11 Groundwater Quantity

This section describes and quantifies the potential effects of the KSM Project (the Project) on groundwater quantity. Hydrogeological characterization is based on baseline data that have been collected since 2008. Assessing the potential effects of the Project has been conducted based on the results of three-dimensional hydrogeological numerical modelling. Modelling exercises included calibration to baseline conditions and predictive simulation of effects on groundwater quantity at key time steps in the evolution of the mine. Complete details of the modelling methodologies and results are presented in Appendix 11-E.

The Application Information Requirements (AIR) specifies that the effects assessment consider mitigation measures to reduce effects, followed by assessment of potential residual effects and their significance (BC EAO 2011). Cumulative effects from other aspects of the Project or other projects in the vicinity of the proposed Project must also be considered. The effects assessment has been conducted by identifying issues using the results of the groundwater model, professional judgement, and consultations with Project geochemists, hydrologists, and water quality experts.

11.1 Project Setting

11.1.1 Overview

A hydrogeology baseline study was undertaken from 2008 through 2012 in the Mine Site and Processing and Tailing Management Area (PTMA). The study focused on data collection to characterize the groundwater quantity in the Project areas as specified in the AIR. The objective of collecting the groundwater information was for use in developing conceptual and numerical groundwater models. Models were then used for predicting groundwater quantity changes arising from Project infrastructure and activities. No groundwater quantity data was available prior to 2008.

Information collected by three independent consulting firms was used to characterize baseline hydrogeology conditions and to develop site models. Data were collected by Klohn Crippen Berger Ltd. (KCB) within the Tailing Management Facility, Rock Storage Facilities, and Mitchell and Sulphurets Valleys for geotechnical engineering design purposes. Data were collected by BGC Engineering Inc. (BGC) within the pit areas for the depressurization analysis. Hydrogeological data was collected by Rescan Environmental Services Ltd. (Rescan) in areas within and down-gradient of the proposed infrastructure for the environmental impact assessment. Complete baseline characterization methodologies and data sets are included in the following:

- KCB (2009; Sub-Appendix H1 of Appendix 4-C, 2008 Site Investigation Report);
- KCB (2010; Sub-Appendix H2 of Appendix 4-C, 2009 Site Investigation Report);
- KCB (2011; Sub-Appendix H5 of Appendix 4-C, 2010 Site Investigation Report);
- KCB (2012a; Sub-Appendix H6 of Appendix 4-C, 2011 Site Investigation Report for the Mine Area);
- KCB (2012b; Sub-Appendix H7 of Appendix 4-C, 2011 Site Investigation Report for the Teigen / Treaty Tailings Management Facility);

- KCB (2012c; Appendix 4-Q, 2012 Site Investigation Report for the Mine Area);
- KCB (2012d; Appendix 4-AB, 2012 TMF Site Investigation);
- KCB (2013a; Appendix 4-J, 2012 Geotechnical Design of Rock Storage Facilities and Design of Associated Water Management Facilities);
- KCB (2013b; Appendix 4-AC, 2012 Engineering Design Update of Tailing Management Facility);
- BGC (2010a; Appendix 11-I, Open Pit Depressurization Analyses);
- BGC (2010b; Sub-Appendix F1 of Appendix 4-C, Mitchell Zone - Open Pit Slope Design - FINAL);
- BGC (2011a; Sub-Appendix F3 of Appendix 4-C, Prefeasibility Study Update - Sulphurets Open Pit Slope Design - FINAL);
- BGC (2011b; Sub-Appendix F4 of Appendix 4-C, Prefeasibility Study Update - Kerr Open Pit Slope Design - FINAL);
- BGC (2011c; Sub-Appendix F5 of Appendix 4-C, Prefeasibility Study Update - Open Pit Depressurization Analyses);
- BGC (2012; Sub-Appendix F12 of Appendix 4-C, 2012 Prefeasibility Study Update: Open Pit Depressurization);
- Rescan (2008; Appendix 11-A, 2008 Hydrogeology Baseline Report);
- Rescan (2010; Appendix 11-B, 2009 and 2010 Hydrogeology Baseline Report); and
- Rescan (2012; Appendix 11-C, 2012 Hydrogeology Baseline Data Report).

11.1.2 Methods to Characterize Groundwater Quantity

Groundwater quantity characterization included three principle data sets: hydro-stratigraphy, permeability, and water levels. Hydro-stratigraphy was characterized by borehole drilling and logging. Permeability was assessed by hydraulic testing (packer tests in boreholes during drilling, and slug tests in installed wells). Water levels were measured in constructed 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 quantity throughout the Mine Site and PTMA. Monitoring sites selected by BGC and KCB were located within the Project footprint.

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 installation of 28 monitoring wells at 14 locations in the Mine Site and PTMA. As of 2012, the groundwater level data from 51 monitoring wells and piezometers in the Mine Site and 43 in the PTMA have been used to calibrate the numerical model for characterization of the baseline groundwater quantity. Characterization of the groundwater quantity setting has also been conducted with use of core log records from numerous other boreholes. The locations of the monitoring wells in the Mine Site and PTMA are shown in Figures 11.1-1 and 11.1-2, respectively. Lithological data acquired from numerous mineral exploration and geotechnical boreholes were also used for site characterization.

Two boreholes were drilled at each of the Rescan monitoring locations, including one shallow borehole (typical depth ranging from 20 to 40 m) and a deep borehole (typical depth ranging from 80 to 120 m). This allowed characterization of vertical hydraulic gradients. Recovery of core allowed for close inspection and logging of overburden and rock material. Logging was conducted with an emphasis on evidence of water flow (e.g., fracture characterization).

Boreholes were drilled using HQ rods (4-inch outer diameter) and completed with 2-inch or 1-inch PVC monitoring wells installed with sand filter pack around the well screen, bentonite seal and grouted to surface, as per British Columbia Ministry of Environment (BC MOE 2009) Technical Guidance on Groundwater Investigation and Characterization. The wells were developed by air lifting until the turbidity in water was low. At least three wells' 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 Groundwater Protection Regulation (BC Reg. 299/2004).

Packer testing was carried out by Rescan, KCB, and BGC in zones within the boreholes that contained relatively high fracture densities. This allowed generation of a vertical profile of hydraulic conductivity in the bedrock. The packer tests were completed as constant head tests and were analyzed using the Thiem (1906) method. Slug tests were carried out in the monitoring wells, including rising and falling head tests. Slug test data were analyzed using the Hvorslev (1951) and/or the Bouwer and Rice (1976) methods built in to the Aquifer Test software (Waterloo Hydrogeologic Inc. 1996).

Water levels were measured in all monitoring wells. At least one measurement was taken during each season in most wells. Water level loggers were deployed in 11 wells by Rescan from October 2009 to December 2010, generating a continuous time series of groundwater level variations in a subset of the wells located in the Mine Site and PTMA.

11.1.3 Mine Site

The Mine Site includes the proposed open pits and underground block caves at the mineral deposits, as well as the proposed Rock Storage Facility (RSF) and Water Storage Facility (WSF). Topographically, the area comprises deep glacial-cut valleys (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 the Mitchell Valley indicate groundwater discharge at elevations ranging from 1,000 masl to 1,150 masl (approximately 300 m above the Mitchell Valley floor at the proposed pit location). Seeps on the southern slope of the Sulphurets Valley (adjacent to the Kerr deposit) indicate discharge at elevations ranging from 1,100 to 1,300 masl.

