11. GROUNDWATER EFFECTS ASSESSMENT

11.1 INTRODUCTION

This chapter presents the baseline hydrogeology conditions, effects scoping process, and assessment of potential effects on groundwater as a result of the proposed Harper Creek Project (the Project). It is based on the baseline data collected for the Project up to April 2014, which are presented in the Harper Creek Project Hydrogeology Baseline Report (Appendix 11-A). Groundwater quantity and quality are important environmental components that sustain the quantity and quality of surface waters, particularly during low-flow seasons and provide a water source suitable for commercial and domestic use. The assessment of the effects on groundwater is based on the baseline information, the results of numerical groundwater modelling (Appendix 11-B), and in accordance with the Project designs.

This chapter follows the effects assessment methodology described in Chapter 8 of this Application for an Environmental Assessment Certificate / Environmental Impact Statement (Application/EIS).

11.2 REGULATORY AND POLICY FRAMEWORK

This section provides an overview of the relevant regulatory framework and requirements for the assessment of potential Project-related effects to groundwater, as summarized in Table 11.2-1.

Table 11.2-1. Summary of Applicable Statutes and Regulations for Potential Groundwater Effects, Harper Creek Project

Name	Level of Government	Description
Water Protection Act (1996a)	Provincial (BC MOE)	Establishes groundwater situated in British Columbia (BC) as property of the province and enacts a system of regulation for extraction and diversion of water.
Environmental Management Act (2003); Waste Discharge Regulation (BC Reg 320/2004); Contaminated Sites Regulation (BC Reg 375/96)	Provincial (BC MOE)	Regulates discharges of waste into the environment (including groundwater) and designates responsibility for contamination of groundwater.
Water Act (1996b) and Groundwater Protection Regulation (BC Reg 299/2004)	Provincial (BC MOE)	Provides a regulatory framework for installation, use, and decommissioning of wells in BC.
Fish Protection Act (1997)	Provincial (BC MOE)	Enables the designation of water management areas and development of plans where there are risks to water quality, including groundwater.
Canada Water Act (1985a)	Federal (Environment Canada)	Establishes controls for the discharges of wastes into water, including groundwater, on land under federal jurisdiction.
Fisheries Act (1985b)	Federal (Fisheries and Oceans Canada)	Regulates any work that would cause the harmful alteration of fish habitat.

In addition to the legislative framework, a range of relevant guidelines have been published by the regulatory agencies (Table 11.2-2). A set of provincial documents provide guidance and establish requirements for hydrogeology baseline and modelling studies in relation to environmental assessment (EA) for mining projects. A set of both provincial and federal documents provide for a broad range of metrics used to gauge water quality and potential impacts on it. It should be clarified that the guidelines for protection of fish and aquatic life are set for surface water quality. Therefore, these guidelines applied for assessment of groundwater quality effect should only be taken as a reference only.

Table 11.2-2. Summary of Applicable Published Guidelines for Potential Hydrogeology Effects, Harper Creek Project

Name	Level of Government	Description
Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators (BC MOE 2012)	Provincial (BC MOE)	Describes the general requirements for groundwater flow and quality baseline characterization for proposed mining projects.
British Columbia Field Sampling Manual (BC MWLAP 2003)	Provincial (BC MOE)	Provides guidance for the procedure, protocol, equipment, and quality control for groundwater sampling.
Guidelines for Groundwater Modelling to Assess Impacts of Proposed Natural Resource Development Activities (Wels, Mackie, and Scibek 2012)	Provincial (BC MOE)	Provides guidance regarding methodologies for the application of numerical groundwater flow and transport modelling for effects assessment of proposed natural resource projects, including mines.
BC MOE Approved and Working Water Quality Guidelines (BC MOE 2014a)	Provincial (BC MOE)	Specifies benchmark levels for a range of water quality metrics applicable for drinking water supply, freshwater aquatic life, and other applications.
Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME 1999)	Federal (CCME)	Specifies benchmark levels for a range of water quality metrics applicable for the protection of freshwater aquatic life.
Canadian Drinking Water Guidelines (Health Canada 2012)	Federal (Health Canada)	Specifies benchmark levels for a range of water quality metrics applicable for drinking water.

11.3 SCOPING THE EFFECTS ASSESSMENT

11.3.1 Valued Components

The British Columbia Environmental Assessment Office (BC EAO) define Valued Components (VCs) as components "that are considered important by the proponent, public, First Nations, scientists, and government agencies involved in the assessment process"(BC EAO 2013). To be included in the Application/EIS, there must be a perceived likelihood that the VC will be affected by the proposed Project. VCs proposed for assessment were identified in the Application Information Requirements (AIR; BC EAO 2011) and in the CEA Agency (2011) Background Information document.

11.3.1.1 Consultation Feedback on Proposed Valued Components

A preliminary list of proposed VCs was drafted early in project planning based on the expected physical works and activities of the reviewable project, type of project being proposed, local area and regions where the proposed project would be located, and consultation with federal, provincial, and local government agencies. A summary of how scoping feedback was incorporated into the selection of assessment subject areas and the groundwater VCs is summarized below in Table 11.3-1.

11.3.1.2 Selecting Valued Components

The interactions of the Project components and activities with the groundwater VCs are listed in Table 11.3-2. The proposed VCs that were selected for assessment for the Project are summarized in Chapter 8, Assessment Methodology, Table 8.4-3. The VCs selected for inclusion in the groundwater effects assessment are presented in Table 11.3-3. This list was presented to the EA Working Group for discussion on August 18, 2011.

Groundwater is present in the subsurface throughout the region. Ecosystems are dependent on the quantity and quality of groundwater, as it sustains the baseflow component of water levels and quality in the surface water environment. The human population in the region is dependent on the quantity and quality of groundwater, because it sustains water supply for a proportion of the water used, and contributes to the sustenance of the natural environments used for subsistence, industry, and recreation.

Groundwater is used for household consumption, agricultural irrigation, commercial and industrial uses, and municipal drinking water supply in the region. The District of Barriere sources its water fully from supply wells (District of Barriere 2011) and the district of Clearwater partially so (District of Clearwater 2012). Water use is further discussed in Section 11.4.

The BC Water Resources Atlas (BC MOE 2013) Aquifer Database includes aquifers along the North Thompson River Valley. These aquifers have been classified as moderately to highly productive, and moderately to highly vulnerable. The classifications of these aquifers indicate presence of a water resource along the North Thompson River Valley that is valued by the local human population and vulnerable to a reduction in input or degradation of water quality.

The Kamloops Land and Resource Management Plan (LRMP) establishes a regional objective to "recognize the interaction of groundwater with surface water sources," (Kamloops Interagency Management Committee 1995) and includes strategies to manage and monitor groundwater levels and quality. References to groundwater quantity and quality in the Kamloops LRMP indicate the value of these environmental components to society.

Official Community Plans implemented by the districts of Barriere and Clearwater specify objectives to protect groundwater quantity and quality. For example the District of Barriere Official Community Plan (2011) states the objective "to protect and enhance the quality of Barriere's rivers, streams and ground water sources in order to provide an integrity level that supports the ecological services of the North Thompson River and Barrière River watersheds." References to groundwater in the community plans near the proposed Project Site indicate the value of the groundwater quantity and quality to local communities.

Table 11.3-1. Consultation Feedback on Proposed Valued Component(s) of Groundwater

	Feedback by*					
Subject Area	**AG**	**G**	**P/S**	**O**	**Issues Raised**	**Proponent Response**
Groundwater Quantity	X				Maintenance of sufficient water flows to creeks below.	Changes in water quantity and potential effects to fish and aquatic habitat have been assessed in the Application. Mitigation and a fish habitat offsetting plan have been developed and are also included in the Application.
Groundwater Quality	X				Subsurface aquifers in the vicinity of the tailings pond and open pit may allow water from the tailings pond or open pit to enter underground aquifers or groundwater.	The BC Water Resources Atlas (www.env.gov.bc.ca/wsd/data_searches/wrbc) Aquifer Database identifies the presence of aquifers along the North Thompson River Valley. Similar fluvial or glaciofluvial aquifers are expected to be present in the shallow subsurface along the Barrière River and Harper Creek valley bottoms. Hydrogeological site investigations have been conducted in the area of the TMF, open pit, and in other areas throughout the Project site. No subsurface aquifers occur in the tailings management area and open pit. Implementation of a Site Water Management Plan and a Groundwater Management Plan will mitigate potential effects of seepage from the TMF and open pit. Water management ponds have been sited at the toe of the TMF dam and non-PAG waste rock stockpile to intercept and collect seepage.
	X				Potential impacts of mining activities within the mine footprint, downstream effects (e.g., contaminant seepage).	The mine layout, the Mine Waste and ML/ARD Management Plan and the Site Water Management Plan are designed to contain contact water within the mine site and prevent its uncontrolled release to the downstream environment. During mine closure water in the receiving environment will meet water quality objectives to protect the downstream environment.
	X				Concern regarding unforeseen weather, seismic or other failure events (equipment, roads, etc.), resulting in the release of contaminants into the Thompson River or Harper Creek or associated aquifers.	An evaluation of the effects of the environment (including earthquakes) on the Project has been undertaken and will be included in the Application. A seismic hazard analysis was completed for the Project by Knight Piesold in March, 2012 to inform the Project Technical Report and Feasibility Study. A Mine Waste and Water Management Design Report was also developed by Knight Piesold in 2014 to evaluate the parameters for design of the water management facilities. These reports will be included in the Application as appendices. The dam safety classification for the project tailings dams is ranked as "very high". The design flood and earthquake levels were adopted from the Canadian Dam Association guidelines for the project: Inflow Design Flood – probable maximum flood (PMF); and Earthquake Design Ground Motion – Maximum Credible Earthquake. There is no discharge from the Project to the North Thompson River watershed. The effects of mine site and TMF discharges to T Creek, P Creek and Harper Creek have been modelled in the water quality predictive model and the effects have been considered in the fish and aquatic resources effects assessment.

(continued)

Table 11.3-1. Consultation Feedback on Proposed Valued Component(s) of Groundwater (completed)

Subject Area	Feedback by*				Issues Raised	Proponent Response
	AG	G	P/S	O		
Groundwater Quality *(cont'd)*		X			Tailings seepage into materials underneath the dam and long-term management.	Geotechnical and hydrogeological site investigations in 2011 and 2012 examined at foundation conditions beneath the TMF embankments to evaluate permeability characteristics. The TMF has been designed to limit seepage at the source, and collect seepage to the maximum practical extent. Detailed results of seepage pathway studies are included in Chapter 11 and Appendix 11-B.
		X			Seepage and runoff including water diversion and groundwater.	The principle design objectives for the waste rock stockpiles and TMF are to ensure protection of the regional groundwater and surface water during Project Operations, Closure and Post-Closure (i.e., long-term), and to achieve effective reclamation at Closure. The design and location of the waste rock stockpiles and TMF has taken into account the following requirements: • situating the TMF and waste rock facilities away from sensitive environmental features including fish bearing drainages; • clustering the facilities to minimize the overall footprint; • permanent, secure, and total confinement of all solid waste materials within engineered disposal facilities; • control, collection, and removal of free-draining liquids from the waste rock and tailings storage facilities during operations for recycling as process water to the maximum practical extent; • prevention of acid rock drainage and minimization of metal leaching from reactive tailings and waste rock; • staged development of the facility over the life of the project and control, collection, and return of free-draining liquids from the waste and tailings facilities during operations for recycling as process water to the maximum practical extent.
		X			Groundwater seepage	Groundwater seepage pathways from the open pit, non-PAG waste rock, LGO stockpiles, and TMF (and PAG waste rock) have been incorporated into the water quality model (Appendix 13-C) and the effects on water quality have been assessed in Chapter 13.
		X			Seepage from the LGO Stockpiles	Predicted seepage pathways sourced in the LGO stockpiles are documented in Appendix 11-B. Proposed mitigation measures to minimize and capture this seepage are described in Chapter 11 (Section 11.5.2). The Groundwater Management Plan (Section 24.8) provides for monitoring down-gradient of the PAG LGO stockpile and an adaptive management strategy to respond if water quality does not meet the specified performance objectives.

**AG = Aboriginal Group; G = Government; P/S = Public/Stakeholder; O = Other*

Table 11.3-2. Interactions of Project Components and Activities with Groundwater

Category	Project Components and Activities	Groundwater Quantity	Groundwater Quality
Construction			
Concrete production	Concrete batch plant installation, operation and decommissioning		
Dangerous goods and hazardous materials	Hazardous materials storage, transport, and off-site disposal		X
	Spills and emergency management		X
Environmental management and monitoring	Construction of fish habitat offsetting sites	X	
Equipment	On-site equipment and vehicle use: heavy machinery and trucks		
Explosives	Explosives storage and use		X
Fuel supply, storage and distribution	Fuel supply, storage and distribution		X
Open pit	Open pit development - drilling, blasting, hauling and dumping	X	X
Potable water supply	Process and potable water supply, distribution and storage	X	
Power supply	Auxiliary electricity - diesel generators		
	Power line and site distribution line construction: vegetation clearing, access, poles, conductors, tie-in		
Processing	Plant construction: mill building, mill feed conveyor, truck shop, warehouse, substation and pipelines		
	Primary crusher and overland feed conveyor installation		
Procurement and labour	Employment and labour		
	Procurement of goods and services		
Project Site development	Aggregate sources/ borrow sites: drilling, blasting, extraction, hauling, crushing		X
	Clearing vegetation, stripping and stockpiling topsoil and overburden, soil salvage handling and storage	X	
	Earth moving: excavation, drilling, grading, trenching, backfilling	X	
Rail load-out facility	Rail load-out facility upgrade and site preparation		
Roads	New TMF access road construction: widening, clearing, earth moving, culvert installation using non-PAG material	X	
	Road upgrades, maintenance and use: haul and access roads	X	
Stockpiles	Coarse ore stockpile construction	X	
	Non-PAG Waste Rock Stockpile construction	X	
	PAG and non-PAG LGO stockpiles foundation construction	X	
	PAG Waste Rock stockpiles foundation construction	X	
Tailings management	Coffer dam and South TMF embankment construction	X	
	Tailings distribution system construction		

(continued)

Table 11.3-2. Interactions of Project Components and Activities with Groundwater (continued)

Category	Project Components and Activities	Groundwater Quantity	Groundwater Quality
Construction *(cont'd)*			
Temporary construction camp	Construction camp construction, operation, and decommissioning	X	
Traffic	Traffic delivering equipment, materials and personnel to site		
Waste disposal	Waste management: garbage, incinerator and sewage waste facilities		X
Water management	Ditches, sumps, pipelines, pump systems, reclaim system and snow clearing/stockpiling	X	X
	Water management pond, sediment pond, diversion channels and collection channels construction	X	
Operations 1			
Concentrate transport	Concentrate transport by road from mine to rail loadout		
Dangerous goods and hazardous materials	Explosives storage and use		X
	Hazardous materials storage, transport, and off-site disposal		X
	Spills and emergency management		X
Environmental management and monitoring	Fish habitat offsetting site monitoring and maintenance	X	
Equipment fleet	Mine site mobile equipment (excluding mining fleet) and vehicle use		
Fuel supply, storage and distribution	Fuel storage and distribution		X
Mining	Mine pit operations: blast, shovel and haul, and pit dewatering	X	X
Ore processing	Ore crushing, milling, conveyance and processing		
Potable water supply	Process and potable water supply, distribution and storage	X	
Power supply	Backup diesel generators		
	Electrical power distribution		
Processing	Plant operation: mill building, truck shop, warehouse, and pipelines		
Procurement and labour	Employment and labour		
	Procurement of goods and services		
Rail load-out facility	Rail-load out activity (loading of concentrate; movement of rail cars on siding)		
Reclamation and decommissioning	Progressive mine reclamation	X	X
Stockpiles	Construction of non-PAG tailings beaches	X	X
	Construction of PAG and non-PAG LGO Stockpiles	X	X

(continued)

Table 11.3-2. Interactions of Project Components and Activities with Groundwater (continued)

Category	Project Components and Activities	Groundwater Quantity	Groundwater Quality
Operations 1 *(cont'd)*			
Stockpiles	Non-PAG Waste Rock Stockpiling	X	X
	Overburden stockpiling	X	X
Tailings management	Reclaim barge and pumping from TMF to Plant Site		
	South TMF embankment construction	X	
	Sub-aqueous deposition of PAG waste rock into TMF	X	X
	Tailings transport and storage in TMF	X	X
	Treatment and recycling of supernatant TMF water		
Traffic	Traffic delivering equipment, materials and personnel to site		
Waste disposal	Waste management: garbage and sewage waste facilities		X
Water management	Monitoring and maintenance of mine drainage and seepage	X	X
	Surface water management and diversions systems including snow stockpiling/clearing	X	X
Operations 2 *Includes the Operations 1 non-mining Project Components and Activities, with the addition of these activities:*			
Processing	Low grade ore crushing, milling and processing		
Reclamation and decommissioning	Partial reclamation of non-PAG waste rock stockpile	X	X
	Partial reclamation of TMF tailings beaches and embankments	X	X
Tailings management	Construction of North TMF embankment and beach	X	
	Deposit of low grade ore tailings into open pit	X	X
Water management	Surface water management	X	
Closure			
Environmental management and monitoring	Environmental monitoring including surface and groundwater monitoring	X	X
	Monitoring and maintenance of mine drainage, seepage, and discharge	X	X
	Reclamation monitoring and maintenance	X	X
Open pit	Filling of open pit with water and storage of water as a pit lake	X	X
Procurement and labour	Employment and labour		
	Procurement of goods and services		
Reclamation and decommissioning	Decommissioning of rail concentrate loadout area		
	Partial decommissioning and reclamation of mine site roads	X	
	Decommissioning and removal of plant site, processing plant and mill, substation, conveyor, primary crusher, and ancillary infrastructure (e.g., explosives facility, truck shop)		
	Decommissioning of diversion channels and distribution pipelines	X	

(continued)

Table 11.3-2. Interactions of Project Components and Activities with Groundwater (completed)

Category	Project Components and Activities	Groundwater Quantity	Groundwater Quality
Closure *(cont'd)*			
Reclamation and decommissioning	Decommissioning of reclaim barge		
	Reclamation of non-PAG LGO stockpile, overburden stockpile and non-PAG waste rock stockpile	X	X
	Reclamation of TMF embankments and beaches	X	X
	Removal of contaminated soil	X	X
	Use of topsoil for reclamation		
Stockpiles	Storage of waste rock in the non-PAG waste rock stockpile	X	X
Tailings management	Construction and activation of TMF closure spillway		
	Maintenance and monitoring of TMF	X	X
	Storage of water in the TMF and groundwater seepage	X	X
	Sub-aqueous tailing and waste rock storage in TMF	X	X
	TMF discharge to T Creek		X
Waste disposal	Solid waste management		X
Post-Closure			
Environmental management and monitoring	Environmental monitoring including surface and groundwater monitoring	X	X
	Monitoring and maintenance of mine drainage, seepage, and discharge	X	X
	Reclamation monitoring and maintenance	X	X
Open pit	Construction of emergency spillway on open pit		
	Storage of water as a pit lake	X	X
Procurement and labour	Procurement of goods and services		
Stockpiles	Storage of waste rock in the non-PAG waste rock stockpile	X	X
Tailings management	Storage of water in the TMF and groundwater seepage	X	X
	Sub-aqueous tailing and waste rock storage	X	X
	TMF discharge		X

Table 11.3-3. Valued Components Selected for Groundwater Effects Assessment

Assessment Category	Subject Area	Valued Components
Environment	Hydrogeology	Groundwater quantity Groundwater quality

Groundwater quality is protected through regulation of waste discharge and contamination under the federal *Water Protection Act* (1996a), *Fisheries Act* (1985b), and the BC *Environmental Management Act* (2003).

Issues raised during the consultation process reflected value for groundwater quantity and quality (Table 11.3-1). Government and Aboriginal groups have expressed concerns over potential contamination of aquifers. Concerns have also been expressed in relation to groundwater being a pathway for effects arriving in the surface water environment, including both surface water quantity and quality.

11.3.2 Defining Assessment Boundaries

Assessment boundaries define the maximum limit within which the effects assessment and supporting studies (e.g., predictive models) are conducted. Boundaries encompass where and when the Project is expected to interact with the VCs, any political, social, and economic constraints, and limitations in predicting or measuring changes. Boundaries relevant to hydrogeology and groundwater are described below.

11.3.2.1 Temporal Boundaries

Temporal boundaries, provided in Table 11.3-4, are the time periods considered in the assessment for various Project phases and activities. Temporal boundaries reflect those periods during which planned Project activities are reasonably expected to potentially affect a groundwater VC. Potential effects will be considered for each phase of the Project as described in Table 11.3-4.

Table 11.3-4. Temporal Boundaries for Groundwater Effects Assessment

Phase	Project Year	Length of Phase	Description of Activities
Construction	-2 and -1	2 years	Pre-construction and construction activities
Operations 1	1 - 23	23 years	Active mining in the open pit from Year 1 through to Year 23.
Operations 2	24 - 28	5 years	Low-grade ore (LGO) processing from the end of active mining through to the end of Year 28.
Closure	29 – 35	7 years	Active closure and reclamation activities while the open pit and TMF are filling.
Post-Closure	36 onwards	50 years	Steady-state, long-term closure condition following active closure, with ongoing monitoring.

The initiation of Construction during Project Year -2 corresponds with the first possible occurrence of a Project-related effect. Any residual effect on groundwater is expected to reach a steady state less than 50 years following completion of Project Closure, as indicated by groundwater modelling exercises (Appendix 11-B).

11.3.2.2 Spatial Boundaries

Project Site

The Project Site is defined by a buffer of 500 m around the primary Project components. Project components include the open pit; the open pit haul road, primary crusher, and ore conveyor; mill plant site with ore processing facilities and intake/outtake pipelines; tailing management facility

(TMF); overburden, topsoil, PAG waste rock, and non-PAG waste rock stockpiles; and non-PAG and PAG LGO stockpiles.

Local Study Area

The local study area (LSA) for the groundwater effect assessment has been delineated such that groundwater catchment basins, which are inferred to be directly hydraulically connected with the proposed Project footprint, are included. Parents to these catchment basins have also been included, with boundaries defined along terrain features that present a high likelihood of overlying groundwater divides. Groundwater catchment basins are inferred to align with surface water catchment basins.

Groundwater catchment basins inferred to potentially receive groundwater from the Project footprint include the topographic basins containing P and T creeks to the west; Baker and Jones creeks to the north; and three un-named tributaries of the Barrière River to the east. The corresponding lower-order catchment basins include Harper Creek, the North Thompson River, and the Barrière River.

The LSA (Figure 11.3-1) has been delineated along watershed divides (BC Ministry of Forests, Land and Natural Resource Operations, 2015) of Harper Creek and the Barrière and North Thompson rivers opposite the proposed infrastructure footprint. Where the boundary deviates from these watershed divides, it follows ridges that separate higher-order streams. This manner of boundary delineation provides for a high likelihood of inclusion of all water that may interact with the Project. Sensitive potential receptors such as the four existing groundwater supply wells located in the North Thompson valley down-gradient of the proposed open pit of the Project, in the catchments of Baker and Jones creeks, have been included within the LSA.

The LSA described herein was also used to establish domain boundaries for the groundwater modelling study and for the hydrogeology baseline characterization studies.

Regional Study Area

The regional study area (RSA) includes the full extents of the LSA and extends further into the environment down-gradient of the Project Site (Figure 11.3-2). Projects with the potential to sustain effects on groundwater that are cumulative with the Project have been included within the RSA boundaries. Sensitive potential receptors such as water supply wells located down-gradient of the Project have been included within the RSA.

Boundaries are set along inferred groundwater divides, which generally align with surface watershed boundaries and large streams.

North of the Project Site, the RSA extends further along the North Thompson River than the LSA, thereby including nearby mineral and lumber projects, as well as existing water supply wells for cumulative effects assessment (CEA). To the south, the full Barrière River catchment basin is included, as well as Projects situated near the town of Barriere.

No administrative or technical boundaries apply to the assessment of hydrogeology conditions or effects of the Project on groundwater.

Figure 11.3-1

Local Study Area for Groundwater Effects Assessment

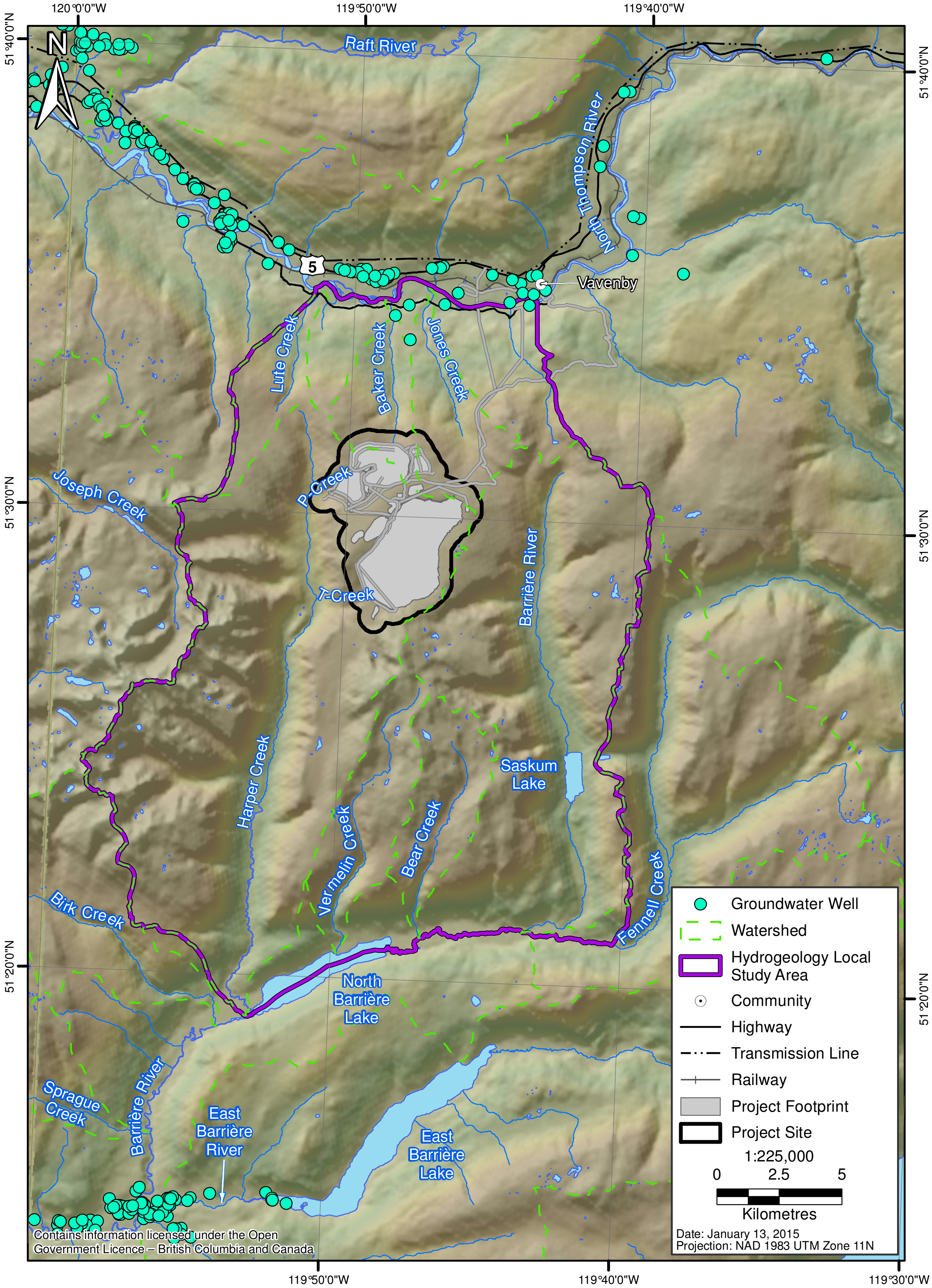
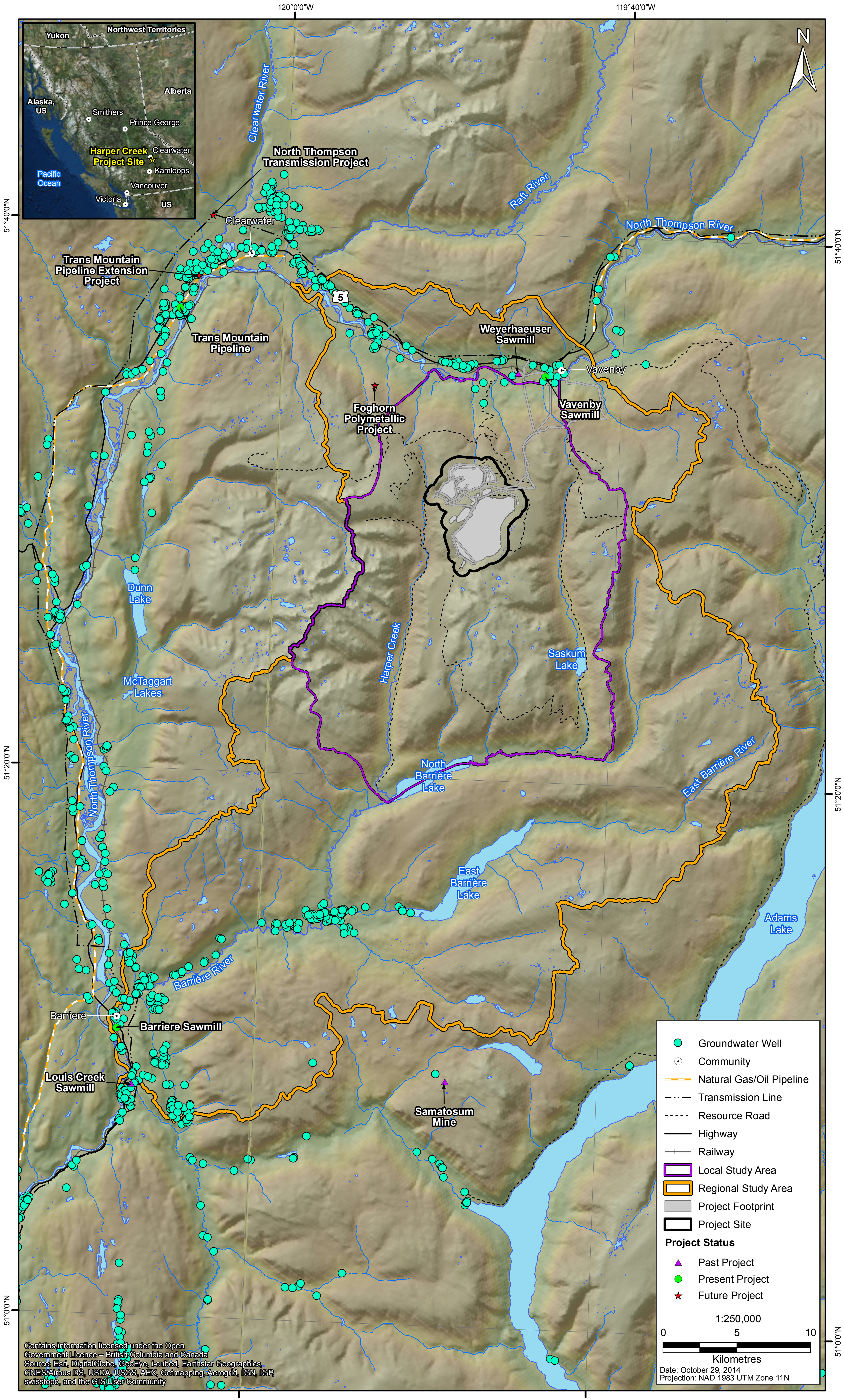


Figure 11.3-2

Regional Study Area Boundary for Groundwater Effects Assessment



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Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

11.4 BASELINE CONDITIONS

11.4.1 Regional and Historical Setting

This section provides contextual information for the baseline hydrogeologic conditions. Pertinent aspects of other environmental components that influence the groundwater system are summarized, including topography, climate and meteorology, hydrology, and geology. Pre-existing developments that may have influenced hydrogeologic conditions in the LSA and RSA are described, including existing groundwater uses and relevant industrial projects and activities.

11.4.1.1 Topography

The Project is located in the Shuswap Highlands, which are characterized by gently sloping plateau areas dissected by deep valleys. The proposed infrastructure is situated in a subalpine area bounded to the north, east, and west by deeply incised valleys. Valley floor elevations near the site are 450 metres above sea level (masl) along the North Thompson River, 1,000 masl along the Barrière River, and 1,300 masl along Harper Creek. The steep valley walls lead up to the Project Site, which is situated at elevations ranging from 1,300 masl to 1,900 masl. The Project Site itself exhibits moderate grading, generally trending upwards to the south.

The Project Site area is covered by thick, coniferous forest with heavy underbrush and logged clear cuts. Small marshy sub-alpine meadows are present at higher elevations.

11.4.1.2 Climate and Meteorology

Climate patterns at the Project Site have been characterized with use of on-site meteorology stations and regional climate stations operated by the Meteorological Services of Canada (Figure 11.4-1). Two weather stations have been active on the Project Site: one at 1,680 masl (active December 2007 to April 2011) and a second at 1,837 masl (active September 2011 to present). A complete description of the climate and meteorology conditions at the Project Site is provided in the Meteorological Baseline Report (Appendix 9-B). Mean monthly precipitation and temperature data acquired at weather stations within and near the Project Site are shown in Figure 11.4-2.

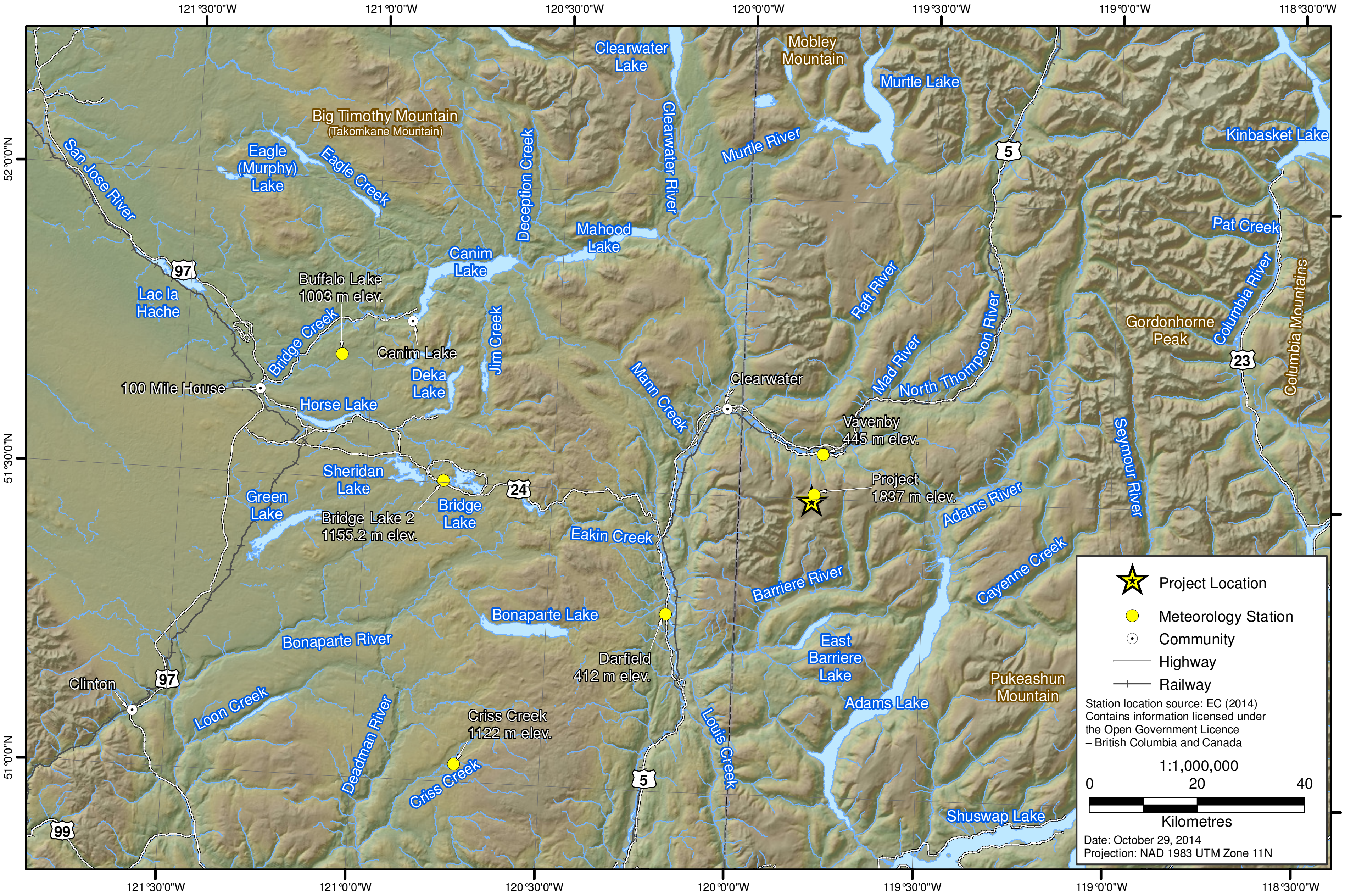
Air temperature at the Project Site is heavily influenced by elevations. The mean annual temperature at 1,680 masl has been estimated to be 0.6°C, and to range from a minimum mean monthly temperature of -9.4°C (December) to a maximum of 10.7°C (July).

The mean annual wind speed is approximately 1.6 metres/second (m/s), with the wind predominantly blowing from the east-southeast year-round, although east-northeast winds are common during the summer periods. The mean annual relative humidity is approximately 75%. Mean annual lake evaporation (potential evapotranspiration) has been estimated empirically to be 428 millimetres (mm), see details in Appendix 9-B.

Precipitation at the Project Site varies in magnitude and form with elevation. The mean annual precipitation at 1,680 masl is estimated to be 1,050 mm, with 49% falling as rain and 51% falling as snow. At the elevations of the proposed infrastructure snowfall is the dominant form of precipitation starting as early as October and ending as late as mid-April. At lower elevations precipitation falls as rain from March to October.

Figure 11.4-1

Meteorology Stations near the Project Site



Station location source: EC (2014)
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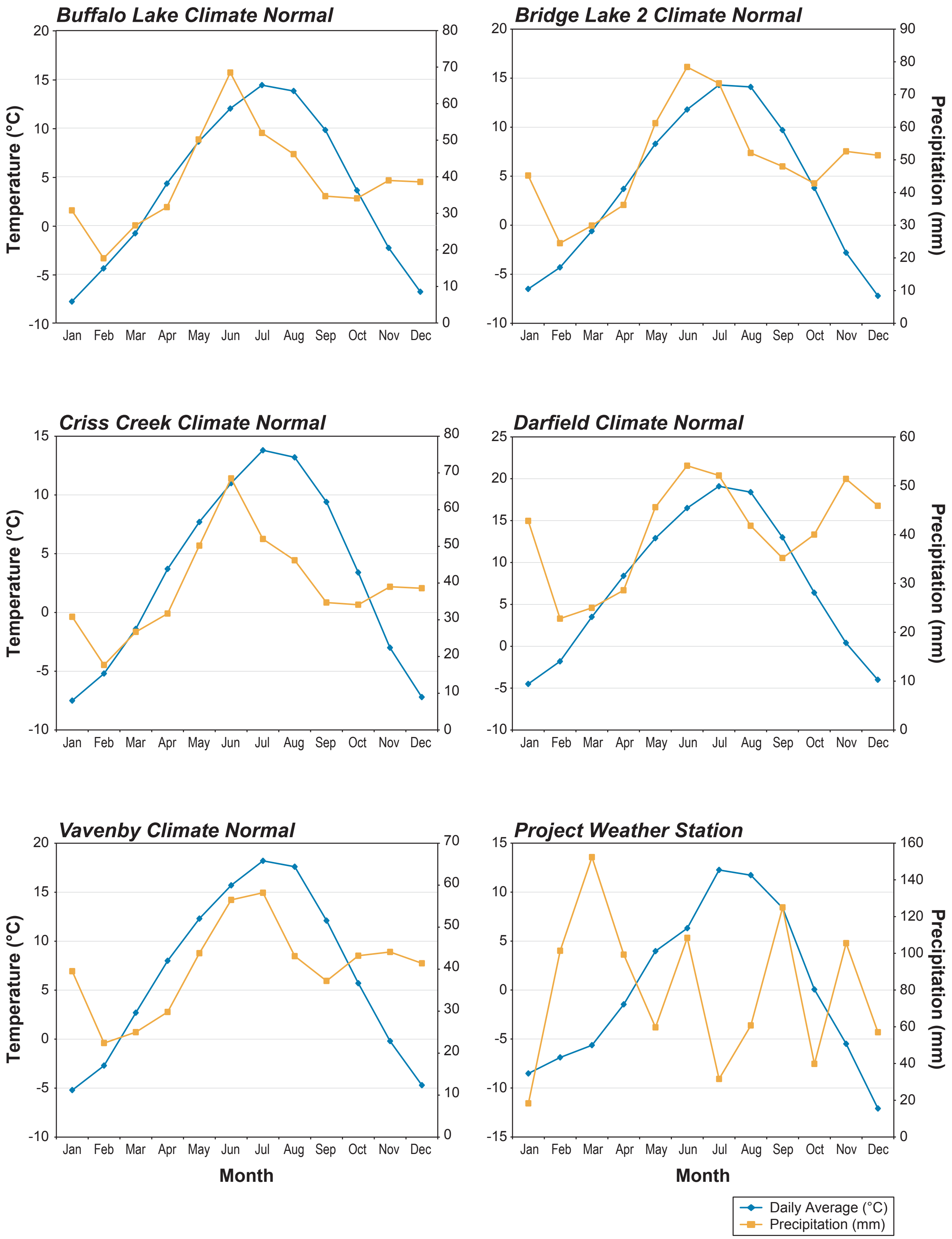
Date: October 29, 2014
Projection: NAD 1983 UTM Zone 11N

Figure 11.4-2

Climate Normal and Site Weather Station Temperature and Precipitation



The regional climate normal data show that precipitation is greatest in early summer (June and July) and mid-fall (October and November).

11.4.1.3 Hydrology

The proposed infrastructure is situated within highland areas of the Harper Creek and the North Thompson River watersheds. These highlands also act as a watershed divide between Harper Creek and the Barrière River.

Harper Creek flows south from its source and discharges into the western end of North Barrière Lake. The Barrière River flows into the lake from the east and continues to the southwest for approximately 25 km before meeting the North Thompson River.

Baker and Jones creeks drain north-facing aspects adjacent to the proposed infrastructure and discharge into the North Thompson River. The North Thompson River drains westward from the outlets of Baker and Jones creeks, turns south at the town of Clearwater, and meets the Barrière River at the town of Barriere.

Mean annual runoff in the region ranges from 7 L/s/km^2 to 29 L/s/km^2, with the majority of runoff occurring during the May and June snowmelt freshet (Appendix 11-B).

Seven gauging stations near the Project Site have provided annual stream flow characteristics (Figure 11.4-3; Table 11.4-1). Peak flows occur as early as mid-May in small tributaries draining catchments at low elevations, and as late as late June in larger streams draining higher elevations (Figures 11.4-4, 11.4-5, and 11.4-6). Flow rates gradually decline over the summer months.

Table 11.4-1. Return Period Seven-day Low Flows for Stream Gauging Stations near the Proposed Development Area

Station ID	Drainage Area (km^2)	Return Period 7-day Low Flow (m^3/s)				Location
		2-year	5-year	10-year	20-year	
BAKER	14.3	0	0	0	0	Baker Creek near confluence with North Thompson River
TSFUS	15	0	0	0	0	T Creek at proposed TMF main embankment
OP	7.7	0.004	0	0	0	P Creek near confluence with Harper Creek
TSFDS	23.4	0.012	0	0	0	T Creek near confluence with Harper Creek
JONESUS	17.6	0.009	0	0	0	Jones Creek 1.5 km from confluence with North Thompson River
HARPERUS	47.1	0.089	0.04	0.02	0.01	Harper Creek upstream of T Creek
08LB076	166	0.481	0.38	0.34	0.31	Harper Creek near confluence with Barrière River

The low-flow season extends from late-summer to early spring. Upper reaches of smaller creeks have been observed to dry up during the winter (e.g., TSFUS). The 2- to 10-year return period low flows may be used to estimate the component of streamflow arising from groundwater discharge (Table 11.4-1). Non-flowing conditions during the low-flow season suggest the stream is not in a groundwater discharge zone upstream of the gauging station.

