e., the ground is unfrozen and hydraulically connected to the sub-permafrost groundwater system). The permafrost is relatively thin (between approximately 2 to 5 m thick) and at a temperature that is close

to 0°C. The permafrost generally contains high ground ice content that could become wet, soft, loose, or permeable when thawed.

5.7.2.3 North Fork of Rose Creek Seepage Interception System Access Road

October 2014, an access road was constructed from the top of the Haul Road down to the upstream side of the NFRD, on the southeast side of NFRC. Some small cuts, approximately 2 to 4 m high, were excavated as part of this work, exposing permafrost soils with varying ground ice contents.

Photographs 5-1 and 5-2 show select views of these cut slopes and their performance as of May 2015.

The majority of the cut slopes appear in satisfactory condition with select areas of permafrost thawing and sloughing and associated seepage points. In one select area, a thin layer of rockfill was pushed onto the slope. This appeared to have a stabilizing effect as opposed to some sloughing permafrost located immediately adjacent (Photograph 5-2).



Photograph 5-1 View of upper portion cut slope along access road upstream of NFRD (May 2015). Note thawing and sloughing permafrost of the left side of the cut.



Photograph 5-2 View of lower portion cut slope along access road upstream of NFRD (May 2015). Note thawing and sloughing permafrost immediately to the right of the light coloured rockfill placed on the left side of the cut.

5.8 Climate

5.8.1 General Climate

The climate around the FMC is typical of sub-arctic continental areas in that it is subject to large annual temperature ranges and moderate amounts of precipitation. Due to prominent terrain features such as the Vangorda Plateau, Anvil Range Mountains, and the Macmillan Highlands that surround the FMC, the site experiences significant seasonal temperature fluctuations and precipitation levels. Cold winters and warm summers are typical for this region. Temperature inversions are frequent because of the mountainous terrain; valley bottoms experience winter temperatures about 10°C cooler than higher elevations. Summer temperatures in the valley bottoms are frequently warmer than upper elevations.

5.8.2 Temperature

5.8.2.1 Regional Temperature Normals and Extremes

Regional daily average temperatures, normals, and extremes were collected from the Environment Canada weather stations at the Faro Airport: the Faro AUT Weather Station, and the Faro Airport Station (Faro A Station). Both stations are shown on Figure 6A-1 and monthly temperature normal and extremes are shown on Figure 6A-3 (in the *Climate Baseline Report* [CH2M, 2014i]). During the winter, the lowest daily average temperature of -24.6°C typically occurs in January. During the summer, the highest daily

average temperature of 21.0°C typically occurs in July. The daily temperature varies by averages of 12°C in summer and 8°C in winter. Regionally, historical Environment Canada data shows a warming trend, where the extreme minimum temperatures in winter have risen by 0.3°C and the extreme maximum temperatures in summer have risen 2.4°C between 1981 and 2010 (AECOM, 2009).

5.8.2.2 Local Temperatures

Two FMC weather stations are located at the FMC; one at the Faro Valley Waste Dump (Faro Dump Station) and the second formerly at the Grum Waste Dump, but now located at a former gravel pit north of that area (Grum Dump Station) (Figure 6A-2 of the *Climate Baseline Report* [CH2M HILL, 2014e]). Temperature measurements at these stations have been collected at each station every 5 seconds, with averages logged hourly. Average temperatures at the Faro Dump Station range from 12.3°C in summer to -15.6°C in winter, while the corresponding average temperatures at the Grum Dump Station range from 12.1°C to -15.5°C. A comparison of concurrent temperature data from the Faro A Station indicates that summer temperatures experienced at the FMC are generally cooler than those measured at Faro. This difference is expected because of the elevation difference between the airport and the FMC. Inversions in such mountainous terrain likely cause recorded winter temperatures at the Faro A Station to be up to 10°C lower than temperatures at the Faro Dump Station. While there are no complete, long-term datasets from the FMC weather stations, a strong correlation has been observed between temperatures measured at the Faro Airport and those registered by FMC weather stations (Figure 6A-6 of CH2M HILL, 2014e; AECOM, 2009).

5.8.3 Precipitation

Precipitation data are available for both the Faro Airport and on-site meteorological stations.

Environment Canada has summarized precipitation climate normals for the Faro Airport using data collected between 1981 and 2010 at the Faro A Station, and these data and analyses have been used in combination with onsite data to characterize precipitation at the FMC. At the time of report development, Environment Canada had not completed analysis for data collected after 2010. During this time period, mean total annual rainfall was 218.4 mm and mean total annual snowfall was 114 centimetres, corresponding to a mean snow water equivalent of 101.3 mm. The total annual precipitation ranged between 166 mm (1988) and 355 mm (1990), with an average of 320 mm per year (CH2M, 2014f).

Monthly rainfall was generally highest between May and September, when snowfall was at a minimum. The wettest months were July and August, with monthly average rainfalls totalling 56.1 mm and 47.5 mm, respectively. Snow-free months were restricted to June and July, with all other months experiencing snowfall from as little as 0.636 centimetre in May to as much as 21.7 centimetres in November (or 0.6 mm and 19.2 mm snow water equivalent for May and November, respectively).

Onsite data records are short and characterization of onsite precipitation conditions relies on the relationships between the regional Faro Airport stations and the onsite stations. These correlations indicate that in the period from May through September the Faro Dump and Grum Dump Stations receive 6.79 percent and 10.01 percent more rainfall, respectively, than the Faro AUT and Faro A stations. During the winter period, the onsite stations receive approximately 25 percent more precipitation (as a water equivalent) than the Faro Airport stations. The development of onsite precipitation records is discussed in more detail in the *Hydrology Baseline Report* (CH2M, 2014g).

5.8.4 Wind Speed and Direction

Surface wind speed and direction at the FMC were assessed for a 5-year period between 2006 and 2010 using measurements collected from the Faro AUT Station and the two FMC stations. This series of years was chosen for the air quality effects assessment and are considered to present a representative summary. Onsite wind speeds averaged 2.13 m/s at the Faro Dump Station and 2.49 m/s at the Grum Dump Station. In comparison, wind speeds at the Faro AUT Station averaged 2.21 m/s. Annually, more

frequent periods of calm winds were observed at the Faro AUT station (approximately 5.3 percent of the recorded hourly wind speeds) than the Grum Dump Station (less than 1 percent of recorded hourly wind speeds). Maximum wind speeds from 1981-2010 Environment Canada climate data at the Faro AUT Station was 25.8 m/s from the northwest, while maximum wind speeds from the Faro Dump and Grum Dump sites, taken from 2003 to 2010 data were 13.5 and 10.3 m/s respectively.

Seasonally, summer wind speeds between May and September averaged 2.35 m/s at the Faro Dump Station and 2.38 m/s at the Grum Dump Station. In comparison, summer winds at the Faro AUT Station averaged 2.21 m/s. Winter wind speeds from October to April averaged 1.96 m/s at the Faro Dump Station and 2.57 m/s at the Grum Dump Station. Comparatively, winter wind speeds at the Faro AUT Station averaged 2.21 m/s, the same as the summer average.

At the Faro AUT Station, the prevailing summer wind directions are from the southeast and northwest, while winter winds originate predominantly from the southeast. At the Faro Dump Station, the prevailing summer wind directions are from the northeast and southwest, while prevailing winter winds are from the southeast. The Grum Dump Station experiences summer winds predominantly from the northwest and winter winds from both the southeast and the northwest.

5.8.5 Solar Radiation

While solar radiation is not a published component of the Environment Canada stations at Faro, the FMC stations did record solar radiation data from December 2003 to July 2009. Data from 2004 to 2008 (5 complete years) were used to characterize onsite solar radiation. Average daily solar radiation calculated using this dataset ranges from the lowest detected levels of 0.129 kW in December to a high of 5.599 kW in June. Highest daily solar radiation levels occurred between April and July, with the lowest daily solar radiation experienced between November and January.

5.8.6 Relative Humidity

Relative humidity data for the site were based on data collected at the Faro A Station between 1981 and 2010. During this time, relative humidity readings were collected twice daily during the summer months (April through October; 06:00 and 15:00), and once daily for the remainder of the year (15:00). The annual average relative humidity at the Faro A Station taken at 15:00 is 62.69 percent with monthly mean values ranging from 41.44 percent (June) to 81.17 percent (November). Relative humidity was generally higher in morning readings, ranging from 74.6 percent (May) to 89.99 percent (September), with an annual average of 81.92 percent..

5.9 Vegetation

The FMC is located within the Yukon Plateau-North Ecoregion, in the Boreal Cordillera Ecozone (Smith et al., 2004). Vegetation in the regional study area (RSA) is typical of boreal, sub-alpine, and alpine ecosystems of this ecozone. In the boreal ecosystems of the Yukon Plateau, forests are dominated by open black spruce stands with moist moss or drier lichen understories. White spruce, occasionally with trembling aspen or lodgepole pine, grows on warmer and better-drained soils (Smith et al., 2004). The subalpine ecosystems, various shrubs and an abundance of lichens dominate the tundra. Low-growing ericaceous shrubs, prostrate willows, and lichens dominate the alpine. Talus slopes are also common at these high elevations, and are typically covered by crustose lichens. Where forest fires have occurred, *P. tremuloides* and balsam poplar (*Populus balsamifera*) are common.

5.9.1 Species at Risk and Rare Plants

Species at risk (SAR) are plant species considered to be extirpated, endangered, threatened, or of special concern by the federal Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The

federal *Species at Risk Act* (SARA) regulates SAR and legislates activities within the critical habitats of those species (Environment Canada, 2013).

The SAR in Yukon Territory are listed based on their COSEWIC standing (YG, 2013a). There are currently three plant species at risk and one under review in Yukon (Table 5-1).

Table 5-1. Plant Species at Risk Potentially Occurring in the Regional Study Area
Faro Mine Remediation Project

Species	Common Name	COSEWIC (date listed)	SARA	NatureServe Ranking of Status in Yukon Territory
<i>Draba yukonensis</i>	Yukon draba	Endangered (November 2011)	Not listed	S1
<i>Micranthes spicata</i>	Spiked saxifrage	Threatened (May 2013)	Not listed	S2
<i>Carex sabulosa</i>	Baikal sedge	Threatened (May 2005)	Threatened	S2
<i>Podistera yukonensis</i>	Yukon podistera	Under Review (November 2014)	Not listed	S2

Rare plants are plant species that are uncommon or infrequently encountered, and includes both species whose status is not known and species that are of conservation concern. A registry of rare plants is maintained in Yukon by the Yukon Conservation Data Centre, including those that are termed as reportable (i.e., for which the Conservation Data Centre is actively seeking records of observations). Rare plants include SAR, but other plants may also be classified as rare.

Three surveys that directly or indirectly targeted rare plants have been completed at the FMC: (1) a rare plant survey by Gartner Lee Limited (GLL) in 2008 focused on areas that are to be disturbed by rock resloping in the overall final remediation plan, (2) a 2007 vegetation study of the local study area (LSA) that focused on vegetation associations, and (3) a vegetation study by Environmental Dynamics Inc. (EDI) (2008) that described vegetation types at the FMC. No rare plant species listed by COSEWIC or SARA were found in these three plant surveys.

5.9.2 Contaminant Concentrations in Vegetation

Past operations at the FMC have resulted in elevated metal concentrations in vegetation at the FMC, compared with territorial background and reference site concentrations (C.E. Jones and Associates Ltd., 2003; GLL, 2006a). Studies in 2002 (C.E. Jones and Associates Ltd., 2003) indicated that elemental deposition was a result of mining operations. The terrestrial effects assessment completed by GLL (2006a) measured elemental concentrations in vegetation and lichen to identify sites with the highest metals concentrations and sites where these concentrations were likely to continue to increase.

5.10 Fisheries

5.10.1 Stream Habitat Descriptions

Regionally, the Rose-Anvil and Vangorda Creek watersheds affected by the FMC encompass an area of 980 and 90 km² and contribute 2 and 0.2 percent of the Pelly River watershed, respectively. The Pelly River watershed has a total drainage area of 49,000 km².

5.10.1.1 North Fork Rose Creek

The NFRC flows through the FMC from north of the Faro Mine Area, approximately 17 km upstream from the Haul Road (Figure 5-22). It originates in a wetland area that also drains towards the Tay River watershed. Several instream ponds are located near the headwaters. Some segments of the existing NFRC Realigned Channel range from 2 to 3 m deep and less than 5 m wide to other segments from 0.2 to 0.8 m deep with wider flat glades with braiding (Table 5-2) (White Mountain Environmental

Consulting [WMEC, 2005a). In general, the upper reaches of the NFRC are dominated by large cobble and boulder habitats that transition to finer substrates closer to the confluence with the FCD. A small lake is located on a branch flowing into the NFRC, which flows out through a steep creek that is impassable to fish (WMEC, 2005a).

Downstream from the FCD, the NFRC ranges from 8 to 12 m wide and has gradients between 0.2 and 2.0 percent (Table 5-2). The stream morphology within this reach is riffle-pool, and the channel is frequently confined (de Graff, 2013). An instream pond is located just upstream from the Haul Road; this pond is approximately 250 by 115 m in spring, but becomes smaller under lower seasonal flows (WMEC, 2005b). The depths of the pond fluctuate accordingly, declining from 4 m in the spring to approximately 1 m in late summer (WMEC, 2005a). The NFRC flows beneath the Haul Road through a constructed rock drain that is impassable to fish.

Downstream from the Haul Road, the NFRC is predominantly confined, approximately 8.5 m wide, and has gradients ranging from 0.4 to 1.6 percent (Table 5-2). This section of NFRC is primarily of riffle-pool morphology, with an area of cascade-pool (de Graff, 2013).

Downstream from the Mine Access Road, the NFRC splits into two channels (Figure 5-23). The original channel joins with the SFRC after flowing through five ponds that were constructed to recharge nearby groundwater wells that supplied process water during mine operations. Culverts are present at the upper end of these ponds, which may seasonally restrict fish movement (de Graff, 2013). The second channel, the North Fork Diversion, was constructed to allow for diversion of sediment-laden water away from the Pump House Pond during spring freshet (GLL, 2002).

5.10.1.2 Faro Creek

North of the FMC, where it originates, Faro Creek is relatively undisturbed. Near the FMC, the creek has been diverted from its original channel around the Faro Pit and into the NFRC (upstream from the Haul Road).

5.10.1.3 South Fork Rose Creek

The SFRC originates upstream from Dixon Lake (north of the Vangorda/Grum Area), flows across the Haul Road and Mine Access Road, then flows northwest along the Access Road, eventually joining with the NFRC (Figure 5-23). Habitat has not been well characterized upstream from the Haul Road; however, the stream reach immediately above the Haul Road has a measured bankfull width of 8.6 m, a gradient of approximately 4.8 percent, and morphology that is predominantly riffle (Table 5-2) (Minnow, 2009). Further upstream, a gradient of 20 percent has been reported (GLL, 2003).

Between the Haul Road and the confluence with the NFRC (a distance of approximately 10 km), the SFRC is between 5 and 10 m wide with gradients ranging from 0.2 to 2.5 percent (Table 5-2). The SFRC varies in this reach from a steeper section with boulder and cobble habitat and slightly steeper gradient (2.2 to 2.5 percent) just downstream from the Access Road to a broader valley that includes the former Freshwater Supply Reservoir (Figure 5-23) (Harder, 1991; AECOM, 2009). Here, the channel meanders through gravels and finer particles and has a gradient of 0.2 percent (AECOM, 2009). Downstream from the former reservoir area, the SFRC has primarily riffle habitat, followed by a wetland complex, then another section of riffle habitat that extends to the confluence with the original NFRC (AECOM, 2009). Boulders and pools provide instream cover for fish throughout most of the SFRC downstream from the access road.

Downstream from its confluence with the NFRC, the SFRC flows through the 250-m by 40-m Pump House Pond, and then receives flow from the North Fork Diversion. From there, the combined NFRC and SFRC become Rose Creek and flow past the RCTA.

Table 5-2. Habitat Characteristics of Creeks in the Vicinity of the Faro Mine Complex^a*Faro Mine Remediation Project*

Reach			Approximate Reach Length (km)	Channel Width (m)	Wetted Width (m)	Gradient (%)	Dominant Substrate	In-stream Cover (%)	Dominant In- stream Cover	Dominant Riparian Vegetation	Source(s)
Rose-Anvil Watershed	NFRC upstream from Haul Road	Reach 1	17	8 - 12	7.6	0.2 - 2	boulder/ cobble	15	boulders, undercut banks, deep pools	shrubs	Robertson 1996 de Graff 2013
	NFRC downstream from Haul Road	Reach 2	2	8.3 - 8.4	6.5 - 6.8	0.4 - 1.6	boulder/ cobble/ gravel	11	boulders, deep pools	shrubs	de Graff 2013
	SFRC upstream from Haul Road	Reach 3	5	8.6	7.7	4.8 - 20	boulder/ cobble	70	boulder	willow	Minnow 2009 GLL 2003
	SFRC (Haul Road to confluence with North Fork)	Reach 4	10	4.9 - 10	4.2 - 6.9	0.2 - 2.5	boulder/ cobble	16	boulders, pools	grasses, shrubs	Robertson 1996 AECOM 2009
	RCD Channel	Reach 5	5	14 - 28	13 - 15	0.1 - 5.5	boulder	15	boulders	shrubs	de Graff 2013
	Rose Creek downstream from FMC	Reach 6	21	15 - 25	12 - 15	0.5 - 1.5	cobble/ gravel	12	pools, boulder, undercut banks	shrubs, alder	Robertson 1996 WMEC 2008 Laberge 2011
	Anvil Creek downstream from Rose Creek	Reach 7	43	35 - 80	NA	0.7 - 1.9	boulder/ cobble	NA	NA	NA	Robertson 1996

Notes:

^adata compiled from relevant tables and figures in reports presented in Appendix 6E, *Aquatic Baseline Characterization* (Minnow, 2014a)).

Note:

NA = no data available

Rose Creek Diversion

The RCD is a 5-km constructed channel located downstream from the NFRC-SFRC confluence that diverts Rose Creek around the RCTA and subsequently offsite (Figure 5-23). In the upper two-thirds of the RCD, stream gradient is typically 0.5 percent or less, with channel widths ranging from 13 to 15 m and relatively homogenous boulder substrate interspersed with cobbles and gravels (de Graff, 2013). The lower third of the RCD has a gradient of 5 percent, with primarily boulder substrate.

5.10.1.4 Lower Rose Creek and Anvil Creek

Downstream from the FMC, Rose Creek flows 21 km to its confluence with Anvil Creek. In this reach, the channel gradient ranges from 0.5 to 1.5 percent, and channel widths range from 15 to 25 m. Substrate in this reach is predominately cobble and gravel (WMEC, 2008a).

After converging with Anvil Creek, the combined watercourse flows an additional 43 km to the confluence with the Pelly River. In this reach, the channel ranges from 35 to 80 m wide, with gradients ranging from 0.7 to 1.9 percent and substrate consisting mainly of boulder and cobbles.

5.10.1.5 Fish Communities and Habitat Utilization

The following section describes existing information on the fish communities and important habitat features in streams near the FMC. These data are based on various site explorations that date back to the mid-1970s, with emphasis on more recent studies describing fish species distribution and abundance. Table 5-3 summarizes fish communities according to watercourse reaches and Figure 5-22 shows habitat features described below on Rose and Vangorda Creeks, respectively.

5.10.1.6 North Fork Rose Creek

Fish migration between the upper and lower portions of NFRC is prevented by the NFRD at the Haul Road. Upstream from the Haul Road, Arctic grayling, slimy sculpin, burbot (*Lota lota*), round whitefish (*Prosopium cylindraceum*) and longnose sucker (*Catostomus catostomus*) have all been reported. Of these, slimy sculpin are most abundant. Very few burbot and whitefish have been observed in the upper reaches of NFRC. Although few Arctic grayling have been captured upstream from the Haul Road in recent studies (de Graff, 2013; EDI, 2013a), higher numbers have been observed (WMEC, 2005a). The pond created by the rock drain appears to provide important over-wintering habitat for grayling because the pond does not freeze to the bottom (EDI, 2013b). Potential spawning habitat for grayling has been identified just upstream from this pond, as well as near the ponds at the headwaters of the NFRC.

In the NFRC downstream from the Haul Road, Arctic grayling, slimy sculpin, burbot, and round whitefish have been reported. Slimy sculpin were the most abundant, though numerous arctic grayling were also present (WMEC, 2005a; de Graff, 2013; EDI, 2013b). Arctic grayling spawning and spawning habitats have been reported both in the NFRC downstream from the Haul Road and in the vicinity of the constructed ponds just upstream from the confluence with the SFRC (WMEC, 2005a; EDI, 2013a). Fish access between the constructed ponds and the lower NFRC is restricted seasonally by culverts, but the NFRC Temporary Diversion provides an alternate route for fish passage from the RCD and SFRC to the NFRC.

5.10.1.7 South Fork Rose Creek

Fish populations in the SFRC upstream from the Haul Road are separated from those in the rest of the system by culverts at the Haul Road and Mine Access Road and by stream gradients of more than 20 percent upstream from the Haul Road. Both of these prevent upstream migration. Arctic grayling and slimy sculpin are the only fish species that have been captured upstream from the Haul Road (Minnow and WMEC, 2009; EDI, 2013a).

Table 5-3. Summary of fish species presence in the vicinity of the Faro Mine Complex (details in Attachment Table E.1 of Appendix 6E)
Faro Mine Remediation Project

Reach			Fish Species						
			Arctic Grayling (<i>Thymallus arcticus</i>)	Juvenile Chinook Salmon (<i>Oncorhynchus tshawytscha</i>)	Slimy Sculpin (<i>Cottus cognatus</i>)	Burbot (<i>Lota lota</i>)	Round Whitefish (<i>Prosopium cylindraceum</i>)	Longnose Sucker (<i>Catostomus catostomus</i>)	Lake Chub (<i>Couesius plumbeus</i>)
Anvil-Rose Watershed	NFRC upstream from Haul Road	Reach 1	✓	NA	✓	✓	✓	✓ ^a	–
	NFRC downstream from Haul Road	Reach 2	✓	–	✓	✓	✓	–	–
	SFRC upstream from Haul Road	Reach 3	✓	–	✓	–	–	–	–
	SFRC (Haul Road to confluence with North Fork)	Reach 4	✓	✓	✓	✓	✓	–	–
	RCD Channel	Reach 5	✓	✓	✓	✓	✓	–	–
	Rose Creek downstream from Faro Mine Complex	Reach 6	✓	✓	✓	✓	✓	✓ ^a	–
	Anvil Creek downstream from Rose Creek	Reach 7	✓	✓	✓	✓	✓	✓	✓

Notes:

^aAECOM 2009. No data records provided.

Source: *Aquatic Baseline Characterization* (Minnow, 2014)

Between the Mine Access Road and the confluence with the NFRC, Arctic grayling, juvenile Chinook salmon, slimy sculpin, burbot, and round whitefish have either been captured or observed, although only Arctic grayling and slimy sculpin have been found in most studies (AECOM, 2009; WMEC, 2005c). In addition to the NFRC (see above), grayling spawning has been reported at the Pump House Pond, located at the confluence of the NFRC and SFRC (WMEC, 2005a).

5.10.1.8 Rose Creek Diversion

Generally, habitat and fish cover in the RCD is constrained by a lack of natural stream processes, homogeneous substrates, and sparse riparian vegetation. Arctic grayling, Chinook salmon, slimy sculpin, burbot and round whitefish have been found within the RCD, but only Arctic grayling and sculpin are common.

Arctic grayling reside in the upper portions of the RCD throughout the year, although some Arctic grayling from this and other areas of the FMC area migrate to the Pelly River to overwinter (EDI, 2013b). Upstream migration of Arctic grayling in the steep lower portion of the RCD was recorded by EDI (2013b). Spawning Chinook salmon were observed once in the RCD (Minnow, 2010).

5.10.1.9 Lower Rose Creek and Anvil Creek

Downstream from the FMC, Arctic grayling, juvenile Chinook salmon, slimy sculpin, burbot, round whitefish, and longnose sucker have been observed or captured. Lake chub (*Couesius plubeus*) have also been captured near the Pelly River. Slimy sculpin were the most frequently captured species in previous studies

The Rose-Anvil Creek system is identified as having low to moderate suitability for Chinook salmon spawning, with suitable but limited habitat for juvenile Chinook salmon (Yukon Placer Secretariat, 2010). WMEC (2010b) also concluded that Anvil Creek would be expected to support only low numbers of spawning Chinook salmon.

5.11 Wildlife

5.11.1 Introduction

The collection of wildlife baseline data for the FMC area dates back to the 1970s, and includes a variety of local and regional studies. The description of wildlife and wildlife habitat in the following section was compiled based on field studies and previous reports, including recent local studies conducted on behalf of Assessment and Abandoned Mines (AAM) as well as regional studies conducted by Environment Yukon:

- A winter tracking survey (ELR, 2012)
- A waterfowl study (ELR, 2013)
- A log of FMC incidental wildlife observations that has been maintained by site C&M contractors (AAM, 2013; unpublished data)
- An early winter moose survey (Clarke et al., 2012)
- A thimhorn sheep lambing survey (Environment Yukon, 2013a; unpublished data)

The following wildlife reports and studies were completed before AAM assumed responsibility for the site in 2009, and were also reviewed to develop the current description:

- A wildlife baseline study report (GLL, 2008b)
- A thimhorn sheep summary report (GLL, 2008c)

Several wildlife information datasets were also reviewed to contribute to baseline information, including breeding bird survey data, Environment Yukon Wildlife Key Areas (Environment Yukon, 2009), and Environment Yukon harvest records. SAR resources, including the Yukon Conservation Data Centre, the SARA Registry, COSEWIC, and NatureServe Canada, were also examined to identify and characterize potential or known SAR within and around the LSA and RSA. These study areas were established to characterize wildlife and wildlife habitat for the FMC and its surrounding area.

Further details about wildlife baseline conditions are provided in the *Terrestrial Wildlife Baseline Report* (ELR, 2014).

5.11.2 Wildlife Local and Regional Study Areas

The wildlife study area encompasses the area defined by the existing disturbance footprint, with the addition of a 1-km buffer, which represents an immediate zone of potential project effects. (Figure 6G-2 in the *Terrestrial Wildlife Baseline Report* [ELR, 2014]). The FMC footprint area is characterized by roads, mine infrastructure, engineered waterbodies (i.e., pits and ponds), and patches of regenerating vegetation communities. Regenerating areas transition to boreal woodlands, as well as to subalpine and alpine ecosystems that are adjacent to the footprint area.

For some wide-ranging wildlife species (e.g., moose, caribou, grizzly bears, and some raptors) the assessment requires an understanding of abundance and distribution in areas extending beyond the LSA. Accordingly, a wildlife RSA was used to describe wildlife populations and to assess effects at a broader geographical scale (Figure 6G-2, ELR, 2014). The RSA was defined as an area extending 15 km beyond the FMC footprint, resulting in a total area of 1,530 km².

5.11.3 Species at Risk

Several SAR have been identified as occurring or having the potential to occur within the LSA or RSA. These species are listed under SARA (2012) or the *Territorial Wildlife Act* (YG, 2013b), or are designated by COSEWIC (2010). Table 5-4 summarizes SAR that are either confirmed or potentially occurring in the LSA and RSA.

Table 5-4. Species at Risk That Are Confirmed or Potentially Occurring in the LSA and RSA
Faro Mine Remediation Project

Species	Confirmed or Potentially Occurring in LSA	Confirmed or Potentially Occurring in RSA	Yukon <i>Wildlife Act</i> Status	SARA Status	COSEWIC Status
Mammals					
Woodland caribou	Confirmed	Confirmed		Special Concern	Special Concern
Grizzly bear	Confirmed	Confirmed			Special Concern
Wolverine <i>Gulo gulo</i>	Confirmed	Confirmed			Special Concern
Avifauna					
Bank swallow <i>Riparia riparia</i>	Confirmed	Confirmed			Threatened
Harlequin duck <i>Histrionicus histrionicus</i>	Confirmed	Confirmed		Special Concern	Special Concern
Horned grebe	Confirmed	Confirmed			Special Concern
Trumpeter swan <i>Cygnus buccinator</i>	Confirmed	Confirmed	Specially Protected		
Olive-sided flycatcher <i>Contopus cooperi</i>	Potential	Confirmed		Threatened	Threatened

Table 5-4. Species at Risk That Are Confirmed or Potentially Occurring in the LSA and RSA
Faro Mine Remediation Project

Species	Confirmed or Potentially Occurring in LSA	Confirmed or Potentially Occurring in RSA	Yukon Wildlife Act Status	SARA Status	COSEWIC Status
Canada Warbler <i>Wilsonia canadensis</i>	Potential	Potential		Threatened	Threatened
Common Nighthawk <i>Chordeiles minor</i>	Potential	Potential		Threatened	Threatened
Rusty Blackbird <i>Euphagus carolinus</i>	Potential	Potential		Special Concern	Special Concern

5.11.4 Abundance and Distribution of Major Wildlife Species

5.11.4.1 Moose

Moose are an important species in Yukon. First Nation and Yukon residents value moose as a big game species, which they rely on for subsistence. Moose are ranked as secure in Yukon (Canadian Endangered Species Conservation Council, 2011).

Important habitats for moose include riparian areas adjacent to rivers, marshes, ponds, and meandering streams; burned or logged areas; and treeline and subalpine areas with abundant shrub forage species. Moose use a range of habitats, from valley bottoms to the subalpine zone within both the LSA and RSA. There are no moose Wildlife Key Areas in the LSA or RSA, and the nearest Wildlife Key Area (moose late-winter range) lies in the Ross River Valley, 45 km east of the Vangorda/Grum Area.

The most recent population data available for moose in the FMC area was collected during a 2011 early winter moose aerial survey by Environment Yukon that covered an area of 6,470 km² (Clarke et al., 2012) and overlaps the RSA. The study results indicated high-quality moose habitats are located throughout the study area, with a high average moose density of 364 moose per 1,000 km² compared to the territory-wide average of 157 moose per 1,000 km² (Clarke et al., 2012). Despite this, a trend analysis indicated the average moose density in the region had declined from the 2004 estimate of 397 moose per 1,000 km². The total moose population within the survey area was estimated to be 2,352 individuals $\pm$ 23 percent, which was lower than the 2004 estimate of 2,450 $\pm$ 27 percent.

Survey results suggested that Game Management Subzone 4-45 (which overlaps the western portion of the LSA) had the highest average moose harvest rate of all Yukon (Clarke et al., 2012; Environment Yukon, 2013b). They also suggested the population within Game Management Subzone 4-45 has declined at an annual rate of two percent from 2004 and a total of 28 percent since 1997 (Clarke et al., 2012). There are moderate to high hunting pressures on moose within the RSA in areas adjacent to the FMC (some of which can be accessed from the FMC Access Road).

Moose were the second most frequently observed species recorded in the FMC Incidental Wildlife Log. They were observed throughout the LSA in every month except November, with the most observations during the summer months (AAM, 2013; unpublished data). Most observations were recorded in the Faro Mine Area, including in the vicinity of the parking lot and guardhouse, the ETA, CVD Pond, ID Pond, Rose Creek, RCD, and FCD, and generally in the Down Valley area. Moose were also observed along the Haul Road and periodically in the Vangorda/Grum Area. Detections of moose within the LSA during the 2012 winter tracking survey revealed that moose use nearly all habitats types found in the LSA, but that their habitat use is focused around riparian areas of Rose Creek and other riparian draws (ELR, 2012).

5.11.4.2 Thinhorn Sheep

There are two subspecies of thinhorn sheep in Yukon: Dall's (*Ovis dalli dalli*) and Stone's (*Ovis dalli stonei*); the southern Yukon is the northern extent for the latter. Sheep in the FMC area are referred to as 'Fannin' and have an intermediate pelage colour between the darker Stone's sheep and the lighter Dall's sheep, which may be the result of crossbreeding (Worley et al., 2004). Fannin sheep are reported to range only in the Pelly and Ogilvie mountains. Neither Stone's nor Dall's sheep have been listed by COSEWIC.

Fannin sheep have been observed in the FMC from May to November, and most regularly in the Vangorda/Grum Area (AAM, 2013; unpublished data). Several sheep were also observed incidentally in this area during September 2013 waterfowl surveys (ELR, 2013), and included a large group of rams, ewes, yearlings, and lambs. Beyond the FMC, most individual sheep have been observed on Mount Mye, Sheep Mountain, and Rose Mountain, with some observed on Mount Kulan and the Yukon Plateau, and in the Blind Creek and Swim Lakes areas (GLL, 2008c). Thirty-one thinhorn sheep Wildlife Key Areas occur within the RSA and include mineral licks, seasonal ranges, and migration corridors; four of these occur within the LSA (Figure 6G-4, ELR, 2014).

Although 2011 aerial survey results for the regional thinhorn sheep population suggest it is stable, the study noted that hunting pressures have increased in the area (particularly in Game Management Subzone 4-45) because of increased access (Environment Yukon, 2011). Furthermore, Environment Yukon (2011) reported the primary management concern for the surveyed population at that time was an increase in mineral exploration activities in the area.

5.11.4.3 Caribou

All woodland caribou of the Northern Mountain population are ranked by COSEWIC and are listed under Schedule 1 of SARA as a species of special concern (Table 5-4).

The annual ranges of four woodland caribou (Northern Mountain population; *Rangifer tarandus caribou*) herds occur in the Faro region, including the ranges of the Tay River, Finlayson, Moose Lake, and Pelly herds (Environment Yukon, 2012). Only the annual range of the Tay River caribou herd overlaps the RSA and for this reason, caribou observed within the LSA most likely belong to the Tay River herd (Alain Fontaine, personal communication, 2013). The Tay River herd was last surveyed in 1996 by Environment Yukon, at which time the population was estimated to be 3,750 individuals. The population is currently considered to be stable (Environment Yukon, 2012).

Woodland caribou feed primarily on ground lichens and tend to use habitats in alpine and subalpine elevations that provide these forage species and vantage points to watch for predators. Winter ranges, migration corridors, and rutting areas used by woodland caribou can be habitats identified by Environment Yukon as Wildlife Key Areas; however, there are no caribou Wildlife Key Areas within the LSA or RSA.

Caribou have infrequently been observed at the FMC according to the FMC Incidental Wildlife Log records (AAM, 2013; unpublished data). Over the 5 years of wildlife reporting to date, there have been 13 recorded caribou observations onsite during the months of May, June, or July. Most observations have been recorded near the Haul Road, Rose Creek, the FCD, and the ETA, as well as near the Grum Waste Dump meteorological station.

5.11.4.4 Grizzly Bear

Grizzly bear (*Ursus arctos*) are often considered to be a keystone species. They are referred to as ecological indicators, as they are critical to ecosystem diversity and integrity. The western population of grizzly bears is listed by COSEWIC as a species of special concern, but currently has no protection status under SARA.

The immediate project footprint has limited habitat that is suitable for grizzly bear life requisites because of the disturbed nature of many areas. Reclaimed areas that support the growth of grasses and shrubby subalpine hillsides, however, likely provide some vegetation species for foraging (e.g., berry-producing shrubs and *Hedysarum sp.*), as well as potential prey items (e.g., ungulates and Arctic ground squirrels).

FMC Incidental Wildlife Log records include 60 grizzly bear sightings and an additional 37 bear (i.e., either black or grizzly bear) sightings from May 2009 to July 2013 (AAM, 2013; unpublished data). Pooled for all years, grizzly bears were sighted between April and October: most frequently in May ($n = 21$), followed by June ($n = 17$). Grizzly bears were consistently observed during May in all 5 years of observation records, while the timing of sightings was not consistent across observation years. Of the 60 grizzly bear records, 4 observations were of sows with either one, two, or three cubs, accounting for a total of 12 of the individual observation records. Over half of the grizzly bear observations occurred in the Faro Mine Area, including areas in proximity to the CVD Pond, RCTA, Faro Pit, and FCD. The remaining observations occurred in the Vangorda/Grum Area (e.g., Grum Pit, Vangorda Flume, and Sheep Pad Pond areas) and along or near the Haul Road.

5.11.4.5 Furbearers

Trapping furbearers is an important economic activity in much of Yukon. The FMC falls within a large group trapping concession that is approximately 35,400 km² in area. Several furbearing species have been observed at the FMC (ELR, 2012; AAM, 2013; unpublished data), including the following:

- American marten (*Martes americana*)
- Ermine (short-tailed weasel; *Mustela erminea*)
- Mink (*Mustela vison*)
- Least weasel (*Mustela nivalis*)
- Fisher (*Pekania pennanti*)
- Wolverine (*Gulo gulo*)
- Canada lynx (*Lynx canadensis*)
- Red squirrel (*Tamiasciurus hudsonicus*)

Among these species, the wolverine is listed as special concern by COSEWIC but is not currently listed under SARA. The wolverine is believed to be stable within Yukon (Yukon Conservation Data Centre, 2011). COSEWIC has indicated the Canada lynx is not at risk and the remaining furbearer species listed above have not been listed by COSEWIC. The *Terrestrial Wildlife Baseline Report* (ELR, 2014) provides more detailed information summarizing furbearer occurrences in the LSA.

5.11.4.6 Canids

Grey wolf (*Canis lupus*), coyote (*Canis latrans*), and red fox (*Vulpes vulpes*) occur throughout Yukon in a variety of habitats. They are currently not listed by either COSEWIC or SARA. These canid species were all detected during the 2012 winter tracking survey at low densities (ELR, 2012). Wolf and fox sightings were the most common records among furbearing species in the FMC Incidental Wildlife Log records (AAM, 2013; unpublished data). Canids are known to use roads and linear corridors to move through the landscape. This behaviour was observed at the FMC (e.g., tracks observed along the Haul Road); however, wolf tracks were also observed in forested stands with pine and mature white spruce (ELR, 2012).

5.11.4.7 Avifauna

The areas surrounding the Town of Faro and the FMC offer suitable habitats for a wide range of avian species, including waterfowl, shorebirds, passerines, upland game birds, and raptors. Many species have been observed in the FMC area (Environment Yukon, 2003); the species most commonly observed while conducting avian surveys included white-winged crossbill (*Loxia leucoptera*), dark-eyed junco (*Junco*

hyemalis), common raven (*Corvus corax*), Swainson's thrush (*Catharus ustulatus*), hermit thrush (*Catharus guttatus*), gray jay (*Perisoreus canadensis*), and American robin (*Turdus migratorius*) (U.S. Geological Survey, 2013; Canadian Wildlife Service, 2007; Tables 6G-7 and 6G-8, ELR, 2014).

Migratory bird species are protected under the *Migratory Birds Convention Act*, and *Yukon Wildlife Act* (YG, 2013b) has provisions for non-migratory species. Specifically, Section 17 of the latter refers to the protection of non-migratory species' eggs and nests. The following avian SAR have been observed at the FMC:

- Bank swallow - Threatened (COSEWIC)
- Harlequin duck - Special Concern (COSEWIC and SARA Schedule 1)
- Horned grebe - Special Concern (COSEWIC)
- Trumpeter swan - Specially Protected (*Yukon Wildlife Act*) (YG, 2013b)

A colony of bank swallows has been observed using a small sandy cliff in a roadside cut bank north of the ID Pond (GLL, 2008a). Bank swallows were also observed in the vicinity of the Vangorda Pit in 2013. The olive-sided flycatcher (*Contopus cooperi*) has not been observed onsite but has been recorded as occurring in the area and is associated with open areas containing, or adjacent to, mixed or coniferous mature forest with snags or tall live trees (COSEWIC, 2007). It is listed by COSEWIC and under Schedule 1 of SARA as a threatened species.

Waterfowl and shorebird habitats in the LSA are limited to constructed pits and ponds onsite and the altered habitats of the NFRC and the RCD. FMC Incidental Wildlife Log records (AAM, 2013; unpublished data) and a recent waterfowl survey (ELR, 2013) indicate that waterfowl and shorebirds visit the FMC during the ice-free season and have been observed to be diving, foraging, dabbling, drinking, and resting in the aquatic habitats onsite (see Appendix 6G, *Terrestrial Wildlife Baseline Report* [ELR, 2014]). Forage availability (e.g., benthic invertebrates, and riparian and aquatic vegetation) varies among the pits and ponds, as do the concentrations of heavy metals in water, sediment, and in the tissues of potential food sources (see Appendix 6G). Results from total metal content analyses of sediments and aquatic and riparian vegetation indicate some sample sites (e.g., ID Pond, Little Creek Pond, and CVD Pond) provide more potential for contaminant availability and uptake than other sites (e.g., the Sheep Pad Ponds or Slot Cut in Grum Pit).

5.11.4.8 Small Mammals

Small mammals are ecologically important, as some species are considered furbearers (i.e., red squirrels) but most are prey species for land-based carnivores and raptors and support an ecosystem food web. Small mammal species are defined here to include snowshoe hare and porcupine, in addition to species (e.g., small rodents and squirrels) typically included within this group.

Several small mammal species have been observed within the LSA (GLL, 2006b; AAM, 2013; unpublished data):

- Northern red-backed vole (*Clethrionomys rutilus*)
- Common shrew (*Sorex cinereus*)
- Heather vole (*Phenacomys intermedius*)
- Deer mouse (*Peromyscus maniculatus*)
- Siberian lemming (*Lemmus sibiricus*)
- Snowshoe hare (*Lepus americanus*)
- Porcupine (*Erethizon dorsatum*)
- Red squirrel

5.11.4.9 Amphibians

Five species of amphibians are known to occur in Yukon Territory; however, based on their distribution, the wood frog (*Rana sylvatica*) is the only one likely to occur in the FMC area (Environment Yukon,

2005). One wood frog was observed by a field crew in the Vangorda/Grum Area during a vegetation classification survey in July 2007 (GLL, 2008b). Wood frogs are not at risk at the territorial or federal level and are not anticipated to be abundant at the FMC. There are no reptile species found within Yukon (Canadian Amphibian and Reptile Conservation Network, 2012).

5.11.4.10 Invertebrates

The Canada darner (*Aeshna canadensis*), a dragonfly species, is ranked as critically imperiled in Yukon by NatureServe (2013) and is not listed by COSEWIC. An occurrence of this species was recorded by the Yukon Conservation Data Centre in the Swim Lakes area, approximately 8.5 km east of the LSA boundary. Specimens of this species have not been observed in other habitats appropriate for the species elsewhere in southern Yukon (Randi Mulder, personal communication, 2013).

5.11.5 Faro Mine Complex Wildlife Habitat Summary

The FMC occurs primarily within mid- to high-elevation boreal forest, which is dominated by white spruce with isolated stands of lodgepole pine and with shrub species in the understory. Subalpine vegetation communities are dominated by scrub birch, subalpine fir, white spruce, some lodgepole pine, and lichen. Above the treeline, alpine areas are characterized by rock and bluffs, low ericaceous and willow shrubs, and an abundance of terrestrial lichen (YEWG, 2004). These ecosystems surround the FMC and are in contrast to the footprint area, which is characterized by roads, mine infrastructure, engineered or altered waterbodies, and patches of regenerating vegetation communities.

Despite the altered state of the FMC, many wildlife species have been observed using LSA habitats to breed (e.g., passerine species that nest in shrubs or adjacent forest stands), migrate (e.g., waterfowl rest on pits and ponds, and Fannin sheep traverse and rest in the Vangorda/Grum Area), and forage (e.g., moose feed on shrubs in riparian areas). Waterfowl and shorebird habitats within the LSA are dominated by constructed pits and ponds at the FMC; waterfowl use these habitats during migration periods and, to a lesser extent, through the summer.

Moose use a variety of habitats from valley bottoms to the subalpine zone within the LSA and RSA. Within the LSA, moose have been observed predominantly in the western portion of the FMC and in riparian draws of the Rose and Vangorda Creek systems.

Woodland caribou feed primarily on ground lichens in alpine and subalpine habitat and infrequently pass through the site. Along with other wide-ranging species such as wolverine and grizzly bear, caribou may travel through the FMC as part of larger range that includes neighbouring mountains and valleys traveled to fulfill a range of life requisites. The FMC woodlands provide year-round habitat for some mustelid species, including American marten, ermine, and mink, as well as small mammals and upland game birds. Canids have been observed at the FMC and make use of both disturbed and undisturbed areas.

The disturbed nature of the FMC footprint limits the presence of key avian and wildlife habitats within the LSA to the sand cliffs such as those north of the ID Pond (that could be used by bank swallows), the thornhorn sheep Wildlife Key Area movement corridors that traverse the Vangorda/Grum Area, and the portion of a thornhorn sheep Wildlife Key Area winter range that extends into the LSA from the slopes of Mount Mye. Within the RSA, Wildlife Key Areas have only been identified for thornhorn sheep and include winter range, spring lambing, and early winter rut areas and movement corridors.

5.12 Archeological and Heritage

The community of Faro was established to service the FMC in the late 1960s; as such, the history and heritage of the Town of Faro is closely tied to the mining industry. While further mineral exploration in the area is important to economic stimulus, tourism has become a major focus of the community and is identified as a priority in the town's Integrated Community Sustainability Plan (Town of Faro, 2007).

Each May, the Town of Faro hosts a Crane and Sheep viewing festival during the annual migration of the Sandhill cranes up the Tintina Trench. This has become a major event for the community and draws visitors from around the territory.

Aboriginal people comprise most of the population of Pelly Crossing and Ross River, with non-Aboriginal residents accounting for less than 15 percent of the total population. In comparison, Faro and Watson Lake are home to a relatively smaller population of Aboriginal people, who account for 15 percent and 35 percent of each community, respectively (Statistics Canada, 2008). Both Kaska and Northern Tutchone are spoken throughout the region; however, English is the predominant language in all communities in the FMC vicinity.

To support this NFRC Project, YG will continue to engage a heritage specialist to conduct a heritage resource overview assessment followed by a more detailed heritage resource impact assessment in specific areas. The assessment entailed a reconnaissance survey and selected shovel testing across areas of field exploration and work areas where disturbance of previously undisturbed areas may occur.

Assumptions and Constraints

6.1 Introduction

This section provides a listing of the assumptions made during preparation of the Preliminary Final DBR, as well as known constraints anticipated to be in place during preparation of the Final DBR. The schedule assumptions provided herein are based on the DBR review meeting with YG and INAC held on January 26, 2016.

6.2 Schedule Assumptions and Constraints

Key schedule dates included in the Draft Design and Construction Schedule for the Conceptual Design include the following:

- Preliminary DDBR submitted to the YG and INAC TRC : August 31, 2015 (Completed)
- TRC review comments provided to CH2M: September 15, 2015 (none provided)
- Final DDBR submitted to the YG and INAC TRC: October 6, 2015 (not required/ no comments)
- Value Engineering (VE) conducted: removed from scope
- Preliminary Final DBR submitted to TRC: March 31, 2016
- TRC review comments provided to CH2M: to be determined (TBD)
- CH2M submits revised Draft Final DBR to TRC: TBD
- TRC/IPRP review: TBD

Because the intended submittal date of the Preliminary Final DBR is near the end of FY 2015, YG noted that review of the Draft Final might not be possible until well into FY 2016. Because of uncertainties regarding future design processes, only the schedule through preparation of the Conceptual Design was reviewed.

Key assumptions regarding the schedule include the following:

1. A Preliminary Final DBR will be developed based on verbal comments received from the TRC on the DDBR.
2. The TRC will review the Preliminary Final DBR.
3. VE will not take place before review by the IPRP as directed by YG.
4. CH2M will have no further involvement in finalization of the design, following presentation to the IPRP.

6.3 Regulatory and Permitting Assumptions and Constraints

It is CH2M's understanding that YG and INAC have not reached final conclusions about regulatory and permitting requirements and approaches for the NFRC Project. Based on the scope of the proposed project, the primary regulatory and permitting requirements arise from the federal *Yukon Environmental and Socio-economic Assessment Act* (YESAA), territorial *Waters Act*, and federal *Fisheries Act*. While there may be other permitting requirements (e.g., for use of explosives if needed), only the stated three instruments have been considered, because these have the most complex application requirements and

are most likely to affect schedules. The requirements associated with each of the three major regulatory instruments are as follows:

1. **YESAA** – There are several activities that form part of the NFRC Project that exceed the thresholds requiring YESAA assessments. Because the Government of Canada (Canada) and YG are proponents of the project, they would be required to issue a YESAA Decision Document before undertaking the project or issuing authorizations (e.g., Water Licence or Fisheries Act Authorization [FAA]) that would permit the project to occur.
2. **Waters Act** – The *Waters Act* prohibits the use of water and deposit of waste into water except as authorized in a water licence. The Waters Regulation defines thresholds for activities that require licences. The proposed stream diversion and dam that are part of the NFRC Project exceed the thresholds for licensing. The Water Board cannot issue any water licence until a YESAA assessment is completed.
3. The 2009 “Minister’s Determination” (under the *Waters Act*) for the FMC provides authority for the YG Assessment and Abandoned Mines Branch to take emergency action on the Minister’s behalf without the benefit of a water licence. YG may determine that the proposed NFRC Project falls within the scope of the Minister’s Determination, in which case a water licence may not be required. As the proponent for activities that would require an authorization from a private individual, it appears that YG still requires a YESAA assessment for the activities, even if it undertakes the activities under the Minister’s Determination.
4. **Fisheries Act** – The *Fisheries Act* prohibits activities that cause serious harm to fish (i.e., “the death of fish or any permanent alteration to, or destruction of, fish habitat” [*Fisheries Act*, Subsection 2(2)]) and the deposit of deleterious substances into fish-bearing waters. Projects that cause serious harm to fish can be undertaken if they are completed in accordance with an FAA issued by the federal Minister of Fisheries and Oceans. The NFRC Project appears to include activities that require an FAA. Fisheries and Oceans Canada cannot issue a FAA until a YESAA assessment is completed.
5. Applications for FAAs generally require detailed information about a proposed offsetting plan, describing methods to compensate for effects on fish and fish habitat. However, regulations under the *Fisheries Act* provide for less onerous application requirements where “a work, undertaking or activity ... needs to be carried on without delay in response to ... (c) an emergency that poses a risk to public health or safety or to the environment or property.” In these circumstances, there may be no requirement to submit offsetting plans as part of the application, but an FAA is still required. These conditions may apply to the NFRC Project. If not, an offsetting plan will be required as part of the project.

For the purposes of the Preliminary Final DBR, CH2M has made the following assumptions about the major regulatory and permitting requirements for the NFRC Project:

1. Implementation of the project will require a YESAA assessment and an FAA.
2. The process for obtaining an FAA does not require development of an offsetting plan. Requirements for developing an offsetting plan are not considered as part of this Preliminary Final DBR.
3. An application to YESAA for assessment of the NFRC Project will cause YESAA assessors to include consideration of other ongoing activities at the FMC (i.e. Care and Maintenance). YESAA assessors are obliged to include activities within the scope of their assessment if the project cannot proceed without them being undertaken, or if the undertaking the project will make those activities inevitable. In this case, water management and water treatment activities at the FMC would almost certainly be included in the scope.

Based on these assumptions, CH2M has concluded that the NFRC Project requires a regulatory approach that addresses YESAA requirements for both the NFRC realignment and ongoing site activities, and

Fisheries Act requirements for the NFRC realignment. The requirement for a water license has not been addressed within this Preliminary Final DBR. The YESAA requirements could be addressed by two separate YESAA processes or a combined process. In either case, CH2M has assumed that the Interim Works Project Proposal (YG, 2014) would, with minor updating and revisions, support the assessment of ongoing activities. It would also provide valuable input for defining site conditions and evaluating effects of the NFRC Project.

CH2M has not completed a detailed schedule for regulatory requirements for the NFRC realignment, as it awaits a decision on whether the parties will seek a water license. Based on the durations of YESAA assessments for other projects, it will now be challenging to complete the YESAA assessment and permitting activities before the scheduled start of construction in July 2017. Meeting this schedule leaves little opportunity for delays at any stage of preparing and processing applications.

6.4 Stage Gate Approvals

All design documents, including the Final DBR, the Preliminary Design, and the Detailed Design, will be prepared as follows:

- Submitted as draft documents to the TRC
- Reviewed by the TRC
- Revised as necessary
- Submitted as revised draft final documents through YG and INAC to the IPRP
- Revised as necessary
- Submitted as a final document for Stage Gate approval by YG and INAC.

Additional detail on the Stage Gate review and approval process is included in Section 15 of this Preliminary Final DBR.

6.5 North Fork Rose Creek Project Assumptions and Constraints

This section describes the current known assumptions and constraints for the technical elements of the NFRC Project. This information is summarized in Table 6-1 according to the NFRC site planning areas.

Table 6-1. North Fork of Rose Creek Project Assumptions and Constraints
Faro Mine Remediation Project

NFRC Project Planning Area	Assumptions and Constraints
FCD	Will be redesigned and constructed at a future date to carry the PMF to the confluence with the NFRC. FCD upgrades are not part of the NFRC Project.
NFRC Realigned Channel	Designed to carry the peak 1-in-500-year flood flow, with freeboard, and carry the peak PMF flood flow without freeboard. Segment 1 of the realigned channel extends approximately 880 m from the confluence with the Faro Creek Diversion to the transition to Segment 2. The relatively flat topography upstream and within Segment 1 constrains options for clean water and impacted water separation. Within Segment 1, the field investigation and groundwater modelling indicate that potentially-contaminated groundwater flow from the WRDs can be intercepted and directed away from the creek by use of a shallow cutoff wall and drainage trench or channel. This approach will reduce the area of impact to the NFRC and reduce the amount of groundwater collected by the contaminated seepage collection system. At the transition between Segment 1 and Segment 2, the design includes a cutoff wall and berms to force groundwater and streamflow into the realigned channel. The cutoff wall will also be designed to prevent headcutting and stabilize the transition between the two segments.