PROJECT # 868-022-58 GIS No. KSM-09-119 March 8, 2013

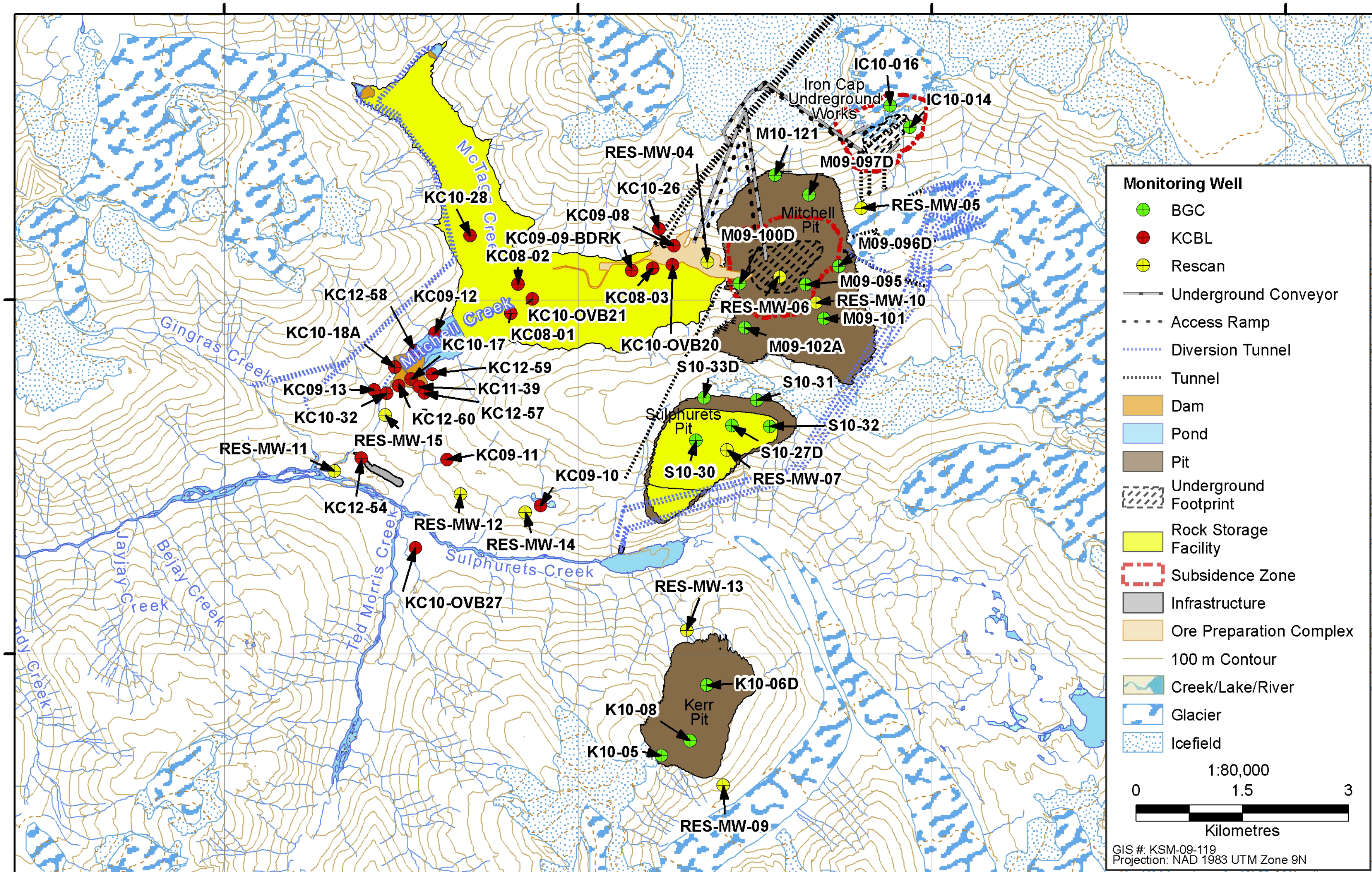

Figure 11.1-1

Groundwater Quantity Monitoring Locations in the Mine Site

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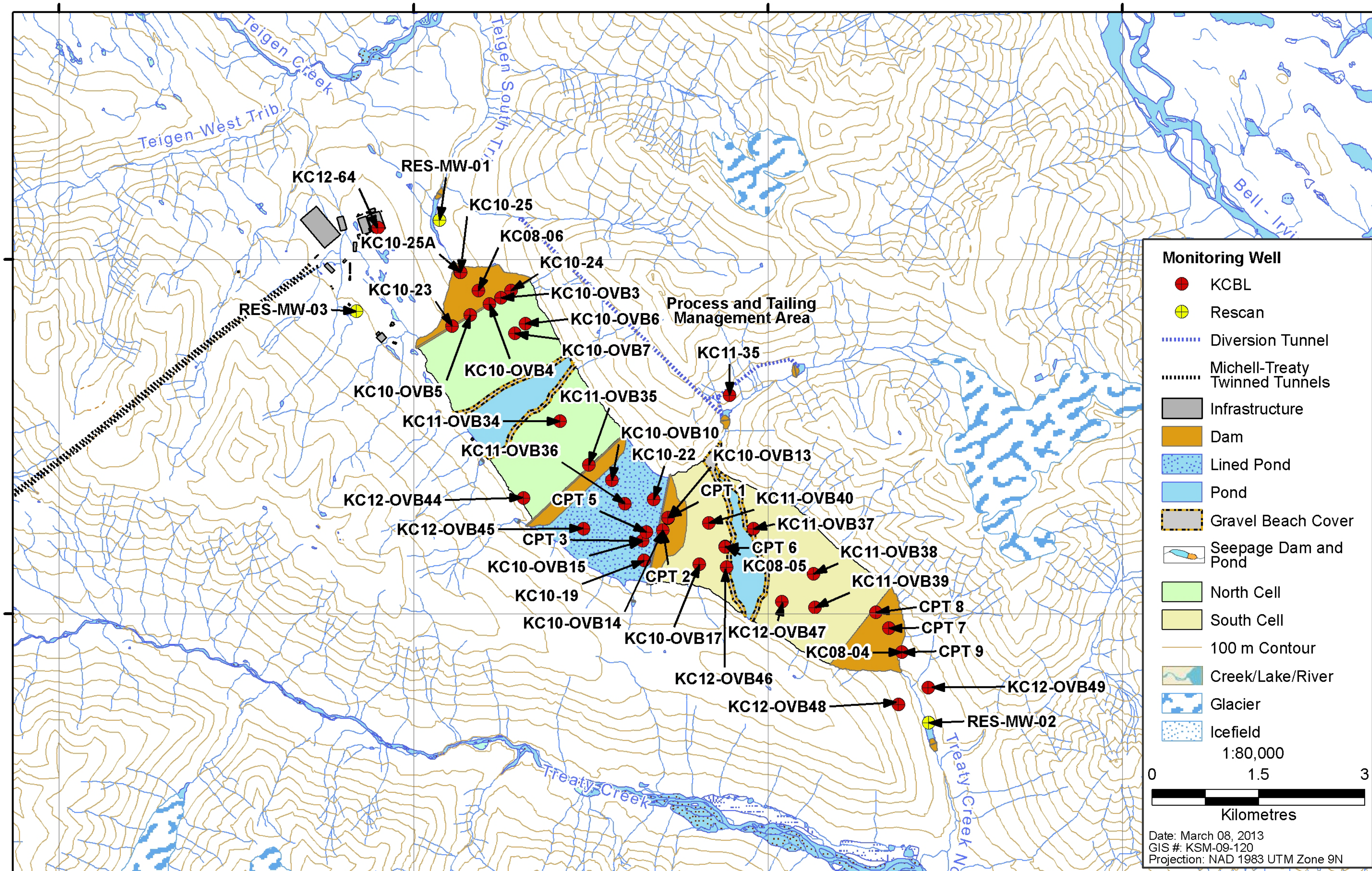


Figure 11.1-2

Groundwater Quantity Monitoring Locations in the Processing and Tailing Management Area

SEABRIDGE GOLD
KSM PROJECT

Rescan
Engineers & Scientists

Generally, 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 (i.e., discharge quality similar to that in the springs/seeps). Groundwater elevations in wells installed in overburden (glacial till) in the Mitchell Valley bottom are similar to the creek bed elevation and show little annual variation (less than 1 m), suggesting hydraulic connection between groundwater and surface water. Groundwater elevations in wells screened in bedrock are higher than wells screened in overburden, indicating upward hydraulic gradients (artesian in some locations) in the Mitchell Valley. 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.

Recharge is considered to be higher in the mountainous areas (orographic effects). For modelling purposes, an estimate of 218 mm/year (or 13% of the mean annual precipitation [MAP] of 1,653 mm) where elevation is over 1,300 masl compares to 115 mm/year (or 7% of MAP) where elevation is less than 400 masl. Beneath glaciers and snowpack, a recharge is estimated at only 40 mm/year, assuming the ground is frozen. The good calibration of the baseline model to the field estimated stream low-flows demonstrates that the recharge rates applied are appropriate. Groundwater discharges in valley bottoms; this has been confirmed by artesian conditions in boreholes located in the Mitchell Valley. Short groundwater flow paths at shallow depths (i.e., transient or interflow) feed smaller mountain streams and acidic, mineralized springs (seeps) observed on the slopes of the Mitchell and Sulphurets valleys. Long groundwater flow paths in deeper bedrock layers are believed to provide a significant portion of the base flow that makes up creek flow in the dry periods (generally November through April).

Seepage rates reporting to streams (also referred to as base flow) in the Mine Site were estimated based on stream low-flow measurements (Table 11.1-1). Stream low-flows were a key instrument in validation of the groundwater flow model. They were also used to assess changes in seepage rates and surface water quantity arising from effects of mine components on groundwater quantity.

Table 11.1-1. Stream Low-flow Rates at Key Locations in the Mine Site

Stream Observation Point	Sulphurets Creek near Mouth (m^3/s)	Sulphurets Lake Outlet (m^3/s)
Gauging Station	SC-H1	SL-H1
Measured average annual 7-day low-flow [a]	2.77	0.33
Regionally-derived annual 7-day low-flow [b]	1.38	0.38
Regionally-derived 10-year 7-day low-flow [c]	0.77	0.19

[a] Measured at installed stream gauging stations.
[b] Estimated at 10-year return period based on long-term regional data.
[c] Estimated at 1-year return period based on long-term regional data.

Three different low-flow calculations are presented to develop an envelope for the average seepage rate reporting to streams. Regionally-derived estimates are computed based on 20-year data sets obtained from regional Water Survey of Canada (WSC) gauging stations. Measured data at the local gauging stations are limited to four years and likely represent an approach to average annual base flow with a residual interflow component. Ten-year low-flow estimates likely represent base flow with a depressed water table.

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 eastern, upper reaches of the Mitchell and Sulphurets valleys. The Mitchell Thrust Fault and Sulphurets Thrust Fault (MTF and STF) both intersect the Mitchell Pit. The STF also intersects the Sulphurets Pit and Iron Cap Block Cave Mine. The MTF divides the overlying Stuhini Group from the underlying Hazelton group rocks. The STF subdivides the Hazelton group with a distinct contrast in alterations in the hanging and footwalls. The proposed Kerr Pit is located entirely within the STF footwall.

Faults, shears, and intensely jointed rock are typically considered the significant hydraulic conductors in this terrain. However, in the eastern reaches of the Mine Site, evidence from cores shows significant mineral precipitation (carbonates, silica, and other secondary minerals) within rock discontinuities. Mineral precipitation tends to reduce hydraulic conductivity. Hydraulic conductivity testing in suspected fault zones has produced variable results that do not support consistently high hydraulic conductivity in faults.

Conceptually and for modelling purposes, the Mine Site has been divided into zones representing different rock types (lithology) and horizontal layers reflecting a general decline in hydraulic conductivity with depth. The layers are in the order of tens of metres thick in the shallow bedrock units, and hundreds of metres thick in the middle and lower bedrock units. The average hydraulic conductivities assumed for lithology and depth are based on field data. It has been shown that the permeability generally declines with depth, and this observation has been used to develop a trend of declining hydraulic conductivity with depth in bedrock at depths beneath those tested in the field. Measurements in shallow bedrock (up to 150 m) have given hydraulic conductivity in the range of 10^{-5} to 10^{-7} m/s. At greater depths, hydraulic conductivity is in the range of 10^{-8} to 10^{-9} m/s. Hydraulic conductivities used in the modelling exercises are discussed in greater detail in the Hydrogeological Modelling Report (Appendix 11-E).

The proposed WSF is situated along the west limb of the McTagg Anticline, in the Stuhini Group. Bedding planes are locally steeply dipping. Small-scale flexural-slip faulting along bedding planes has been documented, in association with tensional forces along the fold limb. A few large faults have been interpreted (Figure 11.1-3), including two that intersect the Water Storage dam (WSD) foundation. Measured hydraulic conductivities are generally relatively low (10^{-7} m/s). Calcite has frequently been observed as fracture infill, which is thought to have a linkage with the CO_2 and high concentration of bicarbonate observed in the downstream groundwater monitoring well RES-MW-11A located at the confluence of the Mitchell and Sulphurets Creeks. Dissolution-enlarged joints have been observed in the calcareous sandstone and siltstone, corresponding with relatively high hydraulic conductivity measurements derived from packer tests (10^{-5} m/s). Occasional heavily fractured zones, possibly corresponding with faults, have also exhibited relatively high hydraulic conductivities around the WSF (up to 10^{-5} m/s). A 24-hour injection test was carried out at a borehole that contained large open fractures, resulting in an estimated hydraulic conductivity of 1×10^{-6} m/s. The dissolution-enhanced calcareous rocks have been represented in the mine site model as high permeability zones (up to 10^{-3} m/s) to account for the potential maximum or worst effects from the environmental impact assessment standpoint.