Figure 11.4-3

Stream Gauging Stations near the Project Site

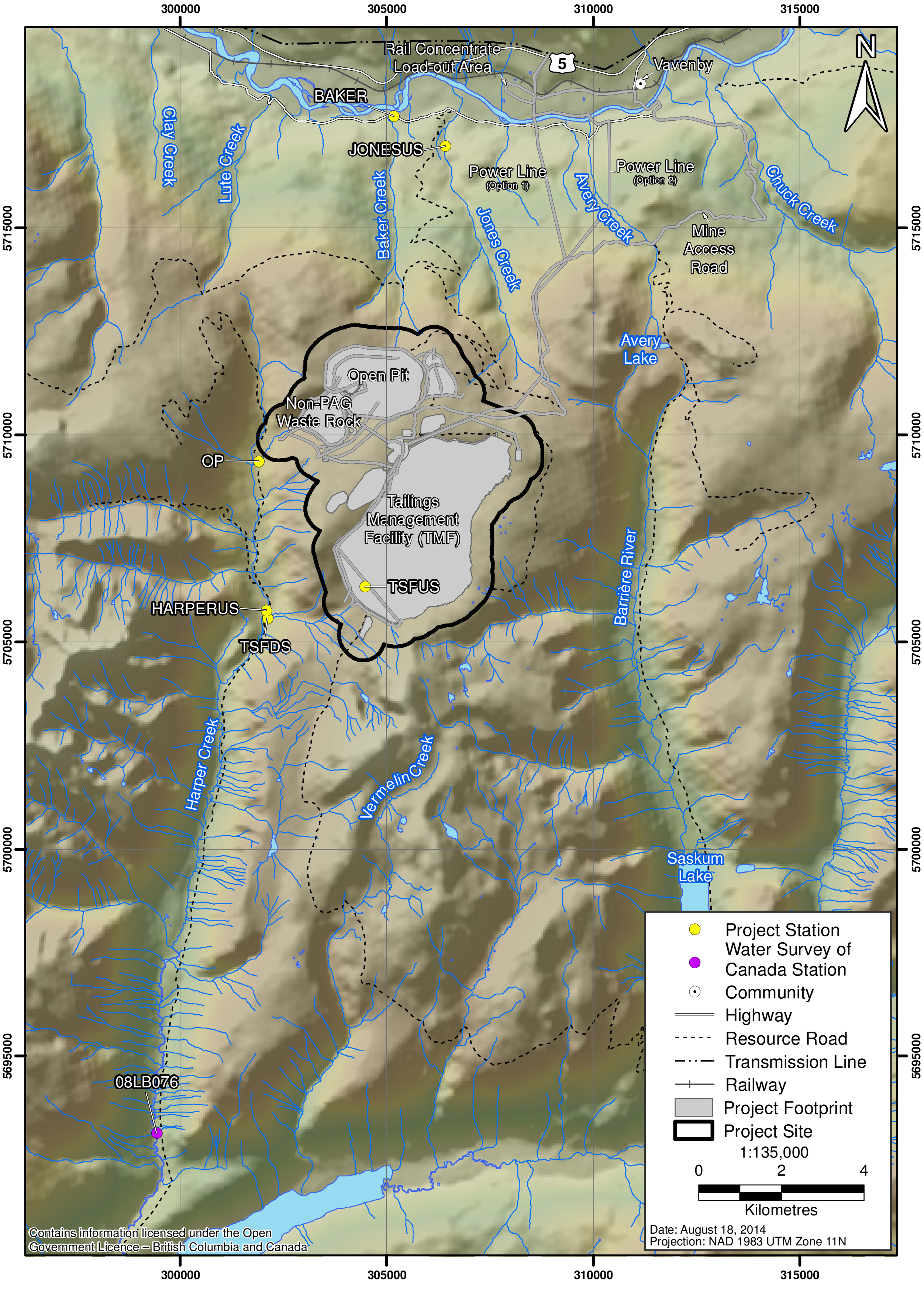


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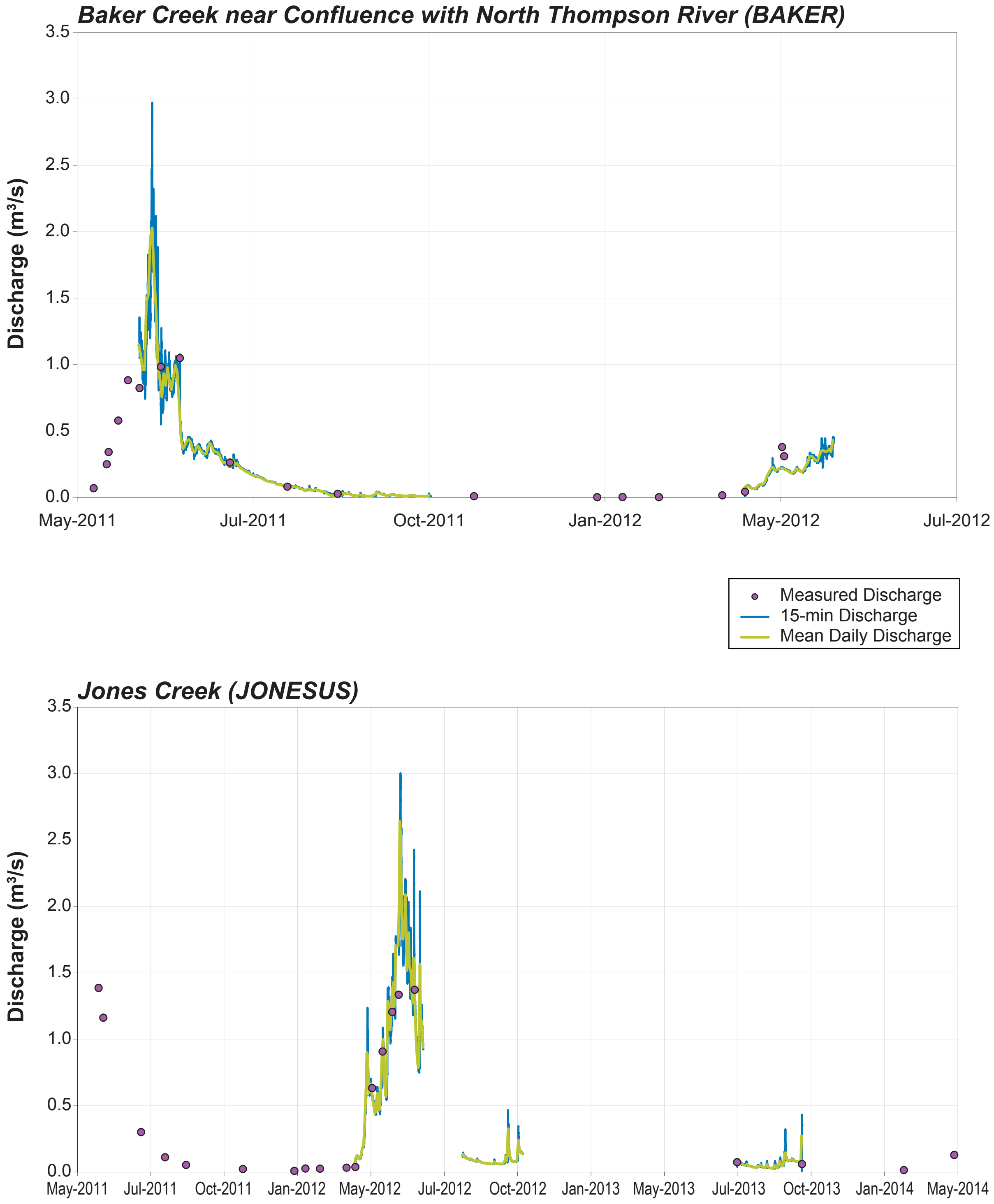
Figure 11.4-4

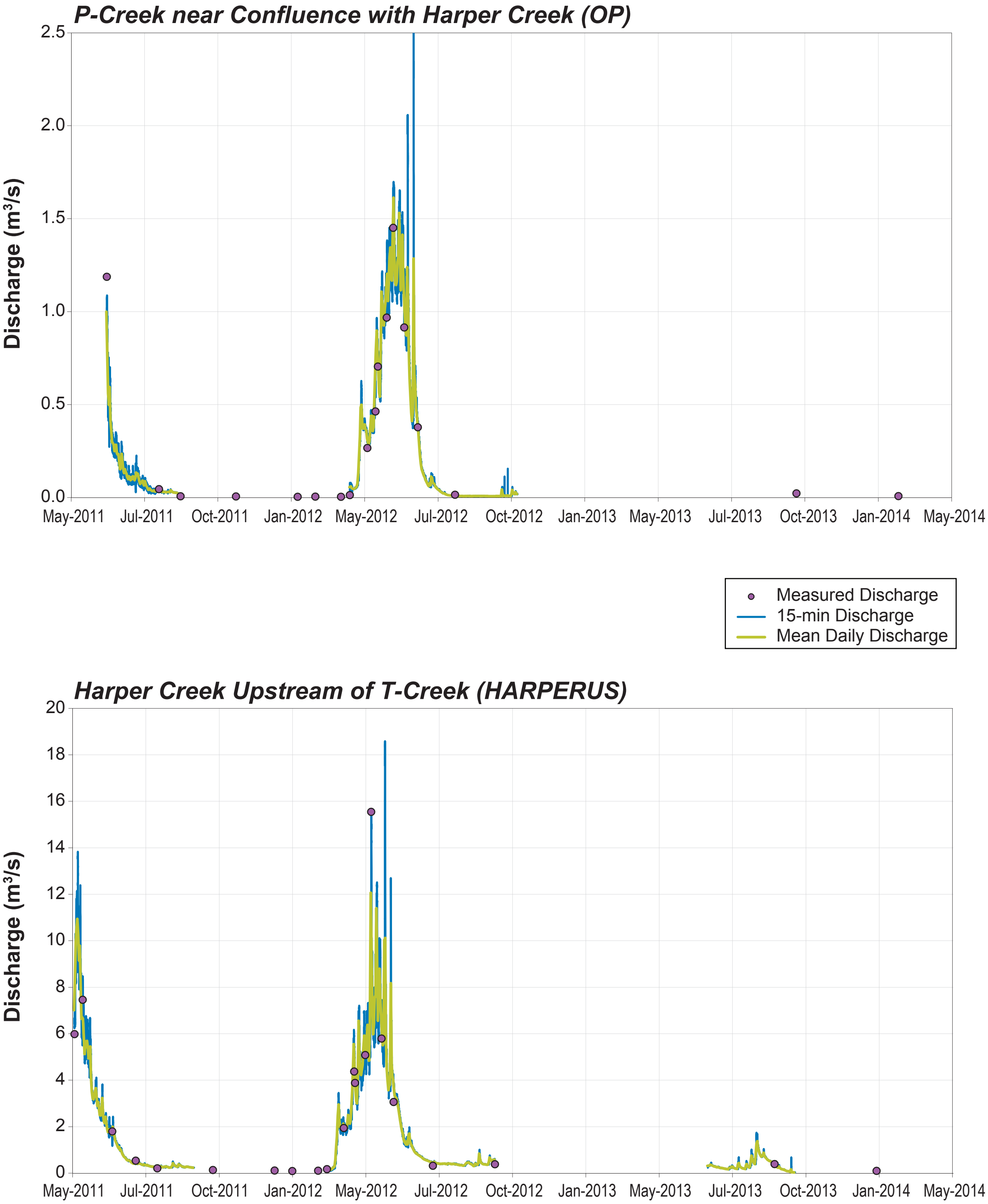
Streamflow Hydrographs near the Project Site



Note: Data gaps (1 Jun to 4 Jun 2012 and 5 Jul to 23 Aug 2012) are due to logger malfunction for Jones Creek.

Figure 11.4-5

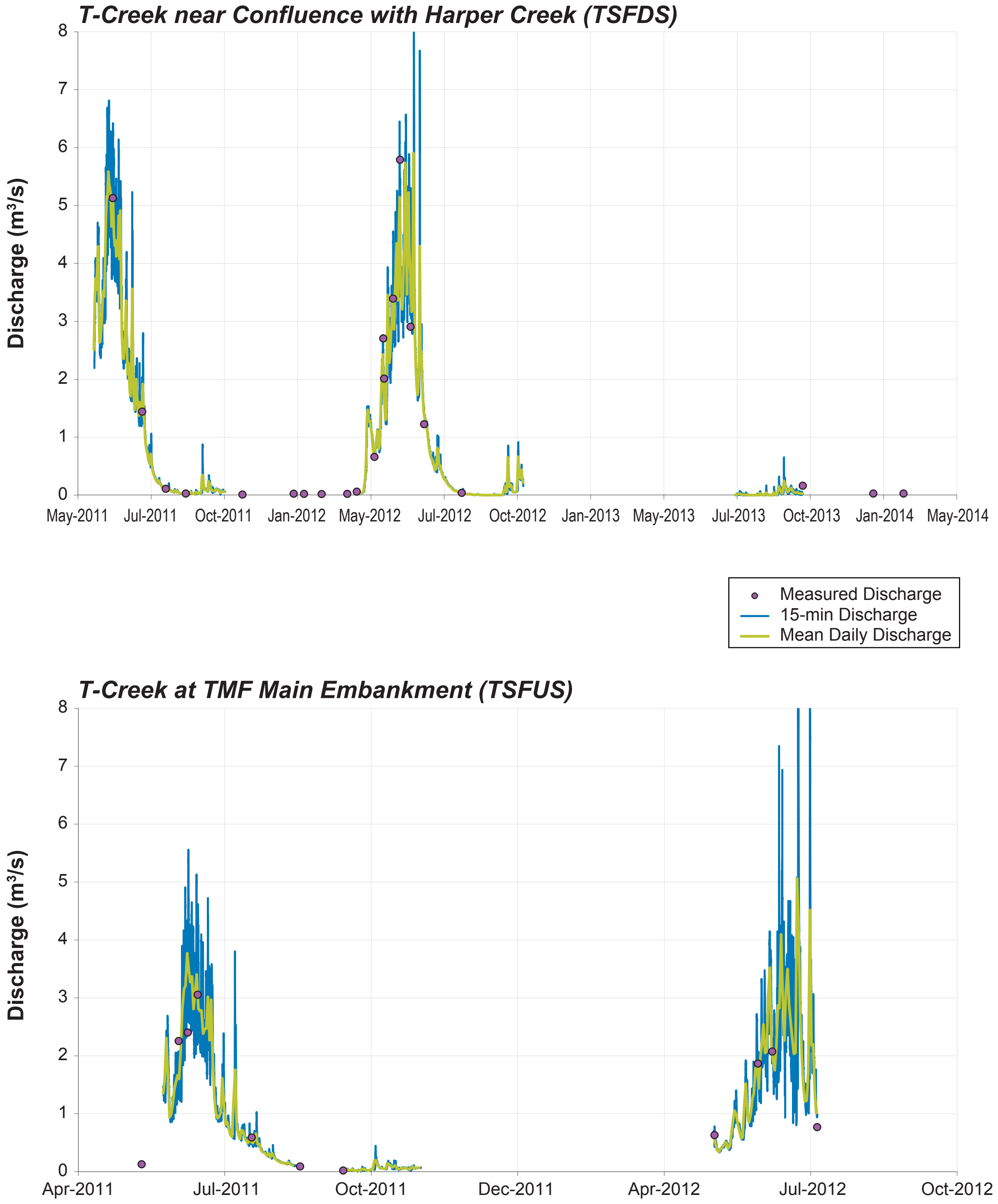
Streamflow Hydrographs near the Project Site



Note: Data from 2013 was removed due to logger malfunction for P-Creek near Confluence with Harper Creek.

Figure 11.4-6

Streamflow Hydrographs near the Project Site


T-Creek near Confluence with Harper Creek (TSFDS)

T-Creek at TMF Main Embankment (TSFUS)

Note: Stage data prior to 24 May 2011 were removed due to ice affecting the stage discharge relationship for T-Creek at TMF Main Embankment. Stage data between 10 Oct 2011 to 8 Jun 2012 removed due to ice affecting the stage-discharge relationship for T-Creek at TMF Main Embankment.

Further information regarding baseline hydrology for the Project is provided in the Hydrology Baseline Report (Appendix 12-A).

11.4.1.4 Geology

The geological setting of the Harper Creek deposit presented below is based on Naas (2012) and Knight Piésold Ltd. (KP 2012a).

Regional Bedrock Geology

The Project is located within structurally complex, low-grade metamorphic rocks of the Eagle Bay Assemblage (EBA) formations, part of the Kootenay Terrain on the western margin of the Omineca Belt in south-central British Columbia. Additionally, the Project Site lies within the Cretaceous Bayonne plutonic belt (Logan 2002) represented by two large batholiths, the Baldy batholith to the south and the Raft batholith to the north of the deposit. Figure 11.4-7 presents the regional bedrock geology and structures.

The EBA incorporates Lower Cambrian to Mississippian sedimentary and volcanic rocks deformed and metamorphosed during the Jurassic-Cretaceous orogeny (Schiarizza and Preto 1987). The Lower Cambrian (and possibly Late Proterozoic) rocks include quartzites, grits, and quartz mica schists (Units EBH and EBQ), mafic metavolcanic rocks, limestone (Unit EBG), and overlying schistose sandstones and grits (Unit EBS) with minor calcareous and mafic volcanic units. These are overlain by mafic to intermediate metavolcanic rocks (Units EBA and EBF) intercalated with and overlain by dark grey phyllite, sandstone, and grit (Unit EBP; Schiarizza and Preto 1987).

The regional structure consists typically of east-west striking, low to moderately dipping stratigraphy. The EBA is divided by four northwest-dipping thrust faults that disrupt the stratigraphic sequence by positioning Cambrian rocks overtop of younger Paleozoic strata.

Bedrock Geology in the Local Study Area

The EBA contains numerous polymetallic massive sulphide deposits mainly within highly deformed and metamorphosed Devonian felsic volcanic rocks (Höy 1999). The Harper Creek deposit is a volcanic-hosted massive sulphide (VHMS) and volcanic-sedimentary hosted massive sulphide or sedimentary exhalative (SEDEX) deposit. The deposit lies within a 1,000-m thickness of volcano-sedimentary stratigraphy. The deposit is hosted in the EBA specifically within the Lower Paleozoic and Greenstone Belts. The deposit is interpreted to be a polymetallic volcanogenic sulphide deposit comprised of lenses of disseminated, banded, and fracture-filling iron and copper sulphides. Copper mineralization is confined to tabular-shaped zones within light silvery grey quartz-sericite phyllites, with lesser amounts of green chloritic phyllite, dark grey carbonaceous phyllite, and light grey sericitic quartzite.

These rocks locally include thin horizons of quartz-feldspathic orthogneiss. A bedrock geology map of the Project Site is shown on Figure 11.4-8.

Figure 11.4-7
Regional Bedrock Geology

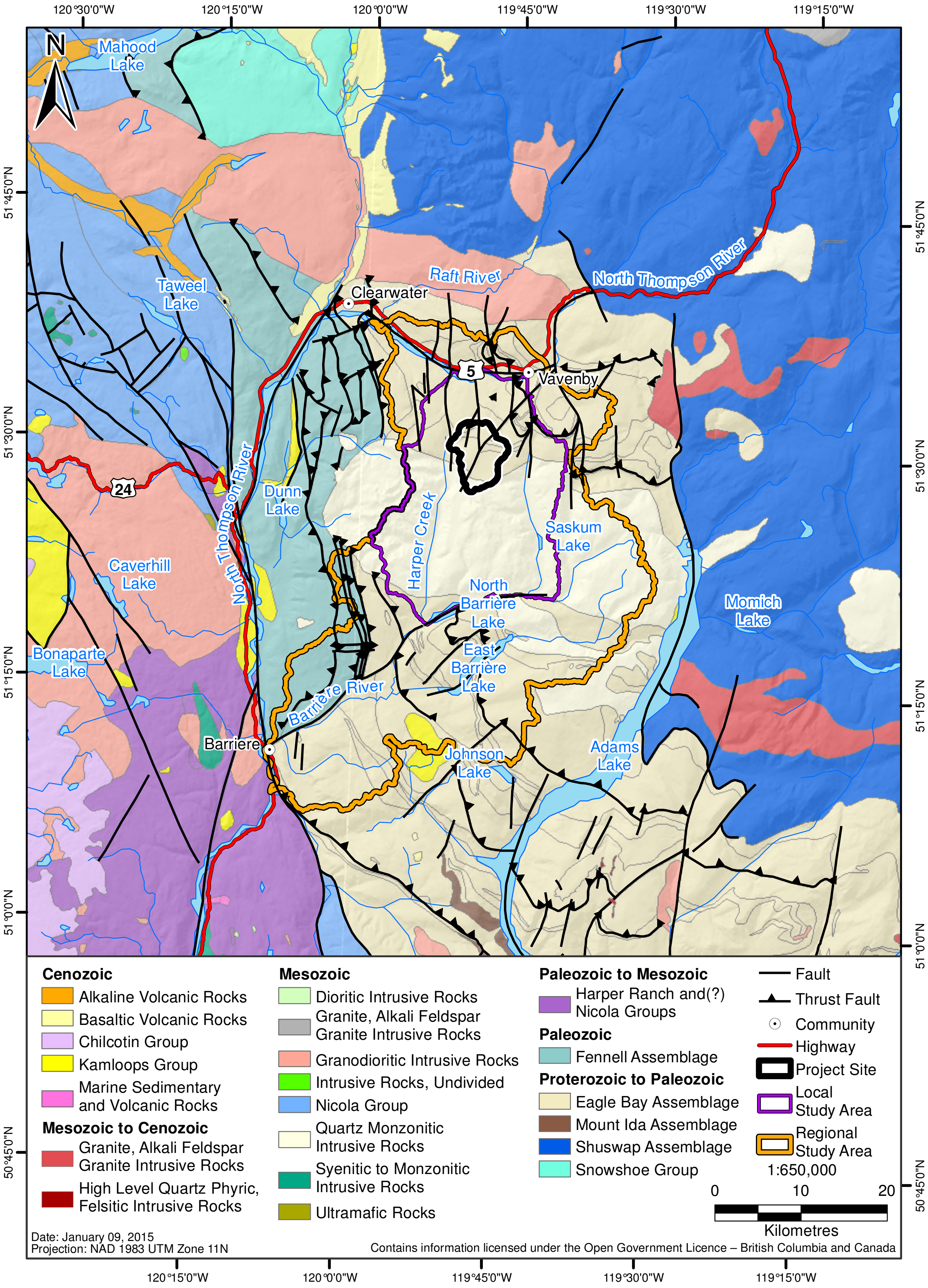
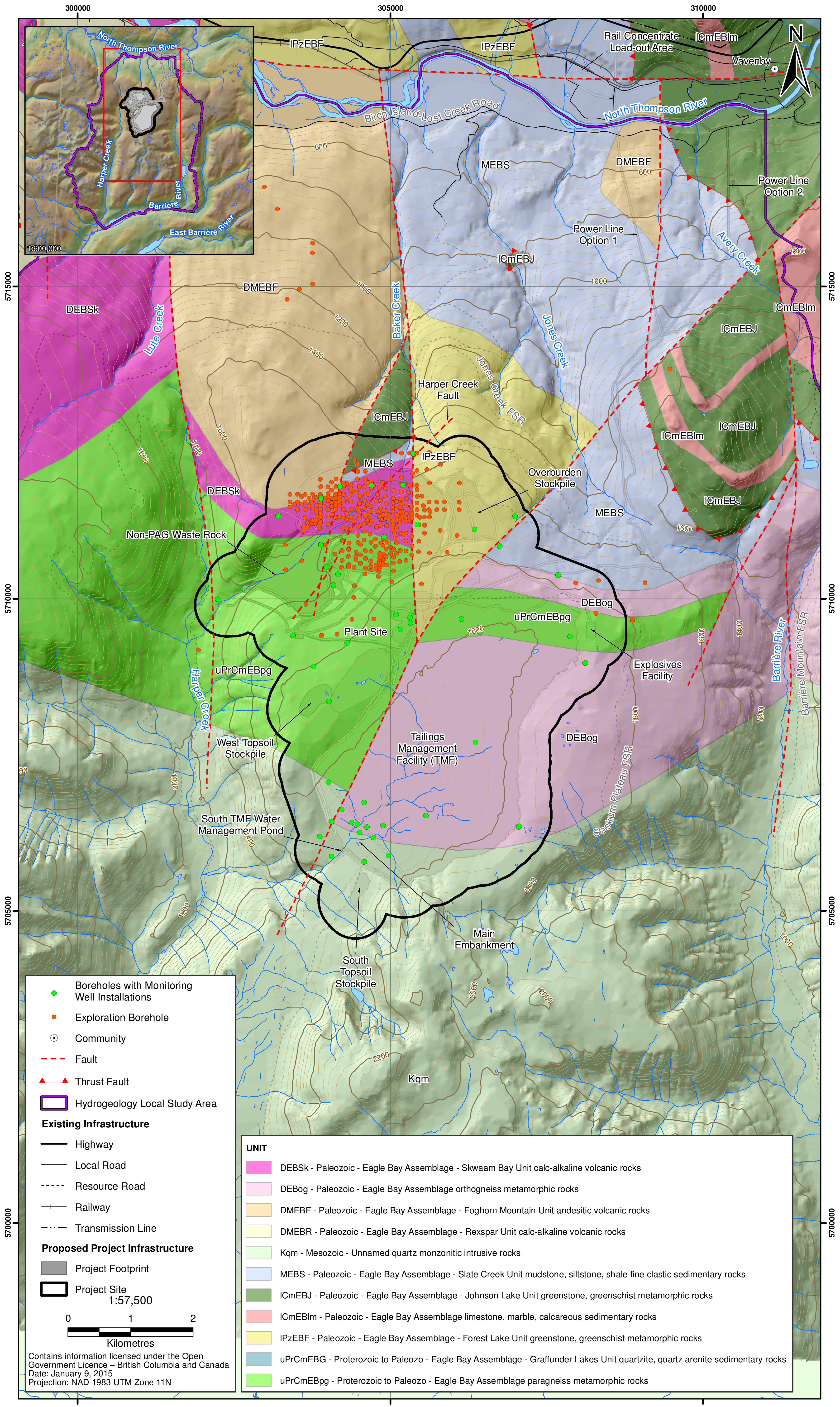


Figure 11.4-8
Bedrock Geology at the Harper Creek Project Site



The nature of the structure in the region is a complex sequence of polyphase deformation consisting of a sequence of thrust faulting, intrusion-related folding and faulting, strike-slip, and normal faulting, all of which impose a complex alteration and metamorphic fabric on the rocks. One of these faults, the Harper Creek fault, bisects the proposed open pit area, dipping approximately 70°-75° to the southeast (Merit 2013).

The Harper Creek Fault commonly contains several wide zones of pale grey to green gougy zones and localized quartz and iron carbonate-healed fault breccias. The structure is composed of several fault zones and varies in thickness from 20 to 50 m. The structure also contains several mafic andesitic dikes that are interpreted as late Tertiary dikes with no regional deformation.

Fault locations and their influence on the local geology are shown in Figure 11.4-8. An interpretation of the geological evolution of the property is presented in Figure 11.4-9.

Overburden and Surficial Geology

Samples of the overburden materials have been collected and logged as part of a terrain reconnaissance program conducted by Knight Piésold (KP 2012a). Samples included road cuts and Test Pits, and logs are provided in Appendices 7A and 7B. Additional information about the surficial geology of the site is provided in the Terrain and Soils Baseline Report (Appendix 5-B).

Figure 11.4-10 presents the distribution of surficial materials proximal to the Project. Additional large format maps are provided in the Reconnaissance Terrain Mapping report (Knight Piésold 2012a).

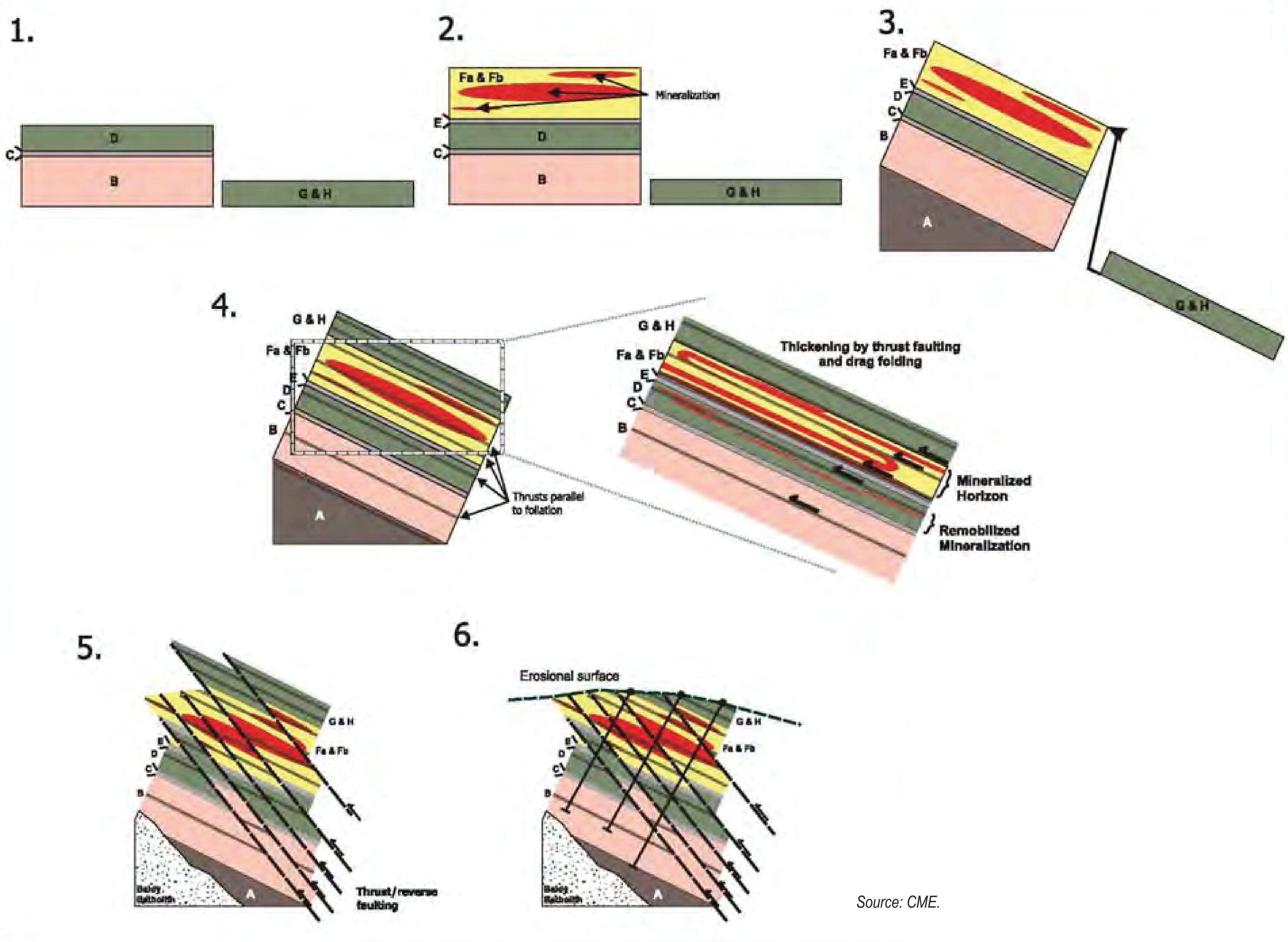
Upland areas containing the proposed Project infrastructure are characterized by a discontinuous veneer (thickness generally less than 2 m) of overburden covering the bedrock. These deposits are predominantly morainal material (glacial till), colluvium, or less commonly, organic materials. Glacial till materials are composed of fine to course gravel with some sand, silt, and trace cobbles. Colluvium is found in steeper terrain and is comprised of silty sand with some gravel and trace cobbles. Organic material is present in swamps and often as a thin layer (up to 0.5-m thick) atop other sediment deposits and consists of fibrous peat.

Overburden is generally thinner as elevation increases and is very thin or absent on hillside spurs and on upper hill slopes. At locations where overburden is thin or absent, bedrock outcrops are characterized by heavy weathering and include schist, phyllite, and granodiorite.

Surficial materials within the lower-lying river and creek valleys are dominated by fluvials and glaciofluvials, with lesser amounts of glaciolacustrine deposits. Fluvial materials have been mapped along the major drainages, including the North Thompson River Valley and the lower reaches of Baker and Jones creeks. The fluvials are typically coarse-grained, consisting of sand, gravel, and cobbles. Glaciofluvial materials are present in the lower reaches of Harper Creek, Jones Creek, and Baker Creek watersheds, and in the North Thompson and North Barrière River valleys. The glaciofluvials are well-graded granular materials consisting of sand, silt, and gravel. Glaciolacustrine deposits have been identified in portions of the T Creek valley, consisting of finer materials (silts and clays).

Figure 11.4-9

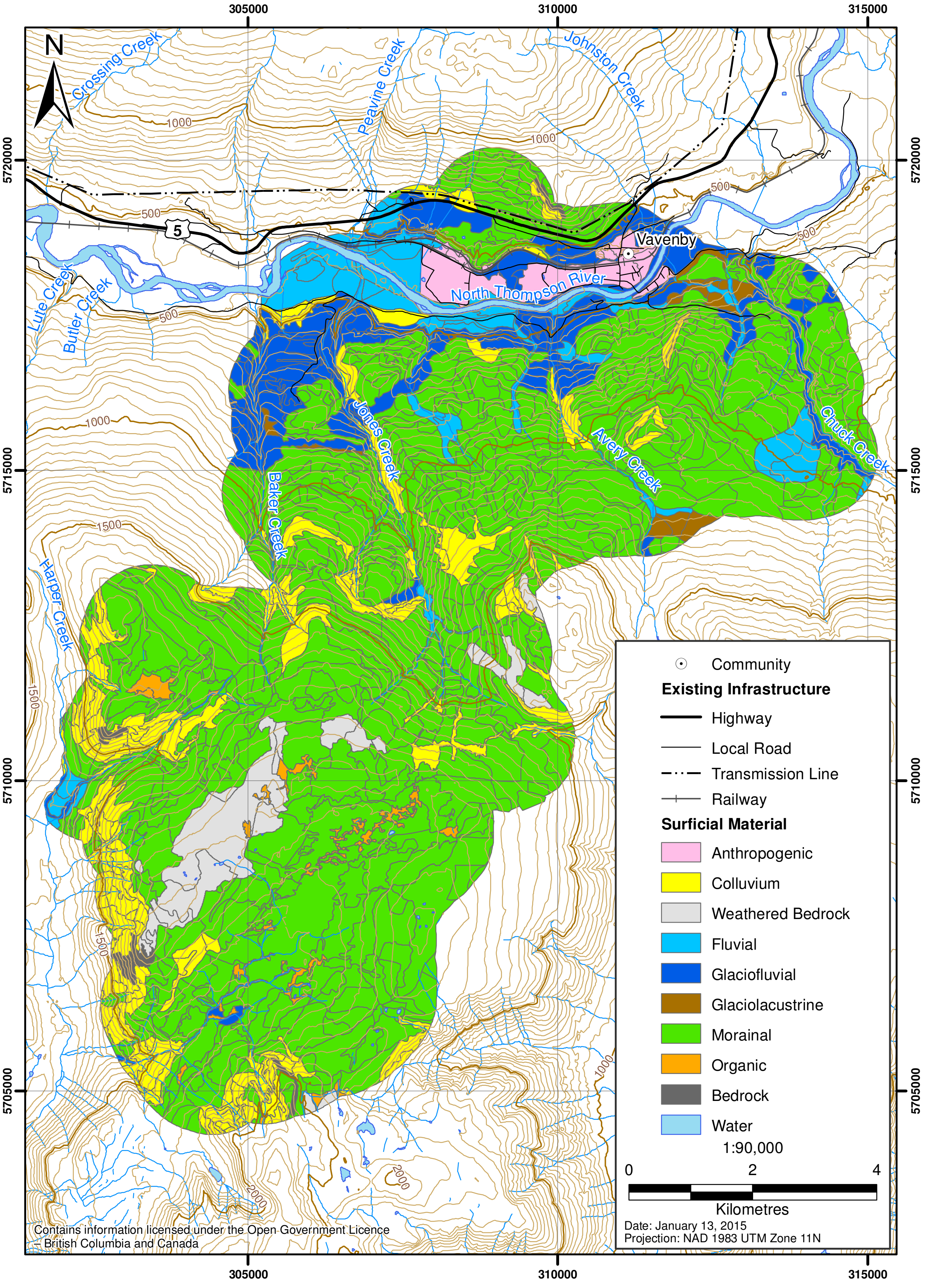
Schematic of the Geological Evolution of the Project



Source: CME.

Figure 11.4-10

Terrestrial Ecosystem Mapping and Terrain Data for Harper Creek Project



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11.4.1.5 Groundwater Use

Groundwater use near the Project was investigated using the BC Wells Database (BC MOE 2014), as obtained from the DataBC Geographic Data Discovery Service. The locations and use classifications of wells registered in the database have been used to interpret water use in the LSA and RSA (Figure 11.4-11).

Wells classified as "unknown" in the database are inferred to be a mix of private domestic and agricultural irrigation water supply wells. Many of the wells classified as "Private Domestic" may also be used to support small farms. Wells classified as "Water Supply Systems" include those providing water supply for campgrounds, resorts, small community developments, and the towns of Clearwater and Barriere.

Commercial and domestic groundwater users are present in the northern-most reaches of the LSA (Figure 11.4-12), along the North Thompson River Valley. Uses include domestic and agricultural water supply. Numerous groundwater users exist in the northern-most and southern-most reaches of the RSA. In the north, registered wells are present along the North Thompson River Valley, and include a mix of domestic (single family) and commercial/industrial (lumber mills and small business) users. In the south, wells are present along the Barrière River valley downstream of East Barrière Lake, and near the town of Barriere. Water users in the south of the RSA include domestic, commercial/industrial (resorts, campgrounds, small businesses), and municipal water supply for the town of Barriere.

Water samples have been collected from active water supply wells situated on the properties nearest to the Project Site (results provided in Appendix 11-A). Reported concentrations of metals, anions and nutrients were below published BC MOE and Health Canada guidelines for drinking water quality. Hardness and turbidity were reported above aesthetic guidelines in certain samples.

11.4.1.6 Historical Activities

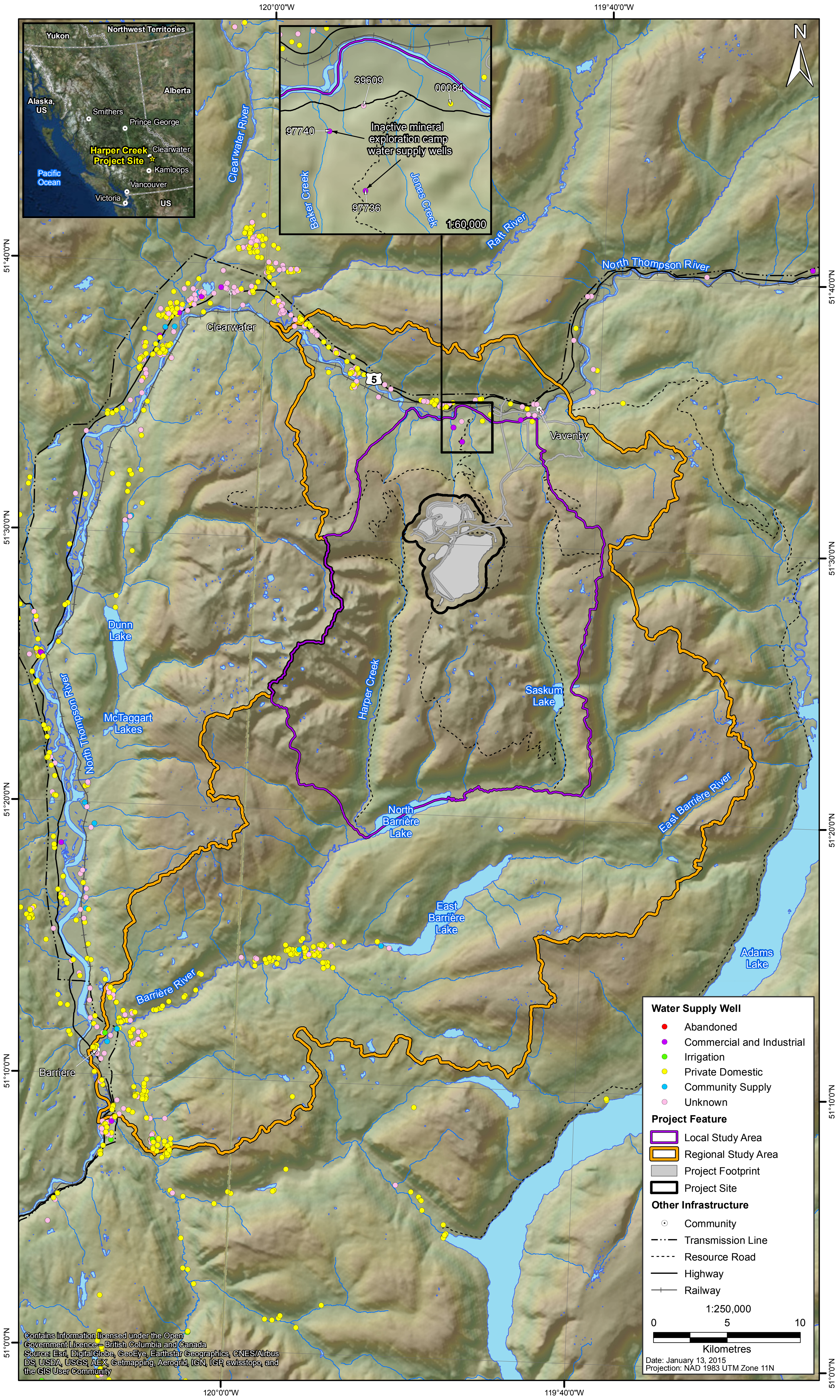
There are a number of past or ongoing activities within the Project Site, LSA, and RSA that influence the current baseline conditions (Table 11.4-2).

Table 11.4-2. Historical Activities Potentially Influencing Hydrogeology Baseline Conditions in the Project Site, Local Study Area, and Regional Study Area

Activity	Location	Influence on Baseline Conditions
Clear-cut logging	Project Site, LSA, RSA	Augmented recharge to groundwater during snow-free season.
Railway, train traffic	LSA, RSA	Possible legacy contamination affecting groundwater quality locally.
Lumber mills	RSA	
Town and villages	RSA	
Free-range cattle grazing and other agriculture	Project Site, LSA, RSA	Augmented nutrient loading.
Drinking water supply	LSA, RSA	Localized reduction in groundwater levels and storage.

Figure 11.4-11

Registered Groundwater Supply Wells in the Regional Study Area



Date: January 13, 2015
Projection: NAD 1983 UTM Zone 11N

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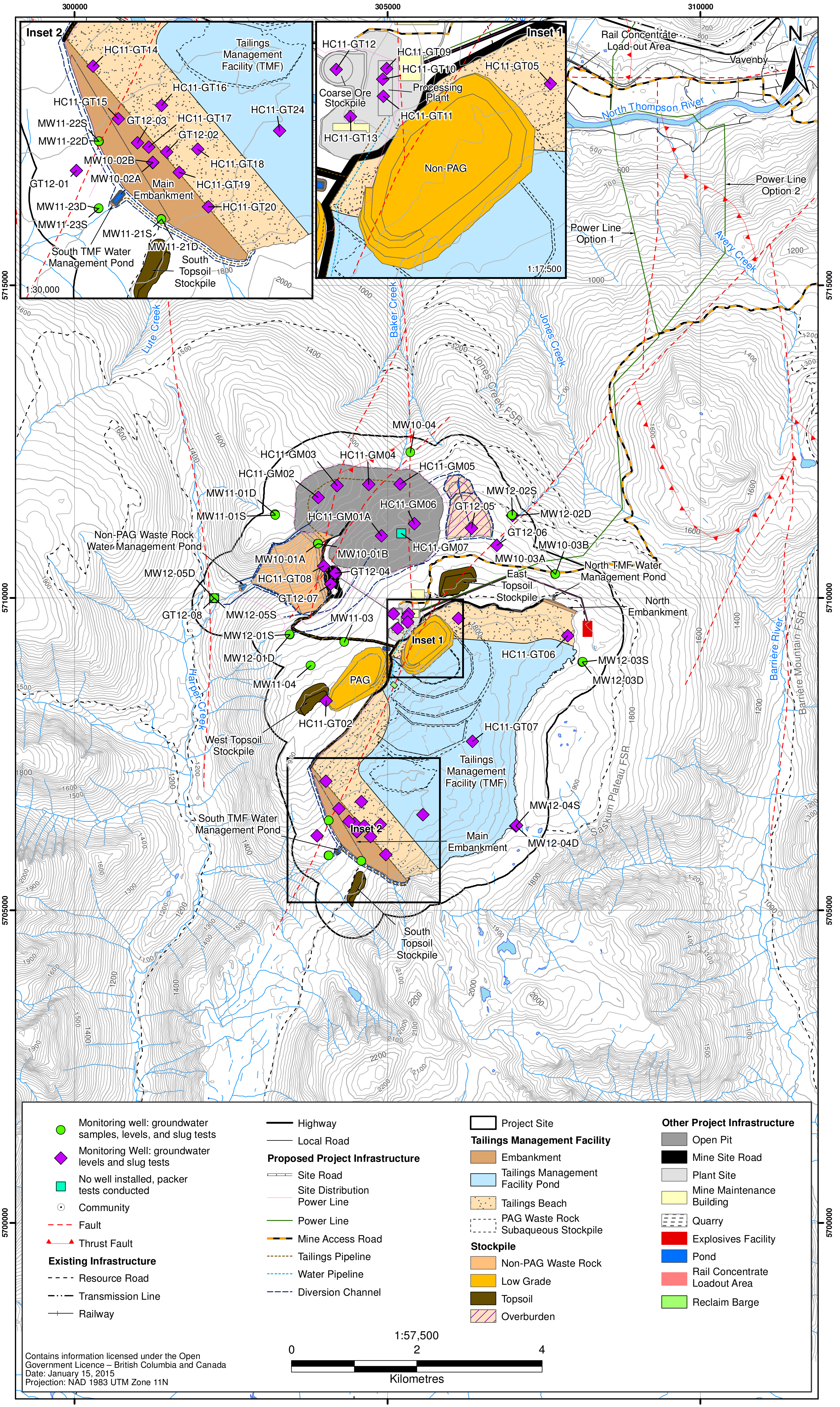
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 11.4-12
Installed Monitoring Wells and Tested Borehole



The influences most activities have had on existing hydrogeological conditions in the Project Site are expected to be negligible, because the Project Site is located up-gradient of most activities.

Water supply wells located at the northern end of the LSA would have the effect of reducing the amount of groundwater in storage along the valley floor, thereby reducing groundwater levels. The radius of influence of these wells is expected to be on the scale of tens to hundreds of metres given their registered uses. Therefore minor reductions in groundwater levels in the LSA are expected to be limited to the far northern reaches along the North Thompson River Valley.

Numerous activities in the RSA are expected to affect groundwater quantity and quality in the localized areas. Active water supply wells (Figure 11.4-11; Section 11.4.1.5) are expected to reduce groundwater levels locally and the combined effect of numerous wells near the town of Barriere may result in a detectable reduction in groundwater levels beneath and near the town. Industrial activities may have localized effects on groundwater due to historic contamination. None of the activities occurring in the RSA outside of the LSA are expected to influence baseline hydrogeologic conditions inside the LSA.

11.4.2 Baseline Hydrogeological Studies

11.4.2.1 Objectives

The objectives of the hydrogeology baseline studies were to:

- characterize the baseline, pre-development groundwater conditions;
- characterize the overburden and bedrock types present;
- estimate hydraulic conductivities of the geologic materials and identify hydrostratigraphic units;
- characterize groundwater levels, flow directions, recharge and discharge zones, and seasonal variability in these;
- characterize groundwater quality and its natural range of variability; and
- provide sufficient baseline information upon which to base assessment of the Project's potential environmental effects and to design an appropriate Groundwater Management Plan (Section 24.8).

11.4.2.2 Sources of Information and Data

Hydrogeologic data were collected for the Project as early as fall 2011, when Klohn Crippen Berger (KCB) conducted a hydrogeologic drilling program. Further field work was conducted in 2011, 2012, 2013, and 2014 by KP. The methods and results of the 2011 and 2012 site investigations conducted by KP have been documented in two geotechnical site investigation reports (KP 2012b, 2013a) and two previous baseline reports (KP 2013b, 2013c). All existing data have been amalgamated into the current Hydrogeology Baseline Report, which is included as Appendix 11-A.

11.4.2.3 Methods

The methodologies used for the Project-specific hydrogeological baseline studies for groundwater quantity and quality included:

- borehole drilling and logging;
- installation of groundwater monitoring wells and development;
- hydraulic conductivity testing (packer and slug tests);
- measurement of groundwater levels, and their use in estimating hydraulic gradients and groundwater flow directions; and
- groundwater quality sampling.