Table 6-1. North Fork of Rose Creek Project Assumptions and Constraints*Faro Mine Remediation Project*

NFRC Project Planning Area	Assumptions and Constraints
	Segment 2 of the realigned channel extend approximately 1,350 m from the intersection with Segment 1 and the Haul Road. Within Segment 2, it is essential that leakage from the realigned channel is minimized, as all leakage will be collected and stored downstream within the Seepage Collection Pond, pumped, and conveyed for treatment. To minimize leakage, the lining system will consist of a double liner and a leakage detection system. Groundwater present on the eastern slope above Segment 2 will be conveyed under the realigned channel and channel dike, will be collected by the contaminated seepage collection trench and conveyed downstream for collection by the Seepage Collection Pond. Following completion of the Conceptual Design, additional analysis should be completed to evaluate the cost and benefit of cutting off the clean water and draining to the realigned channel. Some permafrost and ground ice will remain in the substrate behind the realigned channel in Segment 2 and may thaw in the future. This will need to be monitored. Segment 3 of the Realigned Channel extends from the Haul Road to the Mine Access Road. Two alignments are under consideration for Segment 3. The P4 alignment is approximately 575 m long and the P3 alignment, located southeast of P4, is approximately 660 m long. Because of the difference in length and the steepness of this reach, the P4 alignment may allow greater flexibility in designing for fish passage. The requirements for fishery passage, overwintering, and habitat needs to be evaluated by YG and INAC. As directed by YG and INAC, the baseline design does not specifically include design elements required for fish passage, overwintering, or habitat. As an initial design approach, the realigned channel will be graded to allow fish passage (approximately maximum slope equals 5 to 6 percent). However, design elements such as step pools or protective structures have not been included in the baseline design. The additional requirements that would need to be considered for fish passage or habitat are discussed in Appendix B. Leakage from the realigned channel in Segment 3 is not a concern with respect to causing additional contaminated seepage that would need to be collected by the Seepage Collection Pond. Leakage from the realigned channel will need to be considered in design of the channel for erosion protection and handling the leakage at the Mine Access Road. Segment 4 of the Realigned Aligned Channel extends from the Mine Access Road to the intersection with SFRC. The P4 alignment is approximately 275 m long while the P3 alignment is approximately 110 m long. Leakage from the channel in Segment 4 is not a concern with respect to causing additional contaminated seepage that would need to be collected and treated. Leakage from the realigned channel will need to be considered in the channel design for erosion protection. The junction location of the realigned channel and the SFRC needs to be designed to enable joining of the two streams without causing erosion, either by headcutting or downstream erosion.
Haul Road	A PMF-capacity culvert will be constructed through the Haul Road either using cut and cover or tunneling. The culvert may be concrete or metal. The Haul Road will be rebuilt to facilitate ongoing site-wide O&M and for future site closure activities. The height and width of the Haul Road will be reduced to generate borrow for construction of the realigned NFRC channel dike and roadway. The NFRC construction sequencing will minimize the rehandling of excavated Haul Road borrow, if appropriate for reuse.
Mine Access Road	A new culvert will be constructed through the Mine Access Road to carry the realigned NFRC channel flow. YG Public Works highway design standards apply to culvert sizing. As a result of discussions of the DDBR with the TRC, the Mine Access Road will be designed to convey the realigned channel PMF. Alternatives under consideration include: (1) single arch; (2) twin box culverts; (3) bridge; and (4) a low water crossing. All of the options except for the low water crossing require the road to be raised.
New and Improved Access Roads	New roads will be constructed to allow all-weather access to the realigned channel dike and channel, and to the Seepage Collection Pond, crest of dam (Alternate 1 location), outlet works, pump station, and pond area. The roads will be surfaced similar to the Haul Road at the NFRD.

Table 6-1. North Fork of Rose Creek Project Assumptions and Constraints*Faro Mine Remediation Project*

NFRC Project Planning Area	Assumptions and Constraints
	Road improvements to the existing access road from the Zone II Pit/Zone II Outwash areas and to the NFRC confluence with the FCD will be constructed to enable all-weather access, and may include new culverts. Significant maintenance will be required throughout the winter to maintain access to these locations. Access to either the Alternate 1 or Alternate 2 pond locations for cleanout at the outlet works will require dewatering the pond, assumed to be completed during normal summer operations.
Seepage Collection Pond and Seepage Collection System	Location: Two alternate locations are under consideration for the Seepage Collection Pond. Alternative 1 is a Seepage Collection Pond located downstream of the NFRD and upstream of the Mine Access Road (Figure 3-1). The height of the dam will be in the order of 17 m, measured from the crest to the downstream toe, providing a storage volume of about 300,000 m³. Alternative 2 is an off-channel lined Seepage Collection Pond located downstream of the Mine Access Road (Figure 3-1). Contaminated water from the existing NFRC channel will be directed through a newly constructed and lined diversion channel running from a groundwater cutoff structure located upstream of the Mine Access Road to the lined pond that will be located immediately east of the Original and Secondary Tailings Areas. The pond is a geomembrane lined impoundment with an impounded volume of 358,000 cubic metres below the service spillway crest, not including a dead storage sump. For each of these locations, the requirements for pond storage capacity has been estimated based on estimated runoff from the catchment area (using stream runoff and precipitation data), return storm events, treatment and conveyance capacity, storage at Faro Pit, and an evaluation of cold weather and warm weather operations. Each of the ponds have been sized to provide sufficient capacity to collect and treat the annual precipitation (rainfall and snowmelt) associated with a 200-year annual precipitation return event. The analysis includes storage of mine-impacted water within the Seepage Collection Pond from October through April each year with conveyance to Faro Pit or to the Interim Water Treatment System from May through September. Analyses has been conducted to evaluate the trade-off between treatment capacity, treatment duration, cold weather conveyance to Faro Pit, pond size, and the potential overflow at the Seepage Collection Pond and its effects on the downstream water quality. Impacts to water quality and fisheries during pond overflow events will need to be further evaluated and quantified as part of the regulatory approval process. Because of uncertainties related to timing and volume of the freshet, temperatures, icing, freezing, operations, treatment plant operations, and actually runoff volumes, the pump stations and conveyance pipelines are designed for cold weather operations. The operations plan will include routine snow surveys to determine the potential volume of freshet runoff and measurement of contaminated seepage accumulated within the storage pond over the winter storage period. Both of these factors will be considered in scheduling and implementing pumping operations each spring. Dam Requirements: The embankments at both the Alternate 1 and the Alternate 2 Seepage Collection Ponds locations will be classified as a dam according to CDA guidelines. CDA criteria is expected to apply to the following design elements: hazard classification, selection of design flood and earthquake levels, hydrotechnical storage and discharge capacity adequacy, freeboard requirements, required factors of safety for slope stability (static and seismic load cases), filter design requirements, and surface erosion. Seepage Collection System: Upstream of the Haul Road, the seepage collection systems will make use of the existing creek channel, once the creek has been moved to the realigned channel. The new system will be passive, non-pumped, and have gravity flow throughout, including through the NFRD. The design intent is to keep the contaminated flow below the ground surface and reduce the available oxygen to minimize or delay the production of iron oxyhydroxides. It is expected that this material will be formed over time and that maintenance and replacement of the collection trench will be required periodically.

Table 6-1. North Fork of Rose Creek Project Assumptions and Constraints*Faro Mine Remediation Project*

NFRC Project Planning Area	Assumptions and Constraints
SFRC	The NFRC Project will be designed to minimize impact to the SFRC. Based on the hydrology and flood routing evaluation, berms may need to be constructed within the flood plain to divert flood flows away from the Mine Access Road. Within the area of the RCTA, the NFRC Temporary Diversion will be modified so that mine-impacted seepage from the Seepage Collection Pond is allowed to either seep into the RCAA, or if found to be appreciable, collected and conveyed for treatment.
Borrow Areas	The site investigation data indicates that the identified borrow areas will be adequate for providing the materials needed for both the realigned NFRC channel construction, the NFRC Seepage Collection Pond construction, and the access road construction. Initial testing of several granular borrow sources indicates that long-term durability of the materials and potential degradation of these materials during material handling and placement must be addressed. For riprap materials, several calc-silicate sources have been identified. Testing of these materials indicates that the calc-silicate typically contains 5 to 10 percent sulphides, but also has some amount of net neutralization potential. The use of these materials in clean water channels may not be appropriate. This needs to be further evaluated. An alternate riprap source is the Granitic Rock Outcrop, located approximately 8 km from the NFRC. While the initial evaluation indicates that this material is suitable for all applications and locations, development of the borrow area and transport of the materials must be considered in the design and material selection. The breached Freshwater Supply Dam appears to provide an excellent source of low-permeability and transition materials that will be suitable for construction of the Alternative 1 Seepage Collection Dam and the realigned channel. Note that our initial evaluation indicates that the Haul Road culvert excavation will provide more than a sufficient quantity for the realigned channel. Regulatory analyses is required to determine requirements and constraints for excavating and using the former Freshwater Supply Dam materials. As discussed in Section 5, limited investigations have been conducted to determine subsurface conditions in the area of the Alternative 2 Seepage Collection Pond. The limited data indicates that suitable sand and gravel materials are available within the footprint of the proposed Alternate 2 area for construction of the embankments. This will need to be confirmed during preparation of the preliminary design.
WRDs	The design for the NFRC Temporary Diversion needs to consider potential WRD grading options adjacent to the NFRC. This includes the temporary water diversion channel within the Segment 2 and downstream of the Haul Road. This evaluation needs to consider the following: staging and sequencing of the WRD grading; water management during construction, including flow and water quality; and long-term water collection and treatment following completion of regrading and covering. The Conceptual Design of the Realigned Channel and the Segment 1 cutoff wall and trench system has assumed that the WRD may be graded to a 3:1 slope through a combination of both cut and fill. This is in accordance with the Draft 4A Closure Plan (SRK, 2010d).
RCD	While not part of the NFRC Project, the RCD field exploration includes evaluation of the stability (liquefaction assessment) and seepage from the Secondary Impoundment to the RCD. The evaluation incorporated the findings of the 2013 Seismic Hazard Assessment (Atkinson and Assatourians, 2013). The results of these analyses, recommendations, and conceptual designs are provided in a separate submittal.
IWTS	It is assumed that the mine-impacted contaminated water collected at the NFRC Seepage Collection Pond would be treated at the IWTS to the current effluent quality standards presented in Section 8.1.2, before it is discharged to either the CVD Pond or directly to the environment. If these requirements changes, then the design for the IWTS will need to be evaluated.

Design Approach

7.1 Introduction

This section summarizes the proposed design approach for the NFRC Project, describes the process through which the design will be advanced to completion, and provides a chronological sequence of design and planning milestones. In addition, design team members are identified and design modelling and data collection processes are discussed. The design approach summary supports the following key project objectives as identified by YG and INAC:

- Protect the NFRC and Rose Creek by achieving stable, long-term separation of clean and contaminated mine-impacted water as soon as possible.
- Collect, convey and treat, to the extent practicable, contaminated mine-impacted water emanating from the eastern WRDs towards the NFRC corridor.
- Identify early tender package(s), to the extent practicable, to support local economy, take advantage of local skills, knowledge and labour, and help spread cash flow. (It is acknowledged that permitting requirements may be a primary consideration that controls implementation schedule.)
- Complete the Preliminary Final DBR, including a conceptual design (30%) and a Class 4 cost estimate by March 31, 2016.

7.2 Development of Overall Design

As prescribed by YG and INAC, the DBR serves as a planning document, through the Conceptual Design phase. The DBR presents design objectives, design criteria, the design development and approval process, and design standards that are proposed for the NFRC Project. YG and INAC's review comments on the Preliminary Final DBR will be addressed before completing the NFRC Concept Design and presentation to the IPRP. At the completion of the Conceptual Design phase, the Final DBR will provide documentation of the agreed-upon design approach, criteria, and approval processes.

Section 5 of this Draft DBR includes a summary of pertinent design data, including geological, geotechnical, hydrological, and hydrogeologic data. Detailed presentation of the data is presented in the appendices. This data was used to conduct analyses to establish preliminary sizes of structures and to develop conceptual alternatives for the following facilities:

- NFRC Realigned Channel: Replaces the existing stream channel.
- NFRC Temporary Diversion: Temporary diversion channel for NFRC during construction of the NFRC Realigned Channel.
- NFRC Permanent Seepage Collection Trench: trench that will be used to capture and convey the contaminated mine-impacted water to the area of the NFRD. The mine-impacted water will then flow through the NFRD, down the existing NFRC, and to the NFRC Seepage Collection Pond.
- NFRC Seepage Collection Pond: Retention reservoir used to collect contaminated mine-impacted water before conveyance for treatment. Two alternative locations have been identified: Alternative 1 is located between the Haul Road and the Mine Access Road, and Alternative 2 is downgradient of the Mine Access Road.
- NFRC Seepage Collection Dam: Constructed to retain the contaminated mine-impacted water at the NFRC Seepage Collection Pond Alternative 1 before conveyance for treatment.

- **NFRC Realigned Channel Access Road:** Constructed on top of the dike adjacent to the NFRC realigned channel to provide access for maintenance of the channel.
- **NFRC Seepage Collection Pump Station:** Pumps contaminated mine-impacted water from the Outlet Works of the NFRC Seepage Collection Pond to the IWTS or Faro Pit.
- **NFRC Conveyance Pipeline:** Convey contaminated water from the NFRC Seepage Collection Pump station to the IWTS or Faro Pit.
- **Mine Access Road Detour:** Temporary road that will be constructed to allow continuous access to the Faro Mine Mill Area on the Mine Access Road during construction

The design criteria for these facilities are presented in Section 9.

The TRC did not provide comments pertaining to the Draft DBR, submitted on August 31, 2015. Since submittal of the DDBR, CH2M has evaluated and analyzed data from the 2015 field exploration, completed alternative analysis evaluations as outlined in Section 11, selected preferred alternatives, and developed the Preliminary Final DBR and Conceptual Design.

At this time, there are uncertainties regarding the regulatory and permitting requirements and approaches for the NFRC Project. Section 6.3 discussed a preliminary assessment of the potential regulatory requirements of the NFRC Project. These uncertainties may have an impact on the overall construction schedule of the project; however, it is assumed that the Final DBR and Conceptual Design can be developed as the regulatory aspects of the project are addressed. The Final DBR and Conceptual Design are appropriate levels of design for submittal within a regulatory framework, if determined necessary. As discussed in Section 6, additional analyses will likely be required pertaining to effects and impacts of the proposed construction.

7.3 Design Processes

A Draft NFRC Project schedule was provided to YG and INAC on July 14, 2015. The purpose of the submittal was to outline the potential design and construction approach, obtain the owner's agreement on the near-term design schedule, layout potential construction phasing, and design packages for site operations and planning for funding. As part of the Final DBR process, CH2M will continue to work with YG to update this schedule to include regulatory requirements, owner and IPRP review periods, and requirements for stage gate approvals. Further development of the schedule can be used to establish priorities for the design processes, schedule and identify additional field explorations needed to support the preliminary and detailed design phases, determine any constraints, and evaluate whether processes can be shortened, compressed, or eliminated.

As discussed in Section 7.2, the Preliminary Final DBR includes advancement of the sizing and design of NFRC facilities, based on hydrologic analyses and observations from the 2015 summer field exploration. The goal for the Preliminary Final DBR is to include sufficient engineering information to gain concurrence on potential alternatives. The Final DBR will provide sufficient engineering data that documents the alternative designs evaluated and rational for the selection process before proceeding with the Preliminary Design. For each design stage deliverable, CH2M subject-matter experts will conduct internal quality reviews and will have the CH2M Dam Safety Technical Review Board conduct reviews at all stages. It is CH2M's understanding that the IPRP's review will take place following the TRC review of the Preliminary Final DBR.

The TRC has determined that a VE study will not be conducted at the draft Conceptual Design stage.

7.4 Design and Planning Events

Table 7-1 summarizes the near-term design submittals and proposed review schedule. This summary has been adapted from Draft NFRC Project schedule provided to YG and INAC on July 14, 2015. CH2M will work with YG to integrate regulatory and permitting, owner reviews, stage gate approvals, and procurement requirements into this and the more detailed NFRC Project schedule. Note that the draft schedule includes durations for review by YG, INAC, and the IPRP. Changes to these durations will result in schedule revisions.

Table 7-1. Near-term North Fork of Rose Creek Project Schedule
Faro Mine Remediation Project

Design Deliverable/Planning Event	Start Date	Finish Date
Conduct 2015 Field Work	July 22, 2015	September 1, 2015
Submit NFRC Project Draft DBR to YG	--	August 31, 2015
TRC Review of NFRC Project Draft DBR	September 1, 2015	September 15, 2015
CH2M addresses TRC Comments and Submit DDBR to YG	(no comments)	
Complete Laboratory Testing and Reporting	September 2, 2015	November 24, 2015
Conduct Segment 2 Test Cut	January 5, 2016	February 10, 2016
Conduct VE Study	(TRC removed from scope)	
Prepare and Submit Preliminary Final DBR to YG	December 16, 2015	March 31, 2016
TRC Review of Preliminary Final DBR	TBD	TBD
CH2M address TRC Comments and submit Final DBR to YG	TBD	TBD
TRC/IPRP Review of Final DBR	TBD	TBD
Presentation to IPRP	June 13, 2016	
Stage Gate Approval	TBD	TBD

7.5 Design Team

Table 7-2 lists key design team members and provides a description of their responsibilities.

Table 7-2. North Fork of Rose Creek Project Key Team Members
Faro Mine Remediation Project

Key Design Member	Role/Responsibility
Dick Crim	Project Manager
Jenna Rooney	Task Manager
Joan Stoupa	Closure and Technical Strategy Manager
John Spitzley	Responsible Engineer/Engineering Manager
Dirk Van Zyl	Mine Remediation Strategist
Lisa Alliger	Design Manager/Civil Lead
Paul Davis	Geotechnical Lead – Overall
Jaco Esterhuizen	Geotechnical Lead – NFRC Seepage Collection Pond and Dam
Jim Cassie/BGC	Senior Technical Review-Cold Regions

Table 7-2. North Fork of Rose Creek Project Key Team Members*Faro Mine Remediation Project*

Key Design Member	Role/Responsibility
Jack Seto/BGC	Senior Geotechnical Engineer – Cold Weather Engineering
Tom Mahood	Surface Water Lead
Wim Weldman, Matrix Solutions Inc.	Surface Water Hydraulic Senior Technical Consultant
Peter Lawson	Groundwater Lead
BT Thomas	Geochemical Lead
Jim Stefanoff	Treatment Lead
Mike Riess	Mechanical Lead
Ron Stillmunkes	Conveyance Pipeline Lead
Atul Thakkar	Structural Lead
Louis De Lang, Associated Engineering	Electrical Lead
Bill Duffy	Cost Estimator
Bill Slater	Regulatory Lead
Patti Orr, Minnow	Fisheries Lead
Michael Reimbold	Quality Manager
Rick Riker	Dam Safety-Technical Review Board Lead
Cam Malloch	Site Operation Integration
Clare Humphreys	Constructability Reviewer

7.6 Design, Modelling, and Data Collection Processes

The following modelling has been completed to support the Conceptual Design:

- Surface water hydrological modelling: used to size the NFRC Seepage Collection Pond and structures.
- Surface water hydraulic 1-dimensional (1D) modelling: used to evaluate erosion potential, energy dissipation measures, spillway design, flood routing, and Seepage Collection Pond outlet works.
- Surface water hydraulic 2-dimensional (2D) modelling: used to access the hydraulics of the confluences of the NFRC and the SFRC downstream to the confluence with the RCD.
- Groundwater modelling: used to evaluate the flow conditions on upper NFRC, evaluate anticipated groundwater inflows to the impacted seepage collection system adjacent to the NFRC Temporary Diversion, and size the NFRC Seepage Collection Pond.
- Geochemical modelling: used to provide water quality estimates and long-term chemistry of seepage from the WRDs and predictions of how it may change over time.
- Geotechnical modelling for stability analysis under static, seismic, and rapid drawdown conditions for NFRC Realigned Channel dike and NFRC Seepage Collection Dam.

Section 13 details the modelling conducted and additional modelling needed to support the project design. Surface water hydrologic and hydraulic modelling has been completed during preparation of the Preliminary Final DBR.

Design Objectives

8.1 Introduction

This section defines the overall design objectives of the NFRC Project, as well as specific objectives (qualitative and quantitative) for each site-planning area. The reader is advised that the numerical values presented are draft objectives or guidelines that will need to be further developed and evaluated as a thorough regulatory analysis is completed.

8.1.1 Primary Project Objectives

The primary project objectives for the NFRC Project are to (1) separate, to the extent practicable, clean water in the NFRC watershed from mine-impacted water that is either currently contaminated or predicted to be contaminated in the future by seepage and runoff from the eastern WRDs and (2) convey the contaminated water for treatment. The water would then be treated to the current effluent quality standards presented in Section 8.1.2 before it is discharged to either the CVD Pond or directly to the environment.

The clean water will be separated and routed around the contaminated water through the new NFRC Realigned Channel (which will extend about 1,300 m upstream of the Haul Road) to a culvert through the Haul Road to another culvert at the Mine Access Road, and then to the SFRC. From there, the water is conveyed by the RCD past the tailings area, to Rose Creek, below the CVD.

Contaminated water from the WRDs will be captured by a seepage collection trench, much of it located within the existing NFRC stream channel, and will flow through the NFRD to a Seepage Collection Pond located between the Haul Road and the Mine Access Road.

Ultimately, the primary project objective for the NFRC Realignment Project is to protect water quality both onsite and downstream from the FMC. The *Canadian Water Quality Guidelines for the Protection of Aquatic Life* (CCME, 2013) lists a concentration equal to 0.03 mg/L for zinc. As discussed in Section 5 of the DBR, as a result of emerging discharges from the WRDs, zinc concentrations greater than 1.0 mg/L and 0.4 mg/L have been measured at Monitoring Stations X2 and X14 respectively onsite and downstream from the site. The requirements for aquatic protection needs to be developed through a site specific water quality analysis and regulatory review.

8.1.2 Treatment Plant Effluent Quality Standards

Table 8-1 summarizes the current numeric treatment effluent quality standards listed in expired water Licence Number QZ03-059. The licence also specifies that no waste may contain floating solids, and that all waste discharges must pass a 100 percent, 96-hour LC₅₀ bioassay using Rainbow Trout.

Table 8-1. Current Effluent Quality Standards
Faro Mine Remediation Project

Analyte	Current Effluent Quality Standards
pH	≥6.5 pH units
Suspended Solids	≤15 mg/L
Colour	≤20 Pt-Co units
Ammonia (asN)	1.30 mg/L
Antimony	0.10 mg/L
Arsenic	0.05 mg/L

Table 8-1. Current Effluent Quality Standards
Faro Mine Remediation Project

Analyte	Current Effluent Quality Standards
Cadmium	0.02 mg/L
Copper	0.20 mg/L
Cyanide (as CN)	0.05 mg/L
Lead	0.20 mg/L
Mercury	0.005 mg/L
Molybdenum	0.50 mg/L
Nickel	0.50 mg/L
Selenium	0.05 mg/L
Silver	0.10 mg/L
Zinc	0.50 mg/L

8.2 North Fork of Rose Creek Realigned Channel

Design objectives for the NFRC Realigned Channel include the following:

- The NFRC Realigned Channel will be designed to convey clean surface water from the confluence of the FCD with NFRC to the SFRC. Surface water tributary flows along Segment 1 and Segment 2 will be captured within the NFRC Realigned Channel. The NFRC Realigned Channel will be raised along Segment 2 in elevation to provide separation from underlying contaminated groundwater; Segment 2 of the NFRC Realigned Channel is expected to be lined to prevent the loss of clean surface water to the underlying groundwater system. The NFRC Realigned Channel will be conveyed south via a culvert through the Haul Road and either via a culvert or under a bridge at the Mine Access Road. The NFRD is to remain.
- The recommended approach to separate clean and contaminated water within Segment 1 has been evaluated and will include a cutoff wall and a Seepage Collection Trench that will convey the seepage into the proposed Segment 2 Seepage Collection Trench and ultimately the seepage collection pond.
- The design will provide channel external stability, including slope stability, erosion control, and management of surface water runoff and sediment deposition.
- The design will provide channel internal stability related to seepage, piping, and infiltration, including evaluating the cost effectiveness of a detection and collection system for lining leakage.
- The design will provide for the conveyance of stream flow, including freeboard, and provide a documented process for estimating volumes and flow rates.
- Groundwater will either be collected or diverted, based on location. Interaction between groundwater and surface water will be evaluated to estimate contaminated water capture rates.
- Design must take into account snow, ice, and drifting snow accumulation and maintenance requirements, particularly during the winter and freshet conditions.
- Segment 2 of the NFRC Realigned Channel will be designed to convey surface water flow with negligible leakage through the lining system. The results of the hydrologic analysis presented in Appendix B shows that under average conditions, a leakage rate equal to 1 percent though the Segment 2 liner would result in more than 50,000 m³ of water accumulating within the Seepage

Collection Pond each winter, requiring enlargement of the planned reservoir capacity by over 16 percent, and conveyance for treatment, to obtain the same level of protection.

The Conceptual Design does not include design requirements for fish passage and habitat. Appendix B discusses design features that would be required for the NFRC Realigned Channel, the Haul Road and Mine Access Road to incorporate both fish passage and fish habitat.

8.3 North Fork of Rose Creek Permanent Seepage Collection Trench

Design objectives for the NFRC Permanent Seepage Collection Trench include the following:

- Contaminated mine-impacted water will be captured in the NFRC Permanent Seepage Collection Trench and conveyed by gravity to the NFRC Seepage Collection Pond. To the extent practical and cost effective, the NFRC Permanent Seepage Collection Trench will be located either within the footprint of the NFRC Temporary Diversion or the existing NFRC stream channel.
- As discussed in Section 8.1, the recommended approach for separation of clean water and impacted water in Segment 1 will be via a cutoff wall and Seepage Collection Trench.
- Sizing of the NFRC Permanent Seepage Collection Trench is based on runoff and groundwater analysis and considers tributary areas and potential future regrading and runoff from the WRDs; however, sizing does not consider impacts of coving the WRD.
- The NFRC Permanent Seepage Collection Trench will be a combination of the ditch and a trench filled with drain rock and a perforated pipeline. It is preferable to keep the seepage collection subsurface, but still provide a surface conveyance that can be used if portions of the subsurface trench clogs.
- The primary means of separating clean water and contaminated impacted water in Segment 2 will be to position the NFRC Realigned Channel at an elevation above the NFRC Permanent Seepage Collection Trench and to line the NFRC Realigned Channel.
- The primary means of separating clean water and contaminated mine-impacted water in Segment 3 and 4 will be to maintain a horizontal separation (more than 100 m) between the NFRC Realigned Channel and the NFRC Seepage Collection Pond.

8.4 North Fork of Rose Creek Temporary Diversion

Design objectives for the NFRC Temporary Diversion include the following:

- The NFRC Temporary Diversion of Segment 2 during construction of the NFRC Realigned Channel will be designed using return storm events to determine design size and slope of channel, risk, and the projected construction schedule. A process for handling runoff during extreme events during construction will be developed.
- The NFRC Temporary Diversion will be designed to minimize the volume of seepage from the diversion and to provide construction access to the NFRC Realigned Channel and dike footprint.
- The NFRC Temporary Diversion will be designed so that the temporarily diverted NFRC stream flow does not contact contaminated soils that may be present in the Zone II Outwash area.

8.5 North Fork of Rose Creek Seepage Collection Pond and Dam

Design objectives for the NFRC Seepage Collection Pond and NFRC Seepage Collection Dam include the following:

- The main objective of the NFRC Seepage Collection Pond is to provide storage and containment of contaminated surface water and groundwater entering the existing NFRC drainage or catchment area.
- The initial pond sizing is based on the assumption that mine-impacted water will be stored from October through April each year and that the stored water will be pumped from the pond to the IWTS or Faro Pit from May through September. The required storage capacity will be a function of several parameters, including: (1) treatment system capacity, (2) annual duration the treatment system is operated, (3) rate of pumping during the summer months (May through September), (4) estimate of contaminated runoff from the existing NFRC catchment area downstream of the start of the NFRC realigned Channel location, and (5) estimates of seepage from the FMC WRDs (including the S-Wells and Haul Road SIS) and from the NFRC Realigned Channel.
- The selected NFRC Seepage Collection Pond storage capacity will consider the requirements for treatment capacity, pumping duration and capacity, cold weather operations, geotechnical conditions at the proposed pond location, and seepage.
- Runoff, up to a defined flood event, from contaminated mine-impacted catchment area will be considered “impacted” and will need to be collected in the NFRC Seepage Collection Pond.
- The NFRC Seepage Collection Dam will be designed to reduce seepage of water from the pond to achieve no impact to SFRC or Rose Creek. For the Alternate 1 Pond location, the cutoff will be designed so that all seepage from the Seepage Collection Pond will infiltrate into the RCAA within the existing NFRC diversion downstream of the Pond. For the Alternate 2 Pond location, the pond will be double lined with a seepage detection system to limit seepage to meet the same criteria.
- A submerged toe drain will be designed to prevent impaired functions by precipitates from mine-impacted seepage water through submergence.
- Frost protection will be provided, as required.

The two NFRC Seepage Collection Pond alternative locations and designs are presented in the Preliminary Final DBR.

The objective for seepage control through the Alternative 1 dam foundation is to protect the dam from internal erosion (piping) and to reduce seepage to an acceptable level. Potential criteria to meet this objective includes the following:

- Found the dam directly onto competent bedrock or provide a positive seepage cutoff through the fractured bedrock or overburden material that will tie into the bedrock. Where bedrock is relatively shallow, a cutoff trench that extends from the dam core to the bedrock can be used to control seepage through the overburden. Where bedrock is deep, a seepage cutoff wall such as a soil-bentonite or cement-bentonite cutoff wall should be installed through the overburden material to control underseepage.
- If the bedrock is found to be permeable, a grout curtain will be installed in the rock to reduce seepage. A post-grouting residual permeability of less than 3 lugeons will be targeted.

Similar to the objective for seepage control through the foundation, the objectives for seepage control through the dam embankment is to protect the dam for internal erosion (piping) and reduce seepage to an acceptable level. Potential criteria to meet these objectives include the following:

- Use low-permeability material with a k_v of less than 1×10^{-6} cm/s in the dam core.
- Incorporate internal filter and drain systems in the dam section that will function to lower the phreatic surface in the downstream shell, reduce or eliminate any potential exit hydraulic gradients, and filter particles moving through defects or cracks in the core. It is recommended to use a chimney filter/drain consisting of concrete sand with a minimum width of 1.0 m, and a blanket filter/drain with a minimum thickness of 0.7 m.

The objective for the design of the dam is to construct a stable embankment that will provide long-term reliable performance in capturing and conveying contaminated mine-impacted water for treatment. Potential criteria to meet these objectives include the following:

- Design dam slopes that meet the minimum factors of safety for slope stability required by the CDA guidelines.
- Use shell material that has relatively high permeability and high shear strength that will result in low phreatic surface and minimum margins of safety for slope stability required by the CDA guidelines.
- Riprap will be placed on the upstream shell to protect the embankment material against surface erosion from wave action.

The objectives for O&M of the dam is to provide the most cost-effective, safe, and reliable processes and infrastructure for collection, conveyance, and treatment of contaminated mine-impacted water. In order to meet these objective, the following must be addressed:

- Develop and document definitions of normal, unusual (or flood), and emergency conditions.
- Design and install geotechnical instrumentation including piezometers, drain flow measurement devices, inclinometers, settlement monuments, and thermistors to monitor dam embankment performance.
- Define operating procedures for all expected conditions, including for warm and cold weather conditions and drawdown requirements.
- Provide reliable and highly functional instrumentation and control systems, pumps and pipes, intake and outlet structures that will operate under the design weather conditions, and provide reliable access to critical locations for maintenance during all weather conditions.
- Provide for maintenance of the outlet works intake structure and pond, and removal of precipitates and sediments that accumulate within the pond.

The objectives for the spillway of the dam will be as follows:

- Provide sufficient spill capacity to pass the inflow design flood.
- A design flood event will be selected based on the hazard classification of the dam. Our preliminary assessment is that the dam will have a hazard classification no lower than “High.” The CDA guidelines (2007) suggested that the inflow design flood for a high risk classification be one-third between the 1-in-1,000-year flood and the PMF. The risk classification will be evaluated after the pond capacity requirements are determined, and the consequences of dam failure can be evaluated based on potential storage and estimated water quality.
- Provide spillway channel design to minimize, accommodate, or control blockage from icing buildups.
- Minimize downstream impacts when the spillway passes flood flows.

8.6 South Fork of Rose Creek

Segment 4 of the NFRC Realigned Channel will flow into the SFRC at a location upstream from the existing confluence of the NFRC and SFRC. It may therefore be necessary to modify the SFRC channel downstream of the location where the realigned NFRC flows into the creek. This is anticipated to include armoring portions of the existing bank just down stream from the confluence.

The objectives of the work related to the SFRC include the following:

- Provide adequate capacity to convey the combined NFRC and SFRC flows for the design flood event.
- If necessary, design and construct berms or other containment structures within the SFRC downstream of Segment 4, to protect the Mine Access Road and other existing features.
- Evaluate requirements for isolating the existing NFRC from the connection with the SFRC. The existing diversion will remain in place to convey runoff from the drainage downstream of the proposed dam and will also collect impacted seepage from the NFRC Seepage Collection Pond. For NFRC Seepage Collection Pond Alternative 1 location, the amount of seepage will depend on the effectiveness of the dam structure, the foundation conditions at the dam, and the mitigations implemented to reduce seepage through the foundation. For the NFRC Seepage Collection Pond Alternative 2 location seepage will be controlled by lining the pond.

8.7 Rose Creek Diversion

The design objective for the RCD is to assess the seismic stability of the diversion in the area of the Secondary Dam and make recommendations regarding requirements for stabilizing the dike, if necessary. This will be completed under a separate deliverable. A secondary objective is to evaluate seepage conditions from the Secondary Dam to the RCD and make recommendations regarding mitigation measures. As discussed in Appendix B, additional monitoring data is required to evaluate seepage from the tailings area into the RCD under different infiltration conditions, particularly loading during snow melt and freshet.

8.8 Access Roads

New access roads will be constructed to allow all-weather access adjacent to the NFRC Realigned Channel, along the Segment 1 cutoff wall, upgrading the existing roadway from the northwest WRDs down to the FCD, and to the crest of the NFRC Seepage Collection Dam or embankment, outlet works, NFRC Seepage Collection Pump Station, and pond area. The roads will be surfaced similar to the Haul Road at the NFRD. In addition, improvements to the existing access road from the Zone II Pit and Zone II Outwash areas and to the NFRC confluence with the FCD will be conducted to enable all-weather access and may include new culverts.

Multiple culvert crossings located on the Mine Access Road are under the overall management of YG Public Works, but are monitored and maintained by site personnel because of their potential to impact water quality in the SFRC.

All FMC roadways and associated infrastructure will be maintained to a standard that would prevent, counteract, or mitigate adverse effects to persons, property, or the environment. The following routine maintenance is assumed for the access roads associated with the NFRC Project:

- Maintenance of road surfaces, including snow removal
- Maintenance of roadside safety berms as required by the Yukon Workers' Compensation Health and Safety Board

- Maintenance, including clearing of blockages and debris, of road-side ditches and culverts, to maintain conveyance capacity and minimize the risk of road wash-out or sediment release to the environment
- Culvert steaming during winter, as required to prevent runoff from flowing over top of roadways

8.9 Waste Rock Dumps

Other than periodic physical inspections, as outlined in the *Care and Maintenance Environmental Monitoring, Surveillance and Reporting Plan, Faro Mine Interim Works* (CH2M, 2014j), there are no planned maintenance or regrading activities specifically associated with the waste dumps at the FMC planned for completion before constructing the NFRC Project. Routine monitoring of seepage and groundwater associated with waste dumps and WRDs will be carried out. It is expected that the progression of waste rock chemistry will be assessed outside the scope of this project, as it relates to potential impacts to the receiving environment and need for intervention.

The design of the NFRC Project must take into account potential regrading options for the FMC WRDs, (especially the Northeast WRD, located above Segment 1, and the Intermediate WRD, located above Segment 2), the Haul Road, and the NFRC area upstream of the NFRC Seepage Collection Pond. The design will include minimization of runoff from the WRDs to the NFRC to the extent practical. At the time of Preliminary Final DBR the WRD cover and regrading concepts have not been advanced. The cutoff wall in Segment 1 presented in this Preliminary Final DBR is located where bedrock is relatively shallow. At this location flattening of the WRD slopes would need to be accomplished by cutting back into the WRD. To accommodate flatter slopes without cutting back into the WRDs would require the Segment 1 cutoff wall to be moved closer to the NFRC and require a much deeper cutoff wall. As the NFRC Project design advances compatibility with WRDs regrading will need to be further evaluated.

8.10 Borrow Areas

Borrow material will be required for elements of the NFRC Project. Some of the various material types required for specific uses include the following:

- Low permeability (till) for core materials for the NFRC Seepage Collection Dam covers and potentially as a seepage lining for the NFRC Realigned Channel
- Granular materials (sand and gravel) for concrete aggregate, drainage, backfill, and grading and fill, and zones within the NFRC Seepage Collection Dam
- Coarse riprap (competent cobbles and boulders) for sections within the NFRC Realigned Channel and shell of the NFRC Seepage Collection Dam, both within the channel and exterior to the channel to protect the channel dike slope

As described in Section 3 and Section 5, site explorations have been conducted to identify, delineate, and quantify potential borrow material sources. Additional explorations were conducted in 2015 and, based on the results of these explorations, additional explorations may be required in 2016 to determine the most cost effective sources of materials. For instance, the current data indicates that the Granitic Outcrop, located approximately 8.3 km from the NFRC, has the highest quality riprap material at the site and is the only onsite location suitable for producing acceptable concrete aggregate (based on results of laboratory testing of alkali reactivity and durability). Exploration work will also help to determine geochemical and geotechnical characteristics of source materials at each potential deposit. Borrow materials must be relatively nonreactive, durable, and free of potential leachable contaminants.

Targeted areas will be evaluated for their potential to be developed into economically feasible borrow sources. Many potential borrow locations are located in undisturbed areas. Plans to rehabilitate the

selected borrow areas will be completed as part of the Preliminary Design, after selection of the design and borrow materials is complete. Reclamation planning of borrow sources will include a revegetation plan, which requires input from baseline data collection and information on the volumes of borrow material to be removed, and the fertility and salinity parameters of any available overburden materials.

Design Criteria

9.1 Introduction

This section provides a summary of the applicable preliminary design criteria for the overall design concept and the key design components of the NFRC Project.

9.2 Site-wide Water Balance and Water Quality

The *Description of Water Modelling & Results, Faro Mine Remediation Project* report (CH2M, 2014h) provides a detailed description of the site-wide water balance model; key monitoring stations for monitoring water quality and volumes of flow at critical site locations within NFRC, SFRC, and Rose Creek; and discharges from the CVD and the IWTS. The report presents the methodology and results for the near-term (January 2014 through December 2023) prediction of water quality discharged from the FMC.

Results were presented in terms of percentiles from a range of stochastic simulations, and show the likelihood of having concentrations exceeding guideline values at the following key locations (presented in Figure 9-1):

- NFRC upstream from NFRD at NF1
- NFRC upstream from mine access road at X2
- Rose Creek below confluence of South and NFRC at X3A
- Rose Creek downstream from mine site discharges at X14
- Rose Creek upstream from confluence with Anvil Creek at R4
- Anvil Creek downstream from confluence with Rose Creek at R5
- Anvil Creek near confluence with Pelly River at A1
- Pelly River downstream from Anvil Creek at P4

The model predicts water quality at key locations in the aquatic receiving environment as a result of the contaminant loads from the FMC, specifically seepage from the WRDs and the RCTA, and the discharge of treated water from the IWTS. The near-term water quality predictions presented in the report assume that the recent concentration trends will remain the same for the next 10 years; therefore, whenever a trend in water quality was verified, it was extrapolated for 10 years.

As discussed in Section 5 of the DBR, surface water quality data for the NFRC and Rose Creek demonstrate an increase in zinc concentration in late 2013, originating in the area of the NFRD. The site-wide water quality model has not been updated to include the changes observed in water quality; however updates to the site wide water management tool version of the model provides options for limited water quality evaluation in the receiving environment immediately downstream of the Seepage Collection Pond. The water balance portion of the model has been updated to include tools for evaluating performance of the proposed Seepage Collection Pond and its integration with existing site-wide water management operations. Updates include incorporating (1) Seepage Pond stage-storage relationship, (2) surface water runoff data, and 3) pipeline capacity. A description of the changes to the water balance model and the model results are presented in DBR Section 13.6. Surface Water Management.

Hydrological and hydraulics analyses were completed to support design of the NFRC Realigned Channel, as well as for the proposed NFRC Seepage Collection Pond and the NFRC Permanent Seepage Collection Trench as detailed in Appendix B. For design of the NFRC Realigned Channel, peak instantaneous flow

rates for various return period events up to and including the PMF were developed. For the NFRC Seepage Collection Pond design, a longer duration runoff volume analysis was completed to estimate storage requirements before conveyance for treatment.

As discussed in Appendix B, a flood frequency analysis prepared by CH2M was used as the basis for developing peak instantaneous flow estimates. These flow rates cover a range of return periods from a 1-in-2-year event to the 1-in-1000-year event. Estimates of the Probable Maximum Flood (PMF) event were developed based on the methodology developed previously by Water Management Consultants (2006). Peak instantaneous flow estimates were generated for key points along the NFRC Realigned Channel and Seepage Collection System based on their respective catchment areas. Using peak instantaneous flow measurements and design hydrograph distributions, hydrographs were developed for inclusion in hydraulic modelling analyses.

Previous analyses related to runoff volume over longer durations were reviewed and serve as the basis for developing estimates of runoff volume tributary to the proposed NFRC Seepage Collection Pond, as discussed in Appendix B. Volume estimates were used to quantify required retention volume in the proposed Seepage Collection Pond alternatives based on a range of scenarios in which pumping rates, treatment durations, return period events, and runoff durations are varied.

The following subsections summarize the design criteria for the various surface water management components of the NFRC Project.

9.2.1 North Fork Rose Creek Realigned Channel Design

The NFRC Realigned Channel will be designed based on the following criteria:

- Design Storm Event: PMF with no freeboard or 1-in-500-year with 0.5 m freeboard, whichever is greater
- Low-flow channel will be incorporated into the overall NFRC Realigned Channel design to accommodate a 1-in-10-year flow
- Minimum Channel Slope: 0.5 percent
- Maximum Channel Slope: 4.5 percent (slope optimized initially to reduce flow velocity in consideration of fish passage)
- Maximum Channel Side Slopes: 1V: 3H for interior-lined channel, with safety berms
- Maximum Outside slopes: 1V:1 ½H, with safety berms
- Separate mine-impacted water in Segment 1 and Segment 2, minimize losses from the NFRC Realigned Channel in Segment 2
- Minimum vertical separation between invert of NFRC Realigned Channel and existing creek: 1 m
- Minimum Static Slope Factor of Safety = 1.5
- Minimum Earthquake slope Factor of Safety = 1.1
- Operation and Maintenance: Road access along channel dike
- Maintenance road width: 10 m
- Fish Habitat or Passage: base case developed based on hydraulics; additional consideration to incorporate fish habitat/passage included for consideration
- Avoidance of liquefaction of alluvial sediments in the embankment foundations during the design earthquake

One of the fundamental design criteria for the evaluation of the NFRC Realigned Channel design was the recommendation to use the design flow at the 1-in-500-year return period with sufficient freeboard to accommodate the PMF flow. Flow criteria was discussed through independent reviews and suggested in the design alternative reviews for each of the stream diversions and upgrades recommended at the FMC. Through the independent review of the alternatives, it was decided that the 1-in-500-year flow was acceptable criteria for a number of channel alterations. Designing for the PMF event was appropriate for the NFRC because of the potential impacts of channel breach and the requirement for the channel to be stable for larger event flows including the PMF. The 1-in-500-year flow criteria and the accommodation of the PMF through the addition of freeboard was subsequently adopted for the DBR.

It is recommended that the 1-in-500-year return event design criteria and the PMF event design criteria be revisited in the next stage of design to determine if a lower-return period would sufficiently meet acceptable risk criteria. The risk criteria are not yet assigned to the design and would require development. The risks of debris blockage, slope failure and water-quality impairment should, amongst other criteria, be included in the list.

Regarding the low-flow channel, it is recommended that this design criteria be revisited during detailed design to determine the optimum low-flow channel design for conveying flow based on required low-flow characteristics. The low-flow characteristics that provide additional guidance should be further established to support the determination. This includes consideration of typical winter flows and an allowance for ice cover.

The design life of the NFRC Realigned Channel has not been specifically defined in this DBR; however, the design is defined by a number of criteria such as lining, erosion protection, and culvert crossings. It is recommended that the required design life of the NFRC Realigned Channel be revisited at the detailed design stage based on critical components and also based on an adaptive management approach.

9.2.2 Haul Road Crossing

The NFRC Realigned Channel, Haul Road crossing structure will be designed based on the following criteria:

- Design Storm Event: PMF
- Minimum Slope: 0.5 percent
- Design Life: 100 years
- Fish Habitat or Passage: base case developed based on hydraulics; additional consideration to incorporate fish habitat/passage included for consideration

9.2.3 Mine Access Road Crossing

A preliminary hydraulic analysis was completed to determine the level of service provided by existing Mine Access Road crossing culverts at the FMC. Details of this analysis are included in Appendix B. This was based on estimates of various return period flows using the flood frequency analysis developed by CH2M as well as catchment area and culvert configuration (that is, diameter, material, slope, and cover). This preliminary exploration concluded that existing Mine Access Road culverts have a 50-year or less design life. The NFRC Realigned Channel culvert crossing the Mine Access Road will be designed based on the following criteria:

- Design Storm Event: PMF
- Minimum Slope: 0.5 percent
- Maximum Slope: (slope optimized initially to reduce flow velocity in consideration of fish passage)
- Design Life: 50 years
- Fish Habitat or Passage: base case developed based on hydraulics; additional consideration to incorporate fish habitat/passage included for consideration

It is recommended that the design criteria for the Mine Access Road crossing of PMF flow be revisited at the next stage of design to determine if a lesser-return period flow could satisfy a set of risk-based criteria. The risk components have not been developed at this stage of design. The design criteria should also consider level of service provided by other Mine Access Road crossings outside of the NFRC catchment at the FMC.

9.2.4 North Fork Rose Creek Temporary Diversion

During construction of the new NFRC Realigned Channel, the existing NFRC will be diverted into a Temporary Diversion. The Temporary Diversion will be designed based on the following criteria:

- Design Storm Event: 1-in-10-year without freeboard
- Minimum Slope: 0.5 percent
- Maximum Slope: 6 percent
- Maximum Channel Side Slopes: 1V:3H for lined channel, in locations requiring lining; must be considered in Zone II outwash area and other areas where potential for contaminated soils exist
- Erosion protection: as required based on channel velocities for design storm event
- Design Life: during construction only, although the Temporary Diversion will be left in place and become the permanent seepage collection within Segment 2; potential long-term configuration (trench-filled with gravel and cobbles) or left open needs to be evaluated
- Minimum setback from toe of NFRC Realigned Channel: 2 m
- Fish Passage: fish passage considerations not included in temporary diversion

9.2.5 Estimated Design Flows

Table 9-1 summarizes the preliminary design flows estimates for the NFRC Project components. Details on surface water hydrology can be found in Appendix B.

Table 9-1. Estimated Design Flows
Faro Mine Remediation Project

Flow Location	1-in-500-year Flow (m ³ /sec)	PMF (m ³ /sec)
NFRC (Segment 1 and 2)	124	385
NFRC (Haul Road Crossing)	124	385
NFRC (Segment 3)	126	395
NFRC (Mine Access Road Crossing)	126	395
NFRC (Segment 4)	126	395

9.2.6 Erosion and Scour Protection

Erosion protection will be provided, as necessary, to mitigate against scour and/or erosion issues that can impede fish passage and create scour holes or slope failure. As noted in the Design Guidelines for Bridge Size Culverts (Government of Alberta, 2011), design considerations include the following:

- Design hydrotechnical parameters
- Velocities
- Channel material and susceptibility to scour and erosion
- Embankment slopes

- Fish passage

As detailed in Appendix B, two methods were used to estimate the required rock size, D_{50} ; a quick simplified velocity based equation for non-critical and non-uniform conditions and slopes less than 5 percent (Isbash, 1939; McLaughlin Water Engineers, 1986). Based on these analyses, the recommended class and thickness of rock riprap is presented in Table 9-2.

Table 9-2. Required Class and Thickness of Rock Riprap

Faro Mine Remediation Project

Segment	Average 1-in-500-year Velocity (m/s)	Maximum Total Sheer for 1-in-500-year (N/m^2)	D_{50} (mm)
2	2.6	89	300
3	3.6	322	500
4	3.7	365	500

Notes:

N/m^2 = Newtons per square metre

Recommended D_{50} rock sizes for each segment are listed in Table 9-2. The recommended rock thickness is 2 times D_{50} as per Alberta Transportation guidelines (Government of Alberta, 2011).

It is noted that riprap sizing design is based on the 1-in-500-year event and not for the PMF. Therefore, in the event of a PMF, erosion and scour may occur. This consequence should be revisited during preliminary design and with consideration of assumed design criteria for other key conveyance elements associated with the NFRC Realigned Channel.

9.3 Groundwater Collection

Mine impacted contaminated groundwater will be collected in the NFRC Permanent Seepage Collection Trench. The ditch will be sized based on catchment area and the design return event planned for capture. Determination of the ditch configuration (covered, gravel-filled trench or open ditch) will be made during evaluation of alternative designs in the DBR.

Contaminated groundwater will be separated from the clean NFRC Realigned Channel by the elevation difference (minimum of 1 m) between the new channel and the ditch and by lining the new channel in Segment 2. Mine-impacted water will be collected at the NFRC Seepage Collection Pond and conveyed to the IWTS for treatment or Faro Pit for storage before treatment.

9.4 Water Treatment and Process Engineering

9.4.1 Background

Water collected in the Seepage Collection Pond will require treatment. The volume collected each year will vary in response to hydrologic conditions. The chemistry of the collected water will vary considerably over shorter time spans in response to storm events, as well as over long-term time spans in response to WRD chemistry changes and flow rates of seepage from the WRDs.

Section 5 describes the existing IWTS, which uses lime treatment to neutralize acidity and to precipitate dissolved metals as hydroxides. The IWTS has a capacity of 33 million litres per day (ML/d) (6,000 USgpm). In addition to lime, the IWTS uses polymer and microsand to separate the precipitated metal hydroxides from the water stream using sand-ballasted clarification. Effluent from the IWTS is currently either discharged to the CVD Pond, or discharged to the NWID for discharge at X5. Sludge from

the IWTS is currently piped to the tailings area sludge ponds for dewatering and subsequent periodic excavation and disposal on the nearby tailings.

The IWTS is expected to be operational for at least the next 10 years before a permanent WTP is constructed. Currently, the new NFRC Seepage Collection Pond is expected to start operation in October 2019, in time to collect and store water over that winter. By this time, it is expected that Faro Pit will be lowered back to its typical operational level, which will reduce the annual volume and flow rate pumped to the IWTS, freeing up capacity for treatment of water collected and conveyed to the NFRC Seepage Collection Pond.

Section 13 describes GoldSim modelling work performed to help assess how much pond storage volume is required to store water generated from various hydrological events over the contributing watershed, as well as from other sources such as contaminated seepage from the S-Wells area, NFRD SIS, and groundwater. The GoldSim evaluation also considers the size of the NFRC Seepage Collection Pond pumping system, other treatment demands within the FMC, treatment capacity and annual duration, and the potential for interim storage in Faro Pit.

Section 13 also describes the geochemical assessment performed to help evaluate the quality of water collected in the NFRC Seepage Collection Pond. This assessment includes the temporal change in water quality over time as seepage from the WRDs matures both in terms of flow and strength.

9.4.2 Treatment Process Questions to Answer

Treatment process evaluations performed as part of the NFRC Project focused on answering the following questions:

1. How much IWTS treatment flow capacity is required assuming that the NFRC Seepage Collection Pond water will be treated directly from the pond without interim storage in Faro Pit, or, with interim storage in Faro Pit?
2. What is the expected duration of the IWTS annual operational season with the addition of the NFRC Seepage Collection Pond water?
3. Does the IWTS have sufficient process capacity to treat the NFRC Seepage Collection Pond water in conjunction with other site waters?
4. Will IWTS effluent be of sufficient quality to meet discharge requirements for placement in CVP or directly into the NWID when treating the NFRC Seepage Collection Pond water?
5. How much additional sludge will be generated when treating the NFRC Seepage Collection Pond water?
6. What is the potential increase in annual treatment cost associated with treating the NFRC Seepage Collection Pond water?

Section 13 describes the modelling work performed to assess these questions.

The major assumptions affecting treatment capacity for each alternative are provided herein.

9.4.2.1 Alternative 1 and 2

- Reservoir Pumping Capacity: 126 L/s (2,000 USgpm)
- Conveyance System: Capable of splitting flow (any proportion) between IWTS and Faro Pit IWTS
- Functional Treatment Capacity (accounts for downtime): 347 L/s (5,500 USgpm)
- IWTS Operating Season: Either April 15 to October 15, May 1 to September 30, or year-round

9.4.2.2 Questions 1 and 3: Required IWTS Treatment Flow Capacity

For both alternatives it was found that there is not enough capacity at the IWTS in the spring to directly receive the full volume and the peak volumes pumped from the reservoirs and the balance has to be discharged to Faro Pit. To maintain the reservoir elevation through the summer requires that the discharge continues to be split between both locations. This will require operational coordination amongst all flow sources requiring treatment.