Overburden (thin colluvium on mountain slopes and glacial till in the valley bottoms) thicknesses are variable, with a maximum measured thickness of over 140 m in the Mitchell Valley west of the proposed pit. The maximum depth of overburden in the Sulphurets Valley is over 40 m (between Sulphurets Lake and the confluence of Sulphurets and Mitchell creeks). In the McTagg Valley, overburden depths have not surpassed 10 m in boreholes. Landslides and alluvial fans occur on many steeper valley slopes and are likely to comprise significant pathways for groundwater flow from high to low elevations. The average hydraulic conductivity of the glacial till in the Mine Site is approximately 1×10^{-7} m/s.

Groundwater hydraulic gradients are steep because of the mountainous terrain. The hydrogeological system is generally unconfined. Confined behaviour has been observed in isolated extents along valley bottoms where thick deposits of glacial till overly the bedrock. Groundwater levels tend to be deeper at high elevations and show more seasonal variation, whereas groundwater levels in the valley bottoms are generally shallow and show less seasonal variation. A potentiometric surface was delineated based on groundwater-level observations (Figure 11.1-4).

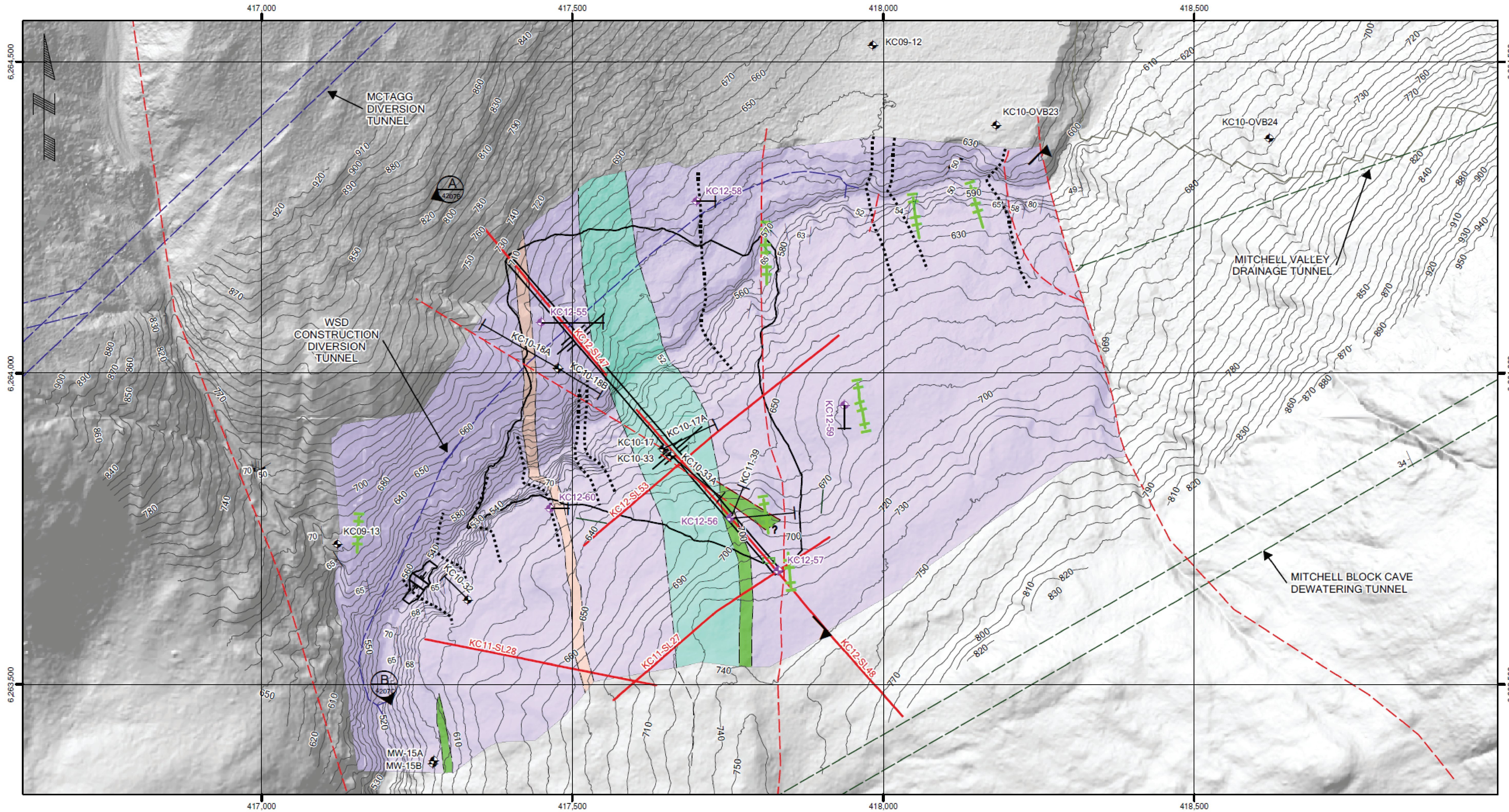
11.1.4 Processing and Tailing Management Area

The PTMA is within a valley spanning the upper reaches of the North Treaty and South Teigen tributaries. Overburden comprises low-permeability (hydraulic conductivity of 1×10^{-7} m/s) glacial till in the valley bottom, up to approximately 30-m thick. Higher-permeability fluvial deposits (hydraulic conductivity of 2×10^{-5} m/s) cross-cut the glacial till along the stream beds of Teigen and North Treaty creeks. Alluvial fans with moderate permeability have been identified along the valley edges, up to 90-m thick. Lateral moraines and scree piles fill the steep sub-catchments on the valley slopes and surrounding mountainous areas (less than 5-m thick).

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). The strike of the sedimentary rock bedding is parallel to the valley axis and is expected to impart flow anisotropy in the bedrock. Hydraulic testing has indicated that bedrock hydraulic conductivity generally decreases with depth, estimated at 1×10^{-6} m/s in shallow fracture zones.

Field investigations indicate that a system of local faults cross-cut the footprint of the North Cell dam (Figure 11.1-5). The northwest-southeast trend suggests that these faults are a product of extensional forces along the axis of the regional-scale syncline that follows the base of the valley. These faults have manifested into fracture zones with evidence of shearing in the core. Hydraulic conductivities are estimated at 10^{-6} m/s (KCB 2013b), approximately an order of magnitude higher than other local fracture systems.

PROJECT # 868-022-21 ILLUSTRATION # a40814w_T February 7, 2013



LEGEND

- 2009-2011 DRILLHOLE
- 2012 DRILLHOLE
- BEDDING
- JOINT
- SEISMIC SURVEY LINE (KCB 2011,2012)
- CONTACT BETWEEN ROCK UNITS (APPROXIMATE LOCATION)
- GRAPHITIC BED
- FELSIC SILL (S)
- INFERRED FAULT
- SILTSTONE AND SHALE
- CALCAREOUS SILTSTONE AND SANDSTONE
- PHYLLITE
- ALTERED VOLCANIC ROCK

NOTES:
1. BASEMAP 2008 10M INTERVAL CONTOUR LIDAR DATA FROM SEABRIDGE
2. UTM ZONE 9N, NAD83
3. LIDAR HILLSHADE SHOWN IN BACKGROUND

NOT FOR CONSTRUCTION

0 250 m

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Adapted from KCBL RSF and Water Management Facilities Design Report D-4207A