Further details regarding instrumentation and operational procedures associated with these methods are documented in Appendix 11-A. Figure 11.4-12 shows the monitoring wells and tested borehole that were used in the hydrogeology baseline studies.

Borehole Drilling and Well Installation

A total of 60 boreholes were used for hydrogeologic data acquisition. Many of these boreholes were drilled in concert with geotechnical and geomechanical site investigations, while others were drilled as a focused effort to collect hydrogeologic data. Numerous boreholes were drilled for mineral resource evaluation, primarily within and near the Open Pit footprint. Mineral resource boreholes have been used in delineation of bedrock geology units and faults, and have otherwise not been used for hydrogeologic data acquisition.

The drilling and geologic sampling methods differed depending on the engineering needs of the borehole and included collection of rock core during diamond rotary drilling in bedrock, and standard penetration tests during ODEX drilling in unconsolidated sediments.

Monitoring wells (often referred to as standpipe piezometers) were installed in 58 boreholes. A target completion zone was established along one interval of hydrogeologic interest in each borehole, with backfilling along the well annulus to isolate the completion zone. A number of wells were installed in a twinned configuration, whereby two wells were installed in separate boreholes side-by-side: one with a deeper completion zone than its twin.

Monitoring wells installed with the intent of hosting groundwater sampling were developed using an inertial pumping system.

Hydraulic Conductivity Estimation

A total of 251 hydraulic tests were conducted to measure hydraulic conductivity of the geologic materials. These included 211 packer tests (Lugeon and falling head response tests) in geotechnical and geomechanical boreholes, and 57 single-well response tests (slug tests) in installed monitoring wells. Packer tests were conducted at depths ranging up to 350 metres below grade (mbg). The methods of Hvorslev (1951) and Lugeon (Houlsby 1976) were used to estimate hydraulic conductivities based on test data.

Groundwater Levels and Flow

Groundwater levels were measured in 57 installed monitoring wells. Pressure transducers were deployed in 23 wells, generating a dataset of water level measurements at hourly intervals. These data were used to generate a potentiometric surface contour map, which was subsequently used for interpretation of groundwater flow directions, horizontal hydraulic gradients, and seepage velocities. Differences in water levels between twinned shallow and deep wells were used to measure vertical hydraulic gradients, which aided in the identification of groundwater recharge and discharge zones.

Groundwater Sampling and Water Quality Characterization

One hundred and seven groundwater samples were collected from 25 wells, including the monitoring wells installed near the proposed Project infrastructure and the water supply wells in the hydrogeology baseline LSA. The purging and sampling procedures were founded upon guidance provided in the following documents:

- British Columbia Field Sampling Manual for Continuous Monitoring and the Collection of Air, Air-emission, Water, Wastewater, Soil, Sediment and Biological Samples. 2003 Edition. BC Ministry of Water, Land and Air Protection (BC MWLAP 2003); and
- Low-Flow (Minimum Drawdown) Ground-Water Sampling Procedures (Puls & Barcelona, 1996).

Water samples were submitted to Maxxam Analytics or ALS Laboratory Group in Burnaby, BC for analysis of physical parameters, dissolved anions, nutrients, total and dissolved metals, cyanides, and total and dissolved organic carbon. Laboratory results were screened against guidelines published by the BC Ministry of Environment (MOE), the Canadian Council of Ministers of the Environment (CCME), and Health Canada. Specific guidelines that were used were derived from the following sources (accessed May 2014):

- BC MOE Approved Water Quality Guidelines (BC MOE 2014a) for the protection of freshwater aquatic life;
- BC MOE Approved Water Quality Guidelines (BC MOE 2014a) for raw drinking water supply;
- CCME Guidelines for the Protection of Aquatic Life (CCME 1999); and
- Health Canada Guidelines for Drinking Water Quality (Health Canada 2012).

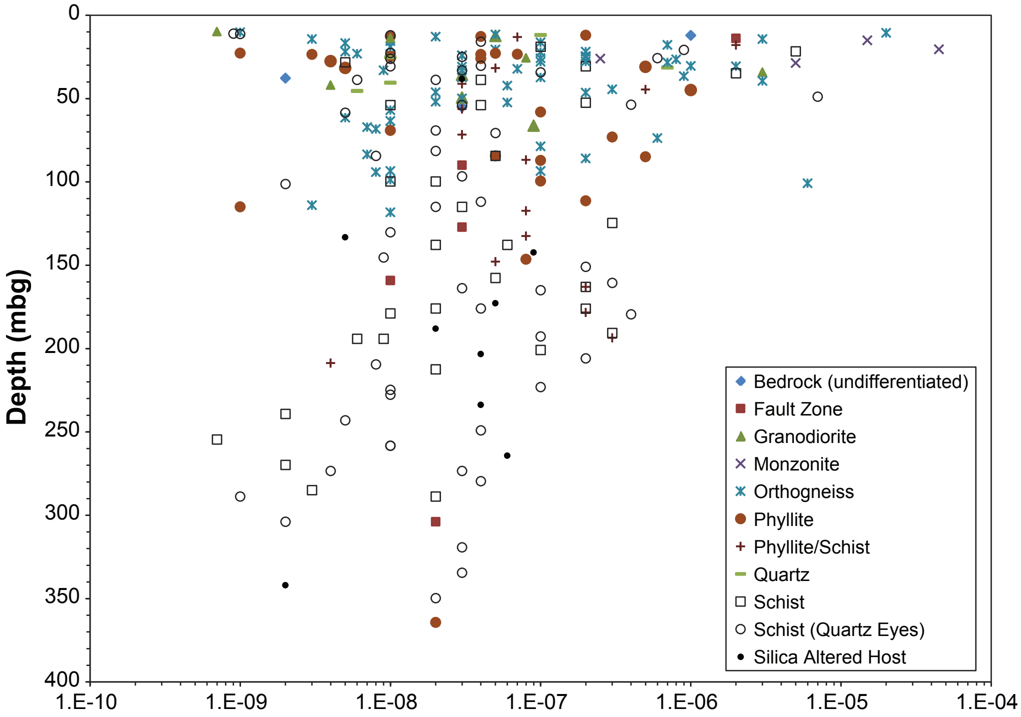
11.4.3 Existing Hydrogeologic Conditions

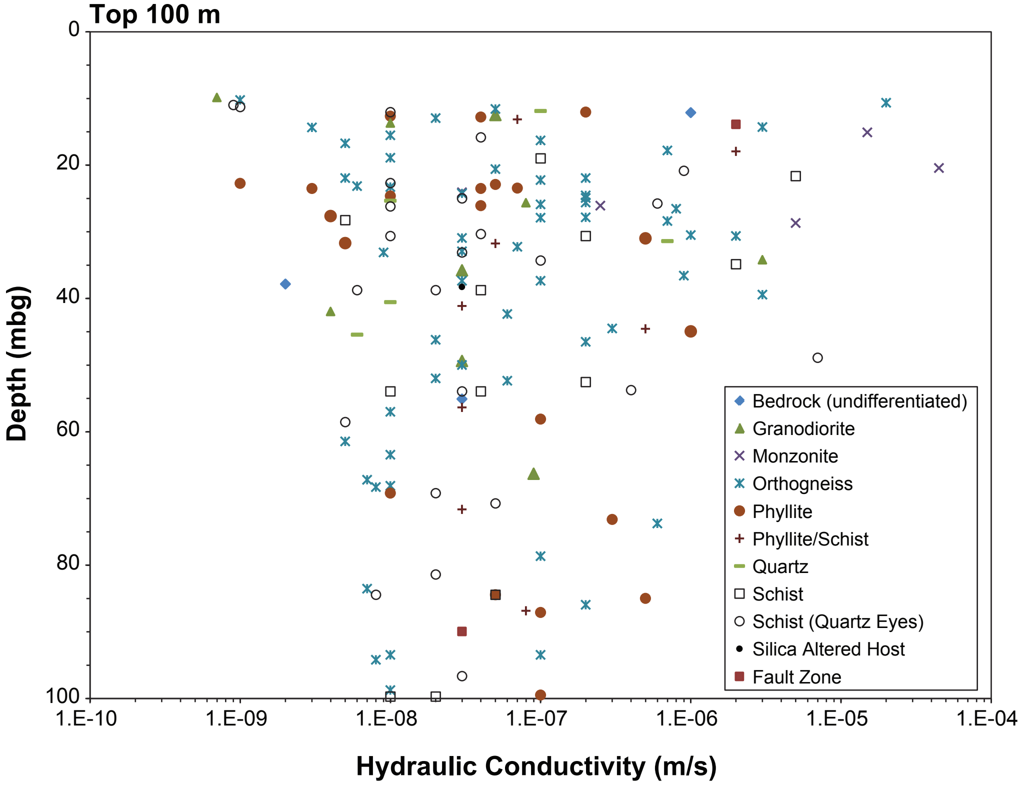
11.4.3.1 Permeability

Hydraulic conductivity (K) measurements have ranged from 5E-5 m/s (equivalent to 5×10^{-5} m/s in scientific notation) to 7E-10 m/s, with a geometric mean value of 3E-8 m/s spanning the full Project Site. A trend of decreasing maximum K with depth appears in the dataset (Figure 11.4-13) at depths exceeding 100 mbg.

Figure 11.4-13

Hydraulic Conductivity Measurements Plotted with Respect to Depth Categorized by Geology along the Test Interval





This trend is likely due to decreasing bedrock weathering and fracturing as depth increases. The lower limit of K (7E-10 to 1E-9 m/s), which does not appear to vary significantly with depth, likely corresponds with very low joint density and possibly approaches the permeability of the primary porosity.

The data available do not show a relation between K and rock type, indicating that secondary porosity (faults and fractures) likely controls permeability. While extensive fracture zones behave as preferential flow pathways, fault zones do not appear to exhibit elevated K relative to the broader joint sets. The measurements in fault zones suggest disintegrated rock infill materials compensate for the higher fracture density. Therefore, major faults present in the Project Site (e.g., Harper Creek Fault) appear not to present site-scale preferential flow pathways.

Analysis reports and tabulated measurements for packer and single well response tests are presented in Appendix 11-A.

Open Pit

The K measurements within and near the proposed open pit footprint range from 7E-10 m/s to 7E-6 m/s, with a geometric mean of 3E-8 m/s. Both the upper and lower limit of the K envelope in the open pit footprint decrease with depth. At depths exceeding 250 m the K envelope ranges from 7E-10 m/s to 7E-8 m/s.

Tailings Management Facility

The K measurements within and near the proposed TMF footprint range from 7E-10 m/s to 2E-5 m/s, with a geometric mean of 5E-8 m/s. No trend appears in the dataset at the range of depths investigated (10 to 118 mbg).

Measurements in the crystalline bedrock (quartz, granodiorite, and orthogneiss) identified beneath the proposed main embankment have a geometric mean of 4E-8 m/s. A fault zone identified in geotechnical borehole HC11-GT18 yielded a K estimate of 3E-8 m/s, which is not divergent from measurements in other nearby geologic settings. The test permeability indicates that this fault zone may not become a preferential flow path under the TMF or pose a risk for the TMF embankment's structural integrity.

Two boreholes tested beneath the tailings pond footprint (HC11-GT07 and HC11-GT24) yielded K values ranging from 2E-6 to 8E-9 m/s, with a geometric mean of 2E-7 m/s. The host rock in both of these boreholes is orthogneiss.

Two boreholes were tested in the foundation of the tailings beach at the north end of the TMF: HC11-GT06 and HC11-GT05. The shallow bedrock in these boreholes consisted largely of orthogneiss and included layers of schist and phyllite. The K measurements in these boreholes varied from 3E-6 m/s to 3E-9 m/s, with a geometric mean of 1E-7 m/s.

Two boreholes have been tested along the ridge that would act as the eastern wall of the proposed TMF: MW12-03S (K = 2E-5 m/s at 12.8 to 15.1 mbg) and MW12-04S (K = 3E-7 m/s at 26.1 to 29.0 mbg). This ridge acts to isolate the proposed tailings pond from the Barrière River catchment basin.

Stockpiles and Plant Site

The K measurements beneath proposed stockpile and plant site footprints generally exhibit a K spread that is consistent with the site-wide dataset.

Tests conducted in boreholes beneath the proposed non-PAG waste rock stockpile and adjacent crusher site yielded K measurements ranging from 2E-9 m/s to 1E-6 m/s, with a geometric mean of 3E-8 m/s.

Tests conducted in boreholes down-gradient of the proposed PAG LGO stockpile and beneath the proposed plant site ranged from 9E-10 to 5E-6 m/s, with a geometric mean of 2E-8 m/s. These boreholes also act to characterize K along the western flank of the proposed TMF.

Relatively high permeability has been measured beneath and near the proposed overburden stockpile, with a range from 2E-7 m/s to 5E-5 m/s and a geometric mean of 1E-6 m/s.

Down-gradient Receiving Environment

Aquifers have been well characterized and exploited for groundwater supply along the North Thompson River. Borehole logs indicate sediments along the North Thompson River are characteristic of granular fluvial sediments, which exhibit high hydraulic conductivity (on the scale of 10-5 to 10-3 m/s). Similar fluvial or glaciofluvial aquifers are expected to be present in the shallow subsurface along the Barrière River and Harper Creek valley bottoms. The bedrock beneath these aquifers is expected to exhibit permeability similar to the bedrock within the Project Site, as similar bedrock units have been observed (belonging to the EBA). As such K of the bedrock in the down-gradient receiving environment is expected to be highly variable in the top 100 m (10-5 to 10-10 m/s), and decreasing with depth below 100 m (10-7 to 10-10 m/s).

11.4.3.2 Groundwater Flow

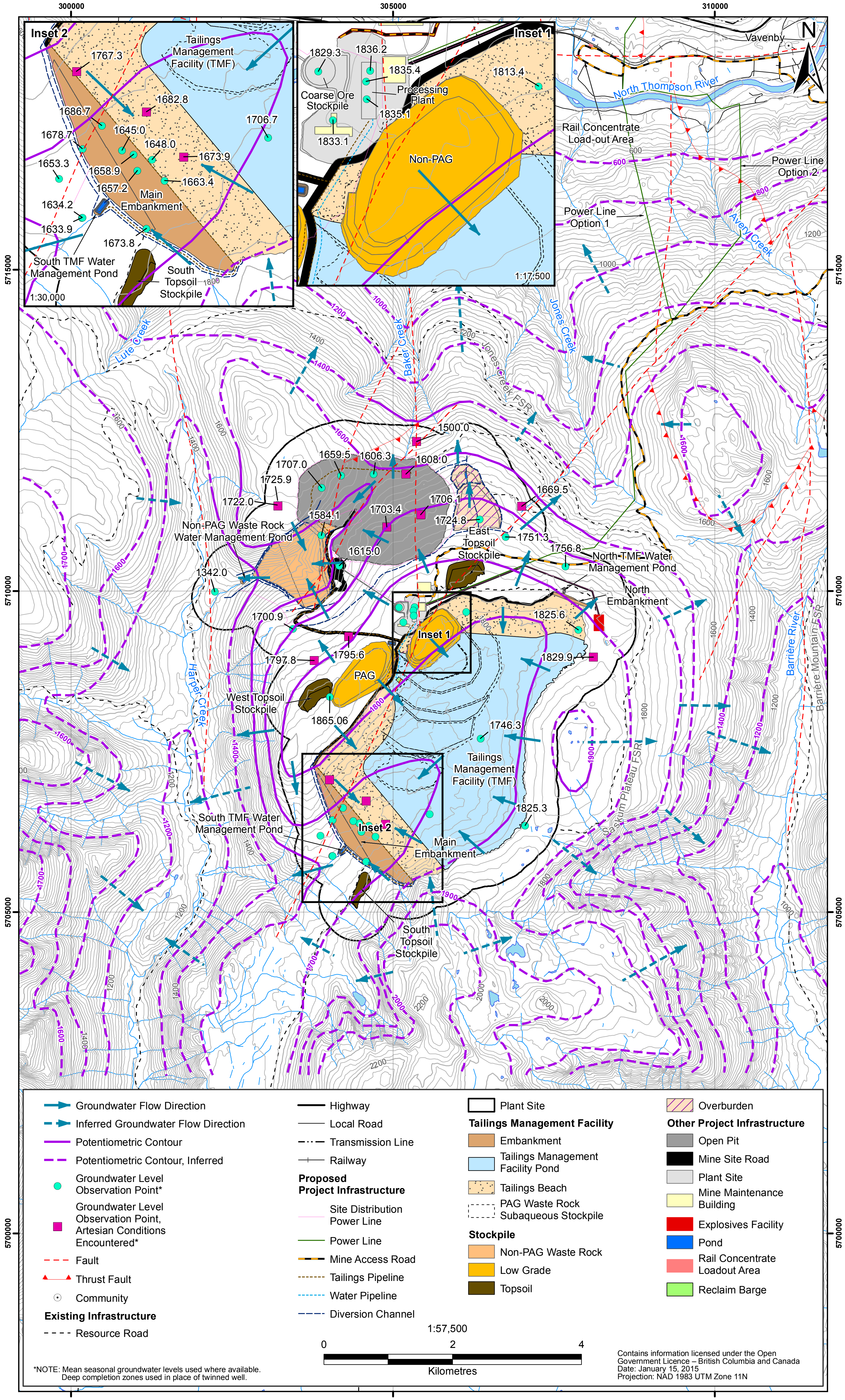
Complete groundwater level records, including manual measurements and continuous records obtained from pressure transducers, are presented in Appendix 11-A.

Groundwater flow generally follows topography (Figure 11.4-14). Hydraulic gradients are greatest along the steep valley walls leading into Harper Creek, the Barrière River, and the North Thompson River from the plateau containing the proposed infrastructure. Along these valley walls horizontal hydraulic gradients are estimated to range from 0.5 to 0.2. A portion of the groundwater situated at the higher elevations at the southern end of the LSA flows northward towards the more gently sloping area containing the proposed TMF. Horizontal hydraulic gradients flowing northward towards the TMF are estimated to range from 0.5 to 0.3.

The majority of the Project Site is situated in gently sloping highlands, where hydraulic gradients are lower than the valley walls to the north, east and west, and the mountainous terrain to the south. A groundwater divide follows the boundary of the proposed TMF footprint to the northwest, clockwise to the southeast. The potentiometric elevation along this divide ranges from 1,850 to 1,950 m. Groundwater situated within the circumference created by this divide flows towards T Creek and Harper Creek, under horizontal hydraulic gradients ranging from 0.2 to 0.1. Groundwater situated to the northwest of this divide flows to the north and northwest trending towards P Creek, under horizontal hydraulic gradients ranging from 0.2 to 0.4.

Figure 11.4-14

Potentiometric Surface in the Baseline Study Area



*NOTE: Mean seasonal groundwater levels used where available. Deep completion zones used in place of twinned well.

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Groundwater elevations in the monitoring wells varied by as much as 4 m and as little as 0.5 m between the seasonal low and seasonal high water levels, with an average variation of approximately 1.5 m. Levels were typically lower in late fall and late winter. The highest groundwater levels were recorded during and following freshet, when snowmelt provides sustained recharge. The extent of seasonal variability is influenced primarily by depth below ground surface, permeability of the overlying formation, and elevation. A set of typical continuous water level records obtained from twinned wells is presented in Figure 11.4-15.

Artesian conditions have been observed in a number of wells: some during spring and early summer only, and some year-round. All wells exhibiting artesian conditions are situated at topographic lows or mid-slope, whereby the hydraulic head of groundwater at higher elevations nearby sustains the hydraulic head in the formation. As such, the artesian wells are regarded as situated in localized discharge zones or under confining conditions in the local.

Upward hydraulic gradients have been measured at most installed twinned well pairs located at lower elevations. The observed upward gradients were sustained year-round in some cases. In other cases the upward gradients weakened or temporarily reversed during the recharge event brought about by freshet. These gradients, alongside frequent artesian conditions, indicate that a proportion of the Project Site exhibits groundwater discharge conditions (movement of groundwater towards ground surface and eventually discharging into the surface water environment). Discharging conditions have been observed beneath and near the TMF, the overburden stockpile, the non-PAG waste rock, the PAG LGO stockpile, and the western half of the open pit. These observations suggest flow at lower-elevation terrain within the LSA is largely driven from the higher-elevation terrain within and near the Project Site.

11.4.3.3 Conceptual Hydrogeologic Model

The conceptual hydrogeologic model has been developed with reference to the baseline meteorologic, hydrologic, geologic, and hydrogeologic conditions. The conceptual model was used as the basis for development of the baseline numerical groundwater model (Appendix 11-B), and has also been revised with consideration for findings of the calibration process for the numerical groundwater model.

A three dimensional block diagram of the conceptual model is provided in Figure 11.4-16. Cross-Sections of the hydrogeologic conceptual model are provided in Figures 11.4-17, 11.4-18, 11.4-19, and 11.4-20. Further discussion regarding the delineated hydrostratigraphic units, aquifers, recharge and discharge, and interaction with the surface water are described in the sections that follow.

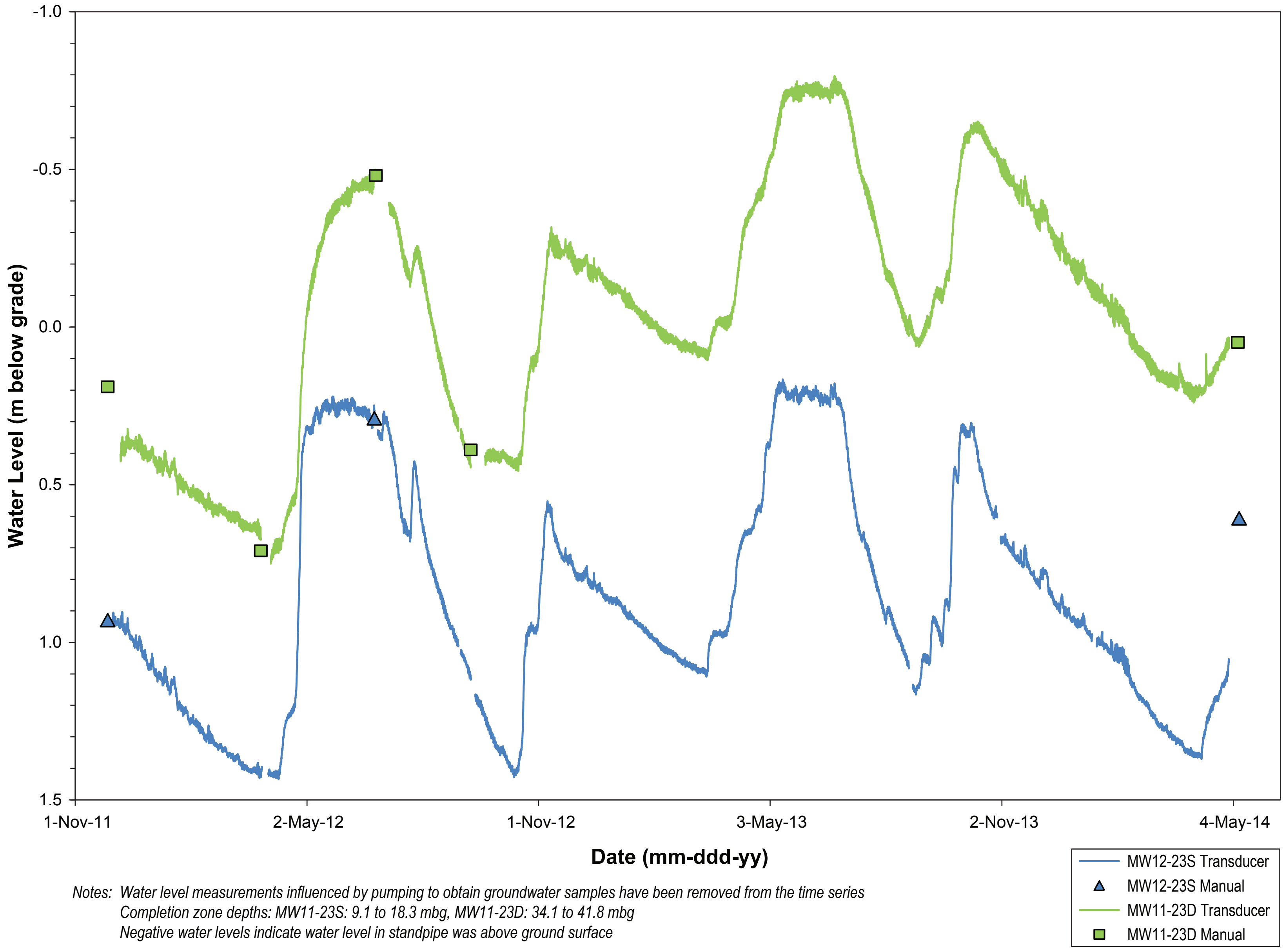
Hydrostratigraphy

A number of hydrostratigraphic units have been delineated (Table 11.4-3) based on hydraulic conductivity testing and subsurface mapping exercises carried out at the site, as well as calibration of a baseline numerical groundwater flow model (Appendix 11-B).

Porous media found in the overburden may be grouped based on their depositional origin. River sediments (glaciofluvials and fluvials) are dominant along major valley bottoms (Harper Creek, Barrière River, and North Thompson River). An extensive glaciolacustrine deposit, overlain by organics, is situated in the upper T Creek drainage basin.

Figure 11.4-15

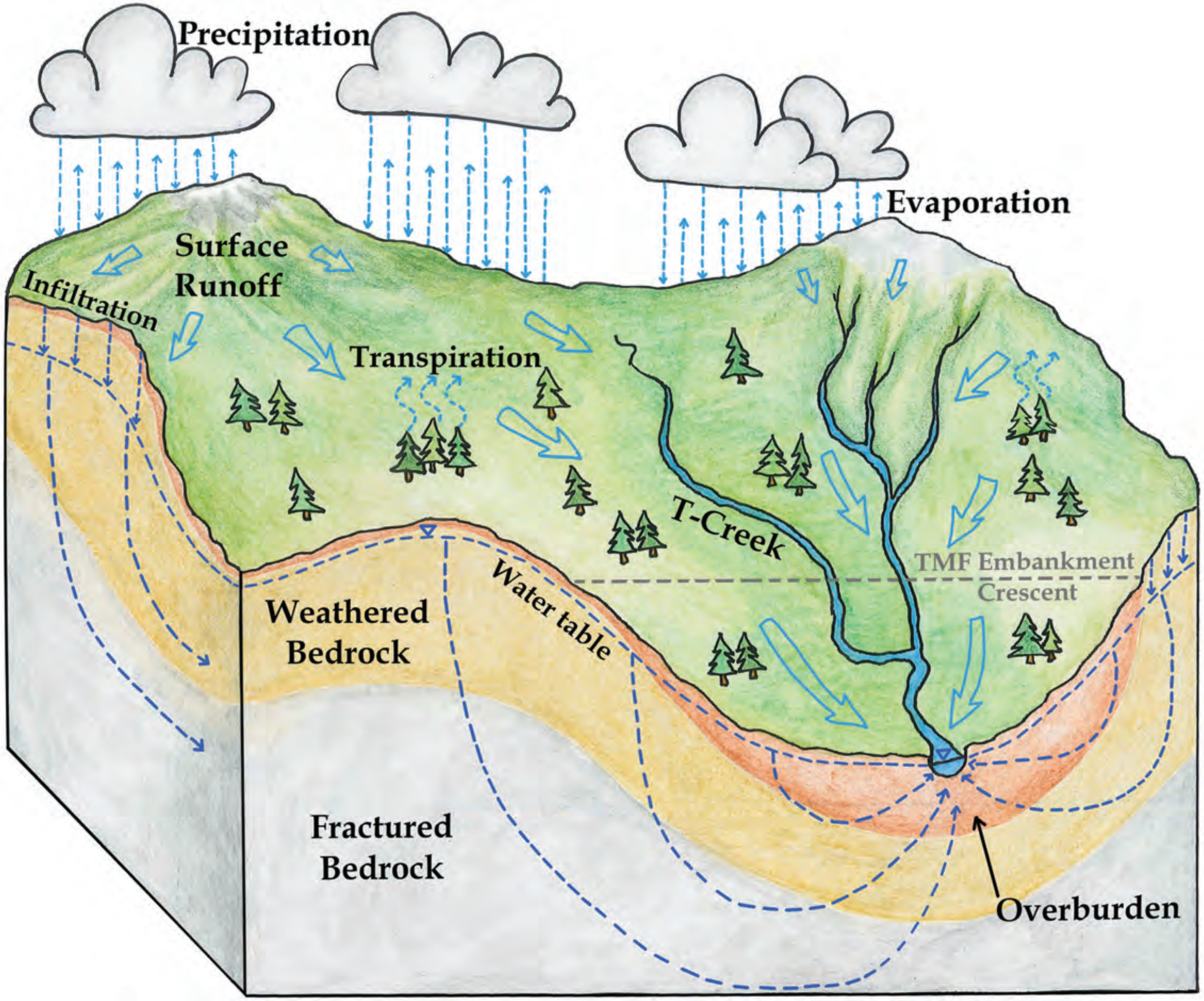
Typical Continuous Water Level Records Obtained from Twinned Wells at the Project Site: MW11-23S and MW11-23D



Notes: Water level measurements influenced by pumping to obtain groundwater samples have been removed from the time series
Completion zone depths: MW11-23S: 9.1 to 18.3 mbg, MW11-23D: 34.1 to 41.8 mbg
Negative water levels indicate water level in standpipe was above ground surface

Figure 11.4-16

Hydrogeological Conceptual Model Block Diagram



Organics are also found in swampy headwater areas south of the Project Site. Morainal sediments are commonly found along tributary valley bottoms and in discontinuous blankets along valley walls and ridge tops. Thin, discontinuous colluvium is found along steep slopes. Morainal, organic, and colluvial deposits are expected to be of little consequence to the site-scale hydrogeologic system due to their limited aerial extents and thicknesses.

Fractured bedrock outcrops are found along ridge tops and along very steep valley walls and otherwise underlies the overburden sediments. The hydraulic conductivity testing indicates no relation between rock type and permeability, nor between fault zones and permeability. Hydrostratigraphic units in the bedrock (Table 11.4-3) have therefore been delineated based on depth. The shallow bedrock (up to 50-m deep) possesses highly variable hydraulic conductivity, reflecting varying extents of weathering. As depth increases, the range of variability of K decreases, alongside decreasing geometric mean K (decreasing joint density and aperture).

Table 11.4-3. Hydrostratigraphic Units Delineated for the Project

Hydrostratigraphic Unit	Location	K (m/s)
Glaciofluvial	Valley bottoms along Harper Creek and upper reaches of the Barrière River	10^{-4}
Fluvial	Valley bottoms along the North Thompson River and lower reaches of the Barrière River	10^{-4}
Glaciolacustrine	Upper T Creek drainage basin	10^{-7}
Shallow fractured bedrock	Upper 50 m of bedrock throughout LSA	5×10^{-7} (5×10^{-5} to 9×10^{-10})
Upper Middle fractured bedrock	Bedrock at depths ranging 50 to 125 m deep	9 x 10^{-8} (7×10^{-6} to 1×10^{-9})
Lower Middle fractured bedrock	Bedrock at depths ranging 125 to 225 m deep	3.5 x 10^{-8} (4×10^{-7} to 4×10^{-9})
Lower Fractured bedrock	Bedrock at depths ranging 225 to 325 m deep	8.5×10^{-9} (7×10^{-10} to 7×10^{-8}
Deep Fractured Bedrock	Lowest tested depths and deeper	2.1×10^{-9} to 2.3×10^{-10}

Representative hydraulic conductivity values have been estimated for each hydrostratigraphic unit (as shown in Table 11.4-3). These values were determined based on the field-tested permeability values of the geological materials and the calibration of the numerical groundwater flow model to represent the existing baseline pre-mining conditions.

Groundwater Flow Rates

Groundwater flow velocities are largely driven by hydraulic gradient and depth (hydraulic conductivity of the secondary porosity decreases with depth and exhibits no geologic controls at the site scale). Adoption of an effective porosity of 0.001 for the fractured bedrock results in estimated seepage velocities varying from 10 centimetres (cm)/year to 40 m/day within and near the proposed TMF footprint, and from 5 cm/year to 30 m/day in the Project Site outside the TMF. The larger flow velocities would be confined to persistent open fractures along valley walls, where hydraulic conductivities and hydraulic gradients are greatest.

Figure 11.4-17

Hydrogeologic Conceptual Model Cross Section Locations

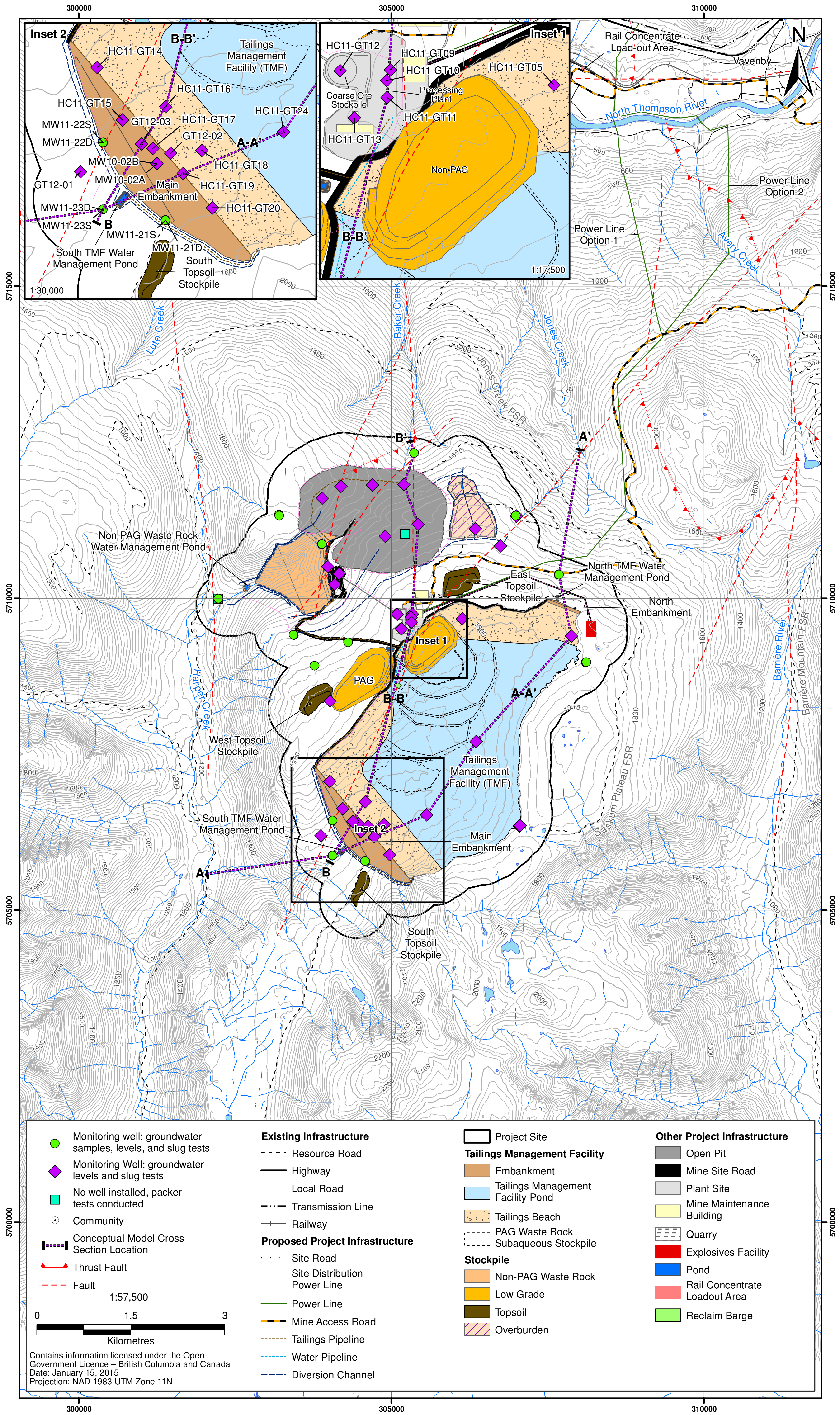


Figure 11.4-18

Cross Section A-A'
Hydrogeologic Conceptual Model

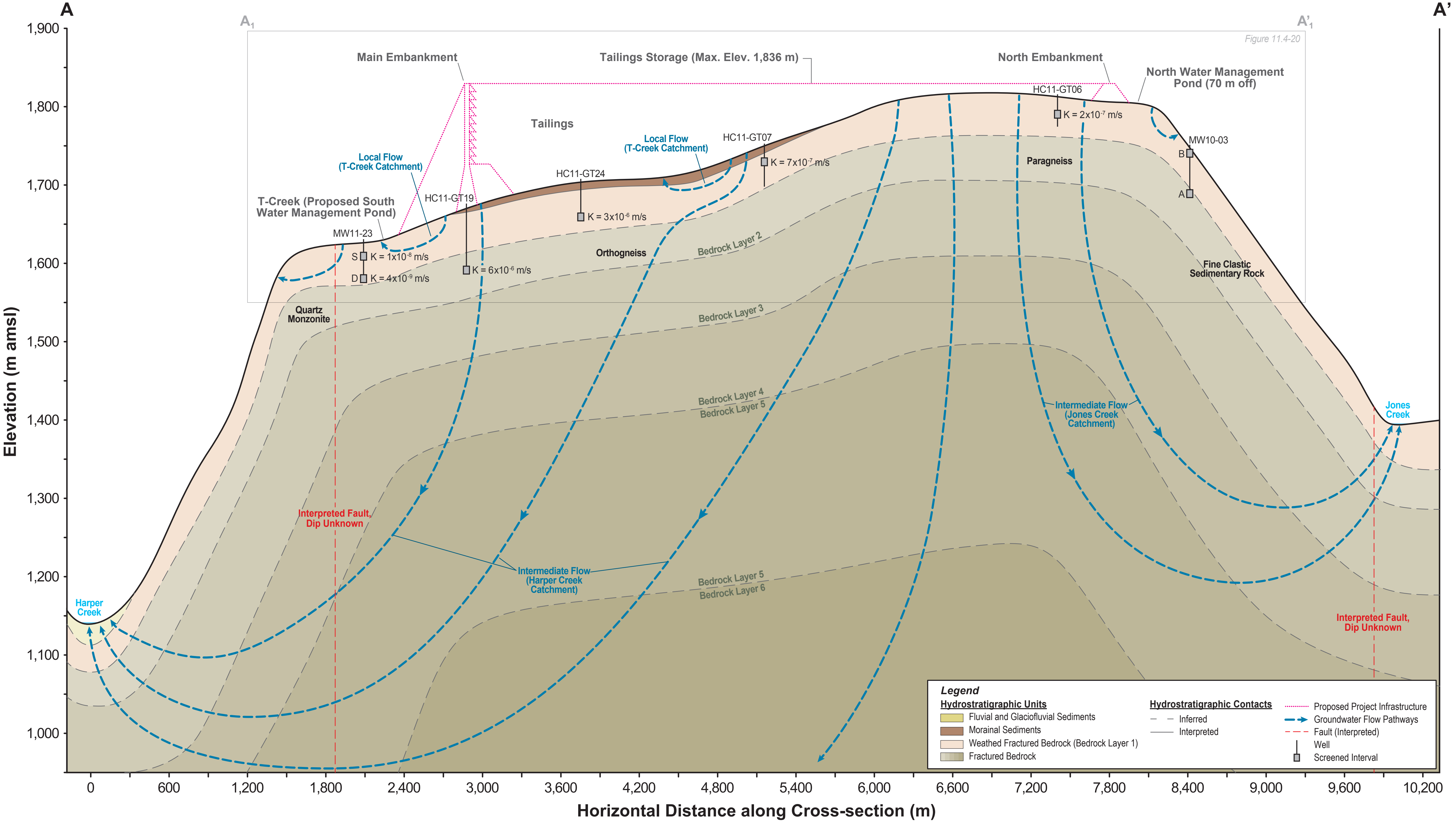


Figure 11.4-19
Cross Section A-A'
Hydrogeologic Conceptual Model (Inset A_1 to A'_1)

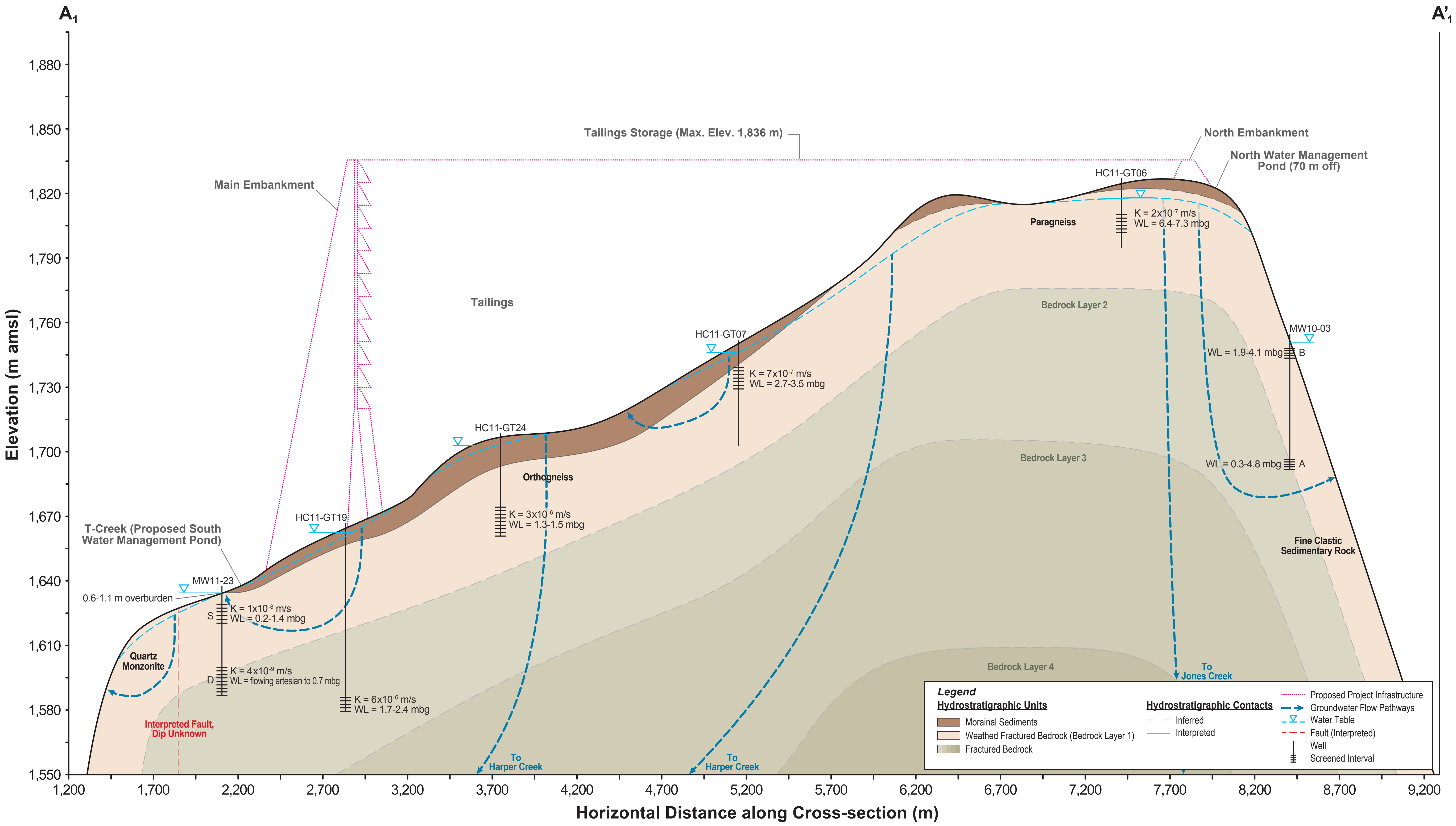
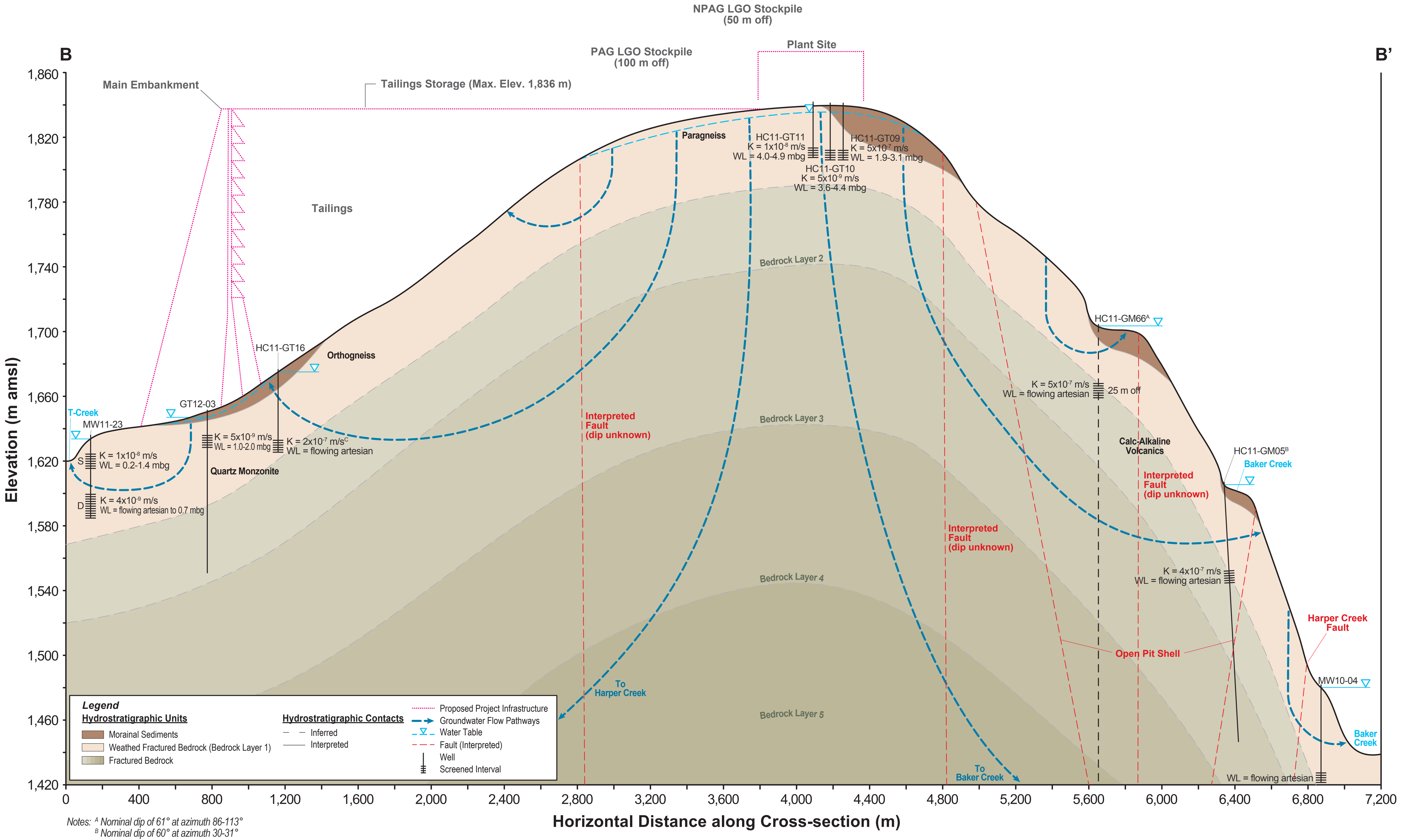


Figure 11.4-20
Cross Section B-B'
Hydrogeologic Conceptual Model



Notes: [A] Nominal dip of 61° at azimuth 86-113°
[B] Nominal dip of 60° at azimuth 30-31°
[C] Measured by borehole Lugeon test along well screen interval

Terrain grading throughout the LSA is similar to the range found at the Project Site, and as such similar hydraulic gradient and flow velocity ranges are expected throughout the LSA.

