

12 Groundwater Quality

This chapter describes and quantifies the potential effects of the KMS Project (the Project) on groundwater quality. Hydrogeological characterization is based on baseline data that has been collected since 2008. The potential effects of the Project have been assessed based on the results of three-dimensional hydrogeological numerical modelling. Modelling exercises included calibration to baseline flow conditions, and predictive modelling of effects to groundwater quality at key stages of the mine during operation and post-closure. Solute transport simulations did not include the complex biogeochemical attenuation processes. Therefore, the predictions are considered to be conservative. Complete details of the modelling methodology and results are presented in [Appendix 11-E](#).

The Application Information Requirements (AIR) document issued by the British Columbia Environmental Assessment Office (BC EAO; 2011) and the Comprehensive Study Scope of Assessment issued by the Canadian Environmental Assessment Agency (CEA Agency et al. 2010) require an effects assessment on groundwater quality. Consideration of mitigation measures that reduce potential effects must be considered, followed by the identification of residual effects and a determination of their significance. Cumulative effects arising from interactions with other projects must also be considered. The effects assessment for groundwater quality has been conducted by identifying issues using the results of the predictive groundwater model; professional judgement; and consultations with Project geochemists, hydrologists, and water quality experts.

12.1 Project Setting

12.1.1 Overview of Baseline Groundwater Studies

A hydrogeology baseline study was undertaken from 2008 to 2012 in the proposed Mine Site and Processing and Tailing Management Area (PTMA) of the Project. The study focused on the collection of data to characterize the groundwater quantity and quality in the Project area as specified in the AIR and Comprehensive Study Scope of Assessment (CEA Agency et al. 2010). The objective of collecting the groundwater quantity information was for development of conceptual and numerical groundwater models. Models were then used for predicting potential effects on groundwater quality that may be caused by the proposed Project. No groundwater quantity data were available prior to 2008.

Groundwater quantity information was collected by three consulting firms. Data were used to characterize baseline hydrogeology conditions and to develop models. Data were collected by Klohn Crippen Berger Ltd. (KCB) within the PTMA, the Water Storage Facility (WSF), and Mitchell and Sulphurets valleys for the geotechnical engineering design; by BGC Engineering Inc. (BGC) within the pit areas for the depressurization analysis; and by Rescan Environmental Services Ltd. (Rescan) in areas within and down-gradient of the proposed infrastructure for the environmental impact assessment. Groundwater quality data were collected from 2009 to 2012 in the monitoring wells, which were installed by Rescan in 2009 to monitor environmental groundwater quality. The sampled monitoring wells are distributed at various locations and

elevations within the critical mine footprints and along the potential flow migration paths in the downstream groundwater environment. The wells have good control of the baseline groundwater quality based on the geological conditions on site, and are adequate from the standpoint of the environmental impact assessment. The piezometers installed by KCB and BGC in various years between 2008 and 2012 were for the geotechnical studies only (see Section 11.1.1 of Chapter 11 and [Appendix 11-E](#)). Details of the groundwater quality data and the methodologies can be found in the hydrogeological baseline reports issued by Rescan ([Appendices 11-A, 11-B, and 11-C](#)). Groundwater quality data were used to define pre-mining conditions, including the range of natural variability of groundwater chemistry. Groundwater quality data were also incorporated in the surface water quality modelling (discussed in Chapter 14).

Impacts of Project activity on groundwater quality are directly affected by the groundwater flow conditions. The groundwater models used to assess effects on groundwater quality use groundwater quantity simulation results as input data sets. The existing groundwater quantity setting is described in Chapter 11 (Section 11.1).

12.1.2 Methods to Characterize Groundwater Quality

Groundwater quality was characterized by sampling water from monitoring wells. Monitoring locations were selected within and down-gradient of the proposed mine infrastructure and at more distant locations in close proximity to potential groundwater receptors (e.g., close to creeks that may receive mining contact water). Rescan hydrogeologists selected monitoring locations with a basin-scale approach to satisfy the requirement to characterize groundwater quality throughout the mining and tailing storage catchments.

Borehole drilling was conducted using rigs with a combination of overburden drilling with eccentric drilling (ODEX) and diamond drilling (DD) capabilities. From June to September 2009, Rescan hydrogeologists supervised borehole drilling and the installation of 28 monitoring wells at 14 locations in the Mine Site and PTMA. As of 2012, the data from Rescan's 22 monitoring wells in the Mine Site, and 6 wells installed in the PTMA, have been used to characterize baseline groundwater quality. The locations of the monitoring wells in the Mine Site and PTMA are shown in Figures 12.1-1 and 12.1-2, respectively. Lithology and hydraulic conductivity data from numerous additional geotechnical and exploration boreholes were used to characterize the physical hydrogeology environment, as discussed in Chapter 11.

Two boreholes were drilled at each of the Rescan monitoring locations, including one shallow borehole (typical depth ranging 20 to 40 m) and one deep borehole (typical depth ranging 80 to 120 m). Boreholes were drilled using HQ rods (4-inch outer diameter) and completed with 2-inch PVC monitoring wells installed with sand filter pack around the well screen, bentonite seal, and grouted to surface as per the BC Ministry of Environment's (BC MOE) *Technical Guidance for Groundwater Investigation and Characterization* (2009). The wells were developed by air lifting until the turbidity in water was low and at least three well volumes were removed from each well during development. A cap was provided for each well and a well monument was installed to protect the PVC stickup. All flowing artesian wells were capped and sealed as per the Ground Water Protection Regulation (BC Reg. 91/2009).

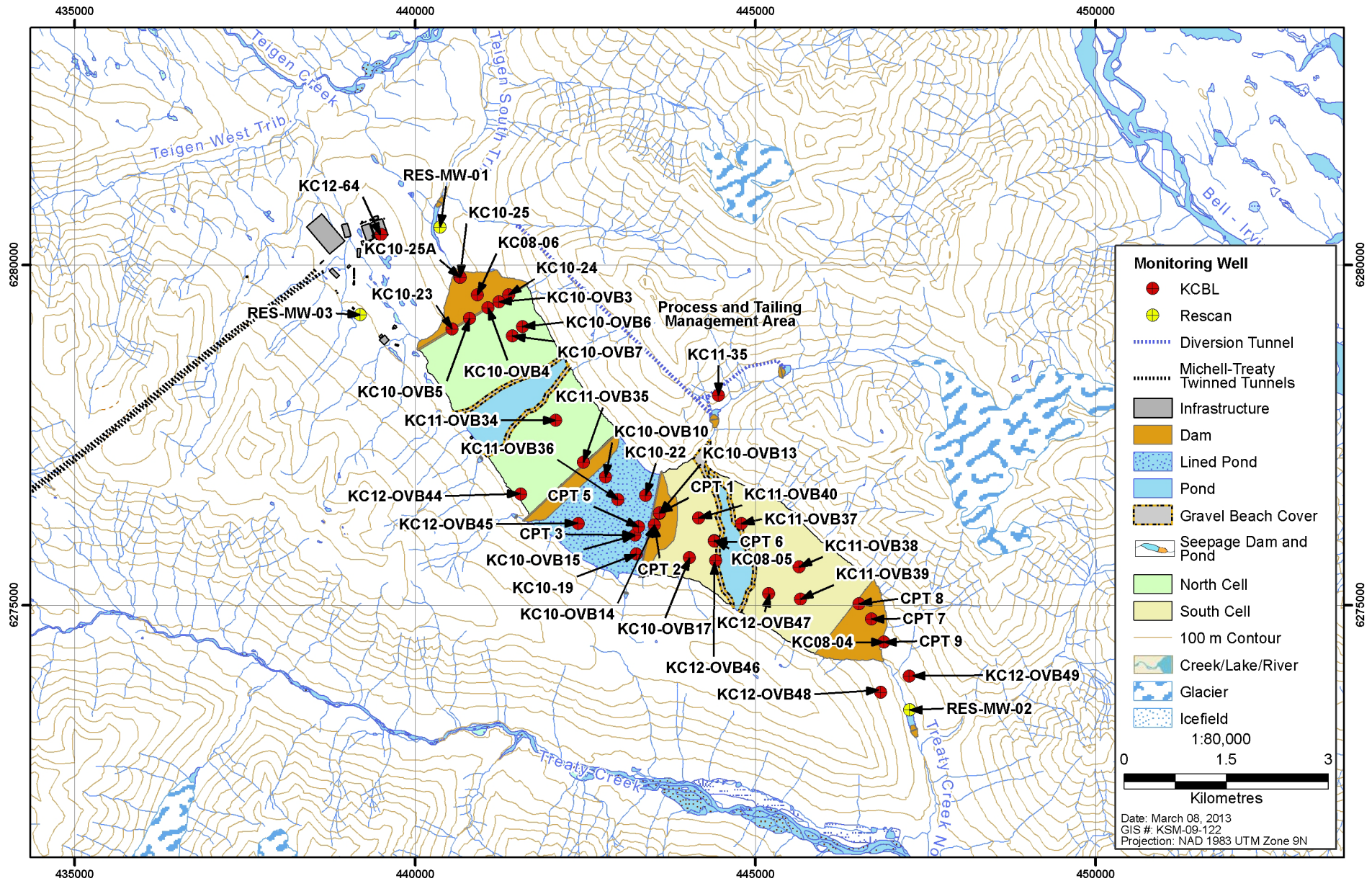


Figure 12.1-2

Figure 12.1-2

Groundwater sampling procedures outlined in provincial guidance documents (BC MOE 2012) were followed. Groundwater samples were collected on a quarterly basis and sent to ALS Laboratories in Vancouver for chemical analysis. Purging and sampling were performed using a Grundfos Redi-Flo2® submersible pump, and a Waterra foot valve on 5/8-inch tubing combined with a Hydrolift pump or air lifting (purge), followed by bailer (sampling). Purging was conducted until the discharge water demonstrated hydrochemical stability. Most of the wells were purged a minimum of three well volumes of water before sampling, except for a few wells with very slow recharge and recovery, where low flow sampling procedure was followed. Groundwater samples were collected for analysis of physical properties, major cations and anions, total and dissolved metals, nutrients, total organic carbon, and cyanide concentrations.

Ten percent of the samples were collected in duplicate for quality assurance / quality control. At least one travel blank and one field blank were also collected during each sampling event.

12.1.3 Mine Site

The Mine Site includes the proposed open pits and underground block caves at the mineral deposits, as well as the proposed Mitchell and McTagg rock storage facilities (RSFs), the Sulphurets Pit backfill RSF, and the WSF. Topographically, the area comprises deep glacial-cut valleys drained by creeks (Mitchell, McTagg, and Sulphurets creeks) with intervening high mountains oriented in an east-west direction. The mountain peaks bounding the Mitchell and Sulphurets valleys reach elevations in excess of 2,000 masl, whereas the valley bottom elevations near the deposits are approximately 800 masl in the Mitchell Valley and 600 masl north of the Kerr deposit. Mineralized springs and seeps on the southern slope of Mitchell Valley indicate groundwater discharge at elevations ranging from 1,000 to 1,150 masl (approximately 300 m above the Mitchell Valley floor at the proposed pit location), and on the southern slope of the Sulphurets Valley (adjacent to the Kerr deposit), ranging from 1,100 to 1,300 masl.

Generally speaking, the groundwater system receives recharge from precipitation and surface runoff at higher elevations, and discharges into the surface water in lower elevations, or evaporates into the air as evapotranspiration. Surface flows are dominated by snowmelt and glacial melt water that sustain summer flows. In the Mitchell Valley, poor-quality water at the toe of the glacier is thought to be affected by groundwater that has contacted mineralized rock, as water quality is similar to that in the springs/seeps. The poor quality contact water leaching out of the ore deposits in the Upper Mitchell and Sulphurets valleys are observed dominantly discharging into the downstream Mitchell and Sulphurets creeks at the current pre-mining conditions. The interactions between surface water and groundwater are interpreted by comparing the water levels in the surface water and the water elevations in the monitoring wells and piezometers. This is considered to be enough for the prefeasibility study stage. If needed, further characterization and quantification of the surface water groundwater interactions can be done in the future detail design or construction phases by using more sophisticated approaches such as a temperature survey, seepage meter survey, and isotopic and tracing analysis.

The western and topographically lower part of the Mine Site is within marine sedimentary and volcanic rocks (Stuhini Group). Regional thrust faults expose volcanic rocks of the Hazelton Group in the area of the proposed Mitchell and Sulphurets pits and to the east of the Mine Site.

Overburden (thin colluvium on mountain slopes and glacial till in the valley bottoms) thicknesses are variable, with a maximum measured thickness of 140 m in the Mitchell Valley west of the proposed pit. The maximum depth of overburden is greater than 40 m in the Sulphurets Valley (between Sulphurets Lake and the confluence of Sulphurets and Mitchell creeks), and 10 m in the McTagg Valley. Landslides and alluvial fans occur on many steeper valley slopes.

The objective of groundwater quality monitoring was to assess ambient groundwater conditions prior to mining activities. Twenty-eight samples were collected from 14 locations (including the PTMA) on four occasions during the 2008 to 2010 baseline programs. Five additional samples were collected in 2012. Relative percent differences (RPDs) calculated for duplicate samples showed good sampling and analytical precision. The target RPD of 20% was exceeded in only one sample for iron and aluminum. The groundwater quality results (summarized in Tables 12.1-1 and 12.1-2) were compared to the British Columbia (BC) freshwater aquatic life (FAL) guidelines (BC MOE 2010) for illustrative purposes. There are no federal or provincial groundwater-specific water quality guidelines or standards.

Wells in the deposit areas showed low pH (3.8 to 5.2). Samples taken from seeps in deposit areas had pH as low as 2.2. Outside deposit areas, pH was within the expected range for natural water (5.5 to 8.5). Average concentrations of sulphate, dissolved iron, and dissolved aluminum exceed the FAL guidelines by factors of 2, 15, and 5, respectively, in samples from wells within the Mine Site. Certain metals concentrations (e.g., copper, chromium, lead, manganese, and zinc) were elevated in groundwater samples from mineralized areas. The highest selenium concentration was 86 µg/L, and the average was 2 µg/L. The highest mercury concentration measured was 0.25 µg/L.

The monitoring well RES-MW-11A, at the confluence of Mitchell and Sulphurets creeks, had anomalous chemistry evident from elevated concentrations of ammonia, boron, nitrate, nickel, thallium, and a high concentration of thiocyanate (142 mg/L at this location in the May 2010 sample). High alkalinity (particularly HCO₃) and CO₂ gas were detected in the well.

This area may be a mixing zone between acidic, mineralized groundwater from the Mitchell Catchment and that sourced in carbonate-bearing bedrock observed near the southeast abutment of the proposed WSF. The dissolution-enhanced carbonate-bearing bedrock at the local WSF has been incorporated in the groundwater modelling as high permeability zone (up to 10⁻³ m/s) to characterize the potential maximum effects on groundwater quantity and quality (see Chapter 11 and [Appendix 11-E](#)). The Piper Plot (Figure 12.1-3) shows the variation in water types (based on major anions and cations) in the different locations of the Mine Site and PTMA.

12.1.4 Processing and Tailing Management Area

The PTMA is within a valley spanning the upper reaches of the North Treaty and South Teigen tributaries. Overburden in the valley bottom is composed of low-permeability glacial till up to approximately 30 m thick. Higher permeability fluvial deposits crosscut the glacial till along the stream beds of South Teigen and North Treaty creeks. Alluvial fans up to 90 m thick, with moderate permeability, have been identified along the valley edges. Lateral moraines and scree piles fill the steep sub-catchments on the valley slopes and surrounding mountainous areas (less than 5 m thick). Further detail regarding overburden permeability and flow patterns are discussed in Chapter 11, Groundwater Quantity (Section 11.1.4), and in [Appendix 11-E](#).

Table 12.1-1. Physical Parameters, Concentrations of Major Anions and Nutrients, and Cyanides in Groundwater in the Mine Site

Parameter	Units	# of Samples	# Samples below Detection	Minimum	Maximum	Average ¹	Standard Deviation	BC MOE Guideline
Physical Parameters								
Colour, True	CU	68	63	2.5	55.5	4.65	9.55	A
Conductivity	µS/cm	68	0	213	7,460	950	1,491	ng
Hardness (as CaCO ₃)	mg/L	69	0	84.6	2,430	314	443	ng
pH	pH	68	0	3.77	8.83	7.58	0.95	ng
Total Suspended Solids	mg/L	68	22	1.5	1,220	56	161	B
Total Dissolved Solids	mg/L	68	0	142	6,620	718	1,189	ng
Turbidity	NTU	68	0	0.12	2,510	79	309	B
Anions and Nutrients								
Ammonia (as N)	mg/L	69	24	0.0025	6.64	0.29	1.21	0.681 ^C
Acidity (as CaCO ₃)	mg/L	68	4	0.5	1,480	54	194	ng
Alkalinity, Bicarbonate (as CaCO ₃)	mg/L	68	1	1.0	3,487	175	560	ng
Alkalinity, Carbonate (as CaCO ₃)	mg/L	68	66	0.5	5	1.06	0.54	ng
Alkalinity, Hydroxide (as CaCO ₃)	mg/L	68	68	0.5	5	1.04	0.54	ng
Alkalinity, Total (as CaCO ₃)	mg/L	68	3	1.0	5,720	285	920	ng
Bromide (Br)	mg/L	68	66	0.025	6.97	0.34	1.16	ng
Chloride (Cl)	mg/L	68	48	0.25	51	3.56	8.80	600
Fluoride (F)	mg/L	68	5	0.04	3.57	0.74	0.78	0.2-0.3 ^D
Sulphate (SO ₄)	mg/L	68	0	11.2	1420	230	299	100
Nitrate (as N)	mg/L	68	65	0.0025	0.178	0.019	0.035	31.3
Nitrite (as N)	mg/L	68	67	0.0005	0.025	0.0029	0.0054	0.06-0.60 ^E

(continued)

Table 12.1-1. Physical Parameters, Concentrations of Major Anions and Nutrients, and Cyanides in Groundwater in the Mine Site (completed)

Parameter	Units	# of Samples	# Samples below Detection	Minimum	Maximum	Average ¹	Standard Deviation	BC MOE Guideline
Anions and Nutrients (cont'd)								
Total Kjeldahl Nitrogen	mg/L	68	38	0.025	10.1	0.49	1.83	ng
Total Nitrogen	mg/L	69	37	0.025	10.1	0.46	1.69	ng
Total Phosphate (as P)	mg/L	24	9	0.0005	0.041	0.0059	0.0103	ng
Total Organic Carbon	mg/L	69	24	0.1	32.1	1.95	4.13	ng
Cyanides								
Total Cyanide	mg/L	69	51	0.00050	0.00350	0.00091	0.00077	ng
Weak Cyanide	mg/L	0	0	n/a	n/a	n/a	n/a	0.01
Free Cyanide	mg/L	0	0	n/a	n/a	n/a	n/a	ng

Notes:

Bold/Italic = exceeds the BC MOE (2010) Guideline.

BC MOE Guideline = BC Water Quality Guidelines (BC MOE 2010).

¹ Average is calculated using half of the detection limit when the result was below it.

ng = no guideline

A = 30-day average transmission of white light > 80% of background

B = Depends on background values

C = Temperature and pH dependent (see guideline). Most stringent guideline applied.

D = Fluoride guideline of 0.3 mg/L if hardness ≥ 50mg/L, guideline 0.2 mg/L if hardness < 50 mg/L

E = Nitrite BC Max depends on Cl conc, see guideline

Table 12.1-2. Total and Dissolved Metals Concentrations in Groundwater in the Mine Site

Units	Total Metals							BC MOE Guideline (total)	Dissolved Metals					BC MOE Guideline (dissolved)
	# of Samples	# of Samples below Detection	Minimum	Maximum	Average ¹	Standard Deviation	# of Samples		# of Samples below Detection	Minimum	Maximum	Average ¹	Standard Deviation	
Aluminum mg/L	69	7	0.002	30.6	1.72	4.47	ng	68	7	0.0010	16.2	0.47	2.14	0.1 ^A
Antimony mg/L	69	16	5.00E-05	0.047	0.0053	0.0093	0.02 ^B	68	17	5.0E-05	0.0487	0.0049	0.0092	ng
Arsenic mg/L	69	2	5.00E-05	0.156	0.018	0.028	0.005	68	3	1.0E-04	0.0841	0.015	0.023	ng
Barium mg/L	69	0	0.00745	0.617	0.076	0.109	5 ^B	68	0	0.00717	0.443	0.048	0.071	ng
Beryllium mg/L	69	64	5.00E-05	0.0050	0.00073	0.00104	0.0053 ^B	3	2	5.0E-05	0.0003	0.00017	0.00011	ng
Bismuth mg/L	69	68	0.00025	0.0050	0.00075	0.00112	ng	3	3	0.00025	0.0013	0.00058	0.00058	ng
Boron mg/L	69	41	0.005	8.23	0.36	1.57	1.2	68	46	0.0050	9.03	0.39	1.70	ng
Cadmium mg/L	69	19	5.00E-06	0.0211	0.00073	0.00283	E, J	68	22	5.0E-06	0.0195	0.00067	0.00269	ng
Calcium mg/L	69	0	28.2	478	95.2	92.3	ng	68	0	28.4	482	94.9	94.7	ng
Chromium mg/L	69	27	0.00018	0.025	0.0037	0.0057	0.001 ^{E, K}	68	60	5.0E-05	0.015	0.0015	0.0030	ng
Cobalt mg/L	69	13	5.00E-05	0.0571	0.0061	0.0124	0.11	68	18	5.00E-05	0.053	0.0057	0.0125	ng
Copper mg/L	69	13	0.0001	14	0.38	1.79	C	68	12	5.0E-05	12.6	0.34	1.64	ng
Iron mg/L	69	0	0.041	44.9	6.1	11.0	1	68	21	0.015	50.7	4.9	10.9	0.35
Lead mg/L	69	14	2.50E-05	0.496	0.012	0.061	D	68	48	2.5E-05	0.089	0.0025	0.012	ng
Lithium mg/L	69	46	0.00105	0.66	0.056	0.158	5 ^B	68	47	0.00109	0.7	0.058	0.165	ng
Magnesium mg/L	69	0	1.1	273	18.8	51.5	ng	68	0	0.985	299	19.3	54.9	ng
Manganese mg/L	69	0	0.0162	3.9	0.85	1.14	E	68	0	0.0118	4.26	0.82	1.16	ng
Mercury mg/L	69	59	5.00E-06	0.000248	1.17E-05	3.14E-05	ng	3	3	5.0E-06	5.0E-06	5.0E-06	0	ng
Molybdenum mg/L	69	0	0.000293	0.131	0.0106	0.0195	2	68	0	0.00026	0.105	0.0098	0.0172	ng
Nickel mg/L	69	19	0.00025	0.087	0.0077	0.0154	0.025-0.150 ^{B, N}	68	22	0.00025	0.085	0.0066	0.0156	ng
Phosphorus mg/L	69	69	0.15	0.64	0.167	0.071	0.005 ^O	68	68	0.15	0.30	0.157	0.031	ng
Potassium mg/L	69	0	0.301	53.2	4.40	10.09	ng	68	0	0.278	55	4.25	10.5	ng
Selenium mg/L	69	37	5.00E-05	0.0859	0.0025	0.0106	ng	68	45	5.0E-05	0.086	0.0025	0.0108	ng
Silicon mg/L	69	0	2.89	47	8.98	6.37	ng	68	0	2.6	15.9	6.96	2.53	ng
Silver mg/L	69	38	5.00E-06	0.0025	0.00020	0.00051	0.0001-0.003 ^F	68	60	5.0E-06	0.00143	6.4E-05	0.00025	ng
Sodium mg/L	69	3	1	1560	116	327	ng	68	0	2.0	1510	111	298	ng
Strontium mg/L	69	0	0.245	5.84	1.28	1.41	ng	68	0	0.245	5.96	1.26	1.43	ng
Thallium mg/L	69	66	5.00E-06	0.001	0.00015	0.00022	0.0003 ^B	3	2	5.0E-06	2.5E-05	1.8E-05	1.1E-05	ng
Tin mg/L	69	47	5.00E-05	0.00427	0.00038	0.00070	ng	68	43	5.0E-05	0.00109	0.00025	0.00027	ng
Titanium mg/L	69	38	0.005	0.668	0.033	0.085	2.0-4.6 ^{B, G}	3	3	0.0050	0.0050	0.0050	0	ng
Uranium mg/L	69	3	5.00E-06	0.0155	0.0020	0.0033	0.3 ^B	68	1	1.0E-05	0.0157	0.0019	0.0032	ng
Vanadium mg/L	69	48	5.00E-04	0.0772	0.0043	0.0100	ng	68	64	5.0E-04	0.010	0.0016	0.0021	ng
Zinc mg/L	69	15	0.0005	0.948	0.068	0.146	H	68	26	0.0005	0.898	0.052	0.133	ng

Notes:

Bold/Italic = exceeds the BC MOE (2010) Guideline.

¹ Average is calculated using half of the detection limit when the result was below it.

-BC MOE Guideline = Approved and Working BC Freshwater Aquatic Life Guidelines (BC MOE 2010).

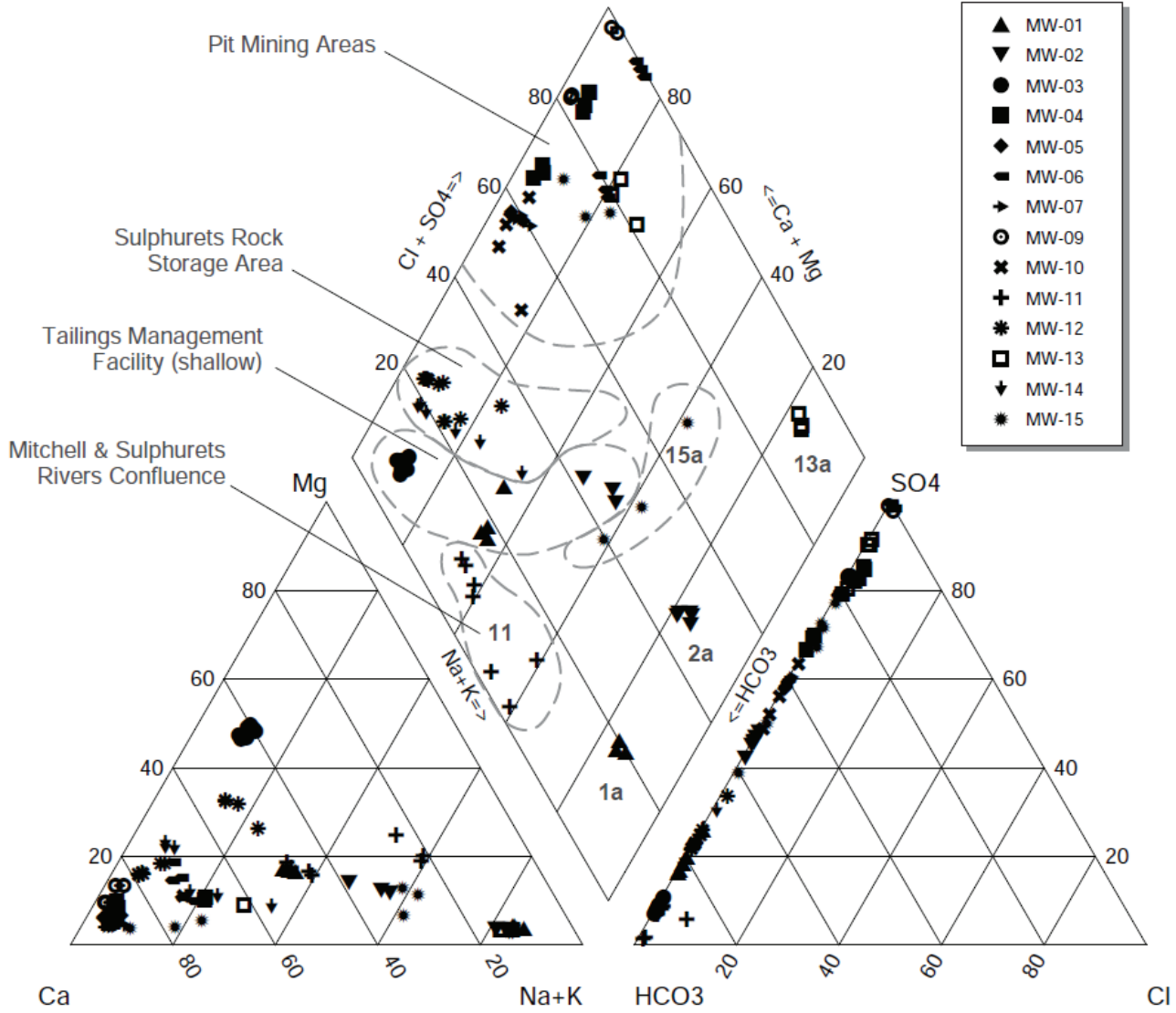
ng = no guideline

A = 0.1 mg/L for pH ≥ 6.5; BC Max = e (1.209 - 2.426 × [pH] + 0.286 × [pH] × [pH]) for pH < 6.5

B = Working BC Max guideline only

C = BC Max T-Cu guideline = 0.001 × (0.094(hardness)+2) mg/L

D = Max Pb guideline = 0.001 × [e(1.273 ln (hardness) - 1.460)] mg/L if hardness > 8mg/L; or 0.003 mg/L if hardness ≤ 8mg/L



The bedrock in the PTMA comprises meta-sedimentary rocks of the Bowser Lake Group, consisting of weakly metamorphosed sandstones, siltstones, mudstones, and occasional conglomerates. Structurally, the rock beneath the proposed site of the Tailing Management Facility (TMF) is characterized by a syncline with steeply dipping beds and occasional minor folds (as observed in outcrop) on the valley slopes and gently dipping on the valley bottoms. Field investigations do not indicate significant faulting under the proposed TMF footprint. Several local small-scale faults have been documented on the slopes of the valley. Bedrock permeability generally decreases with depth. Further detail regarding bedrock permeability and flow patterns are discussed in Chapter 11 (Section 11.1.4) and in [Appendix 11-E](#).

The groundwater quality in the PTMA is calcium bicarbonate (CaHCO_3) type (Figure 12.1-3). Sodium bicarbonate (NaHCO_3) type is predominant in several of the deeper bedrock wells. Groundwater is fresh (total dissolved solid as high as 272 mg/L) with neutral to slightly alkaline pH (ranging from 7.4 to 8.8). Table 12.1-3 summarizes physical properties and major ion concentrations measured for groundwater samples collected in the PTMA.

Dissolved metal concentrations are generally low and ubiquitously below the BC MOE FAL guidelines (BC MOE 2010) for total metals (Table 12.1-4). Total metal concentrations are measured and reported for groundwater samples because existing guidelines are published almost entirely for total concentrations only. Elevated concentrations of total metals with respect to dissolved metals that coincide with a high suspended sediment concentration are considered a sampling method artifact (BC MOE 2012). High suspended sediment concentrations in the groundwater environment are unusual, because flow rates are very low. Therefore, groundwater quality determination is focused on the dissolved component of metals concentrations.

High mountainous areas have been interpreted as recharge zones, with discharge zones in valley bottoms. The groundwater system generally receives recharge from precipitation and surface runoff at higher elevations, and discharges into the surface water in lower elevations or evaporates into the air as evapotranspiration. Surface water infiltrating persistent fractures along valley walls and the colluvial fans on the valley edges are identified recharge mechanisms for the valley sediments. The vertical upward gradient in the valley bottom implies that wetlands and creeks are fed by groundwater discharge. The proposed TMF location, at the bottom of the valley feeding the South Teigen and North Treaty tributaries, provides potential for good hydraulic containment. The interactions between surface water and groundwater are interpreted by comparing the water levels in the surface water and the water elevations in the monitoring wells and piezometers. This is considered to be enough for the prefeasibility study stage. If needed, further characterization and quantification of the surface water groundwater interactions can be done in the future detail design or construction phases by using more sophisticated approaches such as temperature survey, seepage meter survey, and isotopic and tracing analysis.

Table 12.1-3. Physical Parameters, Concentrations of Major Anions and Nutrients, and Cyanides in Groundwater in the Processing and Tailing Management Area

Parameter	Units	# of Samples	# Samples below Detection	Minimum	Maximum	Average ¹	Standard Deviation	BC MOE Guideline
Physical Parameters								
Colour, True	CU	29	29	2.5	2.5	2.5	0.0	A
Conductivity	µS/cm	29	0	213	418	295.7	69.0	ng
Hardness (as CaCO ₃)	mg/L	29	0	18.5	138	78.2	43.4	ng
pH	pH	29	0	7.37	8.78	8.28	0.23	ng
Total Suspended Solids	mg/L	29	23	1.5	121	9.8	29.2	B
Total Dissolved Solids	mg/L	29	0	122	272	175.1	49.3	ng
Turbidity	NTU	29	0	0.2	67.4	6.02	16.41	B
Anions and Nutrients								
Ammonia (as N)	mg/L	29	0	0.0899	0.561	0.36	0.17	0.681 ^C
Acidity (as CaCO ₃)	mg/L	29	17	0.5	28.1	2.03	5.08	ng
Alkalinity, Bicarbonate (as CaCO ₃)	mg/L	29	1	58.6 ¹	126	80.2	16.3	ng
Alkalinity, Carbonate (as CaCO ₃)	mg/L	29	24	0.5 ¹	9.4	1.64	2.11	ng
Alkalinity, Hydroxide (as CaCO ₃)	mg/L	29	29	0.5 ¹	1	0.793	0.251	ng
Alkalinity, Total (as CaCO ₃)	mg/L	29	0	96.2	146	124.8	12.9	ng
Bromide (Br)	mg/L	29	29	0.025 ¹	0.025	0.025	0.000	ng
Chloride (Cl)	mg/L	29	29	0.25 ¹	0.25	0.25	0.00	600
Fluoride (F)	mg/L	29	0	0.08	0.319	0.147	0.077	0.2-0.3 ^D
Sulphate (SO ₄)	mg/L	29	0	7.98	88.4	36.3	32.4	100
Nitrate (as N)	mg/L	29	26	0.0025 ¹	0.0578	0.0065	0.0128	31.3
Nitrite (as N)	mg/L	29	25	0.0005 ¹	0.0296	0.0022	0.0059	0.06-0.60 ^E

(continued)

Table 12.1-3. Physical Parameters, Concentrations of Major Anions and Nutrients, and Cyanides in Groundwater in the Processing and Tailing Management Area (completed)

Parameter	Units	# of Samples	# Samples below Detection	Minimum	Maximum	Average ¹	Standard Deviation	BC MOE Guideline
Anions and Nutrients (cont'd)								
Total Kjeldahl Nitrogen	mg/L	29	0	0.08	0.72	0.348	0.186	ng
Total Nitrogen	mg/L	29	0	0.08	0.72	0.346	0.180	ng
Total Phosphate (as P)	mg/L	11	3	0.0005 ¹	0.0325	0.0095	0.0122	ng
Total Organic Carbon	mg/L	24	8	0.1 ¹	2	0.649	0.481	ng
Cyanides								
Total Cyanide	mg/L	29	24	0.0005 ¹	0.0015	0.000641379	0.000323505	ng
Weak Cyanide	mg/L	0	0	n/a	n/a	n/a	n/a	0.01
Free Cyanide	mg/L	0	0	n/a	n/a	n/a	n/a	ng

Notes:

Bold/Italic = exceeds the BC MOE Guideline (BC MOE 2010).

¹ Average is calculated using half of the detection limit when the result was below it.

–BC MOE Guideline = Approved and Working BC Freshwater Aquatic Life Guidelines (BC MOE 2010).

ng = no guideline

A = 30-day average transmission of white light > 80% of background

B = Depends on background values

C = Temperature and pH dependent (see guideline). Most stringent guideline applied.

D = Fluoride guideline of 0.3 mg/L if hardness ≥ 50mg/L, guideline 0.2 mg/L if hardness < 50 mg/L

E = Nitrite BC Max depends on Cl conc, see guideline

Table 12.1-4. Total and Dissolved Metals Concentrations in Groundwater in the Processing and Tailing Management Area

Units	Total Metals						BC MOE Guideline (total)	Dissolved Metals					BC MOE Guideline (dissolved)		
	# of Samples	# of Samples below Detection	Minimum	Maximum	Average ¹	Standard Deviation		# of Samples	# of Samples below Detection	Minimum	Maximum	Average ¹		Standard Deviation	
Aluminum	mg/L	28	3	0.0045	4.12	0.34	0.96	ng	29	1	0.0015	0.0836	0.015	0.020	0.1 ^D
Antimony	mg/L	28	20	5.00E-05	0.00451	0.00055	0.0013	0.02 ^E	29	21	5.0E-05	0.0045	0.00052	0.0013	ng
Arsenic	mg/L	28	4	5.00E-05	0.00338	0.0013	0.0011	0.005	29	6	5.0E-05	0.00376	0.0012	0.0012	ng
Barium	mg/L	28	0	0.0145	0.151	0.063	0.031	5 ^E	29	0	0.0131	0.0941	0.052	0.028	ng
Beryllium	mg/L	28	28	5.00E-05	0.00025	0.00023	0.000063	0.0053 ^E	3	3	5.0E-05	0.00005	5.0E-05	0	ng
Bismuth	mg/L	28	28	0.00025	0.00025	0.00025	1.7E-19	ng	3	3	0.00025	0.00025	0.00025	0	ng
Boron	mg/L	28	4	0.0050	0.035	0.0190	0.0093	1.2	29	8	0.0050	0.03	0.0159	0.0087	ng
Cadmium	mg/L	28	9	5.00E-06	0.000029	1.36E-05	7.52E-06	E, F	29	14	5.0E-06	0.000049	1.3E-05	1.1E-05	ng
Calcium	mg/L	28	0	5.36	27.2	18.6	7.4	ng	29	0	5.39	26.1	18.0	7.6	ng
Chromium	mg/L	28	14	0.00022	0.00229	0.00057	0.00056	0.001 ^{E, G}	29	29	5.0E-05	0.00025	0.00023	0.00006	ng
Cobalt	mg/L	28	13	5.00E-05	0.00049	0.00013	0.00012	0.11	29	21	5.0E-05	0.00024	0.000077	0.000052	ng
Copper	mg/L	28	16	5.00E-05	0.00118	0.00039	0.00032	H	29	8	5.0E-05	0.00244	0.00026	0.00043	ng
Iron	mg/L	28	7	0.015	1.73	0.22	0.45	1	29	20	0.015	0.092	0.026	0.022	0.35
Lead	mg/L	28	20	2.50E-05	0.00239	0.00027	0.00060	J	29	25	2.5E-05	0.000543	0.000047	0.000096	ng
Lithium	mg/L	28	2	0.0025	0.179	0.052	0.059	5 ^E	29	3	0.0025	0.177	0.055	0.060	ng
Magnesium	mg/L	28	0	1.34	18.7	8.3	6.6	ng	29	0	1.22	18.2	8.1	6.7	ng
Manganese	mg/L	28	0	0.00939	0.242	0.051	0.055	L	29	0	0.0090	0.168	0.044	0.045	ng
Mercury	mg/L	28	28	5.00E-06	5.00E-06	5.00E-06	8.63E-22	ng	3	3	5.0E-06	5.0E-06	5.0E-06	0	ng
Molybdenum	mg/L	28	0	0.00173	0.0168	0.0061	0.0039	2	29	0	0.00162	0.0169	0.0058	0.0039	ng
Nickel	mg/L	28	15	0.00025	0.00193	0.00061	0.00049	0.025-0.150 ^{E, N}	29	26	0.00025	0.00156	0.00037	0.00036	ng
Phosphorus	mg/L	28	28	0.15	0.15	0.15	0	0.005 ^O	29	29	0.15	0.15	0.15	0	ng
Potassium	mg/L	28	0	0.416	1.54	0.96	0.32	ng	29	0	0.48	1.22	0.93	0.26	ng
Selenium	mg/L	28	16	5.00E-05	0.00252	0.00025	0.00052	ng	29	26	5.00E-05	0.0026	0.00022	0.00052	ng
Silicon	mg/L	28	0	3.25	26.7	5.78	5.69	ng	29	0	3.36	5.43	4.22	0.63	ng
Silver	mg/L	28	21	5.00E-06	0.000047	0.000010	0.000011	0.0001-0.003 ^P	29	29	5.0E-06	0.000005	5.0E-06	0	ng
Sodium	mg/L	28	0	5.5	80.9	33	28	ng	29	0	5.6	83.3	34.9	29.2	ng
Strontium	mg/L	28	0	0.42	2.72	1.18	0.65	ng	29	0	0.43	2.49	1.14	0.60	ng
Thallium	mg/L	28	27	5.00E-06	0.00005	0.000046	0.000013	0.0003 ^E	3	3	5.0E-06	5.0E-06	5.0E-06	0	ng
Tin	mg/L	28	25	5.00E-05	0.0002	0.000064	0.000039	ng	29	21	5.0E-05	0.00059	0.000116	0.000147	ng
Titanium	mg/L	28	23	0.0050	0.159	0.017	0.038	2.0-4.6 ^{E, Q}	3	3	0.0050	0.0050	0.0050	0	ng
Uranium	mg/L	28	3	5.00E-06	0.000824	0.00013	0.00019	0.3 ^E	29	4	5.0E-06	0.000289	0.000076	0.000076	ng
Vanadium	mg/L	28	24	5.00E-04	0.0025	0.00071	0.00055	ng	29	29	5.0E-04	0.0005	0.00050	0	ng
Zinc	mg/L	28	13	0.00050	0.0058	0.0015	0.0015	R	29	24	0.00050	0.010	0.0011	0.0019	ng

Notes:

Bold/italic = exceeds the BC MOE (2010) Guideline.