9.4.2.3 Question 2: Expected Duration of the Interim Water Treatment System Annual Operational Season

For both alternatives, prior to the CVD SIS coming on line, it was found that an IWTS operational season of between April 15 and October 15 is preferred over that from May 1 to September 30. However when the CVD SIS is brought online (assumed to occur in 2025) and operates year-round at 176 L/s (2,800 US gpm), the IWTS has insufficient capacity if operated only seasonally and results in Faro Pit filling and overtopping. However this is prevented if the IWTS is operated year-round, and doing so allows Faro Pit water level to be readily maintained at target elevations.

9.4.2.4 Question 4: Interim Water Treatment System Effluent Quality

Section 13 describes geochemical assessments performed to assess the potential water quality collected resulting from Alternatives 1 and 2. The predicted water quality is high in acidity, sulfate, and dissolved metals in comparison to Faro Pit water. To date, other than for a short 1-day test conducted at the end of the 2015 treatment season, the IWTS has only treated water from Faro Pit. Additional operational experience treating a stronger water consisting of a blend of water from Faro Pit, the IP, and the ETA will be gained over the next few years and this information will help determine the ability of the IWTS to also treat a blend containing seepage collection pond water and meet discharge requirements.

9.4.2.5 Question 5: Additional Sludge Generated

The volume of additional sludge generated will vary annually depending on how much water is treated and its strength. Section 13 describes geochemical assessments performed that indicate pond water quality will worsen with time resulting in increasing sludge generation. As described in Section 13 the modelled concentrations and precipitation masses should be viewed as rough estimates for the purposes of planning, since there are many variables in the path from WRD seepage to the pond that are not well known. Both the values and timing of model-predicted concentrations are approximate, but the trend towards a more acidic condition, with elevated trace elements, is very likely given the recently observed trends in WRD seepage and its predicted evolution. While the overall trend is towards increased strength, the timing and slope of change are highly uncertain. Thus the following discussion of estimated sludge production, and its timing, is also highly uncertain.

An estimate of the range of additional annual sludge generation was made for Alternative 1 using the following values which were derived from the flow and geochemistry modelling described above and in Section 13. The Alternative 2 sludge volumes are expected to be relatively similar.

Table 9-3. Solids Formed Values Used to Estimate Sludge Production

Faro Mine Remediation Project

	Year	50th Percentile	90th Percentile	Maximum
Annual Volume Treated (m ³)	Each	615,300	725,000	884,000
Solids Formed in Year 2020 (mg/L dry weight) ^a	2020	2,600	2,600	2,600
Solids Formed in Year 2025 (mg/L dry weight) ^a	2025	6,100	6,100	6,100
Solids Formed in Year 2050 (mg/L dry weight) ^a	2050	6,800	6,800	6,800

Table 9-3. Solids Formed Values Used to Estimate Sludge Production*Faro Mine Remediation Project*

	Year	50th Percentile	90th Percentile	Maximum
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Note:

- a. The same solids formed values were used for each annual volume treated. This is a simplifying assumption as the solids formed will vary.

The estimated sludge production rates based on the Table 9-3 tabulated values are shown in Table 9-4. Volumes are shown for final percent solids by weight, after dewatering, of 10 and 25 wt% solids. A value of 10 wt% solids is likely more applicable to sludge produced by the IWTS after final dewatering in tailings area sludge ponds, and a value of 25 wt% solids is likely more applicable to sludge produced by a permanent high-density sludge treatment plant if deposited in the bottom of Faro Pit lake.

Table 9-4. Estimated Annual Sludge Production Rates*Faro Mine Remediation Project*

	Year	50th Percentile	90th Percentile	Maximum
Annual Volume Treated (m ³)	Each	615,300	725,000	884,000
Year 2020 Sludge Volume at 10 wt% Solids (m ³)	2020	15,000	17,700	21,600
Year 2020 Sludge Volume at 25 wt% Solids (m ³)	2020	5,300	6,200	7,600
Year 2025 Sludge Volume at 10 wt% Solids (m ³)	2025	35,000	41,000	50,300
Year 2025 Sludge Volume at 25 wt% Solids (m ³)	2025	12,500	14,700	18,000
Year 2050 Sludge Volume at 10 wt% Solids (m ³)	2050	39,000	46,000	56,000
Year 2050 Sludge Volume at 25 wt% Solids (m ³)	2050	14,000	16,500	20,100

9.4.2.6 Question 5: Potential Increase in Annual Treatment Cost

The potential increase in annual treatment cost will vary due to the volume and strength of water treated annually. Labor cost is not expected to significantly increase assuming the same size treatment plant is used. The cost for power, maintenance, and analytical testing is also expected to not significantly increase unless the treatment season is extended. If so, these costs will increase somewhat proportionally to the increase in treatment season. The largest increase in annual treatment cost is expected to be in chemicals with lime being the most pronounced. An estimate of the range of additional annual lime consumption was made for Alternative 1 using the following values which were derived from the flow and geochemistry modelling described in Section 13. The Alternative 2 lime consumption amounts are expected to be relatively similar, and the same uncertainties discussed above for sludge production apply to lime demand.

Table 9-5. Lime Demand Values Used to Estimate Additional Lime Consumption*Faro Mine Remediation Project*

	Year	50th Percentile	90th Percentile	Maximum
Annual Volume Treated (m ³)	Each	615,300	725,000	884,000
Lime Demand in Year 2020 (mg/L dry weight Ca(OH) ₂) ¹	2020	6,700	6,700	6,700
Lime Demand in Year 2020 (mg/L dry weight CaO) ²	2020	6,800	6,800	6,800

Table 9-5. Lime Demand Values Used to Estimate Additional Lime Consumption
Faro Mine Remediation Project

	Year	50th Percentile	90th Percentile	Maximum
Lime Demand in Year 2025 (mg/L dry weight Ca(OH)_2) ¹	2025	7,200	7,200	7,200
Lime Demand in Year 2025 (mg/L dry weight CaO) ²	2025	7,300	7,300	7,300
Lime Demand in Year 2050 (mg/L dry weight Ca(OH)_2) ¹	2050	7,300	7,300	7,300
Lime Demand in Year 2050 (mg/L dry weight CaO) ²	2050	7,400	7,400	7,400

¹ Based on 100 percent available Ca(OH)_2

² Based on 75 percent available CaO

The estimated lime consumption rates based on the Table 9-5 tabulated values are shown on Table 9-6. Consumption rates are shown in tonnes per year of CaO and assume a delivered price of \$650 CAD/tonne.

Table 9-6. Estimated Annual Lime Consumption and Cost
Faro Mine Remediation Project

	Year	50th Percentile	90th Percentile	Maximum
Annual Volume Treated (m ³)	Each	615,300	725,000	884,000
Year 2020 Lime Demand (tonnes CaO)	2020	4,600	5,400	6,600
Year 2020 Lime Cost (\$/yr)	2020	\$3.0 million	\$3.5 million	\$4.3 million
Year 2025 Lime Demand (tonnes CaO)	2025	4,900	5,800	7,100
Year 2020 Lime Cost (\$/yr)	2025	\$3.2 million	\$3.8 million	\$4.6 million
Year 2050 Lime Demand (tonnes CaO)	2050	5,000	5,900	7,200
Year 2020 Lime Cost (\$/yr)	2050	\$3.3 million	\$3.8 million	\$4.7 million

In comparison to previous lime consumption the estimated values are significantly higher. The average lime use between 2009 and 2012 was about 570 tons per year of CaO.

9.4.3 Electrical

The NFRC Project requires the following electrical systems:

- Power for Seepage Collection Pump Station
- Temporary electrical re-routing of existing 4.16-kV overhead distribution line during construction of the NFRC Haul Road crossing.
- Power for the Seepage Collection Pond Valve Station
- Power for the proposed future radio repeater station at the Faro Pit.

9.4.4 Primary System

The existing 4.16-kV overhead distribution line is available at the nearby NFRD SIS, but because of the size of the pump station load it is not possible to supply the pump station from this location. The load of the proposed pump station is 600 kVA and the resulting voltage drop will exceed the allowable and practical levels. The total length of that line will be approximately 3,500 m once extended to the pump station location and will require increase in conductor size for almost the entire length to be able to handle the addition of the pump station.

Two available options were identified to supply power to either of the proposed pump station locations. These are as follows:

- **Option 1:** Connect a new spur line to the existing line feeding the main FMC, at the existing ETA spur. Construct a new line approximately 2,400 m in length to either location of the proposed pump station.
- **Option 2:** Install a new 69-kV spur line at the closest point along the existing 69-kV line that powers the Grum site. Terminate this spur line in a new 69-kV step-down substation at either location of the proposed pump station. The length of this new 69-kV spur line would be approximately 800 m to 1,200 m, depending on the pump station location. The step-down substation would make use of a special pad-mount 69-kV, 600V transformer that was first developed and used by Manitoba Hydro.

In comparing the two options, it should be considered that the new line construction is required and the minimum length will be 800 m to 1,200 m, depending on the location of the pump station.

For the purpose of this report both options are shown on the drawings and priced in the cost estimate.

9.4.5 Secondary System

Secondary service at 600 V will be run to the NFRC Seepage Collection Pump Station. The motor control centre, the automatic transfer switch, various building services panelboards, and the programmable logic controller will all be housed in a dedicated section of the pump room. Building services loads such as heating, ventilation, lighting, and other miscellaneous loads will be supplied at 208Y/120 V.

Power supply for the new Seepage Collection Pond valve chamber will be taken from the existing IWTS electrical room at 600 V, and stepped down to 120/208V in the valve chamber.

Power supply for the proposed radio repeater outside the Faro Pit will be taken from the existing 500 kW (Cat) rental generator panelboard. Since this is a rental generator there is a real chance that the connection point for the proposed power supply may be removed. If this generator is removed the existing shore power transformer feeding the generator can still be used for this power supply, and a new pole-mounted panelboard will be required to continue to feed the radio repeater.

9.4.6 Temporary Overhead Electrical Routing

YG worked with a separate consultant to evaluate the feasibility of temporarily rerouting the existing 69-kV-overhead distribution line during construction of the NFRC Haul Road crossing. The excavation limits for the NFRC Haul Road crossing will impact approximately four overhead power poles and approximately 230 m of existing overhead electrical line. The analysis indicated that there are two viable options to temporarily relocate the existing line to maintain electrical service at the Vangorda/Grum Area during the NFRC Haul Road crossing construction, which is anticipated to take two construction seasons to complete. The options are to detour the line around the cut, or to span across the cut with special anchor structures. The two options are equally viable and the estimated costs are also the same. Discussions with electrical maintenance personnel onsite indicated a preference for the option to span across the proposed cut with special anchor structures, which is the recommended option.

9.4.7 Standby Power System

Presently, there are two rental power units onsite. One unit (rated 1600 kW) provides backup power to the IWTS and is able to provide backup power through existing infrastructure to the new pump facility (a maximum of 200 kW). However, this generator is a rental unit and it is not clear how long it will be maintained onsite; for this reason, the new pump station will be designed with a dedicated standby generator of sufficient capacity to operate the pump station in all conditions.

The generator will be diesel fueled and skid mounted in a walk-in style arctic enclosure. The generator capacity will be 600 kW with oversized (800 kW) alternator, capable of operating all three pumps simultaneously, with a fuel capacity of 24 hours. The fuel tank will be sub-base mounted, double walled with leak detection and will not require spill containment. Larger tanks are available with capacity up to 48 hours, but since the site is manned 24 hours and bulk fuel is available on-site.

Note that the generator capacity is intended to operate three pumps with VFDs, which requires the use of an oversized alternator to accommodate the harmonic content from the VFDs. The VFDs will be equipped with bypass starters, allowing each pump to be started at full voltage in case the VFD fails. The generator will only be able to start one of the pumps at full voltage if one VFD fails. If it is desired that all three pumps can be started at full voltage then a much larger generator is required.

9.4.8 Telephone System

A telephone system will not be provided at the NFRC Seepage Collection Pump Station.

9.4.9 Electronic Security System

An electronic security system will not be provided.

9.4.10 Fire Alarm Systems

An automatic fire alarm system will not be provided.

9.4.11 Lightning Protection System

The frequency of lightning strikes in this area of the country does not warrant a lightning protection system nor is lightning protection required by the code; therefore, a lightning protection system for the building will not be provided.

Lightning arrestors will be provided on the electrical system to protect it from lightning and other high-voltage switching surges, as appropriate.

9.4.12 Transient Surge Protection

Transient voltage surge suppression will be provided in the main switchboard, and at other points in the distribution system where required, such as at a change of voltage.

9.4.13 Area Classification

The area classifications will be as follows:

- Hazardous Areas: None
- Highly Corrosive Areas: None
- Nonhazardous and Wet: Outdoor areas
- Nonhazardous and Dry: Main electrical room, pump room

9.4.14 Voltage Selection

- The following standard system voltages will be used: 5 kV, grounded wye, 3-phase, 3-wire
- 600 V, grounded wye, 3-phase, 3-wire
- 208Y/120 V grounded wye, 3-phase, 4-wire

9.4.15 Equipment Voltages

Table 9-7 lists the equipment voltages that will be used.

Table 9-7. Equipment Voltages*Faro Mine Remediation Project*

Use	Voltage
LED Lighting	120 V
Convenience Outlets	120 V
Motor Control	120 V
Motors (less than 0.5 hp)	120 V, 1 phase
Motors (from 0.5 hp to 10 hp)	208 V, 3 phase
Motors (0.10 hp and larger)	600 V, 3-phase

Notes:

hp = horsepower

LED = light-emitting diode

9.4.16 Voltage Drop

Steady-state voltage drop calculations will be performed for long branch circuits and feeders. A 5 percent total voltage drop will not be exceeded from the transformer secondary to the point of utilization (including feeder and branch circuits).

9.4.17 Demand Factors

Table 9-8 lists the demand factors that will be used to size power switchboards, panelboards, and transformers. Connected load will be used for circuit and equipment sizing, in accordance with Canadian Electrical Code (CEC) requirements.

Table 9-8. Demand Factors*Faro Mine Remediation Project*

Service	Demand Factor
Lighting	1 x connected load
Emergency Lighting	1 x connected load
Ventilation Equipment	1 x connected load
Pumps (duty/standby)	0.50 x connected load
Convenience Receptacles	180 volt-ampere (each duplex strap)
Process Loads	1 x full load amperes of non-standby loads plus 25 percent of largest motor

9.4.18 Metering

A digital power meter will be provided at the main electrical switchboard.

9.4.19 Branch Circuits

At a minimum, #12 American Wire Gauge (AWG) copper conductors will be used for lighting and receptacle branch circuits.

Lighting and receptacle branch circuits will not be shared.

A maximum of five duplex receptacles will be installed on a branch circuit.

9.4.20 Panelboards

Branch circuits or feeders on the electrical drawings will identify the panelboard and devices protecting the individual circuit or feeder. Each panelboard will be equipped with 10 **percent** spare breakers.

Panelboard schedules will be prepared, providing the following information:

- Circuit identifications
- Protective device trip ratings
- Number of poles
- Load in volt-amperes by phase
- Rating of main lugs or main circuit breaker
- Short-circuit interrupting rating of the panelboard

9.4.21 Motor Control

Elementary (ladder-type) control diagrams will be prepared at the contract documents design stage (90% Detailed Design).

9.4.22 Equipment Identification

Process and instrumentation diagram tag numbers will be used for motors, instrumentation and control (I&C) devices, and other process equipment shown on electrical drawings.

9.4.23 Distribution System Equipment

The following distribution equipment criteria has been established:

- 600 V distribution: Starters for motors 25 hp (18.65 kW) and larger will be the solid-state, soft-start type. Starters for motors below 25 hp will be full voltage, non-reversing. If required by process demands, variable frequency drives (VFDs) complete with harmonic mitigation, will be provided.
- 600 V and 208Y/120 V power distribution and lighting panelboards with moulded case, bolt-on circuit breakers, and individual short-circuit rating suitable for the available fault current, will be used.

9.4.24 Raceway Systems

To minimize the possibility of interference, efforts will be made to separate raceways involving low-level process control signal wiring and power system wiring.

The following bulleted points are general guidelines for raceway sizing, selection, and installation:

- Conduit sizing will be based on CEC fill limitations.
- Raceways will be exposed on the wall.
- PVC Schedule 40 conduit and fittings will be used for underground and under-slab 4.16-kV and 600-V feeders.
- Rigid galvanized steel conduit and fittings will be used in interior spaces.
- Flexible, liquid-tight conduit will be used for connections where flexibility is required (for example, motors and transformers).
- Spare raceways will be tagged with a nonferrous metal tag attached to the raceway with a nylon strap.

9.4.25 Wire and Cable

The minimum conductor size for power circuits will be #12 AWG.

A minimum conductor size of #14 AWG will be used for discrete control circuits.

9.4.26 Colour Coding

Power and control conductors will be colour-coded in accordance with the CEC.

9.4.27 Enclosures

Canadian Standards Association (CSA) C22.2 No. 94 Type-12 enclosures will be used for equipment in electrical rooms and other controlled environment areas. CSA Type-3R enclosures will be used outdoors and in wet locations, and CSA Type-4X enclosures will be used where equipment is exposed to corrosive environments.

9.4.28 Convenience Receptacles

Receptacles will be surface-mounted on walls or columns.

Weatherproof receptacles will be installed in damp areas.

Ground fault circuit interrupter receptacles will be provided, where required by the CEC. Panelboard or feed-through-type devices will not be used.

9.4.29 Distribution System Protection

9.4.29.1 General

Equipment will be selected with enough momentary and interruption capacity for its location in the system. Series-rated devices or equipment will not be used.

Phase and ground fault protective devices will be provided for the main breaker in main distribution panel.

9.4.29.2 Preliminary Fault and Coordination Analysis

The maximum fault duty will be calculated with sufficient accuracy to establish the required interrupting ratings of circuit protective devices. The general contractor will perform a final short-circuit analysis and protective device coordination study. The study will include an arc flash study, which will provide the specific personal protective equipment requirements for maintaining the associated equipment.

9.4.30 Motor Protection and Control

9.4.30.1 General

Each motor will have a suitable controller and devices to protect the motor and perform the necessary functions.

Starters for motors up to 18 kW will be a full-voltage, non-reversing, with circuit breaker. Starters for motors above 18 kW will be reduced voltage, solid-state, soft-start.

Motor starters will include an ON/OFF/REMOTE or HAND/OFF/REMOTE selector switch with control devices (START/STOP pushbuttons) for operation in the HAND mode.

9.4.30.2 Overload Protection

Each constant-speed motor and adjustable-frequency drive motor will have electronic overload protection in each ungrounded phase.

9.4.31 Alternating Current Induction Motors

Alternating current induction motors will be the premium efficiency-type that contains the following:

- A 1.15 service factor motor for standard motors and a 1.0 service factor for inverter duty.
- National Electrical Manufacturers Association (NEMA) design letter to fit the application (usually NEMA Design B), and locked rotor kVA Code G or lower.
- Copper wire motor windings. Aluminum windings will not be permitted.
- Motors operated by VFDs will be rated for inverter duty.

9.4.32 Grounding

9.4.32.1 Electrodes

A grounding system will be installed around the NFRC Seepage Collection Pump Station transformer. Conductors from the ground grid will be connected to the ground point of the service transformer, the main distribution panel, and other secondary low-voltage distribution transformers.

9.4.32.2 Equipment Bonding

A separate ground conductor (sized according to CEC requirements) will be installed in raceways for power feeders and branch circuit raceways for motor control, lighting, and receptacle loads.

9.4.33 Lighting

Illumination levels (maintained lux) will be designed to meet recommendations in the *IES Lighting Handbook, Eighth Edition* (Rea, 1993). Lighting requirements include the following:

- LED lighting will be used in all areas where cost effective.
- Emergency and exit lights will include a battery. LED-type exit signs will be provided.
- Exterior, wall-mounted lights will be LED type, with sharp- cutoff luminaires to minimize spill light.
- Only light fixtures mounted on the building exterior walls will be used to illuminate the building surroundings.
- Pole-mounted fixtures will not be used.

9.4.34 Heat Tracing

For pipelines required to be used year-round, appropriate insulation and heat tracing will be provided, based on the conditions of the pipe installation (shallow buried or above grade). The FMC has had good experience with pre-insulated, Urecon type piping systems in the past, and this would be specified to support standardization on site. The Urecon system is suitable for both types of installations, and the heat tracing cable is also available at 600 V, which greatly reduces voltage drop and circuit loading issues over long piping runs.

9.5 Pipeline Conveyance System and Mechanical

This section summarizes the mechanical and conveyance design criteria for the following:

- Buried Pipelines – NFRC Conveyance Pipeline from NFRC Seepage Collection Pump Station to IWTS break tank and Faro Pit; year-round operations
- NFRC Seepage Collection Pond pump station

- NFRC Seepage Collection Pond valve and meter station near existing IWTS break tank

9.5.1 NFRC Conveyance Pipeline

The following subsections describe the NFRC Conveyance Pipeline design.

9.5.1.1 Main Assumptions

The conveyance system will be operated year-round, as required. Alternatives 1 and 2 (previously described) are presented for analysis. Each alternative has a different pipeline route to facilitate free drainage of the pipeline back to the ponds. Therefore, there are no low points and sags in the pipeline profiles. This also prevents ice plugs during winter operation and minimizes surge pressures at the pump station from unexpected power outages. The NFRC Conveyance Pipeline will convey contaminated groundwater and surface water from the preferred alternative pond site to the IWTS break tank and the Faro Pit.

9.5.1.2 Pipeline Routes

Pipeline routes for the NFRC Seepage Collection Pond Alternatives 1 and 2 were typically located along roads for ease of maintenance. Alternative 2 requires a portion of new access road in order to eliminate a low point in the pipeline that be created if the Alternative pipeline route followed the Mine Access Road.

9.5.1.3 General Pipeline Criteria

- Design Life: 100 years
- Bury Depth: Most of the conveyance pipelines will be buried except at heated structures, to reduce maintenance costs and significantly increase the design life of the pipelines. All piping will be in an insulated trench except where the bury depth exceeds 3.5 m. Minimum bury depth is 1.5 m.
- Trench Plugs:
 - Pipe trench plugs are installed along the pipe trench to prevent washout of the pipe zone material down slope of culvert crossings.
- Heat Tape:
 - Heat tape is not currently included in the conceptual design below the pipe in insulated trenches but may be required after further geotechnical exploration is complete to support final design. Further geotechnical exploration is recommended to measure the ground temperature at the trench depth to determine if frozen ground maybe encountered during construction.
- Insulated Trench:
 - Pipelines and fiber optic conduit trenches are recommended to be insulated to minimize bury depths.
- Delivery Point Conditions: Free discharge at IWTS break tank, and submerged pipe discharge at Faro Pit delivery point.
- Pipe Cleaning: Pipe pig launchers and receivers will be located at the NFRC Seepage Collection Pump Station and Seepage Collection Pond valve and meter station, as shown in Appendix F.
- Live Load Design: Wheel load of 89.0 kilonewton (kN) (20,000 pounds) with an impact factor of 3.0. This load is similar in magnitude to a fully loaded Caterpillar 980G front-end loader.
- Pipeline Sizing, Pressurized Flow:
 - Maximum Velocity: 2.0 m/s (6.5 frames per second [fps])

- Maximum Flow: 189.3 L/s (3000 USgpm)
- Minimum Flushing Velocity: 0.90 m/s (3.0 fps) except when one pump is running on a temporary basis
- Pipe Condition: Scaled, Hazen Williams C = 110
- Wall Thickness: Dimension Ratio (DR) based on pressure (including surge and vacuum), live and dead loads, and constructability
- Pipeline Sizing, Gravity Flow:
 - Maximum Flow: 189.3 L/s (3000 USgpm)
 - Maximum Percent Full Pipe (d/D, as percentage): 60
 - Pipe Condition: Scaled, Manning's N = 0.014.
 - Minimum Pipe Slope: 0.03500 as shown.
 - Wall Thickness: DR based on vacuum, live and dead loads, and constructability.

9.5.2 Hydraulic Analysis

9.5.2.1 Pressure Flow

A preliminary hydraulic model of the pumping system was developed using Applied Flow Technology's AFT Fathom software. This program was used to assist in determining the following factors:

- Pipe sizes and flow velocities
- Operating pressures along the pipe alignment
- Required pump performance

9.5.2.2 Gravity Flow

A preliminary hydraulic model of the gravity pipeline from the high point vent to Faro Pit was developed using Bentley Systems Inc.'s Haestad Methods Flow Master V8i (SELECT Series 1).

9.5.3 Preliminary Pump and Pipeline Sizing

Table 9-9 summarizes Alternatives 1 and 2 preliminary pump and pipeline sizing requirements based on maximum flow at scaled-pipe condition. The following pipeline segments are as follows:

- Pressure pipeline from Seepage Collection Pond pump station to Seepage Collection Pond valve and meter station, and IWTS break tank
- Pressure pipeline from Seepage Collection Pond valve and meter station to high point vent
- Gravity pipeline from high point vent to Faro Pit

Pumps will be designed to accommodate all pipeline scenarios. Appendix F show the pipeline routes.

Table 9-9. Preliminary Pump and Pipe Sizes

Faro Mine Remediation Project

Alternative	Design Pump Flow Rate	Design Pump Head	Motor Size	Pressure Pipe Seepage Collection Pond Pump Station to Seepage Collection Pond Valve and Meter Station	Pressure Pipe Seepage Collection Pond Valve and Meter Station to High Point Vent	Gravity Pipe High Point Vent to Faro Pit
Alt 1	63.1 L/s (1,000 USgpm)	149.4 m (490 feet)	149 kW (200 hp)	450 mm (18 inch) DR 9 IPS PE4710	450 mm (18 inch) DR 11 IPS PE4710	450 mm (18 inch) DR 11 IPS PE4710
Alt 2		159.7 m (524 feet)				

Table 9-9. Preliminary Pump and Pipe Sizes
Faro Mine Remediation Project

Alternative	Design Pump Flow Rate	Design Pump Head	Motor Size	Pressure Pipe Seepage Collection Pond Pump Station to Seepage Collection Pond Valve and Meter Station	Pressure Pipe Seepage Collection Pond Valve and Meter Station to High Point Vent	Gravity Pipe High Point Vent to Faro Pit
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Pumps will be a vertical-turbine type with an above-grade discharge head. Installation style will be an open-bottom-can intake as defined by Hydraulic Institute Standard 9.8-2012, Figure 9.8.2.6.4, Example 2. Wetted components will be constructed of Type 316 and CD4MCu stainless steel or similarly corrosion and abrasion-resistant materials. Motors will be 1,800 rpm, three phase, 575 V. Pump motors will be driven by variable-speed drives and provided with local and remote control. Representative pump manufacturers include National Pump Co. and Weir Floway, Inc.

9.6 Structural

This section summarizes the structural design criteria for the following:

- Foundations
- Culverts
- NFRC Seepage Collection Pump Station and Seepage Collection Pond Valve and meter station

9.6.1 Design Loads

To determine specified loads for snow, wind, and earthquake design, the facilities will be designed as normal with an importance factor of 1.0.

9.6.2 Dead Loads

Loads will be the actual weight of structures and fixed equipment. Dead loads will be based on NBC (NRC, 2010) standards and CH2M best practices.

9.6.3 Seepage Collection Pond Pump Station Building and Seepage Collection Pond Valve and Meter Station Dead Loads

- Roofing, insulation, and roof deck: 0.5 kPa
- Structural framing: actual weight
- Mechanical and electrical: 0.5 kPa

9.6.4 Floor Live Loads

Floor live loads will be in accordance with the building codes listed in Section 2.5.1. The following minimums will be used:

- Pump Station: 10 kPa
- Valve and Meter Station: 12 kPa
- Transformer pad, if required: actual weight of equipment + 1.0 kPa

9.6.5 Partition Loads

Partition loads are not anticipated in the buildings at this time, but light frame construction partitions are covered.

9.6.6 Roof Live Loads

The roof live load for construction will be 1.0 KPa (non-reducible). Although the design live load will be 1.0 KPa, the roof live load will be independent of snow and wind loads.

9.6.7 Wind Loads

Wind loads will be as follows:

- Hourly wind pressures at 1/50 year return = 0.38 KPa
- Exposure factor $C_e = 0.9$ for open terrain
- Importance factor $I_w = 1.0$ for Ultimate Limit State and 0.75 for Service Limit State
- In accordance with NBC

9.6.8 Snow Loads

The ground snow load at 1/50 year return will be 2.30 KPa, with the associated rain load at 0.1 KPa, $I_s = 1.0$ for Ultimate Limit State and $I_s = 0.9$ for Service Limit State, in accordance with Table C2, Appendix C of the NBC (NRC, 2010).

9.6.9 Rain Loads

Rain load will not be considered, except as previously noted for rain on snow. The preliminary design concept presents a 4V:12H roof pitch from the peak at the centre of the building. Rain will drain off the roof to each side of the building.

9.6.10 Earthquake Loads

Earthquake loads are based on the 2015 NBC at the FMC for an earthquake with a probability of exceedance of 2 percent in 50 years, with the following seismic data:

- $S_a(0.2)$: 0.271
- $S_a(0.5)$: 0.190
- $S_a(1.0)$: 0.123
- $S_a(2.0)$: 0.067
- Peak Ground Acceleration PGA: 0.126
- Site classification: C
- Importance factor (I_E) – building structures: 1.0, unless noted otherwise

Additionally, a site-specific seismic hazard assessment was developed by Atkinson and Assatourians (2013) for the FMC. For an earthquake with a probability of exceedance of 2 percent in 50 years and Site Class C soil conditions, the seismic data are the following:

- $S_a(0.2)$: 0.311
- $S_a(0.5)$: 0.208
- $S_a(1.0)$: 0.118
- $S_a(2.0)$: 0.057
- Peak Ground Acceleration PGA: 0.143
- Site classification: C
- Importance factor (I_E) – building structures: 1.0, unless noted otherwise

It is recommended that the site-specific values from Atkinson and Assatourians (2013) be used for seismic design, specifically when the natural period of the structure is less than 1 second.

9.6.11 Thermal Loads

The local temperature varies from -47°C in winter to 25°C in summer. The enclosed facility will be designed to operate year-round, and will be properly insulated. Equipment will be enclosed, specified for harsh weather conditions, or both.

9.6.12 Load Combinations

Load combinations will be in accordance with NBC and American Concrete Institute 350, based on type of structure. Working stress or limit state design will be selected based on the type of structural elements.

9.6.13 Vibration Loads

Machines that transmit vibrations include centrifugal pumps, fans, compressors, and engine generators. These vibrating machines require special considerations when their supports are designed.

The natural frequency of machinery support structures must be significantly different from the frequency of the disturbing force. If the two frequencies approach each other, resonant vibration will occur. To minimize resonant vibrations, the ratio of the natural frequency of the structure to the frequency of the machinery or other disturbing force should be less than 0.5 or greater than 1.5.

The following points are general principles for designing for vibration:

- Mount all rotating equipment that produces vibrations on concrete foundations or concrete support systems.
- Use vibration isolators or dampeners, where appropriate.
- Consult with manufacturers to obtain recommendations, frequencies, and unbalanced loads.
- Where possible, provide a concrete base on grade, with a mass equal to 10 times the rotating parts of the equipment or at least 3 times the gross weight of the machine, whichever is greater. Where this is not possible or practical, perform a vibration analysis.
- Anchor vibration-sensitive equipment to concrete foundations by using embedded anchor bolts (with sleeves for alignment). Do not use drilled anchors.
- Bolt connections used in steel framing support systems by using high-strength, slip-critical, bolted connections that are properly torqued.
- Steel support beam depths should be greater than 1/20 of the span to minimize perceptible transient vibrations.

9.6.14 Impact Loads

For structures carrying live loads that induce impact, the assumed live loads will be increased by a factor of 1.25.

9.6.15 Cranes and Fork lifts

There will be no crane or fork lift required for this project. A mobile crane would be used for future service of pumps in the NFRC Seepage Collection Pump Station through roof hatches.

9.6.16 Considerations for Chemical Attack on Concrete Structures

Chemical attack on concrete elements, specifically the pump station intake structure and manholes, is a concern for long-term integrity of concrete elements. Concrete mix design requirements and concrete

design and placement practice should consider various factors to maximize concrete performance including:

- Verify water and soil chemistry to which concrete will be exposed in advance of final design.
- Minimum f'_c of 26.7 MPA (4,000 psi)
- Use Type V cement or modified Type II cement
- Use Class F flyash
- Increase concrete density- Add silica fume or fly ash. Silica fume would create a denser concrete
- Minimum cementitious materials content of 88 KN/m³ (560 lb/ft³)
- Limit water/cementitious ratio to 0.4
- Increase concrete cover to rebar; 3 feet minimum and consider more.
- Limit max aggregate size to 25 mm.
- Alkali Silica reactive aggregates shall not be used unless proven to be mitigated by mix design additives.
- Consider coatings or linings if and where water chemistry is particularly problematic for concrete integrity

9.6.17 Geotechnical and Subsurface Considerations

Preliminary borings were drilled and test pits excavated at the site of the Alternative 1 Seepage Collection Dam. The details and results of this investigation are provided in Appendix E, Geotechnical Report. No geotechnical exploration was performed at the site of the NFRC Seepage Collection Pond Alternative 2; however, some limited existing information was available. It was determined that additional subsurface information is required at both sites and it is expected that these additional geotechnical explorations would occur in 2016 for preparation of the Preliminary Design.

9.6.18 Frost Mitigation

The geotechnical report for the WTP states the design frost depth for the building exterior wall without foundation insulation protection is 3.5 m (CH2M, 2012). Similar frost depths are expected at the location of the NFRC structures. Pad foundation support will be below the design frost depth unless insulated. Perimeter insulation will be provided for the perimeter grade beam.

9.6.19 NFRC Seepage Collection Pump Station

One pump station is anticipated for this project. It is anticipated that the pump station room floors will be constructed of concrete slab and will support pump piping, surge tank if required, and other electrical and mechanical ancillary loads.

The foundation will likely consist of a perimeter-grade beam supporting the slab base. The grade beam will be supported by an isolated pad footing or a sono-tube shaft, depending on soil conditions. The pad footing foundations or sono-tube shafts will be founded below the frost depth. Rigid insulation around the perimeter of the grade beam and below the base slab will protect the slab-on-grade from freezing. The sono-tube shaft concept will be used only if it is cost-effective and can be used in a manner similar to pole foundations for electrical. The drawings reflect isolated pad footings.

Concrete masonry unit (CMU) walls with steel joist roof framing and a metal deck superstructure system are presented in the drawings, which will provide a long-service life. Another option would be to consider a concrete roof slab. Structural and architectural elements will need to be considered and reviewed in detail during the detailed design.

The roof and walls will be insulated similar to the WTP, with the roof sloped to drain rain water.

A prefabricated pump house assembly (compared to a cast-in-place structure) was considered, but was dismissed for the following reasons:

- Concrete structures provide a long life compared to a prefabricated assembly.
- Even with a prefabricated assembly, a concrete foundation is required, which reduces cost savings.
- The CMU wall concept will not require super-structure formwork, and structural-steel framing can be used for the roof.
- Because of their size, prefabricated units will incur significant transportation and escort costs.
- There are significant inspection and coordination costs when prefabricated units are selected, because consulting staff must make multiple trips to manufacturing facility locations.
- During construction, changes at the FMC will be very difficult to manage. There will be less flexibility to manage change once the pre-fabricated assemblies are ordered.
- Life expectancy for prefabricated units will be a maximum 30 years versus 75 years for concrete/CMU structures.

9.6.20 Seepage Collection Valve and Meter Station

The Seepage Collection Valve and Meter Station consists of a one-storey enclosed building, to accommodate the piping layout. The pig-launching assembly room floor will be constructed of concrete slab and will support valve, process piping, and other electrical and mechanical ancillary loads.

The foundation will consist of a perimeter-grade beam supporting the slab base. The grade beam will be supported by an isolated pad footing or a sono-tube shaft, depending on soil conditions. The pad footing foundations or sono-tube shafts will be founded below the frost depth. Rigid insulation around the perimeter and under the slab will protect the slab-on-grade from freezing. The sono-tube shaft concept will be used only if it is cost-effective. The drawings reflect isolated pad footings

Similar to the NFRC Seepage Collection Pump Station, CMU walls with steel joist roof framing and a metal deck superstructure system are presented in the drawings, which will provide a long service life. Another option would be to consider a concrete roof slab.. Structural and architectural elements will need to be considered and reviewed in detail during detailed design.

The roof and walls will be insulated similar to the WTP, with the roof sloped to drain rain water.

9.6.21 Transformer Pad

The transformer pad, if required, will consist of a concrete slab-on-grade. This pad will float on-grade, and no special foundation is necessary. The transformer and fuel storage tank will be designed for outside use and harsh weather conditions, and in general will not require maintenance during cold weather. The equipment will accommodate a maximum ± 50 mm of pad movement in the vertical plane.

9.6.22 Haul Road Crossing Structure

Design criteria for the Haul Road culvert will be determined based on the selection of the culvert type and construction method. Culvert types could include arch culverts with concrete footings or reinforced concrete box structures. Construction methods under consideration include cut and cover and tunneling.

9.7 Instrumentation and Controls

This section describes the instrumentation design criteria and the instrumentation requirements for the Seepage Collection Pond pump station, the Seepage Collection Pond valve and meter station, and the integration of the devices at these location into the IWTS control system.

9.7.1 General Design Approach

Currently the IWTS has a treatment capacity of 6,000 USgpm and receives raw water from the break tank. The break tank receives raw water from the Faro Pit, ETA, and ID Pond (future commission). Under normal operating parameters the NFRC Seepage Collection Pump Station will feed raw water to the break tank for processing at the IWTS. The NFRC Seepage Collection Pump Station will consist of three variable-speed pumps, maintaining the raw-water level in the collection pond between maximum and minimum levels. The NFRC Seepage Collection Pond Dam is configured with a spillway when Seepage Collection Pond accumulation is full and inflow exceeds pump capacity. The NFRC Seepage Collection Pump Station pumps raw water to the break tank near the IWTS, if the capacity of the IWTS is insufficient, the break tank is full, and the Seepage Collection Pond is at or over its maximum level of excess raw water collected from the NFRC Seepage Collection Pump Station. The water will be diverted to the Faro Pit.

The NFRC Seepage Collection Pump Station I&C system is intended to control and monitor the level of the water at the NFRC Seepage Collection Pond, maintain pond level, operate pumps as required, and pump water to the break tank for processing. During high accumulation volumes at the pond and low-water treatment capacity at the IWTS, water is to be diverted to the Faro Pit. The NFRC Seepage Collection Pond level is to be monitored continuously and reliably, and transferred to the break tank for treatment, as required. The NFRC Seepage Collection Pump Station will be serviced with utility power and will include a back-up generator sized to operate all pumps with VFDs and capable of handling Direct On Line (DOL) starting motor contactors as backup. Piping and instrumentation diagrams (P&IDs) are prepared as part of the design.

The existing IWTS PLC control system complete with HMI will have pages added to include the NFRC Seepage Collection Pump Station and Seepage Collection Pond valve and metering station and remote pump stations complete with control, monitoring, and logging, as required. A new communication module will be added for communication with the Seepage Collection Pond valve and metering station PLC. The Seepage Collection Pond valve and metering station will provide a central hub for communication links for the NFRC Seepage Collection Pump Station, the existing remote pumps stations through radio link and the IWTS.

Using the Seepage Collection Pond valve and metering station as a central communication hub enables integration with a future WTP and all existing pump stations with a single Ethernet link without transferring all remote signals to the future WTP. This further enables future parallel operation of a new WTP with the existing IWTS and decommissioning the IWTS without disruption.

9.7.2 Recommendations

Assumptions: Flow from Faro Pit (6,000 USgpm max), is directed to the IWTS for processing. Flow from ETA (500 USgpm max), and ID Pond (2,000 USgpm max) are also directed to the IWTS for processing; alternately, the ETA and ID Pond flow can be combined at the Miller Skid pump and directed to the Faro Pit.

Recommendation: Existing flow meters and new flow meters to be installed at the pump stations and have telemetry radios installed and linked to the Seepage Collection Pond valve and metering station for flow summing input to the IWTS control PLC. This is reflected in the P&IDs.

Radio communication link to the Faro Pit pump station will require a radio repeater station because of topographical constraints. This radio repeater station will be located at the Faro Pit temporary generator utility power drop. The exact radio master and slave arrangement will require local knowledge for antenna placement and system configuration.

With the above flow inputs available to operators, the IWTS capacity can be fully used and a number of operating modes developed.

Treatment priorities could be changed, as needed, and accomplished with ease through setting priority flow rates from one or more sources and the balance of processing capacity automatically achieved through mass balance calculated at the PLC.

With flow rates available to the control system, Remote Auto (PLC Control) and Remote Manual (Operator control at HMI via PLC) maximum process capacity is achievable and will eliminate inefficient low flow operation and reduces over feeding the IWTS by overflowing the break tank.

With the recommendations provided herein and signals integrated into the Seepage Collection Pond valve and meter station PLC, input to the IWTS control SCADA system and the new WTP (Future) control system can be achieved with a single link to the Seepage Collection Pond valve and meter station.

If the new WTP (future) will be operated in tandem with the existing IWTS until the latter is decommissioned and a single link to the NFRC Seepage Collection Pond valve and meter station provides seamless integration and transfer of operating control, as required.

9.7.3 Control System Requirements

The control system requirements will govern the selection and configuration of the PLCs and the I&C equipment.

Unless otherwise stated, the pumping process will be fully automated for unattended operation. Complete with backup generator. The system will be capable of manual operation from the pump station building.

9.7.4 Control System Operating Philosophy

The control philosophy is based on integrating with the existing IWTS and associated site network of distributed PLC panels and operator interface terminals (OIT's). The NFRC Seepage Collection Pump Station PLC and OIT will be an extension of the site network of distributed controls and will be on an Allen-Bradley platform. The proposed OIT at the NFRC Seepage Collection Pump Station will allow operators to monitor and control the pumping process from the pump station. The design includes use of an Allen Bradley Panel-view 1500 as an OIT station.

9.7.5 Control Hierarchy

Although the pumping control system configuration has an individual PLC at the pump station and an OIT, it is not hierarchy-based. The pump station PLC makes the operation of the pumps meet delivery demand automatically, as requested from the control room operator interface terminals. The pump station OIT is provided so that the pumping system can be monitored and operated from the pump station.

9.7.6 Pump Monitoring and Control

As a VFD redundancy feature, each pump motor control center (MCC) will include a DOL start contactor complete with overload protection and overload tripped indication to the PLC.

There will be a designated pump control panel for each pump. Each panel will have a LOCAL-OFF-REMOTE (LOR) selector switch, a START-STOP (SS) momentary push buttons, a VFD-DOL (V-D) selector switch, and a speed control device.

When the V-D selector switch on the pump control panel is in the 'V' position the pump will have speed control, from the PLC. When the V-D selector switch is in the 'D' position the pump can be started with both remote (PLC) and local control, but no speed control.

When the LOR switch is in the LOCAL position, start, stop, and speed adjustment (with V-D selector switch in 'V') will be performed locally at the panel for maintenance or testing functions.

Each pump control panel will have pilot light indication of, Power Available, Pump Running, Pump Stopped, VFD fail, VFD, Trouble, Motor Overload, Over Temperature for windings and bearings.

The control functions available for the pumps with PLC system will be as following:

- **Remote VFD-Mode** when the LOR selector switch is in the REMOTE position and the V-D selector switch is in VFD mode:
 - Status monitoring to the PLC system of the LOR and V-D selector switch positions and VFD RUN status
 - 4 to 20 milliampere (mA) 24-V direct current (DC) speed control and speed feedback signals
 - Common drive failure alarm signal to the PLC
 - Special alarms (for example, high temperature and pump discharge pressure low) to the PLC
- **Remote DOL-Mode** when the LOR selector switch is in the REMOTE position and the V-D selector switch is in DOL mode:
 - Status monitoring to the PLC system of the LOR and V-D selector switch positions and DOL contactor RUN status
 - Motor Over Load alarm signal to the PLC
 - Special alarms (for example, high temperature and pump discharge pressure low) to the PLC

The control functions available for the pumps when in LOCAL position will be as following:

- **Local VFD-Mode** when the LOR selector switch is in the LOCAL position and the V-D selector switch is in VFD mode:
 - Status monitoring to the PLC system of the LOR and V-D selector switch positions and VFD RUN status
 - 4 to 20 mA 24 V DC speed control and speed feedback signals from the local VFD key pad.
 - Common drive failure alarm signal to the PLC
 - Special alarms (for example, high temperature and pump discharge pressure low) to the PLC
- **Local DOL-Mode** when the LOR selector switch is in the LOCAL position and the V-D selector switch is in DOL mode:
 - Status monitoring to the PLC system of the LOR and V-D selector switch positions and DOL contactor RUN status
 - Motor Over Load alarm signal to the PLC
 - Special alarms (for example, high temperature and pump discharge pressure low) to the PLC

9.7.7 Instrument Control Panel

The instrument control panel (ICP) in the NFRC Seepage Collection Pump Station building will be equipped with a local PLC having adequate number of input-output points. The panel will include the following features:

- The ICP will be powered from two dedicated circuits from the pump station utility supply distribution panel.

- Each circuit to the ICP to be equipped with a surge protection device (SPD) mounted in the panel. Connection of the SPD will be made to a low-impedance grounding system and will be coordinated with the electrical system design.
- One Double conversion true online UPS sized for 60-minute run times will be the backup power. The UPS will be located within the ICP. A designated relay in the panel will monitor UPS output voltage; upon loss of UPS output voltage the relay will automatically connect the alternate designated circuit to supply power to the ICP panel components.
- Design will consider the heat load generated in the ICP, so overheating does not occur. To protect equipment, the panel will have a louver and filtered force ventilation, as required, to limit temperatures to a maximum of 40°C.

9.7.8 Networking Requirements

Data communications between pump station PLC, OIT, pump VFDs, and backup generator will be through an Ethernet network. The network architecture will ensure robust connectivity, and redundancy. A Device Level Ring (DLR) ring-based communication system will be installed providing resilient communication tolerant to single point cable breakages. Fiber-optic cable will be used for primary communication between the NFRC Seepage Collection Pump Station PLC, the Seepage Collection Pond valve and meter station, and the IWTS PLC, extending the existing DLR. A radio telemetry system is included as outlined in Recommendations provided for communication with remote pump stations, complete with repeater station as required. CAT 6 MCC rated 600 V shielded copper cable to be used for communication within the pump station building and to the back-up generator control cabinet PLC.

9.7.9 Instrumentation and Control

The major components of the I&C system for the pump station will be connected to the pump station PLC to provide control and monitoring. The NFRC Seepage Collection Pump Station will be connected to the Seepage Collection Pond valve and meter station and IWTS PLC network to provide a complete, functional, automated, robust, and redundant system. The control system design will provide process parameters, status indications, and control, as required.

9.7.10 Field Instruments

Field instrumentation will depend on the process requirements. Field transmitters will have local displays. Instruments will be calibrated and installed according to standard guidelines, and will have adequate access for safe operation and maintenance. Discrete and analogue device input-output will be wired to the PLC (instrument control panel) through hard-wired connections.

The instrument schedule, electrical control schematics, and typical control panel layout will be provided during the detailed design. The construction contractor will provide loop diagrams and a detailed control panel layout before the construction phase.

9.7.11 Numbering System

The numbering system for the NFRC Seepage Collection Pump Station to the IWTS will be an extension of the numbering scheme adopted for the replacement WTP to maintain consistency across the FMC.

9.7.12 Equipment Numbering

A standard numbering scheme has been developed for this project that will include unit processes, equipment, and instrumentation. The scheme is for identifying equipment and devices on the P&IDs.

A tag number consists of the unit process, device identification letters, a sequential “loop” number, and an identifier for the building location. It follows the following format:

PP-DDD-LLL-NN

Where:

- PP** = 2-digit unit process designator, which for the NFRC Seepage Collection Pump Station to the IWTS pumping system is 40.
- DDD** = 3-digit device identifier for equipment or 2 to 4 digits for instruments (e.g., PMP for pump, FIT for flow indicating transmitter [integral transmitter], PI for pressure gauge, PSH for pressure switch high).
- LLL-NN** = 5-digit loop number. Where LLL is the location code, which for the Seepage Collection Pond Pump Station is 600, and NN is a sequence number, running from 01 to 03, for pump 1 through 3.

9.7.13 Instrument Numbering

Instruments (such as, flowmeters, pressure gauges, and switches) will have tags with letters based on International Society of Automation (ISA) standards or as noted. The ISA standards table for letter descriptors is shown on the P&ID legend sheet. On P&IDs, the tags will be shown inside a circle. On other drawings, specifications, and lists, the tags will be shown as a string of characters (for example, as 40-FIT-600-01).

9.7.14 Panel Numbers

For clarity, the electrical control panel, like the pump control panel or the generator control panel, will be designated as a local control panel. The PLC panels will be designated as an ICP (instrumentation Control Panel). The typical panel tag numbers shall be as follows:

PP-EEE-XX

Where:

- PP** = 2-digit unit process designator, which for the NFRC Seepage Collection Pump Station pumping system is 40.
- EEE** = 3-digit identifier for panel type
- XX** = 2-digit panel number

9.7.15 Control Narratives

A process narrative will be the starting point for developing the control narrative. Control narratives will be developed to describe in detail the automation and control of the equipment and devices. The narratives will include descriptions for operating the system in Remote-Manual and Remote-Auto modes. The control narrative will also describe reactions to component failure and power failure situations as described below:

- The NFRC Seepage Collection Pond pump station is designed to collect contaminated water from the NFRC, provide reserve holding capacity for fluctuating creek flow and pump the contaminated water to the IWTS for processing.
- During higher than normal creek flows and high levels in the NFRC Seepage Collection Pond and low capacity at the IWTS flow will be directed to the Faro Pit.

- The water level in the NFRC Seepage Collection Pond will be maintained between designated minimum and maximum operating levels. These will be referred to as Maximum Operating Level (Max-OL), and Minimum Operating Level (Min-OL) set points. The Max-OL will be approximately 1 m below the NFRC Seepage Collection Pond spillway elevation.
- There will be a minimum winter level that may be different than a spring-summer minimum level. The winter minimum level is designed to provide sufficient thermal protection, for the NFRC Seepage Collection Pond inlet structure, from freezing with the NFRC Seepage Collection Pond having up to 1 m of ice accumulation.
- The IWTS operator will set the plant inflow rate from each source, the NFRC Seepage Collection Pond pumps will be called to run and the pump quantity and speed will be determined as required to deliver the flow set point. Alternately the Operator could set the flow requirements for the ETA, ID Pond, and Faro Pit. The NFRC Seepage Collection Pond pumps would fill the balance of flow required based on a Max flow set point.
- When the flow rate capacity of the IWTS is less than the required pump flow set point because of the NFRC Seepage Collection Pond level, excess flow will be diverted to the Faro Pit.
- Under normal anticipated operating modes, the IWTS will call for Seepage Collection Pond water when the levels are between the Min-OL and Max-OL. The Seepage Collection Pond pumps will start as required to fulfill the flow set point from the IWTS. The flow set point will maintain the Seepage Collection Pond level at or near static level (that is, matching Seepage Collection Pond inflow).
- The raw water discharged from the Seepage Collection Pond Pump Station enters the Seepage Collection Pond valve and metering station near the IWTS. At the Seepage Collection Pond valve and metering station, the Faro Pit valve is fully open, flow is measured and is diverted to the IWTS and to the Faro Pit, as required based on the herein and following operating constraints.
- When the IWTS is unable to process water from Seepage Collection Pond and water levels are high, pumps will be called to run and flow will be directed to the Faro Pit. Pump flow set point will be determined by Seepage Collection Pond inflow rate. At any time the IWTS has capacity to treat Seepage Collection Pond raw water, the Seepage Collection Pond valve and metering station will divert water to the IWTS.
- Seepage Collection Pond inflow rate will be calculated from pump discharge flow rate and Seepage Collection Pond level change and displayed at the plant control OIT.

9.7.16 Standard Practices

This section describes standard I&C practices for the NFRC Seepage Collection Pump Station project. These standards will be followed where possible throughout the design process.

Field and Pumps Station Instruments

- **Pressure Indicator:** Pressure gauges will be provided in the design where shown on the P&IDs and will include a 4½-inch-diameter dial with Glycerin filled for reduced pointer vibration. Pressure gauges will have a black thermoplastic housing. Pressure will be sensed using a Bourdon tube element to provide an accuracy of ± 0.50 percent. All wetted parts of the gauge will be stainless steel. A pressure snubbing device will be specified to dampen rapid pressure fluctuations caused by pump startup, pipe filling, and valve operation. The gauge will be stem mounted to the process piping using ½-inch male National Pipe Thread and isolation ball valve.
- **Pressure Indicating Transducer:** With output of 4-20 mA DC scaled to an appropriately specified range. Instruments will be located to monitor the NFRC Seepage Collection Pump Station discharge header. The sensing element will be a 316 SST diaphragm with integral temperature compensation

and will use variable capacitance or silicon strain gauge technology. The instrument will be installed per the applicable mounting detail drawing. The transmitter will be loop-powered and shall have a local display calibrated in engineering units.