Groundwater flows preferentially within granular sediments and fractured bedrock with high joint density, where permeability is greatest. Granular sediments found in the LSA include the fluvial and glaciofluvial units found at valley bottoms. The shallow (less than 50-m deep) bedrock contains localized irregular zones of high permeability, which are not expected to constitute meaningful preferential flow pathways at the site scale.

Discussions of groundwater levels, flow directions, and hydraulic gradients are provided in Section 11.4.3.2.

Aquifers and Aquitards

Aquifers are defined here as zones of the subsurface that provide conditions useful as a groundwater resource (high permeability and storage capacity). Aquitards are defined as zones that would not provide a useful groundwater resource (low permeability and storage capacity). K on the order of 10^{-6} m/s or greater may be symptomatic of aquifers; on the order of 10^{-7} to 10^{-8} m/s of semi-aquitards; and 10^{-9} m/s or lower as aquitards.

Aquifers identified in the LSA are presented in Figure 11.4-21.

The glaciofluvial and fluvial units may be classified as aquifers and are expected to be largely under unconfined conditions. Fluvial deposits along the North Thompson River Valley have been tapped by communities and industrial developments, and have been delineated into aquifers by BC MOE (2014).

The shallow fractured bedrock contains aquifers where weathering grade and joint densities are high, and presents aquitard conditions where joint densities are very low. Given the characteristics of the permeability of this unit (wide range of hydraulic conductivities with no identified relations to geology or structures), aquifers are expected to be limited in extent and situated with little relation to the rock type, structural setting, or topography. Confined, semi-confined, and unconfined conditions may occur at smaller scales in the shallow bedrock, whereby irregular zones of low hydraulic conductivity separate aquifers. Unconfined conditions are expected to prevail at the site scale due to the dominance of preferential flow pathways.

The middle and deeper bedrock units may be regarded as semi-aquitards or aquitards because measured permeability is consistently too low to provide a suitable groundwater resource. Groundwater is expected to flow much more slowly in these units than shallower units. Locally confined and semi-confined conditions are expected, whereby isolated zones of higher permeability exhibit confined conditions due to an overlying irregularly shaped zone of lower K. Like the shallower units, unconfined conditions are expected to prevail at the site scale due to the dominance of preferential flow pathways.

Groundwater Budget, Recharge, and Discharge

The groundwater budget has been developed based on watershed modelling and groundwater flow modelling. A global baseline water budget (groundwater and surface water) was developed as part of watershed modelling exercises (Appendix 12-B). The watershed model was calibrated to observed streamflow measurements, and provides groundwater recharge and discharge rates within a number of catchment basins in the LSA (Figure 11.4-22). The baseline groundwater flow model (Appendix 11-B) provides an indication regarding the aerial extent of groundwater recharge and discharge zones, and has been calibrated to observed groundwater levels.

Approximately 15% of mean annual precipitation is estimated to report to the groundwater environment as recharge, as determined empirically (Appendix 12-B, Watershed Modelling Report). The amount of recharge to groundwater increases with elevation, given increasing precipitation with elevation due to the orographic effect. The recharge rate is estimated to range from 64 mm/year along the North Thompson Valley bottom, to 175 mm/year at mountain ridge tops, with a mean of 114 mm/year (Appendix 11-B, Numerical Groundwater Modelling Report).

Ridge tops are expected to receive recharge, while valley bottoms containing streams are expected to continuously discharge groundwater as baseflow in streams. Considerable spatial variability in recharge/discharge conditions is expected to occur along valley walls and mid-slope areas. Seeps and small tributary streams are indicative of local discharging conditions in mid-slope areas.

A number of streams receive discharging groundwater sourced from the Project Site: P Creek, T Creek, Baker Creek, Jones Creek, Harper Creek, the North Thompson River, and their smaller tributaries. Smaller streams flowing through steep terrain (Baker Creek, T Creek, and P Creek) are expected to contain losing reaches, where streamflow enters the subsurface. The extents of losing reaches are expected to increase during periods of low flow, when the groundwater table is at relative lows. Larger streams flowing in valley bottoms (Harper Creek, North Thompson River) are expected to receive discharging groundwater year-round.

11.4.3.4 Groundwater Quality

Tables 11.4-4 and 11.4-5 present the summary data for groundwater quality, with separate calculations for groundwater in the overburden and shallow bedrock (completion zone less than 11 mbg), and deeper bedrock (completion zone greater than 11 m, which were all in bedrock). Results of quality control sampling and analysis and guideline screening for individual samples are provided in Appendix 11-A, Hydrogeology Baseline Report. A series of groundwater quality maps are also provided in Appendix 11-A, showing measured parameter levels (pH, TDS, fluoride, aluminum, arsenic, cadmium, chromium, cobalt, copper, iron, manganese, selenium, and zinc) in the sampled wells.

Physical Parameters

Overburden and shallow bedrock water samples were basic, with pH ranging from 7.83 to 8.28. Deeper bedrock samples were slightly more basic, with pH ranging from 7.70 to 9.38 (occasionally measured above the pH limit of 9.0 for the protection of freshwater aquatic life). Groundwater samples were highly buffered against acid inputs, with mean total alkalinities greater than 40 mg $CaCO_3$/L for water in both overburden and bedrock. Hardness of both overburden and bedrock water samples may be categorized as hard (mean hardnesses of 136 and 123 mg $CaCO_3$/L for overburden and bedrock, respectively; Durfor and Becker 1964). Electrical conductivity and total dissolved solids were highly variable between wells screened in the bedrock, with conductivity values ranging from 75 to 1,080 µS/cm. Conductivity ranged from 248 to 449 µS/cm for water in overburden.

Figure 11.4-21

Aquifers in the Local Study Area

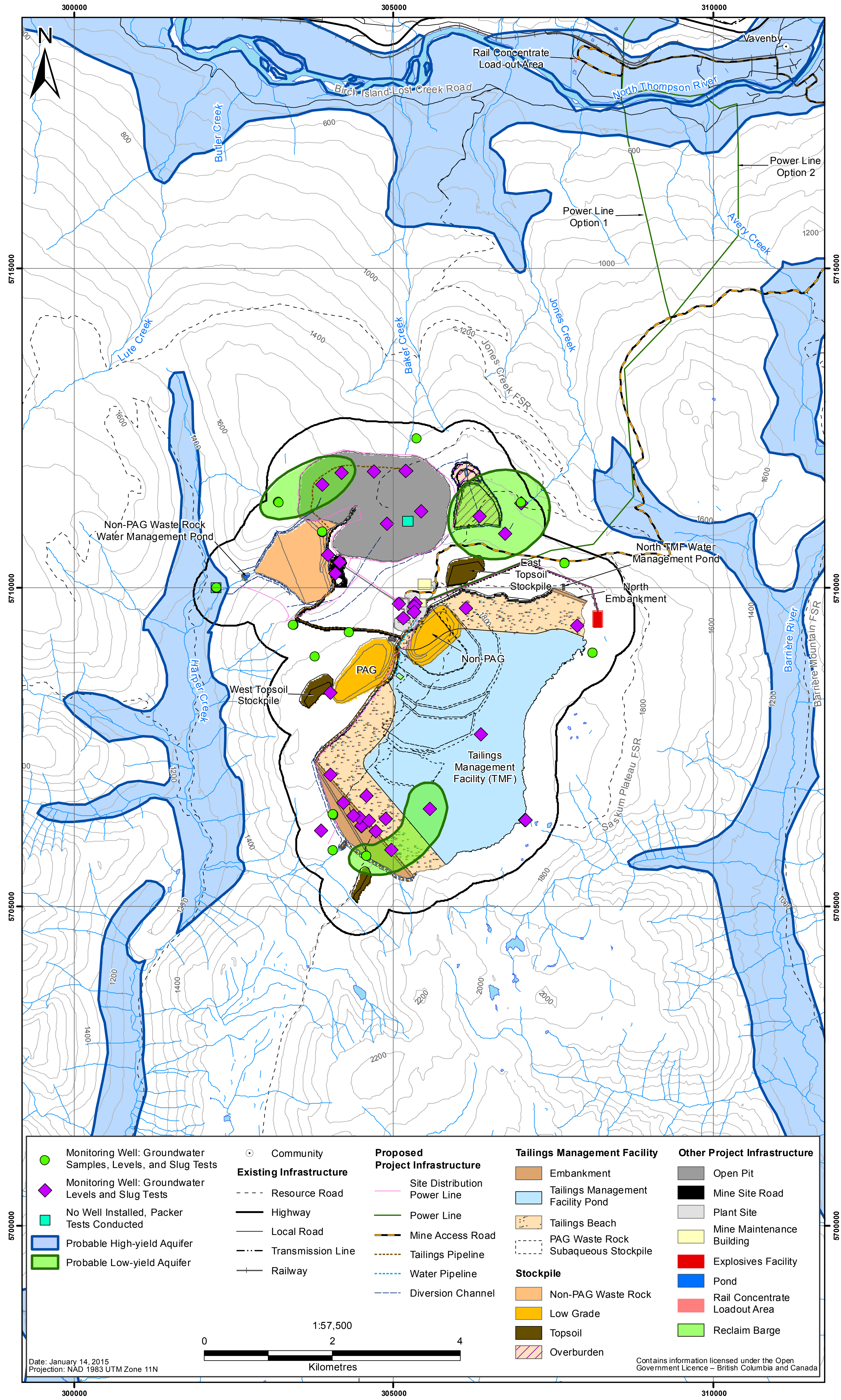
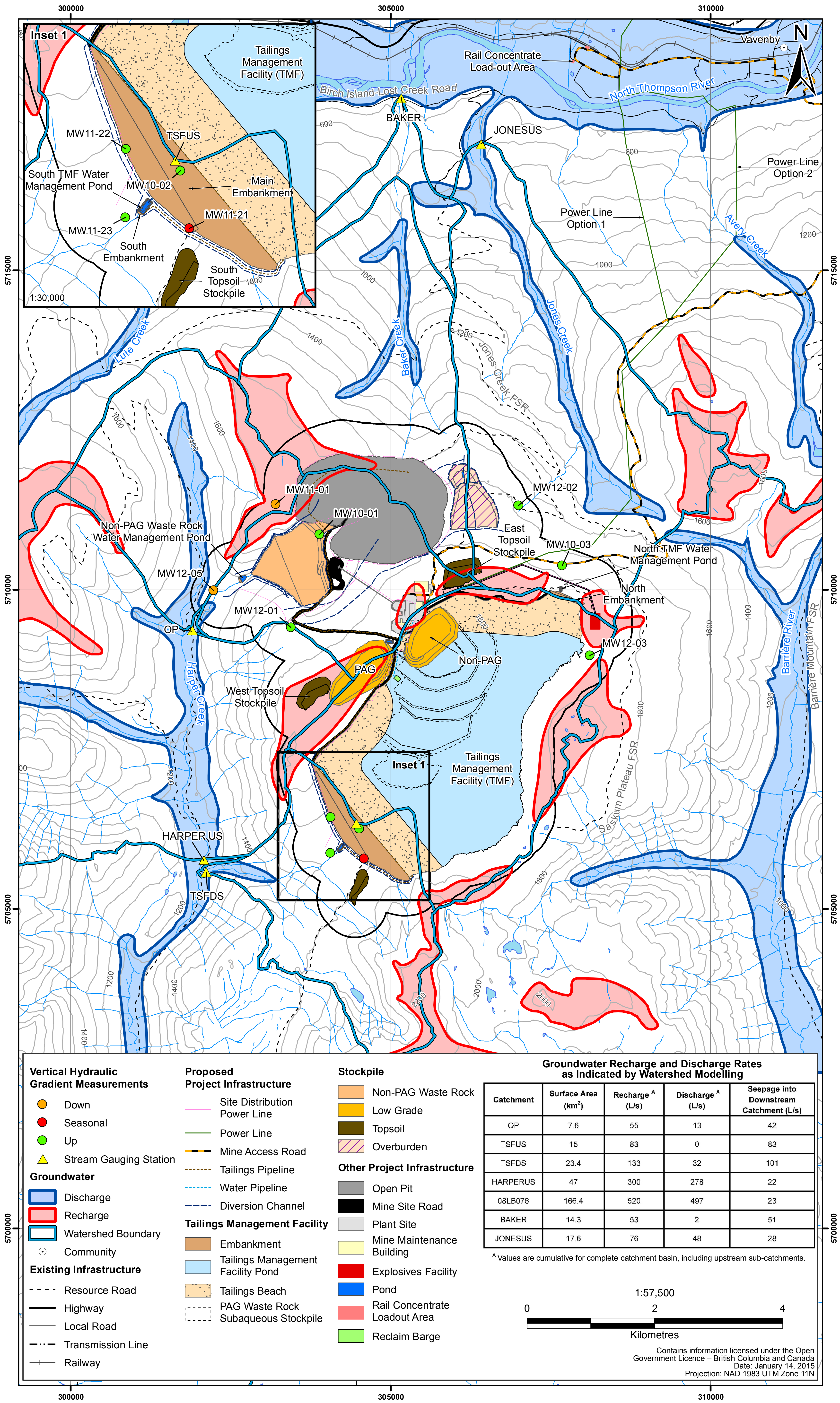


Figure 11.4-22
Groundwater Recharge and Discharge



Groundwater Recharge and Discharge Rates as Indicated by Watershed Modelling

Catchment	Surface Area (km²)	Recharge [A] (L/s)	Discharge [A] (L/s)	Seepage into Downstream Catchment (L/s)
OP	7.6	55	13	42
TSFUS	15	83	0	83
TSFDS	23.4	133	32	101
HARPERUS	47	300	278	22
08LB076	166.4	520	497	23
BAKER	14.3	53	2	51
JONESUS	17.6	76	48	28

[A] Values are cumulative for complete catchment basin, including upstream sub-catchments.

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Date: January 14, 2015
Projection: NAD 1983 UTM Zone 11N

Table 11.4-4. Summary Statistics for Groundwater Samples Collected from Wells Completed in the Overburden and Shallow Bedrock

						Protection of Freshwater Aquatic Life			Drinking Water	
							British Columbia			
Physical Tests	Sample Size	Mean	Minimum	Maximum	Standard Deviation	CCME	30-day	Maximum	Health Canada	British Columbia
Colour	1	2.5	2.5	2.5	-				15	
Conductivity (µS/cm)	10	320	248	449	87.98					
Total Hardness (as $CaCO_3$)	10	168.1	111.0	266.0	64.79					
Dissolved Hardness (as $CaCO_3$)	1	136.0	136.0	136.0	-					
pH	10	8.09	7.83	8.28	0.15	6.5 to 9.0				
Total Suspended Solids	10	3.5	1.5	13.3	3.76					
Total Dissolved Solids	10	202.9	153.0	308.0	57.40				500	
Turbidity (NTU)	10	5.1	0.5	14.0	5.23				0.1	
Total Solids	0	-	-	-	-					
Acidity (as $CaCO_3$)	0	-	-	-	-					
Acidity (pH 4.5)	1	0.25	0.25	0.25	-					
Acidity (pH 8.3)	1	0.25	0.25	0.25	-					
Alkalinity, Bicarbonate (as $CaCO_3$)	10	120.6	98.1	144.0	16.03					
Alkalinity, Carbonate (as $CaCO_3$)	10	0.9	0.3	1.0	0.24					
Alkalinity, Hydroxide (as $CaCO_3$)	10	0.9	0.3	1.0	0.24					
Alkalinity, Total (as $CaCO_3$)	10	118.4	98.1	144.0	17.27					
Alkalinity (PP as $CaCO_3$)	1	0.3	0.3	0.3	-					
Anions										
Bromide (Br)	10	0.04	0.03	0.20	0.06					
Chloride (Cl)	10	0.70	0.25	2.80	0.86	640 short-term; 120 long-term	150	600	250	250
Fluoride (F)	10	0.24	0.18	0.37	0.07	0.12		1.4 - 1.7	1.5	1.5 maximum; 1 30-day
Sulphate (SO_4)	10	55.5	23.2	108.0	37.07		309		500	500
Nutrients										
Ammonia, Total (as N)	10	0.040	0.006	0.099	0.03					
Nitrate (as N)	10	0.052	0.003	0.467	0.15	124 short-term; 3 long-term	3	32.8	10	
Nitrite (as N)	10	0.001	0.001	0.003	0.00	0.06	0.02 - 0.04	0.06 - 0.12	1	1
Nitrate plus Nitrite (as N)	1	0.467	0.467	0.467	-					
Total Kjeldahl Nitrogen	9	0.106	0.025	0.317	0.09					
Total Nitrogen	5	0.074	0.001	0.121	0.06					
Total Dissolved Nitrogen	1	0.025	0.025	0.025	-					
Total Organic Nitrogen	1	0.025	0.025	0.025	-					
Dissolved Organic Nitrogen	1	0.025	0.025	0.025	-					
Dissolved Orthophosphate (as P)	8	0.005	0.001	0.019	0.01					
Dissolved Phosphorus	5	0.010	0.001	0.040	0.02					
Total Phosphorus	10	0.020	0.005	0.060	0.02					

(continued)

Table 11.4-4. Summary Statistics for Groundwater Samples Collected from Wells Completed in the Overburden and Shallow Bedrock (continued)

						Protection of Freshwater Aquatic Life			Drinking Water	
							British Columbia			
Physical Tests	Sample Size	Mean	Minimum	Maximum	Standard Deviation	CCME	30-day	Maximum	Health Canada	British Columbia
Cyanides										
Cyanide, Weak Acid Dissociable	10	0.00231	0.00059	*0.00250*	0.00060		0.005	0.01		
Cyanide, Total	9	*0.00250*	*0.00250*	*0.00250*	0.00000	0.005			0.2	
Cyanide, Free	9	*0.00250*	*0.00250*	*0.00250*	0.00000					0.2
Cyanide + Thiocyanate	1	0.00079	0.00079	0.00079	-					
Organic Carbon										
Total Organic Carbon	7	1.8	0.3	5.1	1.64					4
Dissolved Organic Carbon	4	4.8	0.3	11.4	5.25					
Total Metals										
Aluminum (Al)	10	0.028	0.004	0.092	0.029	0.1			0.1	
Antimony (Sb)	10	0.00034	0.00005	0.00072	0.00029			0.02	0.006	
Arsenic (As)	10	0.01873	0.00086	0.06040	0.02523	0.005			0.01	0.025
Barium (Ba)	10	0.0334	0.0115	0.0472	0.0144		1	5	1	
Beryllium (Be)	10	0.00005	0.00001	0.00005	0.00001			0.0053		
Bismuth (Bi)	10	0.000226	0.000011	0.000250	0.000076					
Boron (B)	10	0.008	0.005	0.025	0.007	29 short-term; 1.5 long-term		1.2	5	5
Cadmium (Cd)	10	0.000036	0.000005	0.000156	0.000050	0.00233 - 0.00567 short-term; 0.00017 - 0.00036 long-term		0.000036 - 0.000077	0.005	
Calcium (Ca)	10	39.2	26.8	49.2	6.5					
Chromium (Cr)	10	0.0006	0.0001	0.0019	0.0006	0.001 - 0.0089			0.05	
Cobalt (Co)	10	0.00122	0.00005	0.00259	0.00116		0.004	0.11		
Copper (Cu)	10	0.00128	0.00025	0.00379	0.00131	0.0026 - 0.004	0.0044 - 0.0106	0.0124 - 0.027	1	0.5
Iron (Fe)	10	0.532	0.058	1.200	0.512	0.3		1	0.3	
Lead (Pb)	10	0.00040	0.00003	0.00171	0.00056	0.004 - 0.007	0.007 - 0.014	0.093 - 0.284	0.01	0.05
Lithium (Li)	10	0.0007	0.0003	0.0017	0.0006			0.87		
Magnesium (Mg)	10	16.57	7.12	33.50	11.50					
Manganese (Mn)	10	0.32	0.14	0.80	0.23		1.09 - 1.78	1.76 - 3.47	0.05	
Mercury (Hg)	10	0.000005	0.000005	0.000005	0.000000	0.000026		0.00002	0.001	0.001
Molybdenum (Mo)	10	0.0026	0.0002	0.0058	0.0018	0.073	1	2		0.25
Nickel (Ni)	10	0.0025	0.0003	0.0093	0.0033	0.103 - 0.15		0.065 - 0.15		
Phosphorus (P)	9	0.07	0.03	0.15	0.06					
Potassium (K)	10	2.10	0.82	3.49	0.99					
Selenium (Se)	10	0.00008	0.00005	0.00021	0.00006	0.001		0.002	0.01	0.01
Silicon (Si)	10	3.65	2.07	4.75	1.10					
Silver (Ag)	10	0.000045	0.000005	0.000392	0.000122	0.0001	0.0015	0.003		
Sodium (Na)	10	5.31	1.29	15.10	4.27				200	
Strontium (Sr)	10	0.14	0.07	0.19	0.04					

(continued)

Table 11.4-4. Summary Statistics for Groundwater Samples Collected from Wells Completed in the Overburden and Shallow Bedrock (continued)

Physical Tests	Sample Size	Mean	Minimum	Maximum	Standard Deviation	Protection of Freshwater Aquatic Life			Drinking Water	
						CCME	British Columbia		Health Canada	British Columbia
							30-day	Maximum		
Total Metals *(cont'd)*										
Sulphur (S)	7	14.13	7.70	35.70	10.21					
Thallium (Tl)	10	0.000009	0.000005	0.000031	0.000008	0.0008		0.0003		
Tin (Sn)	10	0.00029	0.00005	0.00170	0.00054					
Titanium (Ti)	10	0.0048	0.0026	0.0050	0.0008					
Uranium (U)	10	0.0015	0.0005	0.0026	0.0009	0.033 short-term; 0.015 long-term		0.3	0.02	
Vanadium (V)	10	0.0005	0.0005	0.0005	0.0000					
Zinc (Zn)	10	0.0312	0.0015	0.1040	0.0384	0.03	0.023 - 0.140	0.049 - 0.165	5	5
Zirconium (Zr)	1	0.0003	0.0003	0.0003	-					
Dissolved Metals										
Aluminum (Al)	10	0.005	0.001	0.010	0.003	0.1	0.05	0.1	0.1	0.2
Antimony (Sb)	10	0.00024	0.00005	0.00046	0.00019			0.02	0.006	
Arsenic (As)	10	0.01846	0.00076	0.05970	0.02589				0.01	0.025
Barium (Ba)	10	0.0321	0.0119	0.0425	0.0135		1	5	1	
Beryllium (Be)	10	0.00005	0.00001	0.00005	0.00001			0.0053		
Bismuth (Bi)	10	0.000225	0.000003	0.000250	0.000078					
Boron (B)	10	0.008	0.005	0.025	0.007	29 short-term; 1.5 long-term		1.2	5	5
Cadmium (Cd)	10	0.000013	0.000005	0.000034	0.000013	0.00233 - 0.00567 short-term; 0.00017 - 0.00036 long-term		0.000036 - 0.000077	0.005	
Calcium (Ca)	10	39.4	26.4	50.5	7.0					
Chromium (Cr)	10	0.0002	0.0001	0.0008	0.0003	0.001 - 0.0089			0.05	
Cobalt (Co)	10	0.00115	0.00005	0.00249	0.00110		0.004	0.11		
Copper (Cu)	10	0.00027	0.00010	0.00083	0.00028	0.0026 - 0.004	0.0044 - 0.0106	0.0124 - 0.027	1	0.5
Iron (Fe)	10	0.465	0.010	1.230	0.505	0.3		0.35	0.3	
Lead (Pb)	10	0.00006	0.00003	0.00042	0.00012	0.004 - 0.007	0.007 - 0.014	0.093 - 0.284	0.01	
Lithium (Li)	10	0.0007	0.0003	0.0017	0.0006			0.87		
Magnesium (Mg)	10	16.87	7.10	34.70	12.22					
Manganese (Mn)	10	0.31	0.14	0.78	0.22		1.09 - 1.78	1.76 - 3.47	0.05	
Mercury (Hg)	10	0.000005	0.000005	0.000005	0.000000	0.000026		0.00002	0.001	0.001
Molybdenum (Mo)	10	0.0025	0.0002	0.0053	0.0017	0.073	1	2		0.25
Nickel (Ni)	10	0.0023	0.0003	0.0088	0.0031	0.103 - 0.15		0.065 - 0.15		
Phosphorus (P)	9	0.07	0.03	0.15	0.06					
Potassium (K)	10	2.06	0.86	3.26	0.94					
Selenium (Se)	10	0.00008	0.00005	0.00022	0.00007	0.001		0.002	0.01	0.01
Silicon (Si)	10	3.64	2.14	4.72	1.09					
Silver (Ag)	10	0.000005	0.000003	0.000005	0.000001	0.0001	0.0015	0.003		

(continued)

Table 11.4-4. Summary Statistics for Groundwater Samples Collected from Wells Completed in the Overburden and Shallow Bedrock (completed)

						Protection of Freshwater Aquatic Life			Drinking Water	
							British Columbia			
Physical Tests	Sample Size	Mean	Minimum	Maximum	Standard Deviation	CCME	30-day	Maximum	Health Canada	British Columbia
Dissolved Metals ***(cont'd)***										
Sodium (Na)	10	5.18	1.31	14.30	4.07				200	
Strontium (Sr)	10	0.14	0.07	0.18	0.04					
Sulphur (S)	7	13.98	8.14	34.90	9.79					
Thallium (Tl)	10	0.000007	0.000005	0.000022	0.000005	0.0008		0.0003		
Tin (Sn)	10	0.00013	0.00005	0.00069	0.00020					
Titanium (Ti)	10	0.0045	0.0003	0.0050	0.0015					
Uranium (U)	10	0.0015	0.0005	0.0026	0.0009	0.033 short-term; 0.015 long-term		0.3	0.02	
Vanadium (V)	10	0.0005	0.0003	0.0005	0.0001					
Zinc (Zn)	10	0.0210	0.0005	0.0776	0.0278	0.03	0.023 - 0.140	0.049 - 0.165	5	5
Zirconium (Zr)	1	0.0002	0.0002	0.0002	-					
Oil and Grease										
Oil and Grease	0	-	-	-	-					

Notes:

All units are in mg/L unless otherwise noted.

Values below detection limits were replaced with half the detection limit for summary statistics.

Values in italics indicate parameters below detection limits that were higher than guidelines.

Shaded values indicate parameters above applicable guidelines.

Table 11.4-5. Summary Statistics for Groundwater Samples Collected from Wells Completed in the Deeper Bedrock

						Protection of Freshwater Aquatic Life			Drinking Water	
							British Columbia			
Physical Tests	Sample Size	Mean	Minimum	Maximum	Standard Deviation	CCME	30-day	Maximum	Health Canada	British Columbia
Colour	18	4.7	2.5	15.6	4.29				15	
Conductivity (µS/cm)	96	384	75	1,080	203.75					
Total Hardness (as $CaCO_3$)	97	122.3	4.3	618.0	140.42					
Dissolved Hardness (as $CaCO_3$)	25	123.4	6.6	615.0	156.98					
pH	97	8.34	7.70	9.38	0.33	6.5 to 9.0				
Total Suspended Solids	90	9.1	0.5	188.0	21.36					
Total Dissolved Solids	96	242.3	97.0	822.0	148.05				500	
Turbidity (NTU)	89	6.6	0.3	76.4	11.32				0.1	
Total Solids	1	238	238	238						
Acidity (as $CaCO_3$)	1	0.50	0.50	0.50						
Acidity (pH 4.5)	25	0.25	0.25	0.25	0.00					
Acidity (pH 8.3)	25	0.54	0.25	4.90	0.94					
Alkalinity, Bicarbonate (as $CaCO_3$)	96	147.0	37.0	370.0	57.39					
Alkalinity, Carbonate (as $CaCO_3$)	96	4.7	0.3	30.7	7.29					
Alkalinity, Hydroxide (as $CaCO_3$)	96	0.6	0.3	1.0	0.32					
Alkalinity, Total (as $CaCO_3$)	97	144.4	30.0	337.0	57.24					
Alkalinity (PP as $CaCO_3$)	25	3.0	0.3	19.6	5.21					
Anions										
Bromide (Br)	97	0.07	0.01	0.25	0.08					
Chloride (Cl)	97	3.14	0.25	24.00	5.53	640 short-term; 120 long-term	150	600	250	250
Fluoride (F)	97	0.83	0.08	2.63	0.70	0.12		0.4 - 2.1	1.5	1.5 maximum; 1 30-day
Sulphate (SO_4)	97	59.6	5.4	421.0	91.48		128 - 429		500	500
Nutrients										
Ammonia, Total (as N)	97	0.029	0.003	0.350	0.04					
Nitrate (as N)	97	0.007	0.003	0.099	0.01	124 short-term; 3 long-term	3	32.8	10	
Nitrite (as N)	97	0.002	0.001	0.035	0.00	0.06	0.02 - 0.2	0.06 - 0.6	1	1
Nitrate plus Nitrite (as N)	25	0.013	0.010	0.032	0.01					
Total Kjeldahl Nitrogen	72	0.084	0.025	0.246	0.05					
Total Nitrogen	44	0.084	0.001	0.242	0.05					
Total Dissolved Nitrogen	10	0.247	0.025	1.830	0.56					
Total Organic Nitrogen	6	0.049	0.025	0.156	0.05					
Dissolved Organic Nitrogen	10	0.234	0.025	1.830	0.56					
Dissolved Orthophosphate (as P)	71	0.045	0.001	0.220	0.05					
Dissolved Phosphorus	52	0.054	0.001	0.253	0.07					
Total Phosphorus	97	0.070	0.004	0.280	0.07					

(continued)

Table 11.4-5. Summary Statistics for Groundwater Samples Collected from Wells Completed in the Deeper Bedrock (continued)

						Protection of Freshwater Aquatic Life			Drinking Water	
	Sample				Standard		British Columbia		Health	British
Physical Tests	Size	Mean	Minimum	Maximum	Deviation	CCME	30-day	Maximum	Canada	Columbia
Cyanides										
Cyanide, Weak Acid Dissociable	88	0.00188	0.00025	*0.00250*	0.00099		0.005	0.01		
Cyanide, Total	63	*0.00250*	*0.00250*	*0.00250*	0.00000	0.005			0.2	
Cyanide, Free	63	0.00250	0.00250	0.00250	0.00000					0.2
Cyanide + Thiocyanate	25	0.00051	0.00025	0.00200	0.00049					
Organic Carbon										
Total Organic Carbon	72	2.0	0.3	11.0	1.97					4
Dissolved Organic Carbon	48	2.8	0.3	9.9	2.32					
Total Metals										
Aluminum (Al)	89	0.221	0.006	2.290	0.367	0.1			0.1	
Antimony (Sb)	89	0.00053	0.00003	0.00453	0.00076			0.02	0.006	
Arsenic (As)	89	0.00330	0.00014	0.03590	0.00657	0.005			0.01	0.025
Barium (Ba)	89	0.0277	0.0018	0.0866	0.0184		1	5	1	
Beryllium (Be)	89	0.00005	0.00001	0.00034	0.00004			0.0053		
Bismuth (Bi)	89	0.000211	0.000003	0.002500	0.000268					
Boron (B)	89	0.018	0.005	0.150	0.022	29 short-term; 1.5 long-term		1.2	5	5
Cadmium (Cd)	89	0.000032	*0.000003*	0.000395	0.000049	0.00011 - 0.0077 short-term; 0.00004 - 0.00037 long-term		0.0000022-0.000159	0.005	
Calcium (Ca)	89	27.0	1.4	190.0	38.4					
Chromium (Cr)	89	0.0017	0.0001	0.0352	0.0041	0.001 - 0.0089			0.05	
Cobalt (Co)	89	0.00047	0.00005	0.00545	0.00083		0.004	0.11		
Copper (Cu)	89	0.00126	0.00016	0.01110	0.00169	0.002 - 0.004	0.002 - 0.025	0.002 - 0.060	1	0.5
Iron (Fe)	89	0.438	0.017	3.280	0.523	0.3		1	0.3	
Lead (Pb)	89	0.00028	0.00002	0.00267	0.00038	0.001 - 0.007	0.003 - 0.036	0.003 - 0.830	0.01	0.05
Lithium (Li)	89	0.0155	0.0003	0.0651	0.0186			0.87		
Magnesium (Mg)	89	12.38	0.11	45.60	13.88					
Manganese (Mn)	89	0.21	0.01	1.48	0.28		0.62 - 3.32	0.59 - 7.35	0.05	
Mercury (Hg)	86	0.000005	0.000005	*0.000025*	0.000003	0.000026		0.00002	0.001	0.001
Molybdenum (Mo)	89	0.0042	0.0002	0.0634	0.0082	0.073	1	2		0.25
Nickel (Ni)	89	0.0021	0.0003	0.0337	0.0038	0.025 - 0.15		0.025 - 0.15		
Phosphorus (P)	64	0.11	0.03	0.25	0.06					
Potassium (K)	89	1.89	0.43	5.97	1.19					
Selenium (Se)	89	0.00016	0.00002	0.00332	0.00038	0.001		0.002	0.01	0.01
Silicon (Si)	89	4.85	2.69	7.84	1.06					
Silver (Ag)	89	0.000010	0.000003	0.000134	0.000016	0.0001	0.00005 - 0.0015	0.0001 - 0.003		
Sodium (Na)	89	40.33	2.83	179.00	44.45				200	
Strontium (Sr)	89	0.70	0.03	2.45	0.74					

(continued)

Table 11.4-5. Summary Statistics for Groundwater Samples Collected from Wells Completed in the Deeper Bedrock (continued)

Physical Tests	Sample Size	Mean	Minimum	Maximum	Standard Deviation	Protection of Freshwater Aquatic Life: CCME	Protection of Freshwater Aquatic Life: British Columbia 30-day	Protection of Freshwater Aquatic Life: British Columbia Maximum	Drinking Water: Health Canada	Drinking Water: British Columbia
Total Metals *(cont'd)*										
Sulphur (S)	57	20.36	1.92	167.00	33.81					
Thallium (Tl)	89	0.000008	0.000001	0.000050	0.000007	0.0008		0.0003		
Tin (Sn)	89	0.00019	0.00003	0.00176	0.00024					
Titanium (Ti)	89	0.0067	0.0003	0.0841	0.0096					
Uranium (U)	89	0.0053	0.0001	0.0404	0.0095	0.033 short-term; 0.015 long-term		0.3	0.02	
Vanadium (V)	89	0.0009	0.0001	0.0105	0.0014					
Zinc (Zn)	89	0.0068	0.0006	0.0953	0.0127	0.03	0.008 - 0.404	0.033 - 0.429	5	5
Zirconium (Zr)	25	0.0002	0.0001	0.0010	0.0002					
Dissolved Metals										
Aluminum (Al)	97	0.032	0.001	1.110	0.115	0.1	0.05	0.1	0.1	0.2
Antimony (Sb)	97	0.00043	0.00004	0.00395	0.00068			0.02	0.006	
Arsenic (As)	97	0.00255	0.00005	0.02020	0.00435				0.01	0.025
Barium (Ba)	97	0.0250	0.0014	0.0873	0.0175		1	5	1	
Beryllium (Be)	97	0.00004	0.00001	0.00025	0.00003			0.0053		
Bismuth (Bi)	97	0.000186	0.000003	0.000250	0.000108					
Boron (B)	97	0.015	0.005	0.150	0.022	29 short-term; 1.5 long-term		1.2	5	5
Cadmium (Cd)	97	0.000010	*0.000003*	0.000067	0.000011	0.00233 - 0.00567 short-term; 0.00017 - 0.00036 long-term		0.0000022-0.000159	0.005	
Calcium (Ca)	97	27.8	1.4	189.0	39.8					
Chromium (Cr)	97	0.0005	0.0001	0.0132	0.0019	0.001 - 0.0089			0.05	
Cobalt (Co)	97	0.00030	0.00005	0.00524	0.00065		0.004	0.11		
Copper (Cu)	97	0.00043	0.00003	0.01560	0.00166	0.002 - 0.004	0.002 - 0.025	0.002 - 0.060	1	0.5
Iron (Fe)	97	0.222	0.002	2.100	0.380	0.3		0.35	0.3	
Lead (Pb)	97	0.00003	0.00001	0.00022	0.00002	0.001 - 0.007	0.003 - 0.036	0.003 - 0.830	0.01	
Lithium (Li)	97	0.0157	0.0003	0.0677	0.0188			0.87		
Magnesium (Mg)	97	12.63	0.05	46.50	14.02					
Manganese (Mn)	97	0.20	0.01	1.48	0.27		0.62 - 3.32	0.59 - 7.35	0.05	
Mercury (Hg)	86	0.000006	0.000005	*0.000025*	0.000003	0.000026		0.00002	0.001	0.001
Molybdenum (Mo)	97	0.0040	0.0001	0.0702	0.0085	0.073	1	2		0.25
Nickel (Ni)	97	0.0013	0.0003	0.0219	0.0025	0.025 - 0.15		0.025 - 0.15		
Phosphorus (P)	72	0.10	0.03	0.25	0.06					
Potassium (K)	97	1.82	0.42	6.02	1.14					
Selenium (Se)	97	0.00014	0.00002	0.00295	0.00033	0.001		0.002	0.01	0.01
Silicon (Si)	97	4.47	2.64	6.54	1.08					
Silver (Ag)	97	0.000005	0.000003	0.000015	0.000002	0.0001	0.00005 - 0.0015	0.0001 - 0.003		

(continued)

Table 11.4-5. Summary Statistics for Groundwater Samples Collected from Wells Completed in the Deeper Bedrock (completed)

						Protection of Freshwater Aquatic Life			Drinking Water	
							British Columbia			
Physical Tests	Sample Size	Mean	Minimum	Maximum	Standard Deviation	CCME	30-day	Maximum	Health Canada	British Columbia
Dissolved Metals ***(cont'd)***										
Sodium (Na)	97	38.87	2.80	172.00	43.31				200	
Strontium (Sr)	97	0.71	0.03	2.54	0.74					
Sulphur (S)	65	21.38	2.55	166.00	34.09					
Thallium (Tl)	97	0.000006	0.000001	0.000050	0.000005	0.0008		0.0003		
Tin (Sn)	97	0.00009	0.00002	0.00057	0.00009					
Titanium (Ti)	97	0.0038	0.0003	0.0050	0.0020					
Uranium (U)	97	0.0052	0.0001	0.0417	0.0096	0.033 short-term; 0.015 long-term		0.3	0.02	
Vanadium (V)	97	0.0006	0.0001	0.0107	0.0011					
Zinc (Zn)	97	0.0021	0.0001	0.0166	0.0027	0.03	0.008 - 0.404	0.033 - 0.429	5	5
Zirconium (Zr)	25	0.0001	0.0001	0.0004	0.0001					
Oil and Grease										
Oil and Grease	1	2.50	2.50	2.50	-					

Notes:

All units are in mg/L unless otherwise noted.

Values below detection limits were replaced with half the detection limit for summary statistics.

Values in italics indicate parameters below detection limits that were higher than guidelines.

Shaded values indicate parameters above applicable guidelines.

Colour and total dissolved solids levels reported above aesthetic drinking water quality guidelines sporadically.

Anions

Bicarbonate (listed as Alkalinity) and sulphate were the dominant anions in groundwater samples, and were similar in overburden and shallow bedrock (mean bicarbonate and sulphate of 120.6 milligrams/litre [mg/L] and 55.5 mg/L) and deeper bedrock samples (mean bicarbonate and sulphate of 147.0 mg/L and 59.6 mg/L, respectively).

Chloride and fluoride levels were elevated in bedrock samples compared to overburden, particularly in MW11-21D, MW11-23S, and MW11-23D samples. Bromide levels were commonly below detection limits (97% of samples). A piper plot showing the proportions of anions in each well sampled (calculated means) is provided in Figure 11.4-23, which indicates that the dominant type of groundwater in the Project study area is Mg-Ca-HCO_3, while some samples contain greater concentrations of sulphate than bicarbonate.

Fluoride levels appear to be naturally elevated in Project Site groundwater, as every site but one (MW12-02S) had samples above the CCME guideline of 0.12 mg/L for the protection of freshwater aquatic life (1999). Drinking water guidelines for fluoride were also sometimes reported above.

Nutrients

Total Kjeldahl nitrogen (sum of organic and inorganic nitrogen) levels closely matched total nitrogen levels, and concentrations of nitrate and nitrite were low from both overburden and bedrock samples. Mean ammonia levels were 0.040 mg/L and 0.029 mg/L in the overburden and bedrock, respectively. Bedrock had higher total phosphorus levels (mean: 0.070 mg/L as P) compared to overburden samples (mean: 0.020 mg/L as P).

Cyanides

Cyanide levels were low in both overburden and bedrock samples, and the majority of samples (95%) were below detection limits for all forms.

Organic Carbon

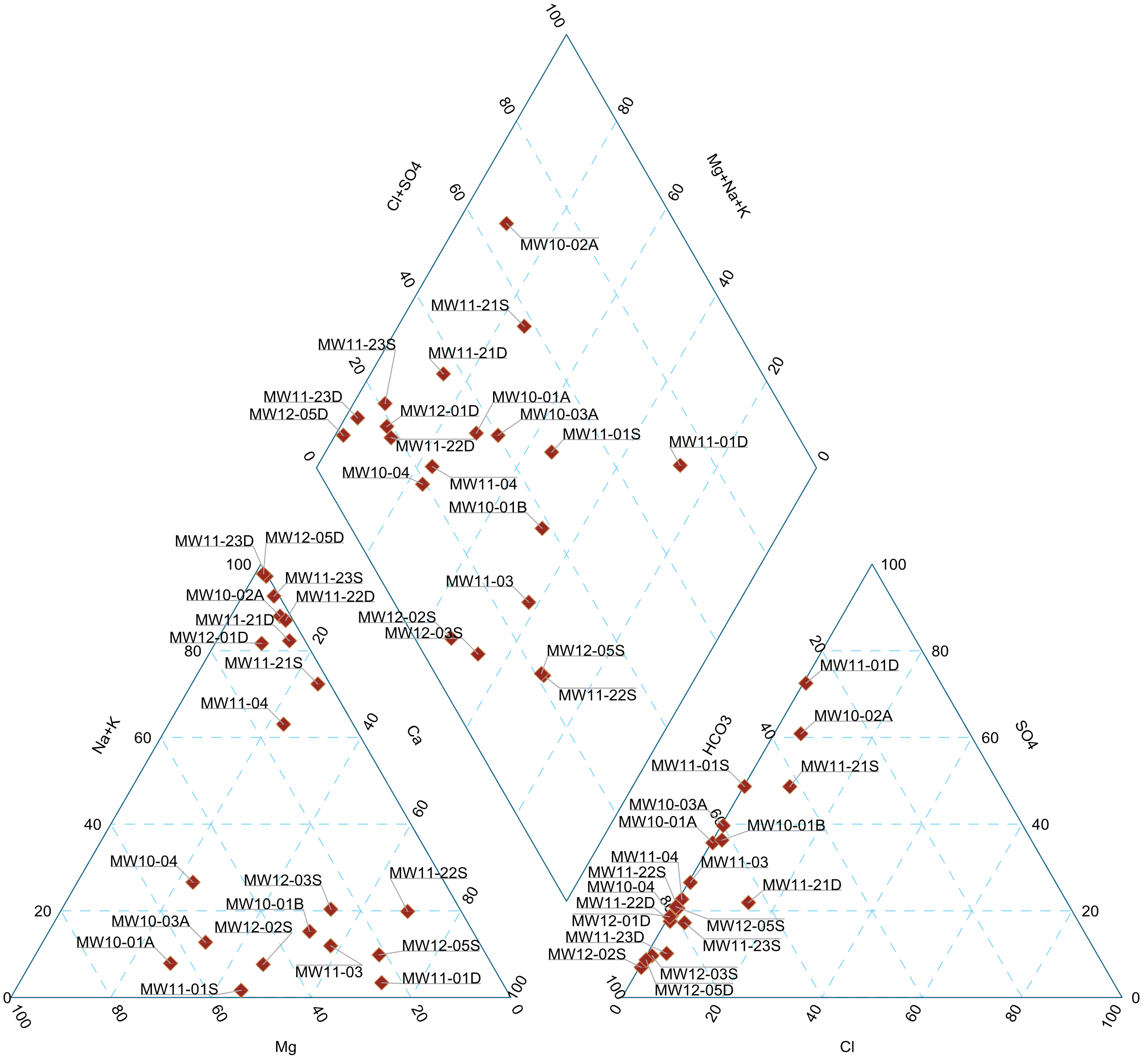
Samples collected from overburden had higher dissolved organic carbon levels than samples from bedrock. Total organic carbon levels were similar between overburden and bedrock samples (with a mean value of approximately 2.0 mg/L for both). Concentrations occasionaled reported above the guidelines for drinking water quality.

Metals

Dissolved metals were compared to total metals guidelines. The discussion that follows focuses on dissolved metals; however, both total and dissolved metals results are presented in Tables 11.4-4 and 11.4-5.

Figure 11.4-23

Piper Plot of Major Ion Chemistry in Sampled Groundwater



The dominant major cations included calcium, sodium, and magnesium. Calcium and magnesium tended to dominate in the overburden and shallow bedrock. Sodium tended to dominate in the deeper bedrock (Figure 11.4-23).

Dissolved aluminum, chromium, molybdenum, selenium, and uranium were elevated in wells completed in the deeper bedrock relative to the overburden and shallow bedrock. The greatest frequency of dissolved metals reported above guidelines occurred in the three wells installed in the TMF main dam foundation. The majority of dissolved mercury (99%), silver (99%), and thallium (86%) groundwater samples were below detection limits.

Project Site groundwater had naturally elevated levels of manganese above the Health Canada drinking water guideline of 0.05 mg/L (Health Canada 2012), with 15 of 20 sites above the guideline. Concentrations of dissolved aluminum, cadmium, chromium, cobalt, copper, iron, selenium, uranium, and zinc were sporadically above guidelines for the protection of freshwater aquatic life. Concentrations of dissolved aluminum and uranium were sporadically above drinking water guidelines.