Figure 11.1-3

Geological Interpretation of the Water Storage Facility Site

PROJECT # 868-022-58 GIS No. KSM-09-117_T March 8, 2013

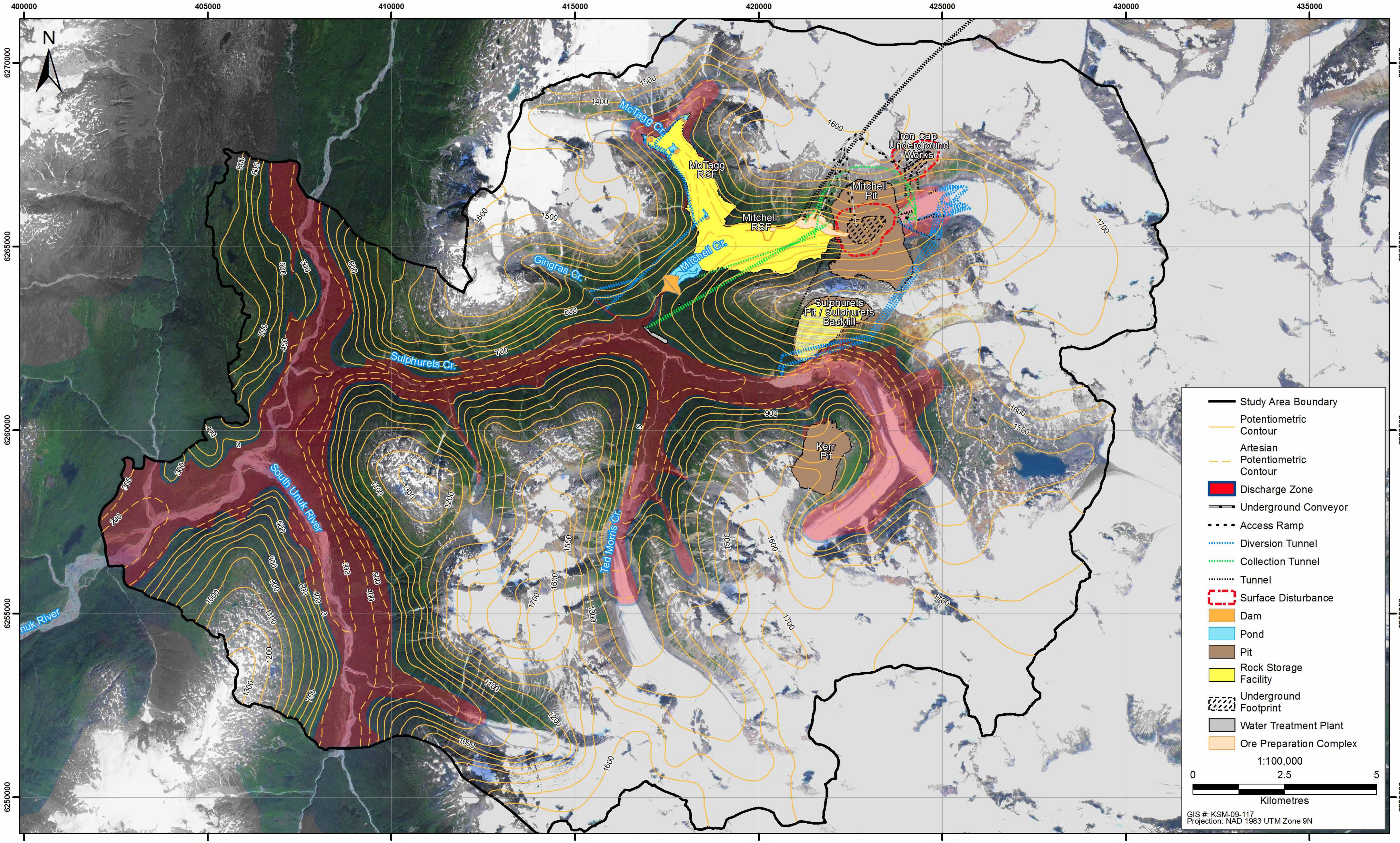

Figure 11.1-4

Potentiometric Surface in the Mine Site

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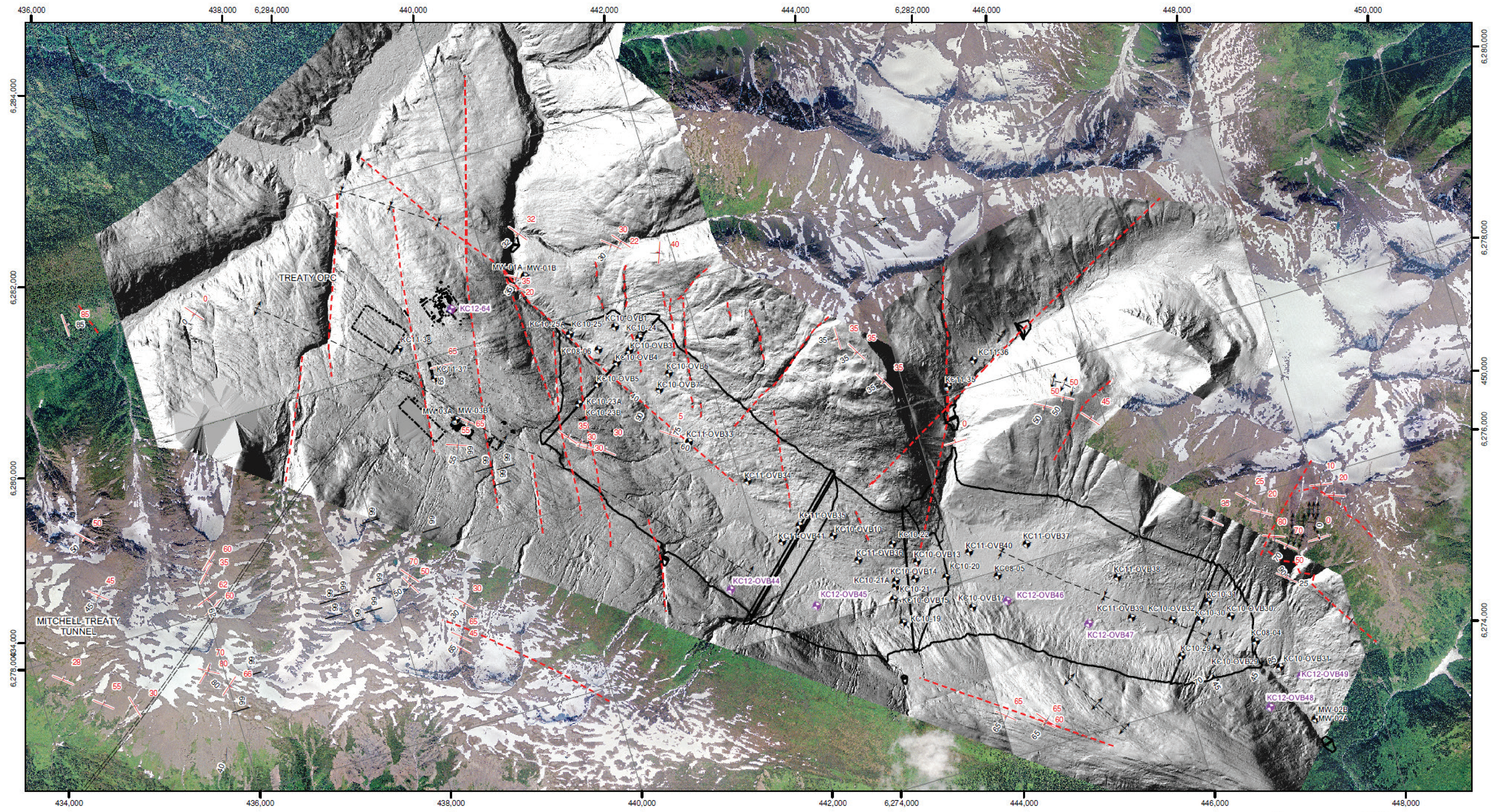

Notes:
1. UTM Zone 9N, NAD83
2. 2008 orthophoto
3. 2008, 2010 LiDAR hillshade

EXISTING DRILLHOLE
2012 BEDROCK AND OVERBURDEN DRILLHOLE
BEDDING
ANTICLINE
FAULT, APPROXIMATELY LOCATED
SYNCLINE
TAILING IMPOUNDMENT AND DAM OUTLINE
LIDAR IMAGE

0 1,000 m

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Adapted from KBCL TMF Engineering Design Report Fig. 2.1

Figure 11.1-5

Plan View of Faults around the Tailing Management Facility

Measured groundwater levels in the PTMA, where wells are predominantly located at lower elevations and valley bottoms, are generally less than 10-m below surface. Annual variability is approximately 2 m. This variability is significantly lower than observed in the Mine Site, where many of the wells are installed at higher elevations. The groundwater levels tend to increase in the late fall, decline in winter, and peak at freshet around May, before declining to lows in the late summer and early fall. This trend corresponds with seasonal precipitation trends. Groundwater-level observations in the PTMA are shown in Figure 11.1-6.

High mountainous areas have been interpreted as recharge zones, with discharge zones in valley bottoms. Surface water infiltrating persistent fractures and colluvial fans along valley walls 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. Similar to the Mine Site, 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. 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.

For modelling purposes, an estimate of 152 mm/year (or 14% of the mean annual precipitation [MAP] of 1,083 mm) where elevation is over 1,300 masl compares to 84 mm/year (or 8% of MAP) where elevation is less than 900 masl. Beneath glaciers and snowpack, a recharge is estimated at only 40 mm/year, assuming the ground is frozen. The good calibration of the baseline model to the field-estimated stream low-flows demonstrates that the recharge rates applied are appropriate.

Seepage rates reporting to streams in the PTMA were determined by stream low-flow estimates (Table 11.1-2). These were a key instrument in validation of the groundwater flow model, and in predicting effects on surface water quantity arising from alterations in groundwater quantity.

Table 11.1-2. Stream Low-flow Rates at Key Points in the Processing and Tailing Management Area

Stream Observation Point	South Teigen Creek Outlet (m^3/s)	North Treaty Creek Outlet (m^3/s)
Gauging Station	**NTWM-H1**	**STWM-H1**
Estimated Baseline Stream Low-flows		
Measured average annual 7-day low-flow [a]	0.20	0.19
Calculated annual 7-day low-flow [b]	0.28	0.15
Calculated 10-year 7-day low-flow [c]	0.13	0.07

a Measured at installed stream gauging stations.
b Estimated at 10-year return period based on long-term regional data.
c Estimated at one-year return period based on long-term regional data.

11.2 Historical Activities

Past human activity in the catchment basins corresponding with the planned KSM Project components include the following:

- exploration and bulk sampling for the Sulphurets Advanced Exploration Project; and
- mineral exploration for the planned Brucejack Mine, Snowfield Project, and KSM Project.

None of these activities are expected to have had a measurable influence on baseline groundwater quantity conditions. Historical activities down-gradient of the KSM Project areas are not expected to have any effects.

11.3 Land Use Planning Objectives

Components of the Project lie within the Cassiar Iskut-Stikine Land and Resource Management Plan (CIS LRMP) and the Nass South Sustainable Resource Management Plan (SRMP; Figure 11.3-1). In particular, the Mine Site lies within the CIS LRMP. The Mitchell-Treaty Twinned Tunnels and Granduc Mine road cross through northern reaches of the Nass South SRMP. Both land use plans include indirect reference to groundwater quantity, by addressing aquatic ecosystem and surface water resource management considerations (BC ILMB 2000; BC MFLNRO 2012).

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

- 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):

- provision of a safe and sufficient drinking-water supply that supports healthy communities;
- maintenance of water quality, water 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 quantity effects assessment must show that mine works will not have adverse consequences on base flows into downstream surface water receiving environments. Receiving environments with high fisheries values are of particular concern.