- **Pressure Switch:** Monitor the pressure via a diaphragm actuated switch with an adjustable pressure setpoint and switch reset when the pressure drops below the setpoint by either a fixed or adjustable deadband, depending on the specific application. The switch will be rated for 10 ampere at 120 V AC. The specification for the pressure switches will use Achcroft, Type 400 B Series pressure switches as the basis of design.
- **Pump Discharge Low Pressure Switch:** This instrument will monitor the pump discharge pressure before the discharge header. The pressure switch will indicate a low pressure as a result of pump failing to produce pressure and will provide a discrete signal via dry contacts to the pump station PLC to stop the pump.
- **Submersible Level transducer:** Submersible level transmitters will be specified for monitoring level in the Seepage Collection Pond. Instruments will be specified with an output of 4-20 mA DC for full transducers range. The construction of the element will be stainless steel construction and mounted in a stilling well. A termination enclosure will be specified to terminate the manufacturer's cable and house the aneroid bellow for the instrument's vent tube.
- **Submersible Temperature transducer:** Submersible temperature element will be specified for monitoring temperature in the Seepage Collection Pond pump inlet duct. Instruments will be specified with a cable length compensation loop and produce an output of 4-20 mA DC for full transducers range. The construction of the element will be stainless steel construction and mounted in a stilling well. A termination enclosure will be specified to terminate the manufacturer's cable and house the temperature transmitter.
- **Level Float Switch:** A float will be used to detect high level in the Break Tank. The switch(es) will be integrally mounted in a stainless steel float and connected to a junction box by an appropriate waterproof cable. The float switches will not contain mercury.
- **Flow Meter:** Magnetic flow meters will be utilized for measuring flow and calculating diverted volumes. The instrument will be installed at the NFRC Seepage Collection Pump Station and in the Seepage Collection Pond valve and metering structure near the IWTS, per the manufacturer's recommendations.
- **Radio communication:** Will be 900 megahertz spread spectrum capable of frequency hopping. Antenna's will be selected and located accordingly to optimize communication, eliminating dead areas.
- **Motor Winding Temperature Monitoring System:** Resistance Temperature devices (RTD) sensors will be specified for installation on pump motors at the pump Station. Each pump will have RTDs at the each motor winding and motor bearings. Allen Bradley RTD modules will provide excitation voltage and convert the signals to provide readout of the temperatures on local and system OITs.

9.7.17 Equipment Protection

The controls and interlocks for protecting equipment (for example, low discharge pressure,) must use conventional control hardware, such as electromechanical relays. The interlocks should be hardwired to the equipment starter or controller, rather than depending on the open-local-close system or other electronic or programmable devices, to operate safely. Local RESET pushbuttons will be provided to reset alarm-lockout functions, as required, at the motor control centres or locally at the equipment control panel.

9.7.18 Personnel Safety

All controls and interlocks provided for personnel safety will use conventional control hardware, such as electromechanical relays. The interlocks will be hardwired to the equipment starter or controller, rather than depending on the PLC/OIT or other electronic or programmable devices to operate safely. Local reset push buttons will reset lockout functions, as required, at the pump control panel or locally at the equipment.

9.7.19 Standard and Failsafe Alarms

Standard alarms will be generated by using open (under “normal” conditions) contacts, which close under the alarm condition.

Critical alarms will employ closed (under “normal” conditions) contacts, which open under the alarm condition, to render a fail-safe condition.

9.7.20 Programmable Logic Control Input/Output Signals

The NFRC Seepage Collection Pump Station PLC will monitor and control pump station process parameters and equipment. Monitoring and control signals will interface with the PLC at the instrumentation control panel. Wherever possible, the following standard signal types should be used:

- **Digital inputs:** Dry contact in field, rated for 24 V DC, powered from the PLC back plane cabinet
- **Digital outputs:** Rated for 24 V dc but with interposing relays in the control panel rated for 2-ampere at 120V AC
- **Analogue inputs:** 4-20 mA at 24-V DC, from 2 wire transmitter (powered from the PLC panel) or 4 wire transmitter (powered in the field)
- **Analogue outputs:** 4-20 mA at 24-V DC, powered from the PLC output module

9.8 Civil and Geotechnical

Note that geotechnical design criteria associated with structures is described above in Section 9.8. This section focuses on design criteria of the Seepage Collection Pond, the NFRC Seepage Collection Dam, culverts, and other non-building related project components.

9.8.1 North Fork of Rose Creek Seepage Collection Pond

Two NFRC Seepage Collection Pond alternatives have been identified and the design criteria are applicable to both.

9.8.1.1 Pond

The NFRC Seepage Collection Pond was sized to collect mine-impacted contaminated seepage from an area of approximately 1.1 km² for Alternative 1 and 1.4 km² for Alternative 2, based on the proposed NFRC Realigned Channel configuration and WRD regrading design. The sizing analysis considered catchment area, return storm events, event durations, treatment capacity, pipeline capacity, downstream water quality, and limitations on operations associated with warm weather and cold weather conditions. An analysis is described in detail in Section 13.

The Alternative 1 NFRC Seepage Collection Pond was designed to control seepage underneath and through the dam and around its abutments. A low-permeability core is incorporated into the embankment and a cutoff core trench extended through the overburden soils into bedrock. Estimates of seepage rates out of the pond were evaluated by three-dimensional numerical groundwater modelling as described in Appendix C, Groundwater Report.

The Alternative 2 NFRC Seepage Collection Pond will have a double-liner system in both the diversion channel and the pond itself, which is anticipated to result in very low seepage rates.

Seepage rates were evaluated within the context of cost for stopping seepage from the pond or dam, and the potential to capture seepage either downstream of the Seepage Collection Dam or allow the seepage to collect within the RCAA and eventually collect at the CVD SIS.

9.8.1.2 Dam

Both the Alternative 1 NFRC Seepage Collection Dam, which is a 17-m-high dam, and the Alternative 2 pond embankments, which has a maximum height of about 10 m are classified as a dam according to CDA guidelines (2007 and as amended in 2013). CDA criteria will apply to the following design elements:

- Hazard classification
- Selection of design flood and earthquake levels
- Hydrotechnical storage and discharge capacity adequacy
- Freeboard requirements
- Required factors of safety for slope stability (static and seismic load cases)
- Filter design requirements
- Surface erosion

The criteria provided in this section focuses on a standards-based assessment approach. Revisions adopted in the 2013 CDA guidelines focus attention on following a risk-informed approach. Whereas a standards-based approach was followed in the conceptual design of the NFRC Seepage Collection Pond alternatives, risk-informed elements, including a failure mode and effects analysis, should be incorporated into final design. This approach would consider failure modes that may otherwise be neglected when following the standards-based framework.

9.8.2 Hazard Classification

Considering the CDA dam safety guidelines as shown in Table 9-10 (CDA, 2007 and as amended in 2013), the impacts from a dam breach will be evaluated based on the results of dam break analyses that will determine the extent of inundation and the potential damage it could cause to other dams downstream of the ponds. Even if the dam breach will only result in inundation of the area upstream of the RCD, with the flood wave being passed through the RCD and through the PMF spillway of the ID without overtopping the ID, it should have a classification of significant or high, because of the composition (toxicology) of the pond content.

If a breach results in a flood wave large enough to overtop the ID, it would be prudent to assume that it could cause the ID to breach. Under such a worst-case scenario, based on *Loss of Life and Infrastructure and Economics* considerations, the dam would have a hazard classification of significant to high. However, the impacts to the environment would likely be catastrophic, resulting in a very high to extreme hazard classification.

According to the results of the dam break analyses (see Section 8 in Appendix B, Hydrotechnical Report), it was determined that a breach of the NFRC Seepage Collection Pond embankments would not result in a flood wave that would be large enough to overtop the ID Pond (that is, it would not result in a catastrophic release of large amounts of tailings and therefore would not warrant an extreme hazard classification). However, since the pond could be filled with waters contaminated with chemicals, it could still result in significant loss or deterioration of important fish or wildlife habitat. Therefore, a high hazard classification for the NFRC Seepage Collection Dam is recommended.

Table 9-10. Dam Classification – CDA, 2007 and amended in 2013
Faro Mine Remediation Project

Dam Class	Population at Risk ^a	Incremental losses		
		Loss of Life ^b	Environmental and Cultural Values	Infrastructure and Economics
Low	None	0	Minimal short-term loss No long-term loss	Low economic losses; area contains limited infrastructure or services
Significant	Temporary	Unspecified	No significant loss or deterioration of fish or wildlife habitat Loss of marginal habitat only Restoration or compensation in kind highly possible	Losses to recreational facilities, seasonal workplaces, and infrequently used transportation routes
High	Permanent	10 people or fewer	Significant loss or deterioration of <i>important</i> fish or wildlife habitat Restoration or compensation in kind highly possible	High economic losses affecting infrastructure, public transportation, and commercial facilities
Very high	Permanent	100 people or fewer	Significant loss or deterioration of <i>critical</i> fish or wildlife habitat Restoration or compensation in kind possible but impractical	Very high economic losses affecting important infrastructure or services (e.g., highway, industrial facility, storage facilities for dangerous substances)
Extreme	Permanent	More than 100 people	Major loss of <i>critical</i> fish or wildlife habitat Restoration or compensation in kind impossible	Extreme losses affecting critical infrastructure or services (e.g., hospital, major industrial complex, major storage facilities for dangerous substances)

Notes:

^a Definitions for population at risk:

None = There is no identifiable population at risk, so there is no possibility of loss of life other than through unforeseeable misadventure.

Temporary = People are only temporarily in the dam-breach inundation zone (e.g., seasonal cottage use, passing through on transportation routes, participating in recreational activities).

Permanent = The population at risk is ordinarily located in the dam-breach inundation zone (e.g., as permanent residents); three consequence classes (high, very high, extreme) are proposed to allow for more-detailed estimates of potential loss of life (to assist in decision making if the appropriate analysis is carried out).

^b Implications for loss of life:

Unspecified = The appropriate level of safety required at a dam where people are temporarily at risk depends on the number of people, the exposure time, the nature of their activity, and other conditions. A higher class could be appropriate, depending on the requirements. However, the design flood requirements might not be higher if the temporary population is not likely to be present during the flood season.

9.8.3 Design Flood and Earthquake

Table 9-11 provides the recommended guidelines (CDA, 2007 as amended in 2013) for required spillway capacity and stability under earthquake conditions based on the dam risk classification. According to these guidelines, dams with a high risk classification should be designed to pass an Inflow Design Flood (IDF) equal to one-third the value between a 1-in-1,000-year flood and a PMF, and to be able to withstand an earthquake with a 2,475-year recurrence interval.

Table 9-11. Flood and Earthquake Loading Conditions, Standards-Based Approach – CDA, 2007 as amended in 2013 (Target Levels for Initial Considerations and Consultation between Owner and Regulator)

Faro Mine Remediation Project

Dam Class ^a	AEP	
	IDF ^b	EDGM ^c
Low	1/100	1/500
Significant	Between 1/100 and 1/1,000 ^d	Between 1/100 and 1/1,000
High	1/3 between 1/1,000 and PMF ^e	1/2,475 ^f
Very High	2/3 between 1/1,000 and PMF ^e	1/2 between 2,475 ^f and 1/10,000 or MCE ^e
Extreme	PMF ^e	1/10,000 or MCE ^e

Notes:

^a As defined in Table 9-6, Dam Classification.

^b Extrapolation of flood statistics beyond 1/1,000 year flood (10^{-3} AEP) is not acceptable.

^c Mean values of the estimated range in AEP levels for earthquakes should be used. The earthquake(s) with the AEP as defined in Table 6-1B is then input as the contributory earthquake(s) to develop the EDGM parameters as described in Section 6.5 of the CDA guidelines.

^d Selected on the basis of incremental flood analysis, exposure, and consequences of failure.

^e PMF and MCE have no associated AEP.

^f This level has been selected for consistency with seismic design levels given in the National Building Code of Canada.

AEP = annual exceedance probability

EDGM = earthquake design ground motion

9.8.4 Nonstructural Failure Modes and Definition of Environmental Design Flood

The technical bulletin, *Application of Dam Safety Guidelines to Mining Dams* (CDA, 2014) lists several nonstructural failure modes associated with mining dams:

- Unplanned release of contaminated water via an emergency overflow spillway
- Release of excessive contaminated seepage downgradient from the dam
- Contamination of groundwater
- Excessive seepage causing the loss of water cover required over a tailings deposit to inhibit sulphide oxidation.
- Excessive erosion by wind resulting in dust releases (in the case of mining dams constructed of tailings)

The first three modes apply to the seepage collection dam. The first bullet is addressed by consideration of the Environmental Design Flood (EDF) in Section 3.5.2 of the technical bulletin. The EDF is defined as “the most severe flood that is to be managed without release of untreated water to the environment.” The technical bulletin notes that typical EDF return periods range from 1-in-50 years to 1-in-200 years, but that more stringent criteria may be required depending on the site conditions. The following are factors that would influence the selection of an EDF:

- Regulatory agency input
- Environmental consequences associated with the frequency, magnitude, and duration of an infrequent release
- Dilution that may be available from flood flows in the receiving water

- Time needed to draw down the EDF volume from the storage area
- Costs associated with varying degrees of environmental control

Given the anticipated toxicity of the contaminated seepage and runoff into the pond, the environmental consequences associated with even an infrequent release may be significant. However, the drainage catchment for the seepage collection pond is small (1.1 km² for Alternative 1 NFRC Seepage Collection Pond and 1.4 km² for Alternative 2 NFRC Seepage Collection Pond), compared to the 127 km² catchment for the NFRC, and much dilution would occur during large flood flows. An EDF with a return period of 1-in-200 years was adopted for this project.

9.8.5 North Fork of Rose Creek Seepage Collection Pond Storage

Contaminated inflows into the NFRC Seepage Collection Pond will consist of surface and/or groundwater from the WRDs and from the relatively small catchment around the existing NFRC upstream of the Haul Road embankment. It will also include groundwater from the eastern slopes that will flow underneath the new realigned NFRC channel.

The design intent is that all inflow up to the EDF will be either stored at the NFRC Seepage Collection Pond, pumped to the Faro Pit for temporary storage before treatment, or pumped directly to the IWTS for treatment. The pond-sizing analysis, presented in Appendix B, Hydrotechnical Report, shows that the combination of 300,000 m³ storage for the Alternative 1 location, 350,000 m³ storage for the Alternative 2 location, and 126 L/s pumping and conveyance will store and convey annual precipitation exceeding the annual 200-year return precipitation volume. Storage is assumed take place October through April and conveyance from the pond from May through September. The actual duration and timing of conveyance out of the pond will depend on the accumulated snow volume, the timing of snow melt, and the freshet volume. The pipelines and pump stations are designed to allow winter operations.

9.8.6 North Fork of Rose Creek Seepage Collection Dam Spillway Design

Based on a high hazard classification, the spillway of the NFRC Seepage Collection Dam should be designed to pass an IDF equal to one-third the value between a 1-in-1,000-year flood and a PMF. However, since the catchment is very small after the NFRC is realigned in the new channel and there are uncertainties in hydrology analyses of small catchments, the IDF was considered to be the PMF [*even the PMF flows are relatively modest*].

Because the NFRD will remain in place in the existing NFRC channel, it could potentially attenuate peak flood flows, i.e., it could retard flow and store water upstream of the rock drain. Results of evaluations performed to assess the attenuation of 1-in-500-year NFRC peak flood flows through the NFRD as part of the design evaluation for the Down Valley Interim Hydraulic Upgrades (CH2M, 2014a) indicate that attenuation depends on the assumption of permeability of the rock drain materials. There is about 18 percent reduction in NFRD peak flow when assuming a high flow-through scenario versus a 38 percent reduction in NFRD peak flow when assuming a low flow-through scenario.

Because the NFRC will be diverted into a new channel, flood flows in the existing channel will be much smaller than the flows in the NFRC for a given design flood. Consequently, the attenuation will be much smaller. Given the uncertainty in estimating attenuation of the relatively smaller flows through the rock drain, it was assumed that no attenuation occurs in the rock drain and the spillway of the NFRC Seepage Collection Pond was designed to pass the full IDF.

The pond area is relatively small and it is anticipated that attenuation of the inflow design flood because of storage in the pond will be small.

Impact of Potential Failure of North Fork of Rose Creek Realigned Channel on Spillway Capacity of North Fork of Rose Creek Seepage Collection Dam

A failure of the NFRC Realigned Channel dike upstream from the Haul Road will result in flows from a much larger catchment entering the NFRC Seepage Collection Dam catchment; therefore, its impact on the safety of the NFRC Seepage Collection Dam was considered.

The following evaluation steps were followed:

1. A breach of the NFRC dike upstream from the Haul Road causes flow from NFRC to enter the contaminated catchment upstream of the Haul Road and impound behind the NFRD as it does currently. The NFRD is part of the Haul Road embankment.
2. The impoundment is the result of water backing up or rising to a water level sufficient for seepage flow through the NFRD. The NFRD seepage flows will then enter into the NFRC Seepage Collection Pond. An increase in flows from a breach of the new NFRC Realigned Channel dike results in a higher water level to create greater seepage.
3. As the breach inflows increase, the water level will continue to rise until it ultimately overtops the dike that forms the right bank of the NFRC Realigned Channel and into the PMF culvert causing a flow split. The flow split changes with the flow from the breach resulting in different water elevations to pass the flow one way or another.
4. The flow split relationship was estimated between the NFRD seepage and flows back into the NFRC Realigned Channel for a range of breach flows up to the NFRC PMF flow.
5. The flows entering the NFRC Seepage Collection Dam assuming a breach with PMF flows in the NFRC are an order of magnitude greater than the estimated PMF from the local drainage basins (with contaminated catchment of 1.1 km² for Alternative 1 and 1.4 km² for Alternative 2).
6. The spillway for Alternative 1 NFRC Seepage Collection Dam is sized to prevent overtopping of the dam assuming a breach with PMF flows in the new NFRC Realigned Channel.
7. The emergency spillway for Alternative 2 impoundment is sized to prevent overtopping of the local PMF only. The diversion canal from the existing NFRC will overtop and washout for flows greater than the local PMF so that these greater flows would not compromise the off channel pond.

9.8.7 Freeboard Criteria

The CDA evaluated freeboard requirements for embankment dams in its *Dam Safety Guidelines* (CDA, 2007 as amended in 2013). The CDA requires calculations to be conducted for normal freeboard and minimum freeboard cases. Normal and minimum freeboard are defined by the CDA (2007 as amended in 2013) as follows:

“Normal freeboard is the difference in elevation between the lowest elevation of the top of the dam and the maximum reservoir operating level.”

“Minimum freeboard is the difference in elevation between the lowest elevation of the top of the dam and maximum still pool reservoir level that would result should the Inflow Design Flood occur.”

In addition, the CDA (2007 as amended in 2013) guidelines require that the thickness of material covering the impervious core of the dam be sufficient to avoid freezing of the core during winter months. The depth of frost penetration at the site is approximately 3 m. Design criteria for determining normal and minimum freeboard are shown in Table 9-12.

Table 9-12. Freeboard Requirements
Faro Mine Remediation Project

Freeboard Condition	Criteria	AEP of associated wind event	Reservoir Water Level
Normal	No overtopping by 95 percent of waves	1-in-1,000-year wind event	Maximum normal elevation
	Thickness of material covering impervious core is sufficient or provide insulation to avoid freezing of core during winter	N/A	
Minimum	No overtopping by 95 percent of waves	Low consequence dam AEP = 1-in-100-year wind event Significant consequence dam AEP = 1-in-10-year wind event High/Very High/Extreme consequence dam AEP = 1-in-2-year wind event	Maximum surge level during passage of the Inflow Design Flood

Note:

N/A = not applicable

Normal freeboard calculations are independent of the risk classification of the dam, requiring that the 1-in-1,000-year wind event be used for normal freeboard calculations. Minimum freeboard calculations have differing Annual Exceedance Probability wind requirements depending on the risk classification of the dam. Given the high hazard classification for the NFRC Seepage Collection Pond, minimum freeboard calculations used the 1-in-2-year wind event.

A minimum freeboard at the Alternative 1 NFRC Seepage Collection Dam of 2.9 m was adopted, which is considered adequate to prevent frost damage given the camber that will be incorporated in the design.

9.8.8 Required Factors of Safety for Slope Stability

Slope stability was evaluated against CDA criteria (CDA, 2007 as amended in 2013) for embankment dams under all pertinent loading conditions. As the CDA criteria recommends, a two-dimensional limit equilibrium slope stability analysis will be performed to evaluate the factor of safety against slope failure. Table's 9-12A and 9-12B summarize the published CDA criteria for static and seismic loading conditions, respectively.

Table 9-12A. CDA Required Factors of Safety for Slope Stability – Static Assessment
Faro Mine Remediation Project

Loading Condition	Minimum Factor of Safety	Slope
End of construction before reservoir filling	1.3	Upstream and downstream
Long term (steady-state seepage, normal reservoir level)	1.5	Downstream
Full or partial rapid drawdown	1.2 to 1.3	Upstream

Source: Adapted from CDA, 2007 as amended in 2013.

Table 9-12B. CDA Required Factors of Safety for Slope Stability – Seismic Assessment
Faro Mine Remediation Project

Loading Condition	Minimum Factor of Safety	Slope
Pseudo-static	1.0	Upstream and downstream
Post-earthquake	1.2 to 1.3	Upstream and downstream

Source: Adapted from CDA, 2007 as amended in 2013.

The liquefaction potential assessment is described in Appendix E, Geotechnical Report.. Results from the assessments for Alternative 1 indicate low liquefaction potential, so that it was not necessary to consider post-liquefaction stability. Since there is less available geotechnical information for Alternative 2, the liquefaction potential for that alternative is uncertain and will have to be confirmed with additional geotechnical explorations and analyses. If it is found that liquefaction potential is high, post-liquefaction stability and seismic deformations will be evaluated.

9.8.9 Filter Design Requirements

The dam was designed to control seepage exit gradients from the embankment and foundation to be within acceptable limits to minimize the risk of piping. Low permeability core in the dam embankment and seepage barrier (such as a grout curtain) in the foundation will reduce the seepage gradients, including exit gradients.

To stabilize seepage exit points, a filter/drainage system consisting of a chimney filter/drain and a blanket filter/drain under the downstream shell was incorporated into the design. Filter design criteria have been established to prevent migration of soil particles from the low permeability core into the drains.

Table 9-13 shows filter design criteria suggested by CDA (2007 as amended in 2013) as developed by Sherard, et al. (1984a, 1984b, and 1989). The criteria are similar to U.S. Army Corps of Engineers (USACE) (1993) and United States Department of Agriculture Natural Resources Conservation Service (1994) criteria. As stated in the CDA guidance (CDA, 2007 as amended in 2013), concrete sand is typically accepted as a satisfactory filter material where the base materials are silts and clays.

Table 9-13. Granular Filter Design Criteria
Faro Mine Remediation Project

Base Soil	Fines	Filter Criteria
1) Fine silts, clays	85 – 100%	$D_{15\text{filter}} \leq 9 \times d_{15\text{base}}$ (not smaller than 0.2 mm)
2) Sandy silts, clays	85 – 100%	$D_{15\text{filter}} = 0.7 \text{ mm}$
3) Sands and gravels	0 – 15%	$D_{15\text{filter}} \leq 4 \times d_{15\text{base}}$
4) Clayey/silty sands ^a .	15 - 40%	Intermediate between (2) and (3) –Depending on fines content

Notes:

a. For typical glacial tills, grading from coarse gravel to fines, field experience has shown that $D_{15\text{filter}}$ should be less than 0.7 mm.

Since the NFRC Seepage Collection Pond will store water contaminated by chemical originating from the WRDs, the filter and drain system must be designed to account for the adverse effects of these waters. The design incorporated the following additional criteria:

- Provide filter and drain materials consisting of inert aggregate to withstand acidic (low pH) attack.
- Design the system to minimize the potential plugging of the drains as a result of chemical precipitates such as iron ochre, which is formed by complex processes in the presence of oxygen and bacteria. These measures include:
 - Encapsulation of the drains with low permeability soil layers or durable bituminous geomembrane layers (Coletanche type)
 - Submergence of the horizontal (blanket) drainage layers
 - Redundancy and robustness of the internal filter/drainage system, for example, the dimensions of the filter/drain layers should be significantly larger than the dimensions of similar works in comparable dams retaining clean water. Also, there should be multiples of critical components, for example, five to ten horizontal drain outlet pipes.
 - Use multiple laterals draining into an open ditch rather than a main collector that drains to a single outlet. Incorporate cleanouts in the pipes with Y connections to allow jet cleaning. Incorporate “goosenecks” in the outlet pipes to prevent oxygen from entering the system.
 - Use large perforations (round holes) rather than small slits. The holes must be cleanly cut since ochre will tend to stick to frayed edges.
 - Use drain gravel surrounding the drain pipes as coarse as possible, but still be able to filter the filter sand.

9.8.10 Surface Erosion

The upstream slope of the Seepage Collection Dam will require protection against surface erosion from wave action and ice loading. Riprap is typically used to provide this protection. A riprap bedding layer will separate the riprap from the embankment material.

The downstream embankment slopes will be protected against surface runoff by either establishing a grassy vegetation cover or adequately sized materials to provide erosion protection, based on the selected downstream slope.

9.9 Construction Staging

The design criteria for construction staging will be developed in conjunction with further development of alternatives and construction schedules in the Final DBR. Considerations in developing the design criteria for construction staging will include the following:

1. Design requirements for selected materials of construction, location, type, and quantity of materials (borrow sources)
2. Construction schedule, time (month) of year for mobilization to the site and time of year for actual construction.
3. Number of construction subcontracts planned for the work
4. Integration of phased construction with site operations
5. Sequence of construction based on funding availability and funding streams; restrictions of funding based on fiscal year budgets

9.10 Climate Change

The life of various infrastructure projects is inherently long such that specific design aspects of the work may become vulnerable to a range of environmental risks over that time span. Climate change and the effect of extreme weather frequency and severity may present challenges to the infrastructure greater than initial design had anticipated. For this reason, it is important for infrastructure projects to anticipate future environmental factors and, assess, design, and implement mitigations to those factors within the design.

In general, adaptive engineering design plans would require the following:

- Considering climate change and extreme weather events and designing accordingly
- Identifying design components most at risk from climate change and extreme weather
- Developing a climate and vulnerability screening analysis, information, and sources, and summarizing changes in temperature, precipitation, and other climactic variables over the design life of the project
- Identifying the vulnerabilities of design components based on climatic changes
- Developing adaptation strategies to address vulnerabilities.
- Developing and implementing design criteria based on evaluation

The following topics will be considered in the adaptive management assessment for the NFRC Project:

- Climate and meteorology effects, including the following:
 - High, low, and normal precipitation
 - High and low extreme temperatures
 - Freeze-thaw cycles
 - Changes in permafrost
 - Climate change
- Geophysical effects, including the following:
 - Snow avalanches
 - Channel debris flow
- Flooding effects
- Wildlife effect

Design Standards

10.1 Introduction

This section summarizes the as applicable design codes, guidelines, and standards to be used for each primary discipline, including international, national, industry, engineering discipline, regulatory and company standards. As with other sections of this Preliminary DDBR, this section will be updated as appropriate in the Final DBR.

10.2 Electrical

The electrical supply system, NFRC Seepage Collection Pump Station, and temporary electrical routing and supply system designs will be based on the following codes and standards:

- Codes:
 - CEC 2015
 - CSA C22.2 No. 0 General Requirements – CEC – Part 2
 - CAN-C235 Preferred Voltage Levels for Alternating Current (AC) Systems, 0–50,000-volt
- Standards:
 - CSA
 - American National Standards Association
 - NEMA
 - Institute of Electrical and Electronic Engineers
 - Insulated Cable Engineers Association
 - Canadian Occupational Safety and Health Administration (OSHA)
 - Underwriters Laboratories of Canada
 - National Fire Protection Association
 - Factory Mutual (FM) Global (YG to confirm if FM Global is an insurance underwriter for FMC, if not this standard can be removed)

Standardization will be applied wherever possible to facilitate O&M activities.

10.3 Mechanical and Pipelines

The NFRC Conveyance Pipeline will be designed in accordance with Plastic Pipe Institute handbook (2007) recommendations and CH2M best practices depending on operations assumptions (i.e., cold or warm weather operation). Where applicable, Chapter 7.2, Design of Belowground Pipelines in Cold Regions, of McFadden and Bennett (1991) and Pipelines in Permafrost: Geotechnical Issues and Lessons (Oswell, 2011) will be used to determine design frost depth, insulation and trench configuration for buried insulated cold weather operation pipeline. Where applicable, air pockets analysis will be based on methods developed by H.T. Falvey (1980). Surge analysis was not performed at the conceptual design stage. However, it is recommended that at the next design phase that if surge protection is required, analysis should address both surge and fatigue for design life requirements.

10.4 Structural

Structural design for foundations, Haul Road and Mine Access Road culverts, valve vaults and the NFRC Seepage Collection Pump Station building will be designed in accordance with the NBC (NRC, 2010), CH2M best practices, and the following guidance documents:

- User Guide, NBC 2005 Structural Commentaries: Commentaries J & K (NRC, 2005)
- ASCE Standard SEI/ASCE 32-01, Design and Construction of Frost-Protected Shallow Foundations (ASCE, 2001)
- 2006 Canadian Foundation Engineering Manual, 4th Ed. (Canadian Geotechnical Society, 2006)

10.5 North Fork of Rose Creek Seepage Collection Dam

Preliminary engineering analyses for conceptual design of the Seepage Collection Dam Alternatives were performed using the CDA dam safety guidelines (CDA, 2007 as amended in 2013). The guidelines addresses relevant topics, including the following:

- Dam-breach analysis and inundation mapping, dam failure consequences, and hazard classification
- Analyses and assessment (hydrotechnical, seismic, geotechnical, and structural)
- Operation, maintenance, and surveillance including visual inspection and dam instrumentation
- Emergency preparedness
- Dam safety review

The design flood flows necessary to determine the required spillway capacity is evaluated based on the hazard classification of the dam. Similarly, the design earthquake loading used for the project depends on its hazard classification. The 2013 revisions updated the suggested earthquake design levels for a standards-based design approach. The revisions also provide suggested design levels for flood and earthquake as a function of societal risk target, when following a risk-informed design approach.

Relevant technical bulletins accompanying the CDA guidelines were used, and include the following:

- Dam Safety Analysis and Assessment (CDA, 2007)
- Hydrotechnical Considerations for Dam Safety (CDA, 2007)
- Seismic Hazard Considerations for Dam Safety (CDA, 2007)
- Geotechnical Considerations for Dam Safety (CDA, 2007)
- Structural Considerations for Dam Safety (CDA, 2007)
- Application of Dam Safety Guidelines to Mining Dams (CDA, 2014)

Additional relevant references are as follows:

- Engineer Manual 1110-2-1902, “Engineering and Design – Slope Stability” (USACE, 2003)
- Engineer Manual 1110-2-2300, “General Design and Construction Considerations for Earth and Rock-Fill Dams” (USACE, 2004)
- Design Standards No. 13, Embankment Dams (U.S. Bureau of Reclamation, 2011)
- Design Standards No. 13, Embankment Dams, Chapter 13 - Seismic Analysis and Design (U.S. Bureau of Reclamation, 2001)
- Seismic Design Guidelines for Dikes, 2nd edition (BC Ministry of Forests, Lands and Natural Resource Operations, 2014)
- “Assessment of Key Design Aspects of a 150-ft-high Earth Dam on Warm Permafrost” (Hammer et al, 1988)

- *Permafrost Engineering Design and Construction*, Chapter 9, Dams and Reservoirs (Johnson & MacPherson, 1981)
- *Soil Strength and Slope Stability*, 2nd edition. (Duncan, et al., 2014).

10.6 Geotechnical

Geotechnical design will be carried out according to the following relevant accepted documents:

- *Frozen Ground Engineering*, 2nd edition (Andersland and Ladanyi, 2004), considered the most accepted, comprehensive, and frequently-cited reference for geotechnical engineering in the far north
- Canadian Foundation Engineering Manual, 4th edition (Canadian Geotechnical Society, 2006) (currently being updated)
- *Soil Strength and Slope Stability*, 2nd edition (Duncan et al., 2014).
- Foundations in Permafrost Engineering Design and Construction (Johnston, 1981)

In situ testing (e.g., SPT, field vane shear test, and permeability [slug test]) and sampling (e.g., thin-walled Shelby tubes) during subsurface explorations will be carried out in accordance with ASTM standard test methods. Groundwater monitoring wells will be installed and groundwater levels measured in accordance with ASTM standard practices. Rock permeability testing (packer test) will be performed in accordance with generally acceptable geotechnical engineering practice.

Soil, rock, and ground ice conditions will be logged and classified for engineering purposes in accordance with Chapter 4 of the Canadian Foundation Engineering Manual. Index properties of soils and fill materials (both natural and processed rock fill) will be tested in the laboratory for geotechnical characterization in accordance with ASTM standard test methods. The geomechanical properties of the rock mass, including discontinuities and joint infill materials, will be characterized in accordance with International Society of Rock Mechanics and ASTM standard guides. Estimates of shear strength parameters of overburden foundation soils and embankment materials were made using guidelines by Duncan et al. (2014). Estimates of shear strengths for frozen, fine-grained soils with ice were made using guidelines by Johnston (1981).

The physical properties and factory and field seams in geosynthetic textile and liner products will be tested in accordance ASTM standard test methods.

Cement used in concrete construction is manufactured to the CSA standard for cementitious materials for use in concrete. Concrete will be manufactured in accordance with CSA standards for concrete materials and construction. Aggregate testing and suitability will be carried out in accordance with CSA standards.

Earthquake loading will be based on recently published site-specific seismic hazard assessment. The seismic hazard assessment for the site was updated in 2013 by Atkinson and Assatourians (2013), resulting in significantly lower estimated ground surface motions associated with local seismic conditions than those presented by Atkinson's previous seismic hazard assessment (2004) (see also project document "Update on the Tectonic Setting of the Faro Mine Complex, Faro Mine Remediation Project," February 12, 2013). The level of earthquake loading for the seepage collection dam will be determined based on its hazard classification, determined in accordance with CDA guidelines (CDA, 2007 as amended in 2013) dam safety guidelines. The geotechnical stability of other slopes, embankments, and foundations under seismic loading will be assessed for a seismic event with a median probability of 2 percent in 50 years (1-in-2,475-year recurrence interval).

The design of the realignment of NFRC will use a number of guidelines and best management practices that are applicable to management of flood protection works (levees and dikes). Those developed by YG will take precedence followed by those developed by British Columbia. These guidelines and best management practices will include the following:

- Best Management Practices for Works Affecting Water in Yukon (YG, 2011)
- Guidelines for Management of Flood Protection Works in British Columbia (BC Ministry of Environment, Lands, and Parks, 1999)
- Dike Design and Construction Guide. Best Management Practices for British Columbia. (BC Ministry of Environment, Lands, and Parks, 2003)
- Environmental Guidelines for Vegetation Management of Flood Protection Works to Protect Public Safety and the Environment (Department of Fisheries and Oceans Canada and BC Ministry of Environment, Lands, and Parks, 1999)

10.7 Climate Change

As stated in Section 9, climate change and the effect of extreme weather frequency and severity may present challenges to the infrastructure greater than initial design had anticipated. For this reason, it is important for infrastructure projects to anticipate future environmental factors and, assess, design, and implement mitigations to those factors within the design.

An adaptive management assessment will be completed for this project in accordance with Technical Circular T-06/15, *Climate Change and Extreme Weather Preparedness and Resilience in Engineering Infrastructure Design* (BC Ministry of Transportation and Infrastructure, 2015).

Potential Alternative Designs

11.1 Introduction

The intent of the design of the NFRC Project is to protect the NFRC by achieving stable, long-term separation of clean (non-contact) water and mine-impacted contaminated water. This will involve constructing a new realigned engineered channel to divert clean water away from areas where the NFRC is currently impacted, or will be impacted in the future, by mine-impacted groundwater and seepage from the WRDs. In general, the existing NFRC footprint will collect mine-impacted contaminated seepage and convey it downstream to the NFRC Seepage Collection Pond, where it will be temporarily stored before being pumped (1) to the Faro Pit for storage and subsequent treatment or (2) to the IWTS, where it will be treated and then discharged to the environment after meeting water quality criteria.

The NFRC Realigned Channel will be lined in Segment 2, upstream of the Haul Road, to minimize the volume of clean water collected in the contaminated water system and requiring treatment. The NFRC Realigned Channel will be offset a minimum horizontal distance of 20 m from the mine-impacted contaminated water collected in the NFRC Permanent Seepage Collection Trench. The NFRC Realigned Channel invert will be elevated above the NFRC Permanent Seepage Collection Trench to minimize the potential for contaminated seepage entering the clean water conveyance system.

CH2M (2015a) evaluated alternative water management and remediation strategies for NFRC. Following are the objectives and approaches of each strategy developed and assessed:

1. Relocate NFRC to the east and lift its invert to obtain positive separation from existing alluvial flow and future WRD seepage. Route this new channel through the Haul Road east of the NFRC through a culvert to maintain the Haul Road for future closure work, and then southwesterly across to the existing SFRC downstream of the Mine Access Road.
2. Keep impacted WRD seeps and groundwater from entering the NFRC by capturing them in the existing creek channel, an additional channel just to the west, or both, depending on the location of the NFRC Realigned Channel.
3. Reduce seeps of clean water from entering the impacted groundwater by reducing the footprint of the WRD-side of the NFRC watershed through selective grading and ditching of the WRDs at the top of the slopes to shed clean water to the south or west. Potential grading or ditching of the WRDs has not been included in the DBR or Conceptual Design.
4. Collect mine-impacted contaminated water from the WRD-side of the NFRC watershed using the same channels used for WRD seeps and convey it to the NFRC Seepage Collection Pond. Create the pond by constructing a dam in the existing NFRC channel below the Haul Road and above the Mine Access Road (Alternative 1 location) or between the Mine Access Road and the RCAA (Alternative 2 location). This collection pond would be sized, to the extent practicable, to store water over the winter. A pump station and pipeline would convey water to the IWTS or Faro Pit for treatment.
5. Collect seeps at their source if it cost-effectively reduces O&M associated with the channel system.

CH2M (2015a) assessed the following three types of mitigations:

- Placement of covers having a range of permeability values over the top surface of the WRDs.
- Incorporation of low-permeability linings within new stream diversions to reduce leakage of clean water to areas requiring collection and treatment.
- Placement of groundwater cutoff walls and SISs.

Cost-benefit analyses were carried out. The results of the analyses indicated that selective placement of linings over areas that are very geochemically reactive may be cost-effective depending on the incremental cost of adding the liner versus the treatment cost of contaminated water. Costs exceeded the benefits for installation of cutoff walls. The preliminary analysis indicated that benefits exceeded costs for adding linings to new diversions.

CH2M (2015a) assessed four alternatives for the NFRC, as summarized in Table 11-1 and shown on Figure 11-1.

Table 11-1. North Fork of Rose Creek Alternatives

Faro Mine Remediation Project

Alternative	Name	Description
TA-1	Draft 4A Alignment— Raised Channel	NFRC reconstructed along existing diversion alignment as a raised channel with a cutoff wall near confluence with FCD. Haul Road removed as a barrier. Ties into the SFRC directly upstream of the existing RCD. Requires design for access road crossing.
TA-2	Alignment 1A	Realignment of NFRC upslope to the east of existing diversion. Haul Road removed as a barrier. Requires design for access road crossing. Ties into new SFRC. Consideration of cutoff walls at confluence with FCD and along SFRC.
TA-3	Cutoff Wall	Groundwater cutoff wall along entire extent of existing NFRC to separate potentially impacted groundwater from clean surface water in NFRC. Requires upgrade and construction of new NFRC along existing alignment to PMF capacity. Haul Road removed as a barrier. Ties into SFRC directly upstream of the existing RCD. Requires design for Mine Access Road crossing.
TA-4	Alignment 1B	Realignment of NFRC upslope to the east of existing diversion upstream of Haul Road and alignment of lower section downstream of the Haul Road to connect with existing NFRC and to RCD. Lining of channel to prevent interaction of potentially impacted groundwater with surface water. Consideration of parallel conveyance channel vertically offset from NFRC to convey impacted surface water and groundwater from WRD to stormwater management facility. Consideration of cutoff walls at confluence with FCD. Haul Road removed as a barrier. Requires design for Mine Access Road crossing. Ties into SFRC directly upstream of the existing RCD. Consideration of cutoff walls at confluence with FCD and along SFRC.

The development of the alternatives involved preparation of conceptual designs to the extent necessary to compare the alternatives. Table 11-2 presents the criteria that were used to assess the alternatives.

Table 11-2. Alternative Assessment Criteria

Faro Mine Remediation Project

Evaluation Criteria	Basis of Evaluation
Implementability and Constructability	Remedial method is tested and sound; full-scale analogues have been implemented and proven effective in this type of environment. Is specialized equipment and labour required to construct? If yes, is this available? Sufficient engineering and other design data are available to fully evaluate constructability What is the level of difficulty in constructing? What changes to site conditions must take place in order to construct? Consideration of cold regions and permafrost impacts?
Effectiveness and Longevity	Extent to which the alternative achieves the FMRP objective. The reliability of the technology in achieving objectives. Durability – long-term performance with minimum maintenance required. Natural versus manmade materials.

Table 11-2. Alternative Assessment Criteria
Faro Mine Remediation Project

Evaluation Criteria	Basis of Evaluation
	Robustness; that is, the ability to adjust to unexpected field conditions, upsets in its operations, and long-term climate changes. Can monitoring determine whether alternative meets the objectives? Adaptability – the ease in which an alternative can be modified to improve its performance. Can it be changed if it does not meet achieve objectives? Risk of failure – does alternative introduce potential risks of failure?
Required Long-term Care and Maintenance	Does alternative require more or less regular/routine maintenance? Is there risk and consequence of failure requiring extensive care and maintenance? Are specialized skills and/or equipment required to perform care and maintenance? Operational ease considering the level of training of the field staff and the harsh weather conditions.
Capital Costs	Qualitative assessment of capital costs.
Operating and Maintenance Costs	Qualitative assessment of routine C&M costs, surveillance and monitoring.
Replacement and Non-routine Maintenance Costs	Qualitative assessment of non-routine C&M costs.
Interaction with Adjacent/Other RUs/Components	Compatibility with other RUs/components. Does the implementation of this alternative help or hinder construction and operation of other RUs/components?

Based on the alternatives evaluation, TA-4 was selected as the recommended alternative (CH2M, 2015a). Using the TA-4 alignment as the basis, four potential NFRC channel alignments (P1 through P4) were developed. Figure 3-1 shows the plan view of these alignments. The alignment and configuration of this alternative has since been refined based on geotechnical data collected in the Phase 1A site exploration of Segment 2 (BGC, 2015) and during the summer 2015 Phase 2 exploration.

11.2 North Fork of Rose Creek Realigned Channel Alternatives

11.2.1 North Fork of Rose Creek Alternative Alignments

As shown on Figure 3-1, the NFRC can be divided into the following six segments:

- Segment 1: first 800 m of NFRC from the confluence with the FCD to the south
- Segment 2: from the Haul Road approximately 1,300 m north to Segment 1
- Haul Road crossing
- Segment 3: between the Haul Road and the Mine Access Road
- Mine Access Road
- Segment 4: south of the Mine Access Road to confluence with the existing SFRC

Siting of the NFRC Realigned Channel requires a contiguous (but not necessarily constant) hydraulic gradient between the channel inlet (Segment 1) and the outlet at the SFRC (Segment 4). Drawings C-6 and C-7 in Appendix F, show the profiles of the P3 and P4 alignments.

Drawing C-8 and C-9 in Appendix F show the typical cross sections assumed in preparation of the plan views and the profiles.

11.2.2 Permafrost Design Considerations

Portions of the re-aligned NFRC channel cross areas underlain by permafrost with a temperature close to melting and potentially contains excess ground ice. Permafrost in these areas could melt with slight changes in surface temperature, and may be thaw-sensitive, that is, they could become wet, soft, or loose, and settle when thawed. In addition, excavated frozen soils containing high ground ice content (for the purpose of concept-level designs, these are frozen soils with more than approximately 15 percent excess ice by volume) are generally unsuitable for reuse as engineered fill materials unless thawed and dried to an extent that it can be compacted to a reasonably dense state. Therefore, there is limited value in selecting an alignment that balances cuts and fills.

In general, following are the general design guidelines for designing and constructing a diversion channel in this area that would require embankment construction or excavations (cuts) into existing ground:

- Minimize cuts in areas with permafrost with high ice content or cuts that penetrate the existing groundwater table.
- Remove frozen soils or organic layers with high ice content beneath the channel embankment footprint to improve the long-term embankment stability.
- Subexcavate frozen soils or organic layers with high ice content that will be left exposed (e.g., cuts) and replace with granular fill.
- Use embankment slopes angles no steeper than 2.5H:1V or cut slope angles no steeper than 3H:1V in areas with high ice content permafrost foundation soils. Steeper slope angles (e.g., 2H:1V) may be used in areas where the ice content in the permafrost foundation soil is low (i.e., less than 5 percent), or where the cut is covered by a 2- to 3-m-thick layer of coarse granular soils that buttresses the slope, slows the rate of permafrost thaw, and readily drains any meltwater that may be expelled because of permafrost thaw. The determination of embankment slopes will also be controlled by requirements for placement of the lining system.
- These initial guidelines will need to be updated in specific design recommendations following review of the Phase 2 site exploration results.

11.2.3 Segment 1

Upstream of Segment 1, the NFRC is relatively flat and there is limited opportunity to provide adequate vertical separation from the existing NFRC and a new, diverted NFRC. Groundwater modelling was completed to simulate the effectiveness of a cutoff wall located within Segment 1, between the Northeast WRD and the existing NFRC. A cutoff wall will be effective in cutting off the seepage and will be approximately 5 m to 10m deep. See Appendix C, Groundwater Report, for further details on the Groundwater Modelling. Drawings C-5 and C-10 in Appendix F details the cutoff wall and seepage collection system. Consequently, the preferred remedial option is to construct the cutoff wall, as opposed to lining the existing NFRC in Segment 1, because of the constructability of lining the existing NFRC. New monitoring wells were installed during the Phase 2 Summer 2015 site exploration at the toe of the WRD for assessing seepage from the WRDs in this segment. For more details refer to Appendix C, Groundwater Report.

Based on the results of the field exploration and the groundwater modelling, the proposed cutoff wall and NFRC Seepage Collection Trench within Segment 1 will be effective in conveying WRD seepage to a location downstream from the Segment 1 and Segment 2 intersection and away from the NFRC Realigned Channel.

Because the proposed NFRC Realigned Channel begins over 800 m downstream from the confluence with the FCD, changes and future alterations to the FCD are not expected to have an impact on the siting and design of the NFRC Realigned Channel. Additional sedimentation from the FCD does need to be considered in future FCD designs.

11.2.4 Segment 2

This segment comprises the area between the end of Segment 1 and the Haul Road. Within this segment, there is an opportunity to raise the new NFRC Realigned Channel vertically above the existing creek to provide separation between the clean and contaminated water systems. Alternative alignments were evaluated, assuming that the channel would either be excavated into the hillslope to the east, constructed within lined embankments, or a balance of the two. Permafrost distribution, ground ice characteristics, and groundwater seepage has been considered in the geotechnical design of the alignment, particularly for evaluating the stability of embankments and cut slopes (e.g., design slope angles and granular covers, and thermal protection blankets, placed over excavated slopes in permafrost) to improve the long-term stability of the cuts. In addition, the current stability of proximal slopes has been assessed.

Given the presence of permafrost with high ice contents (15 percent or greater, by volume) that are thaw-unstable (i.e., could become wet and soft when thawed), the preferred alignment was selected to minimize cuts into the east hill slope containing potentially permafrost soils with high ground ice content. The embankment location and configuration was confirmed following the completion of the Phase 2 site exploration program (for more details, see to Appendix E, Geotechnical Report). The location of the preferred alignment within Segment 2 is shown on Drawings C-2 and C-3 in Appendix F, Conceptual Drawings. Slight modifications to this alignment were made during the development of the conceptual design to account for the presence of ground ice, soft, and organic soils identified during the field exploration. A test cut, completed in January 2016, was an important feature of the exploration program to confirm suitability of the preferred alignment. It is recommended that the test cut be monitored throughout the spring and summer and lessons learned should apply to future design phases.

Within Segment 2, mine-impacted contaminated water will be collected within the NFRC Permanent Seepage Collection Trench and will flow through the Haul Road via the existing NFRD, and ultimately into the NFRC Seepage Collection Pond located downstream from the Haul Road, either at the Alternative 1 or Alternative 2 location. Where practicable, this collection ditch is located within the footprint of the existing NFRC. The ditch will consist of a combination of a gravel-filled trench and an open ditch. Based on the evaluation of geochemical stability (exposure of mine-impacted water to increased aeration), appearance, maintenance, and location with respect to other structures such as the realigned channel dike access road and potential regrading of the WRDs, the preferred alternative includes a subsurface component to keep the seepage buried and to have an open channel ditch above the subsurface drainage to convey seepage in the event that portions of the subsurface drainage get plugged over time. In the event of plugging the subsurface drainage be cleaned or replaced. Options to reduce precipitation of metals within the trench, discussed in Section 11.11, should be considered during the next stage of design. Drawings C-4 and C-10 in Appendix F show details of the NFRC Seepage Collection trench and the NFRC Temporary Diversion within Segment 2.

Drawing C-6 in Appendix F shows the profile of the NFRC Realigned Channel within Segment 2. As shown, a cut of approximately 15 m will be required at the approach to the Haul Road (Station 2+000) for the P3 alignment. It will be important to design this cut to create stability during and after construction. The 2015 field exploration program included borings and test pits to assist in evaluation of the cut. Refer to Appendix E, Geotechnical Report, for details.

11.2.5 Haul Road

A drainage structure is required to convey waters (PMF design criteria) from the realigned NFRC Diversion through the Haul Road. The crossing structure consists of a culvert(s) installed by either cut and cover or by installing the culvert by tunnelling through the road. The crossing is approximately 235 m long. The following alternatives were evaluated for this crossing:

- Alternative 1: Tunnel by Sequential Excavation Method (SEM) a 16 m wide by 8m tall arch culvert
- Alternative 2: Open cut twin 8-m-wide by 8-m-tall concrete box culverts

Concrete is a preferred material because of the corrosion potential of metals. The crossing is located in an area where the depth and extent of the Haul Road cut is minimized.

As shown on Drawings C-6 and C-7 in Appendix F (Station 1+990), an excavation of more than 40 m will be required for the P3 and P4 alignment at the Haul Road. The Haul Road is the preferred borrow area for the NFRC Realigned Channel in Segment 2. In order to use the Haul Road as a borrow source, re-profiling is recommended; however, in order to maintain a 5 percent maximum profile grade, the Haul Road profile can only be lowered by approximately 4.5m. By using these materials for construction of the channel dike there is an opportunity to reduce the volume of material that will need to be placed back on top of the culvert to re-establish the Haul Road.

11.2.6 Segment 3

This segment consists of the area between the Haul Road and the Mine Access Road crossing. Drawing C-2 in Appendix F shows alternative alignments P3 and P4 within Segment 3. The P1 alignment (shown on Figure 3-1) has been ruled out based on the preliminary field exploration work, which demonstrated that the P1 alignment (shown on Figure 3-1) does not have sufficient separation from the NFRC and the NFRC Seepage Collection Pond area. Of the remaining three alignments, the alternatives include traversing across or around (southeast of) the existing borrow area located south of the Haul Road. The P2 alignment (shown on Figure 3-1) cuts directly across the borrow area. The P3 alignment cuts transverse to the borrow area, connects with an existing drainage basin, and then cuts across a disturbed area. The P4 alignment maintains the P3 alignment within the existing drainage.

The preferred alignment under consideration is the P3. The alignments minimize the cut required for installing a culvert through the Haul Road, takes advantage of an existing drainage, provide a minimum offset of about 200 m from the NFRC channel at the NFRC, and is offset more than 400 m from the NFRC Seepage Collection Dam. This buffer minimizes the potential influence (both physical and chemical) that each water management system has on the other. Consequently, channel lining is not proposed for this segment of the NFRC Realigned Channel. Other considerations pertaining to selection of an alignment relate to heritage and cultural resources. The presence of the Trapper's Cabin, located near the P2 alignment, also renders this alignment less favourable. Alignment P4 provides additional channel length but it is not preferred because of the difficulty controlling the NFRC within the channel during high-flow conditions.

Step pools, or some other form of energy dissipation and control, need to be designed, analyzed, and integrated into the next stage of design for both Segment 3 and Segment 4. Detailed hydraulic modelling needs to support development of the design. Because of the lack of precedence for operation and proper functioning of step pools during extreme flow conditions, physical modelling may be required to confirm performance during extreme flow events predicted by the hydraulic modelling.

11.2.7 Mine Access Road

A culvert or bridge will be required to convey waters from the NFRC Realigned Channel from Segment 3 under the Mine Access Road to Segment 4. As discussed in Section 9, the TRC requested that the feasibility of constructing a Mine Access Road crossing to convey a PMF flood be evaluated. The Mine

Access Road has multiple existing culverts that convey flood events less than 1-in-100-year flood event (preliminary analyses of these culverts is presented in Section 5). For reliance on the Mine Access Road, these existing culverts will be evaluated and potentially upsized in the future. The following alternatives have been evaluated for the Mine Access Road crossing:

- Alternative 1: Open-cut twin 7-m-wide by 7-m-tall concrete box culverts
- Alternative 2: Concrete slab bridge with cast-in-place concrete drilled piles
- Alternative 3: Low-water crossing with a concrete culvert sized to convey the 1-in-100-year flood event with the remainder of flow overtopping the Mine Access Road. This alternative includes extensive armoring of the Mine Access Road crest and slopes with concrete. Because of the high costs for slope protection to prevent the road from washing out during a PMF, this alternative was eliminated from further consideration.

Based on the results of the Class 4 cost estimates, presented in Section 19, a concrete slab bridge is recommended for the Mine Access Road, if the PMF capacity remains the design criteria.

11.2.8 Segment 4

This segment consists of the area between the Mine Access Road and the SFRC. The design intent is to connect the NFRC Realigned Channel with the SFRC. The location of the alternative alignments within Segment 4 are dependent on the connections at the Mine Access Road with the Segment 3 alignments and the connection to the SFRC. As with Segment 3, channel lining (riprap) is only required for erosion protection (and not necessarily for creating a barrier to seepage) for this segment. Within the Segment 4 area, berms are required to control flood flows and provide protection for the Mine Access Road and downstream structures. Refer to Drawings C-2 and C-9 in Appendix F for details.