11.5 EFFECTS ASSESSMENT AND MITIGATION

11.5.1 Screening and Analyzing Project Effects

Project activities and components were screened for potential effects by considering their potential to cause changes to each of the VCs. For groundwater quantity, the potential effects were identified with the changes to groundwater levels and flow patterns (referring to flow directions, hydraulic gradients, and flow rates collectively). For groundwater quality, the potential effects were identified with the degradation of groundwater quality.

Potential effects of the Project on groundwater quantity and quality may be broadly grouped into the following categories:

- water management (dewatering and refilling, development of ponds, and diversions) resulting in changes to groundwater levels and flow patterns;
- water table mounding in stockpiles (e.g., waste rock, LGO, and topsoil stockpiles) resulting in changes to groundwater levels and flow patterns due to the change of groundwater recharge;
- seepage of contact water from exposed PAG rock, tailings, and other sources, resulting in potential effects on groundwater quality; and
- accidental events (releases of hazardous substances) causing infiltration of contact water outside otherwise expected areas.

Effects falling into each of these categories are possible during all four phases of the Project; however, the risk arising from these effects varies based on the extent of development, scale of the activity, and the nature of the activity (Table 11.5-1.). Certain potential effects are expected to be of low risk to groundwater quantity and quality (present a low risk of resulting in residual effects without mitigation), and have been excluded from further examination in the groundwater effects assessment.

Table 11.5-1. Risk Ratings of Project Effects on Groundwater

Category	Project Components and Activities	Groundwater Quantity	Groundwater Quality
Construction			
Dangerous goods and hazardous materials	Hazardous materials storage, transport, and off-site disposal		🟡[A]
	Spills and emergency management		🟡[A]
Environmental management and monitoring	Construction of fish habitat offsetting sites	🟢	
Explosives	Explosives storage and use		🟡[A]
Fuel supply, storage and distribution	Fuel supply, storage and distribution		🟡[A]
Open pit	Open pit development - drilling, blasting, hauling and dumping	🟡	🟡
Potable water supply	Process and potable water supply, distribution and storage	🟢	
Project Site development	Aggregate sources/ borrow sites: drilling, blasting, extraction, hauling, crushing		🟢
	Clearing vegetation, stripping and stockpiling topsoil and overburden, soil salvage handling and storage	🟢	
	Earth moving: excavation, drilling, grading, trenching, backfilling	🟢	
Roads	New TMF access road construction: widening, clearing, earth moving, culvert installation using non-PAG material	🟢	
Roads	Road upgrades, maintenance and use: haul and access roads	🟢	
Stockpiles	Coarse ore stockpile construction	🟢	
	Non-PAG Waste Rock Stockpile construction	🟢	
	PAG and non-PAG low-grade ore stockpiles foundation construction	🟢	
	PAG Waste Rock stockpiles foundation construction	🟢	
Tailings management	Coffer dam and South TMF embankment construction	🟢	
	Tailings distribution system construction		
Temporary construction camp	Construction camp construction, operation, and decommissioning	🟢	
Waste disposal	Waste management: garbage, incinerator and sewage waste facilities		🟡[A]
Water management	Ditches, sumps, pipelines, pump systems, reclaim system and snow clearing/stockpiling	🟢	🟢
	Water management pond, sediment pond, diversion channels and collection channels construction	🟢	

(continued)

Table 11.5-1. Risk Ratings of Project Effects on Groundwater (continued)

Category	Project Components and Activities	Groundwater Quantity	Groundwater Quality
Operations 1			
Dangerous goods and hazardous materials	Explosives storage and use		🟡[A]
	Hazardous materials storage, transport, and off-site disposal		🟡[A]
	Spills and emergency management		🟡[A]
Environmental management and monitoring	Fish habitat offsetting site monitoring and maintenance	🟢	
Fuel supply, storage and distribution	Fuel storage and distribution		🟡[A]
Mining	Mine pit operations: blast, shovel and haul, and pit dewatering	🔴	🔴
Potable water supply	Process and potable water supply, distribution and storage	🟢	
Reclamation and decommissioning	Progressive mine reclamation	🟢	🟢
Stockpiles	Construction of non-PAG tailings beaches	🔴	🔴
	Construction of PAG and non-PAG Low Grade Ore Stockpile	🔴	🔴
	Non-PAG Waste Rock Stockpiling	🔴	🔴
	Overburden stockpiling	🟡	🟢
Tailings management	South TMF embankment construction	🟢	
	Sub-aqueous deposition of PAG waste rock into TMF	🔴	🔴
	Tailings transport and storage in TMF	🔴	🔴
Waste disposal	Waste management: garbage and sewage waste facilities		🟡[A]
Water management	Monitoring and maintenance of mine drainage and seepage	🟢	🟢
	Surface water management and diversions systems including snow stockpiling/clearing	🟢	🟢
Operations 2 *Includes the Operations 1 non-mining Project Components and Activities, with the addition of these activities:*			
Reclamation and decommissioning	Partial reclamation of non-PAG waste rock stockpile	🟢	🟢
	Partial reclamation of TMF tailings beaches and embankments	🟢	🟢
Tailings management	Construction of North TMF embankment and beach	🔴	🔴
	Deposit of low grade ore tailings into open pit	🔴	🔴
Water management	Surface water management	🟢	

(continued)

Table 11.5-1. Risk Ratings of Project Effects on Groundwater (completed)

Category	Project Components and Activities	Groundwater Quantity	Groundwater Quality
Closure			
Environmental management and monitoring	Environmental monitoring including surface and groundwater monitoring	🟢	🟢
	Monitoring and maintenance of mine drainage, seepage, and discharge	🟢	🟢
	Reclamation monitoring and maintenance	🟢	🟢
Open pit	Filling of open pit with water and storage of water as a pit lake	🔴	🔴
Reclamation and decommissioning	Partial decommissioning and reclamation of mine site roads	🟢	
	Decommissioning of diversion channels and distribution pipelines	🟢	
	Reclamation of non-PAG LGO stockpile, overburden stockpile and non-PAG waste rock stockpile	🟢	🟢
	Reclamation of TMF embankments and beaches	🟢	🟢
	Removal of contaminated soil	🟢	🟢
Stockpiles	Storage of waste rock in the non-PAG waste rock stockpile	🔴	🔴
Tailings management	Maintenance and monitoring of TMF	🟢	🟢
	Storage of water in the TMF and groundwater seepage	🔴	🔴
	Sub-aqueous tailing and waste rock storage in TMF	🔴	🔴
	TMF discharge to T Creek		🟢
Waste disposal	Solid waste management		🟡 [A]
Post-Closure			
Environmental management and monitoring	Environmental monitoring including surface and groundwater monitoring	🟢	🟢
	Monitoring and maintenance of mine drainage, seepage, and discharge	🟢	🟢
	Reclamation monitoring and maintenance	🟢	🟢
Open pit	Storage of water as a pit lake	🔴	🔴
Stockpiles	Storage of waste rock in the non-PAG waste rock stockpile	🔴	🔴
Tailings management	Storage of water in the TMF and groundwater seepage	🔴	🔴
	Sub-aqueous tailing and waste rock storage	🔴	🔴
	TMF discharge		🟢

[A] *Effect pathway is an accidental event (release of controlled substance or catastrophic failure of a Project component). Potential effects arising from these occurences are discussed further in Chapter 26 and omitted from further examination in this chapter.*

🟢 = *Low risk interaction: a negligible to minor adverse effect could occur; no further consideration warranted.*

🟡 = *Moderate risk interaction: a potential moderate adverse effect could occur; warrants further consideration.*

🔴 = *High risk interaction: a key interaction resulting in potential significant major adverse effect or significant concern; warrants further consideration.*

Project components or activities that are identified as having the potential to present a "moderate to high risk" of generating a residual effect are further examined with consideration for mitigation measures (Section 11.5.2) and through incorporation into the groundwater modelling exercises (introduced in Section 11.5.3). Notice that the potential risks identified and ranked as to be “moderate to high” are for the purposes of the assessment only, and mitigation measures have been designed to minimize the risks (see Sections 11.5.2 for mitigations).

Accidental events, while presenting a potential residual effect to the groundwater environment, are assessed in Chapter 26, Environmental Effects of Accidents and Malfunctions, and not discussed further in this chapter. A range of Environmental Management Plans (EMPs) are proposed to prevent and respond to such events (see Groundwater Management Plan in Section 24.8).

Construction

Potential effects which present the possibility of manifesting into residual effects to groundwater quantity and quality begin with the onset of Construction. The level of potential risk increases with the increase in scale of the Project components and activities as Operations progress.

During the Construction phase, development of the open pit is expected to have the potential to present a moderate risk to groundwater quantity, as dewatering will reduce the groundwater level elevation near the pit. All other construction activities present a low risk to groundwater quantity, except for the potential to release controlled substances (e.g., dangerous goods, hazardous materials, explosives, fuel) and waste disposal that may pose moderate risks to groundwater quality.

Operations

The following activities are classified as having the potential to present a "high risk" to groundwater quantity and quality during Operations 1 phase (Project Year 1 to Year 23): open pit dewatering, PAG and non-PAG waste rock and LGO stockpiling, and storage of tailings (and PAG waste rock and non-PAG LGO stockpiles) in the TMF. These activities, without mitigation, have the potential for significant adverse effects to groundwater quantity and quality (Table 11.5-1).

Dewatering of the open pit is expected to result in the development of a groundwater sink, potentially reducing water levels and groundwater discharge in the down-gradient environment. The presence of blasting residuals and exposed PAG rock inside the open pit presents a potential high risk to groundwater quality in the surrounding geological formations. The LGO and waste rock stockpiles may result in more infiltration of precipitation through the stockpiles and mounding of water inside the stockpiles, causing an increase of recharge into the groundwater system beneath and affecting the groundwater levels and flow patterns in the local. The LGO and waste rock stockpiles also have the potential to generate some seepage of contact water, and therefore present high risks to the groundwater quality beneath the stockpiles and along the flow paths towards the downstream. The storage of the tailings in the TMF (together with the co-disposed PAG waste rock and non-PAG LGO stockpile) is expected to significantly increase the water levels in the valley and to produce some amount of contact water seeping through the base of the TMF, as well as along flow paths towards and possibly beyond the TMF embankments.

The overburden stockpiling may present a moderate risk to groundwater quantity only, due to the potential increase of water infiltration and recharge into the groundwater system beneath. It is expected to pose a low risk to groundwater quality with the Mine Waste and ML/ARD Management Plan (Section 24.9) in place.

Similar to Construction, waste disposal and activities with potential releases of dangerous goods and hazardous materials, explosives, fuel supply/storage and distribution, are expected to have some moderate risks to groundwater quality during the Operations 1 phase (see Table 11.5-1).

During the Operations 2 phase, the activities (including the open pit, the stockpiles, and the TMF) discussed above in Operations 1 will continue to pose high risks to groundwater quantity and quality, and the overburden stockpile will continue to pose a moderate risk to groundwater quantity. In addition, Operations 2 activities including the proposed deposition of LGO tailings into the dewatered open pit and the construction of the north TMF embankment and beach are expected to have high risks to groundwater quantity and quality (Table 11.5-1). The partial decommission and removal of the water management system at the open pit, and the partial reclamation of the non-PAG waste rock stockpile and the TMF are expected to have low risk interactions with no adverse effect to groundwater quantity and quality.

Closure and Post-Closure

Continued water management, including sustenance of a lake in the open pit and a tailings pond in the TMF, poses a high-risk potential effect to groundwater quantity and quality at Closure and Post-Closure. Filling of the open pit and storage of water as a pit lake with the lake level to be controlled at the elevation of 1,530 masl, and the continuous sub-aqueous storage of the tailings and PAG waste rock in the TMF will continue to affect the groundwater levels and flow patterns in the local area. Discharge of contact water via the spillways of the pit lake and the seepage from the TMF presents a high risk to groundwater quality along the flow pathways toward the downstream receiving environment. Storage of waste rock in the non-PAG waste rock stockpile will also have the potential to continue to affect groundwater quantity and quality.

11.5.2 Mitigation Measures

11.5.2.1 Groundwater Quantity

Table 11.5-2a tabulates the major mine components/activities that may affect groundwater quantity (including alteration of groundwater levels and flow patterns), the expected timing of the occurrence of the effect, the proposed mitigation measures in the Project's design and their effectiveness, and the assessed residual effect. These mine components/activities were evaluated as posing moderate and high risks to groundwater quantity (see Table 11.5-1). The mitigation measures are proposed to avoid, reduce, or eliminate effects to groundwater quantity and most of them are considered to be moderately effective. Therefore, some residual effects on groundwater quantity are assessed to still exist with the proposed mitigation measures being implemented. These effects have been assessed with the assistance of the numerical groundwater modelling exercises (introduced in Section 11.5.3 and Appendix 11-B).

Table 11.5-2a. Proposed Mitigation Measures for Groundwater Quantity and their Effectiveness

Groundwater Quantity					
Potential Effect				Mitigation Effectiveness *(Low/Moderate/ High/Unknown)*	Residual Effect *(Y/N)*
Effect Pathway	Component/Activity	Timing	Proposed Mitigation Measure		
Alteration of groundwater levels and flow patterns (flow directions, hydraulic gradients and flow rates) arising from mine activities, waste rock and water management	Open Pit Mining	Construction, Operations 1	Decommission and removal of open pit water management system during Operations 2.	Low	Yes
	Pit Lake	Operations 2, Closure, Post-Closure	Pit refilled with water but with an elevation controlled, and excess water pumped to TMF.	Moderate	Yes
	Non-PAG Waste Rock Stockpile	Operations, Closure, Post-Closure	Concurrent partial reclamation during Operations 2 and final reclamation during Closure; decommission and removal of the Water Management Pond during the final reclamation at Closure.	Moderate	Yes
	PAG Waste Rock Stockpile	Operations, Closure, Post-Closure	Sub-aqueous disposal and managed inside the TMF during Operations, reclaimed with the TMF at Closure.	Moderate	Yes
	PAG Low-Grade Ore Stockpile	Operations	The stockpile is underlain by a low-permeability overburden liner, and the ores will be processed and removed in Operations 2.	Moderate	Yes
	Non-PAG Low-Grade Ore Stockpiles	Operations	The majority is to be stored inside TMF, during Operations 1, processed and removed in Operations 2.	Moderate	Yes
	Overburden Stockpile	Construction, Operations, Closure, Post-Closure	Concurrent reclamation during Operations 2.	Moderate	Yes
	Topsoil Stockpiles	Construction, Operations, Closure	Partial reclamation during Construction and Operations, and removal during Closure.	Moderate	Yes
	Tailings Management Facility	Construction, Operations, Closure, Post-Closure	Concurrent partial reclamation of TMF tailings beaches and embankments during Operations 2, and final reclamation of TMF embankments and beaches during Closure; decommission and reclamation of the Water Management Pond during final reclamation at Closure.	Moderate	Yes

Pit dewatering is necessary to develop the pit during mine construction and to access the ore deposit during Operations 1. It will inevitably lower the water levels and change the flow patterns (flow directions and hydraulic gradients) in the geological formations directly surrounding the pit. No mitigation measures are available to avoid, reduce, or eliminate such effects during these periods of time. During Operations 2, Closure, and Post-Closure, the water levels and flow patterns will gradually recover close to the pre-mining baseline conditions, as the open pit is refilled with precipitation water, surface runoff, and groundwater recharge.

However, a complete recovery is not expected as the pit lake is to be refilled with the water surface at the elevation at 1,530 masl of the pit. Therefore, residual effect on groundwater quantity is expected to occur in the dewatered pit, as well as in the pit lake.

Measures that have been integrated into the Project design (as shown in Table 11.5-2a) to mitigate the potential effects of other key mine components (the stockpiles of non-PAG waste rock, PAG waste rock, PAG/non-PAG LGO, overburden and topsoil, and the TMF), include, e.g., sub-aqueous co-disposal of PAG waste rock into the TMF, partial concurrent reclamation of the non-PAG waste rock and PAG/non-PAG LGO stockpiles and the TMF during Operations 2, and final reclamation of these facilities at Closure. All of these mitigation measures are considered to be moderately effective with respect to reducing the potential effects of the facilities on groundwater quantity. Therefore, residual effects on groundwater quantity are still expected to occur from these facilities.

11.5.2.2 Groundwater Quality

Table 11.5-2b tabulates the major mine components/activities that may affect groundwater quality, the expected timing of the occurrence of the effect, the proposed mitigation measures in the Project's design and their effectiveness, and the assessed residual effect. These mine components/activities were evaluated as having moderate and high risks to cause effects on groundwater quality (see Table 11.5-1).

The key effect pathway leading to potential residual effects on the degradation of groundwater quality is the seepage of contact water. A residual effect arising from this pathway would be characterized by the development of a potential plume of contact groundwater, that is of degraded quality relative to baseline conditions in the local subsurface area.

The objectives of mitigation measures include reducing the potential seepage, the duration of contaminant mass loading, and the magnitude of the degradation of groundwater quality. Four approaches have been used to target these objectives:

- component design features providing for seepage control;
- component siting alternatives that provide for preferred seepage directions;
- ML/ARD management for segregation of PAG and non-PAG materials; and
- EMPs for monitoring and adaptive management.

Table 11.5-2b. Proposed Mitigation Measures for Groundwater Quality and their Effectiveness

Groundwater Quality					
Potential Effect					
Effect Pathway	Component/ Activity	Timing	Proposed Mitigation Measure	Mitigation Effectiveness *(Low/Moderate/ High/Unknown)*	Residual Effect *(Y/N)*
Degradation of groundwater quality due to seepage of contact water	Open Pit Mining	Construction, Operations 1	Design: Pumping the collected dewatering water and storing into the TMF.	High	No
	Pit Lake	Operations 2, Closure, Post-Closure	Design: Pit refilled with water but with an elevation controlled, and excess water pumped to TMF. EMPs: Groundwater Management Plan.	Moderate	Yes
	Non-PAG Waste Rock Stockpile	Operations, Closure, Post-Closure	Design: Runoff diversion and collection ditches; seepage collection and storage in the TMF during Operations; concurrent partial reclamation during Operations 2 and final reclamation during Closure. EMPs: Mine Waste and ML/ARD Management Plan; Groundwater Management Plan.	Moderate	Yes
	PAG Waste Rock Stockpile	Operations, Closure, Post-Closure	Design: Sub-aqueous disposal and managed inside the TMF during Operations, reclaimed with the TMF at Closure. EMPs: Mine Waste and ML/ARD Management Plan, Groundwater Management Plan.	Moderate	Yes
	PAG Low-Grade Ore Stockpile	Operations	Design: The stockpile is underlain by a low-permeability overburden liner with a water management pond collecting the seepage and diverted to the TMF. The ores will be processed and removed in Operations 2. EMPs: Mine Waste and ML/ARD Management Plan, Groundwater Management Plan.	Moderate	Yes
	Non-PAG Low-Grade Ore Stockpiles	Operations	Design: The majority is to be stored inside TMF, during Operations 1, processed and removed in Operations 2. EMPs: Mine Waste and ML/ARD Management Plan; Groundwater Management Plan.	Moderate	Yes

(continued)

Table 11.5-2b. Proposed Mitigation Measures for Groundwater Quality and their Effectiveness (completed)

Groundwater Quality					
Potential Effect					
Effect Pathway	Component/ Activity	Timing	Proposed Mitigation Measure	Mitigation Effectiveness *(Low/Moderate/ High/Unknown)*	Residual Effect *(Y/N)*
Degradation of groundwater quality due to seepage of contact water *(cont'd)*	Overburden Stockpile	Construction, Operations, Closure, Post-Closure	Design: Concurrent reclamation during Operations 2. EMPs: ML/ARD management plan (PAG and non-PAG material sorting).	Moderate	No
	Topsoil Stockpiles	Construction, Operations, Closure	Design: Partial reclamation during Construction and Operations, and used for reclamation and removal during Closure.	Moderate	No
	Tailings Management Facility	Operations, Closure, Post-Closure	Design: Low-permeability embankment materials, seepage collection drains and recovery pond, pumping back; Concurrent partial reclamation of TMF tailings beaches and embankments during Operations 2, and final reclamation of TMF embankments and beaches during Closure; decommission and reclamation of the Water Management Pond during final reclamation at Closure. EMPs: Groundwater Management Plan.	Moderate	Yes
Degradation of groundwater quality due to releases of dangerous goods and hazardous materials, explosives, fuel supply/storage and distribution, and waste disposal	Most components/ activities	All Project phases	EMPs: Emergency Response Plan, Explosives Management Plan, Spill Prevention and Response Plan, Fuel and Hazardous Materials Management Plan, Waste Management Plan, Groundwater Management Plan.	Moderate	Yes

According to the Project's designs, the water flowing into the open pit during dewatering at the mine throughout Construction and Operations 1 will be collected and transferred to the TMF for storage. This mitigation measure is considered to be highly effective from the groundwater quality effect mitigation point of view, and therefore no residual effect is expected to occur in these periods of time. During Operations 2, Closure, and Post-Closure, the pit will be refilled as a pit lake to the elevation at 1,530 masl of the pit and the surplus of water will be pumped to the TMF for storage. Considering that seepage of contact water from the pit lake has been predicted with the numerical groundwater modelling (see Section 11.5.3 and Appendix 11-B), this mitigation measure is considered to be moderate, and some residual effects on groundwater quality in the area surrounding the pit lake and along the flow pathways towards the downstream receiving environment will exist.

The mitigation and control of potential seepage from the stockpiles of waste rock and LGO generally include the following: (1) separating the PAG and non-PAG waste rock, and separating the PAG and non-PAG LGOs; (2) sub-aqueous disposal and management of PAG waste rock and non-PAG LGO separately inside the TMF; (3) a low-permeability overburden liner placed under the PAG LGO stockpile; (4) processing and removal of the LGO stockpiles by the end of Operations 2; (5) collection of surface runoff with diversion ditches and seepage from the stockpiles within the water management ponds and transfer of the collected seepage into the TMF for storage; (6) reclamation during Operations and at Closure; and (7) groundwater monitoring proposed along predicted flow pathways from the non-PAG waste rock and the PAG LGO stockpiles (see Section 24.8), and adaptive management to be implemented if contact groundwater from the stockpiles contributes to the down-gradient water environment not meeting applicable regulatory standards or guidelines. These mitigation measures are considered to be moderately effective, and therefore, a residual effect on groundwater quality has been predicted to occur from these mine facilities (see Section 11.5.3 and Appendix 11-B).

The mitigation plans for the overburden and topsoil stockpiles will include progressive reclamation during Construction and Operations. The topsoil stockpile will be used for mine reclamation and completely removed at Closure. These mitigation plans are considered to be moderately effective, and with the Mine Waste and ML/ARD Management Plan (Section 24.10) in place, no significant residual effect on groundwater quality is expected to occur from these stockpiles.

Seepage reduction and control measures have been included in the design of the TMF main and north embankments (Figures 11.5-1 and 11.5-2). A low-permeability glacial till material has been included at the core of the main embankment (thickness of at least 8 m) and at the upstream wall of the north embankment (width of 4 m). Graded filter materials are planned immediately downstream of the low-permeability materials, serving to sustain integrity of the core and drain seepage passing through the core. Seepage collection drains are included at the base of the filter materials, routing seepage passing through the embankments to seepage collection ponds (referred to as the South TMF water management pond and North TMF water management pond). Seepage passing through the shallow subsurface beneath the embankments is also expected to discharge into the seepage collection ponds, and it will be pumped back into the TMF. The mitigation measures also include the partial reclamation of TMF tailings beaches and embankments during Operations 2, final reclamation of TMF embankments and beaches during Closure, and decommission and reclamation of the water management pond during final reclamation Post-Closure.

The seepage mitigation measures included in the TMF design are expected to moderately reduce, but not eliminate, seepage from the TMF (including the co-disposed PAG waste rock and non-PAG LGO stockpiles). Residual effect on groundwater quality is expected to emanate from the TMF, resulting in development of a solute plume of contact groundwater beneath and immediate down-gradient of the local TMF footprint. Seepage from the TMF has been studied in the numerical groundwater modelling exercises (see Section 11.5.3 and Appendix 11-B). The planned seepage mitigation design features have been incorporated into the simulations. Groundwater monitoring and adaptive management, which are components of the Groundwater Management Plan (Section 24.8), will be used to implement further seepage mitigation if the contact groundwater along the flow pathways results in downstream water quality in T Creek and Harper Creek being of poorer quality than applicable regulatory standards or guidelines.

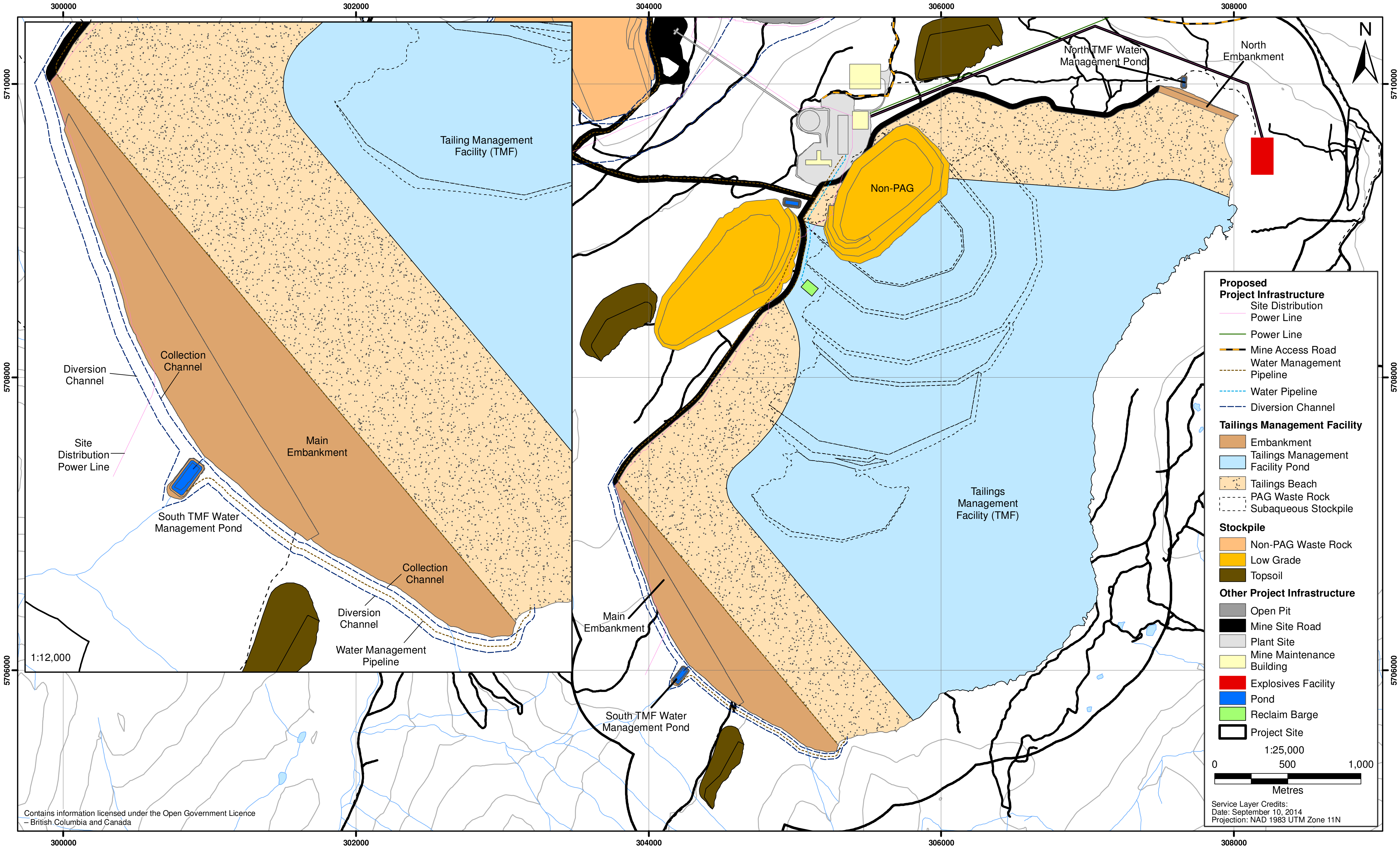
The Groundwater Management Plan (Section 24.8) includes an adaptive management strategy to control seepage where contact groundwater results in water quality degradation above applicable regulatory standards or guidelines at receptors downstream of the key mine components (the pit lake, the non-PAG waste rock stockpile, the PAG LGO stockpile, and the TMF (and the sub-aqueous disposed PAG waste rock and non-PAG LGO stockpiles). Groundwater and surface water sampling will be conducted along flow pathways down-gradient of the mine components expected to generate contact groundwater. Additional seepage control mechanisms may include pumping wells, seepage collection ponds, grout curtains, or other mechanisms that have been shown to be effective in controlling groundwater flow or treat groundwater to reduce metals concentrations in situ. Implementation of the Groundwater Management Plan (Section 24.8) is expected to provide an early warning of the potential effects and assist in developing and implementing the adaptive Groundwater Management Plan in order to minimize the potential effects to groundwater quality.

Finally, degradation of groundwater quality could also be caused by sudden releases of dangerous goods and hazardous materials, explosives, fuel supply/storage and distribution, and waste disposal (Table 11.5-2b). The measures to prevent and mitigate this kind of effect include: an Emergency Response Plan (Section 24.4), Explosives Handling Plan (Section 24.5), Spill Prevention and Response Plan (Section 24.15), Fuel and Hazardous Materials Management Plan (Section 24.7), Waste Management Plan (Section 24.18), and Groundwater Management Plan (Section 24.8). Implementation of the prevention plans and mitigation measures may be moderately effective. Potential effects arising from accidental occurrences are discussed further in Chapter 26 and omitted from further examination in this chapter.

11.5.3 Predicted Residual Effects and Characterization

This section describes the key residual effects of the major mine components and activities that were identified with moderate to high risks (as shown in Table 11.5-1) and are expected to still have some potential effects to groundwater quantity and quality, after the mitigations (as described in the previous Section 11.5.2 and shown in Table 11.5-2a/b) have been applied.

Figure 11.5-1
Layout of the Tailings Management Facility and Main Embankment at End of Operations



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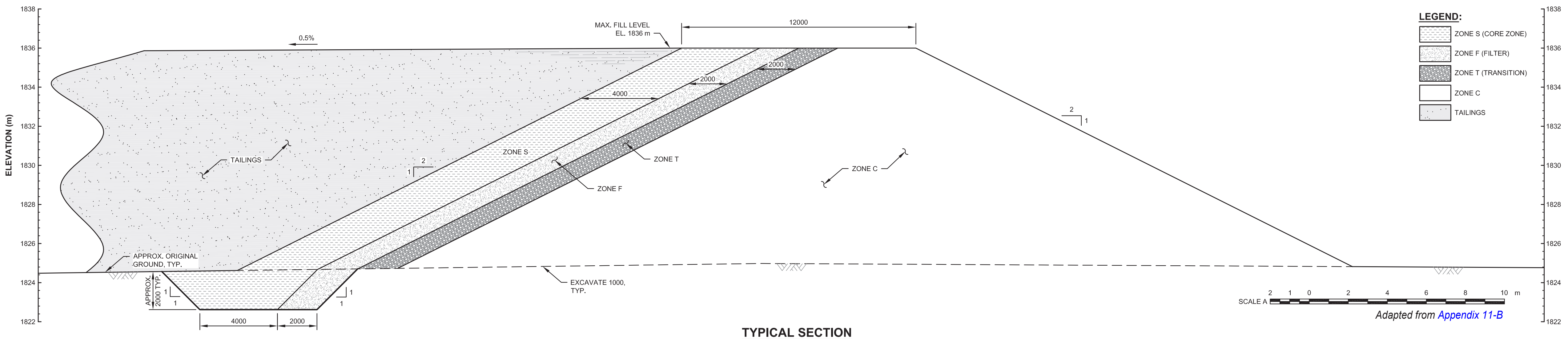
Service Layer Credits:
Date: September 10, 2014
Projection: NAD 1983 UTM Zone 11N

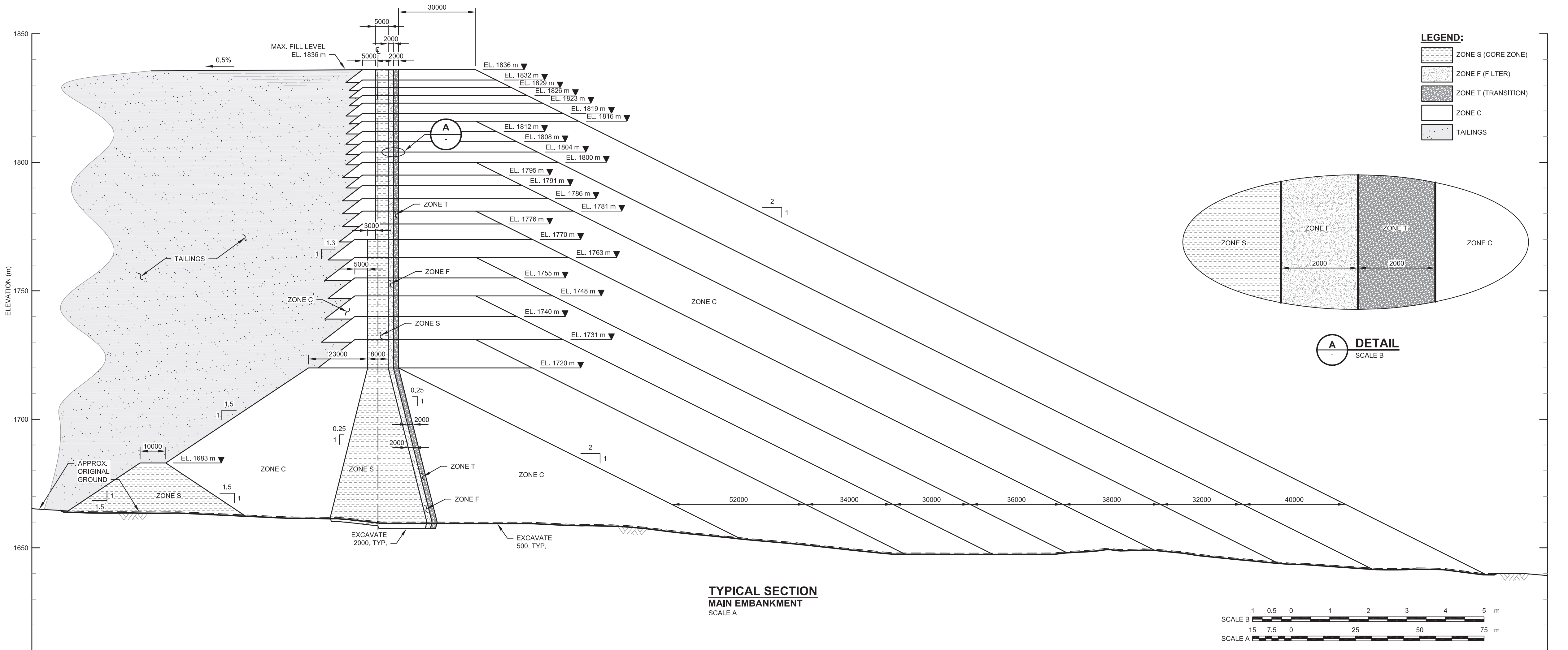
Figure 11.5-2

Typical Cross-sections of Tailings Management Facility Embankments



Adapted from Appendix 11-B

TYPICAL SECTION
NORTH EMBANKMENT
SCALE A



TYPICAL SECTION
MAIN EMBANKMENT
SCALE A

NOT FOR CONSTRUCTION

Note: Dimensions are in millimetres and elevations are in metres, unless noted otherwise.

Source: Knight Piésold Consulting, 2014 (Appendix 11-B).

The residual effect to groundwater quantity was assessed on the basis of the results of the simulated steady-state groundwater flow from a three-dimensional (3D) regional-scale hydrogeological numerical model developed for the Project (see the details in Appendix 11-B). The model was developed using the industry standard software MODFLOW-SURFACT and the approach of representing the discrete fractured bedrock formations with the equivalent porous media. The numerical model was used to support the characterization of the baseline pre-mining conditions in the Project area and to evaluate potential effects of proposed mine facilities on baseline hydrogeological conditions. The baseline model was built with the available baseline hydrogeological information up to April 2014, and the model was calibrated to measured groundwater elevations from 21 on-site groundwater monitoring wells and to synthetic baseflow estimates for five hydrometric stations within the LSA. Using the calibrated baseline model, two predictive model scenarios were developed to assess potential effects of proposed mine development and infrastructure during the following key phases of the Project:

- **Operations** 1: A steady-state model representing the operational period during which the open pit will be completely dewatered. Mine infrastructure including the open pit, non-PAG waste rock stockpile, PAG/non-PAG LGO stockpiles and TMF were simulated at their maximum build-out extents.
- **Post-Closure**: A steady-state model representing Post-Closure conditions during which the pit lake and TMF have reached their designed and maximum water storage volumes respectively, and are discharging excess water, and the LGO stockpiles have been removed and reclaimed.

The residual effect assessed to groundwater quantity (the magnitudes of the potential changes in groundwater levels and flow patterns due to the mining) represents the largest throughout mine Construction, Operations, Closure, and Post-Closure.

The residual effect to groundwater quality was assessed with the reference to the model-predicted advective flow migration pathlines of the potential contact groundwater seepage emanating from the key mine components and with the assumption that 100% of the solute sources from the pit lake, the non-PAG waste rock stockpile, the PAG LGO stockpile, and the TMF would migrate along the flow pathlines towards the downstream receiving environment without any retardation and attenuation. The residual effect assessed to groundwater quality is considered to be highly conservative, due to the fact that the calculation of the solute concentrations in groundwater only accounts for the advection, without incorporation of the effects of dispersion, retardation, and dilution.

11.5.3.1 Residual Effects on Groundwater Quantity

Figure 11.5-3 shows the simulated groundwater head contours (water level elevations), flow directions and catchment basins at the baseline pre-mining, the end of Operations, and Post-Closure conditions. The results show that the mining activities (e.g., the open pit dewatering and the storage of the TMF) will cause significant changes in groundwater elevations and flow patterns (including changes of the groundwater flow directions and catchment divides) within the local mine area. The residual effect of each major specific mine component to groundwater quantity is described in the following paragraphs.

Open Pit and Pit Lake

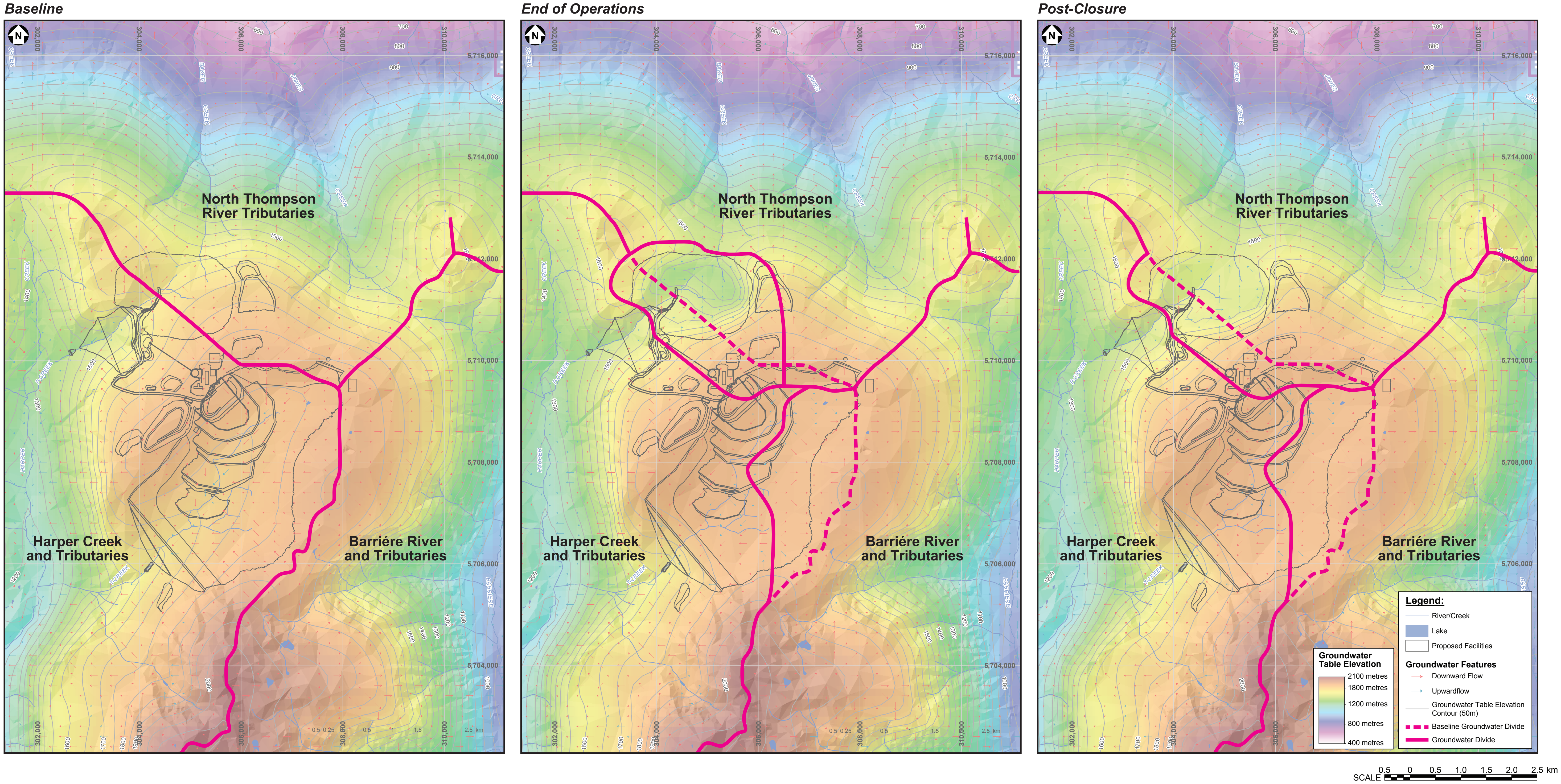
Model results indicate that groundwater level elevations surrounding the open pit are expected to decrease by up to 350 m while the pit is actively excavated and dewatered. As shown in Figure 11.5-3, the pit will become a groundwater sink with inward hydraulic gradients, and it will receive groundwater discharge from the surrounding geological formations. The potential groundwater drawdown and capture zone of the open pit is predicted to extend into the P Creek and Baker Creek watersheds, and the 1-m drawdown contour is to extend approximately 1 km south from the pit rim towards the TMF and approximately 3 km north from the pit rim towards Baker Creek catchment (Figure 11.5-4). The majority of groundwater inflow to the pit comes from up-gradient catchment areas southeast and northwest of the open pit with a small portion originating from the foundation of the non-PAG waste rock stockpile. Groundwater inflow rates are expected to reach a maximum of approximately 16 L/s during Year 24 when the extent of the open pit is largest. The capture zone and flow pathlines (Figure 11.5-5) indicate that the pit dewatering would draw some contact water from the TMF (and the co-disposed PAG waste rock and non-PAG LGO stockpile). The pit dewatering will not affect the water levels in the existing groundwater supply wells located downstream of Baker Creek and Jones Creek valleys near the North Thompson River (see Figure 11.5-6 for the locations of the supply wells numbered as 97736, 97740, 39609, and 00084).

At Closure and Post-Closure, the open pit will be flooded to maintain a pit lake. Groundwater elevations directly surrounding the pit lake are expected to recover to the design elevation of the pit lake water surface (1,530 masl), but not expected to completely recover to the pre-mining baseline conditions. As the pit is refilled with water, the catchment divide is predicted to shift towards the non-PAG waste rock stockpile, in comparison with the baseline pre-mining conditions (see the solid and dash red lines in Figure 11.5-3). The residual effect of the pit on groundwater quantity (changes of water levels and flow patterns) will remain after the mine ceases. The flow particle tracking indicates that while continuing to receive some groundwater discharge from the surrounding area (calculated to be at about 4 L/s by the model), the pit lake will dominantly become a source of groundwater recharge, discharging the contact water (estimated at a rate of approximately 8 L/s) into the upper Baker Creek groundwater system, approximately 3 km upslope of the confluence of Baker Creek with the North Thompson River (Figure 11.5-6). The model results indicate that the pit lake will not discharge towards the P Creek catchment or into the existing domestic water well in the Baker Creek catchment (Figure 11.5-7). Therefore, the water levels in the downstream groundwater supply wells will not be affected by the pit lake during the Closure and Post-Closure phases.

Tables 11.5-3 and 11.5-4 show the simulated groundwater discharge (as baseflows) in the creeks during Operations and Post-Closure, respectively, in comparison with the baseline conditions. The results indicate that the mining activities will potentially cause a significant reduction of the groundwater discharge (as baseflows) in the creeks (over 80% in the P Creek above Harper Creek, around 30% in Baker Creek above Thompson River, 60% in the T Creek, and over 40% in total in Harper Creek above/below the T Creek). The potential reduction of baseflow in Jones Creek is predicted to be relatively small (less than 10%). The reduction of the baseflows in Baker Creek and Jones Creek is predominantly due to the effect of drawdown of groundwater levels predicted in the pit dewatering and refilling. Flow reduction in P Creek is caused by the pit dewatering and water collection at the non-PAG waste rock and LGO stockpiles in the P Creek catchment. The baseflow reduction in T Creek is due to the loss of catchment and water retention within the TMF (discussed further in the TMF effect section below).