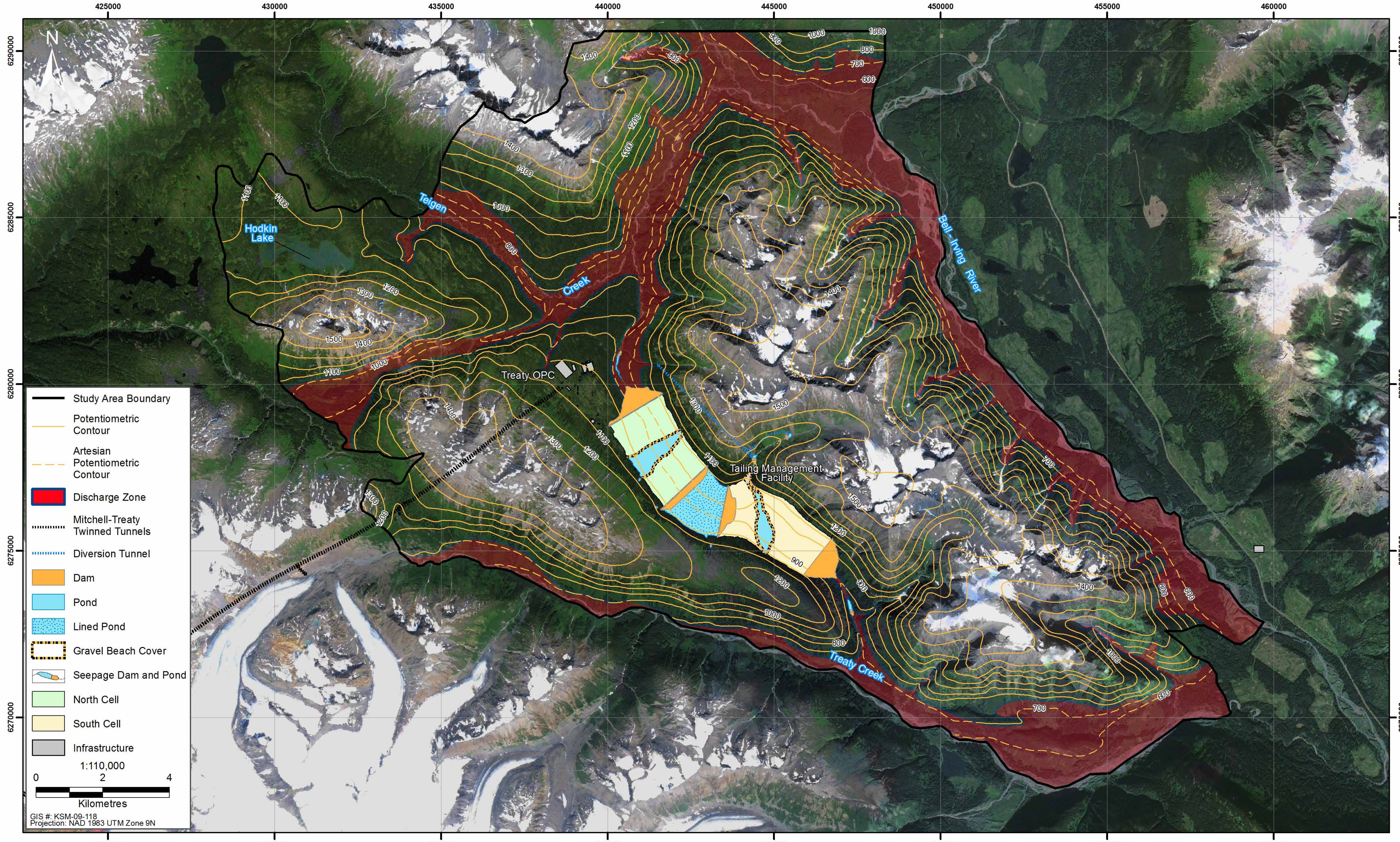

Figure 11.1-6

Potentiometric Surface in the Process and Tailing Management Area

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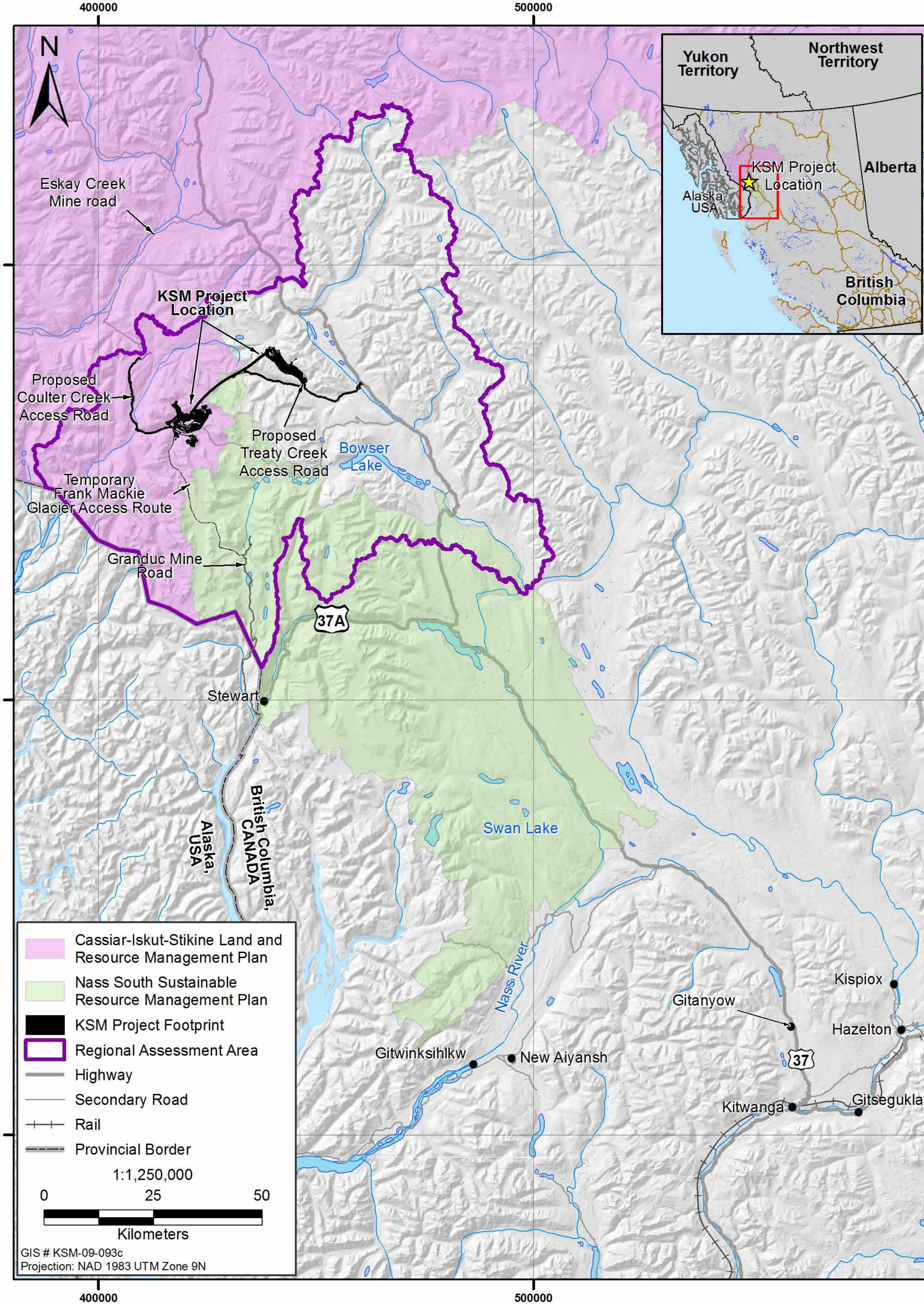

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Cassiar Iskut-Stikine Land and Resource Management Plan and the Nass South Sustainable Resource Management Plan Boundaries in Relation to the KSM Project

Figure 11.3-1

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11.4 Spatial and Temporal Boundaries

11.4.1 Spatial Boundaries

A regional study area (RSA) was defined, encompassing the complete Project footprint, current footprints for the adjacent planned Brucejack Mine and Snowfield Project, and a number of other projects farther away (Figure 11.4-1). All KSM Project components are within the RSA.

Two independent local study areas (LSAs) were defined. One local study area spans the Mine Site (Figure 11.4-2), where the three open pits, underground mining works, rock storage facilities, WSF, tunnels, and other ancillary Project components are clustered. The second spans the PTMA (Figure 11.4-3), where the Treaty Process Plant, TMF, and other ancillary Project components are clustered. Together the two LSAs include all Project components where an assessment of residual effects is necessary. The Coulter Creek access road and Treaty Creek access road are not within the local study areas, but are included in the RSA.

LSA boundaries were delineated based on the groundwater model domains established in the numerical groundwater models (modelling methods and results are outlined in detail in Appendix 11-E). Criteria regarding how boundaries were defined include the following:

1. **Project areas with potential effects –** Spatial boundaries encompassed all Project areas 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 areas up to the end of the post-closure timeframe (refer to Section 12.4.2).
2. **Down-gradient receiving environments –** Receiving environments where surface water quality or quantity may be affected by the Project were included within the spatial boundaries.
3. **Watershed divides –** Boundaries were delineated along natural watershed divides that were far enough downstream of the Project zone of influence to satisfy criteria (1) and (2).

The Mine Site LSA is bounded by high mountain watershed divides in its northern, eastern, and southern extents. The Unuk River is included at the outlet of Sulphurets creek. All groundwater in the Mine Site is expected to flow generally towards 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 PTMA mine components. 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 and to the sea level in the PTMA. At these depths, hydraulic conductivities and seepage rates are typically extremely low.

PROJECT # 868-022-21 GIS No. KSM-09-098f February 7, 2013

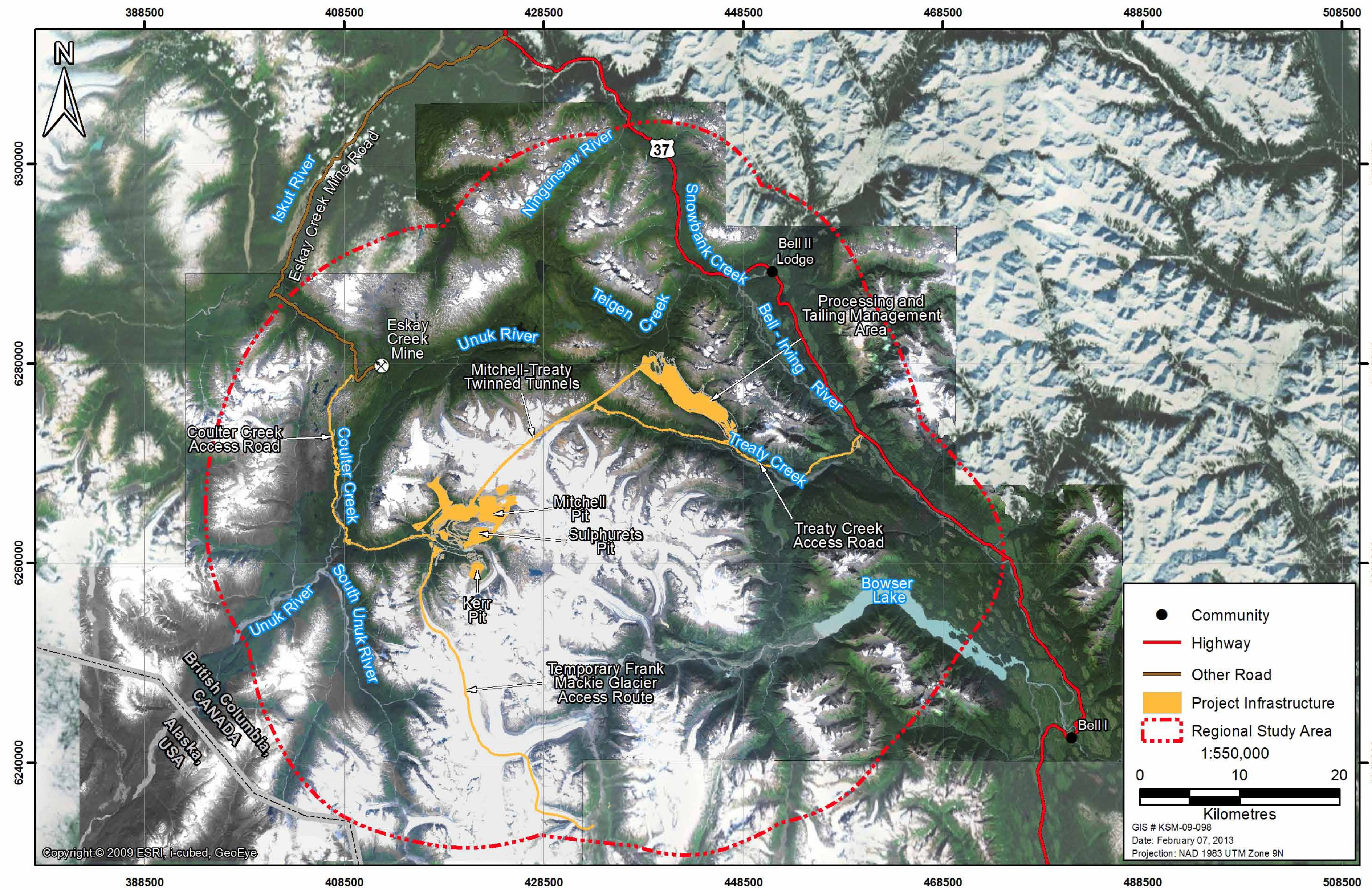

Figure 11.4-1

SEABRIDGE GOLD
KSM PROJECT

Regional Study Area Defined for the Groundwater Quantity Effects Assessment

Figure 11.4-1

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PROJECT # 868-022-58 GIS No. KSM-09-125 March 12, 2013