The discussion regarding step pools and hydraulic design, provided in Section 11.2.6, also applies to the Segment 4 design.

11.3 Seepage Collection Pond

The NFRC Seepage Collection Pond will be constructed to capture contaminated seepage from the WRDs, the Haul Road, and the S-Wells area. Two alternative locations have been identified for construction of the pond (Figure 3-1):

- Alternative 1: NFRC Seepage Collection Pond located downstream of the Haul Road, parallel to Segment 3 of the new NFRC channel, and upstream of the Mine Access Road (Figure 3-2). The pond will be created by building an earth dam across the NFRC valley about 150 m north (upstream) of the Mine Access Road.
- Alternative 2: An off-channel-lined NFRC Seepage Collection Pond located downstream of the Mine Access Road (Figure 3-3). For this alternative, contaminated water from the NFRC drainage (that is, the existing NFRC channel) will be directed through a newly constructed and lined diversion channel connecting a groundwater cutoff structure located upstream of the Mine Access Road to the lined pond located immediately east of the Original and Secondary Tailings Areas.

A third alternative comprising two ponds was initially considered: one pond upstream of the Haul Road that would provide about one-third of the storage capacity and another pond at the same location as the Alternative 1 location with a reduced storage capacity. It was concluded that the construction cost and concept for the lower dam would be similar to Alternative 1 and that the relatively minor benefits realized from a slightly smaller pond (less seepage losses) and lower embankment (less construction cost) would not outweigh the disadvantages and costs associated with developing an additional site to construct a second pond upstream of the Haul Road.

11.3.1 Description of Alternatives

11.3.1.1 Alternative 1

The pond will be impounded by a dam constructed across the existing Rose Creek Valley and located northeast of the Mine Access Road. The design intent is that the impounded pond will be unlined. As detailed in Section 13, the design storage capacity has been determined assuming that water will not be pumped from the pond for 5 to 6 months during the winter, with seepage and runoff waters collected during these months. Analysis has been conducted pertaining to the size of the seepage collection pond, the pipeline conveyance capacity, the IWTS treatment capacity, and warm weather and cold weather operations.

The proposed dam configuration, shown on Figure 11-12, is a zoned earthfill dam consisting of a low permeability material (Zone I) core in the centre with broadly graded granular (Zone II) shells on both the upstream and downstream sides of the core. The height of the dam will be in the order of 17 m, measured from the crest to the downstream toe, providing a storage volume of about 300,000 m³. The final height will depend on the final selected centerline location, which in turn will depend on the geology and the subsurface conditions encountered during additional field explorations.

The crest of the dam is 6 m wide and slopes of 3H:1V. A 5-m-wide bench is situated along the downstream slope at Elevation 1,078 m. The upstream slope is protected against erosion from wave action by a 0.6-m-thick layer of riprap and 0.3-m-thick riprap bedding layer. The downstream slope will receive a 0.4-m-thick layer of topsoil and be seeded. The minimum width of the low permeability core will also be 6 m. A core trench backfilled with low permeability material (Zone 1) with a minimum bottom width of 3 m will extend through the overburden soils to rock.

Since the NFRC Seepage Collection Pond will store water contaminated by chemicals originating from the WRDs, there are a number of design and operating conditions that differ from ponds that stores clean water. The design accounted for the effects of these contaminants on the internal filter and drain systems of the dams (for example, the filter and drain materials will consist of inert aggregate to withstand acidic attack). Another condition is the potential plugging of the drains as a result of chemical precipitates such as iron ochre, which is formed by complex processes in the presence of oxygen and bacteria. To minimize the effects of this type of plugging, special design measures have been incorporated into the design. This includes the following: (1) encapsulation of the internal drains by low permeability material, and (2) maintenance of the horizontal part of the drainage system in a submerged state that includes the use of “gooseneck” outlet pipes to prevent oxygen from entering the system.

A similarly-sized zoned earthfill dam was constructed as the Freshwater Supply Dam (breached in 2004); therefore, there is site precedence for constructing such a dam. It is proposed that some of the zoned fills remaining in the breached Freshwater Supply Dam be used as fill materials for the NFRC Seepage Collection Dam embankment. Preliminary assessments indicate that the breached Freshwater Supply Dam may contain adequate volume of zoned fills that may be reused for dam construction. Additional fill materials, such as filters and riprap, will be imported from elsewhere.

Preliminary findings of the Phase 2 site exploration indicate that foundation conditions in the vicinity of the proposed dam alignment consists of sand till with some cobbles and boulders overlying bedrock (phyllite or schist). The depth to bedrock is generally shallow (less than 6 m deep) south of the existing creek, and deeper (from 6 to over 30 m deep) north of the creek. The bedrock is generally moderately to highly weathered within approximately 3 m of the bedrock surface, and more competent below. Permafrost is discontinuous within the pond footprint, apparently absent south of the creek, but is more prominent in the lower portion of the valley north of the creek, to a distance of approximately 7 to 10 m from the edge of the creek, which is unfrozen (i.e., a talik). The permafrost is relatively thin (between approximately 2 and 5 m thickness) and at a temperature that is close to melting. The permafrost

generally contains high ground ice content that could become wet, soft, loose, or permeable when thawed. Permafrost thaw may also result in settlement. Given the marginal permafrost temperatures, it is likely not practical to construct a frozen cutoff wall with passive ground freezing systems (i.e. thermosyphons), as has been used elsewhere in the Canadian Arctic in areas with colder ambient and ground temperatures.

The design intent is to key the low-permeability core into low-permeability foundation (for example, intact rock). The key will be relatively deep, estimated to be up to 10 m deep. Whereas other seepage barrier options such as a soil-bentonite or cement-bentonite cutoff wall in the foundation were considered, the steepness of the valley slopes in the dam's centerline would make such an installation impractical. Also, given the relatively small length of the dam and the high cost of mobilizing the equipment associated with cutoff wall installation, excavation of overburden soils in a core trench (although deep) and replacement with low-permeability backfill is considered a more economical approach for this site.

Based on the results of packer tests performed in vertical drill holes, the permeability of rock formations below the dam site appears to be generally low ($k < 1 \times 10^{-4}$ cm/s) and no seepage barrier is recommended in the rock foundation at this stage. Additional borings are recommended at the site, including inclined borings to investigate the potential presence of vertical or near-vertical shear zones or faults that could cause significant seepage paths. If these additional investigations revealed high permeability zones, a multi-row grout curtain can be incorporated in the design.

Another option is to line the pond footprint with a geosynthetic liner. The disadvantage with a lined pond is that contaminated waters from the Haul Road, S-Wells, and WRDs will seep through the overburden underneath the liner rather than be captured in the NFRC Seepage Collection Pond. Furthermore, because of the sporadic distribution of permafrost, including zones with high ground ice content, within the pond footprint, ground settlement may occur after the liner subgrade has been prepared, unless all thaw-unstable permafrost has been removed. Significant differential displacements of the liner subgrade may cause liner strains and potentially tears through which contaminated water may be released into the underlying groundwater system. Extensive and widespread foundation preparation may be costly and challenging for construction.

Seepage from the drain pipes, abutments, and foundation is anticipated to be small (less than 3 L/s) and would infiltrate into the relatively permeable soils downstream of the dam or Mine Access Road. Monitoring wells will be installed downstream of the dam to monitor seepage quantity and quality. A seepage interception and collection system (wells or pond) could be installed downstream of the dam, as part of Adaptive Management, if it becomes necessary.

The pump station will be located in the dam embankment at the right abutment, upstream of the low-permeability core. The upstream shell of the dam will be widened by about 8 m to accommodate the vertical pumping wells and the pumping station structure. The facility will have two separate intakes: (1) a low level intake that will be located in the creek bottom with the intake conduit centerline at about Elevation 1,072.7 m, and (2) a high level intake with the intake conduit centerline of 1,084.9 m. The intake structure for both intakes will be a simple reinforced-concrete structure with a stainless steel trash rack. The low-level intake structure will be located about 2 m below the dead pool (Elevation 1,075 m) to provide thermal cover against freezing conditions. The outlet conduit will be HDPE pipe. There are no penetrations in the dam core since the intake pipes (suction headers) and the vertical pumping wells will all be located in the upstream shell of the dam. The pump station is described in detail in Appendix B (Hydrotechnical Report).

The concept for the spillway for the Alternative 1 dam is a riprap-lined trapezoidal channel in the left abutment of the dam. The channel bottom is 4 m wide and the maximum depth of the channel at the dam crest is about 3 m. The side slopes of the channel are generally 3H:1V, except in the vicinity of the crest, where the slopes are flattened to 6H:1V, to allow traffic over the dam crest to continue through

the spillway. The spillway starts at Elevation 1,085.2 m at the upstream end, then slopes up at 2 percent for a distance of about 40 m to Elevation 1,086.0 m. It then slopes up steeply at about 30 percent over a short distance of about 2 m to a maximum elevation of about 1,086.6 m. From this high point, the spillway slopes downstream at 2 percent (same as the crest) over the width of the crest. From the downstream side of the crest, the channel then slopes downstream at 5 percent for a distance of about 70 m to the end of the channel at Elevation 1,083.09 m. The spillway was sized to pass a design flood of $57 \text{ m}^3/\text{s}$, which is the flow through the rock drain upon a breach of the new NFRC channel dike under PMF flow conditions; this flow represent only a portion of the total PMF flow from the NFRC with the remainder of the PMF flows being passed through a new PMF culvert that will be installed in the Haul Road.

11.3.1.2 Alternative 2

Alternative 2 is an off-channel-lined NFRC Seepage Collection Pond located downstream of the Mine Access Road. The pond will have an active storage of $350,000 \text{ m}^3$ and will occupy an area of about $84,000 \text{ m}^2$. The catchment area draining to the Alternate 1 location equals 138 ha.

For this alternative, contaminated water from the existing NFRC channel will be directed through a newly constructed and lined diversion channel extending from a groundwater cutoff structure, located upstream of the Mine Access Road, to the lined pond that will be located immediately east of, and adjacent to the RCTA. The alternative consists of three main elements: (1) upstream cutoff, (2) diversion channel, and (3) a lined pond.

The NFRC diversion channel begins at a groundwater cutoff structure constructed across the existing NFRC channel upstream of the Mine Access Road. The diversion structure will be constructed upon bedrock and embedded within a weathered bedrock trench. The structure will be backfilled with soil on both sides. The diversion channel consists of a constructed earthen channel with a uniform slope and cross section, double geomembrane liner, and riprap channel lining.

The storage pond will be located upstream of the RCTA near the junction of the NFRC original channel, the NFRC Temporary Diversion and the SFRC flood plain. The pond will be developed through construction of an earthen embankment, with a maximum height of approximately 15 metres from the crest to the downstream toe of the embankment on the south side of the pond, nearest the SFRC. The pond will be located within the South Fork flood plain and will be underlain by over 40 metres of alluvial sand and gravel. A deeper till layer has been identified at depth. Groundwater will be located several metres below the bottom of the pond. The pond will be double lined with either HDPE or LLDPE and will contain a seepage collection layer to monitor seepage or defects in the primary liner.

The existing seepage infiltration ponds will be backfilled, following completion of the NFRC realigned Channel. The outside berms of the pond adjacent to the SFRC will be designed to pass a PMF flood event without failure.

The Alternative 2 pond has two spillways; a service spillway and an emergency spillway. The service spillway structure consists of a vertical, square (2.2 m), concrete weirbox installed within the western edge of the lined pond embankment running into and a 750-mm-diameter HDPE outlet pipe that penetrates the embankment and drains spillway discharge water 95 m to the secondary tailings surface. The vertical concrete structure penetrates the reservoir liner. At this time, no provision has been made for managing water directed onto the tailings surface.

When reservoir levels exceed 0.5 m over the service spillway crest (that is, Elevation 1,067.5 m), the emergency spillway will begin to activate. The emergency spillway is a reinforced low point in the reservoir crest that permits safe discharge of overflow into the pump house pond and the Rose Creek Diversion. The emergency spillway is located at STA 0+075 and has a width of 15 m, a crest elevation of 1,067.5 m, and 10H:1V slopes which permit vehicular access across the emergency spillway when there is no flow.

11.3.2 Criteria for Alternative Evaluation

The following criteria were considered for evaluating Alternatives 1 and 2 to make a recommendation regarding a preferred alternative:

- Cost and related uncertainty
- Downstream consequences of failure
- Dam embankment stability and reliability
- Seepage cutoff reliability — dam, dam foundation, and abutments
- Ease and complexity of construction
- Integration with pumping, piping, and power infrastructure
- Integration with overall closure plan
- Adaptability (flows of construction), i.e., to what extent can work be staged to provide flexibility in schedule
- Long-term and replacement cost
- Maintenance and operations cost

The alternative evaluation is discussed in the following section.

11.3.3 Alternatives Evaluation

An evaluation matrix is provided in Table 11-3. For each of the criteria listed in the previous section, a brief summary of the issues for each of the alternatives are provided. The last column provides an opinion on which alternative is considered to have the most favorable disposition for a specific criterion. From a review of the matrix, it is clear that Alternative 2 was the preferred alternative for most of the criteria. For the criteria where Alternative 1 was preferred, it was only by a small margin, with the exception of cost. It is estimated, as detailed in Appendix G, that the construction cost for Alternative 2 will be roughly 40 to 50 percent more than the construction cost for Alternative 1. Based on the criteria considered in Table 11-3, and anticipating higher risk for change orders when constructing Alternative 1, the Alternative 2 NFRC Seepage Collection Dam is recommended as the preferred alternative.

11.3.4 Recommendations for Final Design

The following aspects should be considered during the next stage of design:

Alternative 1 Seepage Collection Pond:

1. Possibility of permafrost occurrence and thawing of the permafrost due to presence of the proposed Alternative 1 pond at the toe of waste dump slope in an area near the S-wells. A preliminary and qualitative assessment is detailed in Section 4.7 in Appendix E, Geotechnical Report.
2. Potential for slope stability problems of pond slopes, specifically on the northwestern slopes, due to thawing of permafrost and rapid drawdown loading conditions. Preliminary analyses are detailed in Section 4.6 in Appendix E, Geotechnical Report.
3. Potential for wave benching and pond slope erosion due to wave action. Pond slopes within the inundation zone will become bare when soil cover, including lichen dies. Mitigation for wave benching, and need for maintenance should be discussed with the client during final design.
4. Filter and drain materials in the dam need to be inert in presence of low pH pond water. Borrow materials must be tested to confirm compatibility.
5. Configuration of the downstream side of the dam and, in particular, the drainage measures shown in the drawing. The concepts should be reviewed for aspects such as (i) chemistry of the pond water, (ii) characteristics of the dam building materials, (iii) foundation conditions, and (iv) constructability and maintenance issues.

Table 11-3. North Fork of Rose Creek Seepage Collection Pond Alternatives Evaluation
Faro Mine Remediation Project

Criteria	Alternative 1	Alternative 2	Most favorable
Estimated Construction Cost	See Appendix G	Appendix G	Alternative 1, but anticipate larger risk of change orders for Alternative 1
Dam Safety and Downstream Consequences of Failure	- Catchment is 1.1 km² and full pool storage is about 300,000 m³; released volume due to dam break under normal operating conditions is smaller than for Alternative 2. - If dam break is due to overtopping, a volume associated with the dam crest of about 565,700 m³ would be released, which is larger than for Alternative 2. - Dam is located in the creek so that there is a larger risk for overtopping during extreme flood events, including the possibility of a NFRC Realigned Channel dike breach	- Catchment is 1.4 km² and full pool storage is about 350,000 m³, released volume due to dam break under normal operating conditions is larger than for Alternative 1. - If dam break is due to overtopping, a volume associated with the dam crest of about 489,300 m³ would be released, which is smaller than for Alternative 1. - The pond will be located off-channel, so that extreme flooding in the existing creek, including the possibility of a NFRC Realigned Channel dike breach, would be routed over an overflow weir in the diversion channel and completely bypass the pond.	- Alternative 2, by small margin - The analysis presented in Appendix B indicates that for either alternative, a dam break would not result in overtopping and breaching of the ID Pond, and associated catastrophic release of tailings. However, there would be significant environmental consequence associated with the release of contaminated pond water. Released volume under overtopping conditions is larger for Alternative 1 than for Alternative 2, whereas released volume under normal operating conditions due to failure modes such as piping or slope failure would be larger for Alternative 2 than for Alternative 1.
Seepage Cutoff Reliability	- Zone earth embankment with low permeability material in dam core and cutoff trench extending to rock below the core; anticipate some seepage around abutments - Hydraulic head for full pool is relatively high, nearly 15 m	- Seepage cutoff structure at start of lined diversion channel is concrete and tight cutoff can be accomplished by keying into bedrock - Hydraulic head is very low at the cutoff structure and in the diversion channel; generally less than 1 m - Geomembrane-lined diversion channel and pond (double-lining system) - Hydraulic head against lined pond embankment is relatively low; about 6 m	- Alternative 2, by significant margin - Because of the lining systems for Alternative 2, the seepage rates from the pond should be very small. Seepage from Alternative 1 pond could be higher given the higher hydraulic head (nearly 15 m versus about 9 m for Alternative 2) and the incorporation of only a partial cutoff may be achievable at the Alternative 1 abutments).

Table 11-3. North Fork of Rose Creek Seepage Collection Pond Alternatives Evaluation
Faro Mine Remediation Project

Criteria	Alternative 1	Alternative 2	Most favorable
Ease and Complexity of construction	• Diversion and Dewatering: Although NFRC will be diverted into new NFRC Realigned Channel prior to construction, significant diversion and dewatering is required for deep core trench excavation and to protect partially constructed works from flood flows. A larger cofferdam and more pumping capacity is required over a longer time period than for Alternative 2. • Embankment construction is relatively complex due to: (1) relatively small construction footprint and steep abutments, (2) difficult access and staging of construction, (3) complicated filter/drain systems to minimize iron ochre clogging issues, (4) higher risk of damage to completed works due to flooding, and (5) challenges associated with zone embankment construction including moisture-conditioning and placement of Zone 1 material. • The reservoir area will need to be cleared of trees and large woody vegetation within the full pond area.	• Diversion and Dewatering: NFRC will be diverted into new NFRC Realigned Channel prior to construction, but diversion and dewatering is still required for excavation to construct concrete cutoff structure at start of diversion channel. The concrete structure could withstand overtopping as compared to the Alternative 1 earth dam, so smaller cofferdam and less pumping capacity is required over shorter time period. • Embankment construction is simpler since (1) construction footprint is relatively large with easy access and staging, (2) embankment construction is straightforward since section is homogeneous and Zone 2 material is easy to place and compact. • Construction includes geomembrane installation. • No need to clear reservoir area of trees and large woody vegetation	• Alternative 2, by significant margin • (Diversion and dewatering requirements are significantly smaller for Alternative 2. Large construction footprint, lower embankment height, and homogeneous section using Zone 2 material makes for simpler construction.)
Integration with Pumping/Piping/Power Infrastructure	• Straightforward integration with pumping/piping/power infrastructure • Potential permafrost below the low level intake will require excavation and replacement with non-frozen soils to prevent unacceptable settlement.	• Straightforward integration with pumping/piping/power infrastructure	Same for both Alternatives
Adaptability (Flows of Construction)	• Small construction footprint with limited opportunity for parallel construction. Sequential activities include diversion, dewatering, excavation, grouting (if required), backfilling of core trench, low level intake installation, embankment construction. Will be challenging to complete within one construction season.	• The construction area has a relatively large footprint and many of construction elements can be concurrent or overlapping	Alternative 2 (by significant margin)
Long-term and Replacement Cost	• Since embankment and spillway are constructed from earth materials, it is considered highly durable.	• Geomembrane materials have a finite lifetime but since it is unexposed it is anticipated to be >100 years. Koerner et al. (2011) noted that the lifetime of HDPE is dependent on field temperature with predicted lifetimes of 446 and	Alternative 1, by small margin (Lifespan of geomembranes less than for earth materials, but still considered to be adequately long).

Table 11-3. North Fork of Rose Creek Seepage Collection Pond Alternatives Evaluation
Faro Mine Remediation Project

Criteria	Alternative 1	Alternative 2	Most favorable
	Replacement costs mostly associated with pumping/piping/ power infrastructure.	106 years, for field temperatures of 20 and 35°C, respectively. Replacement costs associated with pumping/piping/ power infrastructure same as for Alternative 1.	
Maintenance and Operations Cost	- Potential for iron ochre clogging is an issue that will require maintenance. Cleaning of lateral drains required. Monitor to ensure submergence of horizontal drains. - Vegetation debris from pond area including soil cover that is expected to die from contaminated pond water, as well as sediment from sloughing pond slopes could present silting of low level intake. Periodic maintenance would include cleaning the trash rack and dredging of sediment around and against the intake structure.	- Potential for formation of icings and ice jams in diversion channel. Removal of ice and maintenance of riprap slopes in channel will be required. - Lesser sediment and vegetation in water, so that less maintenance is anticipated for the low level intake.	Alternative 2, by small margin

Notes:

°C = degrees Celsius

km² = kilometre square

6. Additional geotechnical explorations including packer testing in inclined borings to evaluate the need for a grout curtain in the bedrock. Results of packer testing performed so far in vertical borings indicate that the bedrock generally has low permeability and that a grout curtain may not be necessary.

Alternative 2 Seepage Collection Pond:

1. Requirement for a double-lining system in the diversion channel and in the pond. Given the proximity to Rose Creek and the vertical distance between the maximum operating water surface in the pond and the creek elevation, there is a significant risk of contaminating the creek when a major defect in the liner develops. Other leak detection systems such as monitoring wells between the pond and the creek need to be considered if a single liner is proposed.
2. Requirement for both a service spillway and emergency spillway. Consider deleting the service spillway since it will spill on the secondary tailings surface and it may require a channel to convey significant flows over the tailings to the intermediate impoundment.

11.4 South Fork Rose Creek

The NFRC Realigned Channel will be connected with the SFRC in the area of the segment 4 and alternative alignments P3. The preferred connection location has been evaluated based on the conditions observed during the field exploration, and evaluation of the local geomorphology and the requirements to establish a stable connection between the NFRC Realigned Channel and the SFRC. Stability in this context includes protection against erosion and anticipation of potential material deposition that could change channel continuity. Based on the results of these analyses, the design includes armoring of the existing banks downstream of the confluence with SFRC with riprap protection. Refer to Drawing C-13 in Appendix F for these details.

At the location of the Pump House Pond, shown on Drawing C-14 in Appendix F, the diversion of SFRC water to the North Fork Diversion will be plugged. This will help to isolate any seepage from the NFRC Seepage Collection Pond from contact with SFRC and allow a small amount of contaminated seepage from the NFRC Seepage Collection Pond to seep into the RCAA. Eventually, likely many years in the future, this small amount of seepage will be picked up at the CVD SIS.

If the Alternative 1 Seepage Collection Pond location is selected, the infiltration ponds, located downstream of the junction of the NFRC and the Mine Access Road (Drawing C-1 in Appendix F), will be filled and revegetated. With the diversion of the NFRC into the NFRC Realigned Channel, the ponds will be isolated from their clean water source. After construction of the NFRC Realigned Channel the principal water source into the infiltration ponds will be the contaminated seepage from the Alternative 1 NFRC Seepage Collection Pond. This seepage, planned to be minimal, will be directed into the North Fork Diversion and allowed to infiltrate into the RCAA.

If the Alternative 2 Seepage Collection Pond is selected, the infiltration ponds will also be filled, but the grading of this area will be modified to convey extreme flood events in case of spillage at the overflow feature at the diversion channel downstream of the Mine Access Road crossing. Because the diversion channel and the Alternative 2 Seepage Collection Pond will be both lined, negligible amounts of contaminated water will seep from the canal and pond.

For the next phase of design, the field investigation should include a bathymetric survey of the Pump House Pond and hydraulic modelling conducted to evaluate removal of the fill and performance of the existing weir. Preliminary hydraulic modelling indicates that the weir can remain in place and that the PMF flood flow can bypass the NFRC Seepage Collection Pond Alternative 2 location with minimal armoring of the embankment side slopes.

11.5 Rose Creek Diversion

Except for modifying the flow at the Pump House Pond and the North Fork Diversion, there are no current plans to modify the RCD within the NFRC Project. At the east limb of the Secondary Dam, seepage from the secondary Tailings Area into the RCD and the stability of the dam under earthquake conditions, with respect to liquefaction potential, were evaluated during the 2015 field exploration (for details, see Appendix E, Geotechnical Report).

11.6 Access Roads

The location of proposed access roads are shown on Drawing C-38 in Appendix F. These include the following:

- NFRC Realigned Channel Access Road (new road): The NFRC Realigned Channel will include a maintenance access road at the top of the dike for the length of the channel.
- Zone II Pit to FCD access road (existing road): Improved access will be constructed following existing roadways from the Zone II Pit area to the Zone II Outwash and to the confluence of the NFRC with the FCD.
- NFRC Seepage Collection Pond access roads (new roads): Access roads will be constructed at the new NFRC Seepage Collection Pond to provide access to the (1) crest of the NFRC Seepage Collection Dam (connection from both abutments), (2) dam spillway, (3) NFRC Seepage Collection Pump Station, and (4) interior of the reservoir for maintenance (removal of precipitates and sediment) at intake structures.
- Access roads will be constructed for the NFRC Seepage Collection Pond Alternative 2 location around the pond, into the pond and the inlet structure, and to the pump station.

11.7 Waste Rock Dumps

The Conceptual Design for the NFRC Realigned Channel and the NFRC Permanent Seepage Collection Trench must consider potential regrading options for the WRDs, in particular the WRDs that are either adjacent to the NFRC within Segments 1 and 2 or adjacent to the S-Wells area. Three different regrading approaches were presented in the *Alternative Status Report* (CH2M, 2015a). For development of the DBR Conceptual Design, regrading of the WRDs to a slope equal to 3:1 (horizontal to vertical) through a balanced cut and fill has been assumed.

Bedrock in Segment 1 is relatively shallow at the location of the proposed cutoff wall. For WRD closure and cover placement, to accommodate flatter slopes without cutting back into the WRDs, the Segment 1 cutoff wall would need to be moved closer to the NFRC, requiring a much deeper cutoff wall. As the NFRC Project design advances, compatibility with WRDs regrading will need to be further evaluated.

These alternative approaches need to be further developed in conjunction with the development of the site-wide remediation strategy and considered as the NFRC Project progresses from the Conceptual Design phase.

11.8 Borrow Areas

Section 3 provides a description of potential borrow source requirements and identifies potential borrow locations in Figures 3-5 through 3-7. Borrow material geotechnical and geochemical data is provided in the Geotechnical Report (Appendix E).

11.8.1 North Fork Rose Creek Realigned Channel

The NFRC Realigned Channel will require construction of a channel dike and geomembrane liner system for conveyance of NFRC flows. Construction of these elements will require processing and import of various materials from the FMRP site. The required materials are summarized in Table 11-4, and the following subsections summarize the recommended borrow approach. Discussion for each of the borrow sites is presented in the Geotechnical Report (Appendix E).

Table 11-4. Borrow Material Summary— North Fork of Rose Creek Realigned Channel

Faro Mine Remediation Project

Material Type	Required In-Place Volume (m³)	Proposed Borrow Source	Approximate Haul Distance (km)
Structural Embankment Fill	189,000	Site (Proposed Haul Road excavation)	n/a
Low Permeability Layer (Till)	55,000	Tailings Borrow Area East	1.5
Riprap Segment 2	34,000	Granitic Outcrop Quarry (undeveloped)	9
Riprap Segment 3 and Segment 4	12,000	Granitic Outcrop Quarry (undeveloped)	9
Riprap Bedding Segment 3 and Segment 4	7,000	Granitic Outcrop Quarry (undeveloped)	9
Unprocessed Granular Fill	69,000	Haul Road Borrow, Granular	0.6
Roadway Surfacing	7,000	Haul Road Borrow, Granular	0.6
Thermal Barrier and Underdrain	91,000	Haul Road Borrow, Granular	0.6
Drain Rock	30,000	Haul Road Borrow, Granular	0.6

Notes:

Haul distance estimated as the required travel distance from center of borrow source to the NFRC crossing of the existing Haul Road. Distance may vary based on contractor approach and actual route taken.

11.8.2 Structural Embankment Fill

The majority of the NFRC channel dike will be comprised of compacted structural embankment fill. The structural embankment fill will be select material obtained from the Haul Road excavation. The results of CH15-107-MW035 boring and other observations, indicate that the majority of the Haul Road at the proposed cut location is run of mine phyllite waste rock. This material will be selectively borrowed and minimally processed to produce suitable embankment fill meeting the minimum requirements noted in Section 3.3.5.8 in Appendix E. Owing to the uncertainty in the size and grain-size distribution of the in situ embankment fill, and the likely variation in run-of-mine material within the size of the cut, the exact processing requirements are uncertain. Additional subsurface data collection will aid in characterization of the material and refinement of processing recommendations. Note that the soft phyllite is susceptible to breakdown over time, and processing to produce a well-graded material which can be placed without excess voids is recommended for the long-term performance of the embankment; that is, a tight embankment will serve to prevent breakdown of the material which could result in instability, reduction in crest height, and/or stressing of the geomembrane liner.

At this design stage, it is recommended that processing will include a visual screening to manually exclude zones of material with evidence of sulfites or excess fines. Relatively soft and friable phyllite waste rock encountered in the excavation must be processed to obtain a well-graded material with the specified gradation (maximum size approximately 300 mm) for use as structural embankment fill. Such processing will likely require selective excavation and transport of suitable materials. It is possible that

the large net cut removed from the haul road embankment may reveal zones of alternate materials which are favorable for embankment construction without processing, such as native gravelly overburden soils or durable waste rock (calc-silicate or granodiorite).

The estimated required in-place volume of structural embankment fill is 189,000 m³. This material is expected to be entirely derived from the haul road embankment excavation required for the realigned channel construction, requiring a short haul distance, but also requiring construction of access roads.

11.8.3 Low Permeability Layer (Till)

The downstream (right) side of the geomembrane channel liner will be underlain by a layer of compacted low permeability glacial till to provide additional seepage resistance in the event of a geomembrane rupture. This low permeability layer will be excavated from the Tailings Borrow Area East and processed to remove coarse particles larger than 75 mm. It is preliminarily recommended that this material contain a minimum of 35 percent fines (percent, by weight, passing the No. 200 sieve).

The estimated required in-place volume of low permeability material is 55,000 m³. This material is expected to be entirely derived from the Tailings Borrow Area East, a haul distance of approximately 1.5 km; however, this haul distance may vary depending on contractor implementation of additional temporary construction access routes. Processing requirements are expected to include screening of particles larger than 75 mm, as well as avoidance of layers or zones of coarser material. Isolated zone of permafrost soils may be encountered in some locations within this borrow area, and such soils should not be permitted for incorporation into the embankment fill.

11.8.4 Riprap and Riprap Bedding

The NFRC Realigned Channel will be armored to protect the underlying channel materials from erosion and scour. The armoring material will be coarse riprap as noted in Section 4 of the Geotechnical Report (Appendix E). Riprap gradations vary along the channel alignment, and the median size (D_{50}) is 300 mm for Segment 2 and 500 mm for Segment 3. The in-place thickness of this material is shown as $2 \cdot D_{50}$. In some locations the riprap will be placed upon a layer of riprap bedding, in other locations articulated concrete block mats (ACBMs) are recommended. Both the riprap and riprap bedding material are hard, durable, angular stone resistant to weathering and freeze thaw processes. It is estimated that Segment 2 will require an in-place volume of 34,000 m³ of 300 mm riprap placed upon ACBMs. Segments 3 and 4 will require placement of 12,000 m³ of 500 mm riprap upon 7,000 m³ of riprap bedding.

Note that the riprap sizing requirement need to be confirmed during detailed hydraulic modelling, which is required for the next phase of the design.

The combined in-place volume of coarse rock fill (riprap and riprap bedding) for the NFRC channel is 133,584 m³. This volume exceeds the estimated quantities of available riprap in the Faro Pit area. It is recommended that this material volume be obtained by development of a new quarry. The preferred quarry material is located at the Granitic Outcrop, with a haul distance of approximately 9 km.

Other riprap sources are also available which may be considered for selection of final design recommendations. Such sources include the following:

- Main Dump -calc-silicate, approximately 40,000 m³, approximately 1.8 km haul, crushing required
- Northeast WRD - approximately 34,500 m³, 1.6 km haul, sorting of waste rock required
- Rose Creek quarry - quantity varies by disturbance, 5 km haul, requires temporary access bridge over RCD channel,
- NFRD - 720,000 m³, 0.2 km haul, requires reprofiling of the Haul Road

These sources, along with development of the granitic outcrop source, and other sources may be available to provide the volume of quality durable riprap necessary to meet riprap demands for the project as dictated by project economics, amount of additional site disturbance, and other factors.

11.8.5 Unprocessed Granular Fill

The unprocessed granular fill material will be placed on the downstream (right) face of the NFRC channel dike. This material provides containment of the structural embankment fill to protect this material from weathering and degradation, this native sandy material is also expected to improve the aesthetics of the completed embankment and allow for better placement of topsoil, if desired to allow vegetation growth. The material is recommended to be granular soil with less than 10 percent fines, and with a maximum allowable size of approximately 300 mm.

The recommended borrow source for the unprocessed granular fill is the Haul Road Borrow Area/Granular. Sandy, gravelly, and cobbly soils available from this borrow source may be loaded and hauled directly to the NFRC channel dike without processing. Manual exclusion of oversize materials using a rock rake, or materials with excess fines is recommended. The estimated in-place volume of unprocessed granular fill is 69,000 m³. This material may be entirely sourced from the haul road borrow area, an estimated haul distance of 0.6 km.

11.8.6 Thermal Barrier and Underdrain

The thermal barrier and underdrain layer is a relatively clean sand or sandy gravel placed on the channel dike subgrade and against the cut (left) face of the channel excavation. This material will be placed to prevent accelerated thawing of frozen soils encountered along the alignment, and will form a pervious underdrain system for conveyance of slope seepage beneath the liner to the Seepage Collection Trench.

The recommended material for the thermal barrier is a clean sand with a maximum particle size of 100 mm and less than 6 percent fines. The estimated required in-place volume of thermal barrier and underdrain material is 91,000 m³. This material can be obtained directly from the Haul Road Borrow area with minimal screening to remove oversized materials. The estimated haul distance is 0.6 km.

11.8.7 Roadway Surfacing

The embankment crest will be topped with a gravel roadway surfacing for vehicle access. This material will be a well-graded sandy gravel material with less than 10 percent fines and a maximum particle size of approximately 40 mm. While it is preferred to use crushed angular gravel, material present on the Haul Road appears to perform well, without processing other than screening over a grizzly.

The estimated required in-place volume of roadway surfacing is 7,000 m³. This relatively small volume of material can be obtained from the Haul Road Borrow Area. The estimated haul distance is 0.6 km.

11.8.8 Drain Rock

The thermal blanket and underdrain material will intercept seepage from the hillside and convey the water beneath the channel to a seepage collection drain system with a perforated pipe embedded in drain rock. The drain rock will also be used as fill placed within the head pond. The drain rock will be clean, durable, rounded to angular rock with no fines and well graded from 50 mm to 10 mm.

The estimated required in-place volume of drain rock is 30,000 m³. This material can be wholly obtained from the Rose Creek Haul Road borrow area and produced by crushing oversized materials and blending with available sands. The estimated haul distance is 0.6 km.

11.9 North Fork of Rose Creek Seepage Collection Pond – Alternative 1

The NFRC Seepage Collection Pond Alternative 1 requires construction of an earthen dam across the existing NFRC channel. The dam will be a zoned embankment dam constructed of imported fill which generally consists of a low permeability glacial till core (Zone 1) supported by a granular fill embankment (Zone 2). Filtration of seepage which permeates the embankment core will be filtered by a sand filter and gravel drain (Zones 4A and 4B). The upstream face of the embankment will be protected from erosion by a layer of riprap and riprap bedding (Zones 3A and Zones 3B).

The embankment will be constructed in a prepared and dewatered excavation trench within the existing north fork channel. The excavated trench materials will be disposed of onsite in a designated spoil disposal area. All required embankment materials will be imported from borrow sources identified elsewhere on the site.

The borrow approach for the required embankment fill materials are described in the following sections. These materials are briefly summarized in Table 11-5. Detailed discussions of borrow area investigation results are described in the Geotechnical Report (Appendix E).

Table 11-5. Borrow Material Summary—North Fork of Rose Creek Seepage Collection Pond Alternative 1
Faro Mine Remediation Project

Material Type	Required In-Place Volume (m ³)	Proposed Borrow Source	Approximate Haul Distance (km)
Embankment Core (Zone 1)	26,500	Fresh Water Supply Dam	2.2
Embankment Shell (Zone 2)	35,400	Fresh Water Supply Dam	2.2
Riprap (Zone 3A)	4,300	Faro Main Dump	4.4
Riprap Bedding (Zone 3B)	1,100	Faro Main Dump	4.4
Filter Sand (Zone 4A)	6,700	Haul Road Borrow/Granular	0.8
Drain Rock (Zone 4B)	2,300	Haul Road Borrow/Granular	0.8
Roadway Surfacing	300	Haul Road Borrow/Granular	0.8
Topsoil	2,100	Site (stripped from reservoir and dam footprint)	n/a

Notes:

Haul distance estimated as the required travel distance from center of borrow source to the NFRC crossing of the existing mine access road. Distance may vary based on contractor approach and actual route taken.

11.9.1 Zone 1 Core Material

The required Zone 1 core material to be used within the Alternative 1 dam is clayey glacial till as described in Section 4 of the Geotechnical Report (Appendix E). It is recommended that this material can be borrowed from the remaining Zone 1 core material of the existing Fresh Water Supply Dam (FWSD), located approximately 2.2 km from the proposed dam site. The freshwater supply dam was breached in 2003, but embankment materials remain on both the left and right (south and north) sides of the SFRC. It is estimated that approximately 26,108 m³ of Zone 1 material remain within the breached embankment at the FWSD. This volume exceeds the required volume of It is anticipated that Zone 1 materials can be exposed, loaded, and hauled directly from the FWSD to the Alternative 1 dam site with minimal processing. The placed fill will be moisture conditioned and compacted to form the new core

material. It is recommended that this material be visually screening for compliance with material specifications and that care be taken to avoid blending with material from adjacent zones during excavation.

It is anticipated that FSWD borrow will need to occur on both sides of the SFRC, requiring installation and removal of a temporary construction access bridge. Following borrow of these materials, it is anticipated that the FSWD site will need to be re-graded and revegetated. Regrading concepts have not been developed at this time; however, these concepts should be advanced during future design phases, considering both the need for short term stabilization of the borrow area, as well as long term closure planning objectives for the FSWD area.

11.9.2 Zone 2 Shell Material

The required Zone 2 shell material to be used within the Alternative 2 dam is a free-draining well graded granular fill material as described in Section 4 of the Geotechnical Report (Appendix E). This material is similar in gradation to the remaining Zone 2 shell material available at the FSWD. Similar to the recommendations for Zone 1, it is recommended that Zone 2 shell material can be directly loaded and hauled from the FSWD to the Alternative 1 dam location with minimal processing. The approximate haul distance is 2.2 km. It is estimated that 42,205 m³ is required at the Alternative 1 dam site, and there is approximately 74,523 m³ of Zone 2 material remaining at the FSWD site.

It is anticipated that FSWD borrow will need to occur on both sides of the SFRC, requiring installation and removal of a temporary construction access bridge. Following borrow of these materials, it is anticipated that the FSWD site will need to be re-graded and revegetated. Regrading concepts have not been developed at this time; however, these concepts should be advanced during future design phases, considering both the need for short term stabilization of the borrow area, as well as long term closure planning objectives for the FSWD area.

11.9.3 Zone 3A Riprap and Zone 3B Riprap Bedding

The upstream face of the Alternative 1 dam and the overflow spillway channel realignment will be armored to protect the underlying channel materials from erosion and scour. The armoring material will be coarse riprap as noted in Section 4 of the Geotechnical Report (Appendix E). The required median size (D_{50}) is 300 mm. The in-place thickness of this material is shown as $2 \cdot D_{50}$. The riprap will be placed upon a layer of riprap bedding. Both the riprap and riprap bedding material are hard, durable, angular stone resistant to weathering and freeze thaw processes. It is estimated that the in-place volume of riprap required for the dam is 4,181 m³, and 1,031 m³ of riprap bedding will be required. These relatively modest quantities can be obtained from several available sources onsite, depending on economics and coordination with other riprap production for the NFRC Realigned Channel.

It is recommended that this material volume be obtained by borrow from the calc-silicate waste rock source identified at the Main Dump. This borrow source is approximately 4.4 km from the Alternative 1 dam site. The available calc-silicate material will required visual screening to excavate acceptable source material, and crushing to develop the required riprap and riprap bedding gradations.

Other riprap sources are also available which may be considered for selection of final design recommendations. Such sources include the following:

- Granitic Outcrop Quarry - granite, approximately 2,700,000 m³, approx. 9 km haul, undeveloped quarry, but considered for development of riprap source for concurrent NFRC Realigned Channel
- Northeast WRD - approximately 34,500 m³, 2.7 km haul, sorting of waste rock required

11.9.4 Zone 4A Filter Sand and Zone 4B Drain Rock

Filter sand and drain rock are needed for filtering and safe handling of seepage through the proposed embankment dam. These materials are alluvial sands and gravels with low fines and strict gradation requirements as described in Section 4 of the Geotechnical Report (Appendix E). Relatively modest quantities of these materials are required, and several possible sources are available near the Alternative 1 dam site. At this time, it is recommended that the Zone 4A filter sand and Zone 4B drain rock be screened from the granular materials available at the Haul Road Borrow, granular source. The haul distance is estimated to be approximately 0.8 km. To produce Zone 4A filter sand, native gravelly sand material will be selectively excavated from the borrow area, avoiding zones of excess fines. The material will then be screened to exclude oversized materials. It is expected that the oversized materials removed from the native deposit can be further screened to produce Zone 4B drain rock. Rounded material is acceptable for use as drain rock; alternatively, oversized rounded material could be crushed to the appropriate gradation.

The Haul Road Borrow area, granular is also recommended for production of thermal blanket and underdrain material for the NFRC channel, and adequate volume is available for both projects.

11.9.5 Roadway Surfacing

The embankment crest and the required access roads will be topped with a granular roadway surfacing for vehicle access. This material will be a well-graded sandy gravel material with less than 10 percent fines and a maximum particle size of approximately 40 mm. It is recommended that the gravel be angular or crushed. A rock crusher will be mobilized to the site to produce the required gradation.

The estimated required in-place volume of roadway surfacing is 300 m³. This relatively small volume of material can be obtained from the Haul Road Borrow Area by blending native sandy gravelly soils with crushed oversized particles produced during processing of thermal underdrain material. The estimated haul distance is 0.8 km.

11.9.6 BTopsoil

The downstream face of the embankment dam will be surfaced with 400 mm of topsoil and vegetated with native grasses. The estimated required in-place volume of topsoil is 2,100 m³. The topsoil will be stripped and stockpiled from the foundation preparation of the dam site and appurtenant access roads. A thorough evaluation of the available quantity of topsoil has not been conducted at this time, however, by inspection, it is expected that adequate volume is available. Future design phases should consider these volumes and allocate topsoil materials for re-use. The haul distance for this material is considered negligible.

11.9.7 Pond Area Preparation

Prior to filling, the pond area will need to be cleared of debris, vegetation, and trees up to elevation 1,088 m, which accounts for the maximum operating water level plus approximately 1.5 m of wave action. Soil along the slopes may have an increased susceptibility to erosion during the clearing process.

Pond slopes within the inundation zone will become bare when soil cover, including lichen dies. Although the pond level will rarely remain constant (it will fill during the winter and will be drawn down in the summer), some wave benching and pond slope erosion should be anticipated. Mitigation for wave benching, and need for maintenance should be discussed with the client during final design.

11.10 North Fork of Rose Creek Seepage Collection Pond – Alternative 2

The Alternative 2 NFRC Seepage Collection Pond will be constructed east of the RCTA. The pond geometry has been developed to maintain construction elevations above the groundwater elevation (1,057.5 m) and to balance cut and fill operations, including considerations for material processing. Construction of this alternative requires approximately 261,700 m³ of excavation. It is anticipated that virtually all embankment materials required for construction of this alternative can be developed by processing the cut materials onsite. Imported material is expected to consist of angular riprap, riprap bedding, and supplementation of topsoil for establishment of native grassy vegetation on the embankment slopes.

Discussion of the borrow materials is discussed in the following sections. The estimated volumes, recommended borrow locations, and approximate haul distances are summarized in Table 11-6. Detailed discussions of the embankment materials are presented in Section 4 of the Geotechnical Report (Appendix E).

Table 11-6. Borrow Material Summary—North Fork of Rose Creek Seepage Collection Pond Alternative 2
Faro Mine Remediation Project

Material Type	Required In-Place Volume (m ³)	Proposed Borrow Source	Approximate Haul Distance (km)
Embankment Fill (Zone 2)	115,400	Site (processed native)	n/a
Select Fill	70,600	Site (processed native)	n/a
Bottom Protection Fill	21,200	Site (processed native)	n/a
Riprap (Zone 3A)	11,400	Faro Main Dump	4.9
Riprap Bedding (Zone 3B)	6,400	Faro Main Dump	4.9
Roadway Surfacing	1,800	Site (processed native)	n/a
Topsoil	7,600	Site (stripped from footprint) and augmented with topsoil stripped from NFRC	n/a

Notes:

Haul distance estimated as the required travel distance from center of borrow source to the center of the Alternative 2 site. Distance may vary based on contractor approach and actual route taken.

11.10.1 Zone 2 Embankment Fill

Zone 2 embankment fill will be processed from native cut materials obtained from the Alternative 2 site. The estimated required in-place volume of Zone 2 embankment fill is 115,400 m³. Processing will involve removal of material larger than 100 mm diameter to produce a relatively well graded sandy gravel fill. It is anticipated that this processing will create approximately 10 to 15 percent rounded to subrounded oversize cobble and boulder sized waste as suggested by observations in test pits within the site footprint.

Excavations and processing will be conducted above the groundwater table, with the possibility for minor localized dewatering for the construction of the pump station sump and intake structure. It is also anticipated that groundwater levels will be decreased in this area once the NFRC diverted into the new realigned channel. Diversion of seepage flows from the NFRC is recommended.

11.10.2 Select Fill Geomembrane Cushion Material

Select fill material will be placed 300 mm thick on both sides of the geomembrane liner to protect the membrane from puncture. The estimated required in-place volume of select fill is 70,600 m³. The select fill is a processed native material processed to a well graded gravelly sand with 25 mm maximum particle size and less than 10 percent fines. This material can be readily processed from the native Zone 2 site materials processed at the site. Screening of the Zone 2 materials on a 25-mm screen will result in approximately 25 to 35 percent waste, although this rounded waste rock is allocated for use as bottom protection fill, as noted in the next section. Because this material is processed from the site, the haul distance is considered negligible.

11.10.3 Bottom Protection Fill

Bottom protection fill consists of 25 to 100 mm diameter clean rounded to subrounded gravels and cobbles produced during processing of select fill. This material will be placed on the reservoir bottom, approximately 300 mm thick, to serve as additional liner protection from maintenance activities in lieu of imported riprap. Because the pond bottom is relatively flat (0.675 percent slope), the use of rounded to subrounded native gravels and cobbles is expected to be acceptable. The estimated required in-place volume of this material is 21,200 m³. Because this material is processed from the site, the haul distance is considered negligible.

11.10.4 Zone 3A Riprap and Zone 3B Riprap Bedding

The riprap and riprap bedding will be placed on the interior slopes of the Alternative 2 impoundment, the diversion channel, and the stormwater ditch to provide erosion protection. For stability purposes, it is recommended that this riprap material consist of imported coarse riprap as noted in Section 4 of the Geotechnical Report (Appendix E). The required median size (D_{50}) is 300 mm. The in-place thickness of this material is shown as $2 \cdot D_{50}$. The riprap will be placed upon a layer of riprap bedding. Both the riprap and riprap bedding material are hard, durable, angular stone resistant to weathering and freeze thaw processes. It is estimated that the in-place volume of riprap required for the dam is 11,400 m³, and 6,400 m³ of riprap bedding will be required.

This material may be obtained by borrow from the calc-silicate waste rock source identified at the Main Dump, provided the required volume is available and the source is proven to be sufficiently sulfide-free. This borrow source is approximately 4.9 km from the Alternative 2 dam site. The available calc-silicate material will require visual screening to excavate acceptable source material, and crushing to develop the required riprap and riprap bedding gradations.

Other riprap sources are also available which may be considered for selection of final design recommendations. Such sources include the following:

- Granitic Outcrop Quarry - granite, approximately 2,700,000 m³, approximately 9 km haul, undeveloped quarry, but considered for development of riprap source for concurrent NFRC Realigned Channel
- Faro Northeast WRD - approximately 34,500 m³, 2.7 km haul, sorting of waste rock required

11.10.5 Roadway Surfacing

The embankment crest and the required access roads will be topped with a granular roadway surfacing for vehicle access. This material will be a well-graded sandy gravel material with less than 10 percent fines and a maximum particle size of approximately 40 mm. It is recommended that the gravel be angular or crushed. A rock crusher will be mobilized to the site to produce the required gradation. This material can be produced by crushing oversized cobbles and boulders screened from site excavations

and blending with native sands. The estimated required in-place volume of roadway surfacing is approximately 1,800 m³.

11.10.6 Topsoil

The downstream face of the embankment dam and associated cut slopes will be surfaced with 400 mm of topsoil and vegetated with native grasses. The estimated required in-place volume of topsoil is 7,600 m³. The topsoil will be stripped and stockpiled from the foundation preparation of the dam site and appurtenant access roads. A thorough evaluation of the available quantity of topsoil has not been conducted at this time; however, by inspection, it is expected that approximately 5,880 m³ is available from the Alternative 2 site. Topsoil volumes are to be augmented by other sources, the excess topsoil generated from excavation for the NFRC Realigned Channel is a possible source. Future design phases should consider these volumes and allocate topsoil materials for re-use. The haul distance for this material is considered negligible.

11.11 Passive Water Treatment Feasibility

Passive water treatment options were evaluated to assist in management of ARD impacted groundwater as part of the NFRC realignment project. Options include: (1) Reducing overall maintenance costs by minimizing plugging in the NFRC Permanent Seepage Collection Trench; (2) Reduce lime demand costs by providing partial or wholesale treatment of the collected seepage water; or (3) Reducing environmental risk by providing secondary containment and treatment capacity during high flow events that could potentially overtop the Seepage Collection Pond.

The effectiveness of natural treatment systems, or those systems which use naturally occurring environmental processes and media to reduce the toxicity of contaminated material (e.g., constructed treatment wetlands), are typically based on areal loading of the contaminant of concern (i.e., g/m²/day) and the required load reductions. Geochemical modelling, presented in Appendix D, suggests that the concentration of the primary contaminant of concern, Zinc (Zn), will be in the 600 to 1,000 mg/L range within the lifetime of the project.

NFRC Permanent Seepage Collection Trench. A gravel bed subsurface collection system (perforated pipe and coarse gravel buried into shallow groundwater) is proposed to intercept iron-rich impacted seepage. This French drain style system for collecting impacted water can be maintained as oxygen scavenging and anaerobic as possible to minimize the oxidizing of iron that could eventually blind the drain. A woodchip collection systems used in conjunction with agricultural field drain tiles used to treat nitrate before discharge to a river or receiving body is one option to consider.

NFRC Seepage Collection Pond. For trace concentrations (<1 mg/L Zn) the literature suggests that free water surface (FWS) and/or subsurface flow (SSF) wetlands are very successful at removing up to about 90% of the Zn (Treatment Wetlands – 2nd Edition, 2009, Kadlec and Wallace). However, for higher concentrations, biochemical reactors (BCR) are more efficient and occupy a smaller footprint than a FWS or SSF wetland. BCRs are designed to generate sulphide through microbial sulphate reduction that reacts with base metals, such as zinc, forming an insoluble metal sulphide precipitate that is retained in the BCR substrate. The substrate is specifically designed to promote microbial sulphate reduction and BCRs are designed to direct influent water vertically through the substrate to maximize contact and thus, metal removal. As such, BCRs are designed based on volumetric loading (i.e., g/m³/day).

Empirical evidence from numerous case studies over the past couple of decades has demonstrated that a cubic meter of BCR substrate can conservatively generate 300 mmoles of dissolved sulphide in the course of a single day on average over the life of the system. Thus, due to the equimolar ratio of sulphide to zinc in a ZnS precipitate, a typical BCR can remove approximately 300 mmoles of dissolved zinc per cubic meter of substrate per day. This assumes no other metals (e.g., iron or copper) in solution can compete for sulphide and does not take into consideration the sizing for pretreatment (e.g., pH

adjustment) and post-treatment (e.g., re-aeration of the anaerobic effluent) passive units required for full-scale implementation.

Treatment requirements using a BCR for reducing the zinc loading is based on the following data that was provided:

- 20 L/sec groundwater flow (range 10 – 50 L/sec winter/freshet flow respectively) = 1,728,000 L/d
- 1000 mg/L Zn = 65,380 mmoles/L

From the above, the daily Zn loading is calculated to be 113,000,000 mmoles/d. Based on typical BCR design to reduce Zn to background levels, each 300 mmoles Zn/d loading requires 1 m³ of media x 113,000,000 mmoles/d = 377M m³ media. At 1.5 m bed operating depth, the required treatment footprint is 251,000,000 m² or 25,106 ha or 251 km². The whole-sale treatment of the collected seepage is not practical. The hydrologic loading is simply too great to allow for a reasonably sized passive treatment system. If the zinc concentration were an order of magnitude lower, the land requirement would be on the order of 25 km², at 10 mg/L zinc concentration, the land area would be just under 3 km². So regardless of the model precision in predicting zinc concentration into the future, it is safe to estimate that zinc concentration in the seepage will exceed 10 mg/L, which would require a passive treatment system too large and impractical for the area available for construction.