Figure 11.5-3

Simulated Groundwater Head Contours, Flow Directions and Catchment Basins: Baseline, End of Operations, and Post-Closure Conditions

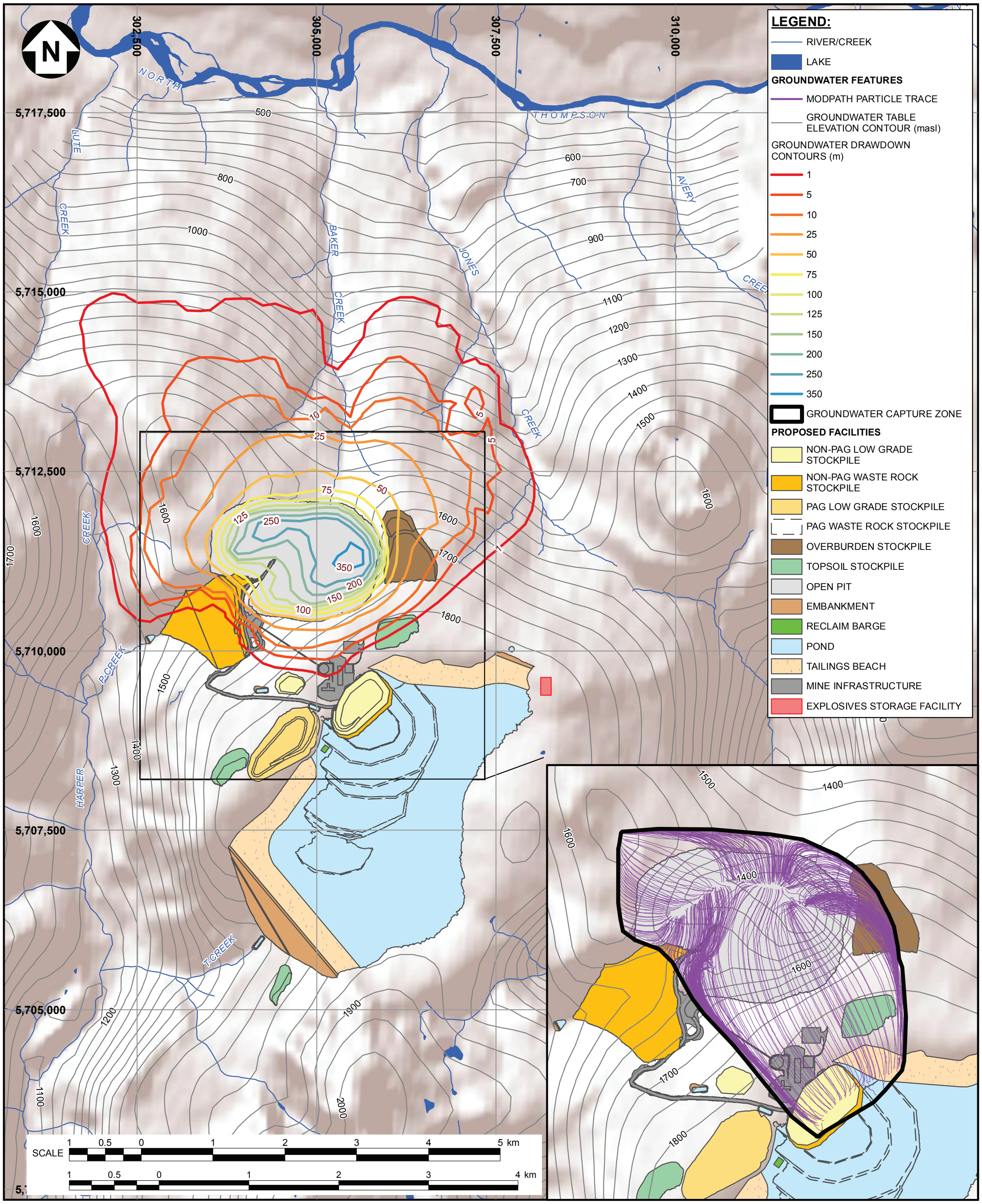


Baseline *End of Operations* *Post-Closure*

Source: Knight Piésold Consulting (2014).

Figure 11.5-4

Predicted Capture Zone and Drawdown Cone Associated with the Open Pit at End of Operations

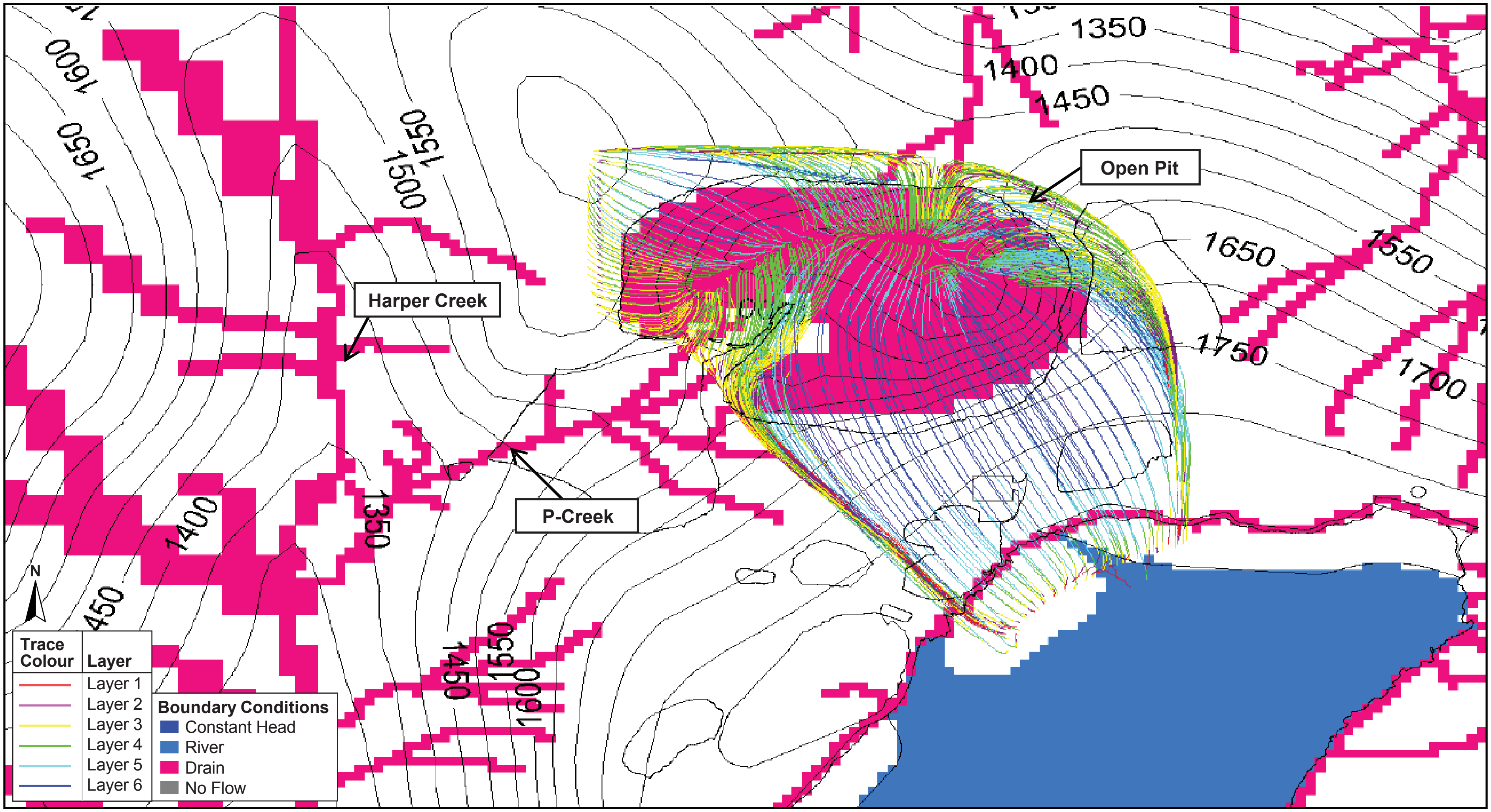


Notes: 1. Base map: trim and NTS mapping, ESRI ARCGIS online shaded relief.
2. Coordinate grid is in metres. Coordinate system: nad 1983 UTM zone 11N.

Source: Knight Piésold Consulting (2014).

Figure 11.5-5

Predicted Capture Zone Flow Particle-tracking Pathlines Associated with Open Pit Dewatering at End of Operations



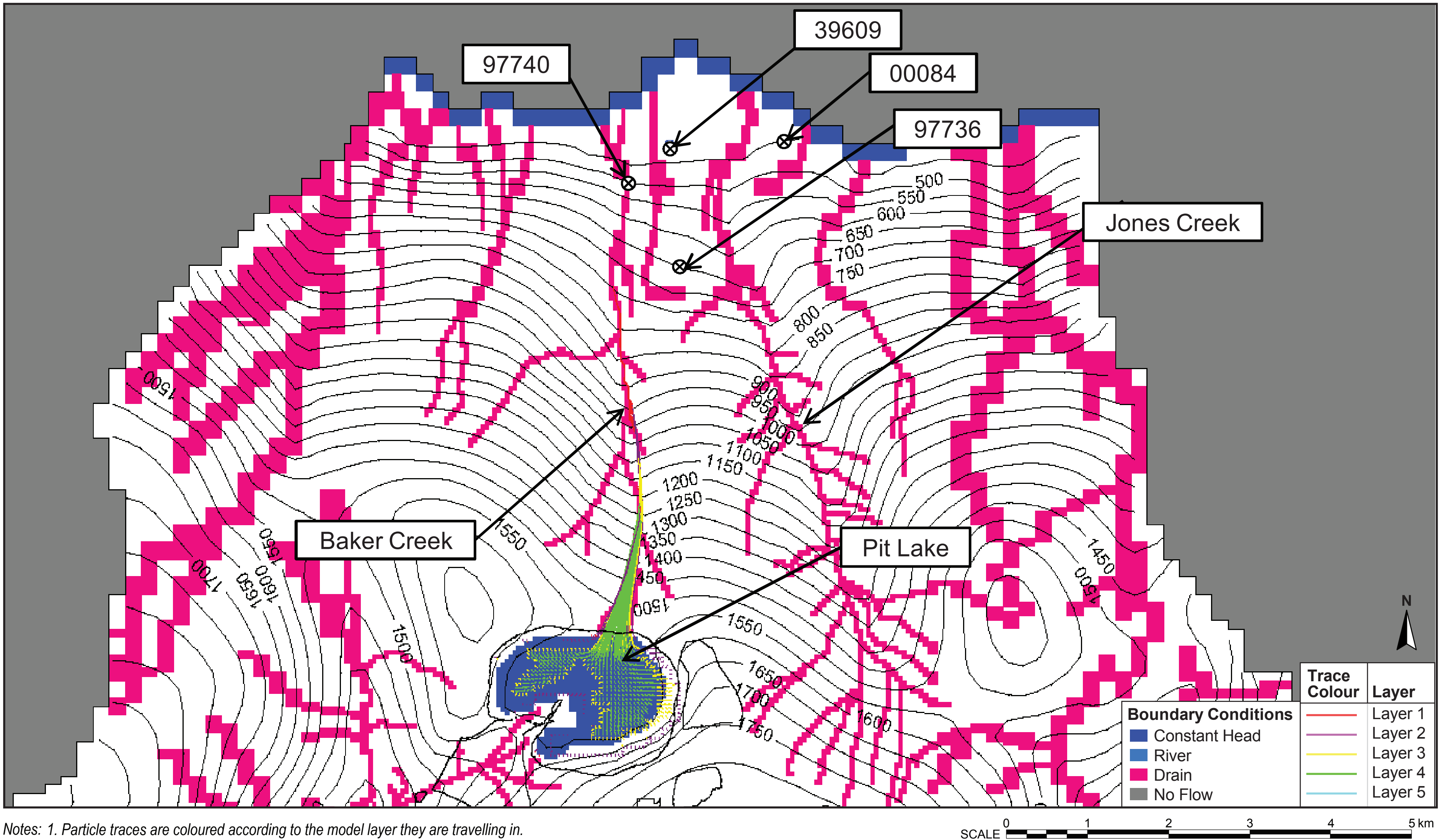
Notes: 1. Particle traces are coloured according to the model layer they are travelling in.
2. Particles were inserted into layers 1 through 4 and tracked forward from source to sink.
3. The contours shown above are of water table elevation (masl).

SCALE 0.5 0 0.5 1.0 1.5 2.0 km

Source: Knight Piésold Consulting (2014).

Figure 11.5-6

Predicted Flow Particle-tracking Pathlines Associated with the Pit Lake during Post-Closure

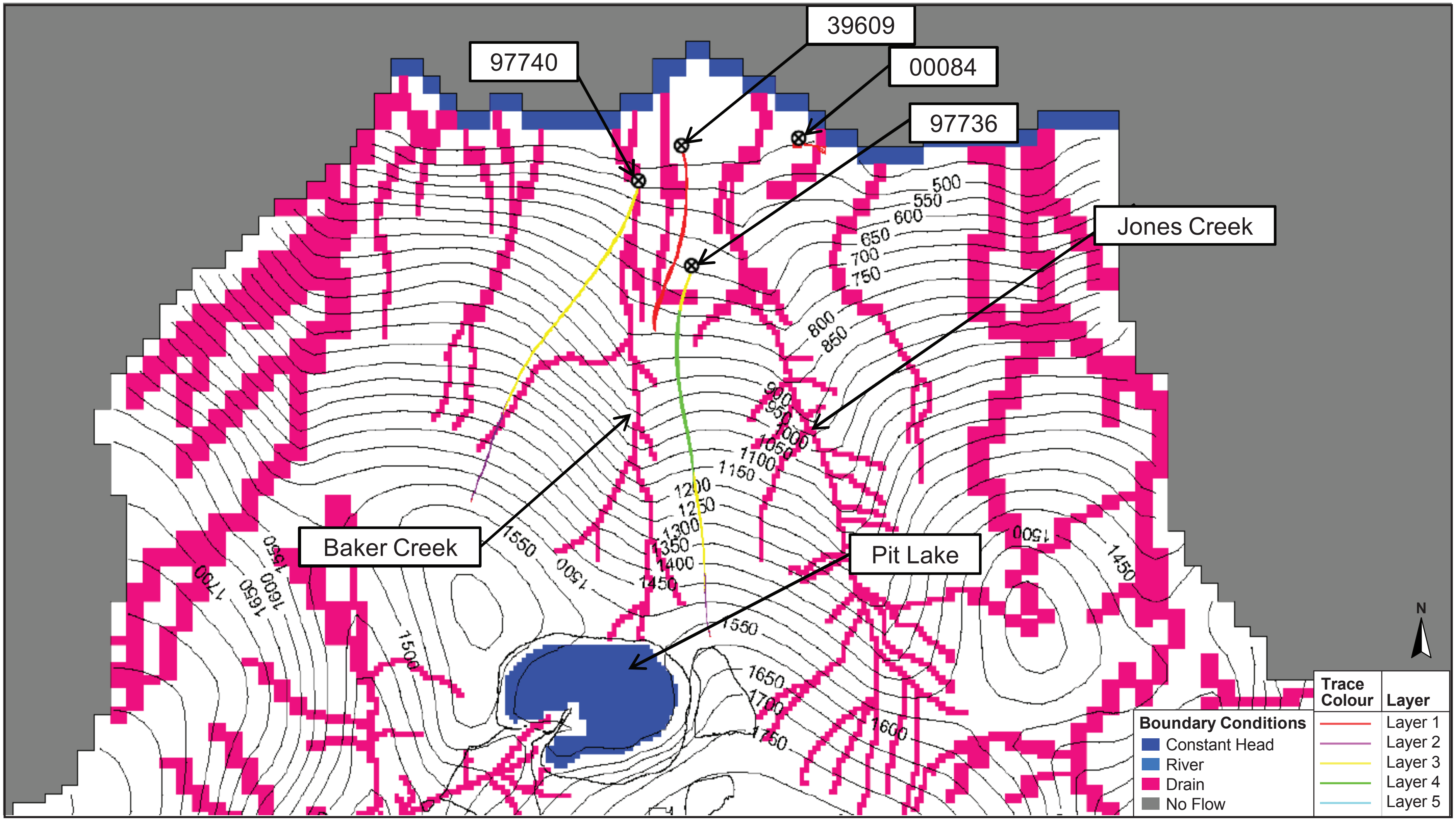


Notes: 1. Particle traces are coloured according to the model layer they are travelling in.
2. Particles were inserted into layer 1 and tracked forward from source to sink.
3. The contours shown above are of water table elevation (masl).
4. Wells 97736 and 97740 are included in model layer 3 and wells 39609 and 00084 in model layer 1.

Source: Knight Piésold Consulting (2014).

Figure 11.5-7

Predicted Reverse Flow Particle-tracking Pathlines for Existing Groundwater Supply Wells Downgradient of the Pit Lake at Post-Closure



Notes: 1. Particle traces are coloured according to the model layer they are travelling in.
2. Particles were inserted into layers 1 and 3 and at the well screen locations tracked backwatds from sink to source.
3. The contours shown above are of water table elevation (masl).
4. Wells 97736 and 97740 are included in model layer 3 and wells 39609 and 00084 in model layer 1.

Source: Knight Piésold Consulting (2014).

Table 11.5-3. Predicted Reduction of Baseflows in the Creeks during Operations

Hydrometric Station (Gauge I.D.)	Baseline Simulated Baseflow (m^3/day)	Operations Simulated Baseflow (m^3/day)	Flow Reduction Percentage (%)
P Creek above Harper Creek (OP Gauge)	1,228	177	86%
Harper Creek above T Creek (HARPERUS Gauge)	20,267	16,745	17%
T Creek above Harper Creek (TSFDS Gauge)	9,103	3,629	60%
Harper Creek at WSC Station (08LB076 Gauge)	62,266	47,289	24%
Baker Creek above N. Thompson (BAKER Gauge)	2,976	2,009	32%
Jones Creek above N. Thompson (JONESUS Gauge)	5,333	4,983	7%

Table 11.5-4. Predicted Reduction of Baseflows in the Creeks at Post-Closure

Hydrometric Station (Gauge I.D.)	Baseline Simulated Baseflow (m^3/day)	Post-Closure Simulated Baseflow (m^3/day)	Flow Reduction Percentage (%)
P Creek above Harper Creek (OP Gauge)	1,228	177	86%
Harper Creek above T Creek (HARPERUS Gauge)	20,267	16,777	17%
T Creek above Harper Creek (TSFDS Gauge)	9,103	3,630	60%[A]
Harper Creek at WSC Station (08LB076 Gauge)	62,266	47,307	24%
Baker Creek above N. Thompson (BAKER Gauge)	2,976	2,170	27%
Jones Creek above N. Thompson (JONESUS Gauge)	5,333	5,050	5%

[A] *The 60% baseflow reduction for T Creek does not include the contribution from TMF spillway discharge in Post-Closure.*

Non-PAG Waste Rock Stockpile

The storage of the non-PAG waste rock stockpile is expected to potentially increase the recharge into the groundwater system under the footprint due to the water mounding likely to occur within the stockpile, and therefore to cause some moderate changes to the groundwater level elevations and flow patterns (e.g., flow directions and hydraulic gradients) in the local. The changes are expected to occur during Operations, Closure, and Post-Closure, despite that the stockpile will be reclaimed at Operations 2 and Closure. The magnitudes of the potential changes will be much smaller in comparison with the changes to be caused by the pit dewatering and refilling (Figure 11.5-3).

However, the baseflow is predicted to reduce by up to 86% in the P Creek by the end of Operations, as well as during Closure/Post-Closure, due to the occupancy of the stockpile and loss of the catchment.

The flow particle-tracking pathlines (Figure 11.5-8) indicate that the groundwater (as seepage) under the footprint of the non-PAG waste rock stockpile will dominantly flow into the P Creek catchment during Operations and Closure/Post-Closure, except for some flows towards the open pit when it is dewatered.

PAG and Non-PAG LGO Stockpiles

The PAG and non-PAG LGO stockpiles to be stored outside the TMF (between the TMF and the non-PAG waste rock stockpile) is expected to slightly increase the recharge into the groundwater system under the footprint due to the potential water mounding within the stockpiles, and therefore may cause some moderate changes to the groundwater level elevations and flow patterns (e.g., flow directions and hydraulic gradients) in the local footprints. The changes are expected to occur mainly in Operations 1, as the ores in the stockpiles will be processed and removed in Operations 2. The changes due to the non-PAG stockpile are expected to be in a very short duration, as the ores will be processed in the first 5 years of Operations 1. Due to the small sizes of the LGO stockpiles and with the consideration that the PAG stockpile is underlain by a low-permeability overburden liner, the magnitudes of the potential changes to groundwater quantity by these facilities will be much smaller in comparison with the pit and the non-PAG waste rock stockpile. They are not predicted to affect the baseflows of any creeks down-gradient.

The flow particle-tracking pathlines (Figures 11.5-9 and 11.5-10) indicate that the groundwater (as seepage) under the footprints of the PAG and non-PAG LGO stockpiles will dominantly flow into P Creek (towards the non-PAG waste rock stockpile) and Harper Creek, while some water from the PAG LGO stockpile could flow towards the TMF.

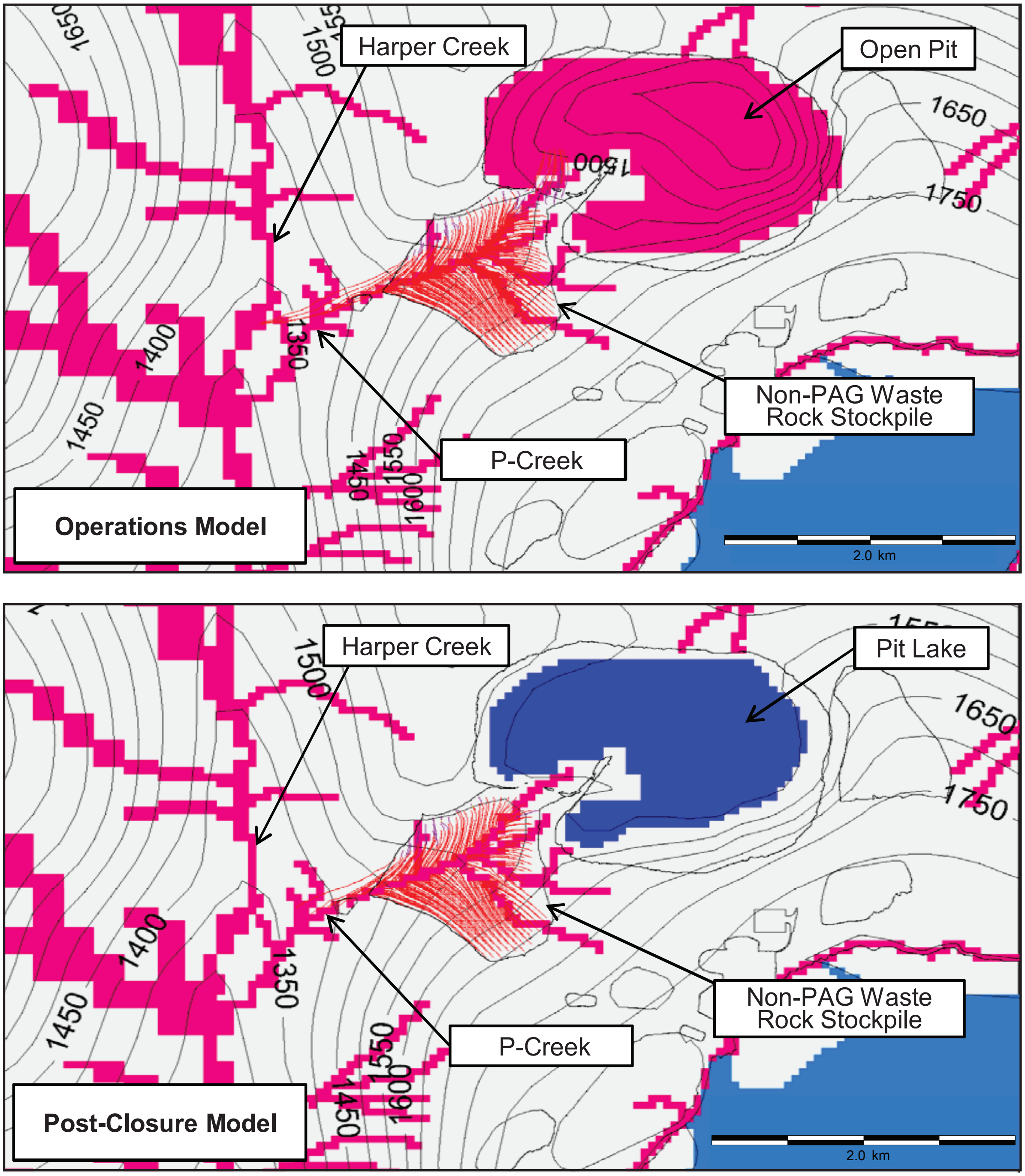
The potential effect of the non-PAG LGO stockpile to be stored inside the TMF on groundwater quantity is accounted in the overall effect of the TMF, and it is discussed in the following TMF section.

Overburden and Topsoil Stockpiles

Similar to other stockpiles, the overburden stockpile is expected to slightly increase the recharge into the groundwater system under the footprint due to the potential water mounding within the stockpile, and therefore may cause some moderate changes to the groundwater level elevations and flow patterns (e.g., flow directions and hydraulic gradients) in the local. The changes are expected to occur throughout the mine life, despite the stockpile being reclaimed at Closure. However, the magnitude of the potential changes to groundwater quantity by the overburden stockpile will be much lower in comparison with the pit. It is not predicted to affect the baseflows of the nearby Baker and Jones creeks. The topsoil stockpiles are also expected to slightly increase the recharge into the groundwater system under their footprints, and therefore, may cause some moderate changes to the groundwater level elevations and flow patterns in the local. However, the effect will be reversed once the topsoil stockpiles are used for reclamation and removed at Operations and Closure.

Figure 11.5-8

Predicted Flow Particle-tracking Pathlines of Seepage from the Non-PAG Waste Rock Stockpile at End of Operations and Post-Closure



Notes: 1. Particle traces are coloured according to the model layer they are travelling in.

2. Particles were inserted into layer 1 and tracked forward from source to sink.

3. The contours shown above are of water table elevation (masl).

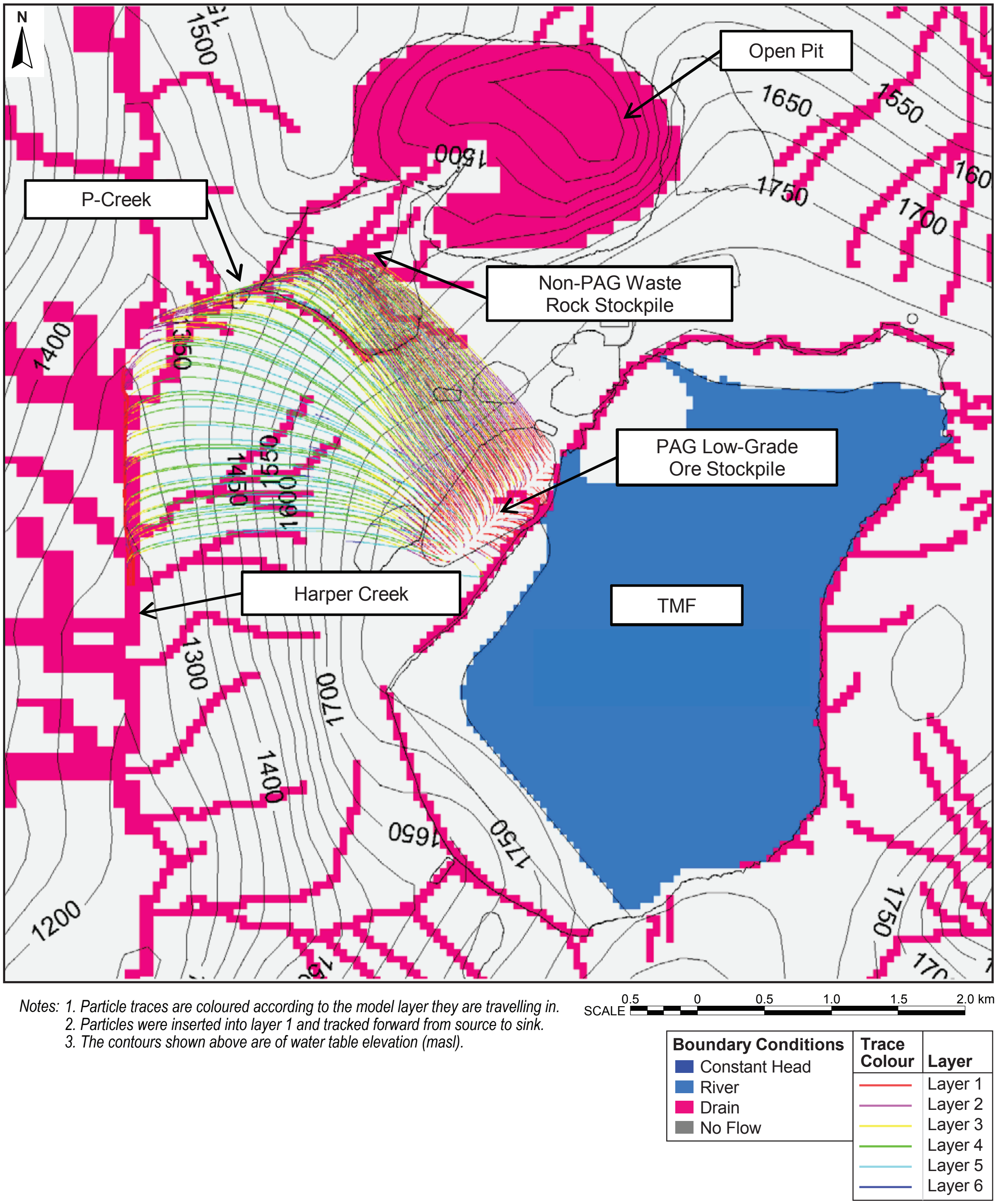
Boundary Conditions
■ Constant Head
■ River
■ Drain
■ No Flow

Trace Colour	**Layer**
—	Layer 1
—	Layer 2
—	Layer 3
—	Layer 4
—	Layer 5

Source: Knight Piésold Consulting (2014).

Figure 11.5-9

Predicted Flow Particle-tracking Pathlines of Seepage from the PAG Low-grade Ore Stockpile at Operations

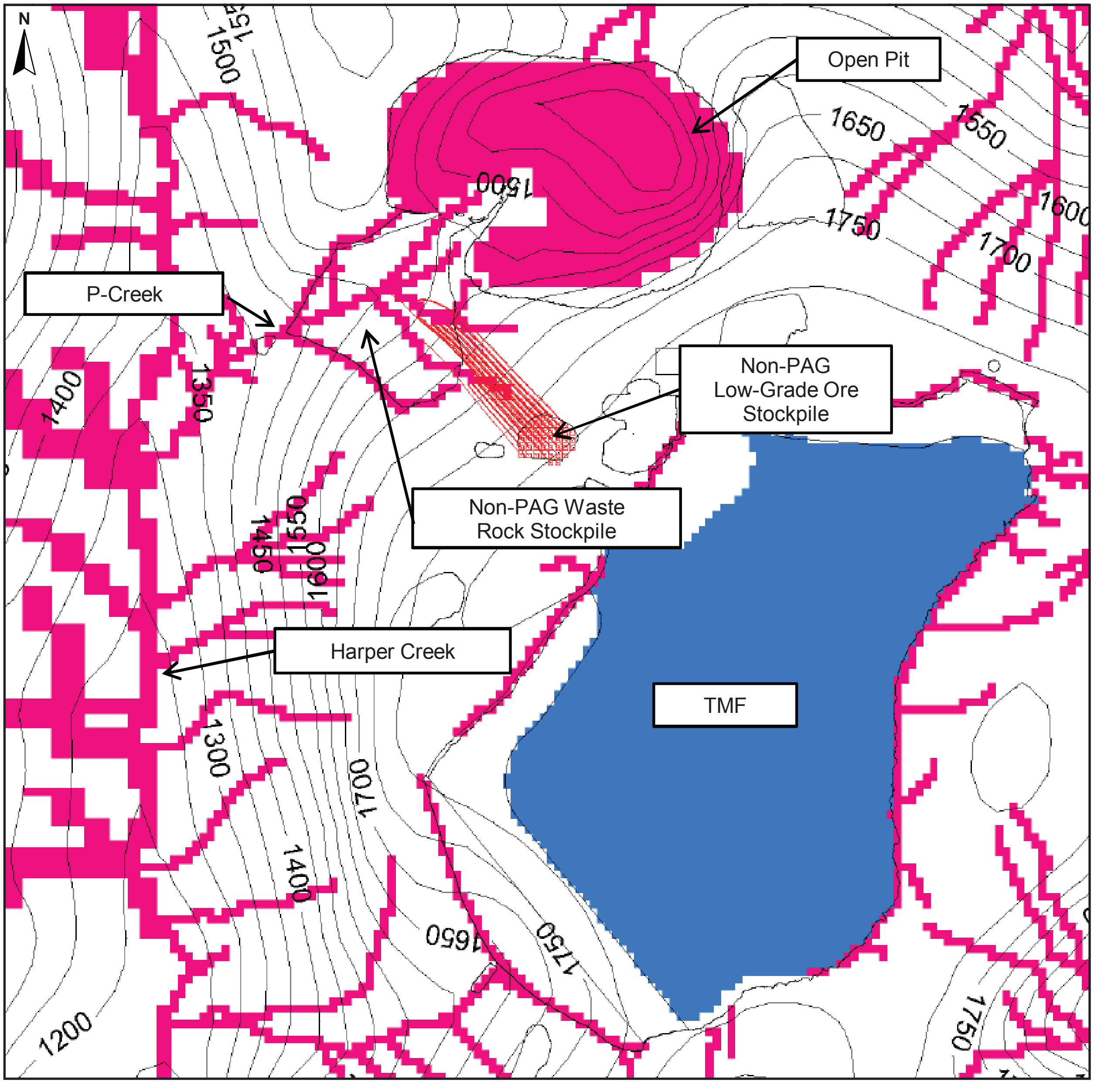


Notes: 1. Particle traces are coloured according to the model layer they are travelling in.
2. Particles were inserted into layer 1 and tracked forward from source to sink.
3. The contours shown above are of water table elevation (masl).

Source: Knight Piésold Consulting (2014).

Figure 11.5-10

Predicted Flow Particle-tracking Pathlines of Seepage from the Non-PAG Low-grade Ore Stockpile at Operations



Notes: 1. Particle traces are coloured according to the model layer they are travelling in.
2. Particles were inserted into layer 1 and tracked forward from source to sink.
3. The contours shown above are of water table elevation (masl).

Boundary Conditions
🟦 Constant Head
🟦 River
🟥 Drain
⬛ No Flow

Trace Colour	Layer
—	Layer 1
—	Layer 2
—	Layer 3
—	Layer 4
—	Layer 5
—	Layer 6

Source: Knight Piésold Consulting (2014).

Tailings Management Facility

According to the Project designs (available in Chapter 5, Project Description), the final stage of the main embankment of the TMF is designed to reach an elevation of 1,836 m, which is approximately 185 m in height at the maximum dam section. According to the numerical groundwater modelling results (Appendix 11-B), the storage of the tailings materials and pond, together with the co-disposed PAG waste rock stockpile and non-PAG LGO stockpile, will cause significant changes to groundwater quantity. As shown in Figure 11.5-3, the groundwater elevations (hydraulic heads) are predicted to increase to over 1,800 masl under the TMF footprint, as well as the immediate surrounding area, due to the storage of these facilities during Operations, Closure, and Post-Closure. As a result, the flow directions and hydraulic gradients in the local TMF valley, as well as the groundwater divide will be altered dramatically from the baseline pre-mining conditions (see the comparison of the solid and dash lines in Figure 11.5-3 for the groundwater divide change). In addition, the storage of the tailings pond water, and the deposits of the tailings, waste rock, and ores will change the permeability and the recharge under the footprints of the TMF (and PAG-waste rock stockpile and non-PAG LGO stockpiles).

The flow particle-tracking simulation results (Figure 11.5-11) indicate that the TMF cell will become a source of groundwater recharge, discharging contact water into the downstream groundwater systems in the catchments of T Creek, Harper Creek, and Jones Creek. The model predicts that some contact water from the TMF will also discharge towards the pit and pit lake, as well as the non-PAG waste rock stockpile. As a contrast, the TMF valley at the baseline pre-mining conditions is receiving groundwater discharge from the surrounding areas. The model results do not suggest that the water levels in the downstream groundwater supply wells would be affected by the TMF.

Finally, as shown in Tables 11.5-3 and 11.5-4, the groundwater discharge (as baseflow) in T Creek is predicted to reduce by 60% during Operations, Closure, and Post-Closure, due to the occupancy of the TMF (and the PAG waste rock and non-PAG LGO stockpiles), the loss of catchment, and the water retention within the TMF.

Characterization of Residual Effects on Groundwater Quantity

Residual effects on groundwater quantity were characterized for the mine phases: Construction, Operations, Closure, and Post-Closure, using the criteria defined in Table 11.5-5. The magnitude, geographic extents, duration, frequency, reversibility, and ecological context were considered in determining the significance of each effect.

Magnitudes were assessed by comparing the changes of groundwater levels and flow patterns, as well as groundwater discharge (as baseflow) into creeks that are predicted to occur, relative to the baseline pre-mining conditions. The magnitudes were also assessed with the consideration of the potential changes of water levels and yields in the existing groundwater supply wells downstream of the mine site. The magnitudes were categorized into four levels: negligible, low, medium, and high.

Geographic extents were assessed with consideration for the spatial extents of the predicted changes of groundwater levels and flow patterns relative to the study area boundaries (LSA and RSA) that have been established (defined in Section 11.3.2). Four spatial extents were assessed for the effect: discrete, local, regional, and beyond regional.

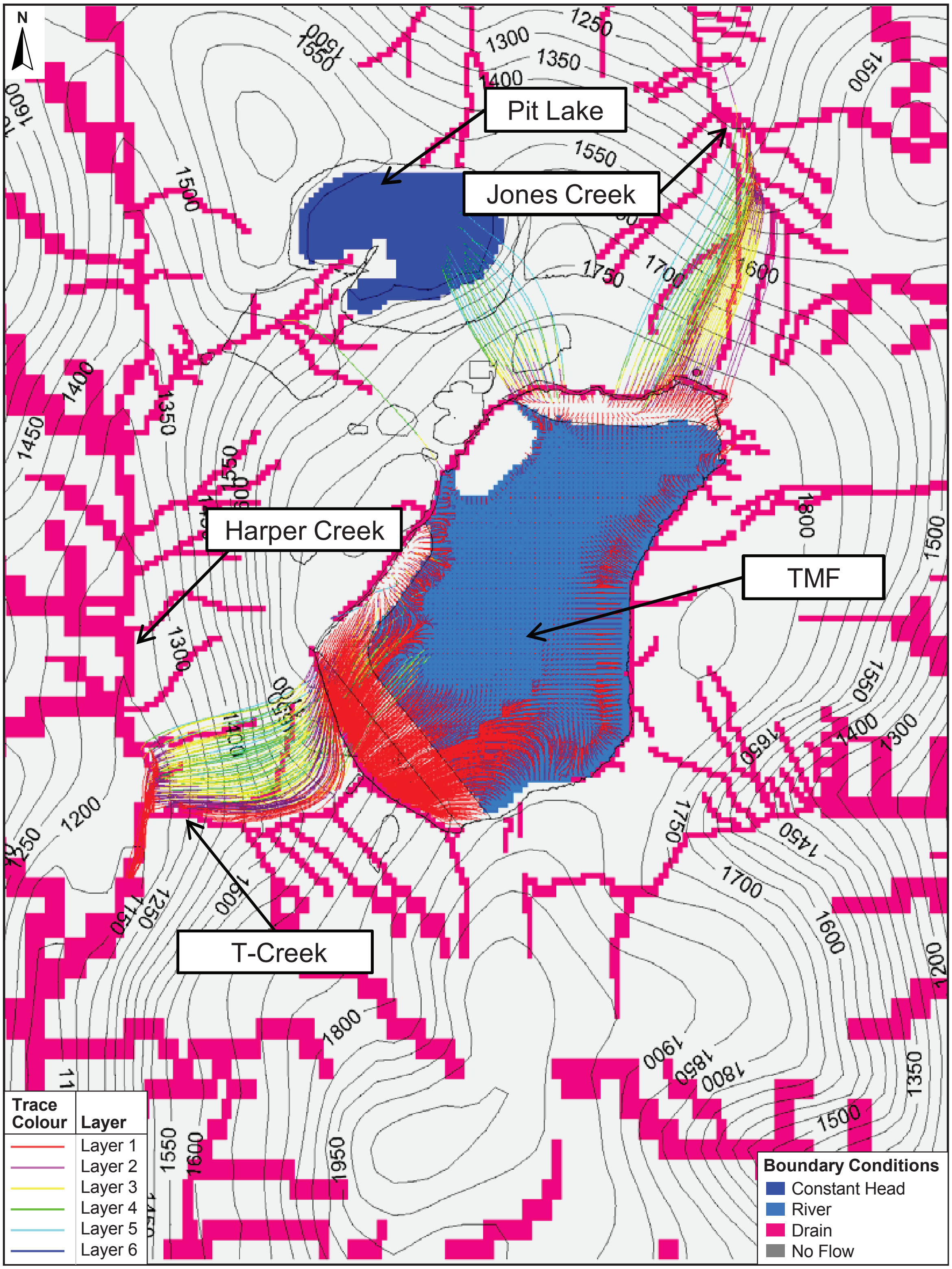
Table 11.5-5. Definitions of Specific Characterization Criteria for Groundwater Quantity

Timing	Magnitude	Geographic Extent	Duration	Frequency	Reversibility	Ecological Context
Construction	**Negligible** No or very little predicted changes to groundwater levels and flow patterns.	**Discrete** Effect is limited to the Project Site	**Short term** Effect lasts 1 to 5 years.	**One Time** Effect occurs once during any phase of the Project.	**Reversible** Effect can be reversed.	**Low** No effect on groundwater quantity is expected at receptors (surface water habitat, groundwater users).
Operations[1]	**Low** Predicted changes to groundwater levels or flow patterns are within the baseline range of variability. Change of groundwater discharge (as baseflow) into creeks is within 10% of baseline conditions. No changes to water levels and yields in the existing groundwater supply wells at downstream of the mine site are expected.	**Local** Effect extends beyond the Project Site, but does not extend beyond an immediate tributary catchment basin draining the Project Site and the LSA.	**Medium term** Effect lasts 6 to 28 years.	**Sporadic** Effect occurs at sporadic or intermittent intervals during any phase of the Project.	**Partially reversible** Effect can be partially reversed.	**Neutral** The effect on groundwater quantity is expected at receptors, but the magnitude of the effect to the receptors is expected to be low.
Closure	**Medium** Predicted changes to groundwater levels or flow patterns exceed the baseline range of variability. Change of groundwater discharge (as baseflow) into creeks is within 50% of baseline conditions, or moderate changes to water levels and yields in the existing groundwater supply wells at downstream of the mine site are expected.	**Regional** Effect extends beyond the LSA boundaries and across the broader region of the RSA.	**Long term** Effect lasts 29 to 50 years.	**Regular** Effect occurs on a regular basis during any phase of the Project.	**Irreversible** Not feasible to reverse the effect.	**High** The effect on groundwater quantity is expected at receptors, and the magnitude of the effect is expected to be medium or high.
Post-Closure	**High** Predicted changes to groundwater levels or flow patterns exceed the baseline range of variability. Considerable changes to the locations of groundwater divides from the baseline conditions, or change of groundwater discharge (as baseflow) into creeks by more than 50% of baseline conditions, or significant changes to water levels and yields in the existing groundwater supply wells at downstream of the mine site are expected.	**Beyond regional** Effect extends beyond the RSA boundaries.	**Far future** Effect lasts longer than 50 years.	**Continuous** Effect occurs constantly during any phase of the Project.		

[1] *Include Operation 1 (from Year 1 to Year 23) and Operation 2 (from Year 24 to Year 28).*

Figure 11.5-11

Predicted Flow Particle-tracking Pathlines of Seepage from the Tailings Management Facility and PAG Wasterock Stockpile at End of Operations and Post-Closure



Notes: 1. Particle traces are coloured according to the model layer they are travelling in.
2. Particles were inserted into layer 1 and tracked forward from source to sink.
3. The contours shown above are of water table elevation (masl).

Source: Knight Piésold Consulting (2014).

Durations were assessed with reference to the temporal boundaries that have been set based on the designed mine phases and lengths of the phases (see Section 11.3.2). The durations were classified into four: short-term, medium-term, long-term, and far-future.

Frequencies were determined with consideration for the nature of the occurrence of the predicted changes of groundwater quantity. The changes were characterized to occur once (one time) only during any phase of the Project, sporadically during any phase of the Project, regularly during any phase of the Project, and continuously or constantly throughout the mine life.

The reversibility criteria account for the likelihoods that the effect will be reversed, or could be reversed (e.g., recovery of water levels with water management in the pit lake). Three criteria were used: reversible, partially reversible, and irreversible.

The context criteria account for the degrees to which existing groundwater receptors are expected to experience the effect (e.g., reduction of water levels and baseflows). The criteria used address the manner that groundwater in the region is valued: as a component of surface water and a resource for human use.

Open Pit and Pit Lake

The open pit dewatering results in high magnitude declines in water levels and therefore significant changes of flow patterns (flow directions, hydraulic gradients, and water divides) at the local scale (within the LSA) during the Construction and Operations phases. The effect is continuous in nature with the maximum decrease of the water levels in the open pit by up to 350 m, but will be partially reversed when dewatering ceases at the end of Operations 1. The drawdown cone and capture zone of the open pit will extend 1 to 3 km into the P Creek and Baker Creek watersheds. Groundwater discharge (as baseflow) will be reduced by a maximum of 32% in Baker Creek and 7% in Jones Creek, as a result of excavation and dewatering of the open pit by the end of Operations 1. The ecological context is expected to be high, as the reduction of the baseflows in the creeks could potentially affect the fish habitat (see Chapter 14 for Fish and Aquatic Resources assessment), despite no effect to the existing water supply wells down-gradient of the open pit being predicted.

At Operations 2, Closure and Post-Closure, the mined open pit will be refilled as a pit lake up to the design elevation at 1,530 masl. The groundwater surrounding the pit will recover to the lake surface elevation, but not completely recover to the pre-mining conditions. Groundwater discharge (as baseflow) will be reduced by 27% in Baker Creek and 5% in Jones Creek. The magnitude of the residual effect is expected to be medium, and it will be continuous in nature, extending into the far future and partially reversible. The ecological context is expected to be high, as the reduction of the baseflows in the creeks could potentially affect the fish habitat (see Chapter 14 for Fish and Aquatic Resources assessment), despite no effect to the existing water supply wells down-gradient of the pit lake being predicted.

Non-PAG Waste Rock Stockpile

The storage of the non-PAG waste rock stockpile will increase the recharge into the groundwater system under the footprint, due to the potential water mounding in the stockpile, and affecting the groundwater flow patterns in the local area. This effect will be continuous in nature during Operations, Closure, and Post-Closure, despite that the stockpile will be reclaimed during

Operations 2 and Closure. Groundwater discharge (as baseflow) is predicted to reduce by up to 86% in the P Creek by the end of Operations, as well as during Closure/Post-Closure, due to the occupancy of the stockpile and loss of the catchment. The magnitude of the effect is high in terms of the reduction of the P Creek baseflow, and the effect may be reversible after a long duration at Post-Closure when the system reaches equilibrium. The ecological context is expected to be high (see Chapter 14 for Fish and Aquatic Resources assessment), as the reduction of the baseflow in the P Creek could potentially affect the fish habitat down-gradient of the facility (This has been taken into account by the Fish Habitat Compensation Plan).