¹ Average is calculated using half of the detection limit when the result was below it.

-BC MOE Guideline = Approved and Working BC Freshwater Aquatic Life Guidelines (BC MOE 2010).

ng = no guideline

A = 0.1 mg/L for pH ≥ 6.5; BC Max = e (1.209 - 2.426 × [pH] + 0.286 × [pH] × [pH]) for pH < 6.5

B = Working BC Max guideline only

C = BC Max T-Cu guideline = 0.001 × (0.094(hardness)+2) mg/L

D = Max Pb guideline = 0.001 × [e(1.273 ln (hardness) - 1.460)] mg/L if hardness > 8mg/L; or 0.003 mg/L if hardness ≤ 8mg/L

12.2 Historical Activities

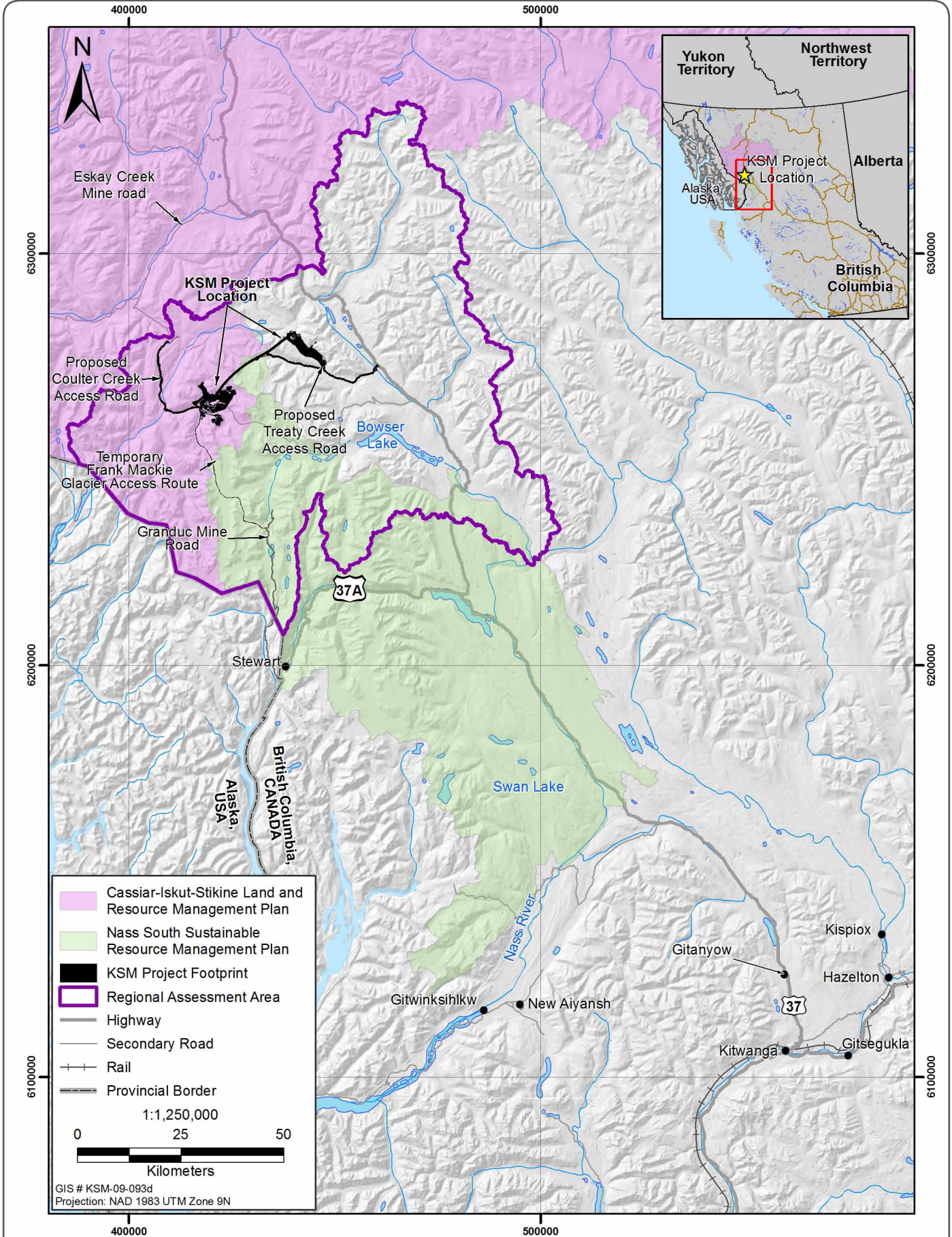
The past Sulphurets advanced exploration project is situated within the Sulphurets Creek drainage basin. This project included mineral exploration and bulk sampling in an area near the Sulphurets Pit. There is evidence to suggest that metal leaching and acid rock drainage (ML/ARD) occurred at an associated waste rock dump that existed from 1986 to 1999 (Price 2005). Thus, activity associated with this project may have affected baseline groundwater quality conditions in the KSM Project Mine Site, particularly in the Sulphurets Valley.

Any plume of contact water that may have resulted from the Sulphurets Project was not identified during associated reclamation activities. Baseline groundwater sampling for the Sulphurets Project did not extend up the Sulphurets Valley beyond the planned Sulphurets and Kerr pits. If effects on groundwater quality extended as far as the wells downgradient in the Sulphurets Valley, the effects would be represented in baseline groundwater characterization. However, baseline groundwater quality in the Sulphurets Valley, as measured in wells installed for the Sulphurets Project's baseline characterization, has been deduced to be unaffected by anthropogenic activity. Elevated concentrations of certain trace metals are interpreted to be a natural derivative of seepage through the local deposits. Potential cumulative effects involving the past Sulphurets Project have been considered in the Cumulative Effects Assessment, and are discussed further in Section 12.9.

Past and ongoing mineral exploration activities in the drainage basins comprising the proposed KSM Project Mine Site could have posed a risk of introducing groundwater contamination. The occurrence of spills of hazardous substances such as fuels and lubricants used in machinery (e.g., drill rigs and camp vehicles) has the potential to affect groundwater quality in the Project area. However, baseline groundwater sampling did not generate any evidence to suggest that past exploration activity had resulted in any measurable site-scale effect on groundwater quality. The potential effects of past, present, and future resource exploration activity in the vicinity of the Project have been considered in the Cumulative Effects Assessment and are discussed further in Section 12.9.

12.3 Land Use Planning Objectives

Components of the Project lie within the Cassiar Iskut-Stikine Land and Resource Management Plan (CIS LRMP; BC ILMB 2000) and the Nass South Sustainable Resource Management Plan (SRMP; BC MFLNRO 2012; Figure 12.3-1). In particular, the Mine Site lies within the CIS LRMP. The Mitchell-Treaty Twinned Tunnels and the Granduc Mine road cross through northern reaches of the Nass South SRMP. Both land use plans include indirect reference to groundwater quality by addressing aquatic ecosystem and surface water resource management considerations.



Cassiar Iskut-Stikine Land and Resource Management Plan and the Nass South Sustainable Resource Management Plan Boundaries in Relation to the KSM Project

Figure 12.3-1

The CIS LRMP provides general directives for aquatic ecosystem and riparian habitat management. Those with implications for groundwater resource management include the following objectives (BC ILMB 2000):

- manage activities so there is no net loss of fish habitat;
- maintain the integrity of watersheds with high fisheries values and domestic water use (licensed and unlicensed); and
- maintain water quality and quantity for naturally occurring aquatic biota within the natural range of variability.

Applicable management provisions within the Nass South SRMP include (BC MFLNRO 2012):

- the provision of a safe and sufficient drinking water supply that supports healthy communities;
- maintenance of water quality and quantity and peak and low flows within the range of natural variability in rivers, streams, lakes, and wetlands to protect the hydrological integrity of their watersheds (water quality includes temperature, turbidity, and chemistry); and
- maintenance of ecological function of streams, rivers, wetland complexes, and lakes, including those that do not support populations of fish.

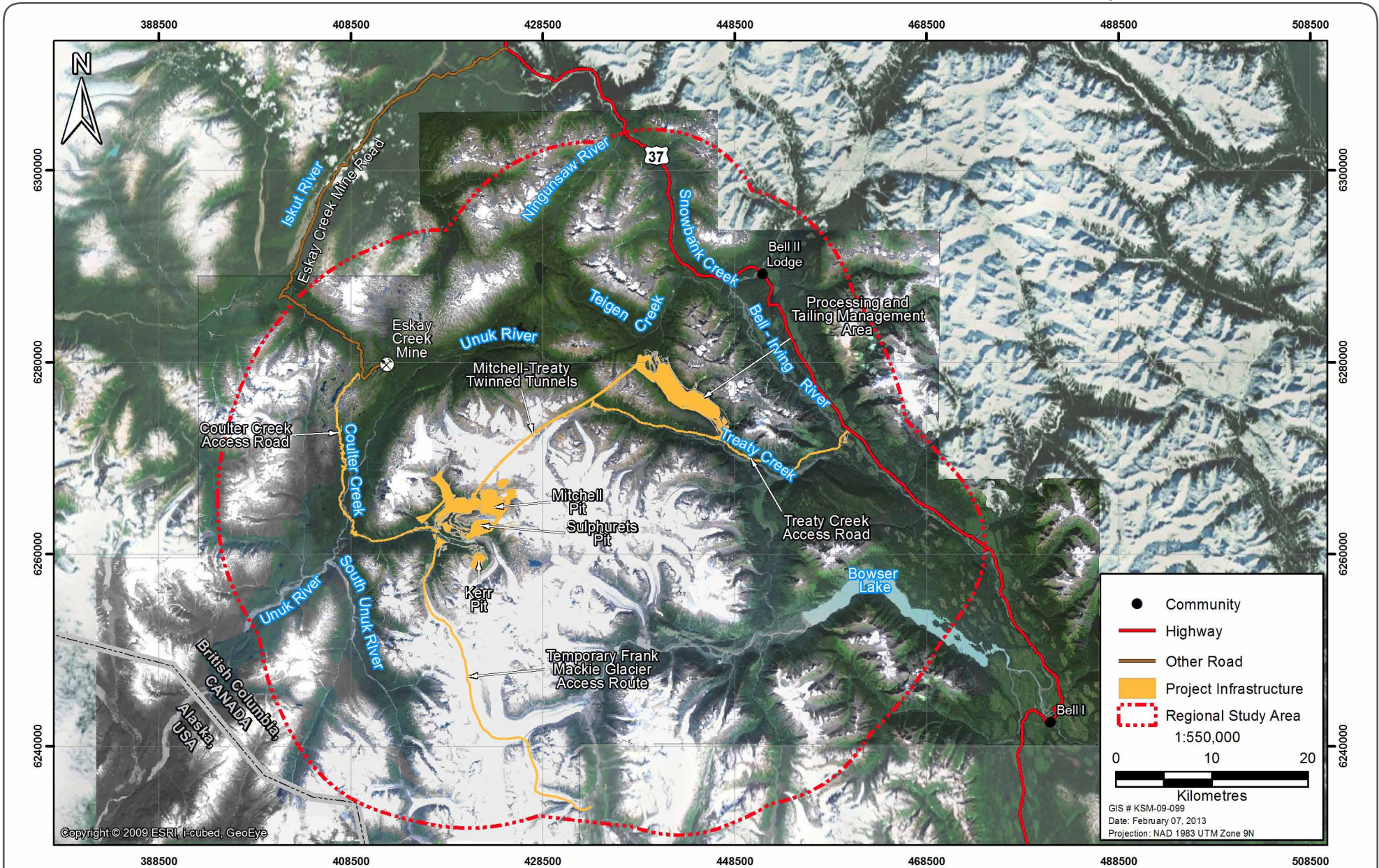
Thus, for the Project to be in alignment with objectives of overlapping land use management plans, the Groundwater Quality Effects Assessment must show that effects on groundwater quality will not have adverse consequences on water quality in downstream surface water receiving environments. Receiving environments with high fisheries values are of particular concern.

12.4 Spatial and Temporal Boundaries

12.4.1 Spatial Boundaries

A regional study area (RSA) was defined, encompassing the complete Project footprint, the footprint for the adjacent planned Brucejack Mine and Snowfield Project, and a number of other projects farther away (Figure 12.4-1). All KSM Project components are within the RSA.

Two independent local study areas (LSAs) were defined. One LSA spans the Mine Site (Figure 12.4-2), where the three open pits, underground mining works, the RSF, the WSF, tunnels, and other ancillary Project components are clustered. The second LSA spans the PTMA, where the Treaty Process Plant, TMF, and other ancillary Project components are clustered (Figure 12.4-3). Together, the two LSAs include all Project components where an assessment of residual effects is necessary. The Coulter Creek and Treaty Creek access roads are not within the LSAs, but are included in the RSA. LSA boundaries correspond with the groundwater model domains established for the numerical groundwater models (detailed in [Appendix 11-E](#)). Criteria regarding how boundaries were defined are outlined below.



Regional Study Area Defined for the Groundwater Quality Effects Assessment

Figure 12.4-1

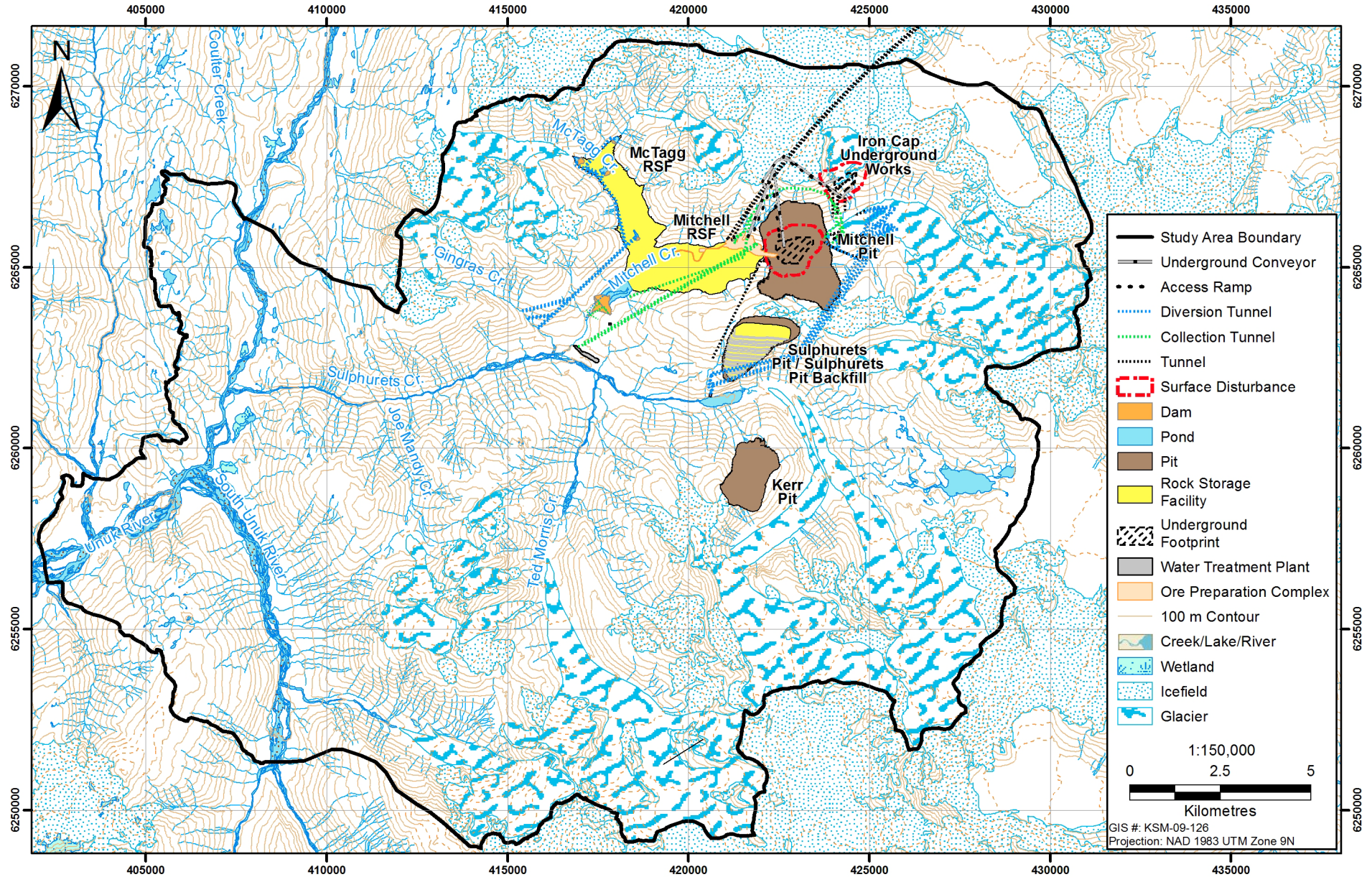


Figure 12.4-2

Mine Site Local Study Area Defined for the Groundwater Quality Effects Assessment

Figure 12.4-2

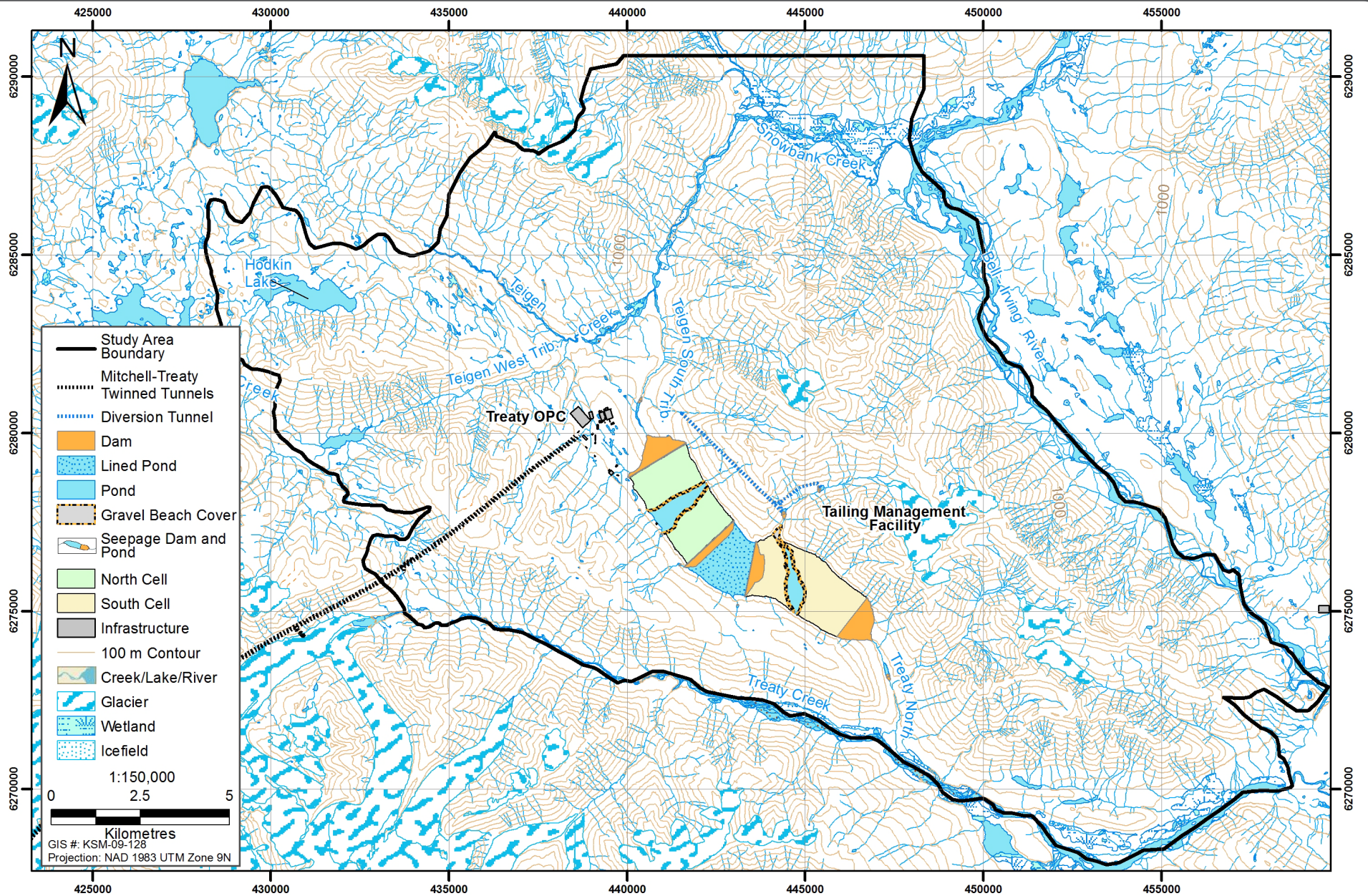


Figure 12.4-3

Processing and Tailing Management Area Local Study Area Defined for the Groundwater Quality Effects Assessment

Figure 12.4-3

1. **Project components with potential effects** – Spatial boundaries encompassed all Project components with potential effects on groundwater quantity or quality. Adequate downstream distances were also incorporated to completely encompass plumes and seepage influences emanating from these Project components up to the end of the post-closure time frame (Section 12.4.2).
2. **Downgradient receiving environments** – Receiving environments where surface water quality or quantity may be affected by the Project were included within the spatial boundaries.
3. **Boundary effects** – Groundwater models must leave a buffer around the area of interest to prevent interaction with the domain boundaries that would produce artificial results.
4. **Watershed divides** – Boundaries were delineated along natural watershed divides that were far enough downstream of the Project's zone of influence to satisfy criteria (1), (2), and (3).

The Mine Site LSA is bounded by high mountain watershed divides in its northern, eastern, and southern extents. The Unuk River is included near the outlet of Sulphurets Creek. All groundwater in the Mine Site is expected to flow generally toward the lower reaches of Sulphurets Creek and its confluence with the Unuk River. The eastern boundary follows a watershed divide immediately to the west of the Unuk River.

The PTMA LSA is bounded to the south and east by Treaty Creek and the Bell-Irving River. These are natural groundwater flow divides for primary catchments expected to receive water from the PTMA. Mountain highlands and upper valley reaches up-slope of Teigen Creek delineate the boundary to the north. Mountain highlands and upper valley reaches up-slope of the Teigen west tributary delineate the boundary to the west.

The groundwater modelling domains extend to depths of -350 masl in the Mine Site LSA and sea level in the PTMA LSA. At these depths, hydraulic conductivities and seepage rates are typically extremely low.

12.4.2 Temporal Boundaries

Temporal boundaries have been established separately for the assessment of Project-related and cumulative effects. The Project-related effects assessment begins when Project construction activity commences and ends after alterations in groundwater quality have reached a final steady state during the post-closure phase. Attainment of steady-state is determined through the groundwater modelling exercises and is specific to each interacting Project component. Groundwater quality was also assessed at key milestones in the development of the Project where these milestones are expected to trigger changes in interactions between Project components and the groundwater environment. Groundwater quantity modelling, a key input to the groundwater quality effects assessment, was conducted using a steady-state approach (discussed in Chapter 11).

12.4.2.1 Mine Site Local Study Area Temporal Domain

Effects on groundwater quality were examined continuously from the beginning of the operation phase. A comprehensive spatial characterization of effects on groundwater quality in the Mine

Site was conducted at key milestones during the evolution of the mine components, including the following:

- **End of the operation phase** – At this time, the proposed pit extents together with the underground mining works will be greatest, with ongoing dewatering. Extents of the RSFs will be maximized. The WSF pond level will be at its peak during mine life. Therefore, volumes of water contacting mine infrastructure prior to seepage into the groundwater environment are expected to reach their maximum during the entire mine operational period at end of operation.
- **200 years post-closure** – After the mine is closed, the Mitchell Pit and the underground mine beneath will be flooded to the controlled refill water level at 810 masl. The Iron Cap Block Cave Mine will also be flooded. The Mitchell and McTagg RSFs will be reclaimed with low permeable soil cover and sludge deposit. The Sulphurets Pit backfill RSF will be covered by geomembrane liners. The WSF pond level will be maintained at its peak level. Seepage emanating from mine infrastructure at the maximum extents has been simulated with the assumption that it will occur continuously for 200 years after the end of mine life, that final pit and RSF extents will be attained, and that planned reclamation will be complete (detailed in the Closure and Reclamation Plan, Chapter 27). For simulation purposes it has been assumed that containment mitigation measures remain operational up to this time. Effects on groundwater quality are expected to attain a steady state prior to this time.

12.4.2.2 Processing and Tailing Management Area Local Study Area Temporal Domain

Effects on groundwater quality were examined continuously from the beginning of the operation phase. A comprehensive spatial characterization of effects on groundwater quality in the PTMA was conducted at key milestones during the evolution of the TMF. These milestones are the following:

- **End of stage 1** – Upon completion of the North Cell, following 25 years of operation.
- **End of stage 3** – Upon completion of the South Cell, at end of operation (Year 51.5).
- **200 years post-closure** – Plume extents were examined 200 years after the final deposition of tailing in the TMF. The TMF enters stage 4 during the Project closure phase. Stage 4 is sustained until water quality in TMF cells is adequate for release into the environment, which will likely be attained in fewer than 100 years post-closure. For simulation purposes, it has been assumed that containment mitigation measures remain operational up to this time. It has also been assumed that tailing water quality would remain poor up to this time for being conservative (the tailing water quality will improve over time with dilution from precipitation, surface water, and groundwater discharge). Effects on groundwater quality are expected to attain a steady state prior to this time.

12.5 Valued Components

Groundwater quality was selected as a valued component (VC), as identified in the BC EAO’s AIR document (2011) and the Canadian Environmental Assessment Agency’s Comprehensive Study Scope of Assessment (2010). Groundwater cannot be separated into distinct components that respond differently to environmental effects. Groundwater quality is valued because it, in turn, influences water quality in receiving surface waterbodies. Groundwater is intrinsically linked with surface water, and therefore influences aquatic ecosystem health. Groundwater is also a potable water resource when water quality is adequate. It is often used for human consumption directly by municipalities and households. In the context of the remote location of the Project, groundwater may foreseeably be used as a potable resource for work camps.

Groundwater quality was identified as a VC by integrating a number of important information sources. These include federal policy, Nisga’a Nation and First Nations considerations, scientific literature, and professional expertise (Table 12.5-1). Groundwater is protected under the *Canada Water Act* (1985), *BC Water Act* (1996a), and *BC Water Protection Act* (1996b).

Table 12.5-1. Identification and Rationale for Groundwater Quality Valued Component Selection

VC	Identified by*				Rationale for Inclusion
	F	G	P/S	O	
Groundwater Quality	X	X	-	X	<p>First Nations and Nisga’a Nation value aquatic ecosystems, which may be affected by degraded groundwater if it reaches surface waterbodies.</p> <p>The BC MOE specifies that proposed resource development projects must take measures to ensure that groundwater resource quality is maintained for present and future uses (BC MOE 2012).</p> <p>Seepage of water from mine waste storage and conveyance facilities may affect groundwater quality, posing a risk to users of discharge groundwater, including fish, people, and terrestrial wildlife.</p> <p>LRMPs in the regional area provide management direction to protect groundwater quality and quantity resources.</p>

* F = First Nation and/or Nisga’a Nation; G = Government; P/S = Public/Stakeholder; O = Other

Groundwater quality contributes to the economic, social, and cultural well-being of Nisga’a citizens because it influences the habitat of culturally significant species such as fish and aquatic plants (School District No. 92 1996; NLG, Province of BC, and Government of Canada 1998; [Appendix 17-A](#), 2009 Vegetation and Ecosystem Mapping Baseline Report). Under the Nisga’a Final Agreement (NFA), Nisga’a citizens have the right to harvest fish and aquatic plants within the Nass Area (NLG, Province of BC, and Government of Canada 1998).

Wilp Skii km Lax Ha, Tahltan Nation, Gitanyow First Nation, and Gitxsan Nation have identified wetlands and surface water resources as culturally important, or as ecosystems that support culturally important plants and animals (Daly 2005; Rescan 2009; Tahltan Heritage Resources Environmental Assessment Team 2009; Gitxsan Chiefs’ Office 2010). The Tahltan Nation has specifically cited concerns regarding fish habitat losses in Teigen and Treaty creeks arising from contact water potentially emanating from the proposed TMF at the KSM Project (Tahltan Heritage Resources Environmental Assessment Team 2009). These are indirect

references to groundwater quality, because groundwater quality affects surface water quality, which in turn affects aquatic life habitat.

12.5.1 Valued Components Included in Assessment

Table 12.5-1 provides a summary of the rationale provided by Aboriginal groups and government agencies for the inclusion of groundwater quality as a VC for the KSM Project.

12.5.2 Valued Components Excluded from Assessment

No VC pertaining to groundwater quality was excluded from assessment.

12.6 Scoping of Potential Effects on Groundwater Quality

Potential effects of the Project on groundwater quality result from the seepage of contact water or other fluids into the groundwater environment. The result of this seepage is an alteration to the parameters that characterize groundwater quality (for example, concentrations of metals, nutrients, salts, and pH). Any change to groundwater quality that results in conditions less favourable for human consumption or aquatic life habitat, as identified in BC water quality guidelines (BC MOE 2010), or as a variation above background levels, is regarded as degradation. Seepage from Project components that may contain contact water (as identified in Table 12.6-1) is expected. Contact water is defined as water that has potentially become degraded by having come into contact with any mine workings where such conditions may be present. Conditions for the generation of contact water include the following:

- ML/ARD arising from exposed rock at the Mine Site and PTMA;
- leaching of blasting residues where they have been used for construction or mining; and
- discharge from the Treaty Process Plant (tailing water).

Introduction of contaminants resulting from accidental releases of industrial or other controlled substances is a possibility that must be considered. Hazardous materials, chemicals, and reagents that have the potential to degrade water quality (e.g., fuels, industrial solvents, lubricants, hydraulic fluids, explosives, and sewage) are expected to be used during all Project phases. Accidental spills resulting in degradation of groundwater quality are possible in both the Mine Site and PTMA, particularly during handling (as identified in Table 12.6-1). This effect is distinguished from seepage associated with waste management sites because the contamination arising in this case is accidental, and therefore can be prevented or avoided through the implementation of environmental management plans (EMPs) that apply standard operating procedures and best practices (mitigation measures and EMPs are further discussed in Section 12.7). Effects of a catastrophic release of contaminants, triggered by a breach of a large engineered containment structure resulting from geohazards or from human-caused accidents and malfunctions, are addressed in Chapters 9, Geohazards; Chapter 34, Effects of the Environment on the Proposed Project; and Chapter 35, Environmental Effects of Accidents and Malfunctions. The possibility of accidental releases of controlled substances is present during all Project phases at active sites. Closure, decommissioning, and reclamation activities will include removal of controlled substance storage systems so that no possibility of releases remains, as specified in the Closure and Reclamation Plan (Chapter 27).

Table 12.6-1. Potential Effects of the Project on Groundwater Quality

Project Region	Project Area	Seepage of Contact Water	Releases of Controlled Substances (wastes, fuels, solvents, sewage, others)
Mine Site	Camp 3: Eskay Staging Camp		X
	Camp 7: Unuk North Camp		X
	Camp 8: Unuk South Camp		X
	Coulter Creek Access Corridor	X	X
	Mitchell Operating Camp		X
	McTagg Rock Storage Facility	X	X
	McTagg Twinned Diversion Tunnels	X	X
	McTagg Power Plant		X
	Mitchell Rock Storage Facility	X	X
	Camp 4: Mitchell North Camp (for the construction of the Mitchell-Treaty Twinned Tunnels)		X
	Mitchell Ore Preparation Complex		X
	Mine Site Avalanche Control		X
	Iron Cap Block Cave Mine	X	X
	Mitchell Pit	X	X
	Mitchell Block Cave Mine	X	X
	Mitchell Diversion Tunnels	X	X
	Upper Sulphurets Power Plant		X
	Mitchell Truck Shop		X
	Water Storage Facility	X	X
	Camp 9: Mitchell Initial Camp		X
	Camp 10: Mitchell Secondary Camp		X
	Water Treatment and Energy Recovery Area		X
	Sludge Management Facilities		X
	Sulphurets Laydown Area	X	X
	Sulphurets-Mitchell Conveyor Tunnel	X	X
	Sulphurets Pit	X	X
	Kerr Rope Conveyor		X
	Kerr Pit	X	X
	Camp 2: Ted Morris Camp		X
	Explosives Manufacturing Facility		X
	Temporary Frank Mackie Glacier Access Route		X
	Camp 1: Granduc Staging Camp		X

(continued)

Table 12.6-1. Potential Effects of the Project on Groundwater Quality (completed)

Project Region	Project Area	Seepage of Contact Water	Releases of Controlled Substances (wastes, fuels, solvents, sewage, others)
Processing and Tailing Management Area	Mitchell-Treaty Twinned Tunnels	X	X
	Construction Access Adit	X	X
	Mitchell-Treaty Saddle Area		X
	Camp 6: Treaty Saddle Camp		X
	Camp 5: Treaty Plant Camp		X
	Treaty Operating Camp		X
	Treaty Ore Preparation Complex		X
	Concentrate Storage and Loadout		X
	North Cell Tailing Management Facility	X	X
	East Catchment Diversion	X	X
	Centre Cell Tailing Management Facility	X	X
	South Cell Tailing Management Facility	X	X
	Treaty Creek Access Corridor	X	X
	Camp 11: Treaty Marshalling Yard Camp		X
Camp 12: Highway 37 Construction Camp		X	
Off-site Transportation	Highway 37 and 37A		X

Notes:

X = components present during phase.

Table 12.6-1 identifies all of the Project components that have a potential to cause an effect on the groundwater environment due to seepage of contact water or because of the release of controlled substances.

12.6.1 Construction

Seepage of contact water from mine infrastructure may occur as soon as conditions for water to become degraded by contact with mine components are in place. Water may become affected in pits, tunnels, drainage ditches, and road alignments upon commencement of excavation and exposure of un-weathered rock.

Excavation into fresh bedrock is planned for the Mitchell and Sulphurets pits during the construction phase, in addition to certain roads, tunnels, and diversion ditches ([Appendix 12-A](#)). Water may become affected in the Mitchell RSF as soon as waste rock is first deposited, which will occur following the onset of pit excavation. Contact water will be directed to the WSF once the Mitchell Pit and RSF become active.

Tailing water will begin to be pumped to the TMF following initial ore processing, which is not planned during the construction phase. Thus, conditions for seepage of contact water sourced in the TMF will not be present until the beginning of the operation phase.

12.6.2 Operation

Most Project areas throughout the Mine Site and PTMA will be active during the operation phase, as identified in [Appendix 12-A](#). Seepage of contact water emanating from mine infrastructure will commence alongside infrastructure development, as outlined in the Project Description (Chapter 4). Potential effects due to seepage of contact water during the operation phase were identified for the following components:

Mitchell Pit and Block Cave Mine – Excavation and dewatering of the Mitchell Pit and Block Cave Mine will be ongoing during the operation phase, exposing un-weathered bedrock, and thereby creating conditions for degraded water quality. Contact water may enter the groundwater environment from the Mitchell Pit and Block Cave Mine. Excavation will continue for the duration of the operation phase, reaching maximum depth and extents at the end of operation.

Kerr Pit – As the Kerr Pit is on the top of a ridge above the Sulphurets Lake and Creek, it is located in a groundwater recharge zone. Excavation of the Kerr Pit will commence at Year 27 of the operation phase, exposing un-weathered bedrock, and thereby creating conditions for ML/ARD. Contact water may enter the groundwater environment from the Kerr Pit.

Sulphurets Pit – Excavation activities in the Sulphurets Pit will be ongoing during Years 1 to 6 and 23 to 27 of the operation phase. Exposure of un-weathered bedrock (e.g., pit walls) will create conditions conducive to generating ML/ARD. Mining of the Sulphurets Pit will be completed at the end of Year 27. Following excavation, the mined out pit will be back-filled with Kerr Pit waste rock. The waste rock backfill presents an opportunity to mitigate some seepage of contact water from the pit. Project mitigation is discussed further in Section 12.7.

Iron Cap Block Cave Mine – Excavation of the Iron Cap Block Cave Mine will commence during Year 32 of the operation phase, exposing un-weathered bedrock, and thereby creating conditions for ML/ARD. Contact water may enter the groundwater environment from the Iron Cap Block Cave Mine.

Rock Storage Facilities – From the initial placement of waste rock in the Mitchell and McTagg RSFs during construction, water will be affected by contact with potentially acid generating (PAG) waste rock. Water will continue to be affected throughout the operation phase, giving rise to the potential for impacts on groundwater quality. The RSFs will increase in size annually during the operation phase, giving rise to potentially greater magnitude effects on groundwater quality.