Overflow Pond: There is potential to apply a natural treatment system as a failsafe in the event of an overflow event at the NFRC Seepage Collection Pond Alternate 1 location by downstream treatment of a small portion of flow if the design capacity of the Seepage Collection Pond is exceeded or a small volume of overflow occurs as a result of pipeline, conveyance, or inability to divert the flow to Faro Pit or the IWTS. A natural treatment wetland could be built adjacent to and just downstream of the NFRC Collection Pond, surrounded by high berms/dikes that have flood control structures at the inlet and the outlet. During normal summer operations a portion of the realigned NFRC could be diverted through this natural wetland to maintain wetland plants and general wetland conditions. In the fall, the inlet and outlet control structures would be closed to allow the basin to fill in the event of a flood. The inlet would be maintained closed during freshet, the outlet could be opened to allow snow melt to escape the wetland, but in the event of a flood event such that the pond is overtopped, the outlet could be closed to retain any water leaving the NFRC Collection Pond. This would essentially create a secondary containment that would limit the impacts to the receiving environment should the pond overflow. After the overflow event, this natural treatment wetland could be pumped back to the collection pond and any residual metals would be treated in the natural treatment wetland. While this system would not be large enough to contain a complete draining of the NFRC Collection Pond due to a catastrophic failure of the pond dam, it would provide a level of containment for any overtopping of the dam due to a flood event. The containment would need to be manually controlled to operate as a containment basin during potential floods and as a natural wetland during normal operating conditions.

Point Source Discharges. While passive treatment is not practical for treating the main loading at the NFRC Collection Pond, it may be an option for addressing seepage from the collection pond or other areas within the NFRC project (e.g., FD-05 and FD-06 seep area) with reduced loading or less stringent effluent targets. For example, passive treatment systems may be an option in similar areas throughout the Faro Mine Complex such as point source discharges (e.g., FD-01 at the headwaters to Lower Guard House Creek) to help reduce overall loading to the WTP and thereby reduce overall lime demand costs. Consideration of passive treatment needs to be evaluated based on short-term capital costs to build the passive treatment system versus long-term estimates of costs savings based on the predicted performance of the passive system.

ARD Mitigation. Another passive treatment option that could be considered at the FMC is ARD mitigation, which involves adding inhibitory compounds to specific “hot spots” (e.g., sulphide cells) in the WRDs in an effort to shut off or slow down ARD generation. Numerous compounds have been tested for ARD mitigation from waste milk whey to sodium laurel sulfate. The selected compound is

added to the WRD hot spot through injection over a few years. The selected compounds then works to either directly inhibit sulfide oxidizing bacteria or to create oxygen starved conditions that inhibit sulfide oxidation and at the same time promote a competitive microbial community that keeps sulfide oxidizers from proliferating.

Field Work

12.1 Introduction

Section 5 describes some key areas of existing known site conditions based on published references, field explorations, and data gathering conducted since 2008 at the FMC, and specifically at the NFRC area. As part of the NFRC Project, additional field work was conducted during the Fiscal Year (FY) 2015/2016 to evaluate key technical considerations and provide design-level data to complete the project's design and develop a Class 4 cost estimate for the Final DBR. Before conducting the FY 2015/2016 exploration, existing data was fully considered to determine an appropriate level of additional field work and data gathering that is intended to reduce design and construction risks, but also meet engineering design standards of practice.

This section describes the phases of field work for the NFRC Project:

- 2015 Phase 1 Exploration: Conducted in April 2015, consisting of borings and test pits to evaluate permafrost and ground conditions in Segment 1 and 2 on the slope east of the existing NFRC.
- 2015 Phase 2 (summer) Exploration: Conducted in July through September 2015, consisting of borings, test pits, geophysical surveys to evaluate subsurface conditions in all segments, the NFRC Seepage Collection Pond, and the RCD.
- 2016 NFRC test cut: The proposed test cut location is immediately east of the haul road, where the deepest cuts in frozen soil are anticipated, and adjacent to the access road from the haul road to the head pond upstream of the NFRD. The test cut was intended to provide the following information:
 - Construction execution (related to seasonal timing)
 - Winter construction (excavation, trafficability, rippability of frozen soils/excavation rates, fill cover placement)
 - Typical organics/vegetation thickness for sizing of topsoil stockpile
 - Stockpiled excavated frozen soils, and opportunities for re-use as fill materials (following thaw).
 - Groundwater seepage and management
 - Cut slope design optimization
 - Design slope angles
 - Granular cover thickness and gradation
 - Rate and depth of thaw of granular cover
 - Effect of cut on snow drifting
 - Effect of post-construction settlement from winter-placed granular cover
 - Maintenance requirements
- Summer 2016 (summer) Exploration: This section provides general recommendations for additional exploration work necessary to advance to the design.

The sections herein describe the field work that was conducted for each site location. For detailed results of this work, refer to Appendices B, C, and E.

12.2 North Fork of Rose Creek Realigned Channel and Rose Creek Diversion

Fieldwork conducted as part of the 2015 Phase 1 and 2 field explorations in support of the NFRC Realigned Channel and the RCD design included the following:

- Rapid geomorphic assessment
- Terrain hazard assessment
- Geotechnical subsurface explorations
- Geophysical subsurface surveys

12.2.1 Fluvial Geomorphic Assessment

A fluvial geomorphic assessment was completed to support the design and construction of the NFRC Temporary Diversion by collecting data pertaining to current channel sediment loads, sediment transport, and geomorphology (such as shape and stability). The assessment tasks included the following:

- Measurement of the analog channel morphometry
- Characterization of the bed material
- Assessment of potential sediment sources, storage, and sinks from approximately 0.5 km upstream, to the NFRC confluence with the RCD

Details of the fluvial geomorphic assessment are included in Appendix B. Key results and observations from the assessment include the following:

- The planform of the existing NFRC channel was relatively invariant from 1949 to 1969. The creation of the FCD, WRDs, and Haul Road have all subsequently impacted the NFRC channel. However, most of the FCD channel planform shows little change since the earliest pre-mine aerial (1949).
- The greatest change exhibited by the NFRC channel is in the number, size, and longitudinal extent of depositional channel bars. There are many more bars seen in the 2012 aerial photograph that are the result of the sediment load introduced by the FCD.
- The increase in floodplain width (which includes channel bars) is evident by the height of valley surfaces. Observations suggest that the NFRC channel is incising through glacial deposits with little deposition, and creating few terrace surface and narrow floodplains. Downstream of the FCD, depositional floodplain surfaces are more extensive both cross-valley and longitudinally. The closer to the active channel, the more likely these areas are to be sediment sources.

12.2.2 Terrain Analysis

A terrain analysis was completed, which involved identification of landforms and geomorphological processes that could affect the NFRC Realigned Channel. A desktop study and hazard zonation were completed to provide a preliminary assessment of the susceptibility to geohazards in particular terrain locations. Terrain stability field assessments (TSFAs) were also used to validate hazard zonation, and to perform ground traverses to evaluate the terrain. The TSFAs focused on specific areas of concern including:

- Unstable or potentially-unstable terrain identified during previous investigations
- Existing and proposed road or trail sections on moderately steep-to-steep slopes
- Gully systems and other areas of concentrated surface or near-surface water flow
- Unstable, potentially unstable, and moderately steep to steeply sloping terrain, downslope of the operations that could be affected by hydrological changes caused by the operations
- Landslide transport and deposition zones
- Drainage from existing roads, trails, or cutblocks upslope of the operations that could affect slope stability

As detailed in Appendix B, observations made during the terrain hazard field assessments were used to produce a terrain map and hazard classification. This map classifies landforms by their genesis, material, and stability.

12.2.3 Geotechnical and Geophysical Explorations

During the 2015 field season, a total of 51 borings were completed for the NFRC Project. These include 12 borings at the NFRC Seepage Collection Dam and NFRC Seepage Collection Pond (see Figure 2-1 in Appendix E, Geotechnical Report), 27 borings along the NFRC Realigned Channel (see Figures 2-2 and 2-3 in Appendix E), six borings at the RCD adjacent to the Rose Creek Tailings Area (see Figure 2-4 in Appendix E), and six borings in the potential borrow area northwest of the proposed NFRC Seepage Collection Dam (see Figure 2-4 in Appendix E). Borehole locations were sited and staked using handheld GPS units, followed by a formal ground survey after completion of drilling.

An initial phase of drilling (Phase 1A) was completed by BGC in April 2015, along the NFRC Realigned Channel north of the Haul Road. This phase consisted of eight borings (CH15-107-MW011 through CH15-107-MW018). The initial phase of exploration is summarized in *Phase 1A Site Investigation* (BGC, 2015) included as Appendix C of Appendix E, Geotechnical Report.

A follow-up phase of drilling (Phase 2) was completed by CH2M between July and September 2015, throughout the NFRC Project area, including for the NFRC Seepage Collection Pond. Details of the Phase 1 exploration program are provided in Appendix E, Geotechnical Report.

The Phase 2 exploration was a more comprehensive program intended to provide more comprehensive subsurface data for geotechnical design of the realigned NFRC channel. However, it was not intended to be a final data collection program, and additional data collection gaps were identified and is proposed in this document.

Additional geotechnical explorations are recommended for NFRC channel realignment as discussed in Section 3.3 of Appendix E, Geotechnical Data Report. Subsequent geotechnical drilling will likely be performed using similar methods employed during Phase 2, including ODEX, direct push, CRREL and HQ size wireline coring methods. Samples will be retrieved from SPT, CRREL, and HQ coring (in rock), and Shelby tubes. Special emphasis should be given to collecting SPT samples and undisturbed samples in the foundation below the NFRC channel realignment embankment to better assess seismic hazard potential, embankment settlement, and fill and cut slope stability. In addition to laboratory testing on selected samples for soil and rock characterisation, additional in situ tests may include packer testing, slug testing, vane shear and downhole geophysical surveys.

12.2.4 Groundwater and Surface Water Monitoring

Although the 2015 Phase 2 field exploration program has a geotechnical focus, there are still some groundwater uncertainties in the NFRC and RCD areas. The purpose of this groundwater exploration program was to collect hydraulic information to better refine seasonal variations in groundwater flow rates, water levels, and water quality. This information will be used to support the design of the possible seepage collection system in Segment 1, by estimating the groundwater seepage that will be collected by the NFRC Permanent Seepage Collection Trench and the NFRC Seepage Collection Pond and evaluating seepage from the Secondary Tailings into the RCD.

12.2.4.1 Water Level Measurements

Fieldwork performed in the 2015 phase 2 field season included collecting groundwater samples from streambed piezometers and groundwater wells installed in 2013 and 2014. In addition, groundwater and surface water levels in the piezometers and stream gauges installed in previous years were also monitored. Specific activities performed include:

- Three staff gauges (CH15-201-SG002 through CH15-201-SG004) were installed in the RCD close to each of the new well pairs that were installed in the Secondary Impoundment Dam Dike (CH15-201-MW001 through CH15-201-MW006) to monitor stream levels during aquifer testing (discussed in Section 3.5). The locations of the installed stream stages are shown in Appendix B.
- Water-level pressure transducers were installed in many of the new well locations to continuously monitor groundwater levels. These transducers were installed using stainless steel cable, and were installed 1 m below the water level in each well. Each transducer was programmed to log the depth and temperature every 4 hours.
- Streambed piezometers were installed in NFRC during the 2013 and 2014 field seasons. During 2013, 17 piezometers were installed north of the NFRD, and during 2014, 16 piezometers were installed south of the NFRD in NFRC. Piezometers were installed as part of a surface water-groundwater interaction study to investigate the nature of groundwater interactions with NFRC. Using this piezometer network, two streambed piezometer monitoring events were completed during the 2015 field season: one from July 7 to 13 and the other from August 26 to 29. Monitoring events included collecting a water sample, measuring depth to groundwater inside, and measuring depth to surface water outside of each piezometer. The results of this study are summarized in Appendix C.

12.2.4.2 Groundwater and Surface Water Sampling

Groundwater samples were obtained from the NFRC study area between October 7 and 13, 2015, and a summary of this can be found in Table 12-1. A total of 31 samples were taken in addition to five duplicates. Samples were collected from all new 2015 monitoring wells with the exception of CH15-107-MW031, which was pumped dry and had no recovery. All analytical results from the groundwater sampling can be found in Appendix C.

12.2.4.3 Aquifer Testing

Aquifer testing was attempted at a total of 19 wells; eleven 4-inch diameter wells and eight 2-inch diameter wells. Of these, two were dry, one was mostly frozen, four did not produce enough water to enable aquifer testing, one produced sand and was only step-tested, and 11 were suitable for step- and constant-rate aquifer testing (Table 12-2).

Field results and analysis are described in the following sections, with the discussion separated into the following three geographic areas:

- Between NFRC and WRDs to the north
- Along the RCD
- East of the NFRC

Figure 4-1 in Appendix C shows the geographic areas where the aquifer tests were conducted and provides a brief summary of the results.

Table 12-1. Field Parameters of the Groundwater Monitoring Wells at Time of Sample Collection – Fall Field Program

Faro Mine Remediation Project

Study Area	Date	Well ID	pH	Specific Conductivity (mS/cm/°C)	Temperature (°C)	ORP (mV)	Turbidity (NTU)	Dissolved Oxygen	
								(mg/L)	(percent)
WRD Seepage Area	13/10/2015	CH15-107-MW029	6.87	2.018	1.5	73	-5	8.45	60.7
	12/10/2015	CH15-107-MW030	6.59	2.067	3.1	92.7	34.6	--	--
	13/10/2015	CH15-107-MW031 ^a	6.72	1.116	2.77	71.5	41.1	--	--
	12/10/2015	CH15-107-MW032	6.77	3.04	1.79	85.2	34.9	2.89	21
	12/10/2015	CH15-107-MW033	6.64	2.105	1.89	84.9	1.5	--	--
	12/10/2015	CH15-107-MW034	5.97	1.23	1.61	152.6	2.9	10.67	76.7
	13/10/2015	CH14-107-MW001	5.15	1.898	2.41	80.4	9.1	--	--
	13/10/2015	CH14-107-MW002	5.1	1.376	2.45	132.7	23.3	--	--
	10/10/2015	CH14-107-MW003	5.8	1.066	3.6	37.4	7.7	--	--
	12/10/2015	CH14-107-MW004	6.54	0.861	2.59	78.5	3.7	--	--
	13/10/2015	CH14-107-MW005A	5.67	0.464	3.1	29.1	64.1	0.55	4.1
	13/10/2015	CH14-107-MW005B	5.81	0.564	2.8	112.9	19.4	0.38	2.8
	12/10/2015	CH14-107-MW006A	6.96	0.489	4.47	77	4	--	--
	12/10/2015	CH14-107-MW006B	6.83	0.616	3.51	52.2	29.3	--	--
NFRC Seepage Dam and Pond	12/10/2015	CH15-107-BH001	6	1.398	0.8	-60.7	160.7	0.28	2
	12/10/2015	CH15-107-MW019	5.76	3.634	1.4	24.7	243.1	1.46	10.9
	12/10/2015	CH15-107-MW022	6.09	1.394	1.8	14.5	19.1	0.28	1.9
	9/10/2015	CH15-107-MW023	6.97	0.619	2.5	-13.5	37.6	--	--
	12/10/2015	CH15-107-MW025	6.36	1.413	0.6	7.7	22.9	0.29	2.1
	9/10/2015	CH15-107-MW026	7.01	0.888	4.28	-125	14.5	--	--

Table 12-1. Field Parameters of the Groundwater Monitoring Wells at Time of Sample Collection – Fall Field Program
Faro Mine Remediation Project

Study Area	Date	Well ID	pH	Specific Conductivity (mS/cm/°C)	Temperature (°C)	ORP (mV)	Turbidity (NTU)	Dissolved Oxygen	
								(mg/L)	(percent)
Seepage Dam and Retention Reservoir (cont.)	10/10/2015	CH14-107-MW007A	6.03	5.104	4.87	36.5	146	--	--
	10/10/2015	CH14-107-MW007B	6.03	1.457	4.1	11.6	-0.5	--	--
	10/10/2015	CH14-107-MW008A	6.24	1.18	2.66	-68.3	4.3	--	--
	10/10/2015	CH14-107-MW008B	6.18	0.754	2.38	34.2	9.6	--	--
	11/10/2015	CH14-107-MW009	5.82	1.789	2.26	46.8	-4.6	--	--
	11/10/2015	CH14-107-MW010	5.67	0.825	2.77	47.4	-10.6	0.1	0.7
RCD	8/10/2015	CH15-201-MW001	7.07	0.664	5.04	6.7	-2.5	5.37	42.2
	8/10/2015	CH15-201-MW002	7.04	0.505	2.2	12.5	21	6.89	50.2
	7/10/2015	CH15-201-MW003	6.09	0.511	4.5	-8.4	0.8	0.23	1.8
	7/10/2015	CH15-201-MW004	6.36	1.19	4.9	-60	1.8	0.34	2.6
	7/10/2015	CH15-201-MW005	6.98	0.24	3.6	24.8	22.8	4.24	32
	7/10/2015	CH15-201-MW006	7.02	0.24	4.5	46.2	3.9	5.08	39.3

^a Well purged dry

-- indicates negative DO readings (YSI calibration off)

cm = centimetre

mS = millisiemens

mV = millivolts

mg/L = milligrams per litre

NTU = nephelometric turbidity unit

Table 12-2. Aquifer Test Summary*Faro Mine Remediation Project*

Location	Well ID	Well Diameter (inches)	Depth To Water (m btoc)	Total Depth (m btoc)	Water Column (m)	Test Results	Rate (L/s)	Draw-down (m)	Geology at Screened Interval	Hydraulic Conductivity (m/d)	Storativity
WRD Seepage	CH15-107-MW029	4	1.58	3.6	2.0	8 hr constant rate test. Drawdown stabilizes at 6 hr.	0.09	0.85	Weathered bedrock	15	0.00001
WRD Seepage	CH15-107-MW030	4	4.06	5.1	1.0	8 hr constant rate test. Drawdown stabilizes at 7 hr.	0.11	0.34	Sand with clay and gravel	20	0.02
WRD Seepage	CH15-107-MW031	4	2.51	4.5	2.0	Pumped dry at 0.03 L/s, very slow recovery (>48 hr)			Sand with silt and gravel, weathered bedrock	0.001	0.05
WRD Seepage	CH15-107-MW032	4	2.46	9.1	6.6	Pumped dry at 0.02 L/s, very slow recovery (>4 days)			Bedrock	0.0014	0.001
WRD Seepage	CH15-107-MW033	4	2.29	3.9	1.6	7.25 hr constant rate test. Stabilizing drawdown.	0.10	0.32	Sand, weathered bedrock	35	0.5
WRD Seepage	CH15-107-MW034	4	2.79	6.1	3.3	8 hr constant rate test. Drawdown stabilizes at 7 hr.	0.05	1.69	Sand, weathered bedrock	2	0.03
RCD / Tailings	CH15-201-MW001	4	2.90	10.0	7.1	7 hr constant rate test, drawdown stable after <30 minutes.	4.00	0.27	Sand and gravel	22	0.000001
RCD / Tailings	CH15-201-MW002	4	2.74	12.0	9.2	Monitoring well: 0.08 m drawdown from MW001 test.			Sand and gravel	22	0.000001
RCD / Tailings	CH15-201-MW003	4	3.80	10.1	6.3	6.5 hr test, drawdown stable after 4.5 hours.	3.54	0.22	Sand and gravel	20	0.005
RCD / Tailings	CH15-201-MW004	4	4.08	13.1	-4.1	Monitoring well: 0.08 m drawdown during MW003 test.			Sand and gravel	14	0.00002
RCD / Tailings	CH15-201-MW005	4	3.25	9.4	6.1	8 hr test at 0.73 L/s, 3.5 hr test at 3.8 L/s	3.77	1.68	Sand and gravel	14	0.00007
RCD / Tailings	CH15-201-MW006	4	3.90	12.1	8.2	Monitoring well: 0.015 m drawdown during MW005 test			Sand and gravel	14	0.00007
Segment 2	CH15-107-PZ031	2	3.82	6.8	3.0	2-hour step test. Sand production, no constant rate test	0.14	1.30	Fine silty sand	3.5	0.003

Table 12-2. Aquifer Test Summary*Faro Mine Remediation Project*

Location	Well ID	Well Diameter (inches)	Depth To Water (m btoc)	Total Depth (m btoc)	Water Column (m)	Test Results	Rate (L/s)	Draw-down (m)	Geology at Screened Interval	Hydraulic Conductivity (m/d)	Storativity
Segment 2	CH15-107-PZ032	2	3.60	7.8	4.2	6-hour constant rate test	0.29	0.69	Fine silty sand	19	0.000001
Segment 2	CH15-107-PZ033	2	4.86	13.3	8.4	5-hour constant rate test. Drawdown stabilizes in <30 minutes, 3 cm drawdown at PZ038.	0.25	0.08	Sand and gravel	100	0.0002
Segment 2	CH15-107-PZ034	2	20.03	21.1	1.0	Pumped dry, recovery in 1.5 hours, slushy water after with no production	--	--	--	--	--
Segment 2	CH15-107-PZ037	2	18.49	20.4	1.9	3.5-hour constant rate test. Water level did not stabilize as anticipated.	0.04	2.25	Sand, silt and gravel	1.4	0.000001
Segment 2	CH15-107-PZ038	2	15.04	19.7	4.7	4.5 hr constant rate test. Drawdown stabilizes at 2 hrs. 2.5 cm drawdown at nearby PZ033.	0.19	1.22	silt, silt with fine sand, coarse sand	0.1, 0.8 and 100	0.0002
Segment 2	CH15-107-PZ039	2	dry	10.0	0.0	none	--	--	--	--	--
Segment 2	CH15-107-PZ040	2	dry	21.2	0.0	none	--	--	--	--	--
Collection Pond and Dam	CH15-107-MW027	4	10.86	21.1	10.2	Pumped dry at 0.006 L/s, very slow recovery (~ 24 hours)	--	--	Silt and sand	0.02	0.0001
Collection Pond and Dam	CH15-107-MW028	4	12.26	13.6	1.4	Slug test, very slow recovery (~ 24 hours)	--	--	Bedrock	0.014	0.003

Note:

cm = centimetre

m btoc = metre below top of casing

North Fork Rose Creek Waste Rock Area

Aquifer testing locations and a brief summary of results is as follows:

- CH15-107-MW029: Hydraulic Conductivity = 15 metres per day (m/d); Storativity = 0.00001
- CH15-107-MW030: Hydraulic Conductivity = 20 m/d; Storativity = 0.02
- CH15-107-MW031: Hydraulic Conductivity = 0.001 m/d; Storativity = 0.05
- CH15-107-MW032: Hydraulic Conductivity = 0.0014 m/d; Storativity = 0.001
- CH15-107-MW033: Hydraulic Conductivity = 35 m/d; Storativity = 0.5
- CH15-107-MW034: Hydraulic Conductivity = 2 m/d; Storativity = 0.03

Rose Creek Diversion Area

Aquifer testing locations and a brief summary of results is as follows:

- CH15-201-MW001: Hydraulic Conductivity = 22 m/d; Storativity = 0.000001
- CH15-201-MW003: Hydraulic Conductivity = 20 m/d; Storativity = 0.005
- CH15-201-MW005: Hydraulic Conductivity = 14-22 m/d; Storativity = 2.0e-5 to 7.0e-5

South Side of North Fork of Rose Creek

Aquifer testing locations and a brief summary of results is as follows:

- CH15-107-PZ031: Hydraulic Conductivity = 3.5 m/d; Storativity = 0.003
- CH15-107-PZ032: Hydraulic Conductivity = 19 m/d; Storativity = 0.000001
- CH15-107-PZ033: Hydraulic Conductivity = 100 m/d; Storativity = 0.0002
- CH15-107-PZ037: Hydraulic Conductivity = 1.4 m/d; Storativity = 0.000001
- CH15-107-PZ038: Hydraulic Conductivity = 0.01-0.08 m/d; Storativity = 0.0002
- CH15-107-MW027: Hydraulic Conductivity = 0.02 m/d; Storativity = 0.0001
- CH15-107-MW028: Hydraulic Conductivity = 0.014 m/d; Storativity = 0.003

The presentation of the field observations during testing and the analysis methods are included in Appendix C, Groundwater Report.

12.2.4.4 Tracer Dilution Study

A tracer dilution study was conducted between the confluence of the FCD with NFRC and the downstream monitoring point X14 on Rose Creek (a length of approximately 9 km). The purpose of the study was to provide an accurate measurement of the stream flow and to assess and quantify significant sources contributing metal loads to the NFRC.

The following summarizes key observations from the tracer study (more details are provided in Appendix B):

- Based on discharge estimates from the tracer study, the volumetric flow rate in NFRC is underestimated by stage and volumetric flow measurements.
- Observed travel time in NFRC from the confluence with the FCD to the NFRD (NF1) is about 160 minutes, for an average stream flow velocity of 0.2 m/s. Arrival at CH15-201-SG001 was observed after about 360 minutes, for an average stream flow velocity of 0.2 m/s, via the section of the channel that flows west downstream of X2 and adjacent to the RCTA. Additional time is required to reach a plateau concentration through the infiltration ponds and Pump House Pond. The leading edge of the tracer arrived at NF1 after about 90 minutes and at CH15-201-SG001 after 240 minutes.
- Key areas zinc loads that entered the NFRC include upgradient of Zone II outwash, downstream of Zone II outwash, downstream of the NFRD; downstream of S-Wells, and adjacent to the East Limb of the Secondary Dam.

- Sulphate loads were observed to increase at similar locations as zinc loads, with the notable difference that the sulphate load downstream of the NFRD did not significantly increase.

12.3 110B North Fork of Rose Creek Seepage Collection Pond

Field explorations performed in 2015 only covered the NFRD Seepage Collection Pond Alternative 1 site. No field explorations targeted for design of a NFRD Seepage Collection Pond Alternative 2 location have been performed. Recommendations for performing geotechnical explorations for Alternative 2 are provided Appendix E, Geotechnical Report. This section describes the geotechnical explorations and the subsurface conditions at the NFRD Seepage Collection Pond Alternative 1 location.

A total of 12 borings and 14 test pits were tested during the 2015 field season for Alternative 1 (Figure 2-1 in Appendix E, Geotechnical Report). Selected samples from the borings and test pits were tested in a laboratory to determine soil index properties, compaction characteristics, and shear strength. In situ testing comprised hydraulic conductivity (packer) testing in rock and slug testing in soil. Data from the borings and test pits were used to evaluate the suitability of the location of the dam embankment, excavation and foundation preparation requirements, soil and rock seepage characteristics, the effect of the presence of ice rich soils and permafrost in the overburden material, and requirements for removal, the long-term stability of fill and cut slopes in the vicinity of the dam foundation, and reuse of excavated material. Monitoring wells and thermistors were installed in the borings to measure seasonal groundwater and ground temperature fluctuations and downhole geophysical surveys were performed to determine shear wave velocities in rock and overburden. Surface geophysical surveys were performed parallel to and perpendicular to the dam foundation and upstream pond to characterize subsurface conditions along pre-determined transect locations.

The specific objectives of the geophysical surveys included the following:

- P-wave reflection tomography to identify potential fractures, faults, or similar microfeatures necessary to support decisions regarding design of the NFRD Seepage Collection Dam and NFRD Seepage Collection Pond
- P-wave refraction tomography to identify potential fracture and fault zones and evaluate depth to bedrock within the subject investigation areas
- Electrical resistivity tomography/induced polarization (ERT/IP) to identify of potential permafrost zones within the shallow subsurface
- Vertical seismic profiles (VSP) at specifically-targeted locations to measure interval seismic velocities in order to accurately constrain velocity analysis during post-processing of surface seismic survey data.
- Former Freshwater Supply Dam: A total of 18 test pits were investigate in this field investigation in July and August 2015, to evaluate fine-grained low permeability material. Five test pits were excavated into the native overburden west of the S-Wells, and 13 test pits were excavated at the former freshwater dam. Six of the test pits at the former Freshwater Supply Dam were excavated by hand using a shovel. Test pit locations are shown on Figure 4-2 in Appendix E, Geotechnical Report. A summary of test pit information can be found in Table 2-2C in Appendix E and detailed logs of the test pits are presented in Appendix E of Appendix E, Geotechnical Data Report. The data from the 13 test pits were used to verify the suitability of the existing core material. Existing fine-grained, low-permeability materials were found to have sufficient properties and quantity to be reused as core material in the new NFRD Seepage Collection Dam.

Additional geotechnical explorations are recommended for NFRD Seepage Collection Pond Alternative 1, as discussed in Section 4.5.2.7 of Appendix E, Geotechnical Data Report. Subsequent geotechnical drilling will likely be performed using similar methods employed during Phase 2, including ODEX, direct

push, CRREL and HQ size wireline coring methods. Samples will be retrieved from SPT, CRREL, and HQ coring (in rock), and Shelby tubes. In addition to laboratory testing on selected samples for soil and rock characterisation, additional in situ tests may include packer testing, slug testing, and downhole geophysical surveys.

Modelling

13.1 Introduction

This section summarizes the modelling to date and the planned modelling that is needed to support the NFRC Project Conceptual Design, including the following:

- Hydrology and surface water modelling
- Hydraulic modelling
- Groundwater modelling
- Site-wide water balance modelling, and
- Geochemical modelling.

13.2 Hydrology and Surface Water Modelling

13.2.1 Hydrology and Surface Water Analysis

Hydrological analyses are required for design of both the NFRC Realigned Channel and the proposed NFRC Seepage Collection Pond. For design of the NFRC Realigned Channel, peak instantaneous flow rates for various return period events up to and including the PMF are required. For the NFRC Seepage Collection Pond design, a longer duration runoff volume analysis is required. Additional analyses are also required to develop design hydrographs, to assess the capacity of existing Mine Access Road culverts and to develop a preliminary sizing methodology for the NFRC Seepage Collection Pond. The following subsections summarize the general hydrology of the NFRC catchment, as well as analyses completed for each design element.

13.2.2 Peak Instantaneous Flow Rate

Estimates of peak instantaneous flow rate for various return period events up to and including the PMF are required for hydraulic design of proposed conveyance systems at the site. Appendix B includes a detailed description of methodologies developed for calculating peak flow rates at the FMC and development of design hydrographs.

A PMF analysis conducted by Water Management Consultants (2006) for the Rose Creek watershed applied the 24-hour PMP (Taylor and Hale, 2006) to the Rose Creek catchment. PMF estimates stated in the Water Management Consultants (2006) report were for catchments ranging from 83.5 km² (SFRC) to 217.3 km² (Lower end of RCD). PMF estimates for the NFRC at the NFRD and at the headwater of the RCD were calculated to be 384 m³/sec and 674 m³/s, respectively. PMF estimates for catchment areas smaller than this were required for the NFRC design. The original HEC-HMS model files were not available thus requiring development of a new model using USACE HEC-HMS Version 4.1 (USACE, 2015). The objective of this model development was to replicate hydrographs presented in Figure 4 of the Water Management Consultants (2006) report for the NFRC, SFRC and lower end of the RCD.

Attached to Appendix B is a report titled *Method for Estimating Peak Flow rates at the FMC* (CH2M, 2015) that details a flood frequency analysis completed by as part of the Vangorda Diversion Design Definition (CH2M, 2014i). A single station frequency analysis was conducted using data collected at a continuous flow data station on Vangorda Creek near the Town of Faro (Station 29BC003). The catchment area tributary to this station is 91.2 km². A regional analysis was then completed using data from several stations in Yukon and Alaska to determine the relationship between catchment area and

peak flow rate. Results from the regional analysis were then used to extrapolate peak flow estimates at Station 29BC003 to smaller catchment areas.

The flood frequency analysis prepared by CH2M is used as the basis for developing peak instantaneous flow estimates. These flow rates cover a range of return periods from a 1-in-2 year event to the 1-in-500 year event, and are used for sizing both the NFRC Realigned Channel and the NFRC Permanent Seepage Collection Trench based on their respective catchment areas.

Table 13-1 includes peak instantaneous flow rates for various return period events calculated for the various locations of interest.

Table 13-1. Peak Instantaneous Flow Rates at Key Locations

Faro Mine Remediation Project

Return Period Event	Peak Instantaneous Flow (m ³ /sec)					
	FCD Above Faro Pit (16.2 km ²)	NFRC Upstream of FCD (98.6 km ²)	NFRC at Haul Road (122.7 km ²)	NFRC Upstream of SFRC (125.9)	SFRC Upstream of NFRC (72.7 km ²)	NFRC East Slope (7.9 km ²)
2-year	1.1	4.9	5.8	5.9	3.8	0.6
5-year	2.3	9.4	11.2	11.4	7.4	1.3
10-year	3.5	14.2	16.8	17.1	11.2	2.0
20-year	5.2	20.6	24.3	24.8	16.3	3.0
50-year	8.6	33.1	38.9	39.6	26.3	5.1
100-year	12.4	46.9	55.1	56.1	37.4	7.3
200-year	17.7	66.4	77.9	79.3	53.1	10.5
500-year	28.3	105.4	123.5	125.8	84.4	16.8

Using peak instantaneous flow estimates described above in combination with a defined hydrograph distribution, hydrographs for various points of interest and for various return period events were developed for incorporation into dynamic hydraulic modelling as described in Appendix B.

13.2.3 Runoff Volume Estimation

For design of the proposed NFRC Seepage Collection Pond, estimates of runoff volume from durations ranging from short-term (days and weeks), event-based scenarios to longer-term (months and annual) averages are required. As detailed in Appendix B, Hydrotechnical Consultants (2006) completed a regional analysis to transpose flood data from regional streamflow gauging stations to the outlets of the proposed Faro Creek and Vangorda Creek Diversions (Hydrotechnical Consultants, 2006). Results of this analysis were applied to the Seepage Collection Pond catchment in order to calculate unit flood values for a range of return periods (1-in-2-year, 1-in-100-year, 1-in-200-year, 1-in-500-year, and 1-in-1,000-year) and range of durations (1 day to 365 days). Surface runoff estimates were combined with estimated groundwater estimates as described in Appendix C. The maximum monthly flow estimate from each of the surface and groundwater flow estimates was used to generate a monthly flow record for various return period events for each of the Seepage Collection Pond catchments.

13.2.4 North Fork of Rose Creek Seepage Collection Pond Sizing

The design intent will be to operate the NFRC Seepage Collection Pond at low levels; however, the design storage capacity will be based on potentially not pumping for 7 months (from October to April) during the winter and to have sufficient storage to allow for collection of seepage and runoff during those months.

Conceptual siting and design of the proposed NFRC Seepage Collection Pond alternatives is discussed in in Appendix E, Geotechnical Report.

A monthly water balance was developed based on estimated inflow rates and assumed pumping rates and durations. The monthly water balance incorporated three pumping rates for each of the various return period events: 63 L/sec (1,000 USgpm), 126 L/sec (2,000 USgpm), and 189 L/sec (3,000 USgpm). For the initial monthly water balance analysis, it was also assumed that runoff was pumped from the NFRC Seepage Collection Pond to the IWTS or the Faro Pit from May until the end of September, while runoff is stored in the NFRC Seepage Collection Pond from October to April. From this analysis, the maximum pond volume was calculated for each pumping rate and for each return period event. Figures 5-10 and 5-11 in Appendix B show the results of the monthly water balance analysis for each of the alternatives. Based on these results, total pond volumes of 300,000 m³ and 350,000 m³ were selected for the Alternative 1 and Alternative 2 NFRC Seepage Collection Pond conceptual designs, respectively.

As shown in Figure 5-10 in Appendix B, the total volume accumulated in the Alternative 1 Seepage Collection Pond for the 2-year and 500-year events is 205,000 m³ and 262,000 m³, respectively. All three assumed pumping rates (63 L/s, 126 L/s, and 189 L/s) are able to pump all stored (from October to April) runoff as well as freshet and summer flows, and achieve an empty pond in October before the onset of the next winter storage period. In the case of the firm capacity (126 L/s), the pumping capacity is sufficient to pump all accumulated runoff from the pond (from October to April), as well as runoff and maintain a dry pond from the end of May through to the onset of storage in October.

As shown in Figure 5-11 in Appendix B, the total volume accumulated in the Alternative 2 NFRC Seepage Collection Pond for the 2-year and 500-year events is 279,000 m³ and 354,000 m³, respectively. For the 63 L/s and 126 L/s pumping scenarios, additional storage capacity is required to accommodate freshet flows. For example, in the case of the 1-in-500-year with a 63 L/s pumping rate scenario, a total of approximately 400,000 m³ is required. However, assuming that the firm capacity of the pumping station of 126 L/s is available starting May 1st, the maximum pond volume is calculated to be 354,000 m³ for the 1-in-500-year event.

Based on these results, total pond volumes of 300,000 m³ and 350,000 m³ were selected for the Alternative 1 and Alternative 2 NFRC Seepage Collection Pond conceptual designs, respectively. The current analysis was intended to develop an initial estimate of required storage volumes in each of the proposed NFRC Seepage Collection Pond alternatives based on relatively conservative input parameters and assumptions.

Additional consideration related to maintenance of the NFRC Seepage Collection Pond water volumes during the no-pump period (from October to April) is required during the next stage of design. It is recommended that operations and maintenance schedules and protocols be developed related to maintenance of pond volumes at defined water surface elevations before freshet and commencement of pumping on May 1. This would include monitoring of snowpack in the catchment or accumulated volumes in the pond to maintain a defined buffer capacity in the ponds before freshet. This may also include commencement of pumping before May 1, in order to draw the water level down enough to achieve the target buffer capacity during April.

13.2.5 Evaluation of Existing Culverts along Mine Access Road

The Mine Access Road extends approximately 22 km from the Town of Faro to the FMC. The road is maintained by YG Public Works: maintenance activities have included localized resurfacing, grading, patching, steaming culverts, and snow clearing. While the two culvert crossings located on the Mine Access Road are under the overall management of YG Public Works, they are monitored and maintained by site personnel because of their potential to impact water quality in the SFRC.

A preliminary exploration was completed to determine the level of service provided by existing Mine Access Road crossing culverts at the FMC. This included the two culvert crossings at the NFRC, as well as three additional culverts to the east. Figure 5-12 in Appendix B illustrates the location of each culvert included in the analysis as well as delineation of their respective catchment areas. A survey was completed by Challenger Geomatics, LLD in 2013 that included culverts along the Mine Access Road.

A preliminary capacity assessment was completed using Culvert Master as detailed in Appendix B. Results of this analysis conclude that the existing NFRC Mine Access Road has capacity to convey a 1-in-50-year event, while culverts C23 and C75 have a 1-in-20-year capacity. Culvert C87 has the smallest catchment area of the culverts included in the analysis and has the smallest capacity approximately equal to a 1-in-2-year event.

As described in Section 5 of Appendix B the NFRC Mine Access Road culvert crossing will be upgraded to provide capacity to convey the PMF event under the proposed condition.

13.3 Hydraulic Modelling

The following sections summarize hydraulic modelling completed to support design of the NFRC Realigned Channel project, as well as the NFRC Seepage Collection Pond. Detailed discussion of modelling methodologies, assumptions, and results is included in Appendix B.

13.3.1 Realigned North Fork of Rose Creek

Hydraulic analysis addresses the requirements related to NFRC Realigned Channel capacity, low flows, fish passage, scour and erosion, stability issues, channel re-alignment, and road crossings at the Haul Road and Mine Access Road. The goal of the hydraulic analysis is to determine the characteristics of a diversion channel and road crossings that convey the 500-year-return period design flow with sufficient freeboard to do the following: convey the PMF flow without overtopping the channel; remain stable for the design life; and require minimum maintenance during its design life. Determination of the NFRC Realigned Channel characteristics was initially carried out using Manning's uniform flow method and later refined by a one-dimensional (1D) HEC RAS modelling. For details on the modelling refer to Appendix B.

The USACE Hydrologic Engineering Center developed HEC-RAS version 4.1.0, a 1D hydraulic model that was used to determine the cross-section average depth, depth-averaged velocity, and water surface elevations (WSEL) for each cross section under consideration. The 1D numerical modelling was prepared to assess the channel performance related to estimates of water depth, velocity, and possible scour. Considering the channel design capacity, it was assumed that the flow would be contained within the cross section. However, a two-dimensional (2D) hydraulic model is required to evaluate the flows at the river confluences, which include the confluence of FCD and NFRC, and the confluence of SFRC and the new NFRC Realigned Channel.

Included in Appendix B are details related to development of the horizontal and vertical alignments of each of the four segments of the NFRC and the channel cross section, which were input to the 1D HEC-RAS model. Two alignments were analysed, with the main difference being the alignment of the proposed NFRC downstream of the Haul Road to the confluence with the SFRC. Also included in

Appendix B is a discussion of erosion, scour, and energy dissipation as well as consideration of debris and channel icing and related impacts to conveyance capacity in the proposed channel.

A preliminary optimization of cross section and profile was completed in order to be consistent with the design criteria outlined in Section 6 of Appendix B, as detailed in Appendix B.

The 1D HEC-RAS model was also used to determine the dimensions of required crossings at the Haul road and Mine Access Road. These road crossings will require drainage culverts and bridge openings to allow the 1-in-500-year design flood and PMF to pass through without road damage or other scour impacts. Selecting a preferred culvert type involves several other factors, which include material and installation cost, special site characteristics and ease of installation. Also, the requirements for fish passage, local preference and other environmental considerations also are considerations in which type of crossing is chosen. The preferred Haul Road crossings were determined to be either twin box or arch culverts while the preferred crossing at the Mine Access Road was determined to be a bridge.

The following summarizes recommendations derived from the preliminary hydraulic analysis as detailed in Appendix B:

- It is recommended that the 1-in-500-year return event design criteria and the PMF event design criteria be revisited in the next stage of design to determine if a lower-return period would sufficiently meet acceptable risk criteria. The risk criteria are not yet assigned to the design and would require development. The risks of debris blockage, slope failure, and water quality impairment should, amongst other criteria, be included in the list.
- It is recommended the channel cross sections be optimized during the next stages of design based on any refined required freeboard or a refinement in the 1-in-500-year level of service, acceptable risk and cost, and benefit analysis on the channel capacity.
- The low-flow condition cross-section components were designed to accommodate a 1-in-10-year flow. It is recommended that this design criteria be revisited to determine the optimum low-flow channel design for conveying flow based on required low-flow characteristics. The low-flow characteristics that provide additional guidance in that regard should be further established to support the determination.
- Winter flows should also be assessed thoroughly, as the flows may be controlling during the low-flow periods.
- The risk of debris jams at the Haul Road and Mine Access Road crossings should be included in the list of criterion to decide the level of service for design opening or crossing option.
- For managing the impacts of ice, it is recommended that a design maximum ice thickness of 0.5 m be used and that a design channel flow velocities greater than 1.0 m/s be considered to minimize ice formation.
- It is recommended that the method of ice formation and the potential impacts of ice formation on the flow regime in the NFRC Realigned Channel alternative designs be examined further through a thorough analysis.
- For the design of required riprap armouring, the use of the Alberta Government document, *Design Guidelines for Bridge Size Culverts* (Alberta Transportation, 2011) is recommended. Use of the recommendations for riprap sizing from the design document results, at the current level of design for the D_{50} rock sizes at Segment 2, Segment 3, and Segment 4 will be 300 mm, 500 mm, and 500 mm, respectively. The rock thickness to be applied should be 2 times D_{50} .
- On steep Segment 3 and Segment 4 reaches, it is recommended that large diameter rocks for rock drop structures and rock weir structures, and channel widening be included in the design to create pool and riffle sequences for energy dissipation. These design elements will reduce the velocities on

these steep slopes and should be rigorously examined at the next stage of the design process to optimize the size the channel, create additional stability and further control the flow regime in the steeper Segments 3 and 4.

- The option of creating a steepened intermediate slope within Segments 2 and 3 around the area of the Haul Road to contain all the flow with the designed channel for PMF discharge has been examined. It is recommended that this option be further analysed at the next stage of design to determine the most effective design based on a cost-benefit analysis and acceptable risk.
- The HW/D greater than 1.0 creates backwater conditions and a decrease in channel capacity for the design cross-section upstream of the Haul Road crossing. Additional measures to contain the flow should be examined in the next stage of design. Additional measures may include matching the discharge by matching elevation rating curve for the culvert inlet with channel cross section.
- The preferred road crossings at the Haul Road, at the current stage of design, are the twin box and arch culverts. The bridge was not considered at the Haul Road because the current road grade with a high embankment would require extensive disturbance and a large volume of excavated material. The three preferred road crossings, at the current stage of design, at the Mine Access Road are a bridge, twin box culvert, and an arch culvert. Hydraulically, these are currently the preferred options; however, these crossings should be further evaluated based on ease of construction and a cost and benefit analyses.
- Further evaluation of strategic sections of channel within, primarily, the confluence of Segments 1 and 2, and the confluence of Segment 4 and SFRC, are recommended to evaluate alternative configurations that would prevent overflow during design events.
- At this stage of design, there have been no significant hydraulic differences identified between NFRC Alignments P3 and P4. Further, more detailed assessments of P3 and P4 should be carried out at the next stage of design.
- During later design stages, winter low-flow depths and velocities that allow freezing at the channel bottom and result in icing need to be further assessed as they may be controlling during the low flow.
- The Haul Road and Mine Access Road crossings of the NFRC Realigned Channel may have significant risk for debris blockage; it is recommended that debris jam potential be assessed further during subsequent design stages.
- Alternative measures that may be considered to control debris include the following:
 - Raising the roadway grade, lengthening bridge structures, increasing culvert sizes, or a combination
 - Incorporating overflow structures so that water can flow around the debris blockage
 - Trapping debris upstream of the crossing structures using debris racks
- It is recommended that the design criteria for the access road crossing of 1-in-500-year return and PMF flow be revisited at the next stage of design to determine if a lesser return period flow could satisfy a set of risk-based criteria. The risk components have not been developed at this stage of design.
- It is recommended that further optimization of the NFRC Realigned Channel cross section and segment slopes be carried out at the next design stage to meet multiple performance criteria including flow depth, flow velocity, and costs of construction.
- It is recommended that, at the confluence of Segment 4 and SFRC, additional consideration of WSELs at the confluence of the segments is required to confirm that flow is contained.

- It is recommended that further analysis of the potential for Mine Access Road crossing that is an “overtopping” design be included in subsequent design stages.

13.3.2 Seepage Collection Pond Dam Hydraulics

Included in Appendix B is a detailed discussion of parameters relevant to the hydraulic analysis and results for the proposed alternatives of the NFRC Seepage Collection Dam. The following provides a summary of analyses and related conclusions related to the NFRC Seepage Collection Pond.

13.3.2.1 Dam Breach

At a minimum, failure or breach of the proposed NFRC Seepage Collection Dam would release an impoundment filled with water that is contaminated with chemicals and that would likely result in significant loss or deterioration of important fish or wildlife habitat. Such an event justifies a high hazard classification. A dam breach large enough to overtop the ID Pond and potentially cause the ID Pond to breach and release tailings-laden water flowing into the downstream environment is justification for a very high- to extreme-hazard classification. A dam breach analysis was performed to determine if the ID Pond would be compromised by a dam breach of either alternative of the NFRC Seepage Collection Pond.

The approach of the breach analysis was to focus on assumptions that determined what combination of parameters and events, if any, would compromise the ID Pond dam. The criteria being that impacts would be mitigated by the residual freeboard for any given configuration of the ID Pond (spillway size, dam height, and freeboard). A spreadsheet calculation with conservative assumptions was initially used to provide guidelines for limiting the volume of the NFRC Seepage Collection Pond. After the size and configuration of the dams was determined to meet the project objective, a 1D dam breach model was performed to more accurately define the downstream consequences.

HEC-RAS version 4.1.0, a 1D hydraulic model developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center was used to perform the dam breach modelling. Using HEC-GeoRAS version 10, the HEC-RAS geometry elements were defined in a geographic information system environment and results in a georeferenced to create a spatially consistent hydraulic model. Cross sections were extracted from a Digital terrain model (DTM) that includes the bathymetry of the ponded areas of both the seepage collection ponds and the ID Pond. The extent of the model represents the seepage collection impoundments to the spillway of the ID Pond.

Dam breach flows caused by dam overtopping from either of the NFRC Seepage Collection Pond alternatives were routed through different configurations of the ID Pond spillway without overtopping the ID Pond. Breach hydrographs predicting maximum peak flows for both scenarios of dam failure (piping and overtopping) were analyzed. The breach flood hydrograph with a piping failure was determined to likely be the worst environmental condition of a breach flood releasing an impoundment filled with contaminated waters with small dilution because of low flows in Rose Creek.

The greatest risk of overtopping the ID Pond is an overtopping failure of the seepage collection dam occurring with base flows equaling the design flood event for the different ID Pond spillway configurations. The results show that the ID Pond is not overtopped even with a PMF flood flow being added at the ID Pond. The scenario represents a remote probability of the dam breach occurring at the same time as the peak of the PMF flood hydrograph.

13.3.2.2 Wave Height and Runup

The CDA recommendations (2007) for calculating significant wave heights based on fetch and wind speed were used to generate wave height estimates for a range of wind speeds corresponding to the 1-in-2-year, 1-in-10-year, 1-in-100-year, and 1-in-1000-year AEPs. Wave heights, wind setup, and wave runup calculations were performed.

The total freeboard required to prevent overtopping of waves generated during an AEP event is the sum of the significant wave height, wind setup, and wave runoff. For normal freeboard calculations, the maximum normal pool elevation is combined with the results from the 1-in-1,000-year AEP wind. For minimum freeboard calculations, the still pool elevation during the 1-in-500-year design flood event is combined with results from the 1-in-2-year AEP wind. The minimum freeboard requirements control the required freeboard elevation. For Alternatives 1 and 2, the minimum freeboard calculations indicate that the design crest elevations (1,089.5m and 1,069.0m for Alternatives 1 and 2, respectively) are sufficient and provide for additional freeboard.

13.3.2.3 Riprap Sizing

Riprap slope protection placed on the NFRC Seepage Collection Dam Alternatives 1 and 2 embankments is expected to provide adequate scour countermeasures for estimated wave heights. The median riprap grain size (D_{50}) selected for design of embankments was determined to be 0.3 m.

13.3.2.4 Flow-through of the North Fork Rock Drain

A failure of the NFRC Realigned Channel dike upstream from the Haul Road will result in flows from a much larger catchment to enter the NFRC Seepage Collection Dam catchment. The flows that flow-through the NFRD from the larger catchment have the potential to far exceed the local flood events. An analysis was completed to consider potential impacts of NFRC failure on the Alternative 1 spillway and Alternative 2 diversion channel sizing. Refer to Appendix B for details.

13.4 Groundwater Modelling

Over the last several years, the Faro Water Modelling Team (FWMT) has developed a suite of modelling tools to address various hydrologic, hydrogeologic, and geochemical issues associated with the FMRP. The main focus of the groundwater modelling FWMT over FY15 has been the refinement of steady-state and transient groundwater models focused on the NFRC area, and the issues associated with the NFRC Temporary Diversion design. The construction and calibration of these modelling tools are fully documented in the FY15 Groundwater Model Development Report (CH2M, 2016). The application of these numerical models to support the NFRC Temporary Diversion design is described in the following sections.

13.4.1 Application of Numerical Models to Support the North Fork of Rose Creek Temporary Diversion Design

The following sections describe the application of both the steady-state and transient models developed for the NFRC area to support the development of the NFRC Temporary Diversion design effort. Simulations of current conditions is described first followed by results of simulations performed to evaluate groundwater conditions resulting from several alternative design options.

13.4.1.1 Simulations of Current Conditions

Steady-state and transient groundwater flow models were constructed and calibrated to reflect recent hydrological conditions. The boundary conditions applied to the models represent either average or time-variable hydrology between water years 2008 and 2015. The current groundwater flow conditions for the NFRC are defined by the results of the simulations performed with the calibrated Faro Groundwater Flow Model (FGFM). This section provides a brief overview of the simulated groundwater flow in the vicinity of the NFRC between the FCD and the SFRC. The reader is referred to the FY15 Groundwater Flow Model Development Report (CH2M, 2016) for a comprehensive review of the FGFM construction and calibration, as well as the discussion of its limitations.

13.4.1.2 Groundwater Flow Directions

Groundwater flow in both the steady-state and transient FGFMs is generally toward the Faro Creek valley and then down valley. The upland areas constitute the recharge areas and the areas along the perimeter of the WRDs and the Faro Creek valley constitute the discharge areas. Groundwater flow within and around the WRDs is more complex. Flow in the immediate vicinity of the Faro Pit flows toward the pit, but groundwater in the western portion of the dumps generally moves south, while groundwater in the eastern portion moves southeast toward NFRC. Some flow in the eastern half of the WRDs is also captured by the Zone II Pit well. General flow patterns can be seen in Figure 5-7 in Appendix C.

Groundwater recharge on the WRDs flows vertically downward until it reaches the premining ground surface. Upon reaching the premining ground surface, it flows south and east depending on the premining topography. Groundwater leaving the WRDs seeps out around the base of the WRDs and also discharges to NFRC and ephemeral streams in the ETA. Some mine-impacted groundwater also flows down the alluvial aquifer underlying NFRC, daylighting farther down the creek valley.

Groundwater in the upland areas, specifically in the northeastern and southeastern portions of the model domain, is supplied mainly by deep percolation of precipitation. Streams and rivers are mainly gaining, with groundwater flow generally following surface topography.

13.4.1.3 Groundwater Discharge to North Fork of Rose Creek

The convention used to describe boundary fluxes in this document is aquifer-centric. 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.