PAG and Non-PAG LGO Stockpiles

The storage of PAG and non-PAG LGO stockpiles outside the TMF (between the TMF and the non-PAG waste rock stockpile) potentially increases the recharge into the groundwater system under the footprints and affects the groundwater flow patterns in the local. The magnitude of the effect on groundwater quantity is expected to be low or medium by considering the sizes of the stockpiles. The effect will be continuous but limited during Operations 1 only, and it will be reversed afterwards, as the ores will be processed during Operations 2 and completely removed at Closure. The ecological context is expected to be low, considering the magnitude of the effect.

Overburden and Topsoil Stockpiles

The storage of overburden in the stockpile will increase the recharge into the groundwater system under the footprint and affect the groundwater flow patterns in the local. The effect will be continuous throughout the mine life and is expected to be irreversible. The magnitude of the effect is estimated to be relatively low, in comparison with the effects of the pit and pit lake nearby. Therefore, the ecological context is expected to be low.

The storage of topsoil in the stockpiles will increase the recharge into the groundwater system under the footprint and affect the groundwater flow patterns in the local. The effect will be limited in duration from Construction to Closure, as the soil will be used for mine reclamation and the stockpiles will be removed at Closure. The effect will be of a low magnitude, will be reversed at Post-Closure, and is considered to be low for the ecological context.

Tailings Management Facility

The construction of the TMF dams and embankments will affect the water levels and flow in the subsurface. The storage of the tailings (and the co-disposed PAG waste rock and non-PAG LGO stockpiles), the storage of the mine water collected from the pit dewatering and the pit lake, and the seepage collected from the stockpiles into the TMF during Operations and Closure/Post-Closure will result in a significant rise in the groundwater levels and change the flow patterns under the TMF footprint and surrounding area. The groundwater divide in the local TMF valley has been predicted to shift significantly. The storage of the low-permeable tailings materials will also alter the overall permeability inside the TMF valley. The effect is continuous in nature throughout and after the mine, and it is irreversible as the TMF is a permanent mine facility. Groundwater discharge (as baseflow) is predicted to reduce by 60% in T Creek and over 20% in Harper Creek downstream, due to the loss of the catchment. The magnitude of the effect would be high. The ecological context is expected to be high, as the effect of reduction of the baseflows in T Creek and Harper Creek could potentially affect the fish habitat down-gradient of the facility (This has been taken into account by the Fish Habitat Compensation Plan).

Likelihood of Residual Effects on Groundwater Quantity

Likelihood refers to the probability of the predicted residual effect occurring on groundwater quantity and is determined according to the attributes identified in Table 11.5-6 below.

Table 11.5-6. Attributes of Likelihood of Effects

Probability Rating	Quantitative Threshold
High	> P80 (effect has > 80% chance of effect occurring)
Moderate	P40 - P80 (effect has 40 - 80% chance of effect occurring)
Low	< P40 (effect has < 40% chance of effect occurring)

The likelihood would be considered to be high if the probability of the predicted residual effect to occur is greater than 80%. The likelihood would be considered as moderate if the probability of the predicted residual effect to occur is between 40% and 80%. The likelihood would be considered to be low if the probability of the predicted effect to occur is lower than 40%. The criteria were set based on professional judgment and experience.

Using the criteria above, the likelihood of all the identified residual effects on groundwater quantity is high (greater than 80% probability of occurrence). The likelihood of the potential effects of the key mine facilities, including the open pit and pit lake, the non-PAG waste rock stockpile, the PAG and non-PAG LGO stockpiles, and the TMF (and the co-disposed PAG waste rock stockpile and non-PAG LGO stockpile), is assessed based on the predictions of the numerical groundwater modeling. The likelihood of the potential effects of the overburden and topsoil stockpiles is assessed based on professional judgment.

11.5.3.2 Residual Effects on Groundwater Quality

Residual effects on groundwater quality are expected to occur, arising due to seepage of contact water. Project components expected to generate residual effects include the pit lake, the non-PAG waste rock stockpile, the PAG LGO stockpile, and the TMF (and the co-disposed PAG waste rock stockpile and non-PAG LGO stockpile inside the TMF). The residual effect of the pit lake on groundwater quality is expected at Closure and Post-Closure, while the effects of all other facilities are expected to occur during Operations, Closure, and Post-Closure.

Plumes of contact groundwater are expected to develop beneath and down-gradient of Project components that contain or convey contact water in the local areas. The quality of the water in these plumes has been characterized based on the geochemical source terms determined in geochemistry studies conducted for the Project (Chapter 6), and the surface water quality modelling that has been used to predict the quality of the contact water (Appendix 13-B). The extents of the plumes have been assessed based on the flow particle-tracking pathlines predicted by the numerical groundwater model (Appendix 11-B).

Forward particle tracking served as the key component of the groundwater modelling exercises for use in assessing potential plume extents. Particles were placed throughout the footprints of the key Project components, and allowed to move in accordance with the predicted flow system into the down-gradient environment. The pathways taken by the particles represent advective solute transport pathways. The extents of particle pathways beneath and down-gradient of a component indicate the extents of advective solute transport pathways sourced in the components being examined.

The extents of particle pathways were used to estimate the plume extents, and the concentration of contact groundwater within these extents were taken to be 100% of the source concentration without provision for any retardation and attenuation. It is expected that mixing with non-contact groundwater, sorption, and chemical reactions would reduce concentrations of contact groundwater along the flow pathways. Dispersion may result in greater plume extent at considerably diluted contact groundwater concentrations. The approach used to assess concentrations in the predicted plume may be regarded as highly conservative, given the likelihood of dilution along the flow pathways.

Open Pit and Pit Lake

Groundwater modelling has indicated the open pit will behave as a groundwater sink during Construction and Operations. Groundwater near the open pit is predicted to report to it continuously while dewatering is ongoing (Figures 11.5-3, 11.5-4 and 11.5-5). Therefore, no plume of contact groundwater is expected to develop in association with the open pit during Construction and Operations.

Seepage pathways leaving the pit lake have been predicted to travel along the Baker Creek catchment basin and report to Baker Creek (Figure 11.5-6). Travel times from the pit lake to Baker Creek are predicted to vary from 2 to 21 years, with a mean of 13 years (see Table 6.1 in Appendix 11-B). A plume of contact groundwater is expected to develop along the predicted seepage pathways.

Contact groundwater quality in this plume emanating from the pit lake would correspond with predicted water quality in the pit lake (Table 11.5-7). Concentrations of certain metals are predicted to be above freshwater aquatic life guidelines (aluminum, arsenic, cadmium, cobalt, mercury, selenium) and drinking water guidelines (phosphorus, selenium). Seepage from the pit lake has not been predicted to arrive at existing groundwater supply wells situated in the downstream of Baker and Jones Creeks, at the base of the North Thompson River Valley.

Non-PAG Waste Rock Stockpile

Seepage pathways leaving the non-PAG waste rock stockpile have been predicted to report, largely, to the downstream water management pond. Approximately 2% of seepage emanating from the stockpile is predicted to bypass the water management pond, and to travel down the P Creek catchment basin, reporting to P and Harper creeks (Figure 11.5-8). Travel times from the stockpile to the receiving surface water are predicted to vary from less than one year to two years (see Table 6.1 in Appendix 11-B). A plume of contact groundwater is expected to develop along the predicted seepage pathways.

Contact groundwater quality in the plume emanating from the non-PAG waste rock stockpile is expected to correspond with the geochemical source terms for the stockpile (Table 11.5-8).

Concentrations of certain parameters within the plume are predicted to be above freshwater aquatic life guidelines (nitrate, nitrite, arsenic, cobalt, selenium) and drinking water guidelines (sulfate, nitrate, nitrite, antimony, selenium).

PAG LGO Stockpile

Seepage pathways leaving the PAG LGO stockpile have been predicted to report to Harper Creek, P Creek, and the non-PAG waste rock water management pond. Approximately 33% of seepage leaving the stockpile is predicted to discharge into Harper Creek and P Creek downstream of the non-PAG waste rock water management pond (Figure 11.5-9). Travel times from the stockpile to the receiving surface water are predicted to range from 6 to 22 years (see Table 6.1 in Appendix 11-B). A plume of contact groundwater is expected to develop along the predicted seepage pathways.

Contact groundwater quality in the plume emanating from the PAG LGO stockpile is assumed to correspond with the geochemical source term for the stockpile (Table 11.5-9). Concentrations of certain parameters within the plume are predicted to be above freshwater aquatic life guidelines (arsenic, cobalt, selenium) and drinking water guidelines (nitrate, nitrite, antimony, selenium).

The contact groundwater source at the PAG LGO stockpile will be eliminated at the end of the Operations 2 phase, when the PAG LGO will have been processed and the stockpile is removed. A progressive improvement in groundwater quality down-gradient of the stockpile will occur at the Closure and Post-Closure, and the residual effect on groundwater quality likely diminishes over a long-term during the Post-Closure.

Non-PAG Low-grade Ore Stockpiles

Seepage pathways leaving the non-PAG LGO stockpile, to be stored between the TMF and the non-PAG waste rock stockpile have been predicted to report to the non-PAG waste rock stockpile and to be collected in the water management pond (see Figure 11.5-10). Effects down-gradient of the Project footprint are therefore not expected to occur.

It is possible that a low-concentration dispersive plume sourced at this non-PAG LGO stockpile could bypass the non-PAG waste rock water management pond. Monitoring will be conducted at wells down-gradient of the water management pond (refer to the Groundwater Management Plan, Section 24.8). Adaptive management will be undertaken if the established performance objectives are not sustained.

The potential seepage effect from the non-PAG LGO stockpile to be stored inside the TMF to groundwater quality is accounted in the overall effect of the TMF and it is discussed in the following TMF section.

Overburden and Topsoil Stockpiles

Geochemical testing has indicated that metal leaching from the materials that will be placed in the overburden and topsoil stockpiles will be minimal or negligible (Appendix 6-A, ML/ARD Characterization Report). Source concentrations of selenium are expected to be above the FWAL guidelines by a factor of 1.7 or less upon leaving the stockpiles, and are expected to be rapidly diluted to levels below the guidelines. Contact groundwater emanating from these facilities will not be degraded to a degree that warrants further consideration.

Table 11.5-7. Contact Groundwater Quality along Flow Pathways Emanating from the Pit Lake into the Baker Creek Catchment Basin

	Guidelines		Baseline[D]			Predicted[C]		
Parameter	WQG FAL[A]	WQG DW[B]	Mean	Standard Deviation	95th Percentile	Operations II: Years 24-28 95th Percentile	Closure & Post-Closure: Years 29 to 50 95th Percentile	Post-Closure: Years 50 to 100 95th Percentile
Hardness (as $CaCO_3$)			118	10.0	130	881	730	261
Anions								
Chloride	150	250	1.3	0.014	1.3	14	14	5.1
Fluoride	Note F	1	0.26	0.022	0.29	0.86	0.79	0.27
Sulfate	Note G	500	27	9.2	42	482	467	194
Dissolved Nutrients								
Orthophosphate			0.024	0.030	0.065	0.085	0.072	0.024
Nitrate (as N)	3	10	<0.0050	na	na	0.0073	0.0057	0.0020
Nitrite (as N)	Note H	1	<0.0010	na	na	0.0018	0.0014	0.00049
Ammonia (as N)	Note V		0.045	0.012	0.064	0.028	0.022	0.0076
Dissolved Metals[E]								
Aluminum	Note J	0.2	0.0043	0.0061	0.014	***0.18***	***0.17***	***0.11***
Antimony	0.2[W]	0.014[W]	0.00024	0.00027	0.00067	0.0057	0.0054	0.0022
Arsenic	0.005	0.025[S]	0.00034	0.00043	0.0010	***0.012***	***0.011***	0.0043
Barium	1[X]		0.039	0.0093	0.048	0.072	0.066	0.027
Berilium	0.0053[X]	0.004[X]	<0.00010	na	na	5.2E-05	5.2E-05	6.3E-05
Bismuth			<0.00050	na	na	0.00026	0.00024	9.8E-05
Boron	1.2	5.0	<0.010	na	0.013	0.31	0.28	0.12
Cadmium	Note T		<0.000010	na	na	***0.0019***	***0.0019***	***0.00052***
Calcium			15	1.9	18	197	183	86
Chromium	0.0089[U,X]		<0.00010	na	na	0.00052	0.00055	0.00073
Cobalt	0.004		<0.00010	na	na	***0.018***	***0.018***	***0.0048***
Copper	Note K	0.5	<0.00020	na	0.00060	0.035	0.032	0.010
Iron	0.35		0.052	0.032	0.097	0.0062	0.027	0.031
Lead	Note L	0.05	<0.000050	na	na	0.00043	0.00042	0.00024
Lithium			0.035	0.0057	0.044	0.037	0.034	0.012
Magnesium			20	1.8	22	175	168	76
Manganese	Note M		0.057	0.076	0.18	0.42	0.38	0.11
Mercury	0.00002	0.001	<0.00001	na	na	***8.4E-05***	***7.1E-05***	***2.5E-05***
Molybdenum	1	0.25	0.0014	0.0013	0.0035	0.12	0.11	0.034
Nickel	Note N		0.00064	0.00040	0.0012	0.015	0.014	0.0049
Phorsphorus		0.01[R]	<0.30	na	na	0.15	0.12	0.041
Potassium			2.8	0.62	3.8	14	13	4.7
Selenium	0.002	0.01	<0.00010	na	na	***0.018***	***0.017***	***0.0067***
Silicon			5.1	0.30	5.5	22	20	7.1
Silver	Note P		<0.000010	na	na	0.00018	0.00017	6.7E-05
Sodium			18	5.2	27	9.9	8.4	2.8
Strontium			2.2	0.19	2.5	2.6	2.4	0.85
Sulfur			9.0	5.2	15	65	53	15
Thallium	0.0003[W]		<0.000010	na	na	0.00011	0.00011	4.8E-05
Tin			<0.00010	na	na	0.0079	0.0077	0.0022
Titanium			<0.010	na	na	0.013	0.012	0.0056
Uranum	0.3[W]		0.00098	0.00050	0.0018	0.0030	0.0029	0.0012
Vanadium	0.006[W]		<0.0010	na	na	0.0043	0.0042	0.0020
Zinc	Note Q	5	0.0033	0.0027	0.0072	0.21	0.21	0.058

Notes:

All concentrations presented in units of mg/L

Thick cell borders indicate values above 95th percentile baseline concentration.

[A] *British Columbia Approved and Working Water Quality Guidelines (BC MOE 2014) for Freshwater Aquatic Life. Approved guidelines for chronic exposure (30 day average) are listed where both maximum and chronic guidelines exist. Bold/underlined values exceed the corresponding guideline.*

[B] *British Columbia Approved Water Quality Gudielines (BC MOE 2014) for Drinking Water. Shaded values exceed the corresponding guideline.*

[C] *Parameter concentrations are representative of surface water quality model (Appendix 13-C) expected case 95th percentile Open Pit water. Calculated for each time frame indicated.*

[D] *Baseline groundwater quality in the Baker Creek catchment basin downgradient of the Pit Lake was determined based on samples collected from MW10-04.*

[E] *All metals guidelines are intended for total concentrations, except those for aluminum and iron.*

[F] *Fluoride - if hardness (as $CaCO_3$) is 10 mg/L the maximum concentration is 0.4 mg/L; otherwise LC_{50} = -51.73 + 92.57 $\log_{10}$ (hardness) * 0.01 mg/L.*

[G] *Sulphate - if hardness is very soft (0-30 mg/L) the guideline is 128 mg/L; if soft to moderately soft (31-75 mg/L) then 218 mg/L; if moderately soft/hard to hard (76-180 mg/L) then 309 mg/L; if very hard (181-250 mg/L) then 429 mg/L; if hardness >250 mg/L then the guideline needs to be determined based on site water.*

[H] *Nitrite - if chloride <2 mg/L the guideline is 0.02 mg/L, if chloride 2-4 mg/L then 0.04 mg/L, if chloride 4-6 mg/L then 0.06 mg/L, if chloride 6-8 mg/L then 0.08 mg/L, if chloride 8-10 mg/L then 0.1 mg/L and if chloride >10 mg/L then 0.2 mg/L.*

[J] *Dissolved aluminum - if pH ≥ 6.5 the maximum concentration is 0.1 mg/L and the 30-day mean is 0.05 mg/L; if pH < 6.5 the maximum concentration is $e^{(1.209 - 2.426pH + 0.286 K)}$ mg/L where K = $(pH)^2$ and the 30-day mean is $e^{1.6 - 3.327\,(median\ pH) + 0.402\,K)}$ mg/L where K = $(median\ pH)^2$.*

[K] *Copper - If average water hardness (as $CaCO_3$) ≤ 50 mg/L the 30-day mean is ≤ 0.002 mg/L; if average water hardness is > 50 mg/L the 30-day mean is ≤ 0.00004(mean hardness) mg/L.*

[L] *Lead - 30-day mean guideline is hardness-dependent: $3.31+e^{1.273Ln(hardness)-4.704}$ / 1000 mg/L.*

[M] *Manganese - 30-day mean concentration = 0.0044(hardness)+0.605 mg/L.*

[N] *Nickel - if hardness (as $CaCO_3$) is 0-60 mg/L the maximum concentration is 0.025 mg/L; if hardness 60-120 mg/L maximum concentration of 0.065 mg/L; if hardness 120-180 mg/L maximum concentration of 0.110 mg/L; if hardness >180 mg/L maximum concentration of 0.150 mg/L.*

[P] *Silver - if hardness is ≤ 100 mg/L the 30-day mean guideline is 0.00005 mg/L; if hardness > 100 mg/L the 30-day mean guideline is 0.0015 mg/L.*

[Q] *Zinc - 30-day mean concentration = 7.5 + 0.75(hardness - 90) / 1000 mg/L.*

[R] *For lakes used as a source of drinking water.*

[S] *Interim guideline*

[T] *Draft Cadmium guideline released June 2014, not approved at time of writing. 30 day mean guideline = 0.02 to $e^{0.762Ln(Hardness)-6.07}$ to 0.172 µg/L*

[U] *Indicated chromium guideline intended for Cr (III) under ministry review for possible formal approval at time of writing.*

[V] *Ammonia guideline pH and Temperature-dependent, and intended for surface water temperatures - provided as benchmark only in groundwater assessment.*

[W] *Working water quality guidelines*

[X] *Working water quality guideline, under ministry review for possible formal approval at time of writing.*

Table 11.5-8. Contact Groundwater Quality along Flow Pathways Emanating from the Non-PAG Waste Rock Stockpile into the P Creek and Harper Creek Catchment Basins

Parameter	Guidelines		Baseline [D]			Predicted [C]
	WQG FAL [A]	WQG DW [B]	Mean	Standard Deviation	95th Percentile	
Hardness (as $CaCO_3$)			79	61	127	1300
Anions						
Chloride	150	250	0.64	0.012	0.65	42
Fluoride	Note F	1	0.42	0.33	0.83	0.86
Sulfate	Note G	500	21	4.0	24	2620
Dissolved Nutrients						
Orthophosphate			0.019	0.029	0.063	0.0E+00
Nitrate (as N)	3	10	<0.0050	na	na	***120***
Nitrite (as N)	Note H	1	<0.0010	na	na	***2.8***
Ammonia (as N)	Note V		0.050	0.016	0.063	***16***
Dissolved Metals [E]						
Aluminum	Note J	0.2	0.0073	0.0040	0.013	0.034
Antimony	0.2 [W]	0.014 [W]	<0.00010	na	na	0.037
Arsenic	0.005	0.025 [S]	0.0023	0.0018	0.0041	***0.025***
Barium	1 [X]		0.027	0.020	0.042	0.071
Berilium	0.0053 [X]	0.004 [X]	<0.00010	na	na	5.0E-05
Bismuth			<0.00050	na	na	0.00025
Boron	1.2	5.0	<0.010	na	0.012	0.30
Cadmium	Note T		<0.000010	na	na	0.00047
Calcium			24	19	39	200
Chromium	0.0089 [U,X]		<0.00010	na	na	0.00050
Cobalt	0.004		<0.00010	na	na	***0.013***
Copper	Note K	0.5	<0.00020	na	na	0.049
Iron	0.35		0.064	0.051	0.12	0.0050
Lead	Note L	0.05	<0.000050	na	na	0.00057
Lithium			0.0031	0.0037	0.0078	0.061
Magnesium			4.6	3.5	7.3	195
Manganese	Note M		0.16	0.11	0.24	0.42
Mercury	0.00002	0.001	<0.00001	na	na	0.0E+00
Molybdenum	1	0.25	0.0023	0.0012	0.0034	0.12
Nickel	Note N		<0.00050	na	na	0.026
Phorsphorus		0.01 [R]	0.100	0.100	<0.050	0.0E+00
Potassium			2.1	1.1	3.1	60
Selenium	0.002	0.01	<0.00010	na	na	***0.16***
Silicon			4.3	0.27	4.7	4.7
Silver	Note P		<0.000010	na	na	0.00019
Sodium			40	49	100	17
Strontium			0.13	0.065	0.18	10.0
Sulfur			7.5	1.1	8.4	0.0E+00
Thallium	0.0003 [W]		<0.000010	na	na	0.00026
Tin			<0.00010	na	na	0.0014
Titanium			<0.010	na	na	0.0050
Uranum	0.3 [W]		0.0017	0.0011	0.0026	0.028
Vanadium	0.006 [W]		<0.0010	na	na	0.0010
Zinc	Note Q	5	<0.0010	na	na	0.039

Notes:

All concentrations presented in units of mg/L

Thick cell borders indicate values above 95th percentile baseline concentration.

[A] *British Columbia Approved and Working Water Quality Guidelines (BC MOE 2014) for Freshwater Aquatic Life. Approved guidelines for chronic exposure (30 day average) are listed where both maximum and chronic guidelines exist. Bold/underlined values exceed the corresponding guideline.*

[B] *British Columbia Approved Water Quality Gudielines (BC MOE 2014) for Drinking Water. Shaded values exceed the corresponding guideline.*

[C] *Parameter concentrations are representative of surface water quality model (Appendix 13-C) expected case 95th percentile Open Pit water. Calculated for each time frame indicated.*

[D] *Baseline groundwater quality in the Baker Creek catchment basin downgradient of the Pit Lake was determined based on samples collected from MW10-04.*

[E] *All metals guidelines are intended for total concentrations, except those for aluminum and iron.*

[F] *Fluoride - if hardness (as $CaCO_3$) is 10 mg/L the maximum concentration is 0.4 mg/L; otherwise $LC_{50} = -51.73 + 92.57 \log_{10}$ (hardness) * 0.01 mg/L.*

[G] *Sulphate - if hardness is very soft (0-30 mg/L) the guideline is 128 mg/L; if soft to moderately soft (31-75 mg/L) then 218 mg/L; if moderately soft/hard to hard (76-180 mg/L) then 309 mg/L; if very hard (181-250 mg/L) then 429 mg/L; if hardness >250 mg/L then the guideline needs to be determined based on site water.*

[H] *Nitrite - if chloride <2 mg/L the guideline is 0.02 mg/L, if chloride 2-4 mg/L then 0.04 mg/L, if chloride 4-6 mg/L then 0.06 mg/L, if chloride 6-8 mg/L then 0.08 mg/L, if chloride 8-10 mg/L then 0.1 mg/L and if chloride >10 mg/L then 0.2 mg/L.*

[J] *Dissolved aluminum - if pH ≥ 6.5 the maximum concentration is 0.1 mg/L and the 30-day mean is 0.05 mg/L; if pH < 6.5 the maximum concentration is $e^{(1.209 - 2.426pH + 0.286 K)}$ mg/L where $K = (pH)^2$ and the 30-day mean is $e^{1.6 - 3.327 (median\ pH) + 0.402 K)}$ mg/L where $K = (median\ pH)^2$.*

[K] *Copper - If average water hardness (as $CaCO_3$) ≤ 50 mg/L the 30-day mean is ≤ 0.002 mg/L; if average water hardness is > 50 mg/L the 30-day mean is ≤ 0.00004(mean hardness) mg/L.*

[L] *Lead - 30-day mean guideline is hardness-dependent: $3.31+e^{1.273Ln(hardness)-4.704}$ / 1000 mg/L.*

[M] *Manganese - 30-day mean concentration = 0.0044(hardness)+0.605 mg/L.*

[N] *Nickel - if hardness (as $CaCO_3$) is 0-60 mg/L the maximum concentration is 0.025 mg/L; if hardness 60-120 mg/L maximum concentration of 0.065 mg/L; if hardness 120-180 mg/L maximum concentration of 0.110 mg/L; if hardness >180 mg/L maximum concentration of 0.150 mg/L.*

[P] *Silver - if hardness is ≤ 100 mg/L the 30-day mean guideline is 0.00005 mg/L; if hardness > 100 mg/L the 30-day mean guideline is 0.0015 mg/L.*

[Q] *Zinc - 30-day mean concentration = 7.5 + 0.75(hardness - 90) / 1000 mg/L.*

[R] *For lakes used as a source of drinking water.*

[S] *Interim guideline*

[T] *Draft Cadmium guideline released June 2014, not approved at time of writing. 30 day mean guideline = 0.02 to $e^{0.762Ln(Hardness)-6.07}$ to 0.172 µg/L*

[U] *Indicated chromium guideline intended for Cr (III) under ministry review for possible formal approval at time of writing.*

[V] *Ammonia guideline pH and Temperature-dependent, and intended for surface water temperatures - provided as benchmark only in groundwater assessment.*

[W] *Working water quality guidelines*

[X] *Working water quality guideline, under ministry review for possible formal approval at time of writing.*

Table 11.5-9. Contact Groundwater Quality along Flow Pathways Emanating from the PAG Low-Grade Ore Stockpile into the Harper Creek Catchment Basin

	Guidelines		Baseline [D]			
Parameter	WQG FAL [A]	WQO DW [B]	Mean	Standard Deviation	95th Percentile	Predicted [C]
Hardness (as $CaCO_3$)			79	61	127	1300
Anions						
Chloride	150	250	0.95	0.35	1.2	42
Fluoride	Note F	1	1.1	0.62	**2.0**	0.86
Sulfate	Note G	500	51	96	126	2990
Dissolved Nutrients						
Orthophosphate			0.018	0.011	0.035	0.0E+00
Nitrate (as N)	3	10	<0.0050	na	na	***59***
Nitrite (as N)	Note H	1	<0.0010	na	na	***1.3***
Ammonia (as N)	Note V		0.024	0.019	0.055	***7.4***
Dissolved Metals [E]						
Aluminum	Note J	0.2	0.0078	0.0038	0.014	0.034
Antimony	0.2 [W]	0.014 [W]	<0.00010	na	na	0.037
Arsenic	0.005	0.025 [S]	0.00054	0.00086	0.0014	***0.025***
Barium	1 [X]		0.026	0.0087	0.033	0.071
Berilium	0.0053 [X]	0.004 [X]	<0.00010	na	na	5.0E-05
Bismuth			<0.00050	na	na	0.00025
Boron	1.2	5.0	0.011	0.0090	0.025	0.30
Cadmium	Note T		<0.000010	na	na	0.00047
Calcium			29	42	70	200
Chromium	0.0089 [U,X]		0.00015	0.00018	0.00046	0.00050
Cobalt	0.004		0.00018	0.00025	0.00055	***0.013***
Copper	Note K	0.5	<0.00020	na	na	0.049
Iron	0.35		0.21	0.53	***0.74***	0.0050
Lead	Note L	0.05	<0.000050	na	na	0.00057
Lithium			0.013	0.017	0.042	0.061
Magnesium			8.2	7.3	16	195
Manganese	Note M		0.100	0.11	0.22	0.42
Mercury	0.00002	0.001	<0.000010	na	na	0.0E+00
Molybdenum	1	0.25	0.00094	0.00061	0.0018	0.12
Nickel	Note N		0.0011	0.00037	0.0016	0.026
Phorsphorus		0.01 [R]	<0.30	na	na	0.0E+00
Potassium			1.5	1.4	4.2	60
Selenium	0.002	0.01	<0.00010	na	na	***0.28***
Silicon			4.8	1.2	6.1	4.7
Silver	Note P		<0.000010	na	na	0.00019
Sodium			29	27	70	15
Strontium			0.69	0.54	1.3	10
Thallium	0.0003 [W]		<0.000010	na	na	0.00026
Tin			<0.00010	na	na	0.0014
Titanium			<0.010	na	na	0.0050
Uranum	0.3 [W]		0.00069	0.00055	0.0014	0.026
Vanadium	0.006 [W]		<0.0010	na	na	0.0010
Zinc	Note Q	5	***0.0016***	0.0020	0.0056	0.039

Notes:

All concentrations presented in units of mg/L

Thick cell borders indicate values above 95th percentile baseline concentration.

[A] *British Columbia Approved and Working Water Quality Guidelines (BC MOE 2014) for Freshwater Aquatic Life. Approved guidelines for chronic exposure (30 day average) are listed where both maximum and chronic guidelines exist. Bold/underlined values exceed the corresponding guideline.*

[B] *British Columbia Approved Water Quality Gudielines (BC MOE 2014) for Drinking Water. Shaded values exceed the corresponding guideline.*

[C] *Parameter concentrations are representative of surface water quality model (Appendix 13-C) expected case 95th percentile Open Pit water. Calculated for each time frame indicated.*

[D] *Baseline groundwater quality in the Baker Creek catchment basin downgradient of the Pit Lake was determined based on samples collected from MW10-04.*

[E] *All metals guidelines are intended for total concentrations, except those for aluminum and iron.*

[F] *Fluoride - if hardness (as $CaCO_3$) is 10 mg/L the maximum concentration is 0.4 mg/L; otherwise $LC_{50} = -51.73 + 92.57 \log_{10}$ (hardness) * 0.01 mg/L.*

[G] *Sulphate - if hardness is very soft (0-30 mg/L) the guideline is 128 mg/L; if soft to moderately soft (31-75 mg/L) then 218 mg/L; if moderately soft/hard to hard (76-180 mg/L) then 309 mg/L; if very hard (181-250 mg/L) then 429 mg/L; if hardness >250 mg/L then the guideline needs to be determined based on site water.*

[H] *Nitrite - if chloride <2 mg/L the guideline is 0.02 mg/L, if chloride 2-4 mg/L then 0.04 mg/L, if chloride 4-6 mg/L then 0.06 mg/L, if chloride 6-8 mg/L then 0.08 mg/L, if chloride 8-10 mg/L then 0.1 mg/L and if chloride >10 mg/L then 0.2 mg/L.*

[J] *Dissolved aluminum - if pH ≥ 6.5 the maximum concentration is 0.1 mg/L and the 30-day mean is 0.05 mg/L; if pH < 6.5 the maximum concentration is $e^{(1.209 - 2.426pH + 0.286 K)}$ mg/L where $K = (pH)^2$ and the 30-day mean is $e^{1.6 - 3.327 (median\ pH) + 0.402 K)}$ mg/L where $K = (median\ pH)^2$.*

[K] *Copper - If average water hardness (as $CaCO_3$) ≤ 50 mg/L the 30-day mean is ≤ 0.002 mg/L; if average water hardness is > 50 mg/L the 30-day mean is ≤ 0.00004(mean hardness) mg/L.*

[L] *Lead - 30-day mean guideline is hardness-dependent: $3.31+e^{1.273Ln(hardness)-4.704}$ / 1000 mg/L.*

[M] *Manganese - 30-day mean concentration = 0.0044(hardness)+0.605 mg/L.*

[N] *Nickel - if hardness (as $CaCO_3$) is 0-60 mg/L the maximum concentration is 0.025 mg/L; if hardness 60-120 mg/L maximum concentration of 0.065 mg/L; if hardness 120-180 mg/L maximum concentration of 0.110 mg/L; if hardness >180 mg/L maximum concentration of 0.150 mg/L.*

[P] *Silver - if hardness is ≤ 100 mg/L the 30-day mean guideline is 0.00005 mg/L; if hardness > 100 mg/L the 30-day mean guideline is 0.0015 mg/L.*

[Q] *Zinc - 30-day mean concentration = 7.5 + 0.75(hardness - 90) / 1000 mg/L.*

[R] *For lakes used as a source of drinking water.*

[S] *Interim guideline*

[T] *Draft Cadmium guideline released June 2014, not approved at time of writing. 30 day mean guideline = 0.02 to $e^{0.762Ln(Hardness)-6.07}$ to 0.172 µg/L*

[U] *Indicated chromium guideline intended for Cr (III) under ministry review for possible formal approval at time of writing.*

[V] *Ammonia guideline pH and Temperature-dependent, and intended for surface water temperatures - provided as benchmark only in groundwater assessment.*

[W] *Working water quality guidelines*

[X] *Working water quality guideline, under ministry review for possible formal approval at time of writing.*

Tailings Management Facility

A contact groundwater plume from the TMF (and the co-disposed PAG waste rock stockpile and non-PAG LGO stockpile) is expected to begin developing beneath and down-gradient of the TMF following commencement of water storage in the facility. At Operations and Post-Closure, a portion of seepage leaving the TMF Pond is predicted to bypass the water management drainage systems along the downstream sides of the main and north embankments. Bypassing contact groundwater is predicted to flow along the Jones Creek and T Creek catchments, reporting to Jones, T, and Harper creeks. Plume extents are expected to correspond with the spatial coverage of the simulated particle track pathways sourced in the TMF (see Figure 11.5-11).

Thirteen percent of contact groundwater passing beneath the main embankment is predicted to bypass the water management pond. Travel times from the TMF pond to T or Harper creeks range from 2 to 30 years, with a mean of 12 years.

While much smaller in volume than from the main embankment, eighty-five percent of contact groundwater passing beneath the north embankment is predicted to bypass the water management pond. Travel times from the TMF pond to Jones Creek range from 2 to 20 years, with a mean of 12 years.

Quality of the contact groundwater emanating from the TMF (and the co-disposed PAG waste rock stockpile and non-PAG LGO stockpile) is expected to correspond with the predicted water quality in the TMF pond, with a lag as pond water quality changes. Non-PAG waste rock used in embankment construction may also contribute to the water quality in these plumes. As a permanent facility, the TMF will be a continuous source during Operations, Closure and Post-Closure. Concentrations of certain parameters in the contact groundwater are predicted to be above freshwater aquatic life guidelines (sulfate, nitrate, nitrite, cadmium, cobalt, copper, selenium, zinc) and drinking water guidelines (selenium, phosphorus). Certain parameters are expected to return below guidelines over the long-term during Post-Closure (Table 11.5-10).

Characterization of Residual Effects on Groundwater Quality

Residual effects on groundwater quality were characterized using the criteria defined in Table 11.5-11. The magnitude, geographic extents, duration, frequency, reversibility, and ecological context were considered in determining the significance of each effect.

Magnitudes were assessed by comparing the parameter concentrations expected to occur in the predicted plumes with the baseline groundwater quality and the provincial guidelines. The parameter concentrations were determined by adopting 100% of the water quality in the source without provision for retardation and attenuation, as indicated by the surface water quality model results and as described at the beginning of Section 11.5.3.2.

Extents were assessed with consideration for the plume extents relative to the study area boundaries that have been established (defined in Section 11.3.2). Plume extents are assumed to be limited to the particle tracking flow pathlines predicted by groundwater modelling simulations. Low-concentration dispersive plumes may reach greater extents than indicated by the particle tracks.

Durations were assessed with reference to the particle track flow path durations (discussed earlier in Section 11.5.3.2 and detailed in Appendix 11-B). The evolution of the Project, such as removal or reclamation of stockpiles and development of new components, was also considering in determining the time frames in which effects will begin and end.

Frequencies were determined with consideration for the nature of the mass loading. Continuous mass loading (e.g., continuous infiltration through a stockpile with metal leaching) would be characterized as a continuous frequency. Instantaneous mass loading (e.g., a spill) would be characterized as “one time”.

The reversibility criteria account for the likelihoods that the effect will be reversed or could be reversed (e.g., remediating a plume) with adaptive management. The feasibility of remediation is considered in determining whether an effect may be partially or completely reversed through remediation.

The context criteria account for the degrees to which existing groundwater receptors are expected to experience the effect. These criteria address the manner that groundwater in the region is valued, as a component of surface water and a resource for human use.

Pit Lake

Seepage of contact water from the pit lake (estimated to be 8 L/s) is predicted to be above provincial FWAL and drinking water guidelines for certain parameters (high magnitude). The plume extents are characterized as local because the affected groundwater is predicted to discharge into Baker Creek within the LSA. The effect is continuous in nature during Closure/Post-Closure and expected to be sustained for more than 50 years (far-future duration). The plume is not feasible to remediate (irreversible). The water quality in the existing supply wells down-gradient of the pit lake are not predicted to be affected, but the ecological context is none-the-less regarded as high due to the discharge of contact water into Baker Creek.

Non-PAG Waste Rock Stockpile

A small percentage (less than 2%) of the seepage from this stockpile is predicted to bypass the seepage collection system and migrate towards P Creek and Harper Creek. This seepage is expected to result in high-magnitude changes in groundwater quality along the flow pathways, due to the predicted levels above provincial FWAL guidelines for sulphate, blasting residuals, and certain metals. Extents may be regarded as local, because the plume is predicted to discharge into Harper and P creeks within the LSA (high ecological context). This effect is continuous in nature during Operations, Closure, and Post-Closure (far-future duration) and it is not feasibly reversible.

PAG Low-Grade Ore Stockpile

The plume emanating from the PAG-LGO stockpile is predicted to yield groundwater quality above certain provincial guidelines and the magnitude is therefore regarded as high. The extents of the highest magnitude effect is expected to peak at the end of Operations 1 when the stockpile will begin to shrink at the onset of LGO processing. Extents are regarded as local because the plume is predicted to discharge into Harper Creek and P Creek within the LSA (high ecological context).

Table 11.5-10. Contact Groundwater Quality along Flow Pathways Emanating from the TMF into the T Creek, Harper Creek and Jones Creek Catchment Basins

			Baseline						Predicted[C]				
	Guidelines		Downgradient of Main Embankment[D]			Downgradient of North Embankment[E]			Construction: Years -1 to -2	Operations: Years 1-14	Operations: Years 15-28	Closure & Post-Closure: Years 29 to 50	Post-Closure: Years 50 to 100
Parameter	*WQG FAL*[A]	WQG DW[B]	Mean	Standard Deviation	95th Percentile	Mean	Standard Deviation	95th Percentile	95th Percentile	95th Percentile	95th Percentile	95th Percentile	95th Percentile
Hardness (as $CaCO_3$)			36	27	80	137	28	169	23	42	60	52	52
Anions													
Chloride	150	250	9.1	7.0	20	<0.5	na	na	0.91	3.8	4.6	3.9	3.1
Fluoride	Note F	1	***1.0***	0.89	***2.4***	0.12	0.0081	0.13	0.035	0.15	0.18	0.13	0.10
Sulfate	Note G	500	31	28	66	39	30	67	17	209	***259***	***228***	179
Dissolved Nutrients													
Orthophosphate			0.085	0.064	0.18	0.029	0.013	0.049	0.0046	0.0034	0.0043	0.0047	0.0047
Nitrate (as N)	3	10	<0.02	na	na	<0.0050	na	na	1.0	***3.1***	***3.2***	1.5	0.33
Nitrite (as N)	Note H	1	0.0040	0.0083	0.030	<0.0010	na	na	***0.026***	***0.072***	***0.073***	0.034	0.0076
Ammonia (as N)	Note V		0.032	0.063	0.071	0.027	0.017	0.045	0.15	0.42	0.42	0.20	0.059
Dissolved Metals[Y]													
Aluminum	Note J	0.2	0.070	0.18	***0.16***	0.0050	0.00095	0.0067	0.024	0.024	0.023	0.026	0.028
Antimony	0.2[W]	0.014[W]	0.00081	0.0010	0.0034	9.0E-05	8.8E-05	0.00028	0.00014	0.0022	0.0030	0.0027	0.0022
Arsenic	0.005	0.025[S]	0.0016	0.0014	0.0036	0.00077	0.00034	0.0012	0.00024	0.0022	0.0029	0.0024	0.0020
Barium	1[X]		0.015	0.010	0.033	0.045	0.030	0.084	0.0082	0.014	0.017	0.013	0.011
Berilium	0.0053[X]	0.004[X]	<0.00010	na	na	<0.00010	na	na	2.8E-05	3.0E-05	3.1E-05	2.5E-05	2.3E-05
Bismuth			<0.00050	na	na	<0.00050	na	na	6.9E-05	9.1E-05	9.5E-05	8.1E-05	7.8E-05
Boron	1.2	5.0	<0.05	na	na	<0.01	na	na	0.058	0.079	0.090	0.068	0.047
Cadmium	Note T		1.5E-05	2.5E-05	3.3E-05	<0.000010	na	na	1.1E-05	***5.6E-05***	***6.6E-05***	***0.00011***	***0.00011***
Calcium			12	9.6	27	23	1.5	25	11	33	41	31	27
Chromium	0.0089[U,X]		0.0011	0.0029	0.0037	7.6E-05	6.0E-05	0.00022	0.00013	0.00019	0.00021	0.00016	0.00016
Cobalt	0.004		0.00023	0.00037	0.00053	0.00015	0.00011	0.00032	0.00063	***0.0050***	***0.0058***	***0.0045***	0.0020
Copper	Note K	0.5	***0.00047***	0.00089	***0.0017***	<0.0002	na	na	0.00074	***0.0054***	0.0067	0.0054	0.0045
Iron	0.35		0.054	0.068	0.20	0.30	0.13	***0.44***	0.0050	0.0050	0.0050	0.0050	0.0050
Lead	Note L	0.05	3.9E-05	4.0E-05	0.00013	<0.000050	na	na	3.5E-05	9.4E-05	0.00011	9.0E-05	8.1E-05
Lithium			0.0087	0.0093	0.030	0.0065	0.0017	0.0086	0.00088	0.0077	0.0093	0.0071	0.0055
Magnesium			1.2	0.92	2.6	20	5.8	26	3.8	26	33	25	22
Manganese	Note M		0.15	0.17	0.56	0.25	0.070	0.33	0.0036	0.038	0.053	0.043	0.040
Mercury	0.00002	0.001	<0.00001	na	na	<0.00001	na	na	1.2E-05	7.7E-06	6.0E-06	6.6E-06	6.6E-06
Molybdenum	1	0.25	0.0085	0.012	0.017	0.00072	0.00028	0.0011	0.0012	0.0092	0.014	0.012	0.012
Nickel	Note N		0.0019	0.0035	0.0040	0.00056	0.00042	0.0014	0.00034	0.0022	0.0027	0.0023	0.0021
Phorsphorus		0.01[R]	0.13	0.064	0.22	0.081	0.049	0.15	0.27	0.19	0.11	0.081	0.075
Potassium			1.7	1.0	3.3	0.86	0.053	0.92	0.82	4.5	5.6	4.9	3.8
Selenium	0.002	0.01	0.00026	0.00049	0.00084	<0.00010	na	na	0.00054	***0.0100***	***0.015***	***0.013***	***0.0074***
Silicon			4.4	1.1	5.7	5.0	0.20	5.3	3.8	3.7	3.5	2.9	2.9
Silver	Note P		<0.000010	na	na	<0.000010	na	na	9.3E-06	2.3E-05	2.9E-05	2.4E-05	2.2E-05
Sodium			69	52	158	7.6	3.4	11	1.3	2.1	2.5	2.0	1.6
Strontium			0.26	0.18	0.53	1.3	0.96	2.4	0.048	0.57	0.84	0.74	0.60
Sulfur			12	13	35	15	9.8	24	10	7.6	7.5	5.3	4.9
Thallium	0.0003[AB]		5.8E-06	3.7E-06	1.5E-05	<0.000010	na	na	6.1E-06	2.5E-05	3.0E-05	2.5E-05	2.2E-05
Tin			0.00010	8.3E-05	0.00026	<0.00010	na	na	0.00026	0.00046	0.00049	0.00051	0.00050
Titanium			0.0034	0.0021	0.0050	<0.010	na	na	0.0017	0.0021	0.0023	0.0018	0.0018
Uranum	0.3[W]		0.010	0.013	0.036	0.0025	0.00050	0.0032	0.00026	0.0013	0.0019	0.0017	0.0013
Vanadium	0.006[W]		0.00088	0.0017	0.0021	<0.0010	na	na	0.00033	0.00042	0.00047	0.00044	0.00045
Zinc	Note Q	5	0.0026	0.0038	***0.0093***	0.00098	0.00084	0.0026	0.0011	0.0071	***0.0079***	***0.012***	***0.011***

(continued)

Table 11.5-10. Contact Groundwater Quality along Flow Pathways Emanating from the TMF into the T-Creek, Harper Creek and Jones Creek Catchment Basins (completed)

Notes:

All concentrations presented in units of mg/L

Thick cell borders indicate values above 95th percentile baseline concentration.

Hatched cell indicates value above 95th percentile baseline concentration in the Jones Creek catchment basin downgradient of the TMF North Embankment.