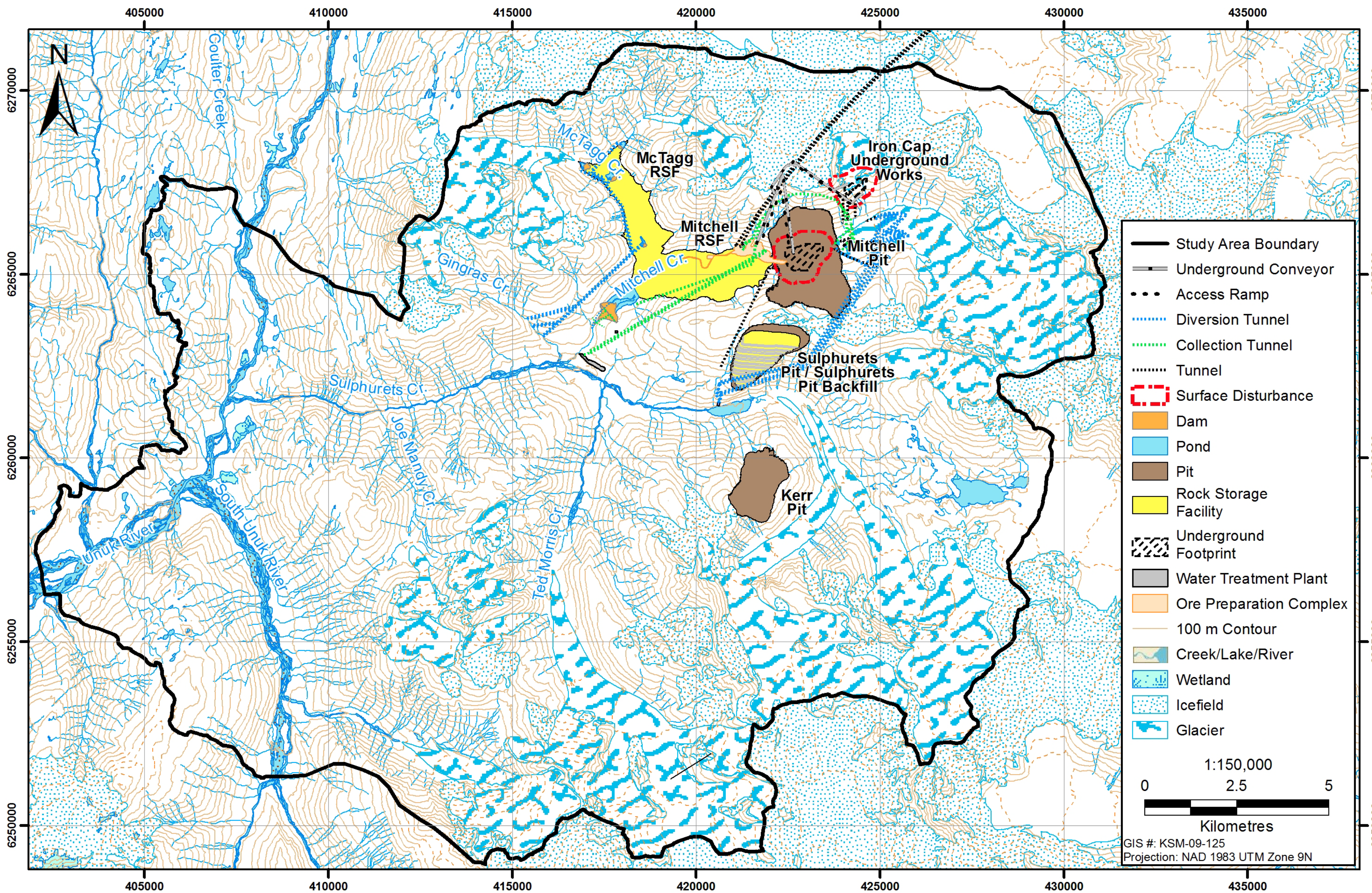

Figure 11.4-2

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

SEABRIDGE GOLD
KSM PROJECT

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Figure 11.4-2

PROJECT # 868-022-58 GIS No. KSM-09-127 March 12, 2013

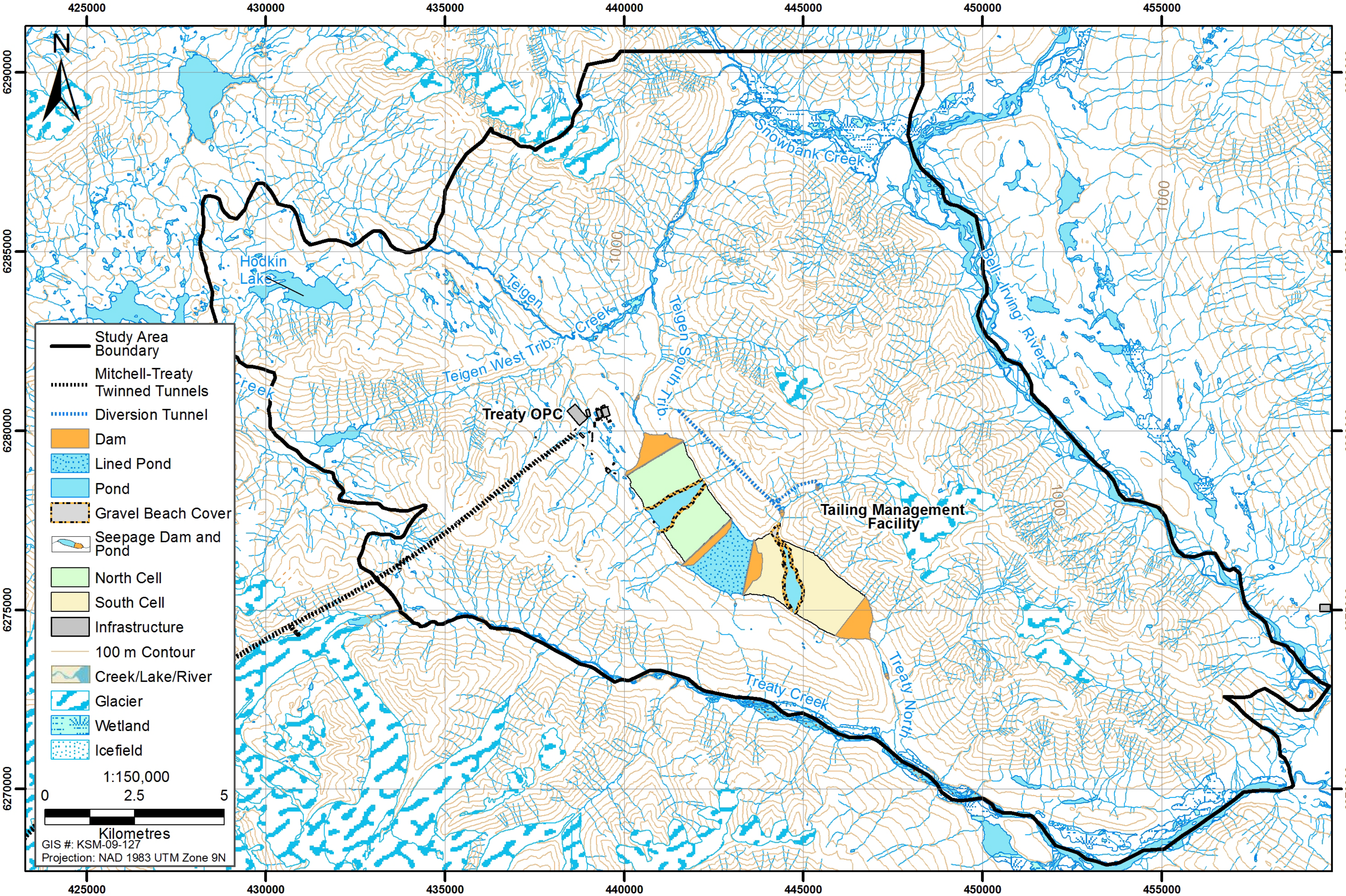

Figure 11.4-3

SEABRIDGE GOLD
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Processing and Tailing Management Area Local Study Area Defined for the Groundwater Quantity Effects Assessment

Figure 11.4-3

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11.4.2 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 activity commences during construction. The Project-related effects assessment ends after alterations in groundwater quantity have reached final steady states during the post-closure phase.

Groundwater flow modelling was conducted using a steady-state approach. A steady-state simulation was conducted for each major stage in Project development, where mine component developments differed such that changes in flow patterns were expected. These stages were different for the PTMA and the Mine Site.

11.4.2.1 Mine Site Local Study Area Temporal Domain

Flow regimes were predicted across the Mine Site LSA for key stages in the development of the Project, which include the following:

- **End of operation phase** – At this time the proposed pit and underground works' extents will be greatest, with active dewatering. The Mitchell and McTagg RSFs have attained their maximum extents. The WSF pond level is at its peak during mine life. Thus, this point in time represents the greatest effects on groundwater quantity expected during the mine operation phase.
- **Post-closure phase** – 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 RSF will be partially reclaimed. The WSF pond level will maintain its peak level. This represents the maximum effects from mine infrastructure potentially occurring for many years after end of operation, with the closure and reclamation complete where it is planned (detailed in Chapter 27, Closure and Reclamation).

11.4.2.2 Processing and Tailing Management Area Local Study Area Temporal Domain

Flow regimes were predicted across the PTMA assessment site for key stages in the development of the TMF, which include 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, following 51.5 years of operation, marking the end of the operation phase.
- **Post-closure** – The TMF enters stages 4 and 5 during the Project closure phase.

11.5 Valued Components

Groundwater quantity was selected as a valued component (VC) as identified in the BC Environmental Assessment Office's AIR (2011) and the Canadian Environmental Assessment Agency et al.'s (2010) Comprehensive Study Scope of Assessment. Groundwater cannot be separated into distinct components that respond differently to environmental effects.

Groundwater quantity is valued as a source of water for human consumption and for its intrinsic links with surface water. Changes to fluxes through the subsurface affect water levels and flows in surface waterbodies, thereby influencing aquatic ecosystems.