As discussed, mine-impacted groundwater discharges to surface water in Faro Pit along the base of the southern and eastern sides of the WRDs through both seeps and river channels, and includes NFRC Segments 2 and 3. A portion of the groundwater also takes a deeper path and flows beneath the NFRC down to the RCAA where it eventually daylight at the series of Rose Creek Valley dams or continues downstream in the RCAA.

Non-impacted groundwater also discharges to the same streams and rivers, and flows down through the RCAA. However, some non-impacted groundwater also flows into other surface water channels, including the FCD and leaves the model domain as surface water. Significant portions of groundwater discharge to NFRC is comprised of non-impacted groundwater. For discharge rates, refer to Table 5-3 in Section 5.4.1.

Steady-state segment-by-segment-groundwater discharge rates to NFRC are shown in Figure 5-8 in Appendix C. These results suggest that within Segment 1, approximately 9.5 L/s of groundwater enters the segment as groundwater underflow, while about 5 L/s flow southward into Segment 2. Within Segment 1, the net groundwater discharge to the NFRC is approximately 4.5 L/s. In Segment 2, approximately 7.5 L/s of groundwater enters the segment, while 1.5 L/s leaves the segment through the NFRD, and 11 L/s of groundwater discharge enters the NFRC. Finally, in Segment 3, approximately 6.5 L/s enters the segment as groundwater underflow, 1.5 L/s is removed through S-Wells pumping, 4.5 L/s enters the NFRC as groundwater discharge, and 0.5 L/s leaves the segment as groundwater underflow.

Transient segment by segment groundwater discharge rates to NFRC are shown in Figure 5-9 in Appendix C. Discharge rates range from 12.0 to 30.9 L/s, with minimum and maximum discharge rates occurring in April and June of each year.

13.4.1.4 Alternative 1 Analysis

Groundwater flow modelling of NFRC remedial design elements was performed by modifying the calibrated groundwater flow models to represent design features consistent with Alternative 1. These modifications to the calibrated models, as well as the results obtained from the model simulations, are described in the following sections.

13.4.2 Segment 1

Design elements for Segment 1 include two components: a cutoff wall and drain in the northeastern dump areas and an alluvial cutoff wall at the head of the NFRC Temporary Diversion between Segments 1 and 2.

13.4.2.1 Cutoff Wall and Drain at the Northeast Waste Rock Dump

Groundwater flows from the WRDs toward the NFRC in Segment 1. In an effort to prevent mine-impacted water from discharging to Segment 1, the design calls for a groundwater diversion system to be installed between the WRDs and NFRC. Figure 5-10 in Appendix C shows the design layout of this feature and the cells representing it in the groundwater flow model.

This feature is modelled with MODFLOW-USG's (Panday 2013) hydraulic flow barrier (HFB) package. HFBs are placed at the interface of two cells and impede flow between them according to the Darcy flux. The HFBs were modelled as 1 m thick with a hydraulic conductivity of 1×10^{-6} centimetres per second (cm/s). The HFBs start at ground surface and end at the top of competent bedrock.

Groundwater underflow blocked by this wall is modelled as being collected by a drain that lies 2 mbgs and runs along the entire length of the wall just upgradient of the wall structure. This drain is simulated using MODFLOW-USG's drain package, which removes water in a given cell when the head in that cell rises above the elevation of the drain invert. Drains remove water at a rate determined by the product of the conductance and the difference between the groundwater level in the cell and the drain invert elevation. Drains are not allowed to add water to the model.

13.4.2.2 Upper North Fork of Rose Creek Cutoff Wall

The design includes a shallow cutoff wall at the upstream end of the NFRC at the junction of Segment 1 and Segment 2 that bisects the alluvial channel of NFRC and is intended to act as a subsurface barrier that promotes clean groundwater to discharge into the Segment 2 NFRC Realigned Channel.

The layout of this cutoff wall is shown in Figure 5-10 in Appendix C. This feature was also modelled using MODFLOW-USG's HFB package, with each HFB having a thickness of 1 m and a hydraulic conductivity of 1×10^{-6} cm/s. This structure was simulated to extend to the base of model layer 2, approximately 10 mbgs.

13.4.3 Segment 2

13.4.3.1 North Fork of Rose Creek Permanent Seepage Collection Trench

The NFRC Permanent Seepage Collection Trench will be located east of the existing native channel. The existing channel is expected to become mostly dewatered because of the cutoff wall and the NFRC Permanent Seepage Collection Trench. Any groundwater seepage discharge to the former channel is expected to be from lateral groundwater inflow.

Phase 1 of the design calls for the construction of the NFRC Temporary Diversion with an integrated subsurface seepage collection system. After the first phase, the NFRC Temporary Diversion will convey surface water runoff from the west toward the end of Segment 2. This seepage collection trench system includes a 1.5 m wide by 1 m deep trench backfilled with drain rock, and a buried 15.3 cm (6 inch)

perforated pipe located at the bottom of the trench. This collection trench will convey the collected seepage to the end of Segment 2 where it will pass through the NFRD.

The seepage collection trench was simulated using the drain boundary condition. The model cells representing the drain system were assigned according to the design layout of the seepage collection trench (Figure 5-8 in Appendix C). The stage was set equal to the design invert elevation of the trench bottom.

13.4.3.2 North Fork of Rose Creek Realigned Channel

The NFRC Realigned Channel design includes an impermeable liner with a leak detection system. This feature is expected to prevent communication between the NFRC Permanent Seepage Collection Trench and the aquifer.

The NFRC Realigned Channel design includes a drain layer beneath the channel that is intended to allow shallow groundwater entering the area from the east to pass beneath the channel and allow this groundwater to pass downgradient through either the former riverbed or the seepage collection channel.

The NRC Realigned Channel also includes an access road along the western bank of the channel. The native river bed will be backfilled as part of the access road construction. The backfilling of the native channel with base rock will effectively create another subsurface drainage feature within the banks of the former native channel. Any groundwater that would discharge to the former channel will then remain as groundwater, and flow along this new drainage feature.

The river boundary cells representing the native NFRC channel in Segment 2 were converted to active cells (nonboundary), and represented as relatively-high-permeability alluvium (Figure 5-11 in Appendix C). This was done because the NFRC would be diverted from the native channel in Segment 2, and the native channel would be filled by base rock, and act to convey groundwater down valley to the end of Segment 2.

13.4.4 Segment 3

The Alternative 1 NFRC Seepage Collection Pond will be located in Segment 3. The S-Wells SIS will be deactivated because the mine-impacted water is anticipated to remain as groundwater or discharge to surface water within Segment 3.

Modifications to the model include: deactivating S-well pumping, removing the river boundary in Segment 3, altering top elevation of the model cells representing the dam, adding the HFB representing the dam core, and including the transient CHD process to simulate time-varying pond stages. These features are shown in Figure 5-12 in Appendix C.

Iterative feedback with surface-water modelling was necessary to reconcile groundwater inflows to the pond and the pond stages. As seepage estimates change, so do the pond volumes and thus stages. Several iterations were made between the surface water and groundwater models to reconcile pond volumes and stages.

13.4.5 Segment 4

The Segment 4 NFRC Realigned Channel design includes an unlined channel; therefore, the groundwater and surface water is able to communicate in Segment 4. As such, a river boundary was used to simulate the two-way exchange between the channel and the aquifer. This exchange is governed by head gradients between the aquifer and the river channel.

The model cells intersecting the river boundary were assigned according to the design layout of the Segment 4 diversion channel (Figure 5-13 in Appendix C). The river stage was set 1 m above the design

channel bottom elevation, consistent with other river boundaries in this model. Bed conductance was computed from the channel dimensions and an assumed Hydraulic Conductivity (K) of 0.5 m/day.

13.4.6 Alternative 1 Groundwater Model Results

Boundary and zone-face fluxes for each segment of the NFRC were extracted from MODFLOW-USG output files. Estimated groundwater discharge to surface water values for each segment, and each simulated runoff return-period were compiled and are shown in Table 5-1. Groundwater discharge to surface water peaks during May of each simulated year as this is when freshet is modelled to occur. As less and less groundwater recharge is applied to the model each month after May, groundwater discharge to surface water decreases through the summer, fall, and winter months until the next May. The decreases in discharge over the summer months is greater than the decreases over the winter months.

This alternative assumes that the ponds will be pumped dry starting in May of each year and maintained dry until October. Pumps could operate during the autumn months if necessary, but will typically be shut down. From October through April, groundwater seepage will fill the pond continuously, so the pond level will reach a maximum stage just before the pumps begin operating in May.

Groundwater discharge to NFRC Segments 2 and 3 represents the seepage that will flow into the NFRC Seepage Collection Pond and accumulate. Estimated flowrates are shown on Figure 5-14 in Appendix C. The maximum estimated rate is 63.6 L/s, which occurs in May of a year that has 500-year return period hydrology, while the minimum estimated rate is 8.4 L/s, which occurs in April of a year that has 2-year return period hydrology. Depending on the year type, seepage rates generally range from about 9 L/s to 20 L/s during the seepage accumulation period (October through April), with October rates being the highest and April rates being the lowest.

Groundwater discharge to Segment 1 of NFRC generally mimics the patterns seen in Segments 2 and 3, but with less variation. Discharge rates in June, July, and August are fairly constant and greater than discharge rates in May, regardless of year type. The maximum discharge rate in the wettest simulation year (500-year return period hydrology) is less than 1.0 L/s greater than the minimum discharge rate in the driest simulation year (2 yr return period hydrology), while variations in discharge rates within the seepage accumulation period of a given year (October through April) are less than 0.5 L/s. Discharge rates during Alternative 1 design simulations range from 7.0 to 7.8 L/s.

NFRC Segment 4 is a losing reach, with leakage from the river to the aquifer being lowest during the summer months and highest during winter and spring; lower during wet years and higher during dry years. The maximum leakage rate in the wettest simulation year (500-year return period hydrology) is 1.2 L/s less than the minimum leakage rate in the driest simulation year (2-year return period hydrology), while variations in leakage rates within the seepage accumulation period (October through April) of a given year are less than 0.5 L/s. Leakage rates range from 3.3 L/s to 4.5 L/s.

13.4.7 Alternative 2 Analysis

As was the case with Alternative 1, groundwater flow modelling of the design elements for Alternative 2 was performed by modifying the calibrated groundwater flow models to represent design features consistent with Alternative 2.

13.4.7.1 Segments 1 and 2

The design and model simulations for Segments 1 and 2 in Alternative 2 are identical to those of Alternative 1. The modifications to the model in Segments 1 and 2 under Alternative 1 were therefore kept unchanged in the simulations for Alternative 2.

13.4.7.2 Segment 3

The Alternative 2 pond location lies downstream of Segment 3 and the Mine Access Road. The design consists of a shallow alluvium cutoff wall, a lined seepage conveyance channel, and a lined seepage collection pond on the NFRC Temporary Diversion downstream of the Mine Access Road. Figure 5-15 in Appendix C shows the layout of these features.

At the end of Segment 3, the design includes a cutoff wall to be installed bisecting the shallow alluvial aquifer of the former NFRC. The intent of this cutoff wall is to drive mine-impacted groundwater to discharge to surface water in Segment 3 before it is collected in the NFRC Seepage Collection Pond. The cutoff wall is approximately 5 to 8 m deep from the ground surface. The cutoff wall was placed in the first two layers of the model, which represent alluvium. The HFB package discussed in Section 5.2.1 was used to model this cutoff wall, with a thickness of 1 m and a hydraulic conductivity of 1×10^{-6} cm/s.

The mine seepage that discharges to Segments 2 and 3 will be collected in a lined channel near the Mine Access Road. From there it will be conveyed through the NFRC Temporary Diversion through a lined channel that will inhibit communication between surface water and the underlying aquifer system.

The Alternative 2 pond will also be lined with a leak-detection system, inhibiting communication between the contents of the collection pond and the aquifer.

13.4.7.3 Segment 4

The design and model simulations for Segment 4 in Alternative 2 are identical to that of Alternative 1. Therefore, the modifications to the model in Segment 4 Alternative 1 were kept unchanged in the simulations for Alternative 2.

13.4.7.4 Alternative 2 Groundwater Model Results

Boundary and zone face fluxes for each segment of the NFRC were extracted from MODFLOW-USG output files. Estimated groundwater discharge to surface water values for each segment, and each simulated runoff return-period, were compiled and are shown in Table 5-2. Groundwater discharge to surface water peaks during May of each simulated year as this is when freshet is modelled to occur. As less and less groundwater recharge is applied to the model each month after May, groundwater discharge to surface water decreases through the summer, fall, and winter months until the next May. The decreases in discharge over the summer months are greater than the decreases over the winter months.

As with Alternative 1, Alternative 2 assumes that the ponds will be pumped dry starting in May of each year and maintained dry until October. Pumps could operate during the winter months if necessary, but will typically be shut down. From October through April, groundwater seepage will fill the pond continuously, so the pond level will reach a maximum stage just before the pumps begin operating in May.

Groundwater discharge to Segments 2 and 3 of NFRC represents the seepage that will flow into the Seepage Collection pond and accumulate. Estimated flowrates are shown on Figure 5-16 in Appendix C. The maximum estimated rate is 58.4 L/s, which occurs in June of a year that has 500 yr return period hydrology, while the minimum estimated rate is 13.0 L/s, which occurs in April of a year that has 2 yr return period hydrology. Depending on the year type, seepage rates range from about 13 to 26 L/s during the seepage accumulation period (October through April), with October rates being the highest and April rates being the lowest.

Groundwater discharge to Segment 1 of NFRC mimics the behaviours seen in Segments 2 and 3, but with less variation. Discharge rates in June, July, and August are fairly constant and greater than discharge rates in May, regardless of year type. The maximum discharge rate in the wettest simulation year (500-year return period hydrology) is less than 1.0 L/s greater than the minimum discharge rate in the

driest simulation year (2-year return period hydrology), while variations in discharge rates within the seepage accumulation period of a given year (October through April) are less than 0.5 L/s. Discharge rates during Alternative 2 design simulations range from 7.0 to 7.8 L/s.

NFRC Segment 4 is a losing reach, with leakage from the river to the aquifer being lowest during the summer months and highest during winter and spring; lower during wet years and higher during dry years. The maximum leakage rate in the wettest simulation year (500-year return period hydrology) is 0.5 L/s less than the minimum leakage rate in the driest simulation year (2-year return period hydrology), while variations in leakage rates within the seepage accumulation period (October through April) of a given year are less than 0.2 L/s. Leakage rates range from 2.0 to 2.5 L/s.

13.4.8 Simulations Supporting Geochemical Modelling

The steady-state groundwater flow model was also used to support the assessment of geochemical conditions and contaminant concentrations in groundwater discharging to NFRC. The geochemical model computes concentrations according to batch mixing of multiple source waters, each of varying chemical compositions. The groundwater model was used to provide inputs to the geochemical models regarding the quantity and proportion of clean- and mine-impacted water that flow into each NFRC segment. Appendix D provides more details on the geochemical modelling analysis.

13.4.9 Assessment Approach

Stream Segments 1 through 3, shown in Figure 5-1 in Appendix C, were used as mass balance control volumes to conduct the geochemical calculations. Flows entering the volumes of each segment were extracted from model output. The component of these flows that represent mine-impacted water were assessed using Mod-Path3DU (Muffels 2014) particle tracking software. The ratio of the WRD-originated flow to the total flow comprises the contaminated fraction of the total flow into the segment.

To quantify the proportions of mine-impacted water that discharge to a particular segment, particle tracking was performed on areas covered by the WRDs. Mod-Path3DU particles were started on the water table within or beneath the WRDs and tracked forward to their ultimate discharge location at a hydrologic boundary (for example, rivers, wells, and ponds). The particle's endpoint boundary type and location data provides the information needed to define the contributing area of each WRD source that discharges to each segment. Multiplying this area by the steady-state recharge rate of the WRDs provides an estimate of the amount of flow that originates from a particular WRD source for each segment. Particle traces generated from this analysis are shown in Figure 5-17 in Appendix C.

Several assessments were made using the technique described herein. For the first assessment, the baseline, or existing conditions simulations were performed to provide information to support development of estimates of existing groundwater conditions within Segments 1 through 3. These segments correspond to particular geochemical model calculation points or nodes. The second assessment was performed using steady-state simulations of Alternative 1 with the Zone 2 well operating. The third assessment was the same as the second, except with the Zone 2 well shut off. Based on the progression of the design at the time of the analysis, the second and third simulations were performed using preliminary designs of Alternative 1.

Flowrates obtained from the pathline analysis were used by the geochemical modelling team to generate contributing mass fractions for different WRDs to specific geochemical model nodes. Flowrates are included in Table 5-3. Mass fractions and geochemical modelling results are included in the Appendix D, Geochemistry Report.

13.4.10 Recommendations

Based on the groundwater modelling work performed with data to support the NFRC Temporary Diversion design, the following additional modelling evaluations are recommended:

- Refine the transient groundwater flow model grid and layering in the vicinity of the seepage collection ponds for Alternatives 1 and 2 to better quantify the hydraulic conditions, groundwater seepage pathways, and potential for groundwater upwelling in the vicinity of and downstream of the dam sites.
- Perform more refined modelling in the vicinity of the groundwater cutoff walls at the boundary between Segments 1 and 2, and at the Segment 3 cutoff wall associated with Alternative 2 to better understand the depth and configuration of wall required to force groundwater up into the lined channels.
- Perform more refined modelling in the vicinity of the Segment 1 cutoff wall/drain system to better evaluate the design parameters associated with that system.

13.5 Geochemical Modelling

This section summarizes the geochemical modelling completed to support the NFRC project design.

13.5.1 Sitewide Geochemical Modelling Work Completed

Geochemical modelling at the FMC has simulated chemical evolution of seepage water and groundwater in three principal pathways:

- Seepage through each individual WRD
- Reactive mixing of WRD seepage in the proportions dictated by the GoldSim model
- Reactive transport modelling in groundwater beneath the RCTA

Each of these model pathways accounts for geochemical processes and constraints, including aqueous speciation, mineral dissolution and precipitation, gas exchange, and adsorption to aquifer matrix minerals. The main objective of the work has been to build on the previous geochemical work by improving the estimation of time-dependent evolution of water quality and to account for key geochemical reactions that influence trace element concentrations in important downstream areas. Accounting for these factors will improve engineering design planning for treatment design, future costs, and prioritization of remedy components. The first two bulleted items above are applicable to the NFRC design, and are briefly described in the following subsections.

13.5.1.1 Waste Rock Dump Seepage

Water chemistry of seepage over time from each WRD was simulated using the PHREEQC software (Parkhurst and Appelo, 2013), based on calibration to observed water chemistry data and WRD composition and properties from three WRDs in the Faro Mine Area. The three WRDs were selected based on the availability of historical seepage data that were specific to and representative of each WRD. They also represent three groups of WRD composition: neutral, future acid-generating, and currently acid-generating. The PHREEQC model involves simulation of representative mineral dissolution and precipitation during the seepage process, and accounts for other geochemical factors such as trace element adsorption where applicable. The acid generation in each WRD is simulated using a kinetic model of pyrite oxidation and dissolution. Pyrite is the chief contributor to acid drainage, and is used here as a representative model of the process that involves other sulphide minerals as well. This kinetic model enables a continuous-time model of acid generation, which is used to match observed increases in sulphate and to predict water quality into the future. Acid neutralization is accounted for using kinetic dissolution models of calcite and equilibrium assumptions with selected silicate minerals. As the pyrite dissolves, initially releasing dissolved iron, sulphate and acidity, the neutralizing minerals partially dissolve, releasing ions and neutralizing the acid generated by pyrite oxidation. Other key kinetic phases, sphalerite (zinc sulphide) and carbon dioxide and oxygen gas diffusion, are also included in the model.

The kinetic model parameters and mineral masses initially present were adjusted to produce a reasonable agreement with historical data for each of the three calibration WRDs.

The seepage simulation was originally calibrated as a batch kinetic reaction model (CH2M, 2014k) and was in the process of being converted to a 1D vertical transport model when work on that phase was suspended in July 2015. Briefly, the vertical transport model was conceptually constructed as follows: water representing background conditions is introduced to the top of each WRD and then is transported incrementally through multiple model cells along a vertical flowpath. Mineral phases are equilibrated in each cell along this flowpath to the base of the WRD. Kinetic dissolution and gas diffusion reactions were modelled in a less-mobile phase of the WRD and the resulting fluid was allowed to diffuse and mix into the mobile phase during transport, emerging from the bottom cell as simulated seepage. Additional mineral phases were modeled kinetically in the vertical transport model, including key silicates present in the waste rock (for example, tremolite, biotite, diopside, and plagioclase). This effort was advanced, but never fully completed at the site-wide level and by the time geochemical modelling work for the NFRC area was initiated, schedule and scope constraints necessitated the return to the calibrated batch kinetic model system (CH2M, 2014k) as the basis for the NFRC geochemistry modelling work.

In most WRD seepage where iron speciation has been directly measured, the dissolved iron that emerges is predominantly in the reduced state, Fe(II) or ferrous iron, which is expected for mildly acidic to neutral (i.e., $\text{pH} \leq 7.0$) seepages that are impacted by pyrite oxidation. During migration through the WRD, however, a portion of the ferrous iron is oxidized to ferric or Fe(III), and is attenuated by precipitation of ferric hydroxide. There is evidence from test pit and borehole logs that oxidation of ferrous iron occurs within the WRDs, as evident by the presence of ferric iron hydroxide precipitates. The presence of ferrous iron in the WRD seepage and observation of ferric hydroxides precipitates within the WRDs confirms that both forms of iron are generated within the WRD, and is supported by the fact that there is far more sulphate than iron emerging at the WRD base, which indicates that the majority of iron is being attenuated by precipitation of ferric hydroxide. Some of the more neutral seeps have no detectable iron, yet still have elevated sulphate. With this in mind, ferric hydroxide is fixed as an equilibrium phase in the model, and this mineral is modelled to represent the adsorption of zinc and other elements onto its surface during seepage. Other mineral phases, including gypsum (calcium sulphate), are allowed to precipitate in the simulations to provide a solubility threshold for applicable species. Though the actual geochemical processes occurring within the WRDs are far more complex, this model represents a reasonable approximation of the overall evolution of water quality. The current batch model, as described herein, was initially calibrated to seep data from three WRDs. However, the parameters assigned to the non-calibrated WRDs were calculated by taking into account the differences in composition and acid-base properties between calibrated and non-calibrated WRDs (CH2M, 2014k).

This PHREEQC prediction method was assembled from published methods and produces balanced, chemically-defensible results for present and future seepage chemistry. The method replaces the previous chemical simulation, which lacked complete documentation of methods and assumptions, used chemically-imbalanced water chemistry, and did not take all relevant chemical reactions into account.

13.5.1.2 Seepage Mixing

In keeping with mixing proportions established in GoldSim, the simulated WRD seepages were mixed to form the downgradient concentrations at catchment drainage points (GoldSim model nodes). Initial results were encouraging (CH2M, 2014k), with very good fits to the past 11 years' worth of observed ETA data. The recent increases in sulphate and zinc at monitoring locations X23 and FCS-4 were predicted by the mixing model, unlike the previous GoldSim model predictions.

Mixing output for the X23 GoldSim model node was used as input to the RCTA model at Faro Creek Canyon.

13.5.2 North Fork of Rose Creek Geochemical Modelling Work Completed

With regard to the NFRC area, the geochemical modelling has provided present and future chemical composition estimates for groundwater and surface water at selected locations using input from the groundwater flow model. The modelling work was divided into two phases: the calibration phase, in which the model parameters were adjusted so that simulated groundwater quality in key areas of the NFRC study area was within the range of recent monitoring well sample data; and simulation of the NFRC Realigned Channel and NFRC Seepage Collection Pond water chemistry under future conditions, using the calibrated model generated in the initial phase.

As seepage from an individual WRD makes its way towards the NFRC, it mixes with other WRD seepages along with regional background groundwater. The mixing proportions of WRD seepage and groundwater for three locations in the NFRC study area were originally estimated in the site-wide water quality model (GoldSim v2) and the WRD mixing model also used these mixing proportions with PHREEQC in previous work (CH2M, 2014a). The areas are termed “nodes” in the GoldSim v2 model and represent outflows from the following groundwater subcatchment areas:

- NFRC node, near the interface between Segments 1 and 2
- ZII node, at the Zone II Pit Outwash area along Segment 2
- X2 node, in the S-Wells area and near the proposed location of the NFRC Seepage Collection Pond

These mixing models were updated for the NFRC study, and the approach was expanded to include two additional mixing models:

- NFRC Segment 2 immediately north of the NFRD (Rock Drain node)
- Transitional zone between NFRC Segments 2 and 3 (groundwater underflow at NFRD SEG2-3A node)

Previous GoldSim v2 estimates of mixing proportions of contributing sources were updated using steady-state flow simulations generated by the groundwater flow model (CH2M, 2016b). These revised mixing fractions were compared to observed groundwater data in each of the five node areas. Where necessary, the mixing fractions were adjusted to calibrate the mixing model to each node’s observed data. The mixing model was run as a static (batch-style) geochemical mixing model with the fluxes from the individual WRDs that contribute seepage to the target area and from background groundwater expressed as fractions of the total flux for a given target area. For each mixing model, the WRD seepage model provides estimated chemical composition of each WRD’s seepage for the calibration period and for selected years into the future, while the background water composition is assumed to remain constant.

Once the geochemical models created for each mixing simulation were calibrated, these models were used to simulate water quality conditions into the future and create a mixing model to simulate the future water composition of the NFRC Seepage Collection Pond. The mixing model for the NFRC Seepage Collection Pond was comprised of three source waters: (1) the NFRC Segment 2 water chemistry as it is directed into the pond, (2) direct groundwater discharge into the pond, and (3) direct rainfall onto the pond footprint. The three components were mixed in proportion to the flows of (1) and (2) predicted by the groundwater flow model, and the direct rainfall based on pond area and average annual precipitation. The model assumes average, steady-state conditions (that is, no seasonal or wet/dry year effects were modelled). Each of the first two sources were themselves the results of mixing models from upgradient sources.

The simulations of future NFRC Realigned Channel and NFRC Seepage Collection Pond water quality were performed for two scenarios: the first assuming the Zone II Pit well will continue to operate at its average extraction rate, and the second assuming this well is shut down. All mixing models assume average, steady-state flow conditions as simulated by the groundwater flow model; seasonal effects and wet and dry year effects were not modelled specifically.

13.5.3 Results of Geochemical Modelling

Results from the calibration phase of geochemical modelling showed agreement between the simulated and observed water quality for each model node, with particular focus of calibration to key parameters pH, sulphate, and zinc. In several areas of the NFRC, in particular the S-Wells area and the NFRC Realigned Channel at station NF2-A, a sharp rise in sulphate and zinc has been observed in recent years. This trend, coupled with observed drop in pH, fits the geochemical conceptual model of neutralization potential being exhausted in the local groundwater flowpaths. With the calcium carbonate buffering capacity removed, the resulting drop in pH causes the partial dissolution of secondary iron minerals along with the carbonates, which releases zinc and other trace metals to solution. The low pH waters associated with the WRDs, and sulphide cells in particular, also contain high concentrations of trace metals, iron, and sulphate in their own right, which without pH buffering will contribute directly to downgradient areas such as S-Wells, the NFRC Realigned Channel, and the planned NFRC Seepage Collection Pond. The overall result is a transition from a moderately-elevated sulphate, pH-neutral water with modest or low zinc to a water with much greater concentrations of sulphate, zinc, and iron, with pH steadily decreasing from previous values. These recent trends were matched reasonably well during calibration, and the increasing trends extend into the future. Details of calibration results are provided in Appendix D.

The calibrated model was then used, as described in the previous section, to predict future water quality and mineral precipitation rate for the Segment 2 NFRC Realigned Channel, for groundwater flowing towards the NFRC Seepage Collection Pond, and eventually for the NFRC Seepage Collection Pond itself. The results of this modelling predict an increasingly acidic pH in the NFRC Seepage Collection Pond, with pH around 4 for the Zone II well operating and around 3.2 for the well shut down. Because the water in the pond has relatively little contact with solids, there is little to buffer the pH as the increasingly acidic WRD and sulphide cell seepages contribute to the pond. The pH is lower for the scenario in which the Zone II well shut down because there is additional WRD flow to the NFRC area that was previously intercepted by this well. Related to this effect, the model predicts both greater dissolved iron concentration and greater iron solids precipitation at the NFRC Seepage Collection Pond with the Zone II well shut down.

The modelled concentrations and precipitation masses, provided in Appendix D, should be viewed as rough estimates for the purposes of design planning, since there are many variables in the path from WRD seepage to the pond that are not well known. Both the values and timing of model-predicted concentrations are approximate, but the trend towards a more acidic condition, with elevated trace elements, is very likely given the recently observed trends in WRD seepage and its predicted evolution.

While noting the model uncertainties, the zinc concentration in the pond is predicted to steadily increase, with concentrations from about 300 to 1,100 mg/L predicted during the 2015 – 2075 period, regardless of whether the Zone II well operates or not. The amount of dissolved iron in the pond was predicted by the model to be very low with the Zone II well operating (approximately 0.01 mg/L); whereas the simulated concentration is much higher with the well shut down (between 35 and 150 mg/L over the 2015 – 2075 period). This is because of the higher solubility of iron at the lower pH predicted for the pond water with the Zone II well not operating. Future trends for each scenario are presented in graphical form and described in more detail in Appendix D. The elevated zinc, sulphate, and other constituents predicted by the model represent mass loading that would be prevented from discharging into Rose Creek, protecting the creek downgradient of the NFRC Seepage Collection Pond.

13.6 Site-wide Water Balance

13.6.1 Faro Water Management Tool

The Faro water management tool was developed with the GoldSim platform in 2013, originally for the FMC 2014 risk assessment meeting held by YG in the Town of Faro. GoldSim is a dynamic, probabilistic simulation software developed and licensed by GoldSim Technology Group (<http://www.goldsim.com>). The GoldSim software is used to model complex systems for decision and risk analysis. GoldSim uses Monte Carlo simulation to compute the uncertainties in the results from the defined uncertainties in the inputs by simulating the system a large number of times (for example, 100 realizations). For each realization, all of the defined uncertain parameters are sampled (i.e., a single random value is selected from the specified distribution describing each parameter). The system is then simulated through time, given a particular set of input parameters, such that the system performance is computed. This results in a large number of separate and independent results, each representing a possible outcome. The results of the independent system realizations are assembled into probability distributions of possible outcomes. As a result, the outputs are not single values, but probability distributions. A licensed copy of GoldSim is required to develop models, GoldSim Player is available for free download to view, navigate, and run existing GoldSim models. The model is set-up through the player version to allow users to modify initial conditions and operations in defined fields to simulate alternate scenarios and view results. Modifications to the initial conditions and operations are made through a series of user dashboards.

The initial Faro water management tool included system components relevant to site-wide water management, and was flexible enough that it could be refined and expanded in the future. The goal of the water management tool was to provide a simplified and flexible model with stochastic capabilities to account for inflow and operations uncertainties and simulate “what if” scenarios. Simulations were focused on near-term future conditions. The model was designed to simulate, the Faro Pit, ID Pond, IWTS, and CVD Pond, and respective inflows and connections including the ETA, S-Wells, and the Zone II Pit. The model also includes, Vangorda Pit, and Grum Pit and the Vangorda/Grum Water Treatment Plant and the existing connections between these storage reservoirs and collection systems (e.g., Grum-V15). Although the water management tool was created to simulate operations within both the Faro Mine Area and the Vangorda/Grum Mine Area, only model capabilities and controls relevant to the Faro Mine Area are described herein.

The model was developed from the Site-wide Water Quality Model (GoldSim model v2 - CH2M, 2014k) to allow streamlined evaluations of water flow rates and storage requirements and was based on a simplified network of the FMC; as such, no water quality assessment was initially implemented. The water management tool runs in a daily time step however it uses average monthly inflows and flows from collection systems developed from the Site-wide Water Quality Model v2.0 as boundary inflows.

Figure 13-1 is a system schematic of the model components existing in the initial water management tool. Elements implemented to represent the NFRC Seepage Collection Pond operation are also shown on this figure and these additions are described in Section 13.6.2.

13.6.2 Faro Water Management Tool Usage to Date

In addition to being used in the 2013 FMC risk assessment meeting conducted by YG, where different assumptions for FMC water management were assessed, the Faro water management tool has also been used to help evaluate the size of the IWTS under various operational and hydrological conditions, and to understand the near-future elevation of Faro Pit under different interim treatment scenarios.

13.6.3 North Fork Rose Creek Seepage Collection Pond Addition

The model was updated with representation of residual NFRC watershed resulting from diversion of the NFRC east of its current alignment and away from the toe of the WRDs, and the addition of a Seepage Collection Pond. The model was updated to simulate either alternative pond location (i.e., immediately downstream of Haul Road [Alternative 1] or east of the RCTA [Alternative 2]). The purpose of updating the Faro water management tool was to support evaluation of Seepage Collection Pond sizing and operations, particularly with respect to the integration of NFRC Seepage Collection Pond operation into the existing site-wide water management operations. Figure 13-1 is a system schematic of the model components implemented to represent the NFRC Seepage Collection Pond to enable simulation of the NFRC Seepage Collection Pond operations the following upgrades to the initial version of the water management tool were implemented:

- Added new storage reservoir to represent NFRC Seepage Collection Pond with options to adjust pond sizing on dashboard including editable stage-storage and area-capacity curves. Option to input stage-seepage look-up table based on input from GW model.
- Develop relevant scenarios where different combinations of collection pond inflows, IWTS and future permanent water treatment plant capacities, Seepage Collection Pond operations, pump capacity, and pond capacities will be evaluated.
- Expanded model connectivity to include surface water and groundwater inputs to NFRC Seepage Collection Pond and connections from the reservoir to the IWTS and Faro Pit.
- Added NFRC Seepage Collection Pond pumping operations and conveyance. Option for collected water to be pumped to either IWTS or Faro Pit. Option to define operating season and pump capacity.
- Added water quality component for NFRC Seepage Collection Pond and downstream receptor.
- Created priority for IWTS treatment demands to allocate water flow from storage areas and collections systems to Faro Pit if IWTS at capacity.
- Created option to route S-Wells, Zone II Pit, NFRD SIS flows to either Faro Pit (current operation) or NFRC Seepage Collection Pond.
- Added representation of CVD SIS with option to define commissioning date and capacity.
- Added representation of the FCD, NFRC and SFRC using runoff distribution and recurrence from catchment areas.
- Updated CVD Pond discharge capacity to account for third siphon (8-inch diameter) installed during summer 2015 and increase maximum daily drawdown from 10 cm/day to 18 cm/day, per C&M new operations.

13.6.3.1 System and Flow Representation

This section summarizes how the model elements are connected, including how watershed catchments, waste dumps catchments and collections systems are connected to storage reservoirs and the IWTS. Figure 13-1 provides the model schematic, a graphical summary of flow connections including connections among catchments, storage elements, and collection and conveyance systems, including SIS, and shows the locations that the model predicts flows and storage volumes/elevations.

The main storage reservoirs – Faro Pit, ID Pond and CVD Pond are shown with their inflow and outflow connections. Collection system ETA, S-Wells, Zone II Pit, CVD SIS are shown with connections to storage reservoirs and IWTS as applicable. FCD is included to account for leakage to Faro Pit and potential

breach which would result in filling of Faro Pit. RCD is not modelled but seepage from RCD to CVP and ID Pond are included in the boundary inflows from GoldSim model V2.

Inflows to the NFRC Seepage Collection Pond include surface water runoff, groundwater that discharges to surface water, collection systems that are directed to the Seepage Collection Pond (e.g., S-Wells, NFRD SIS and Zone II Pit), leakage from the diversion, and direct precipitation. Catchment areas described in Section 13.2, Hydrology and Surface Water Modelling. NFRC Realigned Channel is included to account for leakage to the NFRC Seepage Collection Pond (see Section 13.2.4 – Model Assumptions) and the confluence of NFRC Temporary Diversion and SFRC is represented as a potential downstream receptor of seepage or flow from overtopping the NFRC Seepage Collection Pond dam. As discussed in Section 13.4 – Groundwater Modelling, seepage from the pond may flow west and not enter NFRC Realigned Channel or SFRC; similarly if the Seepage Collection Pond dam was overtopped the flow may infiltrate before reaching NFRC Realigned Channel or SFRC. No seepage collection system downstream of the NFRC Seepage Collection Pond is simulated, which could also mitigate effects of seepage or overtopping.

All the pits and ponds in the system have an elevation-capacity curve that defines the pit volume at a given elevation. The elevation-capacity curve defines the incremental change in elevation for a given change in the volume of the pits and vice-versa. The pits and ponds also have an elevation rule curve based on average monthly historical pit elevations, meaning that releases from those ponds would happen only if the storage was above the rule curve elevation for a given month.

Once flows are generated at the model boundaries (model boundaries represented as undisturbed catchments and waste dumps), flows are routed through the system. The flow through the system is mainly determined by the connections, pump and reservoir operations, and water treatment season and capacity.

As shown on Figure 13-1, water quality concentrations are applied to the NFRC Seepage Collection Pond, and as background water qualities to the receiving environment streams, NFRC Realigned Channel and SFRC. Loading from other locations is currently not implemented in the model.

Surface water flows for the system, with the exception of NFRC Seepage Collection Pond, FCD, NFRC, and SFRC, are generated using stochastic index sequencing that uses the historical precipitation record. This method has been used previously in the Faro water management tool and for the Site-wide Water Quality Model (v2) (CH2M, 2014h). The model includes monthly precipitation data from the Faro Airport Station from 1978 to 2011. Using the stochastic index sequential mode, the model will randomly select a year between 1978 and 2011, as the start of the hydrological sequence for each stochastic run (called realization). This methodology incorporates historical precipitation variability to the model, and makes use of the available precipitation sequence.

Average monthly flows from the Site-wide Water Quality Model (v2) are used as input data for Faro Pit, ID Pond, CVP, ETA, Zone II, and S-Wells in the water management tool. These imported flows are then scaled by the precipitation from each simulation realization (for example, if the precipitation is 10 percent higher than the mean annual precipitation the imported flow values are multiplied by 1.1). Precipitation and flow data used to calibrate GoldSim model v2 are described in the *FY 2012 Site-wide Water Quality Modelling Report* (CH2M, 2013g) and the *Description of Water Modelling and Results, Faro Mine Interim Works* (CH2M, 2014h).

For residual flows in the NFRC catchment, FCD, NFRC and SFRC, the model has three options to generate total annual flow (runoff plus seepage): (1) a fixed amount, (2) sampling the available historical precipitation, or (3) a cumulative probability distribution function based on Table 13-3, the annual runoff depth for select return periods. As described in Section 13.2.3, Runoff Volume Estimation, the runoff data from larger catchments can be used to characterize the flood regimes of the Faro and Vangorda channels without any adjustment for scale effects. The estimated annual runoff depths for various

return periods can be applied to these catchments. A monthly flow pattern is then used to represent the seasonal variations in the magnitude of expected flows during a year. The monthly flow pattern (Table 5-1) developed using data from Station R7, was also applied to these catchments.

For the model scenarios reported herein, Option 3, the cumulative probability distribution function for annual runoff, is used. Annual runoff is computed as a function of catchment area and a stochastic approach to select the annual runoff based on the probability of the occurrence for various return periods, up to the 1-in-1000-year event. This stochastic approach samples a different annual runoff depth each year of the model simulation and for each model realization. Resampling of the annual runoff depth occurs on October 1, so each month of the water year (October through September) reflects the same total annual precipitation. The selected annual runoff is then constant for the water year (October to September) and converted into monthly flows by the monthly flow distribution (Table 5-1).

The cumulative probability distribution approach provides more flow variability than providing a fixed amount or providing the sampling available from historical precipitation records (33 years). However, the model dashboard also provides an option for the deterministic approach, where annual runoff depth can be input as a fixed amount. A user can also run the model using the actual historical hydrological sequence (the index sequential methodology) to scale the annual runoff; this stochastic mode was described for the system flows.

Although the annual runoff calculated from the cumulative probability distribution function includes seepage, the groundwater flow model, described in Section 13.4, is used to generate baseflow to the NFRC ancestral channel and inflow to the NFRC Seepage Collection Pond. Groundwater discharge to the surface water provides the major contribution to flow in the channel during all months of the year except May and June. Therefore, the monthly percentage of annual runoff depth applied in the model (Table 5-1) is applied only for these two months and flow inputs for the remaining months come from the groundwater flow model. Groundwater flow model inputs are needed to estimate the groundwater discharge after the channel has been moved. Replacing the runoff term (which includes seepage) with groundwater discharge to surface water is required to avoid double counting the base flow contribution, which is otherwise included in the calibrated surface water runoff flow. Groundwater discharge to surface water is specific because distribution for each month varies within a return period. Seepage inputs for select return period events (that is, 2 years, 10 years, 50 years, 100 years, 200 years, and 500 years) are applied to the model. The groundwater flow model was run using a pattern of 2-year, 10-year, X-year, -2year sequence, for each of the select return period event (X-year) to account for antecedent moisture conditions.

Groundwater inputs on the dashboard can be entered as totals combined for all segments of the NFRC or for each individual segment. For Segment 1, only groundwater that is estimated to be intercepted by the seepage collection trench/cutoff wall is included. Conservatively, from a pond sizing and water management operations perspective, this is estimated to be about 25 percent of the total groundwater flow in Segment 1. For Segment 2 and Segment 3, net groundwater discharge to surface water, including flow from WRD, from the eastern side of the valley underneath the diversion is included.

All inflows to the modelled system are balanced with all computed outflows, changes in storage volume, or losses from the system (for example, evaporation) for a given time step.

13.6.4 Model Assumptions

Key model controls and base case assumptions are provided in Table 13-2.

Table 13-2. Model Controls and Assumptions for Base Case
Faro Mine Remediation Project

Model Control	Base Case Assumption
Surface Water Inflows	
System (all inflows excluding NFRC Seepage Collection Pond, FCD, NFRC and SFRC)	Stochastic Index Sequential using Historical precipitation
Inflow to NFRC Seepage Collection Pond, FCD, NFRC, and SFRC	Stochastic based on return period runoff depth and catchment area (cumulative distribution to generate runoff based on probability from return period – see Table 13-3) 1.1 km ² for Alternative 1 pond location 1.4 km ² for Alternative 2 pond location Catchment areas for FCD, NFRC and SFRC are shown on Figure 5-7 in Appendix C – NFRC Surface Water Catchment Boundaries
Groundwater Inflows	
Segment 1 - Groundwater discharge to surface water (intercepted by seepage interception trench and cutoff wall)	Stochastic input as monthly distribution based on return event from Groundwater model
Segment 2A - Groundwater discharge to surface water	Stochastic input as monthly distribution based on return event from Groundwater model
Segment 2B - Groundwater discharge to surface water	Stochastic input as monthly distribution based on return event from Groundwater model
Segment 2C - Groundwater discharge to surface water	Stochastic input as monthly distribution based on return event from Groundwater model
Segment 3A - Groundwater discharge to surface water	Stochastic input as monthly distribution based on return event from Groundwater model
Segment 3B - Groundwater discharge to surface water	Stochastic input as monthly distribution based on return event from Groundwater model
NFRC Realigned Channelleakage	Negligible leakage from lined Segment 2 in comparison to other inputs to NFRC Seepage Collection Pond
NFRC Seepage Collection Pond Storage and Operation	
All reservoirs excluding NFRC Seepage Collection Pond	Storage volume/elevation on October 1, 2015
NFRC Seepage Collection Pond Initial Storage	Commissioned on October 1, 2019, initial storage 0 m ³
Maximum Storage Capacity	300,000m ³ for Alternative 1 pond location 350,000 m ³ for Alternative 2 pond location
NFRC Seepage Collection Pond Conveyance Options	NFRC Seepage Collection Pond is pumped to Faro Pit if IWTS capacity is not available (assuming pipelines and controls configured to pump to both locations simultaneously)
Pump Capacity	126 L/s (2,000 USgpm)
Operating Season	April 15 to October 15
IWTS Operation	
Capacity	347 L/s (5,500 USgpm), assuming IWTS operates at about 90% efficiency
Operating Season	April 15 to October 15

Table 13-2. Model Controls and Assumptions for Base Case
Faro Mine Remediation Project

Model Control	Base Case Assumption
CVD SIS	CVD SIS commissioned in 2025 (RGC, 2015) with year round operations at 176 L/s (2,800 USgpm)
IWTS priority for available capacity	1-IP/ETA 2-Faro pit 3-NFRC Seepage Collection Pond/CVD SIS
Pumped Flow to Faro/NFRC Seepage Collection Pond	
Zone II Pump to NFRC Seepage Collection Pond (instead of Faro Pit)	0% to NFRC Seepage Collection Pond; Zone II Pumping Well continues operating
NFRD SIS Percentage of Flows to NFRC Seepage Collection Pond (instead of to Faro Pit)	100% to NFRC Seepage Collection Pond; NFRD SIS shut off upon NFRC Seepage Collection Pond commissioning; water accounted for in Groundwater model inputs
S-Wells Percentage of Flows to NFRC Seepage Collection Pond (instead of to Faro Pit)	100% to NFRC Seepage Collection Pond; S-Wells pump shut-off upon NFRC Seepage Collection Pond commissioning; volume included in inputs from Groundwater flow model

Although leakage from the NFRC Realigned Channel can be specified in the model, evaluation of leakage from the constructed channel (See Appendix E) indicates that the quantity is negligible through the lined channel in Segment 2, compared with other inputs to the NFRC Seepage Collection Pond. Leakage may occur in the unlined Segment 3 and is either accounted for in groundwater flow model inputs or will not reach the NFRC Seepage Collection Pond. Leakage from the pond is accounted for in input values supplied from the groundwater flow model.

13.6.5 Model Period and Scenarios

The model runs from August 2015 through August 2035, and the NFRC Seepage Collection Pond is assumed to be commissioned in October 2019. The model is run in stochastic mode for 100 realizations.

Scenarios were developed to evaluate water treatment system operation season, NFRC Seepage Collection Pond conveyance system operation (pump capacity and season), reservoir size, and groundwater and surface water input to pond. Table 13-3 presents the scenarios that were evaluated.

Table 13-3. Model Scenarios for Alternative 1 Pond Location
Faro Mine Remediation Project

Scenario	Purpose	Conditions
S1.1	Base case	NFRC Seepage Collection Pond Maximum Volume: 300,000 m ³ Pump Capacity: 126 L/s (2,000 USgpm) IWTS Capacity: 347 L/s (5,500 USgpm) Operating Season: April 15 to October 15
S1.2	Assess the effect of later dewatering start	S1.1 except Operating Season: May 1 to September 30
S1.3	Assess the effect of additional inflows to the Seepage Collection Pond	S1.1 with Additional Input to Pond: Zone II Pit pumping well shut-off (100% of previously captured water allowed is input to NFRC Seepage Collection Pond) and groundwater collected by seepage collection trench/cutoff wall in Segment 1

Table 13-3. Model Scenarios for Alternative 1 Pond Location*Faro Mine Remediation Project*

Scenario	Purpose	Conditions
S1.4	Assess impact of wetter climate	S1.3 with Additional Input: Climate change scenario - 30% increase to annual precipitation (assumption that run-off and groundwater inputs directly increase by 30%)
S1.5	Assess water management options (year round water collection), in response to greater inflows	S1.4 NFRC Seepage Collection Pond Maximum Volume: 250,000 m ³ Operating Season: Year round; both NFRC Seepage Collection Pond pump and IWTS FCD breach on May 15, 2026

Table 13-4. Model Scenarios for Alternative 2 Pond Location*Faro Mine Remediation Project*

Scenario	Purpose	Conditions
S2.1	Base case	NFRC Seepage Collection Pond Maximum Volume: 350,000 m ³ Pump capacity: 126 L/s (2,000 USgpm) IWTS Capacity: 347 L/s (5,500 USgpm) Operating Season: April 15 to October 15
S2.2	Assess the effect of a later dewatering start	S2.1 except Operating Season: May 1 to September 30
S2.3	Assess the effect of additional inflows to the NFRC Seepage Collection Pond	S2.1 except Additional Input to Pond: Zone II Pit flows (100% of previously captured water allowed is input to NFRC Seepage Collection Pond) and groundwater collected by seepage collection trench/cutoff wall in Segment 1
S2.4	Assess impact of wetter climate	S2.3 except Additional Input: Climate change scenario - 30% increase to annual precipitation (assumption that run-off and groundwater inputs directly increase by 30%)
S2.5	Assess water management options (year-round water collection), in response to greater inflows	S2.3 except NFRC Seepage Collection Pond Maximum Volume: 300,000 m ³ Operating Season: Year round; both NFRC Seepage Collection Pond pump and IWTS FCD breach on May 15, 2026

Table 13-5. Model Scenarios for Water Quality Assessment For Alternative 2 Pond Location*Faro Mine Remediation Project*

Scenario	Purpose	Conditions
S3.1	Assess effect of seepage and overtopping of on water quality in receiving environment	S1.1 except Operating Season: May 28 to September 30

13.6.6 Model Dashboards

As described in Section 13.2.1, dashboards in the model allow users to modify initial conditions and operations in defined fields. There is a dashboard for site-wide infrastructure (for example, ID Pond, Faro Pit, IWTS, and CVD Pond); collection systems (for example, S-Wells, Zone II Pit, ETA), and general hydrology controls (Figure 13-2). A second dashboard was created for controls specific to NFRC Seepage

Collection Pond (Figure 13-3) and a third dashboard allows water quality inputs to be specified for the NFRC Seepage Collection Pond and for the immediate downstream receptor Figure 13-4.

An image of the site-wide infrastructure model dashboard showing options for the user-defined controls is presented on Figure 13-2 and includes:

- Inflows – precipitation input type (deterministic or stochastic), and sequence.
- Water Treatment – define IWTS treatment capacity and operating season.
- Pumping Controls – set maximum pumping capacity, operating season for all collection and conveyance systems (for example, S-Wells, Zone II pumping well, CVD SIS, NFRD SIS, ETA, IP).
- Storage Controls – define pond elevation operating targets (indicated in the model as a rule curve) and starting pond or pit water elevations.
- Other controls – define FCD leakage rate to Faro Pit, FCD failure assumptions, and CVP and IP operating requirements (for example, maximum daily drawdown).

An image of the NFRC Seepage Collection Pond model dashboard showing options for the user-defined controls is presented on Figure 13-3 and includes:

- Inflows – define annual runoff input type (deterministic or stochastic), monthly runoff distribution pattern, and NFRC Seepage Collection Pond catchment area.
- Monthly Groundwater Inflow – choose from three options to input groundwater inflows to NFRC Seepage Collection Pond. Also an additional option is provided to input leakage from the NFRC Realigned Channel, and to input percentage of flow from Zone II pumping well, NFRD SIS, and S-Wells that discharges to NFRC Seepage collection Pond instead of Faro Pit.
- Storage Controls – store NFRC Seepage Collection Pond according to volume and maximum capacity. Set elevation-capacity curve, capacity-area curve and elevation-seepage curve. Define monthly operating target (indicated in the model as a reservoir target elevation)
- Operation – set maximum pumping capacity, and operating season for operations in the NFRC Seepage Collection Pond. Define priority for treatment when demand exceeds IWTS capacity.

An image of the water quality inputs dashboard showing options for the user-defined controls is presented on Figure 13-4 and allows the user to define water quality of select sources and receiving streams.

13.6.7 Model Results

The results are presented for all stochastic realizations summarized by percentiles. The solid black line indicates the mean (50 percent) result and the light rose colour line indicates the 99 percent (to maximum) or 1 percent (to minimum) result. By defining flow inputs as probability distributions, the results provide a quantified probability of a simulated outcome (for example, there is a 10 percent chance the flow inputs will result in overtopping the dam).

Figure 13-5 provides annual runoff depth generated in the model as resampled each year and for each realization. The simulated mean annual runoff is about 252 millimetres per year (mm/yr), consistent with mean annual runoff for the FMC. During the simulation period, which includes 100 realizations for each year of the model run (that is, a total of 2000 realizations for the simulation period), there are 4 years with events greater than the 1-in-500-year return period event and 18 realizations that result in events at least greater than the 1-in-100-year return period.

Figures 13-6a through 13-7j provide results from the model for Alternative 1 pond location and Alternative 2 pond location, respectively, and for each scenario to facilitate side-by-side comparison of the results. For each scenario, results are presented to show:

- Rate of inflow to NFRC Seepage Collection Pond
- Stored volume in NFRC Seepage Collection Pond
- Spills from NFRC Seepage Collection Pond
- Available storage capacity in NFRC Seepage Collection Pond
- Daily pumping rate from NFRC Seepage Collection Pond (total)
- Daily pumping rate from NFRC Seepage Collection Pond to IWTS
- Daily pumping rate from NFRC Seepage Collection Pond Faro Pit
- Water elevation in Faro Pit
- Daily discharge rate from IWTS
- Spills from ID Pond

13.6.7.1 Alternative 1 Pond Location Results

The following provides key observations from the results of the five scenarios for Alternative 1 pond location.

Inflow to the North Fork of Rose Creek Seepage Collection Pond

For the base case, S1.1 and S1.2, the mean rate of inflow to NFRC Seepage Collection Pond varies from a low of between about 10 to 15 L/s during the winter months to a maximum value of about 35 L/s during freshet, and during extreme events peak inflows reaching up to about 58 L/s.

For S1.3, with the additional discharge from Segment 1 and discharge from Zone II Pit, the mean rate of inflow to NFRC Seepage Collection Pond varies from a low of between about 12 to 20 L/s during the winter months to a maximum value of about 42 L/s during freshet, and during extreme events peak inflows reach up to about 62 L/s.

For the climate change scenario, S1.4 and S1.5, which uses the same inflow assumptions, the mean rate of inflow to NFRC Seepage Collection Pond varies from a low of between about 16 to 25 L/s during the winter months to a maximum value of about 53 L/s during freshet, and during extreme events peak inflows reach up to about 80 L/s.