Water Storage Facility – The WSF will be constructed to store all Mine Site contact water and to attenuate flows prior to the beginning of the operation phase. Contact water from pits, RSFs (Mitchell and McTagg RSFs and the Sulphurets Pit RSF), and construction activities associated with the Mitchell-Treaty Twinned Tunnels and Mine Site haul roads will be diverted to the WSF during the construction phase. Contact water will continue to be directed to the WSF for the duration of the operation phase.

Tailing Management Facility – Discharge of tailing into the TMF begins at the onset of the operation phase. Filling will be limited to the North and Centre cells for the first 25 years of operation. Discharge into the South Cell will commence henceforth. Seepage of contact water into the underlying groundwater flow regime may begin as soon as water begins to accumulate in the cells.

Tunnels, road alignments, diversions – Construction of various excavation works will occur during the operation phase. There is potential for ML/ARD for all existing and new tunnels, road alignments, and ditches, as identified in [Appendix 12-A](#).

12.6.3 Closure and Post-closure

While it is not expected that any new components of the Project or activities will result in interaction with groundwater quality during the closure and post-closure phases, continued seepage of contact water is expected, as discussed below.

Mitchell Pit and Block Cave Mine – Cessation of dewatering and construction of a dam will create conditions for development of a pit lake with water elevation controlled at 810 masl in the Mitchell Pit, along with complete submergence of the Mitchell Block Cave Mine. The refilled Mitchell Pit and Block Cave Mine is expected to remain a groundwater sink, but interaction with the groundwater environment remains a possibility. Ongoing seepage of contact water into the groundwater environment remains a potential effect.

Kerr Pit – Excavation of the Kerr Pit will cease at the end of operation, but dewatering will continue indefinitely with installation of a basal drainage system. A small amount of water may accumulate in the pit briefly during and following major rainfall events. The Kerr Pit is expected to remain a local groundwater sink, but discharges into the groundwater environment through the pit walls and floor remains a possibility. Ongoing seepage of contact water into the groundwater environment remains a potential effect.

Sulphurets Pit – Waste rock deposition in the Sulphurets Pit will be complete at the end of operation. The pit with the backfilled RSF will be dewatered indefinitely via the basal drain. Ongoing seepage of contact water into the groundwater environment remains a potential effect.

Iron Cap Block Cave Mine – Dewatering will cease at the end of operation. This is expected to result in complete submergence of the underground workings in the Iron Cap Block Cave Mine. Groundwater will be allowed to flow freely through the underground workings, as dictated by the natural local flow gradient. Water passing through the Iron Cap Block Cave Mine may become degraded due to contact with exposed fresh sulphide bedrock. Therefore, ongoing seepage of contact water into the groundwater environment remains a potential effect.

Rock Storage Facilities – The Mitchell and McTagg RSFs will remain at their maximum extents during the closure and post-closure phases. Contact water will continue to be generated, giving rise to the potential for an effect on groundwater quality.

Water Storage Facility – Contact water sourced at the Mitchell Pit and Block Cave Mine, Iron Cap Block Cave Mine, Kerr Pit, and RSFs (Mitchell, McTagg, and Sulphurets pits) will continue to drain into the WSF for the duration of the closure and post-closure phases. Therefore, seepage of contact water from the reservoir remains a possibility, and potential effects continue to exist.

Tailing Management Facility – Discharge of tailing into the TMF will stop at the end of the operation phase. Seepage of contact water from the TMF cells will continue during the closure and post-closure phases. Reclamation measures are expected to improve water quality in the cells to a level suitable for discharge into the natural environment at some time during the post-closure period. It is expected that water suitable for discharge will be attained no more than 200 years following closure.

Tunnels, road alignments, diversions – Various excavated works will continue to be exposed during the closure and post-closure phases (identified in [Appendix 12-A](#)), giving rise to ongoing potential for ML/ARD. Certain tunnels will be de-commissioned during or prior to the closure and post-closure phases. De-commissioned tunnels will be capped at entrance portals and allowed to become submerged where they lie below the water table. Without consideration for mitigation options, the potential for ML/ARD remains in decommissioned tunnels and surface diversions.

12.7 Potential for Residual Effects for Groundwater Quality

A potential residual effect on groundwater quality was identified where the possibility of contamination reaching the groundwater environment exists, with consideration for planned mitigation. The determination of potential residual effects is summarized in Table 12.7-1.

12.7.1 Groundwater Quality Degradation due to Seepage of Contact Water

Seepage of contact water to the natural groundwater environment may occur at a number of Project components, as identified in Section 12.6. The result would be potential for development of plumes with degraded water quality emanating from the seepage sources. The development of these plumes would constitute contamination of the groundwater environment, and a residual effect. The nature of this contamination (how it differs from baseline conditions and whether guidelines are exceeded) is considered in the significance determinations (Section 12.8).

The development of plumes is dependent on the groundwater flow conditions and loading conditions in the various mine components. Through Project design considerations and the implementation of mitigation measures, the possibility of contact water leaching into the groundwater environment is reduced to negligible levels for a subset of Project components.

For the remaining Project components where the effects are not able to be completely mitigated, groundwater modelling of contaminant transport was conducted to predict the extents and concentrations of contact water entering the groundwater environment.

12.7.1.1 Mitigation for Degradation of Groundwater Quality due to Seepage of Contact Water

A number of mitigation measures are planned to avoid, reduce, and control effects on groundwater quality, supplemented by monitoring programs. Through discussions with the environmental assessment Working Group, alternative siting and waste disposal options were identified for waste rock. Siting and design decisions were made in accordance with the *Guidelines for Metal Leaching and Acid Rock Drainage at Minesites in British Columbia* (Price and Errington 1998). A number of design features have been incorporated into the WSF and TMF to reduce seepage. Through the application of a Water Management Plan (Section 26.17), water levels can be managed to avoid seepage of contact water. Objectives of implementing the ML/ARD Management Plan (Section 26.14) are to avoid and reduce the potential for ML/ARD. Many mitigation features have been developed iteratively in response to interim modelling predictions and in conjunction with the environmental assessment Working Group.

12.7.1.1.1 *Reducing the Potential for Metal Leaching and Acid Rock Drainage*

Waste Rock Storage Facilities

The locations of the RSFs have been selected with consideration for minimizing the footprint of potential seepage of contact water. The Mitchell and McTagg RSFs are located entirely within the Mitchell Valley up-gradient of the WSF. The Sulphurets backfill RSF will be dewatered indefinitely via a basal drain, resulting in hydraulic containment (discussed in greater detail below). Thus, all waste rock will be located in an environment under hydraulic control, providing for containment of associated contact water.

Tunnels, Diversions, and Roads

Excavated workings will be built in accordance with the ML/ARD Management Plan (Section 26.14), which provides for PAG testing of exposed materials, and identifies storage and handling requirements for excavated PAG materials along sections of alignments that expose PAG materials. Baseline testing for PAG materials has been conducted and used in the development of planned alignments. An assessment of the potential for ML/ARD along Project access roads and during construction activities is provided in Chapter 10, [Appendix 10-B](#). Implementation of the ML/ARD Management Plan is expected to reduce to negligible levels the potential for contact water entering the groundwater environment from road alignments, tunnels, and surface diversions.

12.7.1.1.2 *Mitigation through Project Design*

Tailing Management Facility

Design of the TMF has evolved to include mitigation measures that minimize extents of impact on groundwater quality. An overview of TMF design is described in the Project Description (Chapter 4). Designs and construction plans for the seepage mitigation features are described herein, with reference to the TMF Design Report (KCB 2013b; [Appendix 4-AC](#)). These mitigation features have been integrated into groundwater modelling exercises to assess residual effects on groundwater quality, as discussed in Section 12.8.

Table 12.7-1. Potential Residual Effects on Groundwater Quality

Valued Component	Timing Start	Project Area(s)	Component(s)	Description of Effect due to Component(s)	Type of Project Mitigation	Project Mitigation Description	Potential Residual Effect	Description of Residuals
Groundwater Quality	Construction	Mine Site	Mitchell Pit and Block Cave Mine, Sulphurets Pit, Kerr Pit	Degradation of groundwater quality due to seepage of contact water	Design change, monitoring and adaptive management, management practices	<ul style="list-style-type: none"> Mine dewatering creates groundwater sinks Water level management via gravity drainage post-closure to maintain local groundwater sinks Low-permeability liners and managed drainage for Sulphurets Pit backfill Implementation of Groundwater Monitoring and ML/ARD Management Plans 	No	
	Construction	Mine Site	Iron Cap Block Cave Mine		Design change	<ul style="list-style-type: none"> Mine dewatering creates groundwater sink during operation Submergence of exposed PAG post-closure 	Yes	Degradation of groundwater quality: Development of a plume emanating from Mine Site towards Mitchell Pit.
	Construction	Mine Site	Water Storage Facility		Design change, monitoring and adaptive management, management practices	<ul style="list-style-type: none"> WSF seepage collection pond Seepage cut-off walls under the Water Storage dam (WSD) and seepage collection dams, including trenches and grout curtains up to 130 metres below grade Seepage interception tunnels between WSD and seepage collection dam Implementation of Groundwater Monitoring Plan 	Yes	Degradation of groundwater quality: Development of a plume emanating below the WSD, captured by seepage interception tunnels and the WSF seepage collection pond.
	Construction	Mine Site	Mitchell and McTagg Rock Storage Facilities		Management practices	<ul style="list-style-type: none"> Mitchell and McTagg RSFs location entirely within the controlled catchment basin up-gradient of the WSF Sulphurets laydown area contained by gravity drainage and liner covers Implementation of ML/ARD Management Plan 	Yes	Degradation of groundwater quality: development of a plume reporting to Mitchell Pit and the WSF.
	Construction	Mine Site and PTMA	Tunnels, road alignments, drainage ditches		Design change, management practices	<ul style="list-style-type: none"> Concrete liners in tunnels and drainage ditches where they may intersect PAG rock Implementation of ML/ARD Management Plan. 	No	
	Operation	PTMA	TMF: North, Centre, and South tailing cells		Alternative, design change, monitoring and adaptive management, management practices	<ul style="list-style-type: none"> Low-permeability liner under CIL Seepage collection ponds and dams down-gradient of TMF Fine, poorest-quality tailing discharged into TMF CIL Cell CIL Cell located in centre of TMF where hydraulic gradients are lowest Implementation of Groundwater Management Plan 	Yes	Degradation of groundwater quality: development of plumes passing below the North, Saddle, and Southeast dams. Reporting to the seepage collection dams in the North Treaty Valley. Concentrations as high as 4% of source reaching down-gradient of the North Cell seepage collection dam.
	Construction	Mine site and PTMA	All components that may come into contact with any controlled substance at any time (all Project sites)	Degradation of groundwater quality due to releases of controlled substances	Management practices, monitoring and adaptive management	<ul style="list-style-type: none"> Implementation of EMPs: Spill Prevention and Emergency Response Plan, Domestic and Industrial Waste Management Plan, Dangerous Goods and Hazardous Materials Management Plan 	No	Degradation of groundwater quality, introduction of non-aqueous phase liquids into groundwater environment.

The carbon-in-leach (CIL) Centre Cell of the TMF has been designed to receive the discharge of pyritized finer tailing from the gold recovery circuit process. Discharge into the cell will be approximately 11,500 tpd over the operation phase for a total of 216 Mt of CIL tailing. CIL solids are expected to have an 80% passing grain size of 15 to 35 μm , and vertical hydraulic conductivity of 1×10^{-8} m/s. The Centre Cell has been designed in accordance with the International Cyanide Management Code (ICMI 2011).

A low-permeability high-density polyethylene (HDPE) or low-density polyethylene geomembrane liner has been integrated into the Centre Cell design, spanning the base and walls of the cell. Accelerated testing has shown that service life of HDPE liners can be on the order of one thousand years under the hydrogeochemical conditions expected in the Centre Cell (Rowe and Sangam 2002). Quality monitoring will be an integral part of the liner construction process, including inspection of foundation preparation, weld seams (including pressure testing), and defects.

The Centre Cell has been placed at the centre of the TMF, where a strong natural upward vertical hydraulic gradient provides hydraulic containment from the deeper lithologies. At closure, the adjacent North and South cells will have identical water levels, providing for a very low lateral hydraulic gradient within and under the tailing cells. The combined effect of and low hydraulic gradients towards receiving environments and the geomembrane liner reduces seepage of tailing water emanating into the groundwater environment.

All dams (cell dams and seepage collection dams inclusive) are designed with a low-permeability compacted till core. Design specifications include provision of hydraulic conductivities less than 1×10^{-7} m/s. Till cores will reduce seepage rates through the dams.

Seepage cut-off walls built with low-permeability native fine soils amended with bentonite are planned below the North, Splitter, and Southeast tailing dams. No cut-off wall is planned below the Saddle dam because drainage materials are required in this area to relieve artesian pressure below the Centre Cell liner. Soil cut-off walls will be keyed at least 3 m into existing low-permeability basal till or bedrock. Cut-off wall materials have a design hydraulic conductivity of less than 1×10^{-8} m/s.

Three seepage collection dams have been included downstream of the TMF along the North Treaty and South Teigen valleys. These are designed to capture shallow seepage water emanating from the TMF and pump it back up to the cells. Seepage collection dam locations have been determined based on interim groundwater modelling results, with the aim of minimizing seepage into the down-gradient environment while minimizing the overall TMF footprint. The North Cell and southeast seepage collection dams are designed with grout curtain seepage cut-off walls extending 25 m into bedrock. All three seepage collection dams (North, Saddle, and southeast) will have bentonite-amended soil cut-off walls extending into native low-permeability layers (basal till or bedrock), with design parameters akin to those planned for the cell dams.

Water Storage Facility

Design of the WSF has evolved to include features that will reduce seepage below and through the dam, and into the groundwater environment down-gradient. An overview of designs and construction plans applicable to seepage mitigation features is provided herein. The complete WSF design is documented in KCB (2013a; [Appendix 4-J](#)). Figure 12.7-1 presents a schematic plan of the WSF. These mitigation features have been integrated into groundwater modelling exercises to assess residual effects on groundwater quality, as discussed in Section 12.8.

The Water Storage dam (WSD) will include a 1- to 2-m thick essentially impervious asphalt core. KCB (2013b; [Appendix 4-AC](#)) provides examples of existing dams of similar scale and a discussion of asphalt permeability properties. The foundation will be excavated to bedrock. Figure 12.7-2 presents a schematic cross-section of the WSD.

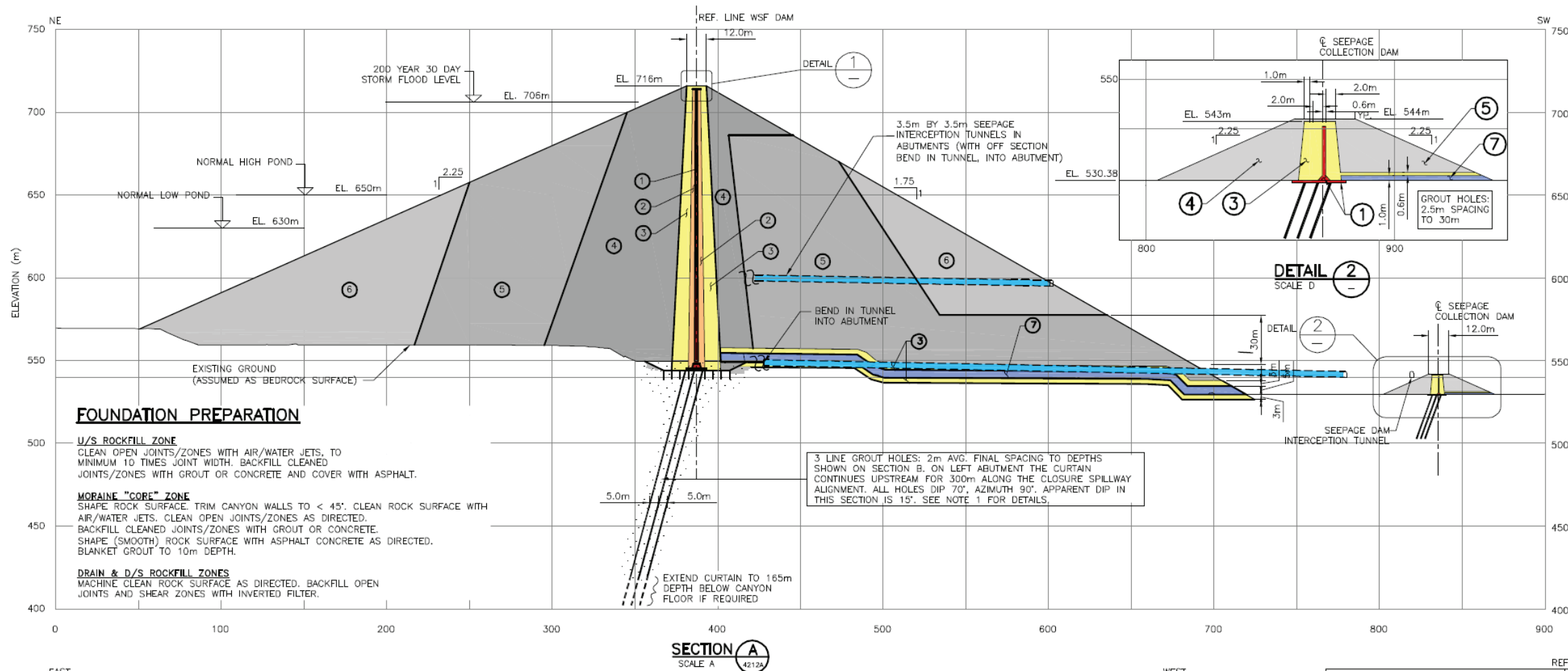
A deep (extending up to 130-m deep) grout curtain is planned below the WSD, extending 165 m east and west of the abutments. The curtain will be angled upstream across bedding planes, which will maximize interception of fractures. Grout will be injected into drill holes spaced no more than 8-m apart. The grout mixture has been designed to minimize permeability, be resistant to the low-pH environment, and to be delivered with adequate mobility to penetrate fractures. Quality control metrics will be checked during and after construction, including grout quality tests and lugeon permeability tests. Estimated permeability is 1×10^{-7} m/s.

A seepage collection dam has been included downstream of the WSD, designed to collect shallow seepage water and re-direct it to the Water Treatment Plant. The dam location has been determined based on interim groundwater modelling results, with the aim of maximizing capture of seepage sourced at the WSF reservoir. A 30-m deep grout curtain and an asphalt core has been included in the seepage collection dam design, akin to the WSD. The grout curtain will extend 160 m laterally into the abutments. Figure 12.7-2 presents a schematic cross-section of the seepage collection dam.

A system of seepage interception tunnels have been included in the subsurface between the WSD and the seepage collection dam grout curtains (shown in Figure 12.7-1). These tunnels function to depress the phreatic surface. A network of drain conduits will be drilled upward and downward from the tunnels. Four tunnels are planned immediately downstream of the WSD grout curtain, and two upstream of the seepage collection dam grout curtain. Tunnels are graded to drain by gravity to near pond level in the seepage collection dam pond.

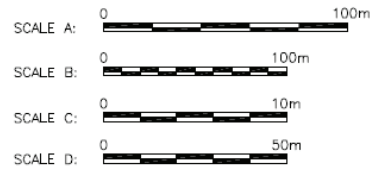
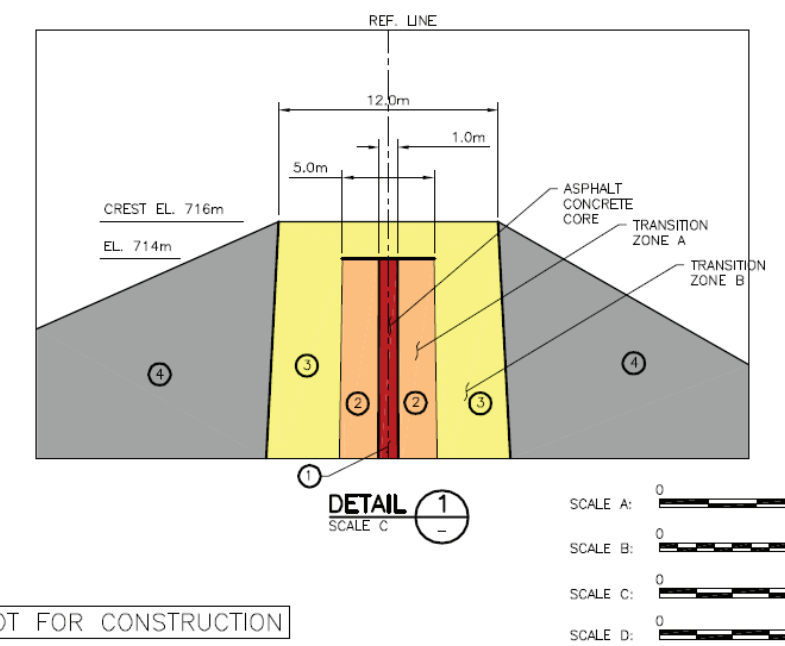
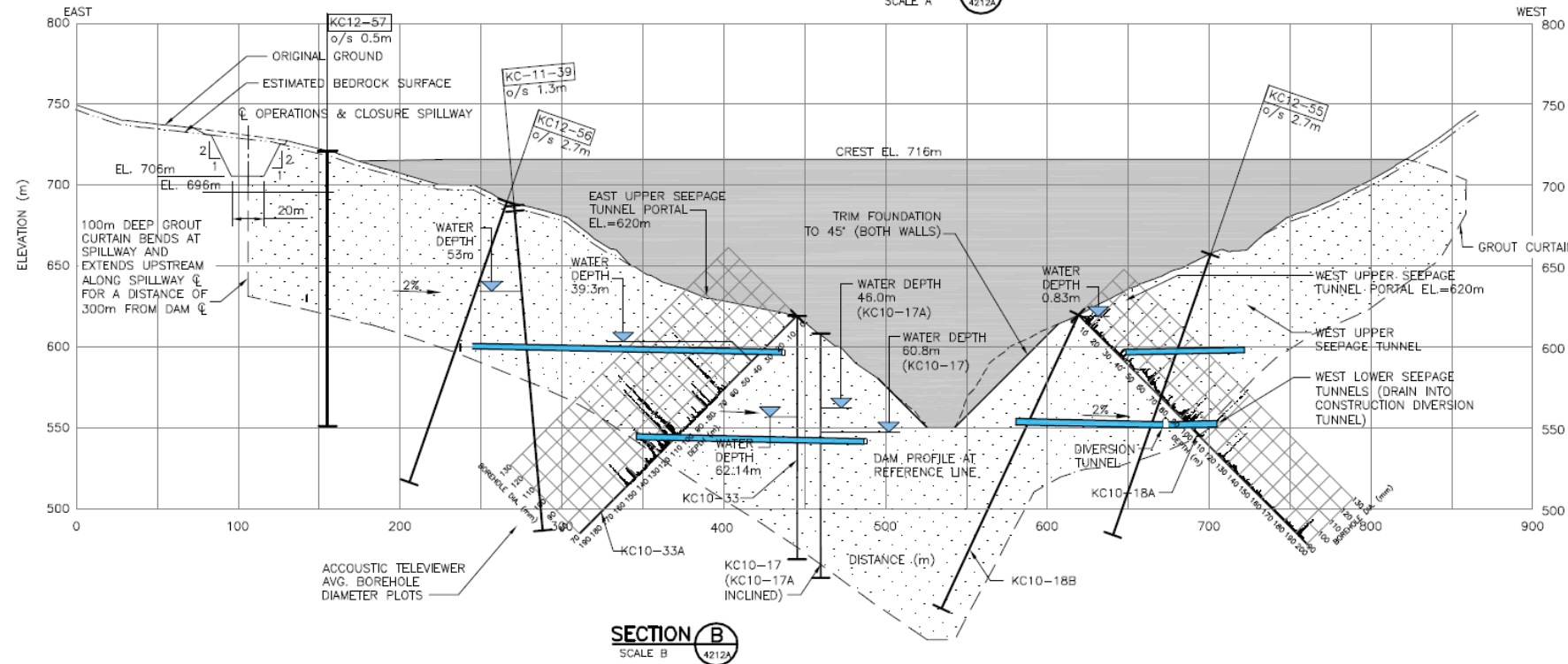
Mine Dewatering and Drainage

Dewatering will be conducted in all pits and block caves during active excavation. The mine dewatering systems were designed by BGC Engineering Inc. (BGC 2012; Sub-Appendix F12 of [Appendix 4-C](#)). While the primary purpose of dewatering is to facilitate ore extraction, hydraulic containment of contact water is a co-benefit. Dewatering during mining will be conducted by a combination of vertical pumping wells and horizontal drains. The Mitchell Pit north wall dewatering adits will function to de-pressurize the north wall of Mitchell Pit. Average extraction rates during mining are estimated to be 11,980 m³/d, 1,200 m³/d, and 1,010 m³/d for the Mitchell, Sulphurets, and Kerr pits, respectively. An estimated 10,300 m³/d will be withdrawn from the Mitchell Block Cave Mine. The Iron Cap Block Cave Mine will yield approximately 2,200 m³/d. Modelling has indicated that all mines will act as groundwater sinks while dewatering is ongoing (discussed further in Section 12.8). This delays development of plumes emanating from each pit.



ZONE	MATERIAL
1	ASPHALT CONCRETE CORE
2	TRANSITION ZONE A OF GRAVEL (0-60MM)
3	TRANSITION ZONE B OF CRUSHED ROCK (0-150MM)
4	WELL COMPACTED QUARRIED NON-REACTIVE ROCK (0-700MM)
5	WELL COMPACTED QUARRIED ROCK (0-700MM)
6	WELL COMPACTED NATURAL GRAVEL OR QUARRIED ROCK (0-1000MM)
7	DRAIN

- NOTES**
1. GROUT HOLES ON EACH ROW WILL BE DRILLED AND GROUTED USING SPLIT-SPACING TECHNIQUE. THE OUTER ROWS WILL BE GROUTED FIRST; THE CENTRE ROW LAST. PRIMARY HOLES WILL BE AT 8M SPACING. SPLIT-SPACING WITH SECONDARIES AND TERTIARIES WILL RESULT IN A FINAL HOLE SPACING ON EACH ROW OF 2 M. ADDITIONAL HOLES MAY BE REQUIRED LOCALLY IN HIGH TAKE AREAS.
- GROUTING WILL BEGIN ON THE OUTER ROW PRIMARIES WITH HIGH MOBILITY GROUT (HMG). WHERE GROUT TAKES ARE HIGH, PROGRESSIVELY THICKER GROUTS WILL BE APPLIED UNTIL REFUSAL IS OBTAINED. THICKER GROUTS INCLUDE HIGHER VISCOSITY HMG'S AND SANDED HMG.
- HMG MIX WILL COMPRISE:
- HIGH SULPHATE RESISTANT CEMENT
 - BENTONITE (TO MINIMIZE BLEED)
 - SILICA FUME (TO FILL SMALL VOIDS AND THUS REDUCE PERMEABILITY)
 - SUPERPLASTICIZER (TO REDUCE WATER CONTENT, REDUCE BLEED AND INCREASE STRENGTH WHILE PROVIDING DESIRED VISCOSITY)
 - WHELAN GUM (TO BIND EXCESS WATER AND REDUCE WASHOUT OF CEMENT AND FINES)
 - CLEAN WATER
- QUALITY CONTROL INCLUDES:
- GROUT QUALITY BY MARSH CONE VISCOSITY OR VISCOMETER AND API PRESSURE FILTER BLEED RESISTANCE, AND
 - PERFORMANCE BY LUGEON WATER PRESSURE TESTS IN VERIFICATION DRILLHOLES ALONG THE CENTRE ROW. MAX. ALLOWABLE = 1 LUGEON (1 LUGEON $\approx 6 \times 10^{-6}$ m/s)



NOT FOR CONSTRUCTION

Figure 12.7-2 Schematic Cross-sections of the Water Storage Facility Dams

12.7.1.1.3 *Water Management*

Water level in the Mitchell Pit and Block Cave Mine will be managed post-closure. A dam and spillway, designed and documented by KCB (2013a; [Appendix 4-J](#)) and installed at the pit outlet to the Mitchell Valley, will maintain a water level of approximately 810 masl in the pit indefinitely (Figure 12.7-3). The designed pit lake water level is below the natural local groundwater level, thereby sustaining a groundwater sink in the mine post-closure (discussed along with modelling results, Section 12.8). As such, hydraulic control will be imposed on the pit, with ongoing drainage down the spillway. The spillway directs water through the Mitchell RSF basal drain to the WSF pond.

The Sulphurets backfilled RSF laydown area drainage system, designed by KCB (2013a; [Appendix 4-J](#)), is expected to maintain water content in the waste rock below saturation, and control all contact water that percolates through the waste rock. Figure 12.7-4 is a schematic diagram of the drainage system. The Sulphurets Pit will have a basal drain installed upon completion of excavation. Sub-horizontal drill holes or tunnels will route accumulated water from the basal drain to a buried pipeline via gravity drainage. Waste rock backfill will be placed in 50-m lifts, with low-permeability bituminous geomembrane liners installed atop each lift. Liners are expected to divert most water entering the pit to a collection pipeline located at the toe of the RSF. Groundwater seeping through the pit walls adjacent to the RSF will come in contact with the waste rock. Water entering the waste rock will accumulate in the basal drain. Components of the Sulphurets laydown area drainage system have been incorporated into the Mine Site groundwater model domain, as discussed in Section 12.8.

Drainage of the Kerr Pit will be sustained indefinitely. Sub-horizontal drill holes or a tunnel will convey water via gravity to a pipeline. The closure drainage system will have a design capacity to contain flow from a 200-year 24-hour rainfall event. A small pit lake will temporarily be present at the south end of the pit during more frequent high precipitation events.

Hydraulic Containment of the Mitchell Valley

The WSF has been designed to capture all surface and shallow groundwater that enters the Mitchell Valley upstream of the WSD. The Mine Site layout has been structured such that most mine facilities, particularly those with the potential to contaminate water, are sited in the Mitchell Valley upstream of the WSF. Baseline ground and surface water quality in the Mitchell Valley is poor, with numerous exceedances of BC MOE guidelines for the protection of freshwater aquatic life (BC MOE 2010). Successful functionality of the WSD and associated seepage collection features for hydraulic control on groundwater emanating from mine components in the Mitchell Valley has been a focal point of the groundwater modelling exercises. Predictions are discussed in Section 12.8.

12.7.1.1.4 *Groundwater Management Plan*

Execution of potential worst-case conservative solute transport model simulations has allowed consideration for uncertainty associated with the input data sets. By assigning constant no-reactive sources in the mining zones without consideration of the retardation and attenuation mechanisms, models are considered conservative estimates of magnitudes and extents of groundwater quality degradation arising from the various mine components. A groundwater quality monitoring plan has developed (Section 26.15), with a primary objective of monitoring downstream effects on groundwater quality.

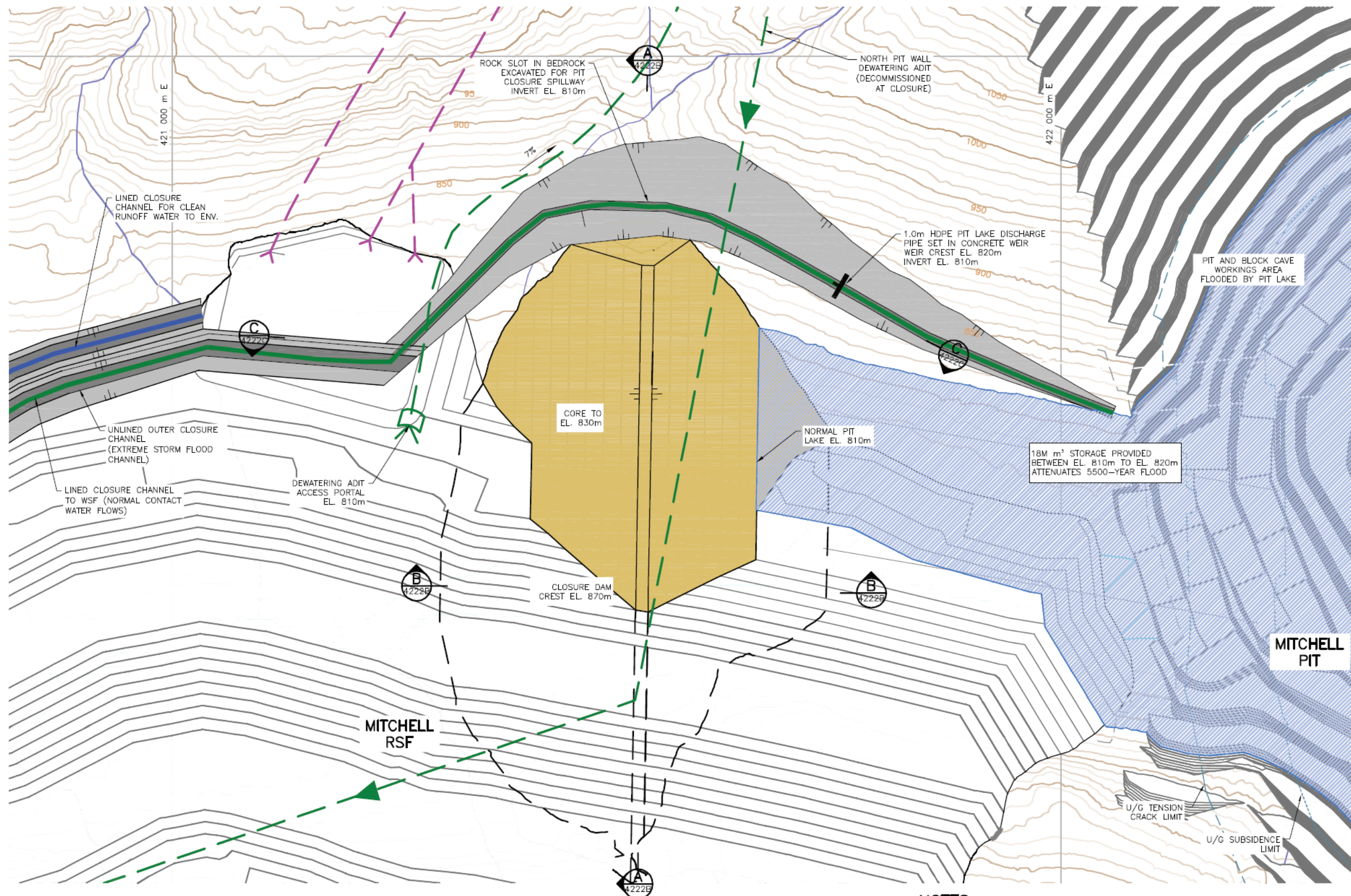
Groundwater monitoring will be conducted on a quarterly (seasonal) basis commencing at the onset of the construction phase, and continuing into the post-closure phase. An adaptive management plan would be initiated if un-predicted exceedances of water quality guidelines occur.

The adaptive management plan would include introduction of new works to control seepage and/or treat the contact water. This may include, for example, construction of an additional seepage collection pond farther downstream, or installation of deep groundwater wells for deeper seepage collection. The design of the new infrastructure would be developed to address the specific nature of the effects, with consultation of qualified hydrogeologists.

12.7.1.2 Residual Effects on Groundwater Quality

Groundwater flow and non-reactive solute transport modelling was conducted to assess potential residual effects on groundwater quality sourced in mines (Mitchell Pit and Block Cave Mine, Iron Cap Block Cave Mine, and the Sulphurets and Kerr pits), reservoirs that store contact water (TMF and WSF), the RSFs, and tunnels. Separate simulations were conducted for the Mine Site and PTMA LSAs. Solute transport modelling was conducted assuming that the sources are constant and non-reactive without consideration of natural attenuation and retardation mechanisms and possible improvement of water quality in the sources over time. Therefore, plume extents are considered conservative. Unity concentrations were applied emanating from the mine components (concentration of 1.0 with no units), whereby the predicted concentrations in the subsurface are some proportion of the input contact water. A cut-off concentration of 0.1% of the source concentration was used to define plume outer boundaries. The predicted groundwater quality results from the modelling provide inputs for the surface water quality modelling. Determination of predicted concentrations for individual analytes in source contact water associated with specific Project components and in the downstream surface water is discussed in Chapter 14. A detailed description of modelling methods, inputs, outputs, and uncertainties is presented in the groundwater modelling report ([Appendix 11-E](#)). These models enabled spatial and temporal delineation of plumes emanating from each applicable Project area, including the distribution of concentrations within these plumes.

Modelling included the base case and sensitivity (worst-case) scenario simulations. The base-case model represents the expected scenario, with recharge and hydraulic conductivity inputs calibrated to field water level and stream flow measurements. Upper and lower cases accounted for uncertainties in the permeability of the geological materials on site. The upper case scenarios included hydraulic conductivities generally half an order of magnitude higher than those in the base case. In areas with possible meso-scale preferential flow pathways in the WSF area, the upper case included hydraulic conductivities as much as two orders of magnitude higher than base case. The calcareous sandstone and siltstone crossing the WSF site was simulated with a hydraulic conductivity on the scale of 10^{-3} m/s in the upper case. The lower case included conductivities half an order of magnitude lower than base case. Wet and dry year scenarios accounted for uncertainty in recharge estimates, e.g., in wetter and drier climates (note that the names of these scenarios do not mean for the transient simulations). The wet year scenario included the recharge twice that of the base-case model. The dry year scenario included recharge half that of base case. Uncertainty in recharge estimates may arise due to high variability in precipitation across the site. Uncertainty associated with overburden characterization and recharge zone identification may contribute to imperfect recharge estimates as well.