Groundwater quantity 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 11.5-1). Groundwater is protected under the *Canada Water Act* (1985), BC *Water Act* (1996), and BC *Water Protection Act* (1996).

Table 11.5-1. Identification and Rationale for Groundwater Quantity Valued Component Selection

	Identified by*				
VC	**F**	**G**	**P/S**	**O**	**Rationale for Inclusion**
Groundwater Quantity	X	X	-	X	First Nations and Nisga'a Nation value aquatic ecosystems, which receive a component of their water from groundwater base flow. The BC MOE specifies that proposed resource development projects must take measures to ensure groundwater resource quantities are maintained for present and future uses (BC MOE 2012). Manipulation of groundwater levels resulting from mine dewatering and waste disposal poses the possibility of effects on groundwater levels and discharge rates to surface water downstream. LRMPs in the regional area provide management direction to protect groundwater quality and quantity resources.

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

Groundwater quantity 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. 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).

The Tahltan Nation, wilp Skii km Lax Ha, 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; THREAT 2009; Gitxsan Chiefs' Office 2010). These are indirect references to groundwater quantity, because groundwater quantity affects surface water quantity, which in turn affects aquatic life habitat.

11.5.1 Valued Components Included in Assessment

Table 11.5-1 summarizes the rationale provided by Aboriginal groups and government agencies for the inclusion of groundwater quantity as a VC for the KSM Project.

11.5.2 Valued Components Excluded from Assessment

No VC pertaining to groundwater quantity was excluded from further assessment.

11.6 Scoping of Potential Effects on Groundwater Quantity

Changes in water levels are the key metric in assessing changes in groundwater quantity. A decline in water level is a manifestation of a decrease in the amount of water in storage. An increase in water level is akin to an increase in the amount of water in storage. Changes in water levels result from changes in groundwater flow rates and directions (rate and direction are referred to collectively as groundwater flow patterns). Changes in water levels and flow patterns may be driven by an imposed change in hydraulic gradient.

Potential effects of the Project on groundwater quantity may be triggered by changes to boundary conditions or properties of the subsurface environment. Changes to boundary conditions would result from alterations of the surface water environment. For example, the introduction of a large artificial pond could provide a significant new source of recharge, thereby creating a local downward flow path. Excavation and dewatering of a pit could result in a groundwater sink, thereby resulting in local flow radially into the pit. Alterations of surface water levels directly connected to the groundwater result in changes to hydraulic gradients, which in turn result in flow rate, flow direction, and ultimately water level changes.

Permeability is the key subsurface property that influences groundwater quantity. Physical barriers such as grout curtains reduce permeability, thereby reducing the local flow rate and possibly resulting in preferential flow in a different direction. Conduits such as tunnels or drainage pipes could create preferential flow pathways, and may behave as groundwater sinks. Any alteration of permeability could result in alteration of groundwater levels.

A number of KSM Project mine components include alterations of the surface water environment, construction of physical barriers in the subsurface, or boring of conduits (identified in Table 11.6-1). Pits and block cave mines are expected to behave as groundwater sinks while dewatering is ongoing. Reservoirs (TMF cells, WSF pond) are expected to produce hydraulic gradients favouring drainage into the adjacent groundwater environment. Tunnels may act as conduits. Seepage cut-off walls are installed as intentional physical barriers to control seepage of water from reservoirs containing contact water. Planned reclamation is expected to change how these components interact with the groundwater environment (e.g., reduction of recharge), but not necessarily bring about return to baseline conditions. Project components with potential effects are identified in Appendix 11-E, with specific reference to effects during each Project phase.

11.6.1 Construction

Changes to groundwater flow arising from interactions with mine components may occur as soon as manipulations of the surface water commence or as soon as conduits or physical barriers have been introduced into the subsurface. Components that would interact with groundwater quantity during the construction phase are identified in Appendix 11-H. Pit dewatering may commence in the Mitchell and Sulphurets pits as stripping progresses. Tunnels excavated during the construction phase may begin to accept groundwater seepage. Seepage cut-off walls constructed in the dam foundations will begin to restrict seepage. Construction of TMF starter dams and seepage collection dams, and the East Catchment diversion tunnel will begin to interfere or reduce the groundwater discharge to the downstream creeks.

Table 11.6-1. Potential Effects from Project on Groundwater Quantity

Project Area	Alteration of Groundwater Levels, Flow Rates, and Directions due to Changes in Boundary Conditions	Alteration of Groundwater Levels, Flow Rates, and Directions due to Changes in Permeability
Mine Site		
Camp 3: Eskay Staging Camp		
Camp 7: Unuk North Camp		
Camp 8: Unuk South Camp		
Coulter Creek Access Corridor		
Mitchell operating camp		
McTagg Rock Storage Facility		
McTagg Twinned Diversion Tunnels		X
McTagg Power Plant		
Mitchell Rock Storage Facility		
Camp 4: Mitchell North Camp (for MTT construction)		
Mitchell Ore Preparation Complex		
Mine Site Avalanche Control		
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		
Mitchell Truck Shop		
Water Storage Facility	X	X
Camp 9: Mitchell Initial Camp		
Camp 10: Mitchell Secondary Camp		
Water Treatment and Energy Recovery Area		
Sludge Management Facilities		
Sulphurets laydown area		
Sulphurets-Mitchell Conveyor Tunnel		X
Sulphurets Pit	X	X
Kerr Rope Conveyor		
Kerr Pit	X	X
Camp 2: Ted Morris Camp		
Explosives Manufacturing Facility		
Temporary Frank Mackie Glacier access route		
Camp 1: Granduc Staging Camp		

(continued)

Table 11.6-1. Potential Effects from Project on Groundwater Quantity (completed)

Project Area	Alteration of Groundwater Levels, Flow Rates and Directions due to Changes in Boundary Conditions	Alteration of Groundwater Levels, Flow Rates and Directions due to Changes in Permeability
Processing and Tailing Management Area		
Mitchell-Treaty Twinned Tunnels (MTT)		X
Construction Access Adit		
Mitchell-Treaty Saddle Area		
Camp 6: Treaty Saddle Camp		
Camp 5: Treaty Plant Camp		
Treaty Operating Camp		
Treaty Ore Preparation Complex		
Concentrate Storage and Loadout		
North Cell Tailing Management Facility	X	X
East Catchment Diversion		X
Centre Cell Tailing Management Facility	X	X
South Cell Tailing Management Facility	X	X
Treaty Creek Access Corridor		
Camp 11: Treaty Marshalling Yard Camp		
Camp 12: Highway 37 Construction Camp		
Off-site Transportation		
Highway 37 and 37A		

X = interaction between component and effect.

Construction of the basal drains under the Mitchell and McTagg RSF may affect the groundwater discharge to the valley bottoms to some degree. Overall effects on groundwater quantity during the construction phase are expected to be low, in comparison with the effects during the mine operation and post-closure phases.

11.6.2 Operation

Groundwater flow patterns would evolve alongside infrastructure development during the mine operation years. Potential effects arising due to different Project areas and components are identified in Appendix 11-H, and discussed below.

Mitchell Pit and Block Cave – Excavation and dewatering of the Mitchell Pit and Block Cave will be ongoing during the operation phase, reaching maximum depth and extents at the end of operation. Therefore, extents of the groundwater sink created by the Mitchell mines are expected to be greatest at the end of the operation phase.

Kerr Pit – Excavation of the Kerr Pit will commence at Year 27 of the operation phase. Development of a groundwater sink is expected due to dewatering. The Kerr Pit is located in the alpine highlands above Sulphurets Lake and Creek, an interpreted groundwater recharge zone.

Sulphurets Pit – Excavation and dewatering of the Sulphurets Pit will be ongoing during the operation phase, and complete by Year 27. Following excavation, the pit will be back-filled with waste rock from the Kerr Pit. Upon attainment of maximum depth a basal drain will be installed, diverting seepage entering the waste rock pile to the WSF. Therefore, the backfilled Sulphurets Pit is expected to remain dewatered for the remained of the operation.

Iron Cap Block Cave Mine – Excavation of the Iron Cap Block Cave Mine will commence during Year 32 of the operation phase, reaching maximum extents at the end of operation. Extents of the groundwater sink created by the mine are expected to be greatest at the end of the operation phase.

Mitchell and McTagg RSFs – Progressive raising of the waste rock piles will introduce an extension to the subsurface environment above the pre-existing ground surface. This may result in mounding of the water table, and a deviation from the natural shallow groundwater flow direction along the valley floors.

Water Storage Facility – The WSF reservoir will have a variable water level during the operation phase. Potential effects have been investigated with consideration for the maximum design water level at the end of operation, whereby the induced changes in groundwater flow patterns would be greatest.

Tailing Management Facility – The onset of discharge into the TMF will result in changing surface water boundary conditions in the PTMA. Filling will be limited to the North and Centre cells for the first 25 years of operation. Effects on flow patterns will evolve with filling of the South Cell. Groundwater flow modelling investigates flow patterns at stages 1 and 3 of TMF construction during the operation phase, representing the maximum extent of the potential effects on groundwater.

Tunnels – All tunnels present during the operation phase (identified in Appendix 11-H) may accept seepage, alter local flow patterns, and act as preferred flow pathways for groundwater.

11.6.3 Closure and Post-closure

It is not expected that any new Project areas will result in interaction with groundwater quantity during the closure phase. Many Project areas will be reclaimed by the end of the operation phase and during the closure phase, resulting in changes to the ways these components interact with the groundwater environment. Components expected to interact with groundwater quantity during the closure phase are identified in Appendix 11-E and discussed below.

Mitchell Pit and Mitchell Block Cave – Cessation of dewatering and construction of a dam will create conditions for development of a pit lake (planned water elevation of 810 masl) in the Mitchell Pit and Block Cave Mine**.** The pit is expected to remain a groundwater sink, as the planned lake elevation is below local groundwater levels.

Kerr Pit – Dewatering of the Kerr Pit will cease at the end of operation, triggering rising groundwater levels locally. However the pit is expected to remain a groundwater sink, because the water level will be managed by collection of seepage through a drainage pipeline near the base of the pit. The drainage system design identifies that temporary ponding will occur after major precipitation events.

Sulphurets Pit and Rock Storage Facility – The Sulphurets Pit will be back-filled with waste rock from the Kerr Pit. The Sulphurets Pit is expected to remain dewatered via the basal drain through the closure and post-closure phases.

Iron Cap Block Cave Mine – Dewatering will cease at the end of operation. This is expected to result in complete submergence of the underground works in the Iron Cap Block Cave Mine. Groundwater would thus be allowed to flow freely through the cave according to the natural flow local gradient. Permanent alteration of local flow paths is possible due to the less restricted flow inside the excavations.