Storage Volume

For the base case, S1.1, results indicate that the stored volume will stay below the maximum capacity of 300,000 m³, with a 126 L/s (2,000 USgpm) pump capacity between April 15 and October 15. For all S1.1 realizations, there is a 50 percent chance that when NFRC Seepage Collection Pond is at maximum stage in the spring before pumping, the available storage capacity will still be about 125,000 m³ or greater; and there are no realizations where there is less than 75,000 m³ of available storage capacity.

For the scenario when pumping does not start until May 1, S1.2, results indicate that the stored volume will stay below the maximum capacity of 300,000 m³. For all S1.2 realizations, there is a 50 percent chance that when NFRC Seepage Collection Pond is at maximum stage in the spring before pumping, the available storage capacity will be about 90,000 m³ or greater; and there are no realizations where there is less than 35,000 m³ of available storage capacity.

With the addition of Segment 1 discharge and discharge from Zone II Pit (S1.3), results indicate that the stored volume will stay below the maximum capacity of 300,000 m³. For all S1.3 realizations, there is a 50 percent chance that when NFRC Seepage Collection Pond is at maximum stage in the spring before pumping, the available storage capacity will be about 70,000 m³ or greater; and there are no realizations where there is less than 20,000 m³ of available storage capacity.

For the scenario representing wetter conditions in response to climate change (S1.4), results indicate that the inflow volume will exceed the maximum capacity of 300,000 m³, with a 126 L/s (2,000 USgpm) pump capacity beginning April 15. However, if the pump and water conveyance system is operated year round (S1.5), these additional flows can be managed. Results from S1.5 indicate that a pond volume of less than 10,000 m³ could be maintained with continuous pumping.

To assess the treatment season duration required under wetter conditions from S1.4, one additional scenario (S1.6) was simulated; plots of the results for this scenario are not presented but the simulation suggests that if the operating season begins February 15 instead of April 15, the volume of water can be managed with typically greater than 75,000 m³ storage capacity at peak stage.

Water Treatment, Conveyance, and Storage

For all scenarios except S1.5, pumping from the NFRC Seepage Collection Pond occurs at the maximum capacity when pumping begins, but quickly the pumping rate needed to maintain a low pond elevation is reduced. For S1.1 and S1.2, the pumping rate required to maintain the pond elevation is less than 40 L/s, at least for inflow less than or equal to the mean. That increases to less than or equal to 45 L/s for S1.3 and 55 L/s for S1.4. For the year-round pumping scenario (S1.5), a pumping rate of 55 L/s or less, maintains the mean inflows; a pumping rate up to 80 L/s is used to manage extreme events. The extreme events could be managed instead by using additional storage capacity in the pond.

Water pumped from the NFRC Seepage Collection Pond is split between being pumped directly for treatment and pumped to Faro Pit for storage; assuming pipelines are configured to allow collected water to flow to either IWTS or Faro Pit, or both simultaneously. There is not enough capacity at the IWTS in the spring to receive the full volume and the peak volumes discharge to Faro Pit. To maintain the pond elevation through the summer, discharge continues to be directed to both locations.

For S1.1 through S1.4, after 2025, all water collected from the NFRC Seepage Collection Pond is discharged to Faro Pit as a result of the base case assumption that a CVD SIS is brought online in 2025 and operates year-round at 176 L/s (2,800 USgpm). It is also based on the assumption that the priority assigned to water treatment demands allocates the water from Faro Pit ahead of water from the NFRC Seepage Collection Pond. That volume of water collected from CVD SIS would quickly fill Faro Pit (Figure 13-15), while the IWTS operated at 6,000 US gpm, 6months of the year (Figure 13-15). Results from S1.5 indicate if the IWTS and associated pipelines were capable of operating year-round, this volume of water collected from the CVD SIS could be managed. Also noticeable with year-round treatment capability (S1.5) is the rapid drawdown of Faro Pit, from the current elevation, which is bought back to target elevation within 1 year rather than about 3 years required under seasonal pumping. Although an aside to the current work focusing on NFRC Seepage Collection Pond, these results highlight future considerations for site-wide water management.

To assess current treatment capacity available to manage additional flows in addition to the estimated treatment demands from the NFRC Seepage Collection Pond (for example, from a future CVD SIS or other collection system), one additional scenario (S1.7) was simulated starting from S1.1, except instead of year-round operations at 176 L/s (2,800 USgpm), a CVD SIS operating year round at 57 L/s (900 USgpm) was simulated. The simulation suggests that year-round conveyance from the NFRC Seepage Collection Pond and treatment would allow Faro Pit to be maintained at the targeted elevation.

Results from these scenarios suggest that the water elevation in ID Pond may at times in future years exceed the spillway elevation, resulting in uncontrolled discharge (Figure 13-15). This condition could be mitigated by increasing the pump capacity to convey additional water from the ID Pond to the IWTS or Faro Pit.

The key findings of this initial consideration of the future competing water treatment demands is that the current infrastructure and operations is not adequate to manage the potential future volumes. Further assessment and consideration of upgrading infrastructure to increase conveyance and

treatment capacity, including year-round water management and treatment operations, is recommended as the site-wide closure plan advances.

13.6.7.2 Alternative 2 Pond Location Results

The following provides key observations from the results of the five scenarios for Alternative 2 pond location.

Inflow to the North Fork of Rose Creek Seepage Collection Pond

For the base case, S2.1 and S2.2, the mean rate of inflow to NFRC Seepage Collection Pond varies from a low of between about 13 to 20 L/s during the winter months to a maximum value of about 35 L/s during freshet, and during extreme events peak inflows reach up to about 75 L/s.

For S2.3, with the additional discharge from Segment 1 and discharge from Zone II Pit, the mean rate of inflow to NFRC Seepage Collection Pond varies from a low of between about 15 to 25 L/s during the winter months to a maximum value of about 40 L/s during freshet, and during extreme events peak inflows reach up to about 78 L/s.

For the climate change scenario, S2.4, and S2.5 which uses the same inflow assumptions, the mean rate of inflow to NFRC Seepage Collection Pond varies from a low of between about 20 to 30 L/s during the winter months to a maximum value of about 55 L/s during freshet, and during extreme events peak inflows reach up to about 100 L/s.

Storage Volume

For the base case, S2.1, results indicate that the stored volume will stay below the maximum capacity of 350,000 m³, with a 126 L/s (2,000 USgpm) pump capacity between April 15 and October 15. For all S2.1 realizations, there is a 50 percent chance that when NFRC Seepage Collection Pond is at maximum stage in the spring before pumping, the available storage capacity will be about 100,000 m³ or greater; and there are no realizations where there is less than 45,000 m³ storage capacity.

For the scenario when pumping does not start until May 1, S2.2, results indicate that the stored volume will stay below the maximum capacity of 350,000 m³, except for a few instances during years with extreme events. For all S2.2 realizations, there is a 50 percent chance that when NFRC Seepage Collection Pond is at maximum stage in the spring before pumping, the available storage capacity will be about 50,000 m³ or greater.

With the addition of Segment 1 discharge and discharge from Zone II Pit, S2.3, results indicate that the stored volume will stay below the maximum capacity of 350,000 m³, except for a few instances during years with extreme events despite initiating pumping April 15. For all S2.3 realizations, there is a 50 percent chance that when NFRC Seepage Collection Pond is at maximum stage in the spring before pumping, the available storage capacity will be about 50,000 m³ or greater.

For the scenario representing wetter conditions in response to climate change, S2.4, results indicate that the inflow volume will exceed the maximum capacity of 350,000 m³, with a 126 L/s (2,000 USgpm) pump capacity beginning April 15. However, if the pump and water conveyance system is operated year round, S2.5, these additional flows can be managed. Results from S2.5 indicate that a pond volume of less than about 10,000 m³ could be maintained with continuous pumping.

Water Treatment, Conveyance and Storage

Key observations regarding water treatment, conveyance, and Faro Pit storage from Alternative 2 pond location scenarios are similar to the observations from Alternative 1 pond location. Results are provided in Figure 13-7a through Figure 7j but are not described further. Refer to discussion on results for Alternative 1 pond location for key observations.

Water Quality

Water quality results (Figure 13-8) in Rose Creek (that is, downstream of the confluence of NFRC Realigned Channel and SFRC) from S3.1, indicate that based on seepage rates up to about 2 L/s when the NFRC Seepage Collection Pond is at full stage, the mean zinc concentration ranges from about background 0.005mg/L, during pond operation and high stream flows in Rose Creek, to about 1 mg/L during high pond water levels and low stream flows and mean sulphate concentration ranges from 10 to 15 mg/L.

Results from S3.2 indicate that discharge overtopping the NFRC Seepage Collection Pond in late May between 41 and 53 L/s (Figure 13-10) predicts zinc concentrations in Rose Creek to range from about 3 to 4 mg/L, and mean sulphate concentrations from 30 to 40 mg/L.

These modeled results reflect a simple load balance of the released water from the NFRC Seepage Collection Pond with NFRC and SFRC. Constituents in water that discharges to the receiving environment may follow a flow path that does not discharge to Rose Creek or these constituents may be subjected to geochemical reactions (for example, adsorption, ion exchange, and precipitation) that results in short transport distances. Preparation of an adaptive management plan and surveillance monitoring of groundwater concentrations downstream of the NFRC Seepage Collection Pond will allow mitigative actions to be implemented to prevent or minimize the volume of seepage discharging to the receiving environment.

Internal Design Reviews

14.1 Introduction

This section summarizes the CH2M internal review process that will be implemented on this project, key contributors, and peer reviews and quality reviews planned for NFRC Project documents and designs.

14.2 Quality Management Plan

A Design Quality Management Plan (DQMP) has been prepared for NFRC design deliverables. The DQMP establishes the process for quality control review, including internal design reviews summarized below.

14.2.1 Continuous Quality Control Process

Continuous quality control (QC) is a process that provides frequent and timely quality input and control. QC minimizes rework through timely interaction between the QC review team and the design team.

In addition to discipline leads, CH2M has identified key review staff (i.e., senior technical consultants [STCs]) who will review and address overall project and site operation integration: each discipline or technical area has a specific discipline or technical reviewer. Frequent communication between the reviewers and the leads is the most important element of the continuous QC process. Reviewers will be actively engaged during the design process.

14.2.2 Review

Reviewers will review design work products and calculations for technical accuracy, completeness, and compliance with design criteria, codes, guidelines, and standards (as defined in this Preliminary Draft DBR), and with discipline best practices. Reviewers will verify the design documents conform to the requirements in the DBR (and subsequent updates and modifications)..

The STCs will review the documents for technical accuracy and consistency with the technical requirements of the project and verify the requirements are effectively addressed by the design. The following items will be considered by the STCs during their review:

- Are the key assumptions and design decisions sound and documented?
- Are there areas where the risks appear to be higher than normal? How are these addressed?
- Are safety factors or probabilities in conformance with reasonable standards of practice?
- Are there items of significance that have not been addressed?
- Have the O&M considerations of the design been adequately considered and addressed?
- Are the client's requirements or preferences satisfied?
- Does the design satisfy the applicable performance requirements?
- What problems remain to be solved? Can the problem be solved in a reasonable manner and appropriate time frame?
- Does the design or report appear to be satisfactory to proceed to the next phase of development?
- Is the design capable of meeting the project cost objectives?
- Is the design consistent with local practice, material availability, and soil conditions encountered?

- Does the design satisfy applicable health and safety, environmental, and regulatory requirements?
- Is the design in compliance with applicable laws, regulations, codes, standards, and specifications?
- Is the level of design detail sufficient to support preparation of a Class 4 cost estimate within the prescribed estimate accuracy limits?
- Are documents clear and unambiguous?

Table 14-1 lists quality reviewers for the NFRC Project.

Table 14-1. List of Quality Reviewers

Faro Mine Remediation Project

Team Member	Role
TAR 21 – NFRC Project	
Dick Crim	Project Manager
Mike Reimbold	Design Quality Manager (DQM)
Joan Stoupa	Project Integration QC Reviewer
Dirk Van Zyl	Overall QC Reviewer, Dam Safety
Jim Stefanoff	Integration of NFRC Project with Water Treatment
Jim Cassie/BGC	Senior Technical Reviewer: Cold Regions
Jack Seto/BGC	Cold Weather Geotechnical QC Reviewer
Phil Pasteris	Hydrology QC Reviewer
Dave Bunte	Geochemistry QC Reviewer
Wim Veldman/Matrix Solutions	Hydraulics QC Reviewer
Wendall Thiessen	Electrical QC Reviewer
Chris Funk	Pipelines and Mechanical QC Reviewer
Rick Riker	Geotechnical: Technical Review Board Lead (Dam Safety)
Peter McCreath/ Clearwater Consultants LTD.	Hydraulics and Hydrology: Technical Review Board (Dam Safety)
Fred Matich/ MAJM Corporation	Mining, Geotechnical: Technical Review Board (Dam Safety)
Lonnie Reese	Cost-estimating QC
Clare Humpherys	Bidability, constructability, and operability Review
Cam Malloch	Maintenance and Site Operations Integration QC Reviewer
Clare Humphrey	Construction and Operations and Maintenance Review
Tlicho Engineering and Environmental Services Ltd. (TEES)	Operability and Maintenance

14.2.3 Milestone Reviews

The following milestone review process will be followed for deliverables at each design milestone (i.e., Draft DBR, Final DBR, Conceptual Design, Preliminary Design, and Detailed Design):

1. Design quality chartering meeting(s) will be held after each deliverable phase is kicked off to review the objectives and critical success factors of the project and the roles and responsibilities of the QC team, and to establish expectations around continuous QC.

2. Before starting the review, the reviewer and lead will discuss the key project assumptions, issues or areas of concern, and schedule, and will review the specific items contained in the risk register as it relates to the specific reviewers' technical discipline.
3. The DQM will schedule a meeting with the discipline leads after reviews are completed to discuss any major comments and concerns and to determine how those items will be resolved.
4. The schedule for document review will be posted on the FMRP SharePoint site and used as the tool to inform reviewers of time required.
5. All reviewer comments are to be placed on the QC Review Form (QRF), which will be distributed at each review period. If additional clarification is required, such as providing a drawing markup, the QRF comment should be keyed to the additional detail and the markup included with the returned form. The DBR (provided as a Word file) may be revised in tracked changes mode if the reviewers are able to easily see all review comments and responses. The QRF must be returned to the DQM by the date indicated in the schedule.
6. The DQM will verify that all reviewers have completed their review and provided comments. The DQM will consolidate comments, if necessary, assign responsibility for each comment, and distribute the QRF to the discipline leads, the Project Manager, and the Design Manager.
7. The discipline leads, the Project Manager, and the Design Manager will review and respond to comments assigned to them. If a comment is unclear, the lead will call the reviewer to obtain additional clarification to adequately address the comment. If resolution cannot be made, the lead is to inform the DQM, who will then engage the Project Manager, Design Manager, and technology leads, as appropriate, to resolve the issue.
8. The DQM will be responsible for determining that all comments have been responded to and will send the completed form to the reviewers for their review and concurrence with the responses.
9. The reviewers, Project Manager, and Design Manager will sign the Document Review Record Form (or provide an email with the appropriate wording from the form) as evidence of their concurrence with the responses to their comments and send the signed form to the DQM.
10. The DQM will also confirm that discipline checklists have been signed and that calculations have been reviewed in accordance with the DQMP and that these documents are in the project files.
11. Unresolved issues will be tracked by the DQM on an Issue Tracking Form. Comments on the Issue Tracking Form will be resolved at the beginning of the next phase. No item will be on the Issue Tracking Form at the end of the design.

14.2.4 Dam Safety Technical Review Board

The Dam Safety Technical Review Board (TRB) will be engaged in this project because of the unique issues associated with the new Seepage Collection Pond Dam and the NFRC Realigned Channel dike. The TRB has been effectively engaged in the Rose Creek Remediation Project in review of the RCTA Alternative Analysis and is familiar with the project and its unique challenges.

The TRB will review the NFRC design at the milestone reviews. These include the portions of the Draft DBR, Preliminary Final DBR, and Conceptual Design. The TRB will review the Draft DBR concurrent with review by the TRC and review the Preliminary Final DBR before it is submitted to YG.

The formal TRB consists of the following members:

- Rick Riker/CH2M
- Peter MacCreath/ Clearwater Consultants LTD.
- Fred Matich/ MAJM Corporation

Dirk van Zyl, Professor of Mining Engineering at the University of British Columbia and subconsultant to CH2M, will also provide focused review of the NFRC Seepage Collection Dam design components.

14.2.5 Calculation Review

All design calculations will be documented and reviewed. Calculations are to be reviewed in detail by a competent peer, comments addressed, and calculations signed by the peer reviewer before they are sent to the assigned QC reviewer. Peer review of calculations is to occur before the formal QC review period.

14.2.6 Cost Estimates

All cost estimates will be reviewed before they are submitted to YG. Estimates are to be reviewed and approved by CH2M's Environmental Services Business Group chief estimator or his designee (currently Lonnie Reese/senior cost estimate reviewer), before CH2M's Review and Approval Workflow.

14.2.7 Bidability, Constructability, and Operability Reviews

A formal bidability, constructability, and operability and maintenance review will be performed before submitting the Conceptual Design to YG. These reviews will be performed in parallel with the QC reviews. To minimize the impact of these reviews, the leads are encouraged to communicate regularly with the constructability, and operability and maintenance reviewers throughout the design process as these reviewers are a part of the continuous QC process.

Review comments will be recorded on the QRF and the responses and adjudication tracked in the same manner as the design milestone review process described in Section 14.2.3.

14.2.8 Interdisciplinary Coordination

Interdisciplinary coordination and reviews take place at the end of each design phase. Each lead is responsible for reviewing the documents for coordination with other disciplines during the internal review period. However, leads should be coordinating throughout the design process. The interdisciplinary reviews are identified in the schedule as the ITR [Internal Technical Review].

14.3 Quality Control Review Documentation

The following will be in the project files to document the internal design review process:

- Project checklists (e.g., signed discipline checklists and data management checklists) as applicable to the phase of design and design content. Each lead is responsible for putting completed forms in the project file. Copies of the forms or verification that this is complete will be given to the Project Manager, the Design Manager, and the DQM.
- Document review record (either the signed form or email) indicating the reviewer has reviewed the responses to their comments, is in agreement with how they have been addressed, and that the project may move to the next phase. The DQM will obtain the completed record and put in the project file.

QRFs and comments will be purged from the project files. Checklists and document review records are sufficient documentation of the review process.

14.4 Value Engineering Study

Value engineering was removed at the Conceptual Design stage as directed by YG.

Owner's Design Reviews

15.1 Introduction

This section summarizes the Owner's design review processes, external reviewers, and control points for the NFRC design. This includes interaction with the TRC and external Owner Consultant/ IPRP processes.

15.2 Technical Review Committee

It is CH2M's understanding that the TRC is responsible for managing the review of documents submitted to YG by CH2M, conducting reviews, coordinating with IPRP for their reviews, and providing comments to the CH2M design team from both the TRC and the IPRP. Further, we also understand that the TRC will be responsible for managing the stage gate approval process and providing approval of design deliverables to CH2M.

Concurrent with preparation of this Draft DBR, the TRC review processes has not been fully defined. CH2M will assist YG and INAC, as requested, in developing a formalized review process that incorporates anticipated review schedules, a comment adjudication process, and documentation procedures.

The preliminary design schedule presented in the Draft DBR provides 10 working days for the TRC to review the Draft DBR and 10 working days to review the Final DBR. CH2M requests that the TRC confirm that this is acceptable. CH2M also requests a confirmation on whether design review meetings should be scheduled with the TRC and the CH2M design team for review of the Draft DBR and the Final DBR. These meetings will need to be scheduled as soon as possible to assure availability of both the TRC and CH2M team.

An informal brainstorming session conducted in June 2015 was helpful and useful in identifying issues, establishing priorities, and understanding constraints. CH2M conducted a workshop in October 2015 to walk through the Draft DBR with YG. Only minimal verbal comments were provided by YG during the workshop. In January 2016, CH2M conducted a process presentation summarizing (1) preliminary requests from the modelling performed to date and (2) progress on alternative design. Only minimal verbal comments were provided by YG during the presentation.

15.3 Independent Peer Review Panel

At the time this Preliminary Final DBR is being prepared, the role and review responsibility of the IPRP for the NFRC Project has not been fully conveyed to CH2M.

Presently, it is CH2M's understanding that the IPRP will review the Final DBR in June after the TRC comments pertaining to the Preliminary Final DBR have been addressed. CH2M will address comments and submit a Final DBR for IPRP review. A tentative review meeting with the IPRP is scheduled for June 13, 2016.

15.4 Value Engineering Study

As directed by YG, VE will not be conducted during initial preparation of the DBR or the Conceptual Design. VE is recommended following the IPRP review of the DBR and before finalization of the Concept Design.

Engineering Deliverables

16.1 Introduction

This section describes the engineering deliverables to be developed during the Conceptual Design phase for each engineering discipline and summarizes the general content of each deliverable. This section also includes a high-level list of deliverables to be produced for the successive design phases (Preliminary and Detail Design phases).

16.2 Conceptual Design

The Conceptual Design includes the development of a sufficiently detailed layout to prepare a Class 4 cost estimate. The Conceptual Design phase engaged the necessary engineering design disciplines (e.g., civil, geotechnical, civil, pipeline, mechanical, electrical, I&C, and structural) to prepare the Conceptual Design drawings.

16.2.1 Conceptual Design Drawings

The Conceptual Design drawing provide the required plan, profiles, and sections for the NFRC Project elements. The Conceptual Design is included are included in Appendix F.

As outlined in Section 13, the Design Definition phase included the various modelling and analysis work required to support the Conceptual Design. The Final DBR includes the following appendixes to support the Conceptual Design:

- Appendix B - Hydrotechnical Report
- Appendix C - Groundwater Report
- Appendix D - Geochemical Report
- Appendix E - Geotechnical Report

16.2.2 Class 4 Cost Estimate

Figure 16-1 summarizes the classes of cost estimates in accordance with AACE International (AACE). In accordance with the *Northern Contaminated Sites Program, Major Project Standards & Guidance Manual* (AANDC, 2013), a Class 4 cost estimate is developed for the Conceptual Design phase. The typical expected accuracy range for a Class 4 cost estimate equals –15 to –30 percent on the low side and +20 to +50 percent on the high side. This type of estimate is primarily used to develop a preliminary budget for the NFRC Project. As design progresses beyond the Conceptual Design, revised cost estimates will be prepared that have a narrower uncertainty band as a result of the more detailed level of design. The Class 4 cost estimate is prepared using information available and the current level of project definition. Actual project costs will depend on final design, scope of work, actual labour and material costs, competitive market conditions, schedule implementation, and other variables. Therefore, final project costs will vary from the cost estimates in the Class 4 cost estimate. Project funding needs must be reviewed before making specific financial decisions related to project evaluation and adequate funding.

The Class 4 cost estimate will comply with the standard AACE approach and also include the following indirect costs:

- Procurement
- Construction management (engineer's onsite oversight, responsible engineer's support, requests for information and submittal reviews)
- Construction closeout and handoff
- Environmental monitoring
- Compliance water and borrow sampling during construction and traffic control

16.3 Preliminary Design Phases

Once the stage gate approval of the Conceptual Design is complete, the Preliminary Design (60%) phase will begin. During this level of design, a preliminary design report is developed, the drawings are further developed and refined, and the first draft of the technical specifications and scope of work are prepared. A Class 3 cost estimate is also prepared.

The following preliminary design reports should be prepared:

- Field Exploration (Phase 3)
- Hydrology
- Groundwater
- Hydraulics (Spillway and Outlet Works)
- Pump Station and ARD Piping

16.4 Detailed Design Phases

Once the stage gate approval of the Preliminary Design is complete, the Detailed Design (90%) phase will begin. During this level of design, a detailed design report is completed, the drawings and the technical specifications are finalized, and a Class 2 cost estimate is also prepared.

The following final design reports should be prepared:

- Geotechnical
- Hydrology
- Groundwater
- Hydraulics (Spillway and Outlet Works)
- Pump Station and ARD Piping

Planning Deliverables

17.1 Introduction

This section summarizes the planning deliverables that have been prepared to date for the NFRC Project and provides an overview of the planning deliverables that will be prepared for the NFRC Project through the Final DBR submittal. This section also summarizes the key components of the Task Authorization Requests (TARs) and describes how the TARs interface with the engineering deliverables.

17.2 North Fork Rose Creek Scoping Workshop

On February 26 and 27, 2015, CH2M, YG, and INAC conducted a scoping workshop for the NFRC Project with the objective of designing and constructing the project in a 5-year timeframe. The meeting minutes of this workshop were submitted to YG on March 3, 2015. During the scoping workshop, conceptual project components were identified and high-level fieldwork needs were discussed for each of the project components. CH2M used the fieldwork needs identified in the scoping workshop to support the development of the NFRC scoping documents and TARs, as discussed in Section 17.3.

17.3 Task Authorization Requests

TARs are prepared after a general scope for work is identified and are developed in conjunction with the YG Project Manager. Table 17-1 outlines the NFRC Project TARs that have been submitted to YG and INAC to date. Each TAR consists of the following key components: scope, schedule, key staff, cost opinion, and work breakdown structure (WBS).

Table 17-1. NFRC Project TAR Summary
Faro Mine Remediation Project

TAR	Scope	Submitted to YG	Approved by YG	Status
TAR021-2015-001	Phase1A Drilling Exploration – Preliminary characterization of ground ice conditions upstream of the NFRD	April 2, 2015	April 10, 2015	Complete. Final report submitted to YG on July 17, 2015.
TAR021-2015-002	Summer field exploration program, laboratory analysis, data management, partial scope for field reporting, Draft DBR, and Value Engineering Study Scope to be executed by August 31, 2015	May 21, 2015	June 30, 2015	Complete. Draft DBR was submitted on August 31, 2015. Final Field Reports are included in Appendix B, C and E.
TAR021-2015-003	Remove geotechnical laboratory analysis and value engineering from scope	July 7, 2015	July 15, 2015	Complete.
TAR021-2015-004	Extend scope and schedule of Draft DBR	August 12, 2015	August 21, 2015	In progress.

Table 17-1. NFRC Project TAR Summary
Faro Mine Remediation Project

TAR	Scope	Submitted to YG	Approved by YG	Status
TAR021-2015-005	Extend schedule for activities contracted under TA002 beyond August 31, 2015	August 21, 2015	August 12, 2016	Complete. Draft DBR was submitted on August 31, 2015.
TAR021-2015-006	Addition to Geotechnical lab analysis	September 10, 2015	September 24, 2015	Complete. Geotechnical lab analysis is included in Appendix E.
TAR021-2015-007	Correction to WBS codes used in TAR021-2015-006	October 1, 2015	October 15, 2015	N/A.
TAR021-2015-008	NFRC Test Cut	October 19, 2015	November 19, 2015	Construction Complete. Reporting in progress and scheduled for submission on March 31, 2016.
TAR021-2015-009	Prepare Final DBR	November 4, 2016	December 4, 2016	In progress. Scheduled for submission on March 31, 2016.

After TARs are submitted to YG, they are processed and reviewed by TRC and YG project controls staff. Comments, if any, from TRC and YG are compiled and transmitted to CH2M. Once comments have been received, an amendment is drafted and the TAR is resubmitted. Acceptance and authorization of the TAR is generally a 4-week process from time of submission to authorization.

In 2015, YG requested that a scoping document be submitted in advance of TARs. This document provides high-level details about the scope and schedule that would be further detailed in the TAR. CH2M will continue to prepare scoping documents to confirm that scope and schedules meet YG's needs before preparing the detailed TAR.

In addition to the TARs outlined in Table 17-1, CH2M anticipates preparing TAR021-2016-001, which will include scope to address comments from the Technical Review Committee on the Preliminary Final DBR, prepare the Final DBR, present the Final DBR to the IPRP, and scope deliver transition documents as requested by YG/INAC.

17.4 Schedules

During the TAR process, baseline schedules are developed with YG's input and approval. These schedules assume agreed upon external review periods. The baseline schedule will be updated based on actual timing and receipt, TAR approval, design review comments, and stage gate reviews.

Project Scope

18.1 Project Scope

Project scope information is not included in the Preliminary Final DBR because CH2M's scope includes only the submission of the Final DBR, with the final design to be completed by others. The intent of this section is to include the development of a draft WBS complete with WBD dictionary describing each Work Package.

Project Cost

19.1 Project Cost

Project cost information is included in Appendix G. Appendix G includes the Class 4 accuracy cost estimate, complete with a basis of estimate and alternative costing where applicable. Appendix G will be submitted in a separate submittal after the Preliminary Final DBR is submitted.

Project Schedule

20.1 Construction Schedule

A preliminary construction schedule has been prepared for this project and is included in Appendix H. Key components and critical elements of the schedule are provided in Table 20-1. The design schedule has been developed based on experience to date pertaining to the design review process.

In addition, the regulatory framework for the project needs to be identified and integrated into the schedule.

Table 20-1. Key Elements of Project Schedule
Faro Mine Remediation Project

Task	Start	Completion	Notes
Conceptual Design	Apr 2016	Oct 2016	Includes Value Engineering and stage gate approval
Field Work 2016	Jun 2016	Nov 2016	Field work needs to be conducted at NFRC Seepage Collection Pond Alternatives 1 and 2 locations if both carried forward. Includes laboratory testing and reporting
Preliminary Design	Oct 2016	Feb 2017	Includes Stage Gate Approval
Detailed Design	Feb 2017	Jun 2017	Includes Stage Gate Approval
Preconstruction	Feb 2017	Nov 2017	Includes advertising, pre-bid site visits, legal review, contract award
Construction 2018			
Site Specific Plans	Nov 2017	Feb 2018	Site offices, equipment, personnel
Mobilization	Feb 2018	Feb 2018	Site offices, equipment, personnel
Site Development	Mar 2018	Jul 2018	Temporary water supply, erosion protection measures, develop borrow sources, initiate concrete aggregate, riprap, other lining materials production
NFRC Segment 2	Feb 2018	Nov 2018	Construct and move NFRC to temporary channel; NFRC Realigned Channel – clear, grub, excavate, foundation prep, place thermal barrier, GW collection and structural fill, channel lining and ACBM.
Haul Road Crossing	Feb 2018	Oct 2018	Excavation, placement of waste slab and bottom culvert slab
NFRC Segment 3	May 2018	July 2018	Excavation channel and dike
Mine Access Road	Apr 2018	Nov 2018	Excavation, foundation prepare, culvert or bridge construction
Construction 2019			
NFRC Segment 2	Apr 2019	Oct 2019	Riprap, sediment pond and cutoff wall at Segment 1-Segment 2 junction.
Haul Road Crossing	Apr 2019	Oct 2019	Construct culvert side walls, top deck, apron, and wing walls.
NFRC Segment 3	May 2019	Aug 2019	Place riprap and construct step pools
NFRC Segment 4	May 2019	Aug 2019	Excavation, foundation prepare, embankment, and riprap placement; open up Pump House Pond to RCD
NFRC Seepage Collection Pond	May 2019	Oct 2019	Construct access roads, ARD pipelines to IWTS and Faro Pit, clear and grub dam footprint; clear reservoir footprint, process borrow materials, initial dam core cleaning (above creek level), construct powerlines

Table 20-1. Key Elements of Project Schedule
Faro Mine Remediation Project

Task	Start	Completion	Notes
Divert NFRC to Realigned Channel		Oct 2019	Divert NFRC to new NFRC Realigned Channel
Construction 2020			
NFRC Segment 1	Apr 2020	Jun 2020	Cutoff wall and NFRC Permanent Seepage Collection Trench
NFRC Segment 2	Jun 2020	Jul 2020	Complete NFRC Permanent Seepage Collection Trench
Haul Road Crossing	May 2020	Aug 2020	Complete Haul Road Culvert backfill
Seepage Collection Pond (Alternative 1)	May 2019	Sep 2019	Construct cofferdam, divert mine-impacted water to pipelines, complete dam excavation, placement of dental concrete at dam core, foundation preparation, dam construction, pump stations, electrical and I&C. Remove Cofferdam, startup and shakedown.

Key Assumptions and Milestones

1. Clearing, grubbing, excavation, and placement of the thermal barrier and initial material placement on the dike footprint in Segment 2 of the NFRC Realigned Channel will be completed during the winter (March-April 2018).
2. Excavation of the Haul Road will start in March 2018, initially, material will be moved to temporary storage until the Segment 2 dike is ready for structural fill placement, scheduled to start April 2018.
3. Completion of the Haul Road excavation and placement of the culvert waste slab and bottom slab must be completed by fall of 2018 so that the Haul Road culvert walls, deck, and wing walls can be completed, and NFRC diverted to NFRC Realigned Channel by fall 2019
4. The schedule includes placement of the lining system and the ACBM in Segment 2 of the Realigned Channel in 2018. This work can take place in 2019 without impacting the schedule to divert the creek by the end of 2019. The critical work for diverting the creek is completion of the Haul Road culvert walls, apron, and wing walls.
5. For the NFRC Seepage Collection Pond Alternate 1, placement of the cofferdam, excavation, and completion of foundation preparation cannot take place until the NFRC has been diverted into the NFRC Realigned Channel, scheduled for completion fall 2019. If delayed, this work cannot likely take place during freshet and dam construction completion will be delayed. Without the diversion in place, as discussed in Appendix B, the 2-year peak flow is estimated to equal approximately 5.8 m³/s (93,000 USgpm), while the 10-year peak flow equals about 16.8 m³/s (266,000 USgpm). The design to capture and divert either of these flow events would require a much larger cofferdam and an extensive network of pipes.
6. As soon as the NFRC is diverted into the NFRC Realigned Channel in October 2019, additional steps can be taken to capture a significant portion of the contaminated flow downstream of the Rock Drain. This can be done in conjunction with construction of the cofferdam and pipelines, scheduled for early 2020; or completed in November 2019.
7. For the NFRC Seepage Collection Pond Alternate 2, construction of the cutoff wall and the connection to the new diversion ditch (conveyance to pond) cannot take place until NFRC diverted to NFRC Realigned Channel. Because most of construction of the NFRC Seepage Collection Pond Alternative 2 can take place off channel, tie-in and startup can be completed in July 2020.

Conceptual Design

21.1 Conceptual Design

The conceptual design for the NFRC includes the components by project Segment as follows.

Segment 1

- Cutoff Wall and NFRC Permanent Seepage Collection Trench and access road
- Upgrading the existing access road from the Northeast WRD down to the confluence of NFRC and the Faro Creek Diversion
- Sediment pond at the confluence of Segment 1 and Segment 2

Segment 2

- Lined NFRC Realigned Channel with access road
- Temporary division
- Permanent NFRC Permanent Seepage Collection Trench and trench
- Access road for access from the Haul Road down to the NFRC Realigned Channel Access Road
- Access road to from the Zone II access road across the NFRC Permanent Seepage Collection Trench to the NFRC Realigned Channel Access Road.

Haul Road Crossing

- Alternative 1- Tunnel new arch culvert
- Alternative 2- Open cut a new twin concrete box culverts
- Haul Road reprofiling for use as borrow

Segment 3

- Alternative 1 – Riprap-lined Realigned NFRC Realigned Channel Access Road along P3 alignment
- Alternative 1 – Riprap-lined NFRC Realigned Channel Access Road along P4 alignment

Mine Access Road Crossing

- Alternative 1- Open cut a new twin concrete box culverts
- Alternative 2- Bridge over NFRC Realigned Channel Access Road
- Alternative 3- Low water crossing
- Mine access road reprofiling

Segment 4

- Alternative 1 – Riprap-lined NFRC Realigned Channel Access Road, along P3 alignment
- Alternative 1 – Riprap-lined NFRC Realigned Channel Access Road, along P4 alignment

SFRC Confluence

- Alternative 1 – Riprap-lined confluence and existing back protection at the P3 alignment confluence with SFRC
- Alternative 1 – Riprap-lined confluence and existing back protection at the P3 alignment confluence with SFRC

SFRC Confluence

- Alternative 1 – NFRC Seepage Collection Dam and Pond
- Alternative 2 – NFRC Seepage Collection Pond
- Pump station
- Buried conveyance pipeline to IWTS and the Faro Pit
- Electrical infrastructure to provide power to the pump station, transformer, and standby generator
- New meter and valve station (includes a pigging assembly) near the IWTS
- Instrumentation and controls for operation of the pump station

Borrow areas are also included in the conceptual design drawings.

For more details refer to the Conceptual Design Drawings in Appendix F.

Operation and Maintenance

The construction of the NFRC Project will require changes to the O&M program at the FMC, both during construction of the NFRC Project and after construction is completed. When establishing the NFRC construction work packages, it will be important to evaluate the O&M requirements that may best be handled by the NFRC Construction Contractor versus the C&M Contractor. The coordination, roles and responsibilities for security, health and safety, and regular inspections will be determined before construction work begins. As the final design progresses it will be important to identify all of the O&M parties and their responsibilities during and after construction. Coordination with the site Care and Maintenance Contractor will be critical throughout the final design process. The purpose of this section is to provide a high level summary of the type of operation and maintenance that would be expected during construction and post construction of the NFRC Project.

22.1 Operations and Maintenance Plans during Construction

Preliminary plans for O&M of the NFRC during construction will include the plans listed herein. These plans will be developed during the Preliminary and Detailed Design phases.

- Water Management and Monitoring Plan
- Operation, maintenance, repair, and monitoring
- Environmental management and monitoring
- Adaptive management
- Risk management
- Sediment and Erosion Control Plan

22.1.1 Water Management and Monitoring Plan

Water management for the NFRC during construction will be required to maintain the temporary diversion and the existing seepage interception systems, including the NFRD SIS, S-wells, and Zone II pump. After the NFRC is diverted into the NFRC Realigned Channel, the relatively small flows in the existing NFRC may be captured and conveyed for storage and treatment.

The NFRC Temporary Diversion will be designed to a 1-in-10-year storm event without freeboard. The NFRC Realigned Channel Dike and excavation through the Haul Road is planned to be completed during the first year of construction. Completion of the dike and the excavation will enable handling of elevated flood events but will increase the risk of flood flows impacting the Haul Road Culvert construction planned for the second year of construction. A process for handling runoff during extreme events during construction will be developed.

Monitoring wells along the base of the WRD will be monitored to observe water quality trends and to evaluate the movement of mine-impacted groundwater from the WRDs towards the creek or down the valley. This will determine the timing of construction of a cutoff wall and collection trench to capture mine-impacted water flowing from the WRD towards the NFRC.

22.1.2 Operation, Maintenance, Repair and Monitoring

During construction, access roads will be monitored and maintained for erosion and wear. Regular maintenance and grading will be conducted to ensure driving safety. Snow should be removed as required during the winter to allow for passage of inspection or maintenance vehicles. Culverts should be inspected and steamed if necessary to prevent water runoff from flowing over the road. Safety berms should be maintained in accordance with the Yukon Workers' Health and Safety Board guidelines.

Embankments should be maintained and inspected for sloughing or slumping to maintain road edges and prevent failure.

The length of the NFRC Temporary Diversion should be monitored regularly for blockage or obstacles that would obstruct flow. Side slopes should be maintained to prevent sloughing and slumping that may block flow. During precipitation events, flow should be directed to the channel and potential erosion of the channel monitored.

Collection ditches, temporary diversions, or any other flow channels should be checked regularly for blockage by slumping of side walls or buildup of organic materials. Blockages should be cleared on a regular basis to keep channels clear.

22.1.3 Sediment and Erosion Control Plan

A Sediment and Erosion Control Plan should be prepared based on best practices for sediment and erosion control in Yukon.

The potential for increased water flow due to clearing of vegetation or construction of a ditch or road should be closely monitored to prevent the increase of sediments in runoff. Signs of erosion or sloughing such as rilling, sloughing or slumping along channel construction or roadways should be monitored and steps taken to prevent sedimentation in receiving water environments. This could include construction of berms, other barriers, sedimentation ponds, or covering with erosion control fabrics, gravel, or cobbles to prevent erosion into stream channels.

Temporary sedimentation ponds or other features created to slow the flow of water and promote sedimentation will be included in the design. Minimal volumes of sediment laden flow can be directed into natural depressions, or vegetated areas to allow natural treatment and filtration. Larger volumes should be directed into sediment settling ponds. Constructed sediment settling ponds should be checked regularly to provide sufficient freeboard and to remove the sediment, if necessary.

Monitoring of civil works should identify erosional features such as rilling, sloughing and slumping. The potential for increased water flow due to clearing of vegetation or construction of a ditch or road should be closely monitored to prevent the increase of sediments in runoff. Erosion or sloughing along channel construction or roadways should be monitored and maintained to prevent sedimentation in receiving water environments or failure of slopes.

Areas along the newly-constructed Realigned Channel or the temporary diversion should be monitored for potential for slumping or sloughing and melting permafrost. Particular attention should be given to the east side of the Realigned Channel, where there may be a higher potential for slope movement.

22.2 O&M Plans Post Construction

Preliminary plans for O&M post construction will include the plans listed below. These plans will be further developed during the Preliminary and Detailed Design phases.

22.2.1 Water Management and Monitoring Plan

22.2.1.1 Water Management

Water management for mine-impacted water is based on collection and storage through October to April in the NFRC Seepage Collection Pond and conveying impacted water to the water treatment plant, or to the Faro Pit for storage, from May to September.

Water collected in the NFRC Seepage Collection Pond will require treatment. The volume collected each year will vary in response to hydrologic conditions. The chemistry of the collected water will vary considerably over shorter time spans in response to storm events, as well as over long-term time spans

in response to WRD chemistry changes and flow rates of seepage from the WRDs. Pumping will begin in April, with water pumped and split between treatment in the IWTS and storage in the Faro Pit depending on available IWTS capacity.

22.2.1.2 North Fork of Rose Creek Seepage Collection Pond and Dam, Intake Structures and Outlet Works, Spillway, and Control Room

The NFRC Seepage Collection Pond will store and contain annual precipitation and mine-impacted surface water and groundwater entering the existing NFRC drainage or catchment area. As per the O&M for C&M activities, the water management strategy for the site will incorporate monitoring of winter snowfall and estimates for spring melt will be considered for the pond. The pond must be maintained to contain the volume of winter precipitation expected during the winter season. This may require careful calculation of volumes planned for conveyance to either the water treatment plant or the Faro Pit. With a pumping capacity of 126 L/s (2,000USgpm) and additional emergency pumping capacity up to 189 L/s (3,000USgpm), the pond should be pumped to minimum levels by the end of October to achieve a near--empty pond for capturing winter flows. For either the Alternative 1 or Alternative 2 pond locations, a minimum dead pool will be maintained over the winter to prevent icing of the low-level intake structure.

North Fork of Rose Creek Seepage Collection Pond Alternative 1

Alternative 1 will have an active storage of 300,000 m³ storage assuming storage during October through April. The pond will be impounded by a dam constructed across the existing Rose Creek Valley and located east of the Mine Access Road. At present, the design intent is that the pond will be unlined. Alternative 1 was designed to reduce/limit seepage beneath and through the dam and around the abutments. A low-permeability core is incorporated into the embankment and a cutoff core trench extended through the overburden soils to bedrock. Instrumentation will include piezometers and settlement monuments. These will need to be monitored frequently during first filling and the first year of operation and less frequently during subsequent years. Discharge from the filtrate system and seepage will need to be monitored daily during pond filling each year.

North Fork of Rose Creek Seepage Collection Pond Alternative 2

Alternative 2 will have an active storage of 350,000 m³ storage and will occupy an area of about 84,000 m². Mine-impacted water from the existing NFRC channel will be directed through a newly constructed and lined diversion channel extending from a groundwater cutoff structure, located upstream of the Mine Access Road, to the lined pond that will be located immediately east of, and adjacent to, the RCTA.

North Fork of Rose Creek Seepage Collection Pond, Dam, and Spillways

The proposed dam configuration for Alternative 1 is a zoned earthfill dam consisting of a low permeability material (Zone I) core in the centre with broadly graded granular (Zone II) shells on both the upstream and downstream sides of the core. The spillway for Alternative 1 NFRC Seepage Collection Dam is sized to prevent overtopping of the dam assuming a breach in the new NFRC Realigned Channel such that some of the breached flows would flow be through the NFRD and the other portion would flow back into the channel and through the new PMF culvert in the Haul Road.

The emergency spillway for Alternative 2 impoundment is sized to prevent overtopping of the local PMF only. The diversion canal from the existing NFRC will overtop at an overflow structure for flows greater than the local PMF so that these greater flows would not compromise the off-channel pond.

Two spillways are planned for the for Alternative 2 pond location; a service spillway and an emergency spillway. Each spillway will be inspected to prevent blockages by erosion, organic matter or buildup of sediments. The service spillway will be maintained to allow flow from a concrete weirbox in the lined pond embankment to an outlet pipe that penetrates the embankment and drains onto the secondary tailings surface. The emergency spillway will allow safe discharge of overflow into the Pump House pond

and RCD when reservoir levels are 0.5 m over the service spillway crest. This channel should also be maintained clear of blockages that may prevent the free flow of water through the spillway.

22.2.2 Operation, Maintenance, Repair and Monitoring

22.2.2.1 North Fork of Rose Creek Realigned Channel Segments 1 through 4, Haul Road, and Mine Access Road

The length of the diversion will be monitored regularly by driving or walking the length of the construction. Flow should be unobstructed from organic matter or sediment. Vegetation growth along the edges or on the slopes of the diversion should be kept to a minimum, removing vegetation as required to maximize flow rates to maintain PMF volumes.

The Haul Road crossing structure and the Mine Access Road crossing should be maintained to be clear and free from debris, sediment, or ice. This will be problematic at the Haul Road culvert because of the length of the culvert.

22.2.2.2 North Fork of Rose Creek Permanent Seepage Collection Trench, Segments 1 and 2 and Rock Drain

The NFRC Permanent Seepage Collection Ditch should be routinely inspected for organic matter or sediments creating blockages or excessive silting or sedimentation. Pooling or flow of water in the channel should initiate an inspection of the buried perforated pipe, which otherwise will be inspected on a monthly basis to check for blockage or sediments in the pipeline.

22.2.2.3 Water Treatment at the Interim Water Treatment System

The actual duration and timing of conveyance from the NFRC Seepage Collection Pond will depend on the accumulated snow volume, the timing of snow melt, and the freshet volume. The Care and Maintenance operator will need to monitor each of these and adjust the startup, duration, and pump rate volumes based on site and weather conditions. The IWTS will not have the capacity to treat the full available volume from the ID Pond, the Seepage Collection Pond, and the other ARD sources in the spring. The Seepage Collection Pond will need to be emptied during the summer, which will require discharge to be managed between the IWTS and the Faro Pit. This will require operational coordination between all flow sources requiring treatment. The Water Management Tool, described in Section 13, can be used to assist in prioritizing storage and treatment requirements.

22.2.2.4 Integration of Faro Pit, Intermediate Dam Pond, North Fork of Rose Creek Seepage Collection Pond, and Interim Water Treatment System (ref Section 13)

Current water balance modelling results indicate that water pumped from the NFRC Seepage Collection Pond should be conveyed at the planned 126 L/s capacity when pumping begins at the beginning of the treatment season. Pumping rates required to empty the pond will be reduced as the pond level decreases. Water will be conveyed either to the IWTS or the Faro Pit; the IWTS does not have the capacity to treat the full volume of the NFRC Seepage Collection Pond and the peak volumes from the Faro Pit.

22.2.2.5 North Fork of Rose Creek Seepage Collection Pond and Pump Station

Pumps are designed to convey flow to either the IWTS or the Faro Pit. A metering and valve station will be located near the IWTS. Normal operating flow rate is 126 L/s (2,000 USgpm) with additional capacity to 189 L/s (3,000 US gpm). Pumps will be vertical-turbine type with an above-grade discharge head, with stainless steel or similarly corrosion and abrasion-resistant material components. Motors will be 1,800 revolutions per minute, three phase, 575 V. Pump motors will be driven by variable-speed drives and provided with local and remote control. The pump stations will be designed to allow winter operations.

The facility for Alternative 1 will be located in the dam embankment at the right abutment, upstream of the low permeability core. The pump station will have two separate intakes: (1) a low-level intake that will be located in the creek bottom with the intake conduit centerline, and (2) a high level intake. The intake structure for both intakes will be a simple reinforced-concrete structure with a stainless steel trash rack. The low-level intake structure will be located about 2 m below the dead pool (Elevation 1,075 m) to provide thermal cover against freezing conditions. The outlet conduit will be HDPE pipe. There are no penetrations in the dam core since the intake pipes (suction headers) and the vertical pumping wells will all be located in the upstream shell of the dam.

The Alternate 1 dam filter system and drains are subject to potential plugging as a result of chemical precipitates such as iron ochre formed in the presence of oxygen and bacteria. To minimize the effects of this plugging special design measures have been incorporated into the design, including: (1) encapsulation of the filter drain pipe by low permeability material at the toe of the dam, and (2) maintaining the horizontal part of the drainage system in a submerged state including the use of “gooseneck” outlet pipes to prevent oxygen from entering the system. Discharge from the piping will need to be monitored and the pipelines routinely inspected.

The pump station for the Alternative 2 pond location is located in the northeastern corner of the NFRC Seepage Collection Pond. The NFRC Seepage Collection Pond valve and meter station consists of a one-storey enclosed building, to accommodate the piping layout. The floor will be constructed of concrete slab and will support valve, process piping, pig launcher, and other electrical and mechanical ancillary loads.

Pumping for the NFRC Seepage Collection Pond will begin in April and May, at the same time as other ARD collection and conveyance systems are started. The timing may be adjusted depending on volumes of water in the pond and the projected volume for freshet and spring run-off. Treatment or storage for mine-impacted water sources on site will be prioritized based on storage volume available, recommended maximum elevations and available throughput at the IWTS.

22.2.2.6 North Fork of Rose Creek Conveyance Pipeline

The water collected in the NFRC Seepage Collection Pond will be conveyed via a pressurized pipeline from the pond pump station to the Valve and Meter Station and IWTS break tank located near the IWTS. Another pressure pipeline will convey the water from the Valve and Meter Station to the high point vent located between the IWTS and the Faro Pit. A gravity pipeline will convey the flow from the high point vent to the Faro Pit. All pipelines will be designed to allow winter operations.

The pipeline will convey contaminated water from sources that have been known to cause precipitation buildup inside pipelines with exposure to oxygen. A camera should be used annually or semi-annually to determine if this buildup occurs and the extent of buildup over time. Pig launching/receiving assemblies will be installed within the NFRC Seepage Collection Pond pump station and the Valve and Meter Station to facilitate the clearing of precipitate buildup in the pipeline.

22.2.2.7 Instrumentation and Control System

The NFRC Seepage Collection Pump Station I&C system is intended to control and monitor the level of the water at the NFRC Seepage Collection Pond, maintain pond level, operate pumps as required, and pump water to the break tank for processing. The NFRC Seepage Collection Pond level needs to be monitored continuously and reliably, and flow diverted either to the Faro Pit or transferred to the break tank for treatment, depending on the available treatment at the IWTS. The NFRC Seepage Collection Pump Station will be serviced with utility power and will include a back-up generator sized to operate all pumps concurrently. VFDs serving pump motors will be equipped with DOL bypass starters to permit operation should a VFD fail. P&IDs are prepared as part of the design.

22.2.2.8 Ditches, Culverts, and Stream Crossings

Ditches, culverts and stream crossings should be monitored and maintained to prevent water runoff from flowing over the road. During winter, ditches or culverts should be steamed to prevent icing over roadway. Debris or blockage from organic matter or sediments should be cleared as soon as possible to maintain flow.

22.2.2.9 Roads and Access Routes

Each access road should be monitored for erosion or wear. Regular maintenance and grading should be conducted during the summer months to ensure driving safety. Snow should be removed as required during the winter to allow for routine passage of inspection or maintenance vehicles. Safety berms should be maintained in accordance to the Yukon Workers' Health and Safety Board guidelines. Embankments should be maintained and inspected for sloughing or slumping to maintain road edges and prevent failure.

22.2.3 Environmental Management and Monitoring

The overall Environmental Management Plan for the site will incorporate any changes or adjustments as the NFRC is handed over to the C&M Contractor. A number of monitoring systems will be added to the program to provide environmental compliance and check that systems are functioning as they should.

Monitoring wells will be installed along the base of the WRD to determine the flow of mine-impacted water in the valley. Monitoring wells will be installed downstream of the dam to monitor seepage quantity and quality.

Leak detection systems will be installed in the NFRC Temporary Diversion channel and the NFRC Seepage Collection Pond. These systems will be used to check for damage and detect leaks in the liner, allowing clean water into the mine-impacted water system. Each system will be monitored regularly for leakage of clean water from the lined channel of the diversion in Segment 2 or mine-impacted water from the NFRC Seepage Collection Pond.

22.2.4 Adaptive Management

Adaptive Management Plans (AMPs) will be developed to provide timely evaluations of site uncertainties and develop timely responses to adjust to evolving site conditions. Monitoring data will be evaluated to determine when and what the response may have to be. Data from the monitoring wells installed downstream of the dam may indicate the need for a seepage interception and collection system (wells or pond) downstream of the dam. The leakage interception system may also indicate that the liner under the clean water diversion has developed a leak or has been damaged; the AMP would identify the appropriate response and next steps.

The AMP will also provide a plan for changing concentrations or volumes of mine-impacted water onsite. Surveillance monitoring of groundwater concentrations downstream of the NFRC Seepage Collection Pond will allow mitigative actions to be implemented to prevent or minimize the volume of seepage discharging to the receiving environment. The Faro Water Management Tool can be used to recalculate and model volumes and the capacity of IWTS to manage the changing sources of mine-impacted water.

22.2.5 Risk Management

A Risk Management Plan will be developed to continually re-evaluate, identify, and mitigate risks to health, safety, and the environment. This plan will be incorporated into the overall site risk management plan in order to manage the site.

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