LEGEND

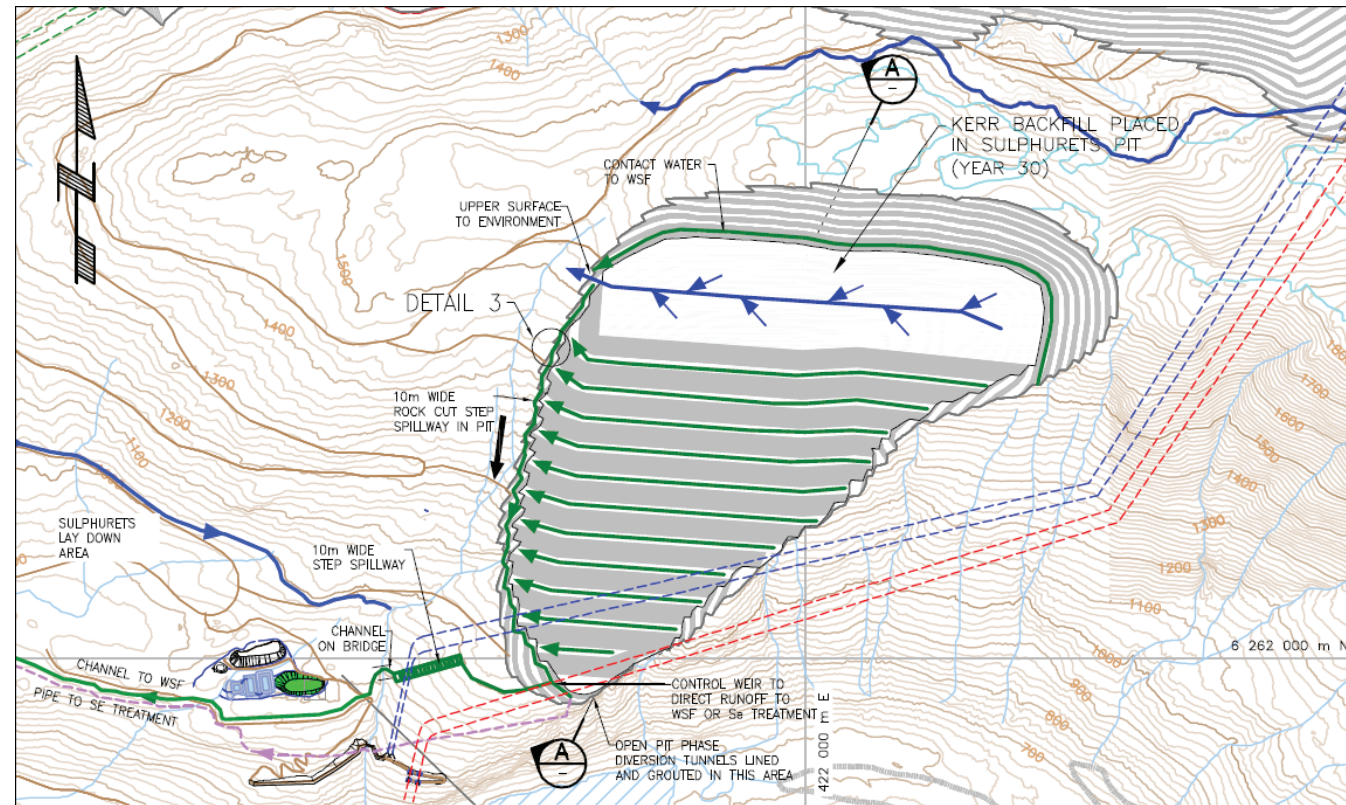
- ORIGINAL GROUND CONTOURS
- NORMAL FLOOD LEVEL IN PIT
- CONTACT WATER DIVERSION
- EXCAVATION BOUNDARIES
- U/G SUBSIDENCE LIMIT
- U/G TENSION CRACK LIMITS

NOTES

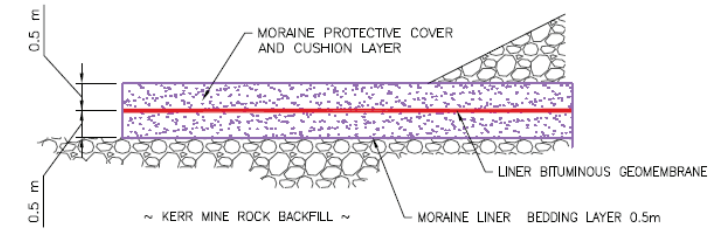
1. BASEMAP 10m INTERVAL CONTOUR LIDAR DATA RECEIVED FROM SEABRIDGE, SEPT, 2008, AND 20m INTERVAL CONTOUR FROM BC TRIM DATA.
2. DATUM: NAD83 UTM ZONE 9.

Figure 12.7-3

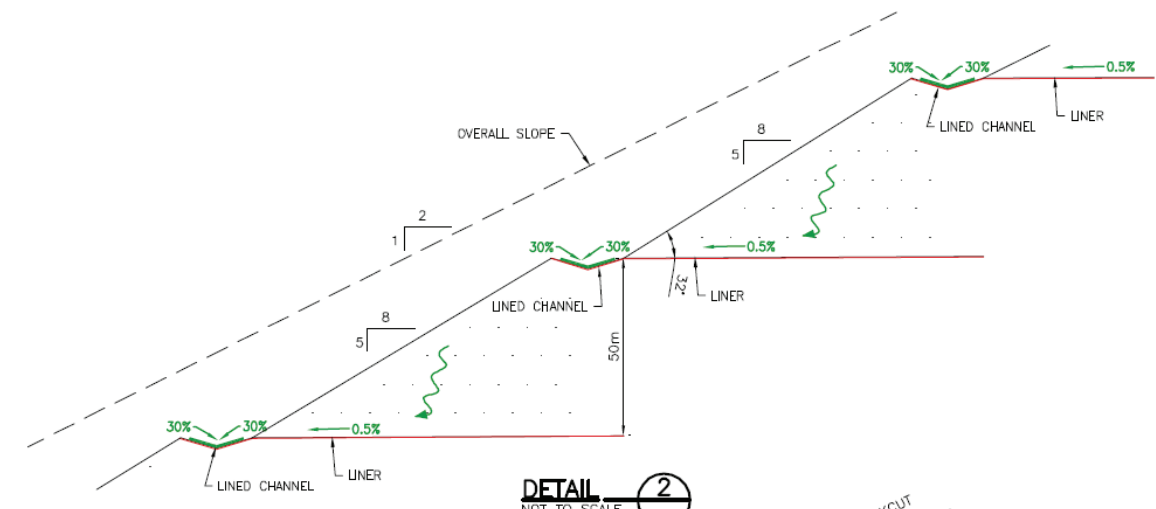
Schematic Plan of Mitchell Pit and Block Cave Mine Post-operation Drainage System



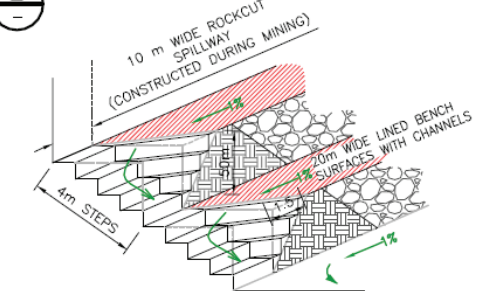
PLAN
SCALE A



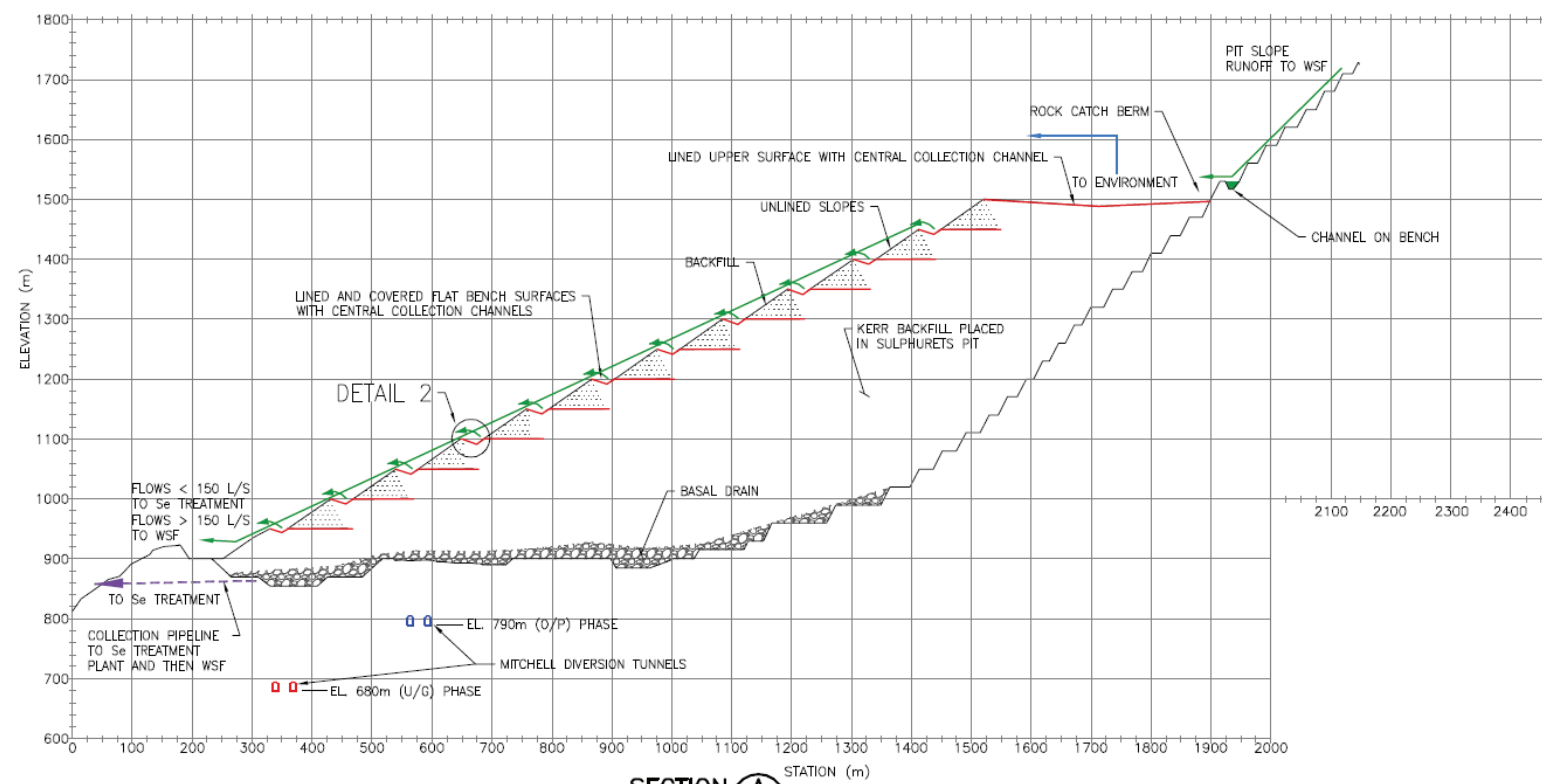
BENCH UNDER SLOPE AND UPPER SURFACE COVER AND LINER DETAILS
SCALE C



DETAIL 2
NOT TO SCALE



ROCK CUT STEP SPILLWAY IN PIT - DETAIL 3
NOT TO SCALE



SECTION A
SCALE B

LEGEND

- FRESH WATER DIVERSION CHANNEL
- PIPELINE TO SE TREATMENT PLANT
- CONTACT WATER TO Se TREATMENT < 150 L/S TO WSF > 150 L/S
- BITUMINOUS GEOMEMBRANE

NOTES

1. BASEMAP 10m INTERVAL CONTOUR LIDAR DATA RECEIVED FROM SEABRIDGE, SEPT, 2008, AND 20m INTERVAL CONTOUR FROM BC TRIM DATA.
2. DATUM: NAD83 UTM ZONE 9.

NOT FOR CONSTRUCTION



In addition, for verification purpose, sensitivity simulations were carried out with the Mine Site post-closure model to examine the effects of a few other key model inputs on groundwater quality, including a higher recharge rate (30% of the main annual precipitation) under the Mitchell and McTagg RSFs, a higher recharge rate (5% of the main annual precipitation) at the Sulphurets Pit backfill RSF, one order of magnitude lower effective porosities of the bedrock units, and one order of magnitude larger dispersivities of all geological materials, respectively. Sensitivity simulations were also done with the PTMA post-closure model for the model inputs, including one order of magnitude higher permeability of the tailings, flow boundary conditions for the tailing cells, one order of magnitude lower effective porosities of the bedrock, and one order of magnitude larger dispersivities of all geological materials, respectively.

Calcareous sandstone and siltstone located in the WSF area has shown evidence of dissolution, which could indicate the presence of karstic features (KCB 2013a; [Appendix 4-J](#)). Seepage interception tunnels with a high density of offshoot drill holes have been included in the WSF design to serve the function of intercepting open and dissolution-widened fractures. Further site investigation will be conducted during the detailed design phase at the WSF site to assess foundation suitability to satisfy seepage and geotechnical considerations for the current WSF design.

Local faulting has been identified towards the north end of the TMF, trending northwest-southeast, and passing through the North dam and North Cell seepage collection dam foundations (KCB 2013b; [Appendix 4-AC](#)). Faulting in this area has been intercepted by boreholes, and has been shown to manifest into fracture zones with hydraulic conductivity on the scale of 10^{-5} m/s.

Despite the application of mitigation measures, residual effects on groundwater quality arising from seepage of contact water from mine infrastructure are predicted (summarised in Table 12.7-1). This includes seepage from the TMF, Iron Cap Block Cave Mine, the Mitchell and McTagg RSFs, and the WSF. Groundwater modelling, which incorporates mitigation measures included in mine component designs, predicts development of plumes of contact groundwater emanating from these sources.

The potential for residual effects on groundwater quality have been ruled out for a number of sites. Groundwater modelling predicts sustenance of radial-inward flow paths around open pits that will contain contact water. Implementation of EMPs will reduce to negligible levels the potential for contact water reaching the groundwater in certain areas.

No residual effects arising from seepage of contact water are expected to be sourced at the lined tunnels, diversions, or roads, with implementation of the ML/ARD Management Plan (Section 26.14).

12.7.1.2.1 Mine Site Local Study Area Modelling Results

The groundwater flow and transport model for the Mine Site LSA simulated seepage of contact water emanating from the RSFs, WSF, and all pits and block cave mines. Model design incorporated baseline groundwater data collected in the area from 2008 to 2012, in addition to available meteorological, hydrologic, and geologic data for the same period.

Maximum plume extents were documented at end of operation, and 200 years following closure for the base-case and sensitivity (worst-case) scenarios. An overview of simulated flow

directions and plume extents is provided in Figures 12.7-5, 12.7-6, 12.7-7, 12.7-8, and 12.7-9 for the base case and the sensitivity (worst case) scenarios that include the upper and lower cases, and the wet year and dry year cases. Flow patterns and concentration distributions for all scenarios (at various depths in plan view and cross-sections) are presented in the groundwater modelling report ([Appendix 11-E](#)). The additional sensitivity simulations of the Mite Site post-closure model, but with a higher recharge rate under the Mitchell and McTagg RSFs and at the Sulphurets Pit backfill RSF, or with lower effective porosities of the bedrock, or with larger dispersivities of the geological materials, demonstrate highly similar plumes as those in the base case.

Mitchell Pit and Block Cave Mine

Flow modelling indicates that the Mitchell Pit and Block Cave Mine will act as a local groundwater sink for the duration of operation through to post-closure (Figures 12.7-5 and 12.7-6). This resulted in no development of a contact water plume in the simulation. Therefore, no residual effect on groundwater quality arising from contact water sourced from the Mitchell Pit and Block Cave Mine is expected. Water discharged from the mine to sustain dewatering will be routed through the Mitchell RSF basal drain from the onset of operation through to post-closure. All sensitivity (worst-case) scenario simulations indicate containment of water entering both the Mitchell Pit and Block Cave Mine.

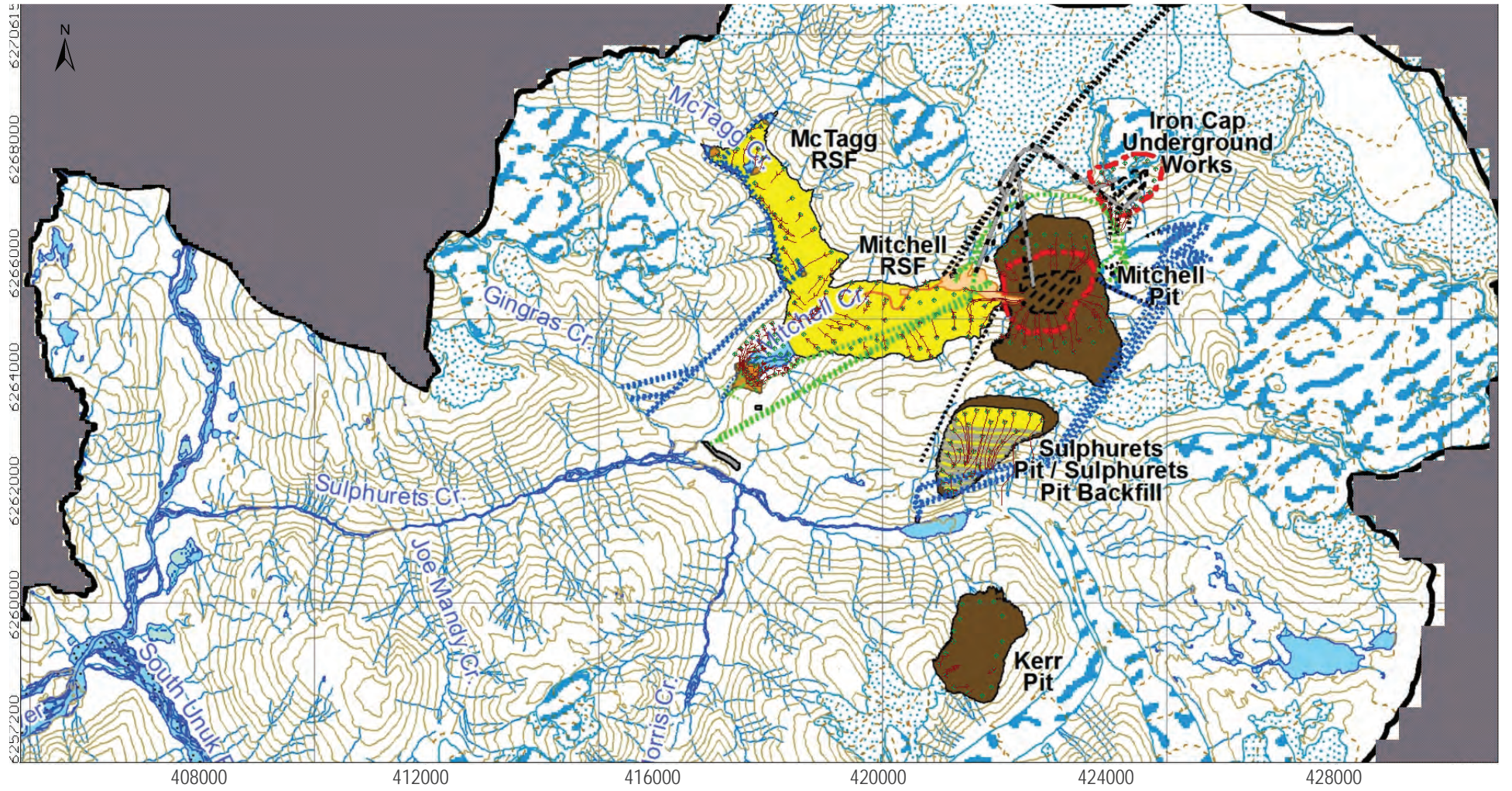
Mitchell and McTagg Rock Storage Facilities

A plume of contact water is expected to develop immediately below the RSF footprint, constituting a residual effect on groundwater quality. Constant loading will result in unity (100% of the source) concentrations being attained in the shallow groundwater early during the operation phase, and sustained throughout the post-closure phase.

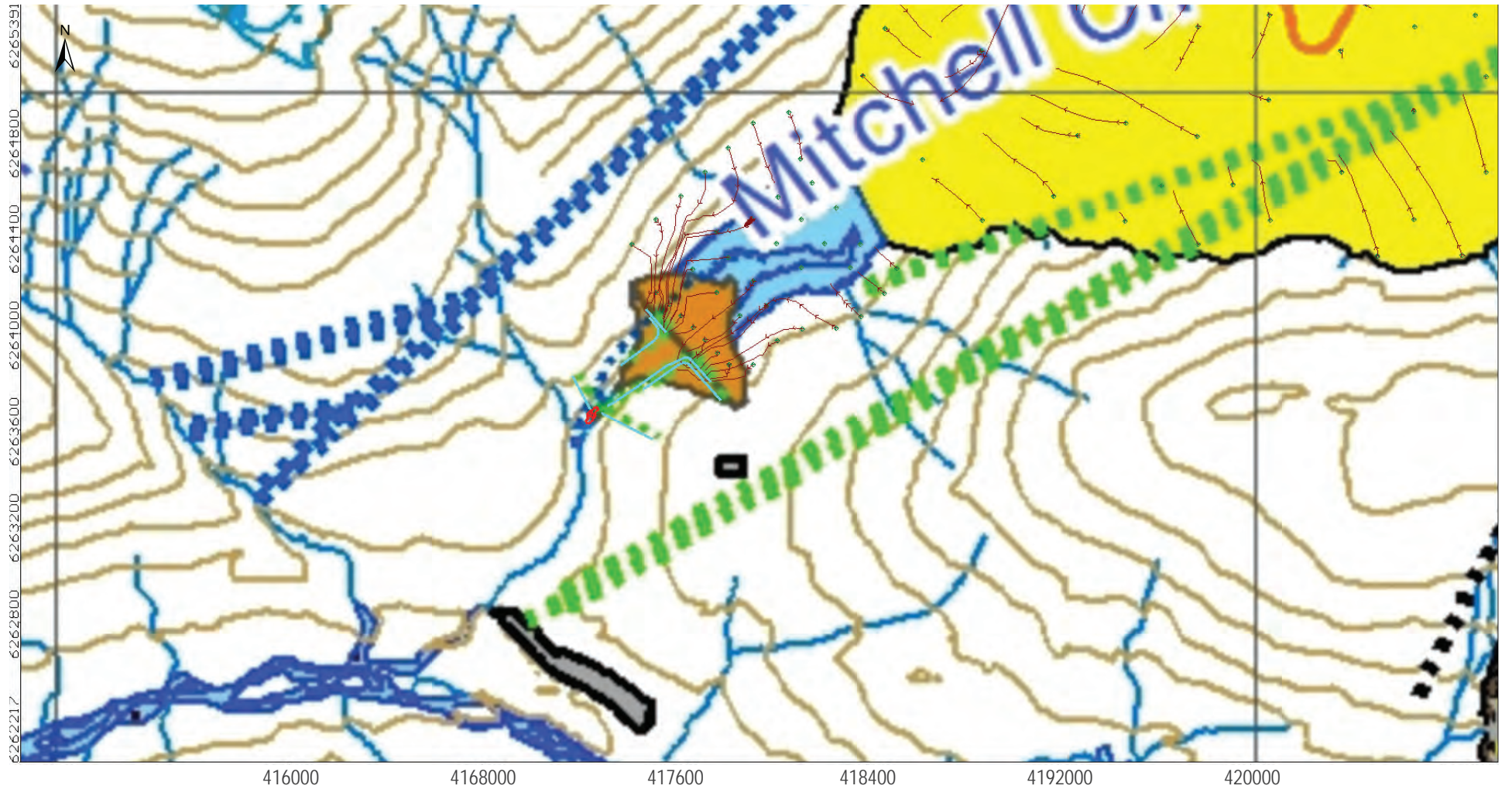
This plume is predicted to be contained entirely within the controlled catchment spanning the Mitchell Valley upstream of the WSF, as indicated by the predicted flow pathways (Figure 12.7-5 and 12.7-6) and plume extents (Figure 12.7-7 and 12.7-8). Sensitivity (worst-case) scenario simulations also show containment (Figure 12.7-9). A shallow groundwater divide, arising from water table mounding within the Mitchell RSF, will split plume migration between the Mitchell Pit and the WSF. The plume is predicted to daylight at 100% of the source concentrations in both the WSF water storage pond and the Mitchell Pit. Seepage rates passing through the RSF and reporting to the WSF water storage pond are predicted to be approximately 9,200 m³/day (106 L/s) during operation, and 9,700 m³/day (113 L/s) during post-closure. Subsequent seepage from the WSF is discussed in the corresponding following section. No seepage of contact water into the environment is predicted from the Mitchell Pit, as described previously in this section.

Iron Cap Block Cave Mine

The Iron Cap Block Cave Mine has been predicted to behave as a local groundwater sink for the duration of operation, following initial excavation during year 30 (Figure 12.7-5). Thus, no plume has been predicted to develop during the operation phase. Uncontrolled drainage through the mine following end of operation may result in the development of a contact water plume. The nature of this plume may include blasting residuals and ML/ARD. The potential for ML/ARD from the Iron Cap Block Cave Mine following flooding is discussed further in Chapter 10 (Geochemistry). A constant source of contact water has been assumed from this source for the groundwater effects assessment, commencing at the beginning of the closure phase.

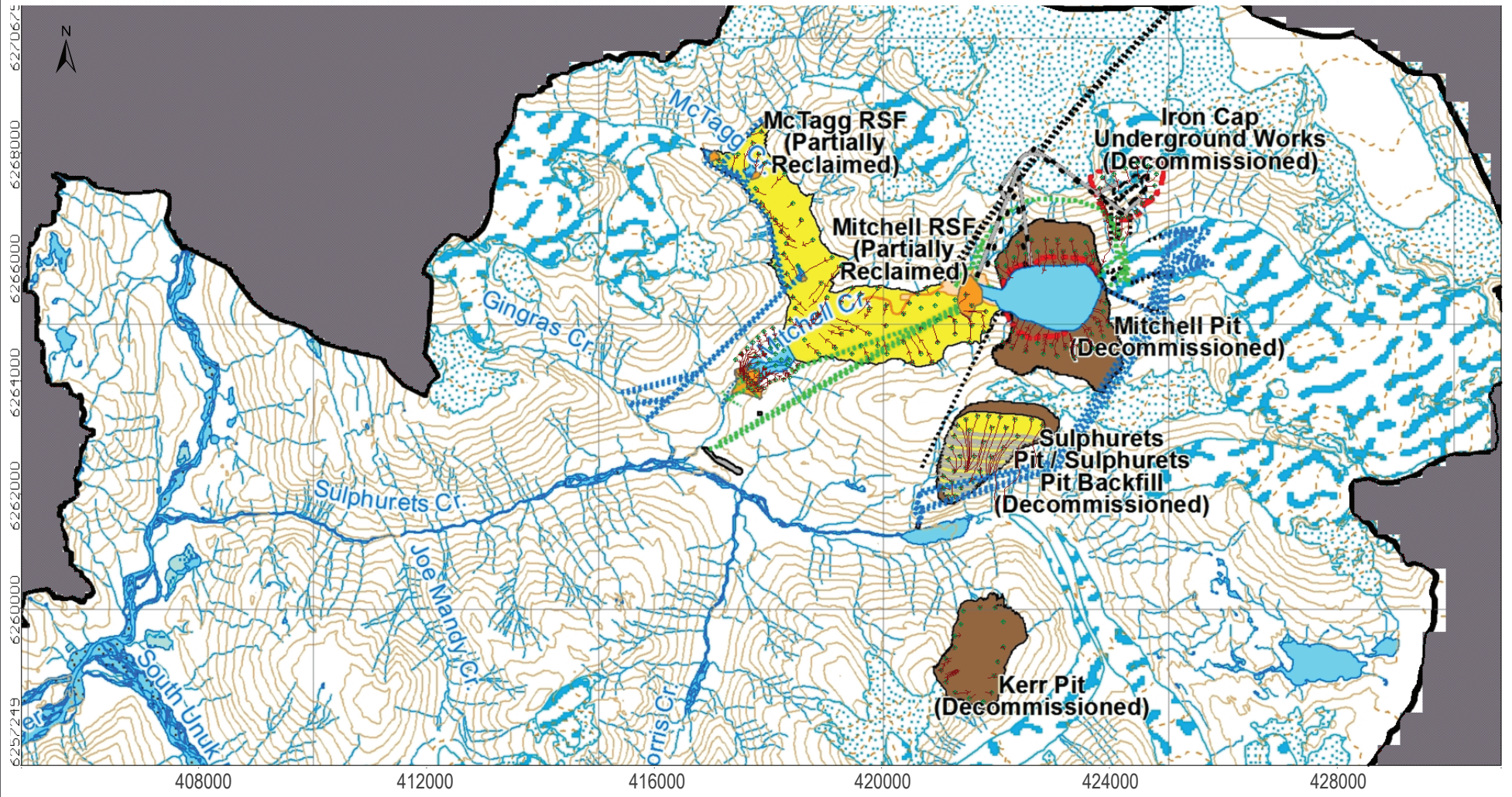


Local WSF

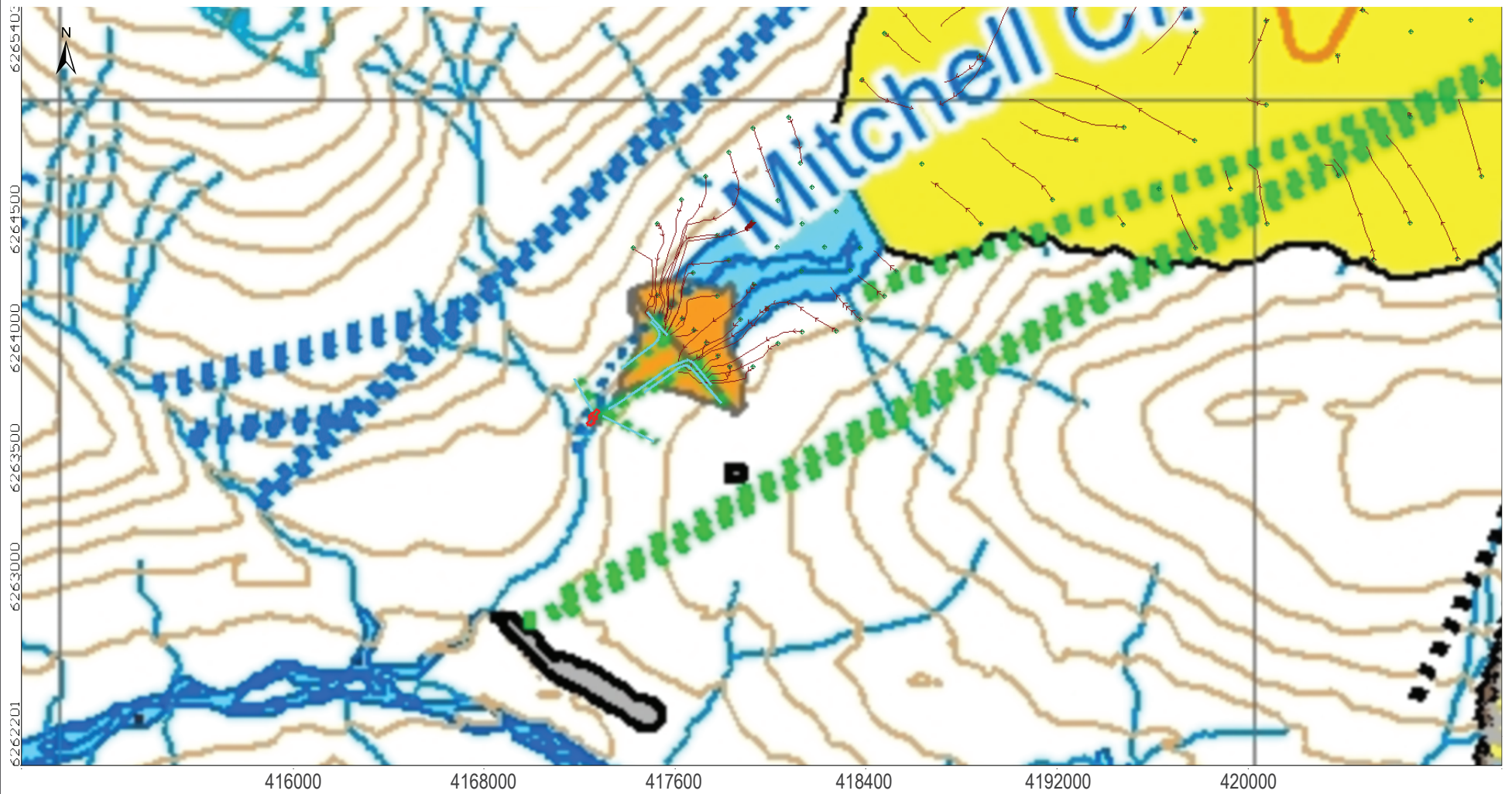


Note: Each mark on pathlines represents flow distance in 10 years.

Legend	
	Flow Pathline
	Seepage Collection Dam
	Seepage Collection Tunnels
	Underground Conveyor
	Diversion Tunnel
	Collection Tunnel
	Tunnel
	Surface Disturbance
	Dam
	Pond
	Pit
	Rock Storage Facility
	Underground Footprint
	Water Treatment Plant
	Ore Preparation Complex
	Glacier
	Icefield
	Creek/River/Lake
	Inactive Cells

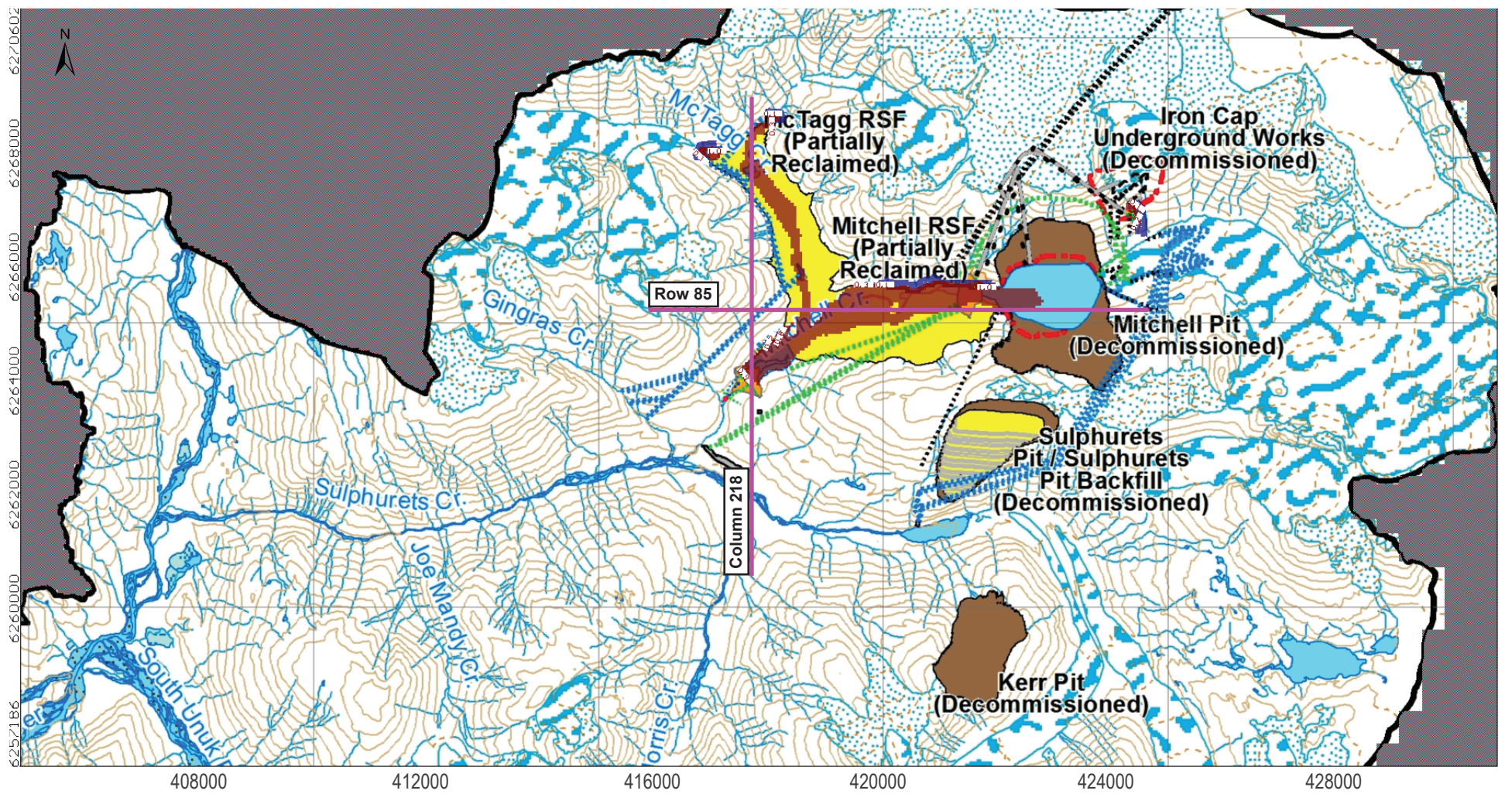
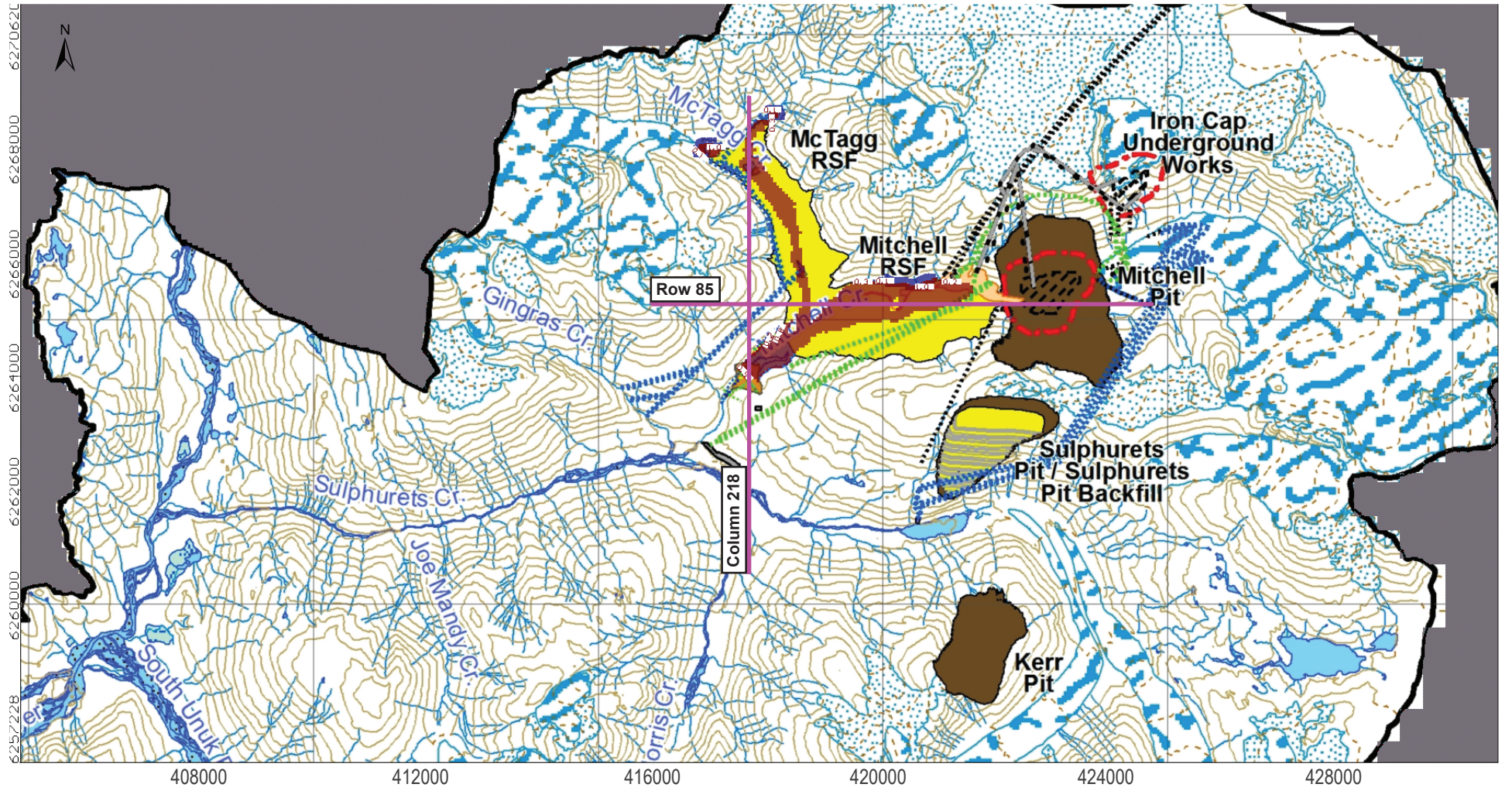


Local WSF



Note: Each mark on pathlines represents flow distance in 10 years.