[A] *British Columbia Approved and Working Water Quality Guidelines (BC MOE 2014) for Freshwater Aquatic Life. Approved guidelines for chronic exposure (30 day average) are listed where both maximum and chronic guidelines exist. Bold/underlined values exceed the corresponding guideline.*

[B] *British Columbia Approved Water Quality Gudielines (BC MOE 2014) for Drinking Water. Shaded values exceed the corresponding guideline.*

[C] *Parameter concentrations are represetative of surface water quality model (Appendix 13-C) expected case 95th percentile tailings pond water. 95th percentiles were calculated for each time frame indicated.*

[D] *Baseline groundwater quality in the T-Creek catchment basin downgradient of the TMF determined based on samples collected from seven wells: MW10-02A, MW11-21D and S, MW11-22D and S, MW11-23D and S*

[E] *Baseline groundwater quality in the Jones Creek catchment basin down-gradient of the TMF was determined based on samples collected from two wells: MW10-03A, and MW12-02S*

[F] *Fluoride - if hardness (as* $CaCO_3$*) is 10 mg/L the maximum concentration is 0.4 mg/L; otherwise* $LC_{50} = -51.73 + 92.57 \log_{10} (\text{hardness}) * 0.01$ *mg/L.*

[G] *Sulphate - if hardness is very soft (0-30 mg/L) the guideline is 128 mg/L; if soft to moderately soft (31-75 mg/L) then 218 mg/L; if moderately soft/hard to hard (76-180 mg/L) then 309 mg/L; if very hard (181-250 mg/L) then 429 mg/L; if hardness >250 mg/L then the guideline needs to be determined based on site water.*

[H] *Nitrite - if chloride <2 mg/L the guideline is 0.02 mg/L, if chloride 2-4 mg/L then 0.04 mg/L, if chloride 4-6 mg/L then 0.06 mg/L, if chloride 6-8 mg/L then 0.08 mg/L, if chloride 8-10 mg/L then 0.1 mg/L and if chloride >10 mg/L then 0.2 mg/L.*

[J] *Dissolved aluminum - if pH ≥ 6.5 the maximum concentration is 0.1 mg/L and the 30-day mean is 0.05 mg/L; if pH < 6.5 the maximum concentration is* $e^{(1.209 - 2.426pH + 0.286 K)}$ *mg/L where* $K = (pH)^2$ *and the 30-day mean is* $e^{1.6 - 3.327 (\text{median pH}) + 0.402 K)}$ *mg/L where* $K = (\text{median pH})^2$*.*

[K] *Copper - If average water hardness (as* $CaCO_3$*) ≤ 50 mg/L the 30-day mean is ≤ 0.002 mg/L; if average water hardness is > 50 mg/L the 30-day mean is ≤ 0.00004(mean hardness) mg/L.*

[L] *Lead - 30-day mean guideline is hardness-dependent:* $3.31+e^{1.273Ln(\text{hardness})-4.704} / 1000$ *mg/L.*

[M] *Manganese - 30-day mean concentration = 0.0044(hardness)+0.605 mg/L.*

[N] *Nickel - if hardness (as* $CaCO_3$*) is 0-60 mg/L the maximum concentration is 0.025 mg/L; if hardness 60-120 mg/L maximum concentration of 0.065 mg/L; if hardness 120-180 mg/L maximum concentration of 0.110 mg/L; if hardness >180 mg/L maximum concentration of 0.150 mg/L.*

[P] *Silver - if hardness is ≤ 100 mg/L the 30-day mean guideline is 0.00005 mg/L; if hardness > 100 mg/L the 30-day mean guideline is 0.0015 mg/L.*

[Q] *Zinc - 30-day mean concentration = 7.5 + 0.75(hardness - 90) / 1000 mg/L.*

[R] *For lakes used as a source of drinking water.*

[S] *Interim guideline*

[T] *Draft Cadmium guideline released June 2014, not approved at time of writing. 30 day mean guideline = 0.02 to* $e^{0.762Ln(\text{Hardness})-6.07}$ *to 0.172 μg/L*

[U] *Indicated chromium guideline intended for Cr (III) under ministry review for possible formal approval at time of writing.*

[V] *Ammonia guideline pH and Temperature-dependent, and intended for surface water temperatures - provided as benchmark only in groundwater assessment.*

[W] *Working water quality guidelines*

[X] *Working water quality guideline, under ministry review for possible formal approval at time of writing.*

[Y] *All metals guidelines are intended for total concentrations, except those for aluminum and iron*

Table 11.5-11. Definitions of Specific Characterization Criteria for Groundwater Quality

Timing	Magnitude	Geographic Extent	Duration	Frequency	Reversibility	Ecological Context
Construction	**Negligible** No or very little predicted changes to groundwater quality from baseline conditions.	**Discrete** Effect is limited to the Project Site.	**Short term** Effect lasts 1 to 5 years.	**One Time** Effect occurs once during any phase of the Project.	**Reversible** Effect can be reversed.	**Low** No effect on groundwater quality is expected at receptors (surface water habitat, groundwater users).
Operations[1]	**Low** Predicted changes to groundwater quality are within the baseline range of variability. No changes to groundwater quality in the existing groundwater supply wells at downstream of the mine site are expected.	**Local** Effect extends beyond the Project Site, but does not extend beyond an immediate tributary catchment basin draining the Project Site and the LSA.	**Medium term** Effect lasts 6 to 28 years.	**Sporadic** Effect occurs at sporadic or intermittent intervals during any phase of the Project.	**Partially reversible** Effect can be partially reversed.	**Neutral** The effect on groundwater quality is expected at receptors, but the magnitude of the effect to the receptors is expected to be low.
Closure	**Medium** Predicted changes to groundwater quality exceed the baseline range of variability. Exceedances of guidelines are not expected, except where they are present in baseline conditions, or moderate changes to groundwater quality in the existing groundwater supply wells at downstream of the mine site are expected.	**Regional** Effect extends beyond the LSA boundaries and across the broader region of the RSA.	**Long term** Effect lasts 29 to 50 years.	**Regular** Effect occurs on a regular basis during any phase of the Project.	**Irreversible** Not feasible to reverse the effect.	**High** The effect on groundwater quality is expected at receptors, and the magnitude of the effect is expected to be medium or high.
Post-Closure	**High** Predicted changes to groundwater quality is expected to exceed the baseline range of variability and the guidelines, or significant changes to groundwater quality in the existing groundwater supply wells at downstream of the mine site are expected.	**Beyond regional** Effect extends beyond the RSA boundaries.	**Far future** Effect lasts longer than 50 years.	**Continuous** Effect occurs constantly during any phase of the Project.		

[1] *Include Operation 1 (from Year 1 to Year 23) and Operation 2 (from Year 24 to Year 28).*

Duration has been characterized as far-future. It is expected that the magnitude will be reduced to moderate or lower following removal of the stockpile at the end of Operations, but a tailing effect is expected to sustain non-baseline conditions into the far future. Dilution following removal of the stockpile source provides for partial reversibility. The mass loading is continuous in nature for the duration of the stockpile's presence.

Non-PAG LGO Stockpiles

Seepage from the non-PAG LGO stockpile stored outside the TMF footprint is predicted to report to the non-PAG waste rock stockpile and will be collected in the water management pond, and the extents are therefore regarded as discrete. The magnitude is high, as parameter concentrations similar to the non-PAG waste rock are expected to occur in the contact groundwater (nearly identical geochemical source terms, as described in Appendix 6-A, ML/ARD Characterization Report). Concentrations in the contact groundwater are expected to peak at the end of Operations 1, when the stockpile will be at its largest and the LGO processing will commence.

Duration of the potential effect on groundwater quality has been characterized as far-future. It is expected that the magnitude will be reduced to moderate or lower following removal of the stockpile at the end of Operations, but a tailing effect is expected to sustain non-baseline conditions into the far future. Dilution following removal of the stockpile source provides for partial reversibility. The mass loading is continuous in nature for the duration of the stockpile's presence.

Ecological context is regarded as neutral. The contact groundwater is predicted to be intercepted by the non-PAG waste rock water management pond, with collected seepage pumped to the TMF. The receiving surface waterbody is present immediately down-gradient of the water management pond.

The potential seepage from the non-PAG LGO stockpile to be stored inside the TMF footprint is accounted in the overall effect of the TMF and is characterized in the following TMF section.

Overburden and Topsoil Stockpiles

As discussed in the residual effect on groundwater quality above, with the Mine Waste and ML/ARD Management Plan (Section 24.10) implemented, contact groundwater emanating from these facilities will not be degraded to a degree that warrants further consideration. Therefore, no characterization is required for these facilities on the potential effect to groundwater quality.

Tailings Management Facility

The TMF has been assessed in combination with the planned co-disposed materials (PAG waste rock stockpile and non-PAG LGO stockpile) during Operations, Closure, and Post-Closure. The plume of contact groundwater beneath and down-gradient of the TMF has been taken to be equivalent to the tailings water in the facility, for which the water quality has been predicted with simulation of these co-disposed materials.

The contact groundwater leaving the TMF is predicted to include parameters above certain provincial guidelines (high magnitude). A component of the plume is predicted to extend beyond the seepage collection systems planned for the north and main embankments. According to the predicted advective flow pathways, seepage bypassing the main embankment is expected to report to T Creek and Harper Creek, while seepage bypassing the north embankment is predicted to report to Jones Creek (high ecological context). The extents are regarded as local, because the plume will attain a steady state discharging into the surface water within the LSA.

The plume of contact groundwater associated with the TMF is predicted to be far-future in duration because the TMF as a permanent mine facility will provide a continuous source. This is regarded as an irreversible effect because the expected size of the plume and its source (the TMF pond) makes it unfeasible to remediate to baseline conditions.

Likelihood of Residual Effects on Groundwater Quality

The criteria applied for assessing the likelihood of residual effects on groundwater quality are the same as those for groundwater quantity (seeing Table 11.5-6). The likelihood of all the identified residual effects on groundwater quality is assessed to be high (greater than 80% probability of occurrence), except for the overburden and topsoil stockpiles with a low likelihood. Geochemical testing has indicated that water quality will be affected by the excavation and exposure of materials in the open pit (Appendix 6-A, ML/ARD Characterization Report). Surface water quality modelling (Appendix 13-B) has indicated that water contacting these exposed materials will be of degraded quality. The seepage pathways predicted by the numerical groundwater modelling simulations are calibrated to site conditions.

There is a strong likelihood that dispersive mixing, sorption, and chemical reactions will reduce magnitudes of the expected effects. These factors were not incorporated into the groundwater modelling exercises.

11.5.4 Significance of Residual Effects

The significance determination of the predicted potential residual effects on the VCs of groundwater quantity and quality follows the process presented in the Effects Assessment Methodology (see Chapter 8, Section 8.6.5), and the severity of the residual effects is ranked according to a minor, moderate and major scale. The significance ratings are determined as below:

- **Not significant (minor or moderate scale)**: Residual effects on groundwater quantity and quality have low or moderate magnitude; local to regional geographic extent; short- or medium-term duration; could occur at any frequency, and are reversible or partially reversible in either the short or long-term. The effects are either indistinguishable from baseline pre-mining conditions (i.e., occur within the range of natural variations of groundwater levels, flow patterns, and chemical parameters), or distinguishable at the individual level. Follow-up groundwater monitoring and adaptive management plans may or may not be required.
- **Significant (major scale)**: Residual effects on groundwater quantity and quality have high magnitude; regional or beyond regional geographic extent; duration is long-term or far future; and occur at multiple frequencies. Residual effects are consequential (i.e., reduction of baseflows in the creeks potentially affecting fish habitat or water supply wells) and are

irreversible. Follow-up groundwater monitoring and adaptive management plans are required.

11.5.5 Confidence and Uncertainty in Determination of Significance

Confidence and uncertainty in determination of significance for the groundwater effects are assessed primarily based on the available hydrogeological baseline data and reliability of the data, the numerical groundwater modelling techniques used and assumptions made, the effectiveness of mitigations, and the resulting predictions. Confidence attributes are provided in Table 11.5-12.

Table 11.5-12. Attributes of the Confidence in the Significance of the Effects Assessment for Groundwater

Confidence Rating	Threshold
High	The baseline hydrogeological system at the pre-mining conditions in the Project Site and along the receiving environment is fully characterized with all of the necessary data, and the system is well understood. The groundwater modeling is implemented with sensitivity analyses for the uncertainties of the model input parameters (e.g., the permeability and recharge). The effectiveness of the mitigation measures is well known. The cause-effect relationships are well understood. The uncertainties and variations of the predicted effects are expected to be low.
Moderate	The baseline hydrogeological system at the pre-mining conditions in the Project Site and along the receiving environment is moderately understood due to the limitation of the available data. The groundwater modeling is implemented without sensitivity analyses for the model input parameters. The effectiveness of the mitigation measures is moderately known. The cause-effect relationships are not fully understood, and there is a moderate degree of uncertainty. While results may vary, predictions are relatively confident.
Low	The baseline hydrogeological system at the pre-mining conditions in the Project Site and along the receiving environment is poorly characterized and understood, and the data are incomplete. The groundwater modeling is implemented without sensitivity analyses for the model input parameters. The effectiveness of the mitigation measures may not yet be proven. The cause-effect relationships are poorly understood. There is a high degree of uncertainty and final results may vary considerably.

11.5.6 Summary of the Assessment of Residual Effects on Groundwater

The residual effects on groundwater quantity and quality, and their characterization criteria, likelihood, significance determination, and confidence evaluations are summarized in Table 11.5-13.

Groundwater Quantity

The likelihood of the residual effect to be caused by the open pit dewatering on groundwater quantity (drawdown of the water levels and alterations of the flow patterns and catchment divide, and the reduction of the groundwater discharge (as baseflows) in P Creek and Baker Creek) would be high. Although the magnitude is high in terms of the drawdown of groundwater level down to 350 m and the reduction of the baseflows in Baker Creek and P Creek, the effect is predicted to occur within the local area only (not beyond the LSA) in a relative short- or medium-term duration (during the Construction and Operations 1), and the effect of groundwater level drawdown is partially reversible in the long-term when the mine ceases. At Operations 2, Closure and Post-Closure, as the pit will be refilled to a design elevation at 1,530 masl, the groundwater levels and flow patterns in the surrounding formations will partially recover close to the pre-mining baseline conditions. The residual effect of the pit lake is expected to be of a high likelihood and long-term duration (extending into Post-Closure), but the effect will be limited at the local scale (within the LSA) with a medium magnitude. Therefore, the overall residual effect of the open pit dewatering and the pit lake on groundwater quantity is assessed to be not significant (moderate) beyond the Project Site and immediately downstream area. The confidence of the assessment is moderate, based on the criteria in Table 11.5-12.

The likelihood of the residual effect of the non-PAG waste rock stockpile on groundwater quantity (e.g. change of the water levels and flow patterns due to the potential increase of the recharge into the groundwater system under the footprint) would be high. Although the magnitude of the effect is high in terms of the reduction of the P Creek baseflow, the effect may be reversible after a long duration at Post-Closure when the system achieves equilibrium, and the effect is limited in the local P Creek catchment within the LSA. Therefore, the overall rating of the residual effect of this facility on groundwater quantity is assessed to be not significant (moderate) beyond the local catchment. The confidence of the assessment is moderate, based on the criteria in Table 11.5-12.

The likelihood of the residual effects of the PAG and non-PAG LGO Stockpiles on groundwater quantity (e.g., change of the water levels and flow patterns due to the potential increase of the recharge into the groundwater system under the footprint) would be high, before the ores are processed and the facilities are removed at the end of Operations. The effect will be of a low or medium magnitude, a relatively short-term duration (only in Operations 1), reversible and limited in the local area between the non-PAG Waste Rock Stockpile and the TMF (within the LSA). Therefore, the residual effects of these facilities on groundwater quantity are assessed to be not significant (moderate). The confidence of the assessment is moderate, based on the criteria in Table 11.5-12.

The likelihood of the residual effects of the overburden and topsoil stockpiles on groundwater quantity (e.g. increase of recharge into the groundwater system under the footprints) will be moderate. Considering the low magnitude and the local extent, the effect will be not significant (moderate). The confidence of the assessment is moderate, based on the criteria in Table 11.5-12.

The likelihood of the residual effect of the TMF (together with the co-disposed PAG waste rock and non-PAG LGO stockpiles) on groundwater quantity (including the increase of the water levels, the alteration of the flow patterns and the shift of the local catchment groundwater divides, as well as the reduction of the baseflows in T Creek and Harper Creek) would be high. The effect is predicted to be of a high magnitude, continuous, long-term, and irreversible. However, it is predicted to occur in the local TMF valley and immediately downstream catchment, i.e. not to extend beyond the LSA. Therefore, based on the significance ratings in Section 11.5.4, the effect is assessed to be not significant (moderate) beyond the local catchment. The confidence of the assessment is moderate, based on the criteria in Table 11.5-12.

Table 11.5-13. Summary of Residual Effects on Groundwater Quantity and Quality, Likelihood, Significance, and Confidence

Key Effect	Component/ Activity	Phase	Summary of Residual Effects Characterization Criteria *(magnitude, geographic extent, duration, frequency, reversibility, resiliency)*	Likelihood *(high, moderate, low)*	Significance of Adverse Residual Effects		Confidence *(high, moderate, low)*
					Scale *(minor, moderate, major)*	Rating *(not significant; significant)*	
Groundwater Quantity							
Alteration of groundwater levels and flow patterns (flow directions, hydraulic gradients and flow rates) arising from mine activities, waste rock and water management	Open Pit Mining	Construction, Operations	Pit dewatering results in high magnitude declines in water levels and therefore significant changes of flow patterns (flow directions, hydraulic gradients and water divides) at the local scale during the Construction and Operations phases. The effect is continuous in nature with the maximum decrease of the water levels in the open pit by up to 350 m, but will be partially reversed when de-watering ceases at end of Operations. The capture zone of the Open Pit will extend into the P Creek and Baker Creek watersheds. Baseflow will be reduced by a maximum of 32% in Baker Creek and 7% in Jones Creek, as a result of excavation and dewatering of the Open Pit by the end of Operations. The water levels and flow in the existing groundwater supply wells at the downstream of the Pit are predicted not to be affected.	high	moderate	not significant	moderate
	Pit Lake	Closure, Post-Closure	At Closure and Post-closure, the mined Open Pit will be refilled as a Pit Lake at the spill elevation of 1,530 masl. The groundwater surrounding the Pit will recover to the lake surface elevation, but not completely recover to the pre-mining conditions. Baseflow will be reduced by 27% in Baker Creek and 5% in Jones Creek. The magnitude of the residual effect is expected to be medium, and it will be continuous in nature and extends to far future, and partially reversible. The water levels and flow in the existing wells at the downstream of the Pit Lake are predicted not to be affected.	high	moderate	not significant	moderate
	Non-PAG Waste Rock Stockpile	Operations, Closure, Post-Closure	The storage of the non-PAG waste rock stockpile will increase the recharge into the groundwater system under the footprint, due to the potential water mounding in the stockpile, and affecting the groundwater flow patterns at the local scale. This effect will be continuous in nature during Operations, Closure and Post-closure, despite that the stockpile will be reclaimed at Operation 2 and Closure. Baseflow is predicted to reduce by up to 86% in the P Creek by the end of Operations as well as during Closure/Post-closure, due to the occupancy of the stockpile and loss of the catchment. The magnitude of the effect is high in terms of the reduction of the P Creek baseflow, and the effect may be reversible after a long duration at Post-closure when the system achieves equilibrium.	high	moderate	not significant	moderate
	PAG Waste Rock Stockpile	Operations, Closure, Post-Closure	The storage of the PAG waste rock stockpile will increase the recharge into the groundwater system under the footprint, and affecting the groundwater flow patterns at the local scale. This effect will be continuous in nature during Operations, Closure and Post-closure. As the PAG waste rock will be co-disposed inside the TMF, the effect of this facility is incorporated in the effect assessment of the TMF. The effect is considered not reversible, and the magnitude would be high with consideration of the significant change of the water levels and flow patterns at the local scale, and the predicted loss of the baseflow in the downstream creeks.	high	moderate	not significant	moderate
	PAG Low-Grade Ore Stockpile	Operations	The storage of PAG LGO stockpile potentially increases the recharge into the groundwater system under the footprint, and affecting the groundwater flow patterns at the local scale. The magnitude of the effect on groundwater quantity is expected to be low or medium by considering the sizes of the stockpiles, and the effect will be limited during Operations 1 only and will be reversed afterwards, as the ores will be processed at Operations 2 and completely removed at Closure.	high	moderate	not significant	moderate
	Non-PAG Low-Grade Ore Stockpiles	Operations	The storage of non-PAG LGO stockpiles potentially increases the recharge into the groundwater system under the footprints, and affecting the groundwater flow patterns at the local scale. The magnitude of the effect on groundwater quantity is expected to be low or medium by considering the sizes of the stockpiles, and the effect will be limited during Operation 1 only and will be reversed afterwards, as the ores will be processed at Operation 2 and completely removed at Closure. The larger stockpile will be stored in the TMF, and its effect is incorporated in the TMF.	high	moderate	not significant	moderate
	Overburden Stockpile	Construction, Operations, Closure, Post-Closure	The storage of overburden in the stockpile will increase the recharge into the groundwater system under the footprint, and affecting the groundwater flow patterns at the local scale. The effect will be continuous throughout the mine life, and is expected to be irreversible. The magnitude of the effect is estimated to be relatively low, in comparison with the effects of the Pit and Pit Lake nearby.	moderate	moderate	not significant	moderate
	Topsoil Stockpiles	Construction, Operations, Closure	The storage of topsoil in the stockpiles will increase the recharge into the groundwater system under the footprint, and affecting the groundwater flow patterns at the local scale. The effect will be limited at the duration from Construction to Closure, as the soil will be used for the mine reclamation and the stockpiles will be removed at Closure. The effect will be in a low magnitude and will be reversed at Post-closure.	moderate	moderate	not significant	moderate
	Tailings Management Facility	Construction, Operations, Closure, Post-Closure	The construction of the TMF dams and embankments will affect the water levels and flow in the subsurface. The storage of the tailings, the mine water collected from the Pit dewatering and the Pit Lake, and the seepage collected from the stockpiles into the TMF during the Operations and Closure/Post-closure will result in a significant rise in the groundwater levels and change the flow patterns under the TMF footprint and surrounding area. A shift of catchment basin divides along the TMF site are predicted. The storage of the low permeable tailings materials will also alter the overall permeability inside the TMF valley. The effect is continuous in nature throughout the mine life and is irreversible, as the TMF is a permanent mine facility. Baseflow is predicted to reduce by 60% in T Creek and over 20% in Harper Creek downstream, due to the loss of the catchment. The magnitude of the effect would be high.	high	moderate	not significant	moderate

(continued)

Table 11.5-13. Summary of Residual Effects on Groundwater Quantity and Quality, Likelihood, Significance, and Confidence (completed)

Key Effect	Component/ Activity	Phase	Summary of Residual Effects Characterization Criteria *(magnitude, geographic extent, duration, frequency, reversibility, resiliency)*	Likelihood *(high, moderate, low)*	Significance of Adverse Residual Effects		Confidence *(high, moderate, low)*
					Scale *(minor, moderate, major)*	Rating *(not significant; significant)*	
Groundwater Quality							
Degradation of groundwater quality due to seepage of contact water	Pit Lake	Closure, Post-Closure	Seepage of contact water from Pit Lake (estimated to be 8 L/s) results in high magnitude change in groundwater quality in the surrounding formations at the local scale. The seepage is predicted 100% to discharge into Baker Creek watershed in an average of 13 years. The effect is continuous in nature during Closure/Post-closure, and not feasibly reversible. Implementation of the Groundwater Management Plan would be required. The water quality in the existing supply wells at the downstream of the Pit Lake is predicted not to be affected.	high	moderate	not significant	moderate
	Non-PAG Waste Rock Stockpile	Operations, Closure, Post-Closure	A small percentage (< 2%) of the seepage from this stockpile is predicted to bypass the seepage collection system and migrate towards P Creek and Harper Creek in an average of 1 year, despite that the majority of the seepage through the foundation of the stockpile is predicted to be captured by the non-PAG waste rock stockpile water management pond and the Open Pit. The seepage could cause moderate magnitude changes in groundwater quality along the flow pathways at the local scale. This effect is continuous in nature during Operations and Closure/Post-closure, and it is not reversible. Implementation of the Groundwater Management Plan may be required.	high	moderate	not significant	moderate
	PAG Waste Rock Stockpile	Operations, Closure, Post-Closure	Seepage from the PAG Waste Rock Stockpile mixes with the seepage originating from the TMF and the PAG Low-Grade Ore Stockpile, and could cause high magnitude changes in groundwater quality under the TMF footprint and downstream flow paths along the T Creek, Harper Creek and Jones Creek at the local scale. This effect is continuous in nature during Operations, Closure and Post-closure, and it is not reversible. Implementation of the Groundwater Management Plan would be required.	high	moderate	not significant	moderate
	PAG Low-Grade Ore Stockpile	Operations	Seepage from PAG LGO Stockpile is predicted to migrate along three pathways: A portion (22%) of the seepage will discharge to the TMF and will be collected there, a second portion (47%) will flow towards the non-PAG waste rock stockpile and be collected in the water management pond there and conveyed to the TMF for storage, and the balance (33%) will flow in groundwater as unrecovered seepage towards P Creek and Harper Creek. The unrecovered seepage from this source is conveyed within groundwater discharging into the P Creek (7%) and Harper Creek (26%). The seepage will affect the groundwater quality along the pathways. The effect will mainly occur during Operation 1 and become less once the ores are processed at Operation 2 and removed at Closure, but the chemicals leaching from the ores are likely to continue to cause an residual effect on the groundwater quality during the Post-closure. The effect is considered to be of a moderate magnitude and partially reversible. Implementation of the Groundwater Management Plan would be required.	high	moderate	not significant	moderate
	Non-PAG Low-Grade Ore Stockpiles	Operations	Seepage from the Non-PAG Low-Grade Ore Stockpile stored inside the TMF will mix with the seepage originating from the TMF and the PAG Waste Rock Stockpile, and could cause high magnitude changes in groundwater quality under the TMF and downstream at the local scale. Seepage from the Non-PAG Low-Grade Ore Stockpile stored outside the TMF footprint (between the TMF and the Non-PAG Waste Rock Stockpile) is small and 100% is collected in the water management pond of the Non-PAG waste rock stockpile. The effect of the seepage from these stockpiles will mainly occur during Operation 1 and become less once the ores are processed at Operation 2 and removed at Closure, but the chemicals leaching from the ores are likely to continue to cause an residual effect on the groundwater quality during the Post-closure. The effect is considered not reversible. Implementation of the Groundwater Management Plan would be required.	high	moderate	not significant	moderate
	Overburden Stockpile	Construction, Operations, Closure, Post-Closure	With the ML/ARD management and mitigation plans implemented, the quality of the seepage water originating from the Overburden Stockpile is anticipated to be reasonably good, and therefore will not cause a significant effect to the groundwater quality in the local.	low	minor	not significant	high
	Topsoil Stockpiles	Construction, Operations, Closure	With the mine management and mitigation plans implemented (e.g. covering and using it for reclamation, and removing at Closure), the seepage from the Topsoil Stockpiles will not significantly affect the groundwater quality at the local scale.	low	minor	not significant	high
	Tailings Management Facility	Operations, Closure, Post-Closure	Seepage of contact water from the TMF (together with the co-disposed PAG Waste Rock Stockpile and Non-PAG Low-Grade Ore Stockpile) is predicted to bypass the seepage collect systems and migrate into the downstream environment. 10% of the seepage under the main TMF embankment and foundation is predicted to migrate into Harper Creek (above the confluence of T Creek) in an average of 12 years, and 3% is to migrate into the T Creek in an average of 10 years; 85% of the seepage under the northern TMF embankment and foundation is predicted to migrate into Jones Creek in an average of 12 years; 95% of the seepage from the Northwest Boundary of the TMF Pond is predicted to migrate into the Pit and Pit Lake in an average of 8 years, and the balance of 5% is to migrate into the non-PAG Waste Rock Stockpile in an average of 23 years. The seepage from the tailings and the PAG/non-PAG materials could result in high magnitude changes in groundwater quality beneath the TMF footprint and along the flow paths in those catchments. This effect is continuous in nature through the mine Operations and Closure/Post-Closure, and it is not feasibly reversible. Implementation of the Groundwater Monitoring Plan would be required.	high	moderate	not significant	moderate

Groundwater Quality

The likelihood of the residual effect to be caused by the pit lake on groundwater quality (degradation of groundwater quality due to the seepage of contact water) would be high. Although the contact water from the pit lake (predicted to be above provincial FWAL guidelines) is predicted to cause a continuous and irreversible residual effect on groundwater discharging into Baker Creek (in a high magnitude and with a far-future duration), the effect is characterized as local within the LSA, and the water quality in the existing supply wells down-gradient of the pit lake is not predicted to be affected. Therefore, based on the significance ratings in Section 11.5.4, the effect is assessed to be not significant (moderate) beyond the Project site and local catchment. The confidence of the assessment is moderate, based on the criteria in Table 11.5-12. A follow-up groundwater monitoring plan has been developed as part of the Groundwater Management Plan (see Chapter 24.8), and an adaptive management plan can be initiated if the monitoring results show that the effect on the downstream receiving environment is significant.

The likelihood of the residual effect of the non-PAG waste rock stockpile on groundwater quality (degradation of groundwater quality due to the seepage of contact water) would be high. The majority of the seepage leaving this stockpile has been predicted to report to the downstream water management pond, and only 2% is to bypass the water management pond and report to P- and Harper creeks. The effect is predicted to be local within the LSA, despite that the change of the groundwater quality along the flow pathways would be continuous and irreversible (with a far-future duration) and certain parameters in the plume are expected to moderately exceed freshwater aquatic life and drinking water guidelines. Overall, the effect is assessed to be not significant (moderate) beyond the local catchment, based on the significance ratings in Section 11.5.4. The confidence of the assessment is moderate, based on the criteria in Table 11.5-12. A follow-up long-term groundwater monitoring plan has been developed as part of the Groundwater Management Plan (see Chapter 24.8), and an adaptive management plan can be initiated if the monitoring results show that the effect on the downstream receiving environment is significant.

The likelihood of the residual effect of the PAG LGO Stockpile on degradation of groundwater quality would be high. The magnitude is high because groundwater quality along the seepage pathways from the PAG LGO is expected to exceed certain provincial guidelines. However, the effect will peak at the end of Operations 1 and start to reverse after the ore is processed by the end of Operations and removed at Closure. Although it may extend to far future into Post-Closure and may be partially reversible to the baseline conditions, the magnitude of the residual effect will be reduced to moderate or lower eventually. The effect is regarded as local in the P- Creek and Harper Creek catchments within the LSA. Therefore, the effect is assessed to be not significant (moderate) beyond the local catchments, based on the significance ratings in Section 11.5.4. The confidence of the assessment is moderate, based on the criteria in Table 11.5-12. A follow-up long-term groundwater monitoring plan has been developed as part of the Groundwater Management Plan (see Chapter 24.8), and an adaptive management plan can be initiated if the monitoring results show that the effect on the downstream receiving environment is significant.

Similar to the PAG LGO stockpile, the likelihood of the residual effect of the seepage from the non-PAG LGO stockpile (stored outside the TMF footprint) on groundwater quality would be high with a high magnitude. Although the effect along the seepage pathways is expected to be continuous and partially reversible (possibly extending to far future), the seepage is predicted to report to the non-PAG waste rock stockpile and will be collected in the water management pond, and the magnitude will also be reduced to moderate or lower following removal of the stockpile at the end of Operations. The effect is regarded as local within the LSA, and therefore it is assessed to be not significant (moderate). The confidence of the assessment is moderate. The potential effect of the seepage from the non-PAG LGO stockpile will be monitored with the long-term monitoring wells proposed downgradient of the non-PAG waste rock stockpile as part of the Groundwater Management Plan (see Section 24.8), and an adaptive management plan can be initiated if the monitoring results show that the effect on the downstream receiving environment is significant.

The likelihood of the residual effects of the overburden and topsoil stockpiles on groundwater quality will be low with the Mine Waste and ML/ARD Management Plan implemented. Therefore, it is assessed to be not significant (minor). The confidence of the assessment is high.

The likelihood of the residual effect of the TMF (together with the co-disposed PAG waste rock and non-PAG LGO stockpiles) on groundwater quality would be high. The effect is predicted to be of a high magnitude (the groundwater quality along the predicted seepage pathways towards the T and Harper creeks in the south and towards Jones Creek in the north is expected to exceed the provincial guidelines), and the effect will be continuous, far-future in duration, and irreversible. However, it is predicted to occur in the local TMF valley and the immediately downstream catchment, i.e., not to extend beyond the LSA. Therefore, the overall effect of the TMF (and the co-disposed PAG waste rock and non-PAG LGO stockpiles) on groundwater quality is assessed to be not significant (moderate) beyond the local catchment. The confidence of the assessment is moderate, based on the criteria in Table 11.5-12. A follow-up long-term groundwater monitoring plan has been developed as part of the Groundwater Management Plan (see Chapter 24.8), and an adaptive management plan can be initiated if the monitoring results show that the effect on the downstream receiving environment is significant.

11.6 CUMULATIVE EFFECTS ASSESSMENT

11.6.1 Scoping Cumulative Effects

11.6.1.1 Valued Components and Project-related Residual Effects

The Project is predicted to have residual effects on groundwater quantity and groundwater quality, and therefore these two valued components have been included in the cumulative effects assessment (CEA). All residual effects to groundwater quantity and quality that are predicted to result from the Project have been included in the CEA, including the following:

- changes of groundwater levels and flow patterns (flow directions, hydraulic gradients, groundwater catchment divides, and discharge as baseflows), arising from key mine components and activities; and
- degradation of groundwater quality due to the seepage of contact water and resulting plume development originating from the key mine components and activities.

11.6.1.2 Defining Assessment Boundaries

Similar to the effects at project level, there are assessment boundaries that define the maximum limit within which the CEA is conducted. Boundaries relevant to hydrogeology are described below.

The temporal boundaries for the identification of physical projects and activities have been categorized into past, present, and reasonably foreseeable future projects and are defined as follows:

- **Past**: no longer operational projects and activities that were implemented in the past 50 years. This temporal boundary enables any far-future effects from past projects and activities[1] to be taken into account.
- **Present**: active and inactive projects and activities.
- **Future**: certain projects and activities that will proceed, and reasonably foreseeable projects and activities that are likely to occur. These projects are restricted to those that: 1) have been publicly announced with a defined project execution period and with sufficient project details for assessment; and/or 2) are currently undergoing an environmental assessment; and/or 3) are in a permitting process.

The spatial boundary for the identification of other physical projects and activities for the assessment of cumulative groundwater effects is the same as the regional study boundary for hydrogeology, as shown in Figure 11.3-2 in Section 11.3.2.

11.6.1.3 Projects and Activities Considered

Past, present, and reasonably foreseeable future projects and activities considered for the overall CEA of the Project and the methodology used for the CEA are presented in Chapter 8. Table 11.6-1 shows the list of the projects and activities. The project list was developed from a wide variety of information sources, including municipal, regional, provincial, and federal government agencies; other stakeholders; and companies' and businesses' websites.

As shown in Figure 11.3-2, only a few projects and activities exist within the RSA (the same boundary for the CEA on groundwater). They include: (1) The Foghorn Polymetallic Project; (2) Three sawmills: Weyerhaeuser Sawmill, Vavenby Sawmill, and Barriere Sawmill; (3) Supply wells for groundwater use.

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[1] Far-future effects are defined as effects that last more than 37 years, as per Table 8.6-2: Attributes for Characterization of Residual Effects.

Table 11.6-1. Impact Matrix for Screening and Ranking Potential Cumulative Effects on Groundwater

	Past Projects			Present Projects								Reasonably Foreseeable Future Projects						
Residual Effects of the Harper Creek Project on VCs	Weyerhaeuser Sawmill	Samatosum Project	Louis Creek Sawmill	Highland Valley Copper	Bone Creek Hydroelectric	Trans Mountain Pipeline	Kamloops Groundwater Project	New Afton	Cache Creek Landfill Extension	Vavenby Sawmill	Barriere Sawmill	North Thompson Transmission Project	Ruddock Creek Project	Trans Mountain Pipeline Expansion	Foghorn Project	Tranquille on the Lake	Shannon Creek Hydroelectric	Ajax Project
Groundwater Quantity																		
Alteration of groundwater levels and flow patterns (flow directions, hydraulic gradients and flow rates)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Groundwater Quality																		
Degradation of groundwater quality	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

(continued)

Table 11.6-1. Impact Matrix for Screening and Ranking Potential Cumulative Effects on Groundwater (completed)

Residual Effects of the Harper Creek Project on VCs	Activities										
	Aboriginal Harvesting	Hunting	Trapping	Fishing	Non-commercial Recreation	Commercial Recreation	Mining and Mineral Exploration	Transportation	Agriculture	Forestry	Water Use
Groundwater Quantity ***(cont'd)***											
Alteration of groundwater levels and flow patterns (flow directions, hydraulic gradients and flow rates)	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
Groundwater Quality ***(cont'd)***											
Degradation of groundwater quality	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢

Notes:

🟢 = *Negligible to minor risk of adverse cumulative effect; will not be carried forward in the assessment.*

🟡 = *Moderate risk of adverse cumulative effect; will be carried forward in the assessment.*

🔴 = *Major risk of adverse cumulative effect or significant concern; will be carried forward in the assessment.*

The Foghorn Polymetallic Project is a mineral claim and proposed uranium mine, with the potential for future work mining other commodities including fluorite, celestite, rare earth metals, and molybdenum. It is on hold due to a provincial ban on uranium exploration and mining. It is a small project with a footprint size of 3,129 ha, and its start and end time, as well as the production capacity are unknown at this stage. Considering the relative short mine life (only 28 years) of the proposed Harper Creek Project, the Foghorn Project would be unlikely to have an temporal interaction with the Project. Also because it is located outside the LSA and in another watershed at the downstream of the Thompson River (Figure 11.3-2), the Foghorn Project is considered to have no spatial interaction with the Project.

Weyerhaeuser Sawmill site is owned by Yellowhead Mining Inc. The sawmill site has a footprint size of 79.3 ha. It was in operation from 1965 to 2003, and it is currently closed with no plans for resuming operation. Therefore, this sawmill is considered to have no temporal interaction with the Project. This sawmill is located in the north side of North Thompson River valley, outside the LSA. It is considered to have no spatial interaction with the Project.

Vavenby Sawmill is owned by Canfor. It is currently an active sawmill operation processing approximately 13% of the annual cut in the Kamloops Timber Supply Area. It produces 480 million board feet of spruce-pine-fir lumber per year. The footprint size and the start/end dates of this sawmill are unknown. As this sawmill is located in the north side of North Thompson River valley, outside the LSA, it is considered to have no spatial interactions with the Project.

Barriere Sawmill is owned by Gilbert Smith Forest Products. It started operating in 1968 and is still active now with the production of cedar. The footprint size of this sawmill is 11 ha. This sawmill is located near the town of Barriere, at the mouth of the Barrière River at the North Thompson River, outside the LSA, and at the southwestern edge of the RSA. Therefore, this sawmill is considered to have no spatial interaction with the Project.

As shown in Figures 11.3-1 and 11.3-2, there are a lot of supply wells existing for groundwater use in the region. Most of the existing wells are located along the North Thompson River and Barrière River valleys, and outside of the LSA. Only four existing wells are located within the LSA, at the downstream of the open pit. These four water supply wells have spatial and temporal interactions with the mining activities of this Project.

11.6.2 Screening and Analyzing Cumulative Effects

Table 11.6-1 presents the potential risks of the past, present and future projects and activities assessed to generate cumulative effects on the predicted residual effects of the Project to groundwater quantity and quality. The risks were assessed according to the locations of the listed projects and activities relative to the RSA and LSA of the Project, as well as their possible spatial and temporal interactions with the Project.

Projects situated outside the hydrogeology RSA were considered to have no risk of causing effects that would be cumulative with the Project. The Projects and activities within the RSA but outside the LSA with no spatial and/or temporal interactions were assessed to have negligible or minor risks for causing cumulative effects to groundwater quantity and quality, due to the fact that the residual effects of the Project to groundwater quantity and quality have been predicted to be limited in the local Project site and immediate downstream catchments (within the LSA), as described in Section 11.5.3. The risks of the projects and activities located within the LSA and with spatial/temporal interactions with the Project were assessed based on the numerical groundwater modeling results (Section 11.5.3 and Appendix 11-B) and professional judgment.

As discussed in Section 11.6.1, the Foghorn Polymetallic Project and the three sawmills (Weyerhaeuser Sawmill, Vavenby Sawmill and Barriere Sawmill) are located inside the RSA but outside the LSA. They have no spatial and/or temporal interactions with the Project. Therefore, the risks of these projects were assessed to have negligible or minor risks for causing cumulative effects to groundwater quantity and quality. As a result, no further assessment of these projects is required for cumulative effects.

Also as discussed in Section 11.6.1, most of the existing supply for groundwater use in the region are located outside of the LSA, and only four existing wells are located within the LSA (downstream of the open pit). These four water supply wells have spatial and temporal interactions with the mining activities of the Project. Results of the modelling undertaken by Knight Piesold (see Section 11.5 and Appendix 11-B) indicate that the groundwater quantity and quality in these wells will not be affected by the Project (e.g., the pit dewatering and pit lake, or the TMF). Pumping water from these wells may generate small drawdown cones in the local area surrounding the wells (see Sections 11.4.1.5 and 11.4.1.6), but the drawdown cones are not expected to extend to or overlap with the model-predicted drawdown cone of the open pit dewatering, or to reach the TMF. Therefore, these wells would not cause cumulative effects in addition to the residual effects that are predicted for the Project. The water supply wells located outside the LSA (along the North Thompson River and Barriere River valleys) are at a considerable distance from the Project site and they may drawdown the water level in the local areas (see Sections 11.4.1.5 and 11.4.1.6), but they will not cause any cumulative effects, as the residual effects of the Project on groundwater quantity and quality have been predicted to be limited within the Project site and immediate downstream catchments (within the LSA) only. Therefore, no further assessment on the existing water supply wells is required for cumulative effects.

11.6.3 Mitigation Measures

No mitigation is required, as the past, present and future projects and activities are all identified with negligible or minor risks to cause cumulative effects on groundwater.

11.6.4 Cumulative Residual Effects and Characterization

No cumulative effects on groundwater quantity and quality are expected from the past, present and future projects and activities.

11.7 CONCLUSIONS FOR GROUNDWATER

The groundwater flow modeling has demonstrated that the proposed Project will affect groundwater quantity and quality significantly within the local mine site and immediate downstream catchments of the P-, T-, Harper, Baker and Jones creeks. With the implementation of the mitigation measures designed for the key mine components and activities (including the open pit dewatering and pit lake, the non-PAG waste rock stockpile, the PAG and non-PAG LGO stockpiles, the overburden and topsoil stockpiles, and the TMF together with the co-disposed PAG waste rock and non-PAG LGO stockpiles), the overall residual effects of the Project for both groundwater quantity and quality are assessed to be **not significant (moderate)** beyond the LSA (Table 11.7-1).

No cumulative effects are anticipated from the past, present and future projects and activities located in the hydrogeology study area. The existing supply wells for groundwater use in the downstream of the open pit are predicted not to be affected by the mining.

A follow-up groundwater monitoring plan has been developed as part of the Groundwater Management Plan (Chapter 24.8) to monitor the potential effects on groundwater in the catchments in the downstream of the major mine components. An adaptive management plan can be initiated if the monitoring results show that the effect in the receiving environment is significant enough to warrant further attention.

Table 11.7-1. Summary of Residual and Cumulative Effects on Groundwater Quantity and Quality, Mitigation and Significance

Residual Effects	Project Components/ Activities	Project Phase	Mitigation Measures	Significance of Residual Effects	
				Project	Cumulative
Groundwater Quantity					
Alteration of groundwater levels and flow patterns (flow directions, hydraulic gradients and flow rates) arising from mine activities, waste rock and water management	Open Pit Mining	Construction, Operations	Decommission and removal of open pit water management system during Operations 2.	not significant (moderate)	not significant (moderate)
	Pit Lake	Closure, Post-Closure	Pit refilled with water but with an elevation controlled, and excess water pumped to TMF.	not significant (moderate)	not significant (moderate)
	Non-PAG Waste Rock Stockpile	Operations, Closure, Post-Closure	Partial reclamation during Operations 2 and final reclamation during Closure; decommission and removal of the Water Management Pond during the final reclamation at Closure.	not significant (moderate)	not significant (moderate)
	PAG Waste Rock Stockpile	Operations, Closure, Post-Closure	Sub-aqueous disposal and managed inside the TMF during Operations, reclaimed with the TMF at Closure.	not significant (moderate)	not significant (moderate)
	PAG Low-Grade Ore Stockpile	Operations	The stockpile is underlain by a low-permeability overburden liner, and the ores will be processed and removed in Operations 2.	not significant (moderate)	not significant (moderate)
	Non-PAG Low-Grade Ore Stockpiles	Operations	Stored in the TMF catchment during Operation 1, processed and removed in Operations 2.	not significant (moderate)	not significant (moderate)
	Overburden Stockpile	Construction, Operations, Closure, Post-Closure	Progressive reclamation during Operations 2.	not significant (moderate)	not significant (moderate)
	Topsoil Stockpiles	Construction, Operations, Closure	Partial reclamation during Construction and Operations, and removal during Closure.	not significant (moderate)	not significant (moderate)
	Tailings Management Facility	Construction, Operations, Closure, Post-Closure	Partial reclamation of TMF tailings beaches and embankments during Operations 2, and final reclamation of TMF embankments and beaches during Closure; decommission and reclamation of the Water Management Pond during final reclamation at Closure.	not significant (moderate)	not significant (moderate)

(continued)

Table 11.7-1. Summary of Residual and Cumulative Effects on Groundwater Quantity and Quality, Mitigation, and Significance (continued)

Residual Effects	Project Components/ Activities	Project Phase	Mitigation Measures	Significance of Residual Effects	
				Project	Cumulative
Groundwater Quality					
Degradation of groundwater quality due to seepage of contact water	Pit Lake	Closure, Post-Closure	Design: Pit refilled with water but with an elevation controlled, and excess water pumped to TMF. EMPs: Groundwater Management Plan	not significant (moderate)	not significant (moderate)
	Non-PAG Waste Rock Stockpile	Operations, Closure, Post-Closure	Design: Runoff diversion and collection ditches; seepage collection and storage in the TMF during Operations; concurrent partial reclamation during Operations 2 and final reclamation during Closure; decommission and removal of the Water Management Pond during the final reclamation at Closure. EMPs: Mine Waste and ML/ARD Management Plan; Groundwater Management Plan	not significant (moderate)	not significant (moderate)
	PAG Waste Rock Stockpile	Operations, Closure, Post-Closure	Design: Sub-aqueous disposal and managed inside the TMF during Operations, reclaimed with the TMF at Closure. EMPs: Mine Waste and ML/ARD Management Plan, Groundwater Management Plan	not significant (moderate)	not significant (moderate)
	PAG Low-Grade Ore Stockpile	Operations	Design: The stockpile is underlain by a low-permeability overburden liner with a water management pond collecting the seepage and diverted to the TMF. The ores will be processed and removed in Operations 2. EMPs: Mine Waste and ML/ARD Management Plan, Groundwater Management Plan	not significant (moderate)	not significant (moderate)
	Non-PAG Low-Grade Ore Stockpiles	Operations	Design: Stored in the TMF catchment during Operation 1, processed and removed in Operation 2. EMPs: Mine Waste and ML/ARD Management Plan; Groundwater Management Plan	not significant (moderate)	not significant (moderate)

(continued)

Table 11.7-1. Summary of Residual and Cumulative Effects on Groundwater Quantity and Quality, Mitigation, and Significance (completed)

Residual Effects	Project Components/ Activities	Project Phase	Mitigation Measures	Significance of Residual Effects	
				Project	Cumulative
Groundwater Quality (*cont'd*)					
Degradation of groundwater quality due to seepage of contact water (*cont'd*)	Overburden Stockpile	Construction, Operations, Closure, Post-Closure	Design: Progressive reclamation during Operations 2. EMPs: ML/ARD management plan (PAG and non-PAG material sorting)	not significant (moderate)	not significant (moderate)
	Topsoil Stockpiles	Construction, Operations, Closure	Design: Partial reclamation during Construction and Operations, and used for reclamation and removal during Closure.	not significant (moderate)	not significant (moderate)
	Tailings Management Facility	Operations, Closure, Post-Closure	Design: Low-permeability embankment materials, seepage collection drains and recovery pond, pumping back; Concurrent partial reclamation of TMF tailings beaches and embankments during Operations 2, and final reclamation of TMF embankments and beaches during Closure; decommission and reclamation of the Water Management Pond during final reclamation at Closure. EMPs: Groundwater Management Plan	not significant (moderate)	not significant (moderate)

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