Legend			



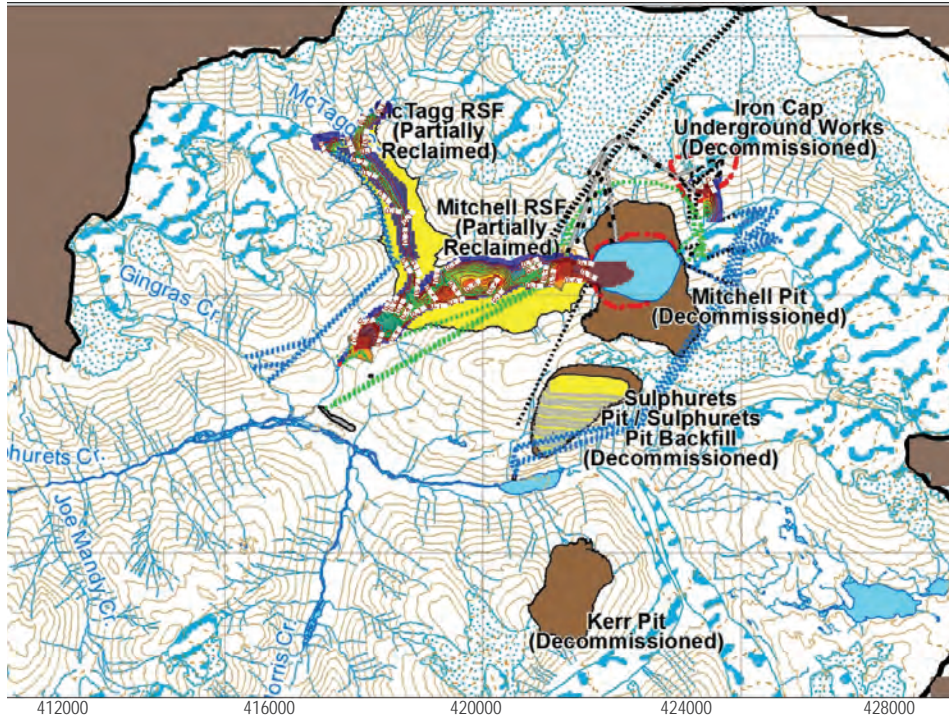
Legend					

Figure 12.7-7

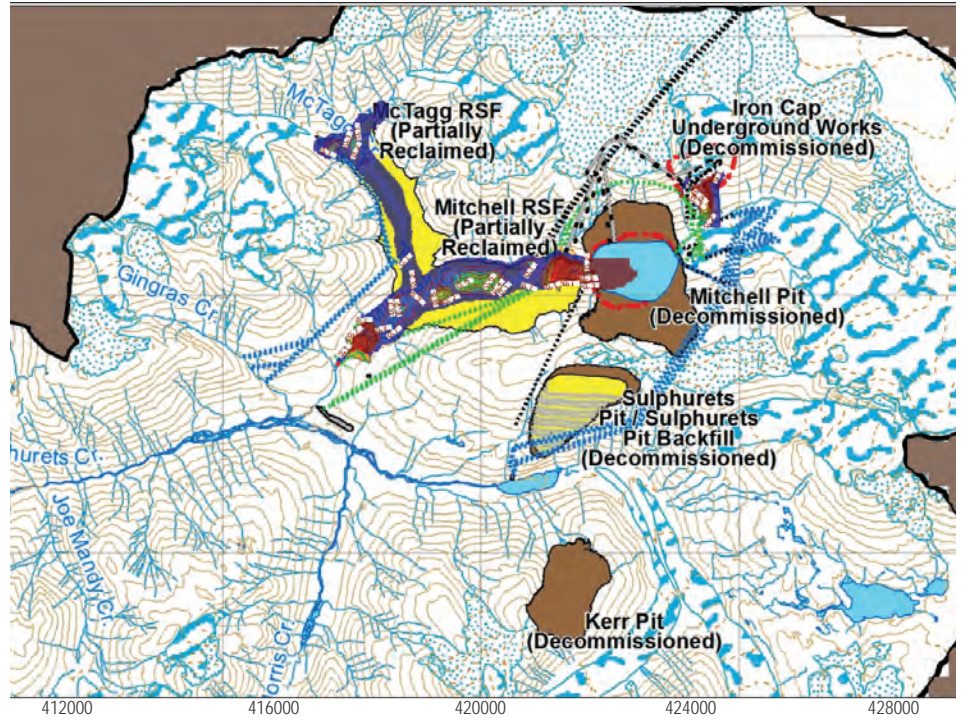
Predicted Plumes Sourced at Project Components in the Mine Site at End of Operation and 200 Years Post-closure (Model Layer 1: Shallow Groundwater Environment)

Figure 12.7-7

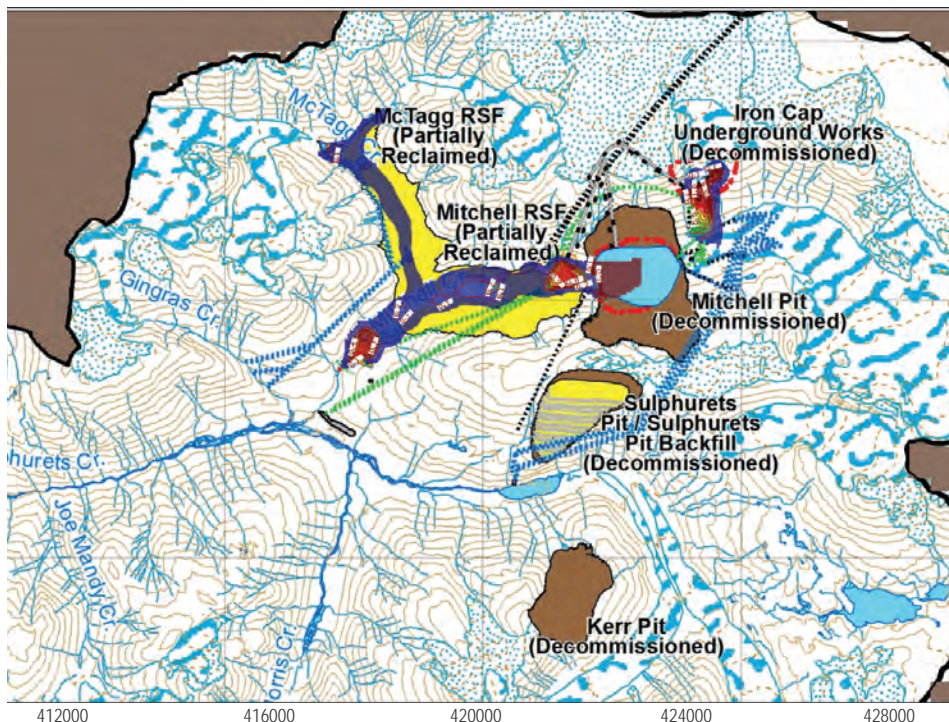
Layer 2



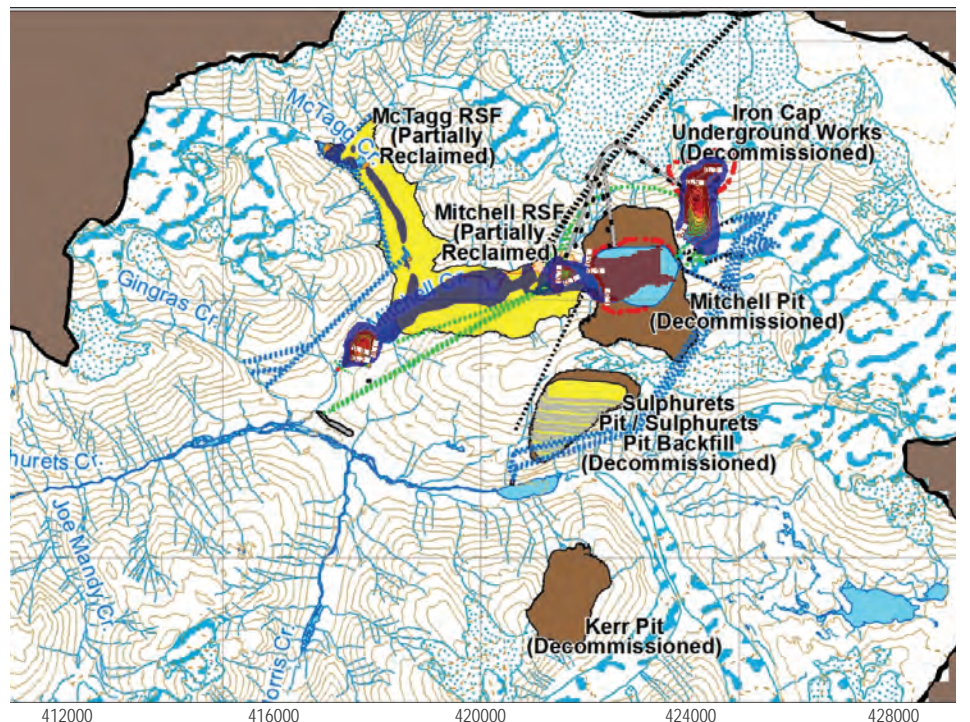
Layer 3



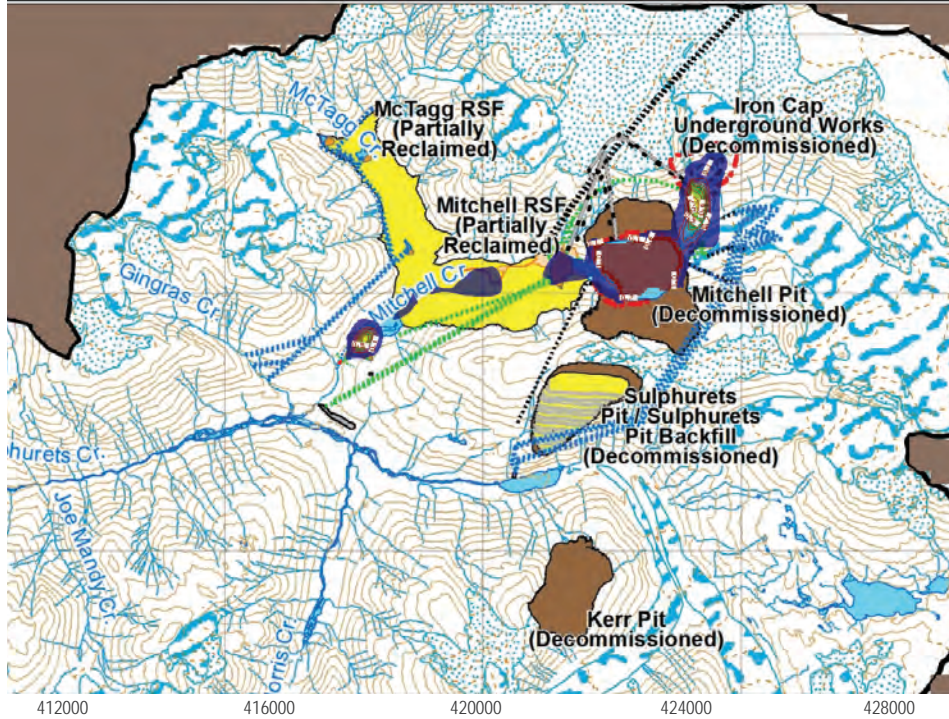
Layer 4



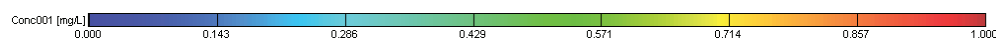
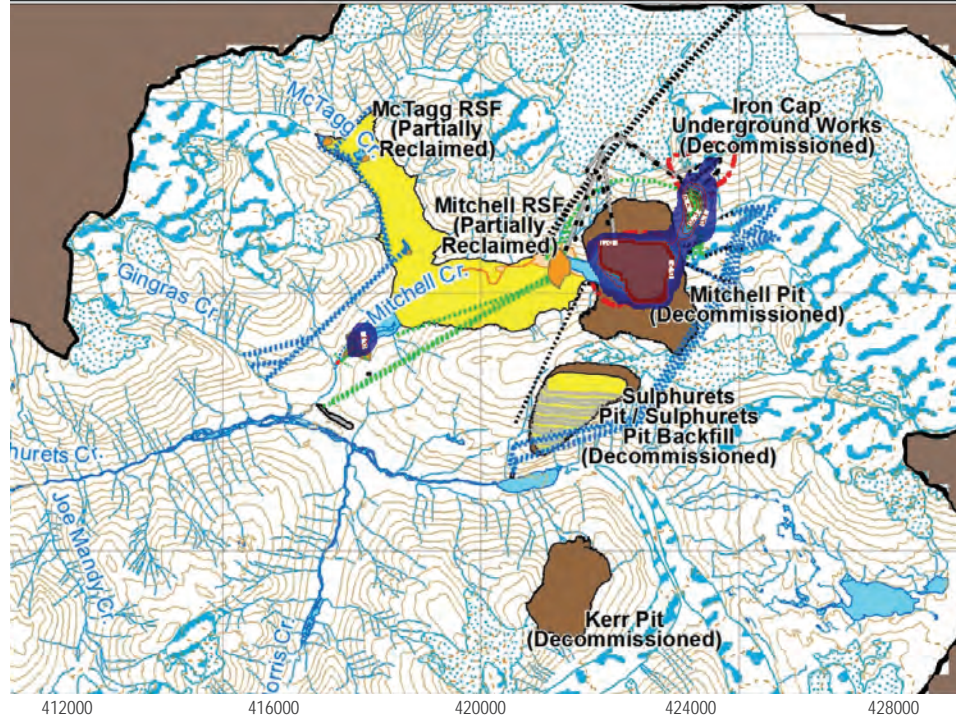
Layer 5



Layer 6



Layer 7



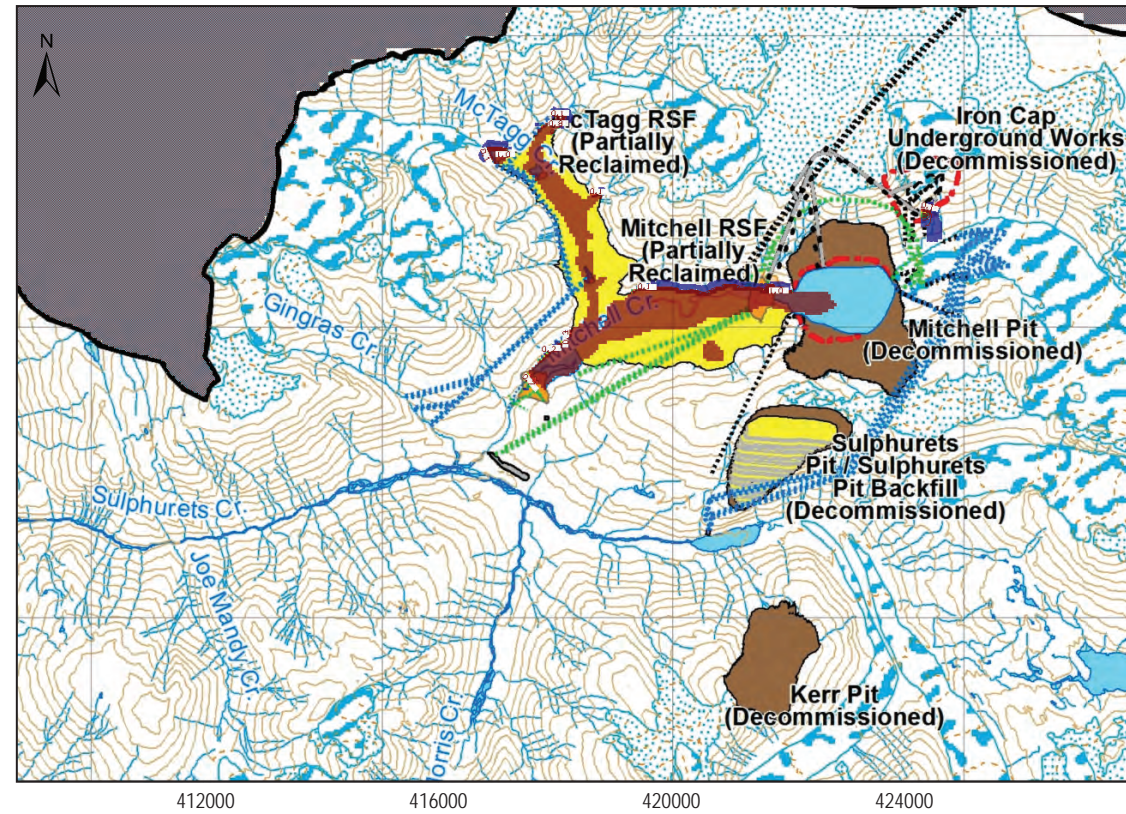
Legend			
Concentration Isoleth	Underground Conveyor	Surface Disturbance	Rock Storage Facility
Diversion Tunnel	Dam	Underground Footprint	Glacier
Collection Tunnel	Pond	Water Treatment Plant	Icefield
Tunnel	Pit & Pit Lake	Ore Preparation Complex	Creek/River/Lake
			Inactive Cells

Figure 12.7-8

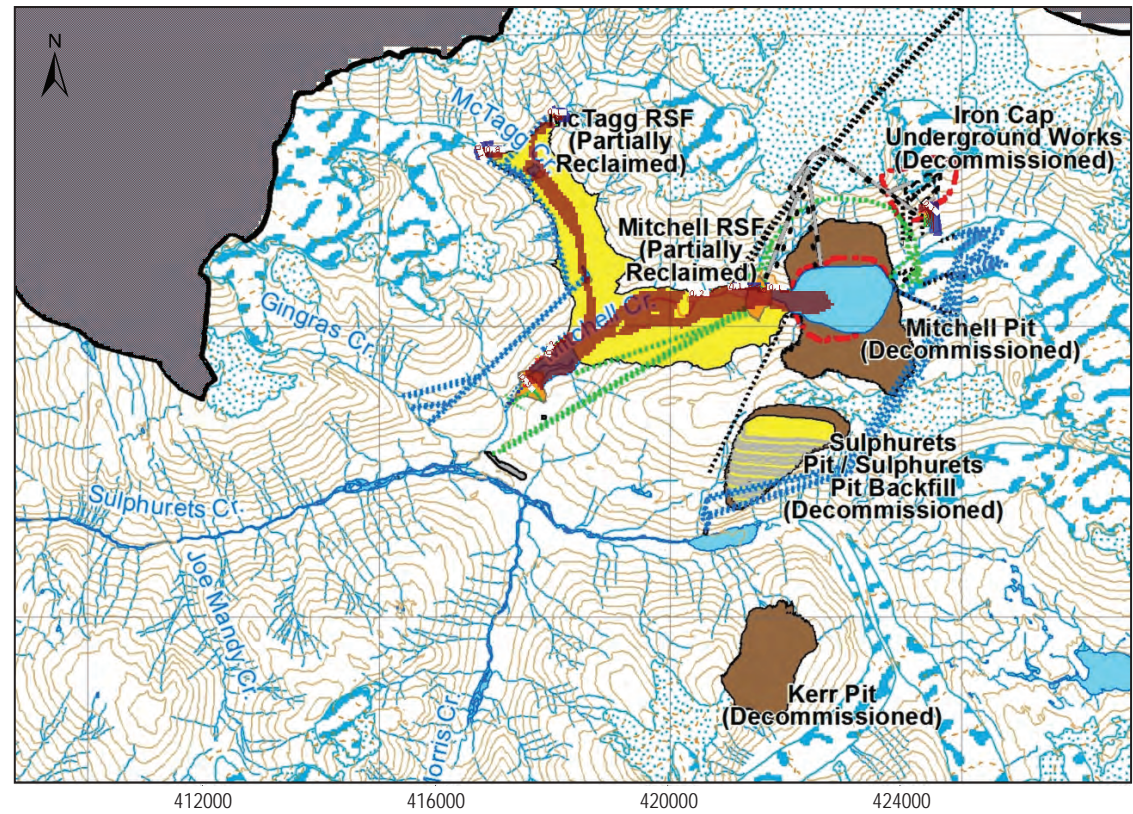
Predicted Plumes Sourced in Project Components in the Mine Site at 200 Years Post-closure (Model Layers 2 - 7: Deep Groundwater Environment)

Figure 12.7-8

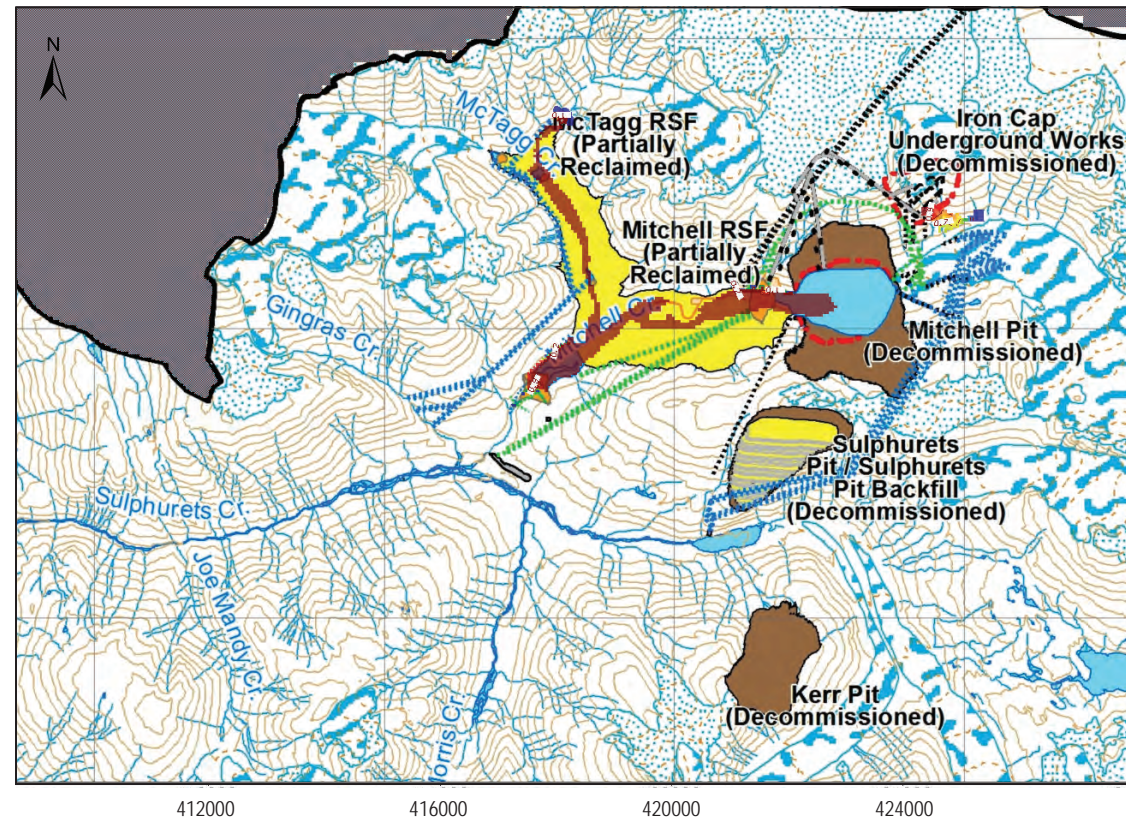
a) Wet Year



b) Dry Year



c) Upper Case



d) Lower Case

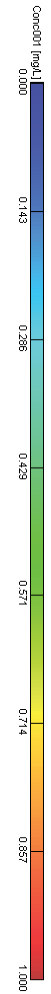
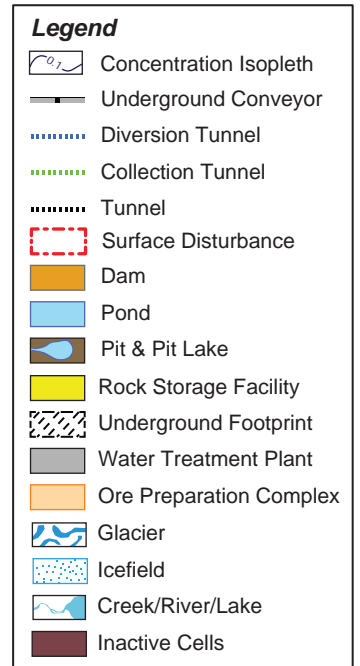
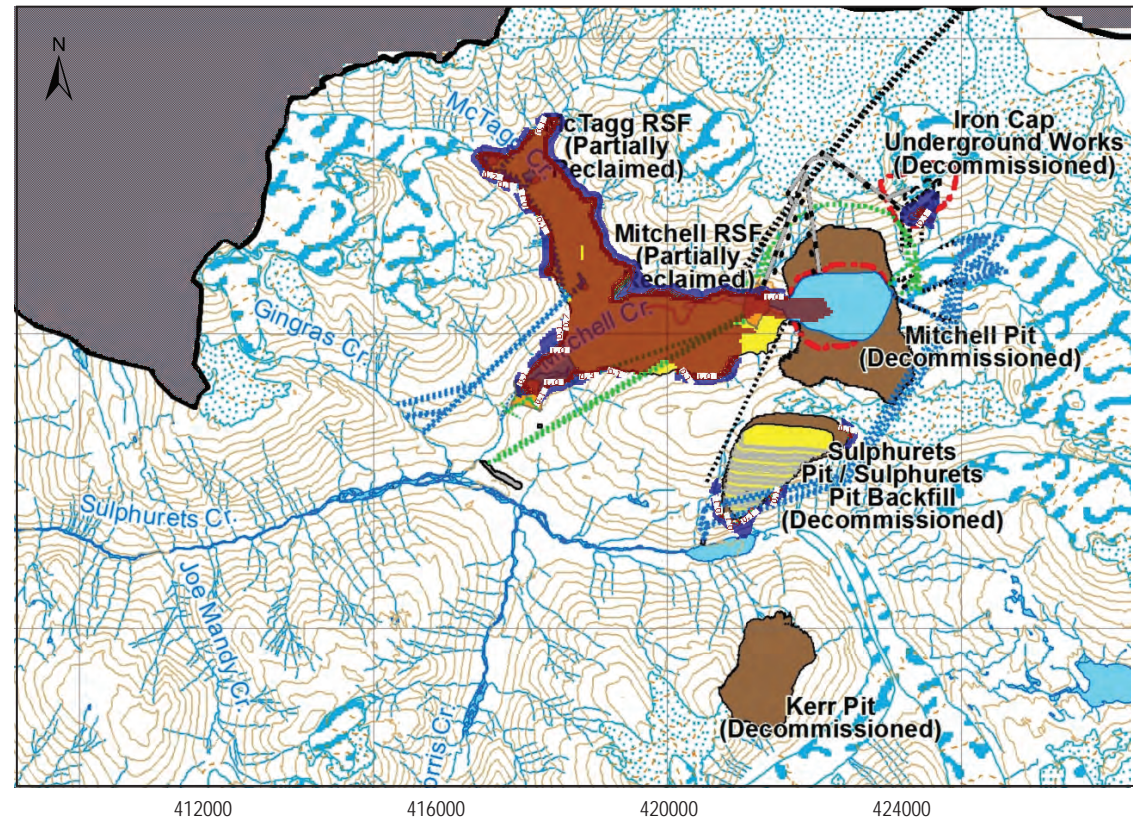


Figure 12.7-9
Plumes Sourced in the Mine Site for Worst Case Scenario Simulations at 200 Years Post-closure (Model Layer 1: Shallow Groundwater Environment)

A plume has been predicted to emanate from the Iron Cap Block Cave Mine at post-closure, constituting a residual effect on groundwater quality. It is predicted to migrate along the groundwater flow paths trending to the south towards the base of the Mitchell Valley (Figures 12.7-6 and 12.7-7). The flow model indicates that all groundwater passing through the Iron Cap Block Cave Mine after end of operation will daylight into the Mitchell Pit. Complete capture is also demonstrated in the solute transport simulations. Sensitivity (worst-case) scenario simulations all indicate capture of the plume emanating from the Iron Cap Block Cave Mine in the Mitchell Pit (Figure 12.7-9).

The plume emanating from the Iron Cap Block Cave Mine is predicted to be contained entirely within the controlled catchment spanning the Mitchell Valley upstream of the WSF. Sensitivity (worst-case) simulations also demonstrate containment. All seepage within this catchment is predicted to report to the WSF, or be re-directed to the Water Treatment Plant following discharge into the Mitchell Pit.

Sulphurets Pit and Rock Storage Facility

Flow modelling indicates that the Sulphurets Pit and backfilled RSF will act as a local groundwater sink (Figures 12.7-5 and 12.7-6). This is the result of active dewatering during excavation, and installation of basal drains upon completion of excavation. The geomembrane covers are expected to minimize infiltration of precipitation. The basal drains will effectively dewater the pits, draining contact water and preventing it from entering the groundwater environment. Simulations indicate that groundwater discharge into the pit will be approximately 24 m³/day (0.3 L/s) during operation, and 24.5 m³/day (0.3 L/s) at post-closure.

Isolated flow paths have been predicted to leave the Sulphurets Pit from its eastern locale, sourced in the unsaturated zone. No plume has been predicted to develop (Figures 12.7-7 and 12.7-8). Geomembrane covers will minimize contamination of water entering the Sulphurets RSF from above.

The upper-case, wet year, and dry year scenarios do not result in a plume emanating from the Sulphurets Pit (Figure 12.7-9). The lower-case scenario indicates that a dilute plume (concentrations as high as 10% of source) will emanate into the shallow groundwater toward Sulphurets Lake, and toward a small creek adjacent to the eastern wall. The low hydraulic conductivities used in the lower-case simulation result in an elevated water table in the upper reaches of the mountains, and heightened ambient hydraulic gradients. Lower-case results indicate groundwater discharge into the pit would be greater than base-case predictions, and approximately 540 m³/day (6 L/s) during both operation and post-closure phases. Steady-state concentrations reporting to Sulphurets Lake would be less than 1% of source.

Seepage and surface water flows along the Sulphurets Valley outside of the groundwater sinks created by the pits will not be contained, and will discharge into the downstream environment. Monitoring at a well between the Sulphurets Pit and Sulphurets Lake is planned. This is described further in the Groundwater Management Plan (Section 26.15).

Kerr Pit

Flow modelling indicates that the Kerr Pit will act as a local groundwater sink (Figure 12.7-5 and 12.7-6). This is the result of active dewatering during excavation, and installation of basal drains upon completion of excavation. The basal drains will effectively dewater the pits, draining contact water to the WSF and minimizing it from entering the groundwater environment.

Sensitivity (worst-case) scenario simulations do not indicate that a plume will develop at Kerr Pit (Figures 12.7-7 and 12.7-8). However, particle tracking conducted for the upper-case simulation indicates that some water in the pit wall could discharge into deep groundwater ([Appendix 11-E](#)). No plume is expected to daylight in the downstream Sulphurets Creek and Sulphurets Lake (Figure 12.7-9).

Water Storage Facility

The WSF reservoir was simulated as a constant-source solute boundary condition superimposed on a constant-head boundary condition. A plume is predicted to develop directly below the footprint of the reservoir, commencing when contact water begins ponding. This constitutes a residual effect on groundwater quality.

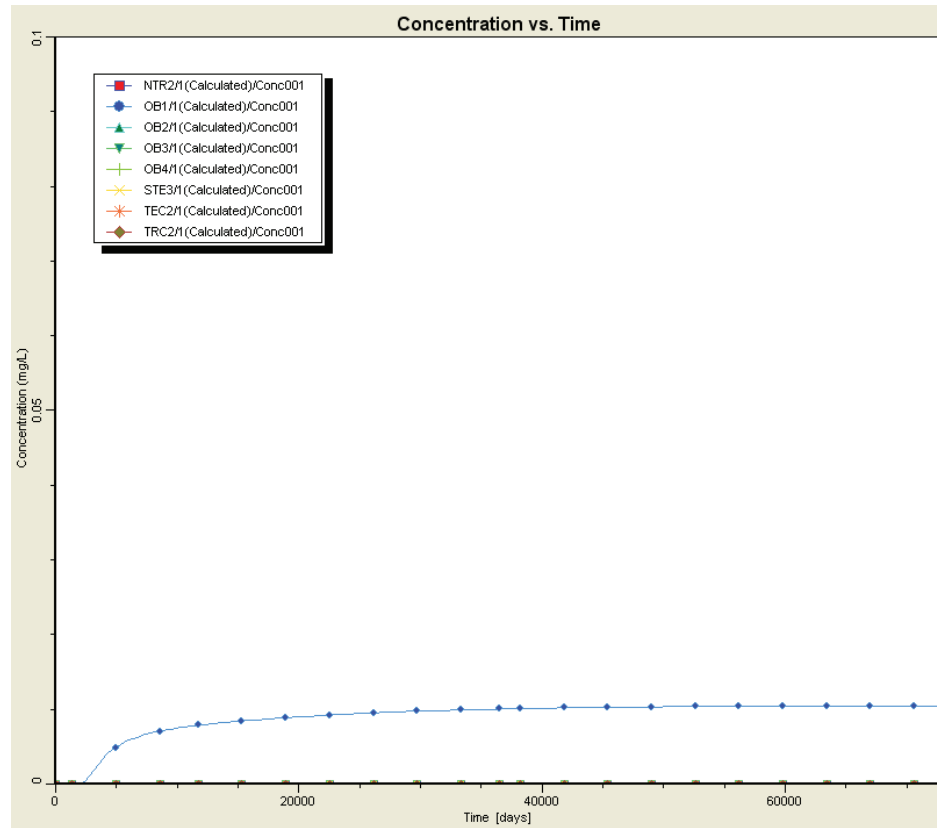
This plume is predicted to travel below the WSD, and be captured by the seepage interception tunnels (Figures 12.7-7 and 12.7-8). A low-concentration plume travels down the Mitchell Valley beyond the WSD footprint. No contact groundwater is predicted to discharge into the Mitchell Creek beyond the seepage collection dam.

The plume emanating from the WSF has been predicted to attain a steady-state approximately 30 years after end of operations, as indicated by simulated breakthrough curves at planned monitoring wells (Figure 12.7-10). At steady-state (maximum plume extents), the plume component passing beyond the WSD is captured by the WSF seepage collection pond.

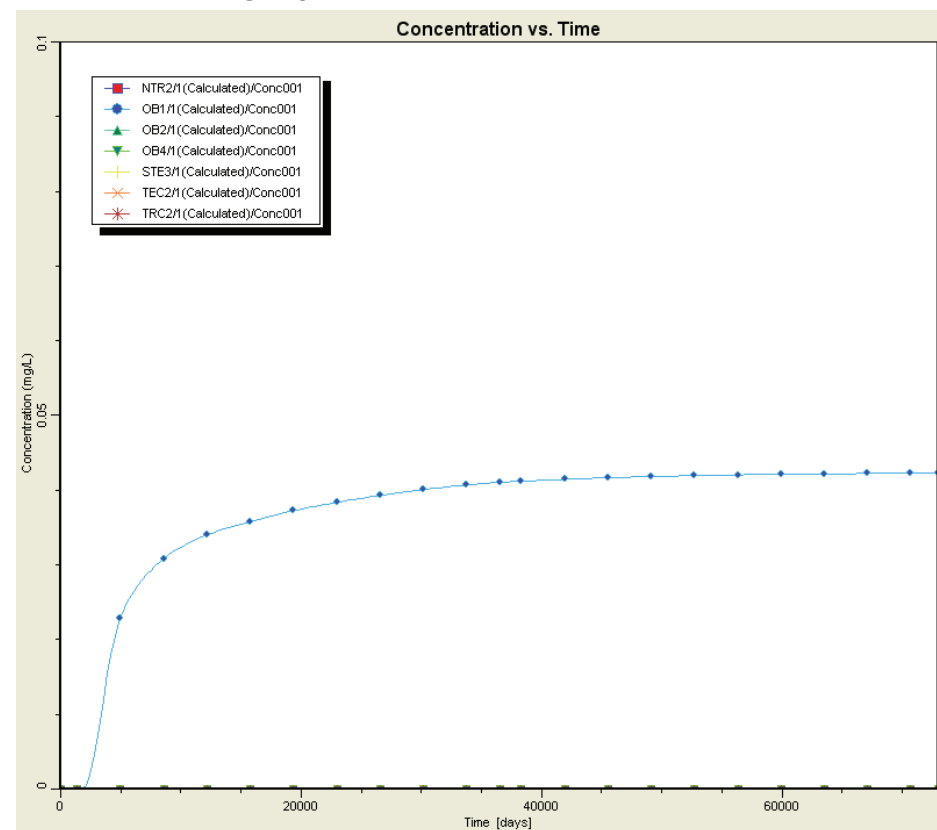
Capture of the seepage beneath the WSF is indicated in flow results of sensitivity (worst-case) scenario simulations. The upper-case scenario results in shallow flow paths that bypass the WSD around the southeast abutment, reporting to seepage interception tunnels farther downstream. Seepage leaving the dam and travelling into deeper bedrock exits the zone influence of the seepage control mechanisms, resulting in development of a plume extending into the downstream groundwater environment (Figure 12.7-11). Steady-state concentrations in the downstream groundwater environment are below 5% of the source. The plume does not report to Sulphurets Creek at levels exceeding 0.1% of the source concentration.

Very high hydraulic conductivities (10^{-3} m/s) have been used for the upper-case scenario within the band of calcareous sedimentary rock identified in the WSF area. However, the behaviour of dissolution-widened fractures in this area is not completely understood, and cannot be fully captured by the modelling approach used. Therefore, monitoring at wells down-gradient of the WSF is planned. This is described further in the Groundwater Management Plan (Section 26.15).

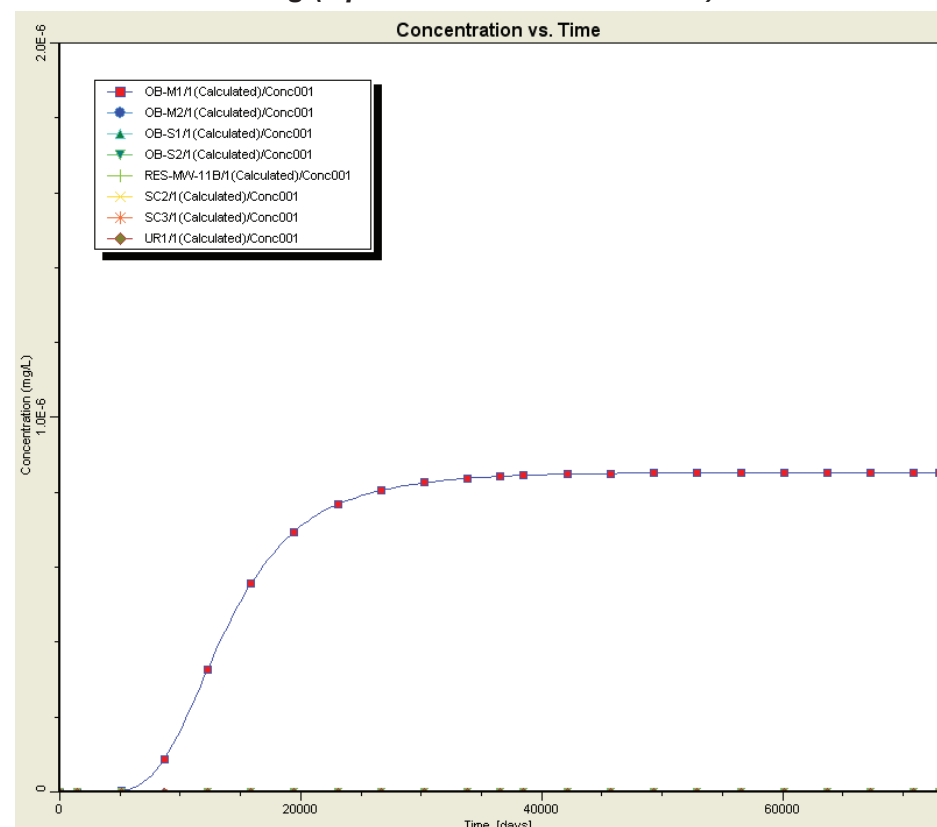
PTMA Monitoring (Operation and Early Closure)



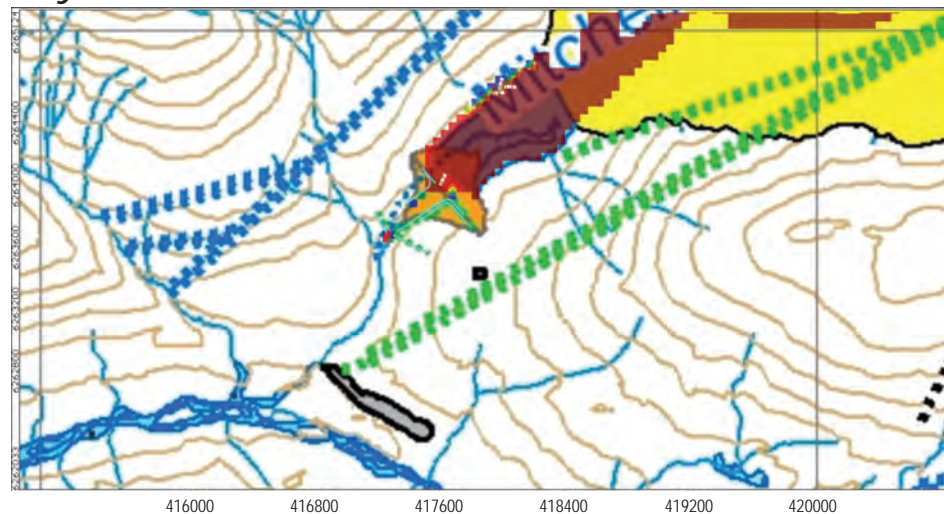
PTMA Monitoring (Operation and Post-closure)



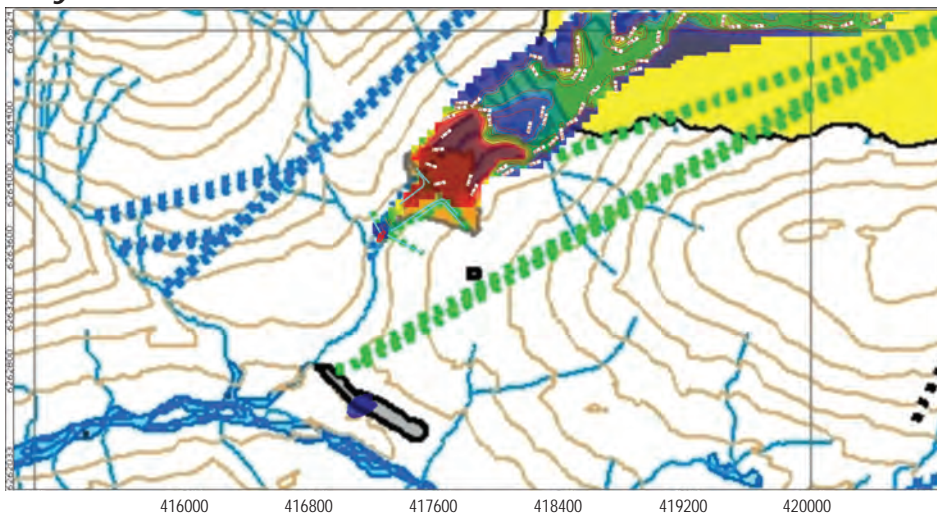
Mine Site Monitoring (Operation and Post-closure)



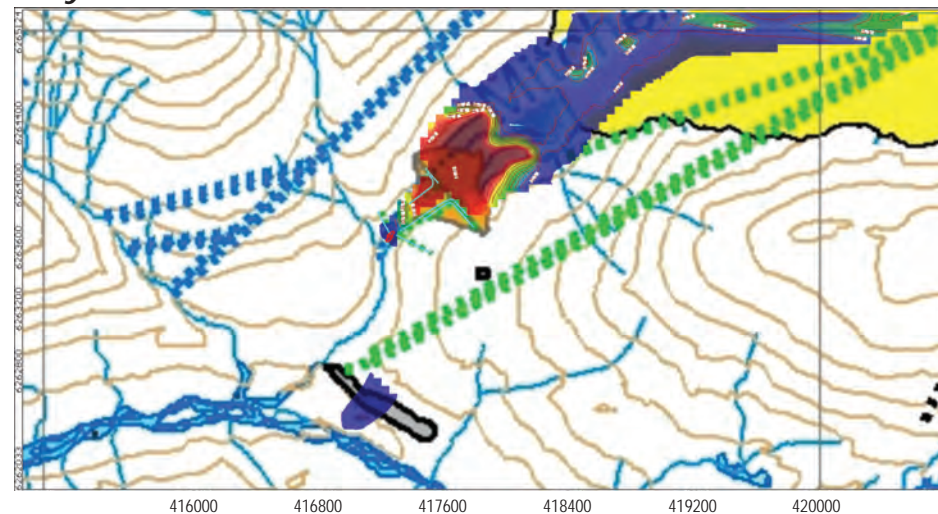
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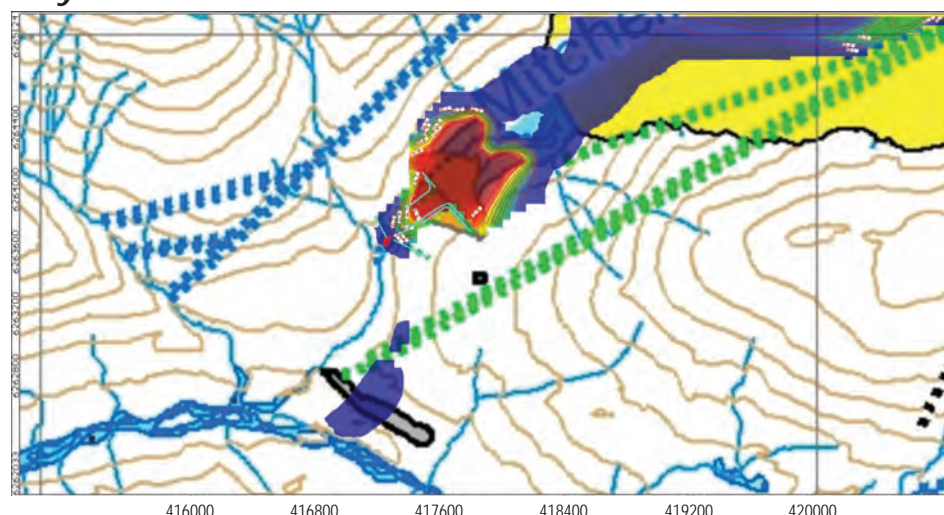
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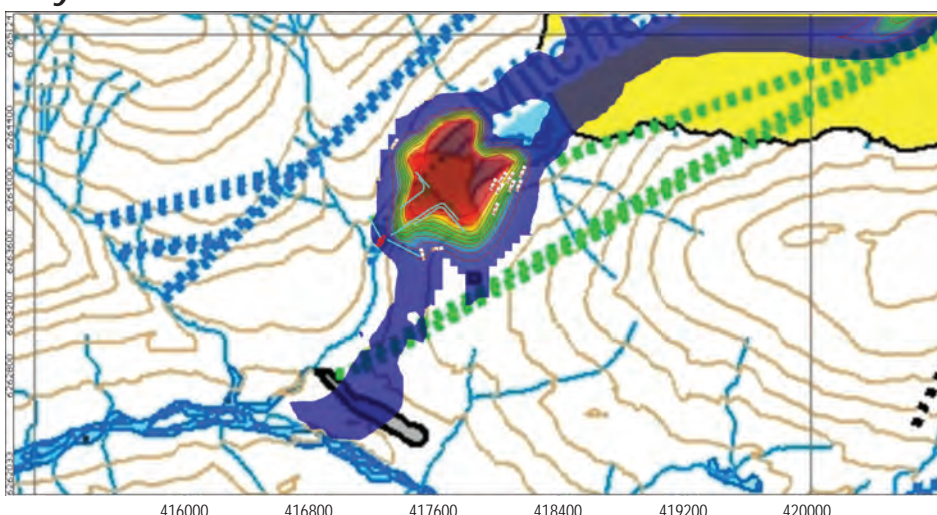
Layer 3



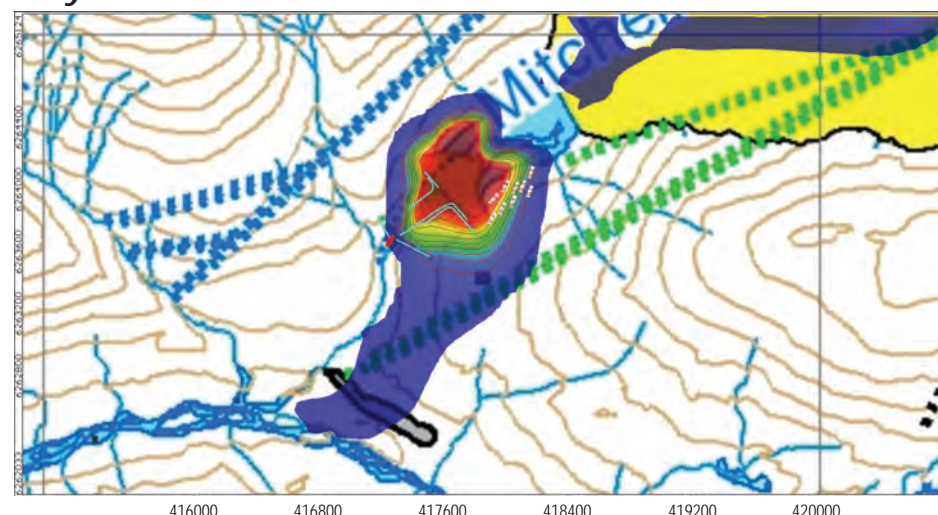
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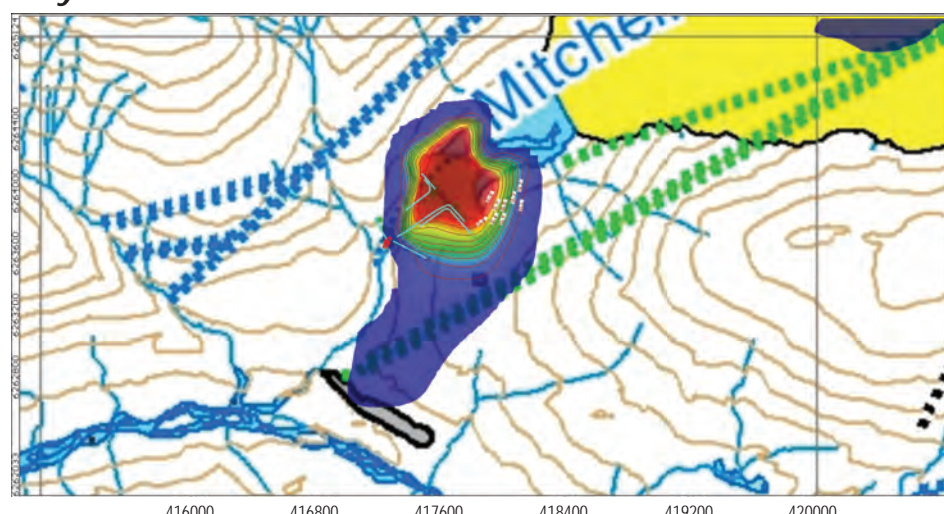
Layer 5



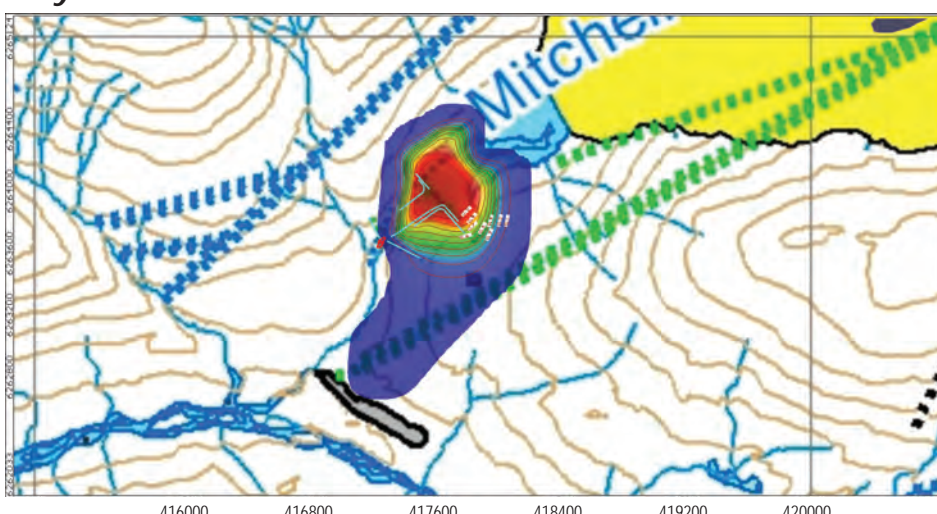
Layer 6



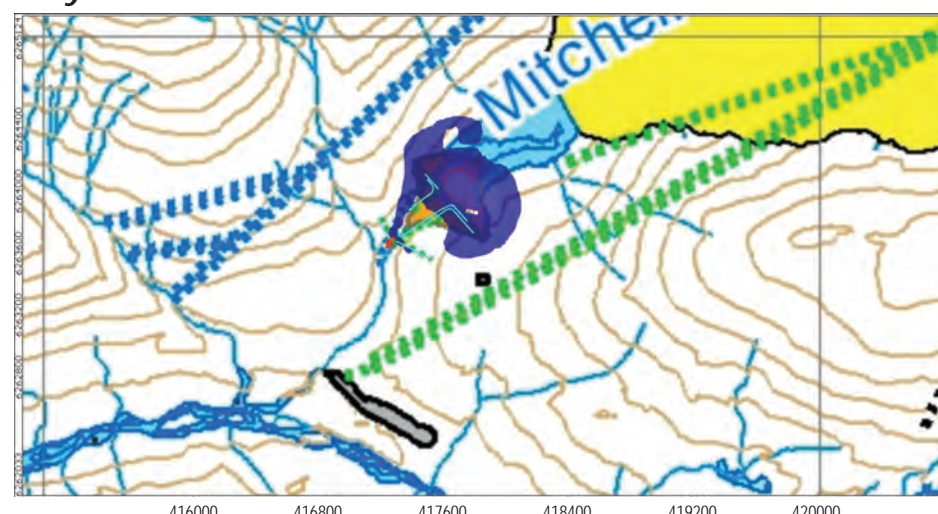
Layer 7



Layer 8



Layer 9



Legend

Concentration Isopleth	Diversion Tunnel	Dam	Water Treatment Plant
Source Zone	Collection Tunnel	Pond	Creek/River/Lake
Seepage Collection Dam	Tunnel	Rock Storage Facility	
Seepage Collection Tunnels			

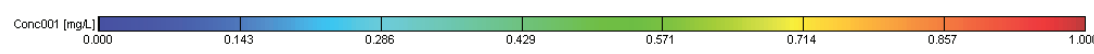


Figure 12.7-11
Plume Sourced in the Water Storage Facility for the Upper Case Scenario 200 Years Post-closure

12.7.1.2.2 Processing and Tailing Management Area Local Study Area Modelling Results

Plumes of contact (tailing) groundwater emanating from the three TMF cells were predicted. Therefore, residual effects sourced at the three TMF cells have been identified. All predictions discussed herein are derived from the base-case (expected case) simulation, unless specified otherwise.

The groundwater flow and non-reactive solute transport model for the PTMA local study site simulated constant source boundary conditions in the three TMF cells. Constant unit (100%) sources were assumed to sustain from beginning of operation to 200 years after end of operation. Model design incorporated baseline hydrogeological data collected in the area from 2008 to 2012, as well as available meteorological, hydrologic, and regional geologic data from the same period.

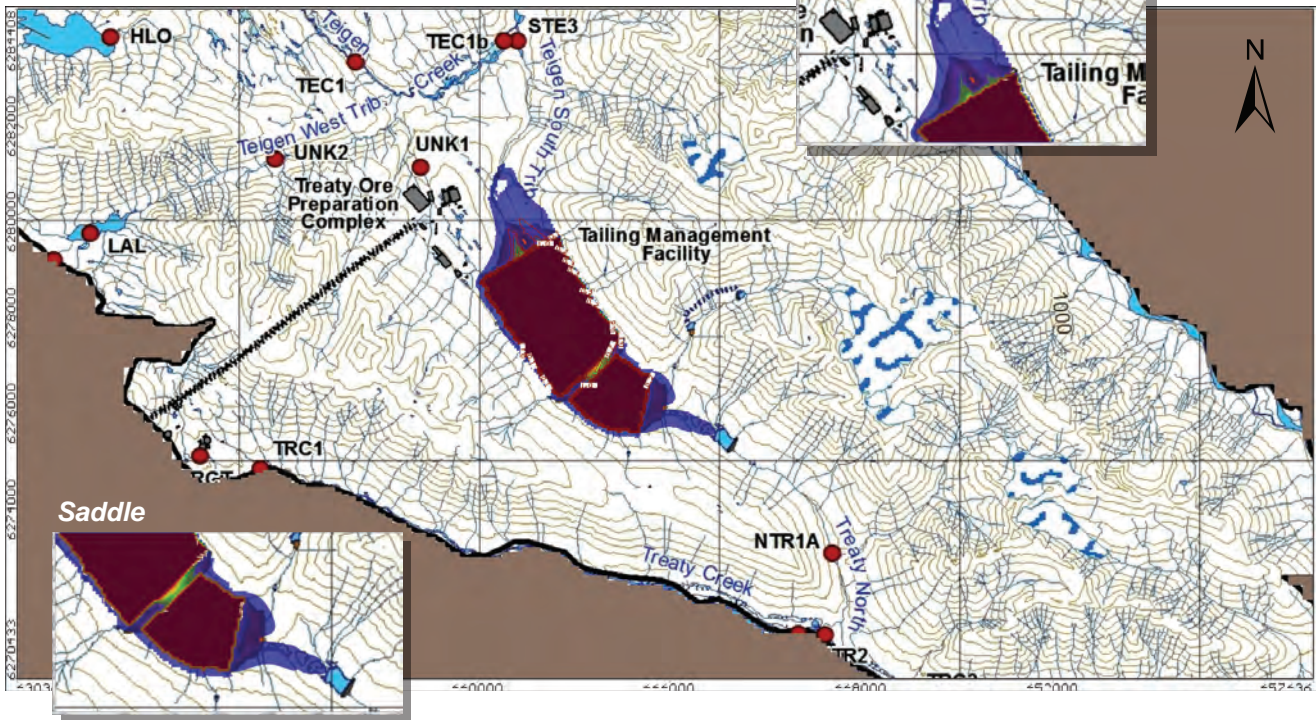
Maximum plume extents were documented at a mid-operation phase in Year 25 (when plant discharge transitions from the North Cell to the South Cell), end of operation, and 200 years following closure for the base case and the sensitivity (worst-case) scenarios. Plume extents and concentration distributions for all scenarios are presented in the groundwater modelling report ([Appendix 11-E](#)). Predicted plume extents in the base case at operation year 25, end of operation, and 200 years post-closure are presented in Figures 12.7-12, 12.7-13, and 12.7-14, respectively. Sensitivity (worst-case) scenarios solute transport results 200 years after end of operation are presented in Figure 12.7-15.

Plumes are predicted to develop directly below the TMF footprints. This includes the North Cell and Centre Cell during operation stage 1 up to year 25, and all three cells from year 25 onwards.

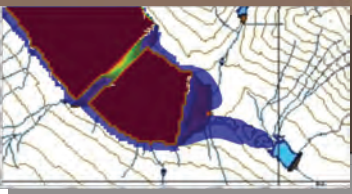
Plumes emanating from the Centre Cell and South Cell travel down-gradient to the south, along the North Treaty Valley. During stage 1 of the TMF design (up to operation year 25), the plume emanating down the North Treaty Valley is sourced at the Centre Cell only. At end of operation and post-closure, the plume is sourced at the South Cell only. Seepage emanating from the Centre Cell is predicted to become hydraulically contained once the three cells attain equal water levels, which is expected to occur toward the end of operation. Prior to hydraulic containment, the plume emanating to the south is including contact (tailing) water sourced at the Centre Cell and South Cell. Seepage from the Centre Cell with the geomembrane liners installed on the sides and beneath is predicted to be small (less than 2 L/s), resulting in very low concentrations in the plume.

The concentrations of the plumes emanating down the North Treaty Valley reduced rapidly down-gradient. Post-closure, the plume (sourced at the South Cell) is predicted to attain a steady-state 40 years after the South Cell is in full capacity at end of operation with the assumed constant head and source. Surface water quality modelling predicts improvement in tailing cell water quality post-closure (Chapter 14); therefore, the simulation of constant loading post-closure is conservative. All contact water emanating from the TMF down the North Treaty Valley has been predicted to be captured in the Saddle and southeast seepage collection ponds.

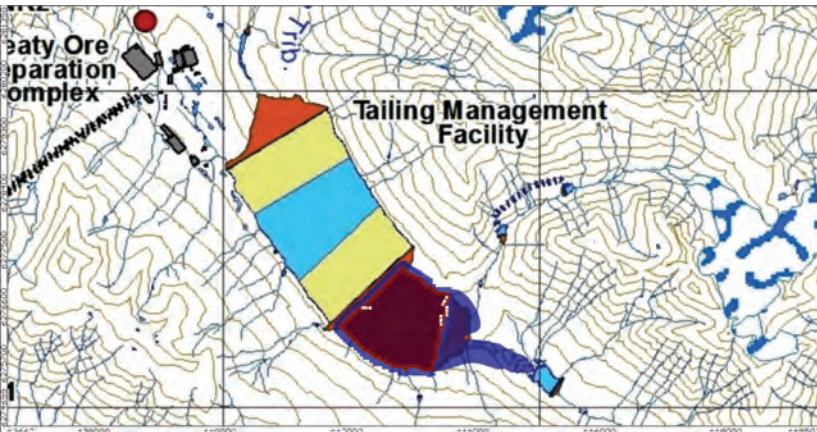
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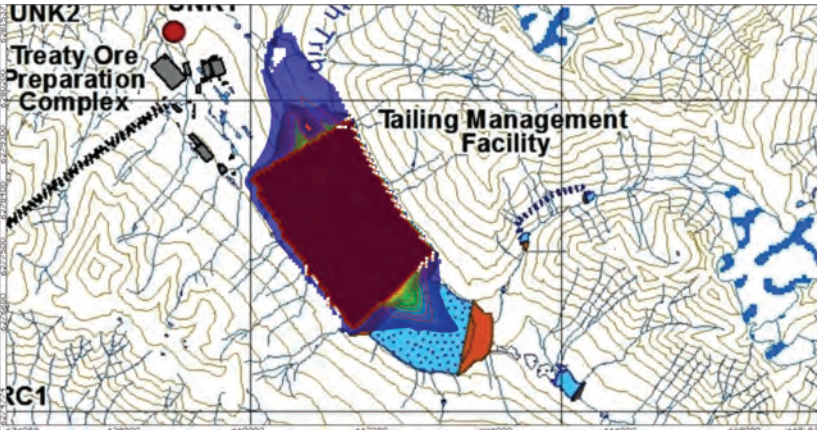
Saddle



CIL Cell



Flotation Cell

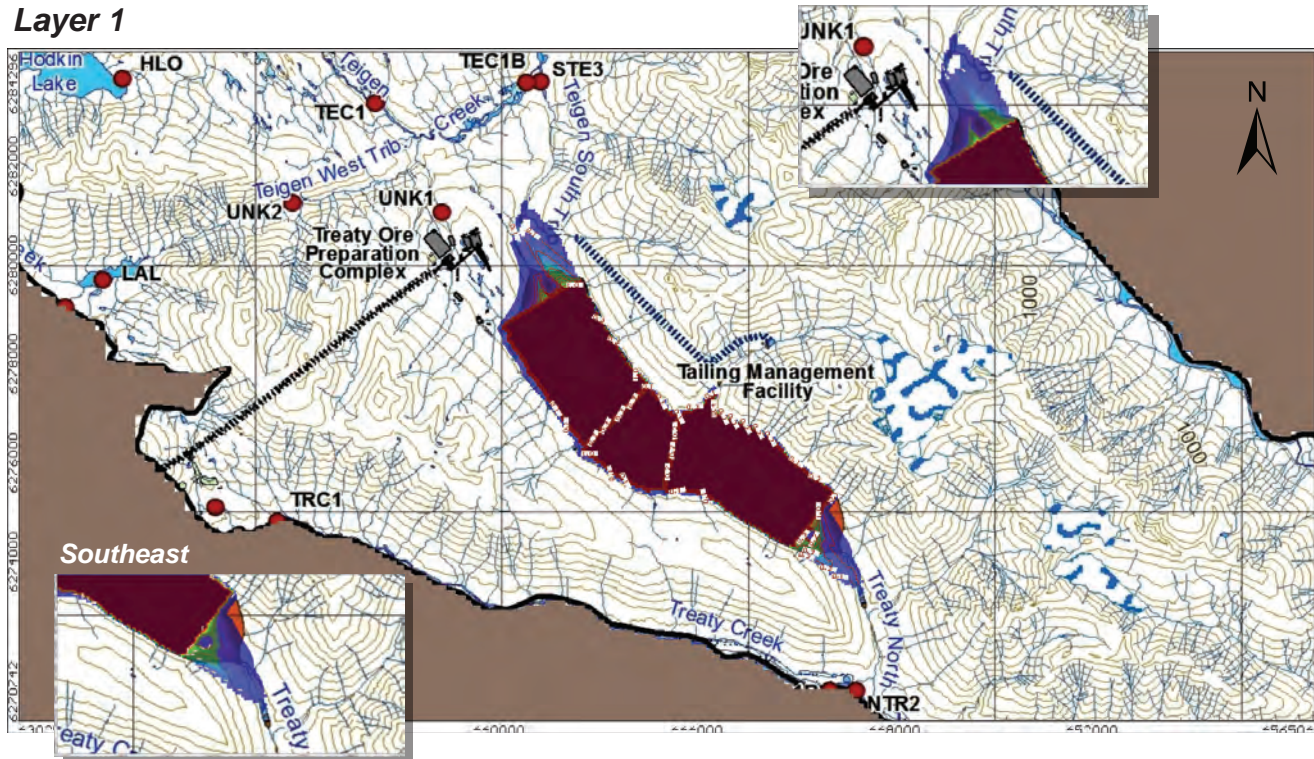


Legend

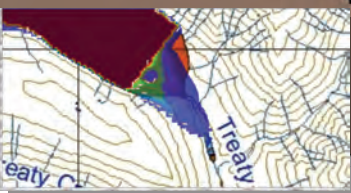
- Source Zone
- Concentration Isoleth
- STE3 Surface Water Quality Monitoring Station
- Plant Site
- Tailing Dam
- Tailing Pond
- TMF North Cell
- CIL Cell
- Seepage Collection Dam and Pond
- Conveyor Tunnel
- Diversion Tunnel
- Glacier
- Creek/River/Lake
- Wetland
- Inactive Cells



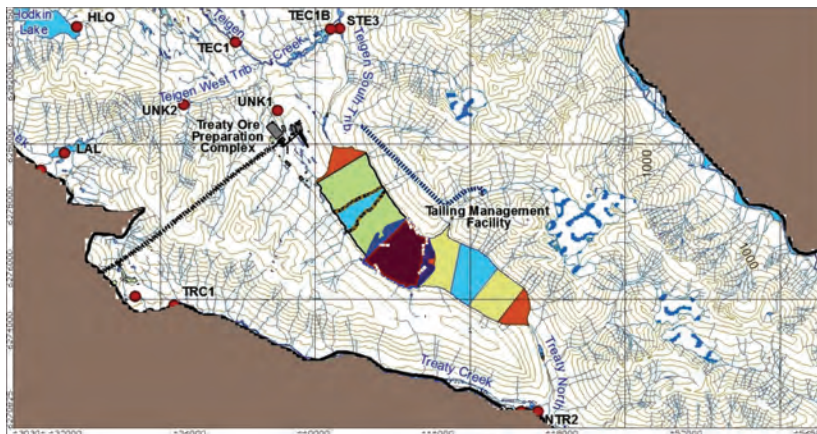
Layer 1



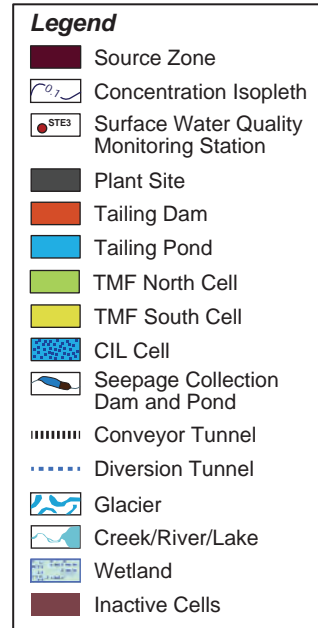
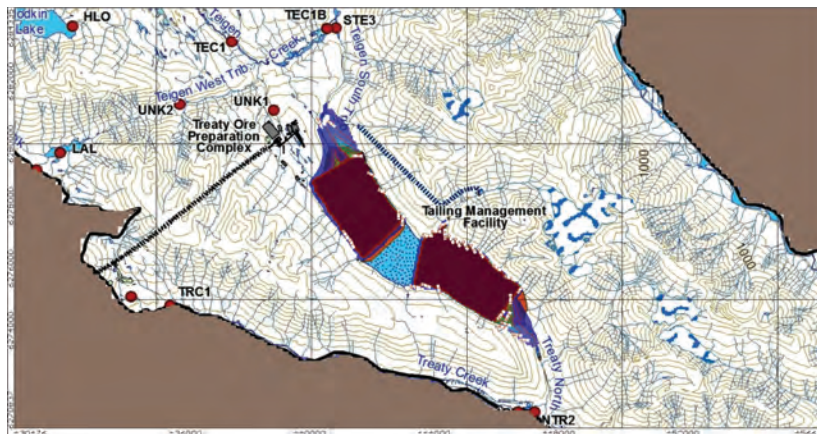
Southeast



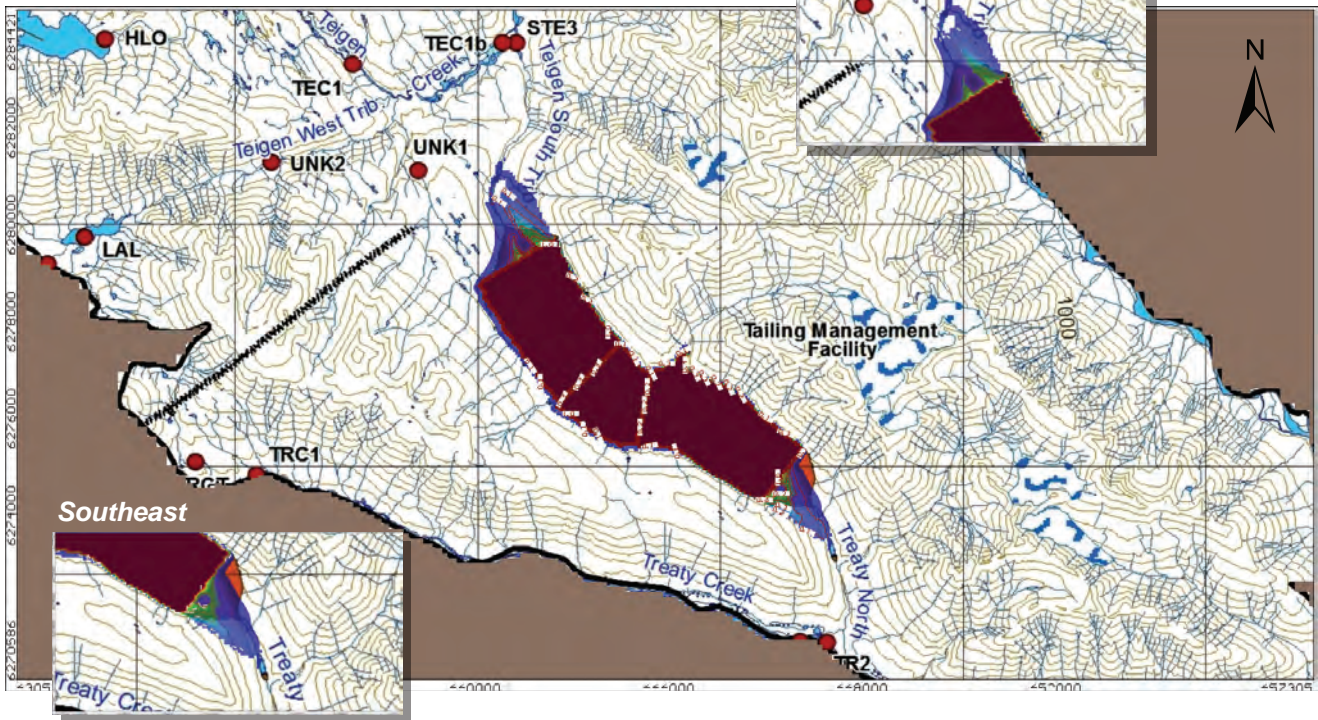
CIL Cell



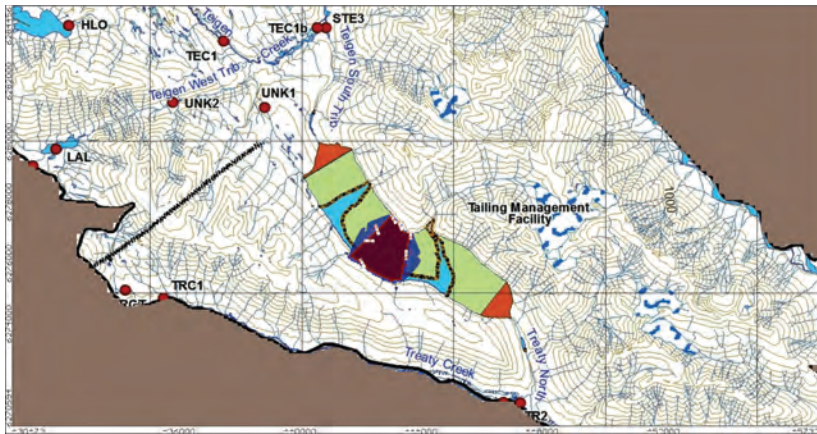
Flotation Cell



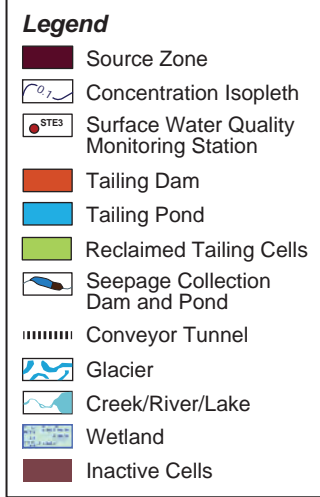
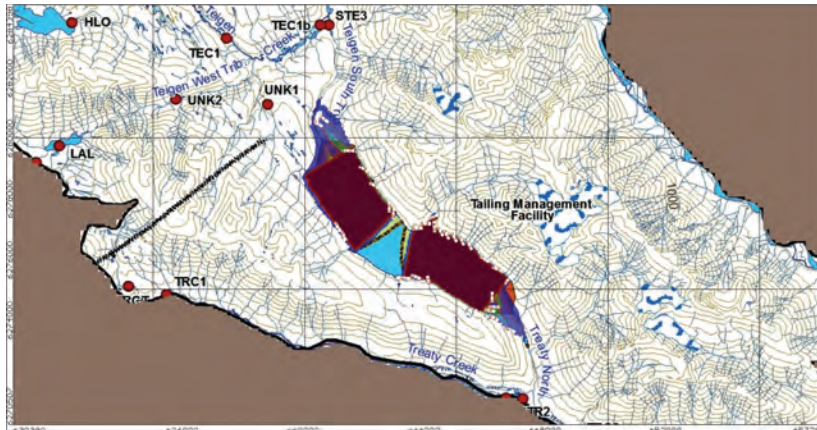
Layer 1



CIL Cell



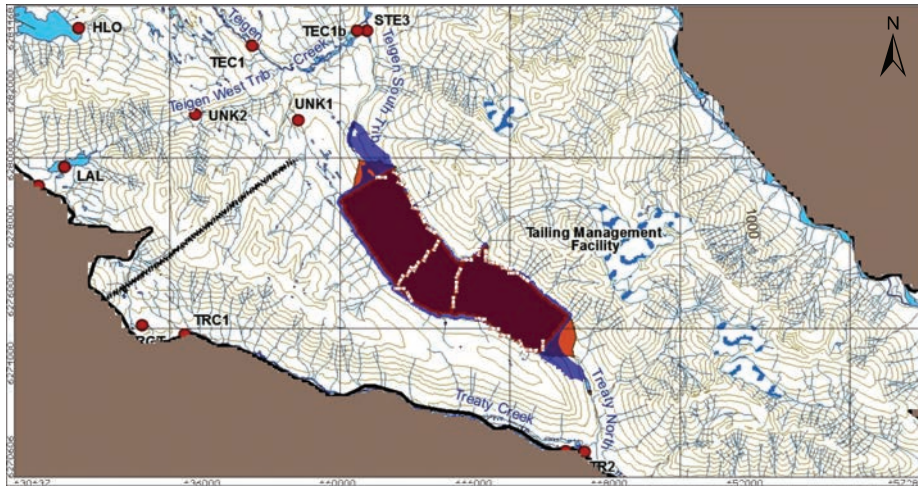
Flotation Cell



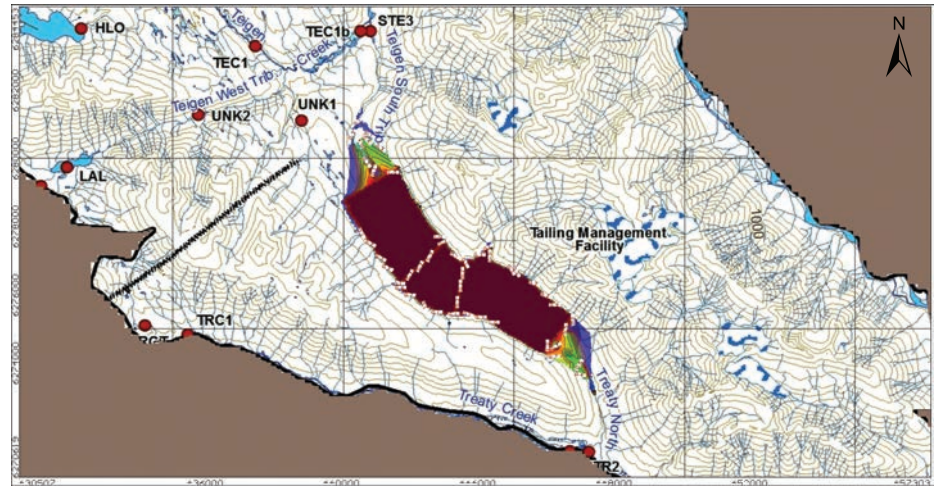
Predicted Plumes Emanating from the Tailing Management Facility 200 Years after End of Operation

Figure 12.7-14

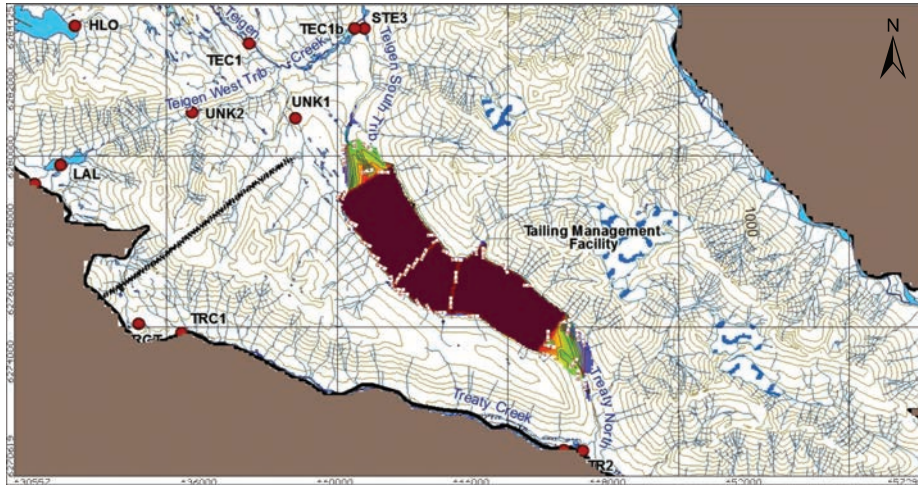
a) Wet Year



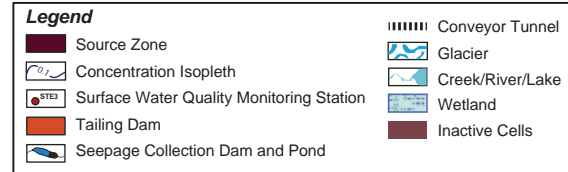
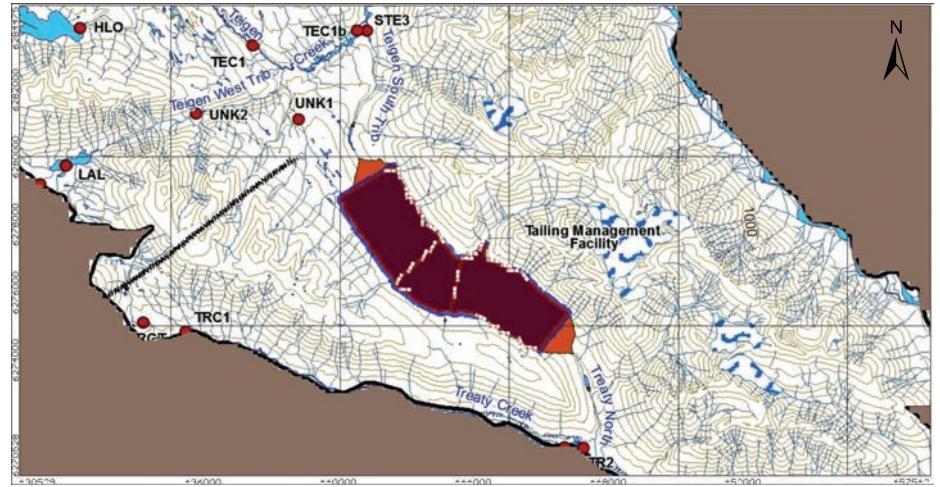
b) Dry Year



c) Upper Case



d) Lower Case



The plume emanating from the North Cell travels down-gradient to the north, down the South Teigen Valley. The concentrations of the plume reduce rapidly down-gradient. The plume is predicted to attain a steady-state 40 years after the North Cell is in full capacity at end of Stage 1 Year with the assumed constant head and source (highly conservative). Attainment of a steady state was determined by observing breakthrough curves at the monitoring wells (Figure 12.7-10), and by comparing plume size and concentration distributions at progressive time steps. Two scenarios were considered in the determination of arrival at steady-state in the PTMA: operation and early closure (operations terminated after Year 25), and operation and post-closure (operations terminated after Year 51.5, as planned).

At steady-state, concentrations representing 4% of the North Cell flotation tailing source are predicted to extend beyond the North Cell seepage collection dam. Plume boundaries (concentration 0.1% of source) are predicted to extend as far as 50 m beyond the North Cell seepage collection dam.

The upper-case scenario resulted in the most extensive plumes among the sensitivity (worst-case) scenarios. The upper-case scenario results indicated that concentrations as high as 4% would extend beyond the seepage collection dam along the South Teigen Tributary Valley. Steady-state plume concentrations (200 years post-closure, which is 160 years after attainment of steady-state) and extents around the TMF are shown in Figure 12.7-15 for the sensitivity (worst-case) scenarios. Predicted effects on surface water quality arising from the plume reporting to the South Teigen Tributary are discussed in Chapter 14 (Surface Water Quality). The upper-case model does not predict concentrations greater than 0.1% of South Cell flotation tailing source extending beyond the southeast seepage collection dam at any time.

The additional sensitivity simulations of the post-closure model, but with one order of magnitude higher dispersivities, one order of magnitude lower effective porosities of the bedrock units, or with one order of magnitude higher permeability of the tailings, verify that the seepage from the TMF will be captured in the north, saddle, and southeast seepage recovery areas. The simulation of the post-closure model, but using the general head boundaries (instead of the constant head boundaries) to represent the tailing cells, together with the higher tailing K values, also verify that the seepage from the TMF is captured in the north, saddle, and southeast recovery areas.

Overall, the results demonstrate that the seepage from the TMF will have limited effect on the groundwater quality downstream beyond the seepage collection dams, and is unlikely to be a concern to the groundwater quality in the South Teigen Tributary and the North Treaty Tributary catchments outside the TMF footprint.

12.7.2 Releases of Controlled Substances

Throughout the Project life, from construction to post-closure, there will be facilities on site storing and using industrial fluids and producing wastes. Whenever these substances are being stored, handled, or used there is a possibility of accidental release. If these substances reach the subsurface they may affect groundwater quality.

Implementation of a number of EMPs will reduce the frequency of release and will set out a framework for response to a release. Effects of spills will be highly localized with these plans in place, and will involve remedial clean-up actions immediately, if necessary.

12.7.2.1 Mitigation for Releases of Controlled Substances

Spills or leaks of industrial fluids are directly addressed in the EMPs that will be implemented and enforced by site personnel. Applicable EMPs include:

- the Dangerous Goods and Hazardous Materials Management Plan (Section 26.7);
- the Spill Prevention and Emergency Response Plan (Section 26.10); and
- the Domestic and Industrial Waste Management Plan (Section 26.6).

All facilities will be designed with appropriate containment structures for spills and leaks as well as collection and disposal systems. Personnel will be trained in appropriate materials handling methods, and standard operating procedures will be developed to ensure their consistent application. When releases do occur, personnel will follow established spill response protocol.

12.7.2.2 Potential for Residual Effects

With appropriate substance management and spill response protocol in place and enforced, the frequency and severity of spills and leaks are expected to be very low. Undertaking remedial action in the event of an unmanaged spill or leak will minimize impact on groundwater quality. Therefore, no residual effect on groundwater quality is expected due to releases of controlled substances.

12.8 Significance of Residual Effects for Groundwater Quality

12.8.1 Residual Effect Descriptors for Groundwater Quality

Residual effect descriptors (also referred to as significance determination criteria) for groundwater quality are focused on characterization of plumes emanating from sources of contamination. They are described herein and are summarized in Table 12.8-1.

Magnitude – The magnitude of an effect indicates how much the contact water being discharged into the groundwater environment differs from the natural groundwater quality, and whether it meets guidelines. BC water quality guidelines for the protection of freshwater aquatic life and drinking water (BC MOE 2010) were used. The groundwater modelling did not simulate transport of the numerous individual constituents that determine groundwater quality. Concentrations of constituents in plumes were estimated with reference to concentrations in the sources. Surface water quality modelling enabled forecasting of concentrations of individual constituents in the sources (Chapter 14). Ninety-fifth percentile concentrations predicted over the 100-year expected case surface water quality simulations were used.

Geographic Extent – Geographic extent may vary from the Project footprint (local) to inter-provincial (beyond regional). The local scale is also applied in the event that a plume is contained entirely within a controlled environment. A catchment-basin approach was used, whereby landscape extents exceed mine disturbance footprints but do not extend beyond the source catchment basin, into the parent catchment basin. A regional effect extends into the parent catchment basin, and may extend across the RSA. Plume extents are delineated by a cut-off of 0.1% of source concentration.

Duration – The duration criterion has been established with levels that vary from short term (less than five years) to longer than the expected mine life (greater than 50 years, referred to as far future).

Frequency – The frequency criterion describes the nature of contaminant loading into the subsurface, whether it be instantaneous pulse-loading (specified as “once,” “sporadic,” or “regular”) or continuous.

Reversibility – Links the feasibility (cost burden, availability of adequate technology, and time frame) of groundwater remediation with the nature of the contamination. This is intimately linked with the size of the plume, and the feasibility of eliminating residual effects completely. Irreversible contamination is that which cannot feasibly be remediated.

Context – For the groundwater effects assessments, the context criterion has been used to account for the social and ecological value of the groundwater being affected. If the affected water is not adequate to sustain aquatic ecosystems, and is not potable, the context is low because its social and ecological value is low. If the affected water is ideal for sustenance of aquatic life and human consumption, the context is moderate or high. The high level is reserved for circumstances where the affected water is regionally unique in its resource potential. Suitability for sustenance of aquatic life and human consumption has been determined with reference to water quality guidelines for the protection of freshwater aquatic life and raw drinking water (BC MOE 2010).

Probability – Probability describes the likelihood of an effect occurring, where a high probability indicates that there is a high likelihood of occurrence. A qualitative approach has been used for the groundwater quality effects assessment.

Confidence – The confidence criterion addresses the level of certainty associated with the determination of the magnitude, extent, and duration of impacts on groundwater quality. Low confidence indicates that there is considerable uncertainty. The confidence determination is made with reference to the sensitivity (worst-case) scenarios in comparison with the base-case (expected case) scenario, as well as baseline model calibration quality. Where a sensitivity (worst-case) simulation prediction diverges from a base-case prediction, uncertainty is implied in the predictions. Confidence is regarded as high where there is strong alignment between base-case and sensitivity (worst-case) predictions, and where a strong fit has been demonstrated between simulated baseline conditions and field measurements.

12.8.2 Residual Effects Assessment for Groundwater Quality

Residual effects on groundwater quality arising from seepage of contact water have been predicted, emanating from the following Project components:

- Mitchell and McTagg RSFs;
- WSF water storage pond;
- Iron Cap Block Cave Mine;
- TMF North, Centre, and South cells.

Table 12.8-1. Definitions of Significance Criteria for Groundwater Quality Residual Effects

Timing <i>What phase of the Project is the effect associated with?</i>	Magnitude <i>(negligible, low, medium, high)</i>	Geographic Extent <i>(local, landscape, regional, beyond regional)</i>	Duration <i>(short-term, medium-term, long-term, far future)</i>	Frequency <i>(once, sporadic, regular, continuous)</i>	Reversibility <i>(reversible short-term, reversible long-term, or irreversible)</i>	Context <i>(ecological resilience and/or unique attributes) (low, neutral, high)</i>	Probability <i>(low, medium, high)</i>	Confidence <i>(low, medium, high)</i>	Significance <i>(Not Significant: minor, moderate; Significant: major)</i>	Follow-up Monitoring <i>(Not required, required)</i>
Construction	Negligible. There is no detectable change from baseline conditions.	Local. The effect is limited to the Project footprint and stays within a controlled environment.	Short term. The effect lasts up to five years.	Once. The effect occurs once during any phase of the Project.	Reversible short-term. Groundwater quality can be remediated to baseline conditions within a few years.	Low. Baseline groundwater quality in the affected area is not suitable for sustenance of aquatic life or human consumption. Affected water is not predicted to reach surface water receptors.	Low. An effect is unlikely but could occur.	Low (< 50% confidence). High degree of uncertainty in predictive modelling, as reflected in the sensitivity analysis. Worst-case simulations produce two or more grade increases for significance determination criteria, as compared to the base-case simulation. High level of uncertainty in feasibility of key mitigation design components that have been incorporated into the predictive modelling.	Not Significant (minor). Residual effects have no or low magnitude, local geographical extent, short or medium-term duration, and occur intermittently, if at all. There is a high level of confidence in the conclusions. The effects on the VC (at a population or species level) are indistinguishable from background conditions (i.e., occur within the range of natural variation as influenced by physical, chemical, and biological processes). Land-use management objectives will be met. Follow-up monitoring is optional.	Not required
Operation	Low. Groundwater quality is expected to differ from baseline conditions, but is within the range of natural variation. Guideline exceedances are possible where they fall within the range of natural variability.	Landscape. The effect extends beyond the Project footprint, but does not extend beyond the immediate drainage basin of the source.	Medium term. The effect lasts up to 25 years.	Sporadic. The effect occurs at sporadic or intermittent intervals during any phase of the Project.	Reversible long-term. Groundwater quality can be remediated to baseline conditions after many years.	Neutral. Baseline groundwater quality is acceptable for sustenance of aquatic life and/or human consumption. However, it is not unique in its resource potential.	Medium. An effect is likely but may not occur.	Medium. (50 – 80% confidence): Moderate degree of uncertainty in predictive modelling, as reflected quantitatively in the sensitivity analysis. Worst-case simulations produce up to one grade increase for a significance determination criterion, as compared to the base-case simulation. Some uncertainty may exist in the feasibility of mitigation design components that have been incorporated into the predictive modelling. For example, they may have never been used before at this scale, or there may be moderate uncertainty in associated calculations and models.	Not Significant (moderate). Residual effects have medium magnitude, local, landscape or regional geographic extent, are short-term to chronic (i.e., may persist into the far future), and occur at all frequencies. Residual effects on VCs are distinguishable at the population, community, and/or ecosystem level. Ability of meeting land use management objectives may be impaired. Confidence in the conclusions is medium or low. The probability of the effect occurring is low or medium. Follow-up monitoring of these effects may be required.	Required
Closure	Medium. Groundwater quality is expected to differ from baseline conditions and likely approaches the limits of natural variation. Most constituents are expected to be below or equal to BC MOE guidelines where this is the case for baseline conditions.	Regional. The effect extends into a downstream parent drainage basin. The effect may extend across the regional study area.	Long term. The effect lasts up to 50 years.	Regular. The effect occurs on a regular basis during any phase of the Project.	Irreversible. Groundwater quality cannot feasibly be remediated to baseline conditions.	High. Baseline groundwater quality is ideal for human consumption and/or sustenance of aquatic life. It is regionally unique in its resource potential.	High. An effect is highly likely to occur.	High. There is greater than 80% confidence in predicted magnitude, extent and duration of effects. There is little discrepancy between worst-case and base-case predictions. Mitigation design components have been used previously at similar scales, and associated calculations are robust.	Significant (Major). Residual effects have high magnitude, regional or beyond regional geographic extent, are chronic (i.e., persist into the far future), and occur at all frequencies. Residual effects on VCs are consequential (i.e., structural and functional changes in populations, communities and ecosystems are predicted). Ability to meet land use management objectives is impaired. Probability of the effect occurring is medium or high. Confidence in the conclusions can be high, medium, or low. Follow-up monitoring is required.	

(continued)

Table 12.8-1. Definitions of Significance Criteria for Groundwater Quality Residual Effects (completed)

Timing <i>What phase of the Project is the effect associated with?</i>	Magnitude <i>(negligible, low, medium, high)</i>	Geographic Extent <i>(local, landscape, regional, beyond regional)</i>	Duration <i>(short-term, medium-term, long-term, far future)</i>	Frequency <i>(once, sporadic, regular, continuous)</i>	Reversibility <i>(reversible short-term, reversible long-term, or irreversible)</i>	Context <i>(ecological resilience and/or unique attributes) (low, neutral, high)</i>	Probability <i>(low, medium, high)</i>	Confidence <i>(low, medium, high)</i>	Significance <i>(Not Significant: minor, moderate; Significant: major)</i>	Follow-up Monitoring <i>(Not required, required)</i>
Post-closure	High. Groundwater quality is expected to differ significantly from baseline conditions and exceed the limit of natural variation. A number of constituents are expected to exceed BC MOE guidelines as a result of the effect.	Beyond Regional. The effect extends beyond the regional study area. Effect may cross provincial or state boundaries.	Far future. The effect lasts more than 50 years.	Continuous. An effect occurs constantly during any phase of the Project.						

Table 12.8-2 summarizes the residual effects assessment for groundwater quality. Significance was determined with direct reference to the groundwater modelling results. Important modelling results for residual effects characterization are presented in Section 12.7.1. Modelling results are presented in full in the groundwater modelling report ([Appendix 11-E](#)).

Seepage of contact water is continuous from the onset of activity at a particular Project area. Thus, the frequency of loading is regarded as continuous for all residual effects. The probability of interaction between contact water and the natural groundwater environment is regarded as high for all Project areas where seepage into the environment has been identified in the simulations. There is no evidence to suggest that infiltration of contact water will not occur. All other significance determination criteria vary between Project components, and are discussed separately for plumes emanating from each component.

No residual effects have been predicted in association with contact water emanating from the Mitchell Pit, Mitchell Block Cave Mine, Sulphurets Pit, or Kerr Pit. No plumes have been predicted to develop sourced in these mines by base-case modelling. Sensitivity (worst-case) scenarios indicate that uncertainty in the characterization of hydraulic conductivity could result in discharge of contact water from the Kerr Pit and Sulphurets Pit RSF, as indicated by predicted flow paths. No plume is expected to emanate from the Kerr Pit and to daylight in the downstream Sulphurets Lake and Creek. The possibility of a plume emanating from the Sulphurets Pit RSF has been addressed by inclusion of a monitoring well sited along flow paths that have been simulated to leave the pit (refer to the Groundwater Monitoring Plan, Section 26.15).

12.8.2.1 Seepage of Contact Water from the Mitchell and McTagg Rock Storage Facilities

Magnitude – Concentrations of contact water in the subsurface are predicted to be as high as 100%, immediately below the RSF footprints. Predicted RSF contact water quality indicates that most constituents would have concentration elevated far above natural baseline variability and guidelines (Table 12.8-3). Concentrations of aluminum, copper, iron, and cadmium are forecast to exceed guidelines for freshwater aquatic life by 500-fold or more. Therefore, the magnitude is regarded as high.

Duration – Seepage of contact water will commence at the beginning of the operation phase and will be sustained through to the end of the operation phase as waste rock continues to be placed in the RSFs. Water quality draining from the RSFs will remain of poor quality for the post-closure phase. Thus, the duration of the residual effect will be greater than 50 years and is regarded as far-future.

Extents – The plume does not extend beyond the RSF footprints, as defined in the expected extents of placed waste rock and the WSF reservoir immediately down-gradient. Therefore, extents are regarded as local.

Reversibility – Remediation to baseline conditions is not expected to be feasible due to the size of the plume and continuous loading. Therefore, the reversibility is regarded as irreversible.

Context – Baseline shallow groundwater quality in the Mitchell Valley is poor and unsuitable for human consumption and the sustenance of aquatic life. Measurements of certain trace metals concentrations have approached or exceeded guidelines, including aluminum, arsenic, chromium, and iron. Acidic pH values (as low as 4.5) have been documented. The context is therefore regarded as low.

Confidence – Sensitivity (worst-case) scenarios and the base-case scenario all indicated containment of the plume emanating from the RSF within the Mitchell Valley upstream of the WSD. Predictions were made with the calibrated Mine Site LSA model, which showed a strong fit to measured groundwater levels in a large number of wells/piezometers, and to measured creek low flows. Therefore the confidence is regarded as high.

Significance – With consideration for the high magnitude but local extent, the residual effect on groundwater quality sourced at the RSF has been determined to be **not significant (moderate)**.

12.8.2.2 Iron Cap Block Cave Mine

Magnitude – Concentrations of contact water in the subsurface are as high as 100%, immediately down-gradient of the mine footprint. Predicted closure and post-closure contact water quality in the Iron Cap Block Cave Mine includes a number of constituents that exceed the range of baseline variability, as well as a number of guideline exceedances (Table 12.8-3). Concentrations of aluminum, cadmium, copper, and iron are forecast to exceed guidelines for the protection of freshwater aquatic life by more than 100-fold. Therefore, the magnitude is regarded as high.

Duration – Seepage of contact water will commence at the end of operation and will continue indefinitely. Thus, the duration of the residual effect will be greater than 50 years and is regarded as far-future.

Extents – The plume extends down-gradient of the mine footprint and attains a steady state along a flow pathway that reports to the Mitchell Pit. It remains within the controlled catchment in the Mitchell Valley up-gradient of the WSF. Therefore, the extents are regarded as local.

Reversibility – Remediation to baseline conditions is not expected to be feasible due to the continuous loading. Therefore, the reversibility is regarded as irreversible.

Context – Baseline shallow groundwater quality in the Mitchell Valley is poor and unsuitable for human consumption and the sustenance of aquatic life. Measurements of certain trace metals concentrations have approached or exceeded guidelines, including aluminum, arsenic, chromium, and iron. Acidic pH values (as low as 4.5) have been documented in groundwater in the upper valley. The context is therefore regarded as low.

Confidence – Sensitivity (worst-case) and base-case scenarios all indicated containment of the plume emanating from the Iron Cap Block Cave Mine within the Mitchell Valley upstream of the Mitchell Pit. The predictions were made with the calibrated Mine Site LSA model, which showed a strong fit to measured groundwater levels in a large amount of wells/piezometers, and to creek low-flow measurements. Therefore the confidence is regarded as high.

Table 12.8-2. Summary of Residual Effects on Groundwater Quality

Description of Residual Effect	Project Component(s)	Timing of Effect	Magnitude	Extent	Duration	Frequency	Reversibility	Context	Likelihood of Effects		Significance Determination	Follow-up Monitoring
									Probability	Confidence Level		
Degradation of groundwater quality due to seepage of contact water	Mitchell and McTagg Rock Storage Facilities	Construction	High	Local	Far future	Continuous	Irreversible	Low	High	High	Not Significant (Moderate)	Not Required
	Iron Cap Block Cave Mine	Closure	High	Local	Far future	Continuous	Irreversible	Low	High	High	Not Significant (Moderate)	Not Required
	Water Storage Facility	Construction	High	Local	Far future	Continuous	Irreversible	Low	High	High	Not Significant (Moderate)	Required
	Tailing Management Facility North Cell	Operation	High	Landscape	Far future	Continuous	Irreversible	Neutral	High	High	Not Significant (Moderate)	Required
	Tailing Management Facility Centre and South Cells	Operation	High	Local	Far future	Continuous	Irreversible	Neutral	High	High	Not Significant (Moderate)	Required
Overall Residual Effect	All	Post-closure	High	Landscape	Far future	Continuous	Irreversible	Neutral	High	High	Not Significant (Moderate)	Required

Table 12.8-3. Estimated Constituent Concentrations in Sources of Residual Effects on Groundwater Quality in the Mine Site

Parameter/ Constituent	Units	Guidelines (BC MOE 2010)		Baseline 95% Max. ^C	Sources					
		Freshwater Aquatic Life	Drinking Water		Iron Cap Block-Cave		Mitchell & McTagg RSFs		Water Storage Facility	
					Mean	95th Percentile	Mean	95th Percentile	Mean	95th Percentile
Hardness	mg/L as CaCO ₃		ng	433	211	243	717	1228	376	646
Nutrients and Major Anions										
Ammonia	mg/L as N	R	ng	0.62	0.0021	0.0077	2.9	6.5	0.35	1.1
Fluoride (F)	mg/L	Q	1.5	0.96	20	48	34	68	13	24
Nitrate	mg/L as N	3	10	0.028	0.010	0.031	23	53	3.7	10
Nitrite	mg/L as N	0.02 ^S	1	0.0044	0.00049	0.00088	0.00050	0.0013	0.0016	0.0022
Phosphate (PO ₄)	mg/L as P	ng	ng	0.011	0.046	0.087	0.31	1.1	0.36	0.56
Sulphate (SO ₄)	mg/L	100	500 [~]	311	506	1112	2814	4125	1042	1541
Cyanides										
CN (WAD) ^A	mg/L	0.005	ng		0.00012	0.00031	0.0E+00	0.0E+00	5.2E-05	0.00010
CN (Total)	mg/L	ng	ng	0.0011		N/A				
Dissolved Metals										
Aluminum (Al)	mg/L	M, V	0.2	1.1	16	38	74	112	25	39
Antimony (Sb)	mg/L	0.02 ^E	ng	0.0074	0.019	0.045	0.18	0.40	0.074	0.15
Arsenic (As)	mg/L	0.005	0.025 ^D	0.022	0.034	0.081	0.39	0.61	0.13	0.21
Barium (Ba)	mg/L	5 ^E	ng	0.067	0.15	0.32	3.8	8.0	1.4	2.5
Beryllium (Be)	mg/L	0.0053 ^{E,T}	ng	0.00031	0.014	0.035	0.056	0.12	0.026	0.056
Boron (B)	mg/L	1.2	5	0.85	0.098	0.23	0.45	0.91	0.18	0.35
Cadmium (Cd)	mg/L	E, F	ng	0.0014	0.036	0.050	0.095	0.14	0.035	0.052
Calcium (Ca)	mg/L	ng	ng	121	78	88	146	204	81	112
Chromium (Cr)	mg/L	0.001 ^{E, G}	ng	0.0023	0.0097	0.023	0.079	0.17	0.035	0.070
Cobalt (Co)	mg/L	0.004 ^T	ng	0.0091	0.087	0.12	0.22	0.32	0.10	0.14
Copper (Cu)	mg/L	H, T	0.5	0.79	12	16	29	44	15	22
Iron (Fe)	mg/L	0.35 ^V	ng	7.8	68	164	882	1444	281	451
Lead (Pb)	mg/L	J, T	0.05	0.0059	0.094	0.14	0.23	0.34	0.098	0.13
Lithium (Li)	mg/L	0.014 ^{E,T}	ng	0.10	0.0053	0.011	0.27	0.54	0.099	0.17
Magnesium (Mg)	mg/L	ng	ng	34	3.8	5.7	86	175	42	89
Manganese (Mn)	mg/L	L, T	ng	1.1	1.8	4.2	13	19	5.4	7.0
Mercury (Hg)	mg/L	2.0E-5, T	0.001	2.5E-06 ^B	2.0E-05	4.2E-05	0.00047	0.00091	0.00021	0.00041
Molybdenum (Mo)	mg/L	1, T	0.25	0.015	0.011	0.018	0.41	0.63	0.12	0.19
Nickel (Ni)	mg/L	0.025-0.150 ^{E, N}	ng	0.011	0.020	0.027	0.050	0.073	0.030	0.044
Selenium (Se)	mg/L	0.002	0.01	0.0054	0.026	0.052	0.097	0.14	0.035	0.053
Silver (Ag)	mg/L	0.0001-0.003 ^P	ng	0.00013	0.00043	0.0010	0.0024	0.0047	0.0011	0.0025
Thallium (Tl)	mg/L	0.0003 ^E	ng	3.3E-05	0.00075	0.0018	0.0075	0.016	0.0028	0.0051
Uranium (U)	mg/L	0.3 ^E	ng	0.0028	0.14	0.33	0.27	0.57	0.10	0.19
Vanadium (V)	mg/L	0.006 ^T	ng	0.0021	0.0025	0.0055	0.14	0.30	0.048	0.087
Zinc (Zn)	mg/L	K, T	5	0.088	2.4	3.3	6.1	8.9	2.7	4.1

Notes:

Shaded = exceeds baseline range of variation, as indicated by 95% confidence interval

Bold/Italic = exceeds Fresh Water Aquatic Life Guideline (BC MOE 2010)

Outlined = exceeds drinking water quality guideline (BC MOE 2010)

ng = no established guideline

N/A = Plume concentration not available, not included in TMF surface water quality model.

^A Only total CN⁻ concentrations analysed for baseline sampling, and baseline concentrations are very low. Total baseline CN⁻ concentrations assumed to be entirely WAD.

^B All measured concentrations below detection limit, half detection limit used as estimate of background concentration.

^C 95% confidence interval determined for all samples collected at all wells in the Mine Site

^D Interim guideline

^E Working water quality guideline, not formally endorsed

^F Cd guideline hardness-dependent: [Cd] = 0.001 * 10^{0.86[log(hardness)] - 3.2} mg/L

^G Cr guideline = 0.0010 mg/L (Cr VI), or 0.0089 (Cr III) which is interim. Most stringent guideline applied

^H Cu guideline hardness-dependent. [Cu] = 2 ug/L for Hardness < 50 mg/L, otherwise [Cu] = 0.04*Hardness in ug/L

^J Pb guideline hardness-dependent. For Hardness<8 mg/L [Pb] = 3 ug/L, otherwise use chronic guideline: [Pb] = 3.31+exp(1.273*ln(Hardness)-4.704) in ug/L

^K Zn guideline hardness-dependent: [Zn] = 7.5 ug/L for Hardness < 90 mg/L, else [Zn] = 7.5+0.75*(Hardness-90) in ug/L

^L Mn guideline hardness-dependent: [Mn] = 0.0044*Hardness+0.54 in mg/L

^M Al guideline pH-dependent: 0.1 mg/L for pH>6.5. For pH<6.5 [Al]=exp(1.209-2.426*pH+0.286*pH²)

^N Ni guideline hardness-dependent: [Ni] = 0.025 mg/L at hardness 0-60 mg/L as CaCO₃, 0.065mg/L at 60 - 120 mg/L, 0.110 mg/L at 120 - 180 mg/L, 0.150 mg/L at > 180 mg/L

^P Ag guideline hardness-dependent: [Ag] = 0.003 mg/L for >100mg/L, 0.0001mg/L for ≤ 100mg/L

^Q F⁻ guideline hardness-dependent: [F⁻] = 0.1*(-51.73+92.57*log(Hardness)) in mg/L

^R NH₃ guideline temperature- and pH-dependent, as tabulated in BC MOE (2012). Average baseline groundwater temperature assumed (5.0 °C)

^S Nitrite guideline higher for chloride concentrations greater than 2 mg/L

^T Chronic exposure guideline. Acute guidelines listed only were chronic guidelines have not been established.

^U Aesthetic guideline only

^V Guidelines applies specifically to dissolved component. Unless specified otherwise, guidelines for metals apply to total concentrations.

Significance – Given containment of the plume emanating from the Mitchell RSF in the Mitchell Valley upstream of the WSF, the residual effect has been determined **not significant (moderate)**.

12.8.2.3 Water Storage Facility

Magnitude – Concentrations of contact water in the subsurface are as high as 100%, immediately below the facility footprint. Predicted water quality in the WSF reservoir includes concentrations of numerous constituents above the range of natural baseline variability, as well as a number of guideline exceedances for metals, anions, and nutrients (Table 12.8-3). Concentrations of iron, copper, cadmium, and aluminum are forecast to have concentrations that exceed guidelines for freshwater aquatic life by more than 100-fold. The magnitude is therefore regarded as high.

Duration – Seepage of contact water from the WSF reservoir will commence during the construction phase and will be sustained indefinitely through post-closure. Thus, the duration of the residual effect will be greater than 50 years and is regarded as far-future.

Extents – The plume emanating from the WSF is predicted to be captured by the seepage interception tunnels and seepage collection pond. Therefore, extents are regarded as local.

Reversibility – Remediation to baseline conditions is not expected to be feasible due to the continuous loading. Therefore, the reversibility is regarded as irreversible.

Context – Baseline shallow groundwater quality in the Mitchell Valley is poor and unsuitable for human consumption and the sustenance of aquatic life. Measurements of certain trace metals concentrations have approached or exceeded guidelines, including aluminum, arsenic, chromium, and iron. The context is therefore regarded as low.

Confidence – Predictions were made with the calibrated Mine Site LSA model, which showed a strong fit to measured groundwater levels in a large amount of wells/piezometers, and to creek low-flow measurements. Sensitivities (lower case, wet, and dry climates) and base-case scenarios indicated containment of seepage emanating from the WSF pond. The upper case (worst-case) scenario (with high permeability), however, resulted in a plume potentially extending beyond the influence of seepage controls in deep groundwater, and possibly approaching the Sulphurets Valley floor with low concentrations (less than 5% of the source) in deep groundwater, although no plume appears in shallow groundwater or daylights in the Sulphurets Creek. The carbonate rock band identified in the WSF area (and extending to the southeast) was modelled with a hydraulic conductivity on the scale of 10^{-3} m/s. Hydraulic conductivities on this scale are representative of preferential flow conduits, such as the dissolution-widened fractures observed on site. However, the locations and persistence of dissolution-enhanced features cannot be fully captured by field data collection, or by the modelling approach used. The seepage interception tunnels may not provide for a high probability of intercepting flow through conduits. Therefore, the confidence is regarded as medium.

Significance – With consideration for the high magnitude but local scale, and moderate confidence, the residual effect arising from seepage of contact water from the WSF is considered **not significant (moderate)**. A number of long-term groundwater monitoring wells are planned along the Mitchell and Sulphurets valleys down-gradient of the WSF, as described in the Groundwater Management Plan (Section 26.15).

12.8.2.4 Seepage of Contact Water from the Tailing Management Facility

Magnitude – Concentrations of tailing water in the subsurface, immediately below the TMF footprint, are as high as 100%. Concentrations of specific constituents forecasted within the TMF cells (as determined by Surface Water Quality Modelling, discussed in Chapter 14) are identified in Table 12.8-4. Predicted water quality in all TMF ponds includes concentrations of numerous constituents above the range of natural baseline variability, as well as a number of guideline exceedances for metals and nutrients. Concentrations of sulphate, selenium, and nitrate are forecast to exceed guidelines for freshwater aquatic life by 10-fold or more. Equivalent concentrations are expected in the subsurface, corresponding with a plume concentration of 100%. Magnitudes are thus regarded as high for all three cells. The plume emanating from the North Cell is predicted to extend beyond the North Cell seepage collection pond at concentrations as high as 4% of the source. This would result in concentrations of a number of constituents exceeding the range of natural variability in groundwater (Table 12.8-5). No guideline exceedances are predicted. The magnitude of effects beyond the TMF footprint at the landscape scale can therefore be regarded as moderate.

Duration – Seepage of contact water will commence at the beginning of the operation phase and will be sustained through the end of the operation phase as tailing continue to be discharged into the TMF. Water quality in the TMF will remain of degraded quality for some time past the end of operation. Thus, the duration of the residual effect will be greater than 50 years and is regarded as far-future.

Extents – The plume emanating from the North Cell is predicted to extend beyond the North Cell seepage collection dam at concentrations exceeding the 0.1% cut-off, and as high as 4% of source. This plume is not predicted to reach the down-gradient parent catchment basin. Therefore, extents are regarded as landscape for the North Cell. The magnitude of the effect beyond the North Cell seepage collection dam would be moderate because no guideline exceedances are predicted to arise from tailing water concentrations diluted to 4% (Table 12.8-5). Plumes emanating from the Centre and South cells are predicted to be captured entirely by the Saddle and southeast seepage recovery ponds, and extents are thus regarded as local.

Reversibility – Remediation to baseline conditions is not expected to be feasible due to the size of the plume and continuous loading. Therefore, the reversibility is regarded as irreversible.

Context – Baseline groundwater quality in the PTMA is suitable for human consumption and the sustenance of aquatic life. However, it is not regionally unique in this sense. The context is therefore regarded as neutral.

Table 12.8-4. Estimated Constituent Concentrations in Sources of Residual Effects on Groundwater Quality in the Processing and Tailing Management Area

Parameter/ Constituent	Units	Guidelines (BC MOE 2010)		Baseline 95% Max. ^C	Source					
		Freshwater Aquatic Life	Drinking Water		North Cell		South Cell		Centre (CIL) Cell	
					Mean	95th Percentile	Mean	95th Percentile	Mean	95th Percentile
Hardness	mg/L as CaCO ₃		ng	96	582	802	677	808	598	786
Nutrients and Major Anions										
Ammonia	mg/L as N	R	ng	0.43	1.8	2.9	1.6	2.3	13	32
Fluoride (F)	mg/L	Q	1.5	0.18	3.3	5.9	4.4	6.8	0.28	0.92
Nitrate	mg/L as N	3	10	0.012	28	50	36	56	1.6	6.5
Nitrite	mg/L as N	0.02 ^S	1	0.0047	0.11	0.17	0.0040	0.0049	0.026	0.062
Phosphate (PO ₄)	mg/L as P	ng	ng	0.018	0.093	0.14	0.15	0.18	0.78	1.1
Sulphate (SO ₄)	mg/L	100	500 ^U	50	855	1478	1141	1706	776	1437
Cyanides										
CN (WAD) ^A	mg/L	0.005	ng		0.020	0.034	0.036	0.047	0.23	0.40
CN (Total)	mg/L	ng	ng	0.00078						N/A
Dissolved Metals										
Aluminum (Al)	mg/L	M, V	0.2	0.023	0.29	0.49	0.36	0.54	0.023	0.071
Antimony (Sb)	mg/L	0.02 ^E	ng	0.0010	0.0019	0.0026	0.0027	0.0033	0.0082	0.014
Arsenic (As)	mg/L	0.005	0.025 ^D	0.0018	0.016	0.029	0.022	0.033	0.060	0.12
Barium (Ba)	mg/L	5 ^E	ng	0.064	0.15	0.26	0.20	0.30	0.026	0.060
Beryllium (Be)	mg/L	0.0053 ^{E,T}	ng	7.5E-05	0.00035	0.00049	0.00038	0.00051	0.00017	0.00029
Boron (B)	mg/L	1.2	5	0.020	0.098	0.17	0.13	0.19	0.018	0.041
Cadmium (Cd)	mg/L	E, F	ng	1.8E-05	2.9E-05	4.4E-05	3.8E-05	5.1E-05	6.6E-05	0.00012
Calcium (Ca)	mg/L	ng	ng	21	219	300	255	300	231	300
Chromium (Cr)	mg/L	0.001 ^{E, G}	ng	0.00026	0.0021	0.0035	0.0026	0.0040	0.00028	0.00067
Cobalt (Co)	mg/L	0.004 ^T	ng	9.9E-05	0.0015	0.0022	0.0022	0.0029	0.0058	0.010
Copper (Cu)	mg/L	H, T	0.5	0.00044	0.0034	0.0054	0.0056	0.0070	0.030	0.053
Iron (Fe)	mg/L	0.35 ^V	ng	0.036	0.032	0.042	0.023	0.030	0.012	0.020
Lead (Pb)	mg/L	J, T	0.05	8.7E-05	0.00040	0.00069	0.00051	0.00078	8.3E-05	0.00018
Lithium (Li)	mg/L	0.014 ^{E,T}	ng	0.080	0.012	0.019	0.015	0.021	0.0088	0.016
Magnesium (Mg)	mg/L	ng	ng	11	8.1	13	9.9	14	4.8	8.9
Manganese (Mn)	mg/L	L, T	ng	0.062	0.064	0.11	0.079	0.12	0.022	0.043
Mercury (Hg)	mg/L	2.0E-5, T	0.001	2.5E-06 ^B	9.7E-05	0.00017	0.00013	0.00019	8.6E-06	2.6E-05
Molybdenum (Mo)	mg/L	1, T	0.25	0.0075	0.092	0.16	0.13	0.19	0.100	0.18
Nickel (Ni)	mg/L	0.025-0.150 ^{E, N}	ng	0.00051	0.0024	0.0039	0.0030	0.0044	0.0019	0.0034
Selenium (Se)	mg/L	0.002	0.01	0.00044	0.021	0.035	0.028	0.041	0.026	0.047
Silver (Ag)	mg/L	0.0001-0.003 ^P	ng	2.5E-06 ^B	4.4E-05	7.4E-05	5.8E-05	8.5E-05	4.1E-05	7.5E-05
Thallium (Tl)	mg/L	0.0003 ^E	ng	2.5E-06 ^B	0.00013	0.00020	0.00015	0.00021	2.6E-05	5.0E-05
Uranium (U)	mg/L	0.3 ^E	ng	0.00011	0.00019	0.00034	0.00025	0.00039	2.3E-05	6.3E-05
Vanadium (V)	mg/L	0.006 ^T	ng	0.00050	0.0098	0.017	0.013	0.019	0.0018	0.0041
Zinc (Zn)	mg/L	K, T	5	0.0019	0.011	0.019	0.015	0.022	0.013	0.023

Notes:

Shaded = exceeds baseline range of variation, as indicated by 95% confidence interval

Bold/Italic = exceeds Fresh Water Aquatic Life Guideline (BC MOE 2010)

Outlined = exceeds drinking water quality guideline (BC MOE 2010)

ng = no established guideline

N/A = Plume concentration not available, not included in TMF surface water quality model.

^A Only total CN⁻ concentrations analysed for baseline sampling, and baseline concentrations are very low. Total baseline CN⁻ concentrations assumed to be entirely WAD.

^B All measured concentrations below detection limit, half detection limit used as estimate of background concentration.

^C 95% confidence interval determined for all samples collected at all wells in the PMTA

^D Interim guideline

^E Working water quality guideline, not formally endorsed

^F Cd guideline hardness-dependent: [Cd] = 0.001 * 10^{0.86[log(hardness)] - 3.2} mg/L

^G Cr guideline = 0.0010 mg/L (Cr VI), or 0.0089 (Cr III) which is interim. Most stringent guideline applied

^H Cu guideline hardness-dependent. [Cu] = 2 ug/L for Hardness < 50 mg/L, otherwise [Cu] = 0.04*Hardness in ug/L

^J Pb guideline hardness-dependent. For Hardness<8 mg/L [Pb] = 3 ug/L, otherwise use chronic guideline: [Pb] = 3.31+exp(1.273*ln(Hardness)-4.704) in ug/L

^K Zn guideline hardness-dependent: [Zn] = 7.5 ug/L for Hardness < 90 mg/L, else [Zn] = 7.5+0.75*(Hardness-90) in ug/L

^L Mn guideline hardness-dependent: [Mn] = 0.0044*Hardness+0.54 in mg/L

^M Al guideline pH-dependent: 0.1 mg/L for pH>6.5. For pH<6.5 [Al]=exp(1.209-2.426*pH+0.286*pH²)

^N Ni guideline hardness-dependent: [Ni] = 0.025 mg/L at hardness 0-60 mg/L as CaCO₃, 0.065mg/L at 60 - 120 mg/L, 0.110 mg/L at 120 - 180 mg/L, 0.150 mg/L at > 180 mg/L

^P Ag guideline hardness-dependent: [Ag] = 0.003 mg/L for >100mg/L, 0.0001mg/L for ≤ 100mg/L

^Q F⁻ guideline hardness-dependent: [F⁻] = 0.1*(-51.73+92.57*log(Hardness)) in mg/L

^R NH₃ guideline temperature- and pH-dependent, as tabulated in BC MOE (2012). Average baseline groundwater temperature assumed (5.0 °C)

^S Nitrite guideline higher for chloride concentrations greater than 2 mg/L

^T Chronic exposure guideline. Acute guidelines listed only were chronic guidelines have not been established.

^U Aesthetic guideline only

^V Guidelines applies specifically to dissolved component. Unless specified otherwise, guidelines for metals apply to total concentrations.

Table 12.8-5. Estimated Maximum Constituent Concentrations (below the Footprint and beyond the North Seepage Collection Dam) in the Plume Emanating from the Tailing Management Facility North Cell

Parameter	Units	Freshwater Aquatic Life	Drinking Water	Baseline Average	Baseline 95% Max. ^C	Estimated Constituent Concentrations for Given Plume Concentrations	
						4% (outside Footprint)	100% (Footprint)*
Hardness	mg/L as CaCO ₃		ng	78.2	96	107	802
Nutrients and Major Anions							
Ammonia	mg/L as N	R	ng	0.36	0.43	0.46	2.9
Fluoride (F)	mg/L	Q	1.5	0.147	0.18	0.38	5.9
Nitrate	mg/L as N	3	10	0.0065	0.012	2.0	50
Nitrite	mg/L as N	0.02 ^S	1	0.0022	0.0047	0.0089	0.17
Phosphate (PO ₄)	mg/L as P				0.018	0.0055	0.14
Sulphate (SO ₄)	mg/L	100	500 ^U	36.3	50	94	1478
Cyanides							
CN (WAD) ^A	mg/L	0.005	ng			0.0014	0.034
CN (Total)	mg/L	ng	ng	0.00064138	0.00078	0.00062	
Total Metals							
Aluminum (Al)	mg/L	M, W	0.2	0.015	0.023	0.034	0.49
Antimony (Sb)	mg/L	0.02 ^E	ng	0.00052	0.0010	0.00060	0.0026
Arsenic (As)	mg/L	0.005	0.025 ^D	0.0012	0.0018	0.0024	0.029
Barium (Ba)	mg/L	5 ^E	ng	0.052	0.064	0.061	0.26
Beryllium (Be)	mg/L	0.0053 ^{E,T}	ng	5.0E-05	7.5E-05	6.8E-05	0.00049
Boron (B)	mg/L	1.2	5	0.0159	0.020	0.022	0.17
Cadmium (Cd)	mg/L	E, F	ng	1.3E-05	1.8E-05	1.5E-05	4.4E-05
Calcium (Ca)	mg/L	ng	ng	18.0	21	29	300
Chromium (Cr)	mg/L	0.001 ^{E, G}	ng	0.00023	0.00026	0.00036	0.0035
Cobalt (Co)	mg/L	0.004 T	ng	0.000077	9.9E-05	0.00016	0.0022
Copper (Cu)	mg/L	H, T	0.5	0.00026	0.00044	0.00046	0.0054
Iron (Fe)	mg/L	0.35 ^W	ng	0.026	0.036	0.027	0.042
Lead (Pb)	mg/L	J, T	0.05	0.000047	8.7E-05	7.3E-05	0.00069
Lithium (Li)	mg/L	0.014 ^{E,T}	ng	0.055	0.080	0.053	0.019
Magnesium (Mg)	mg/L	ng	ng	8.1	11	8.2	13
Manganese (Mn)	mg/L	L, T	ng	0.044	0.062	0.046	0.11
Mercury (Hg)	mg/L	2.0E-5, T	0.001	2.5E-06	2.5E-06 ^B	9.2E-06	0.00017
Molybdenum (Mo)	mg/L	1, T	0.25	0.0058	0.0075	0.012	0.16
Nickel (Ni)	mg/L	0.025-0.150 ^{E, N}	ng	0.00037	0.00051	0.00051	0.0039
Selenium (Se)	mg/L	0.002	0.01	0.00022	0.00044	0.0016	0.035
Silver (Ag)	mg/L	0.0001-0.003 ^P	ng	2.5E-06	2.5E-06 ^B	5.4E-06	7.4E-05
Thallium (Tl)	mg/L	0.0003 ^E	ng	2.5E-06	2.5E-06 ^B	1.0E-05	0.00020
Uranium (U)	mg/L	0.3 ^E	ng	0.000076	0.00011	8.7E-05	0.00034
Vanadium (V)	mg/L	0.006 T	ng	0.00050	0.00050	0.0012	0.017
Zinc (Zn)	mg/L	K, T	5	0.0011	0.0019	0.0018	0.019

Notes:

Shaded = exceeds baseline range of variation, as indicated by 95% confidence interval

Bold/Italic = exceeds Fresh Water Aquatic Life Guideline (BC MOE 2010)

Outlined = exceeds drinking water quality guideline (BC MOE 2010)

ng = no established guideline

N/A = Plume concentration not available, not included in TMF surface water quality model.

* Source concentration taken to be 95th percentile concentration for expected case surface water model results over the mine life from beginning to end of operations.

^A Only total CN⁻ concentrations analysed for baseline sampling, and baseline concentrations are very low. Total baseline CN⁻ concentrations assumed to be entirely WAD.

^B Measured concentration below detection limit. Average is calculated using half of the detection limit where it exceeded measured concentrations.

^C 95% confidence interval determined for all samples collected at all wells in the PTMA

^D Interim guideline

^E Working water quality guideline, not formally endorsed

^F Cd guideline hardness-dependent: [Cd] = 0.001 * 10^{0.86[log(hardness)] - 3.2} mg/L

^G Cr guideline = 0.0010 mg/L (Cr VI), or 0.0089 (Cr III) which is interim. Most stringent guideline applied

^H Cu guideline hardness-dependent. [Cu] = 2 ug/L for Hardness < 50 mg/L, otherwise [Cu] = 0.04*Hardness in ug/L

^J Pb guideline hardness-dependent. For Hardness<8 mg/L [Pb] = 3 ug/L, otherwise use chronic guideline: [Pb] = 3.31+exp(1.273*ln(Hardness)-4.704) in ug

^K Zn guideline hardness-dependent: [Zn] = 7.5 ug/L for Hardness < 90 mg/L, else [Zn] = 7.5+0.75*(Hardness-90) in ug/L

^L Mn guideline hardness-dependent: [Mn] = 0.0044*Hardness+0.54 in mg/L

^M Al guideline pH-dependent: 0.1 mg/L for pH>6.5. For pH<6.5 [Al]=exp(1.209-2.426*pH+0.286*pH²)

^N Ni guideline hardness-dependent: [Ni] = 0.025 mg/L at hardness 0-60 mg/L as CaCO₃, 0.065mg/L at 60 - 120 mg/L, 0.110 mg/L at 120 - 180 mg/L, 0.150 mg/L at > 180 mg/L

^P Ag guideline hardness-dependent: [Ag] = 0.003 mg/L for >100mg/L, 0.0001mg/L for ≤ 100mg/L

^Q F⁻ guideline hardness-dependent: [F⁻] = 0.1*(-51.73+92.57*log(Hardness)) in mg/L

^R NH₃ guideline temperature- and pH-dependent, as tabulated in BC MOE (2012). Average baseline groundwater temperature assumed (5.0 °C)

^S Nitrite guideline higher for chloride concentrations greater than 2 mg/L

^T Chronic exposure guideline. Acute guidelines listed only were chronic guidelines have not been established.

^U Aesthetic guideline only

^V Guidelines applies specifically to dissolved component. Unless specified otherwise, guidelines for metals apply to total concentrations.

^W Guideline specified for dissolved component

Confidence – Sensitivity (worst-case) scenarios all generate concentrations as high as 4% of source extending beyond the North Cell seepage collection dam. Sensitivity to hydraulic conductivity estimates is demonstrated. Tailing water concentrations of 4% of source introduce concentration of a number of constituents that exceed the range of natural variability (Table 12.8-5). This is equivalent to base-case simulation predictions, demonstrating conservative design of the TMF seepage control systems. No increase in duration, extent, or magnitude of effects was produced in any sensitivity (worst-case) simulations. The predictions were made with the calibrated Mine Site LSA model, which showed a strong fit to measured groundwater levels in a large amount of wells/piezometers, and to creek low-flow measurements. Therefore confidence is regarded as high.

Significance – With consideration for the high magnitude at the local scale, moderate magnitude at the landscape scale, and no effect at the regional scale, effects arising from seepage of tailing water is considered **not significant (moderate)**.

12.8.2.5 Overall Effect on Groundwater Quality

Groundwater quality will be affected by development of the Project. However, the effects will not be significant and will be restricted to the immediate catchment basins containing Project component footprints.

Conservative (non-reactive) groundwater solute transport modelling indicated that plumes of contact water will emanate from the TMF, RSFs, WSF water storage pond, and Iron Cap Block Cave Mine. With infrastructure designed to reduce and control seepage, these plumes are expected to attain maximum extents that do not surpass a landscape scale. Concentrations extending beyond the mine footprints have been predicted to be very low, where they occur. Concentrations as high as 4% of flotation tailing source have been predicted beyond the TMF footprint in the South Teigen Valley. This may result in concentrations of certain constituents that exceed the range of natural variability, but is not predicted to result in any guideline exceedances. No other plume has been predicted to extend beyond the mine footprints. Therefore, the overall residual effect on groundwater quality has been determined to be **not significant (moderate)**.

12.9 Potential Cumulative Effects for Groundwater Quality

The potential for cumulative effects on groundwater quality arising due to interaction with other nearby projects and human activities were investigated. Potential effects that were examined for Project-specific residual effects were included in the cumulative effects assessment. These include degradation of groundwater quality due to seepage of contact water from the mine components.

12.9.1 Scoping of Cumulative Effects

12.9.1.1 Spatial Linkages with other Projects and Human Actions

The major groundwater divides used to delineate the LSAs were used to assess potential spatial overlap of groundwater quality impacts arising from other projects. Modelling exercises have

shown that extents of plumes emanating from Project areas that interact with the groundwater environment will not surpass these boundaries. A 1 km buffer around the Mitchell-Treaty Twinned Tunnels and Coulter Creek access road footprints was also used to account for potential releases of industrial fluids along these corridors. The following projects and activities are considered to have a potential spatial overlap with effects on groundwater quality (Figure 12.9-1, Table 12.9-1):

- the proposed Brucejack Mine;
- the proposed Snowfield Project;
- the past Sulphurets Project;
- the Northwest Transmission Line; and
- mineral and energy resource exploration.

12.9.1.2 Temporal Linkages with other Projects and Human Actions

Temporal overlaps of past, present, and future projects and land use activities are identified in Table 12.9-1. All projects and activities that have a spatial overlap with the KSM Project's effects on groundwater quality also have a potential temporal overlap. These include the following:

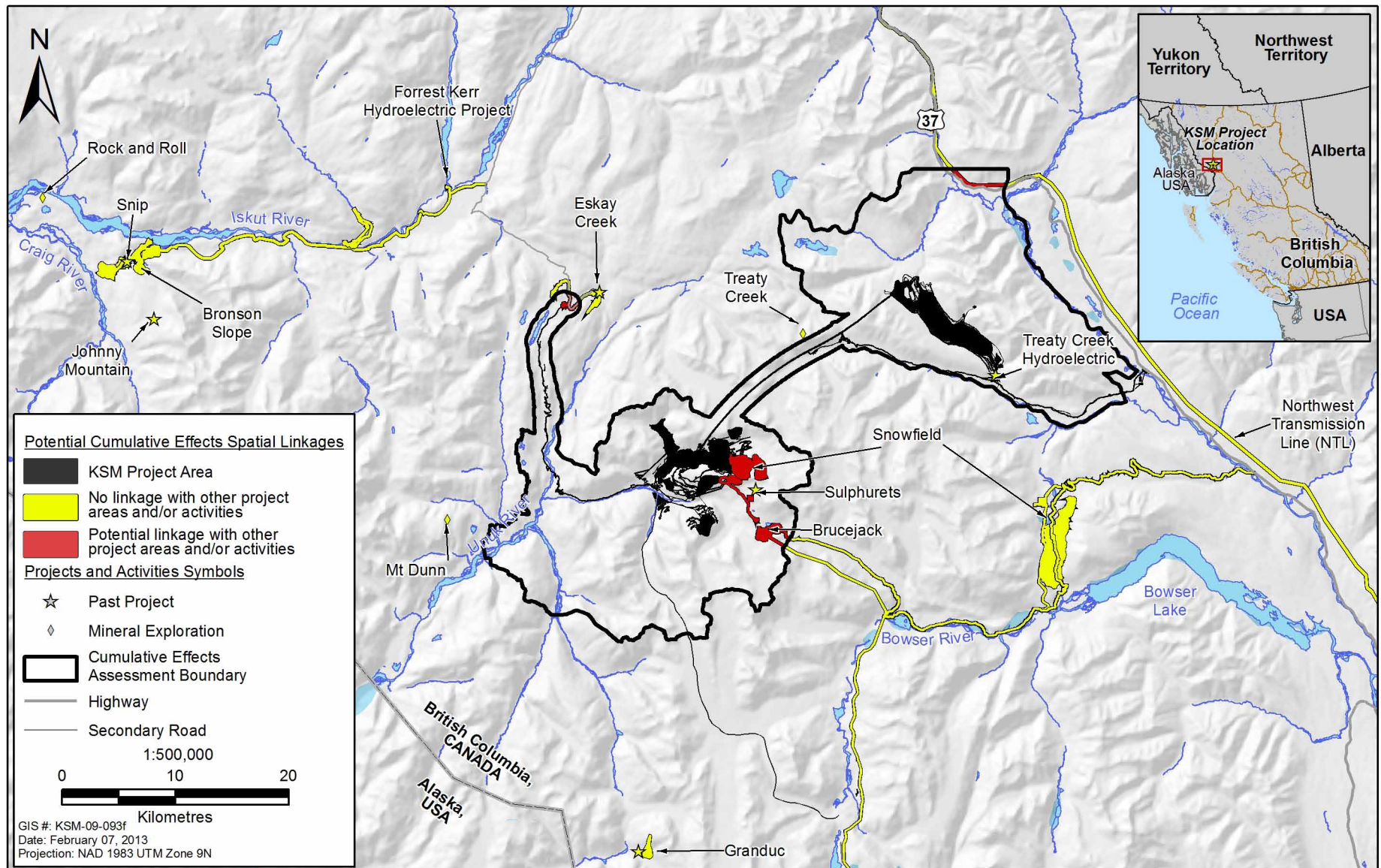
- the proposed Brucejack Mine;
- the proposed Snowfield Project;
- the past Sulphurets Project;
- the Northwest Transmission Line; and
- mineral and energy resource exploration.

Groundwater contamination can persist long after human activity at a site has ceased. Activity at the planned Brucejack Mine and Snowfield Project is expected to overlap temporally with that at the KSM Project; therefore, a temporal overlap of impacts on groundwater quality is possible.

12.9.2 Cumulative Effects Assessment for Groundwater Quality

A summary of possible interactions for each project identified in Section 12.9.1 is presented in Table 12.9-2. Most projects are at a distance at which interactions are not expected, as discussed in Section 12.9.2.1. The proximity of the planned Snowfield Pit to the planned Mitchell Pit is such that potential cumulative effects on groundwater quality exist, as discussed in Section 12.9.2.2.

The Snowfield Project is in an early stage of exploration and has not yet entered the BC Environmental Assessment process. Therefore, infrastructure plans are highly uncertain. The most recent infrastructure plans, detailed in Wardrop (2010), identify an open pit and adjacent waste rock dumps in the Upper Mitchell Valley. Tailing disposal was planned for the Scott Creek watershed, several basins to the northeast. Potential interaction applies to infrastructure that would be located in the Mitchell Valley.



**KSM Project Cumulative Effects Issue Scoping:
Potential Spatial Linkages for Groundwater Quality**

Figure 12.9-1

Table 12.9-1. Summary of Potential Linkages between KSM Project and other Human Actions in regard to Groundwater Quality

Action/Project		Past	Present	Future
Past Projects	Eskay Creek Mine	NL	NL	NL
	Granduc Mine	NL	NL	NL
	Johnny Mountain Mine	NL	NL	NL
	Kitsault Mine (Closed)	NL	NL	NL
	Snip Mine	NL	NL	NL
	Sulphurets Project	X; past mine site within Mine Site local assessment site boundaries	NL	NL
	Swamp Point Aggregate Mine	NL	NL	NL
Present Projects	Forrest Kerr Hydroelectric	NL	NL	NL
	Long Lake Hydroelectric	NL	NL	NL
	Northwest Transmission Line	NL	X; current/recent construction activity within TMF local assessment site	NL
	Red Chris Mine	NL	NL	NL
	Wolverine Mine	NL	NL	NL
Reasonably Foreseeable Future Projects	Bear River Gravel	NL	NL	NL
	Bronson Slope Mine	NL	NL	NL
	Brucejack Mine	NL	NL	X; Project mine sites may overlap temporally and spatially
	Galore Creek Mine	NL	NL	NL
	Granduc Copper Mine	NL	NL	NL
	Kitsault Mine	NL	NL	NL
	Kutcho Mine	NL	NL	NL
	McLymont Creek Hydroelectric	NL	NL	NL
	Arctos Anthracite Coal Mine	NL	NL	NL
	Schaft Creek Mine	NL	NL	NL
	Snowfield Project	NL	NL	X; Project mine sites may overlap temporally and spatially
	Storie Moly Mine	NL	NL	NL
	Turnagain Mine	NL	NL	NL
	Treaty Creek Hydroelectric	NL	NL	NL

(continued)

Table 12.9-1. Summary of Potential Linkages between KSM Project and other Human Actions in regard to Groundwater Quality (completed)

Action/Project		Past	Present	Future
Land Use Activities	Agricultural Resources	NL	NL	NL
	Fishing	NL	NL	NL
	Guide Outfitting	NL	NL	NL
	Resident and Aboriginal Harvest	NL	NL	NL
	Mineral and Energy Resource Exploration	X; KSM Project and Brucejack Mine Exploration Activity	X; KSM Project and Brucejack Mine Exploration Activity	X; KSM Project and Brucejack Mine Exploration Activity
	Recreation and Tourism	NL	NL	NL
	Timber Harvesting	NL	NL	NL
	Traffic and Roads	NL	NL	NL

Notes:

NL = No linkage (no spatial and temporal overlap, or potential effects do not act in combination).

X = Potential spatial and temporal linkage with Project or action.

Table 12.9-2. Summary of Projects and Activities with Potential to Interact Cumulatively with Expected Project-specific Residual Effects on Groundwater Quality

Description of KSM Project Residual Effect	Potential for Cumulative Effect: Relevant Projects and Activities				
	Snowfield Project	Brucejack Mine	Sulphurets Project	Northwest Transmission Line	Mineral and Energy Resource Exploration
Degradation of groundwater quality arising from seepage of contact water	Possible Interaction	No Interaction	No Interaction	No Interaction	No Interaction
Degradation of groundwater quality arising from releases of industrial fluids	No Interaction	No Interaction	No Interaction	No Interaction	No Interaction

12.9.2.1 Project-specific Residual Effects on Groundwater Quality that are Not Likely to Result in Cumulative Effects

No interactions are expected between the KSM Project and most nearby activities and projects. Effects on groundwater quality associated with the Project are predicted to be local or landscape in extent, thereby minimizing potential for interaction with projects that are not likely to be immediately adjacent to KSM Project components. Nearby projects and effects not expected to interact are discussed individually below, with specific reference to the residual effects identified for the KSM Project.

12.9.2.1.1 Seepage of Contact Water Emanating from the Past Sulphurets Project

Price (2005) documents characterization of contamination arising from a waste rock dump created by the Sulphurets Project. Bulk sampling and pilot production (conducted by New Hawk Gold Mines Ltd.) occurred from 1986 to 1990, and generated 124,000 t of PAG waste rock. Waste rock was deposited in a shallow pad adjacent to Brucejack Creek. Standpipes installed immediately below the waste rock indicated that acid rock drainage had occurred, along with leaching of sulphate and certain trace metals (arsenic, copper, lead, and zinc). A comprehensive subsurface site investigation to delineate groundwater contamination associated with the Sulphurets waste rock dump was not conducted. However, it seems probable that a plume of ML/ARD contact water was generated. Seepage through the abandoned underground workings may also have produced ML/ARD contact water.

Groundwater modelling for the KSM Project has not predicted any plume emanating into the Sulphurets Valley. Flow modelling indicates that shallow seepage emanating from the Upper Sulphurets Valley, where relict Sulphurets Project works are located, will discharge into Sulphurets Lake (Figure 12.9-1). Deep seepage will also remain in the Sulphurets Valley. Therefore, no interaction of effects on groundwater quality is expected.

12.9.2.1.2 Seepage of Contact Water Emanating from the Planned Brucejack Mine

The planned Brucejack Mine will be sited around Brucejack Lake in the Upper Sulphurets watershed, immediately adjacent to the past Sulphurets Advanced Exploration Project. Potential effects on groundwater quality identified for the Brucejack Mine include the following:

- ML/ARD arising from exposure of fresh rock in the underground;
- ML/ARD arising from tailing and waste rock dumps; and
- releases of industrial fluids.

Groundwater modelling for the KSM Project has not predicted any plume emanating into the Sulphurets Valley. Flow modelling indicates that shallow seepage emanating from the Upper Sulphurets Valley, where the Brucejack Mine is planned, will discharge into Sulphurets Lake (Figure 12.9-1). Deep seepage will also remain in Sulphurets Valley. Therefore, no interaction of effects on groundwater quality is expected.

12.9.2.1.3 Northwest Transmission Line

As shown in Figure 12.9-1, only a short section of the Northwest Transmission Line (NTL) is crossing the northeastern corner of the PTMA LSA boundary and is over 10 km away from the TMF footprint. Effect on groundwater quality for the NTL could arise due to accidental releases of industrial fluids, but it is expected to be isolated with short duration and low probability of occurrence. No interactions with the KSM Project are expected. Therefore, the overall residual effects on groundwater quality in the PTMA remain unchanged (not significant, moderate) and do not surpass the landscape scale.

12.9.2.1.4 Mineral and Energy Resource Exploration

Effects on groundwater quality arising from past, present, and future mineral resource exploration activity within the LSAs could arise due to releases of industrial fluids. These effects would be similar in nature to those described for releases associated with the KSM Project and the Northwest Transmission Line. Given the local scale, low probability of occurrence, and short-term reversibility of releases, no interactions are expected.

12.9.2.2 Cumulative Effect of Groundwater Quality Degradation Due to Seepage of Contact Water from the Planned Snowfield Project

The proximity of the planned Snowfield Project to the planned Mitchell Pit (Figure 12.9-1) is such that there is potential for cumulative effects on groundwater quality. No effects assessment data existed for the planned Snowfield Project at the time of writing. To evaluate cumulative residual effects with the Mine Site of the KSM Project, it has been assumed that infrastructure in the Upper Mitchell Valley will be limited to an open pit, waste rock dumps, and a conveyor/transport tunnel. This is consistent with preliminary plans (Wardrop 2010). Cumulative effects may arise due to seepage of contact water emanating from the Snowfield Pit and waste rock dumps, and for releases of industrial fluids.

12.9.2.2.1 Project-specific Cumulative Effects Mitigations for Degradation of Groundwater Quality due to Seepage of Contact Water

The Snowfield Project footprint is located in the Mitchell Valley, upstream of the KSM Project WSF. All seepage in this catchment basin is controlled, as discussed in Section 12.7. The KSM Project does not include plans for any mitigation measures specifically targeting cumulative effects on groundwater quality.

12.9.2.2.2 Other Project/Activity Mitigations to Address Groundwater Quality Degradation due to Seepage of Contact Water

The Snowfield Project is in an early stage of exploration and has not yet entered the BC Environmental Assessment process. Therefore, specific mitigation measures to address seepage of contact water have not yet been developed.

Dewatering would be required for extraction in the Snowfield Pit. This would create a groundwater sink, similar in nature to that predicted for the Mitchell, Sulphurets, and Kerr pits during the KSM Project operation phase. Whether decommissioning would involve management of the water level in the pit remains uncertain.

12.9.2.2.3 Determination of Potential for Residual Cumulative Effect and Significance

Potential cumulative residual effects have been identified for the planned Snowfield Project. Introduction of a lake with an unmanaged water level in the Snowfield Pit could result in the development of a contact water plume. Introduction of waste rock dumps around the Snowfield Pit could result in the development of ML/ARD contact water plumes as well.

Flow modelling (not incorporating the Snowfield Project infrastructure) indicates that all seepage in the Mitchell Valley upstream of the WSF will report to either the WSF water storage pond or

the Mitchell Pit from construction to post-closure of the KSM Project. The Snowfield Pit would also receive seepage water during active dewatering, and behave as a groundwater sink. If the water level in the pit were unmanaged following decommissioning, seepage emanating from the pit and waste rock dumps would report to the Mitchell Pit. If the water level in the pit were managed following decommissioning, the pit would operate as a local groundwater sink. Seepage emanating from the waste rock dumps would report to either the Snowfield Pit or the Mitchell Pit. Thus, any uncontrolled contact water generated by the Snowfield Project in the Upper Mitchell Valley would be contained.

The significance determination criteria for cumulative effects arising from contact water seepage associated with the planned Snowfield Project are rationalized below and are summarized in Table 12.9-3.

Magnitude – The Snowfield Pit would penetrate the same deposit as the Mitchell Pit. Therefore, contact water quality is expected to be similar to that associated with the KSM Project, and the magnitude is not expected to change (high).

Extent – Most recent delineations of pit and waste rock dump footprints have been entirely within the Mitchell Valley catchment up-gradient of the WSF. Therefore, future development of the Snowfield Project may result in additional plumes (sourced in the pit and waste rock dumps) developing in the controlled catchment upstream of the WSF. Since these plumes would be within the controlled catchment, their extent may be regarded as local. Thus, the cumulative effect would not entail an increase in the spatial scale of residual effects relative to Project-specific effects.

Duration – All groundwater quality degradation arising from seepage of contact water associated with the KSM Project is expected to be far-future in duration. Therefore, seepage of contact water associated with the Snowfield Project is not expected to increase the duration of effects.

Frequency – Frequency of loading of contamination would likely be continuous, which is consistent with Project-specific effects.

Reversibility – Remediation to pre-existing conditions is not expected to be feasible due to continuous loading. Therefore, reversibility is expected to be irreversible for plumes emanating from the Snowfield Project components. This is consistent with Project-specific effects.

Context – Baseline shallow groundwater quality in the Mitchell Valley is poor and unsuitable for human consumption and the sustenance of aquatic life. Measurements of certain trace metals concentrations have approached or exceeded guidelines, including aluminum, arsenic, chromium, and iron. Acidic pH values (as low as 4.5) have been documented in the Upper Mitchell Valley. The context is therefore regarded as low for plumes that may emanate from potential Snowfield Project works in the Mitchell Valley. The context for cumulative residual effects remains neutral due to effects in the PTMA where baseline water quality is suitable for human consumption and sustenance of aquatic life.

Table 12.9-3. Summary of Cumulative Residual Effects on Groundwater Quality

Description of Residual Effect	Other Project(s) Activity(ies)	Timing of Effect	Magnitude	Magnitude Adjusted for CE	Extent	Extent Adjusted for CE	Duration	Duration Adjusted for CE	Frequency	Frequency Adjusted for CE	Reversibility	Reversibility Adjusted for CE	Context	Context Adjusted for CE	Likelihood of Effects				Significance Determination	Significance Determination Adjusted for CE	Follow-up Monitoring	Follow-up Monitoring Adjusted for CE
															Probability	Probability Adjusted for CE	Confidence Level	Confidence Level Adjusted for CE				
Degradation of groundwater quality due to seepage of contact water	Snowfield Project	Construction	High	High	Local	Local	Far future	Far future	Continuous	Continuous	Irreversible	Irreversible	Neutral	Neutral	High	High	High	High	Not Significant (Moderate)	Not Significant (Moderate)	Required	Required
Overall Effect	All	Post-closure	High	High	Local	Local	Far future	Far future	Continuous	Continuous	Irreversible	Irreversible	Neutral	Neutral	High	High	High	High	Not Significant (Moderate)	Not Significant (Moderate)	Required	Required

Note:
CE = Cumulative Effect

Probability – The probability of contact water seepage is dependent on the nature of the KSM Project component designs and mitigation measures used. This probability is unknown for the Snowfield Project at the time of writing due to uncertainties that remain in design plans. However, this cannot increase the probability of residual effects, because it is high for KSM Project-specific effects.

Confidence Level – There is considerable uncertainty in mine component designs and locations for the Snowfield Project. However, it is highly unlikely that any useful hydraulic control imposed for the Snowfield Project would result in uncontained contact water seepage in the Mitchell Valley. Therefore, the confidence level has been regarded as high.

Significance – The Snowfield Project did not result in any adjustments to significance determination criteria relative to KSM Project-specific residual effects. Thus, cumulative effects arising from interactions with the Snowfield Project have been determined to be **not significant (moderate)**.

12.9.2.3 Overall Cumulative Effect on Groundwater Quality

The KSM Project will affect groundwater quality. The past Sulphurets Project, the planned Brucejack Mine, the Northwest Transmission Line, and the mineral and energy resource exploration do not interact with water that is predicted to be affected by the KSM Project. Thus, potential interactions only exist for the Snowfield Project.

The Snowfield Project is in an early stage of exploration, and most recent infrastructure plans indicate that cumulative effects would be confined to the Upper Mitchell Valley. Mixing of plumes may increase contaminant loads in the groundwater environment. However, catchment isolation measures planned for this locality will contain any additive effects. Thus, cumulative effects remain local and not significant.

12.10 Summary of Assessment of Potential Environmental Effects on Groundwater Quality

Contact water seepage will affect groundwater quality throughout the Project life and beyond, thereby resulting in residual effects. Mitigation measures have been integrated into certain Project components to minimize seepage of contact water and to control plume extents. The key result of mitigative design features is the prevention of residual effects on groundwater quality that surpass local to landscape extents. No effects on groundwater quality are expected outside of the primary catchment basins within which the contact water has its sources. Thus, effects on groundwater quality have been determined to be not significant (Table 12.10-1).

Accidental releases of controlled substances present the risk of isolated local contamination. Implementation of EMPs is expected to minimize the frequency of loading to the groundwater environment. No residual effects are anticipated to arise from accidental releases.

The past Sulphurets Project, planned Brucejack Mine, and planned Snowfield Project are all located in upper reaches of the catchment basins with planned KSM Project mine components. The continuous nature of contact water seepage from mine waste disposal sites indicates a

possibility of extensive plumes associated with these projects. However, the Brucejack Mine and Sulphurets Project footprints are located in groundwater flow regimes that do not interact with water that is predicted to be affected by the KSM Project. The Snowfield Project is in an early stage of exploration, and most recent infrastructure plans indicate that cumulative effects would be confined to the Upper Mitchell Valley. Mixing of plumes may increase contaminant loads in the groundwater environment. However, catchment isolation measures planned for this locality will contain any additive effects. Thus, cumulative effects do not have greater extents than Project-specific effects, and they are not significant.

Table 12.10-1 provides a summary of all potential and residual effects considered in this assessment.

12.11 Groundwater Quality Conclusions

The KSM Project will affect groundwater quality. Seepage of degraded water from mine waste disposal sites (TMF, WSF, and RSFs), and the Iron Cap Block Cave Mine, has been predicted to occur by groundwater modelling exercises. Contact water seepage would occur for the duration of the mine life, and would continue for an uncertain amount of time following end of operation. The magnitude of degradation would be high, because elevated levels of certain metals would enter the groundwater environment, resulting in exceedances of guidelines for human consumption and the protection of freshwater aquatic life.

Degradation of groundwater quality will be confined to the immediately vicinity of the footprints of the TMF and Mitchell Valley mine components upstream of the WSF. Mitigation measures included in infrastructure designs in these areas will minimize seepage of degraded water into the downstream groundwater environment. No exceedances of accepted provincial water quality guidelines have been forecast outside of the mine footprints, in the regional downstream receiving groundwater environment.

Residual effects arising from the KSM Project are expected to interact with those from the planned Snowfield Project. Any additive effects on groundwater quality would be hydraulically contained in the Mitchell Valley upstream of the WSF. No significant effects on groundwater quality, either Project-specific or cumulative, have been identified.

Table 12.10-1. Summary of Assessment of Potential Environmental Effects: Groundwater Quality

Valued Component	Phase of Project	Potential Effect	Key Mitigation Measures	Significance Analysis of Project Residual Effects	Significance Analysis of Cumulative Residual Effects
Groundwater Quality	Construction through post-closure inclusive	Degradation of groundwater quality due to seepage of contact water	<ul style="list-style-type: none"> • Alternative site selections (RSFs, TMF Centre Cell) • Mine dewatering and water level management • Seepage control mechanisms (TMF and WSF) • Low-permeability liners (TMF Centre Cell, Sulphurets Pit RSF, select sections of tunnels) • Implementation of EMPs: TMF, ML/ARD, WSF, groundwater 	<p>Not Significant (moderate): Highly contaminated groundwater expected in the Mitchell Valley due to contact water emanating from the Mitchell and McTagg RSFs, and WSF, as well as drainage from the Kerr Pit and Sulphurets laydown area. Highly contaminated groundwater expected within footprint of TMF. All contamination localized around mine footprint. No guideline exceedances forecasted outside of local mine watersheds (in the parent watersheds) with planned seepage controls.</p>	<p>Not Significant (moderate): Interaction with the planned Snowfield Project is possible. Plumes may emanate from planned waster rock dumps and open pit. Any resulting plume would be contained in the Mitchell Valley, due to demonstrated effectiveness of the WSF. No augmentation of significance determination.</p>
	Construction through post-closure inclusive	Degradation of groundwater quality due to releases of controlled substances	Implementation of EMPs	No residual effect	No Interactions

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