Mitchell and McTagg RSFs – The waste rock piles will have attained their maximum extents at the end of the operation phase. The potentiometric surface is expected to be permanently higher than pre-mining. Permanent deviations of flow directions along valley floors are possible. Any effect on groundwater quantity sourced in the Mitchell or McTagg RSF during the post-closure phase is expected to be steady-state in nature, because the facilities themselves will be in a static state.

Water Storage Facility – Contact water sourced at the Mitchell Pit, the Iron Cap Block Cave Mine, the RSF, the Kerr Pit, and the backfilled Sulphurets Pit will continue to drain into the WSF for the duration of the closure period. Simulations used for the effects assessment assumed the reservoir water elevation would be sustained at the maximum design level throughout the closure and post-closure phases.

Tailing Management Facility – Discharges of process water into the TMF will stop at the end of the operation phase. Tailing cell water elevations will remain static from end of operation through the closure phase. The surface of the tailing will be reclaimed. Water quality in the TMF cells is forecast to improve during the post-closure phase (as discussed in Chapter 14). Simulations used for the groundwater quantity effects assessment assumed the TMF cell water elevations would be sustained at the post-closure design level up to the end of the temporal domain.

Tunnels – All tunnels present during the closure phase (identified in Appendix 11-H) may accept seepage, alter local flow patterns, and act as preferred flow pathways for groundwater.

The closure phase has been integrated with the post-closure phase for the groundwater quantity effects assessment. Project component changes planned to take place during the closure phase, such as reclamation of certain components, were treated to be in their final state in the model used to predict flow patterns during the post-closure phase. The effects of the mine to groundwater quantity are expected to be the same at the closure and post-closure phases.

11.7 Potential for Residual Effects on Groundwater Quantity

The potential for residual effects on groundwater quantity was determined by assessing whether interactions between Project components and the groundwater environment would result in changes to groundwater levels, flow rate, or flow direction, after implementation of planned mitigation measures. Interactions were examined using groundwater flow modelling. Mitigation measures included in infrastructure design were integrated into the simulations. This includes measures designed to mitigate effects on other VCs that may have adverse effects on groundwater quantity. Modelling was also used to guide development of additional mitigation measures, which have been included in the Groundwater Management Plan (Section 26.15). Potential residual effects and mitigation measures that address these effects are summarized in Table 11.7-1.

Potential residual effects arising from the two primary effect pathways (alterations of boundary conditions and permeability) are identified, following by planned mitigation measures that address these effects. An overview of the modelling exercises is then provided, followed by results of the modelling exercises. The model results are interpreted for identification of residual effects arising from the combination of the two effect pathways.

11.7.1 Changes in Groundwater Levels and Flow Patterns due to Alterations in Boundary Conditions and Mitigation

Modifications to the surface water environment are planned in a number of Project areas, as discussed in Section 11.6. The Mine Site model included simulation of dewatering at the four deposits (Mitchell Pit and Block Cave, Sulphurets Pit, Kerr Pit, and Iron Cap Block Cave Mine), and development of a pond at the WSF reservoir and the associated seepage collection pond. The PTMA model included simulation of tailing and ponds in the three TMF cells and the associated seepage collection ponds.

Dams built for the TMF and WSF reservoirs include sub-foundation seepage control mechanisms. These are alterations to the permeability of the medium, with potential residual effects discussed in Section 11.7.2. Identification of potential residual effects was conducted with consideration for the combined effects of changes to boundary conditions and changes to permeability (Section 11.7.5)

No mine infrastructure plans include design components specifically intended to mitigate effects on groundwater quantity. However, the closure plans for certain mine components that interact with the groundwater environment provide for a return towards natural drainage conditions.

Dewatering of the Mitchell Pit will cease following completion of extraction. This will allow development of a pit lake that will rise to a planned level at 810 masl in the pit, which is lower than the valley base in the current pre-mining conditions. The water levels surrounding the pit will tend to recover towards pre-existing conditions. However, a complete return to baseline water levels is not expected. Maintenance of a pit lake water level below the ambient water level is planned, partly as a mitigation measure to contain poor quality water (discussed in Chapters 12 and 14).

A Tailing Management Facility Management and Monitoring Plan has been created (Section 26.4). This plan describes the discharge of water from the cells following cessation of operation when water quality is sufficient. Removal of the TMF ponds is expected to result in a trend towards baseline groundwater flow conditions.

Table 11.7-1. Potential Residual Effects on Groundwater Quantity

VC	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 Quantity	Construction	Mine Site	All de-watered mines (pits and block caves)	Alteration of boundary conditions: imposition of arificial lower water levels in mine workings (de-watering). Water levels lower than baseline will be sustained to perpetuity in most of these components.	None	Cessation of de-watering will provide for partial recovery of water levels, however this does not constitute mitigation.	Yes	Decrease in groundwater levels, creation of a groundwater sink with radial inward flow.
	Operations	Mine Site and PTMA	Tunnels	Alteration of permeability: creation of prefered flow conduits.	Design Change	Concrete liners in tunels where they intersect high-permeability zones.	No	These components have been incorporated into groundwater flow mdoelling, but no effects water levels, flow rates, or directions have been detected.
	Operations	Mine Site	decomissioned tunnels, Iron-Cap Mine following submergence	Alteration of permeability: creation of preferred flow conduits; homogenization of pore pressure between hydrogeologically distinct zones.	Design Change	Concrete liners in tunnels where they intersect high-permeability zones.	No	Permanent alterations of permeability will exist in these locations, but no effects on groundwater levels, flow rates, or flow directions have been detected.
	Operations	Mine Site	Mitchell & McTagg Rock Storage Facilities	Alteration of boundary conditions: water level mounding resulting from rising ground elevation due to placement of waste rock.	None	None	No	Permanent increase in elevation of water table. Temporary flow reversal in shallow groundwater near Mitchell Pit during operations phase.
	Construction	Mine Site	WSF: Water Storage Pond, Water Storage Dam (seepage cut-off wall), seepage interception tunnels and Seepage Collection Pond	- Alteration of permeability: seepage cut-off walls (decrease in permeability), seepage collection tunnels (preferred flow conduits). - Alteration of boundary conditions: creation of artificial lake.	None	Many components of the WSF are project mitigation measure to control seepage of contact water, which result in adverse effects on groundwater quantity.	Yes	Permanent alteration of permeability below dams. Change in groundwater flow rate and direction. Decrease in natural basin drainage, possibly affecting discharge to surface water.
	Construction	PTMA	TMF cells, seepage collection ponds, and reservoir dams	- Alteration of permeability: grout curtains decreasing permeability. - alteration of boundary conditions: creation fo artificial lakes.	Monitoring and adaptive management	Implementation of TMF monitoring and management plan, with provisions to drain TMF lakes when water quality is adequate for discharge.	Yes	Permanent alteration of permeability below dams. Change in groundwater flow rate and direction. Decrease in natural basin drainage, possibly affecting discharge to surface water.

If effects will likely differ in scope due to disparate Project components or areas, then use multiple lines to demonstrate these causal relationships and varying mitigations.

11.7.2 Changes in Groundwater Levels and Flow Patterns due to Alterations of Permeability and Mitigation

Alterations of permeability are planned in a number of Project areas, as discussed in Section 11.6. These may have residual effects on groundwater quantity because they affect flow rates and directions. LSA models account for low-permeability grout curtains included in design plans for dams at the TMF and WSF. Deposition of waste rock in the Mitchell and McTagg RSF and the Sulphurets Pit will create a high-permeability medium that did not previously exist. Preferential flow paths potentially created by tunnels and submerged areas of pits and block cave mines have also been included in models.

According to the engineering design, the tunnels will be lined with concrete liners, therefore it is expected that the quantity of groundwater seepage into and through the tunnels would be small during operation and post-closure. In addition, certain tunnels will be decommissioned after the mine is closed, as identified in Chapter 4. Decommissioning will involve capping the tunnels at all portals. It is expected to further reduce the quantity of seepage through the tunnels, because drainage to ground surface will no longer be allowed. The overall effect of the tunnels on the adjacent groundwater environment would be insignificant during operation and post-closure.

No mitigation is planned for constructed grout curtains. These are permanent design features that cannot be removed in a manner that allows a return to baseline groundwater flow conditions. Grout curtains are installed to reduce seepage of contact water along sensitive flow paths. The intended result is a reduction in potential residual effects on groundwater and surface water quality (Chapters 12 and 14).

No mitigation is planned for the flow paths created by pit lakes and submerged underground works.

11.7.3 Changes to Groundwater Flow and Water Levels Predicted by Modelling Exercises

Rescan conducted groundwater flow modelling with the objective of predicting changes to groundwater flow rates and directions and groundwater levels. Well-calibrated three-dimensional representative models were developed for each of the Mine Site and PTMA LSAs. Complete details of modelling methodologies and results are presented in Appendix 11-E. The groundwater quantity effects assessment is largely based on the results of the modelling exercises conducted by Rescan.

The base-case model represents the expected scenario, with recharge and hydraulic conductivity inputs calibrated to field water level and stream flow measurements. Sensitivities associated with the uncertainties of the subsurface geological materials and the groundwater recharge rates were carried out to investigate the possible maximum effects or worst-case scenarios. The simulations of upper and lower cases accounted for uncertainty in the permeability of the geological materials. The upper-case simulations included hydraulic conductivities of half an order of magnitude higher than those in the base case. In the WSF area, to account for the potential preferential flow paths, the identified calcareous sandstone and siltstone in the WSD foundation and abutments was simulated with a hydraulic conductivity of 1×10^{-3} m/s for the upper case. The lower-case simulations included conductivities of half an order of magnitude lower than base case. The simulations of 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 simulation included recharge twice that of the base-case model. The dry year simulation included recharge half that of the base case.

In addition, for verification purposes, 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 flow, including a higher recharge rate (30% of the main annual precipitation [MAP]) under the Mitchell and McTagg RSFs, a higher recharge rate (5% of the MAP) at the Sulphurets Pit backfill RSF, and one order of magnitude lower effective porosities of the bedrock units, respectively. Sensitivity simulations were also done with the PTMA area post-closure model for the model inputs, including one order of magnitude-higher permeability of the tailing, flow boundary conditions for the tailing cells, and one order of magnitude lower effective porosities of the bedrock, respectively.

Local-scale hydrogeological models were also carried out by the engineers of the Project's engineering designs. BGC conducted flow modelling for design and estimation of groundwater inflows into the pits and block caves (BGC 2010a, Appendix 11-I; 2011c, Sub-Appendix F5 of Appendix 4-C; 2012, Sub-Appendix F12 of Appendix 4-C). KCB conducted flow modelling for WSD and associated seepage mitigation system design (KCB 2013a, Appendix 4-J; 2013c, Appendix 11-F). KCB also conducted flow modelling for the design of TMF dams and associated seepage mitigation systems (KCB 2013b, Appendix 4-AC; 2013d, Appendix 11-G).

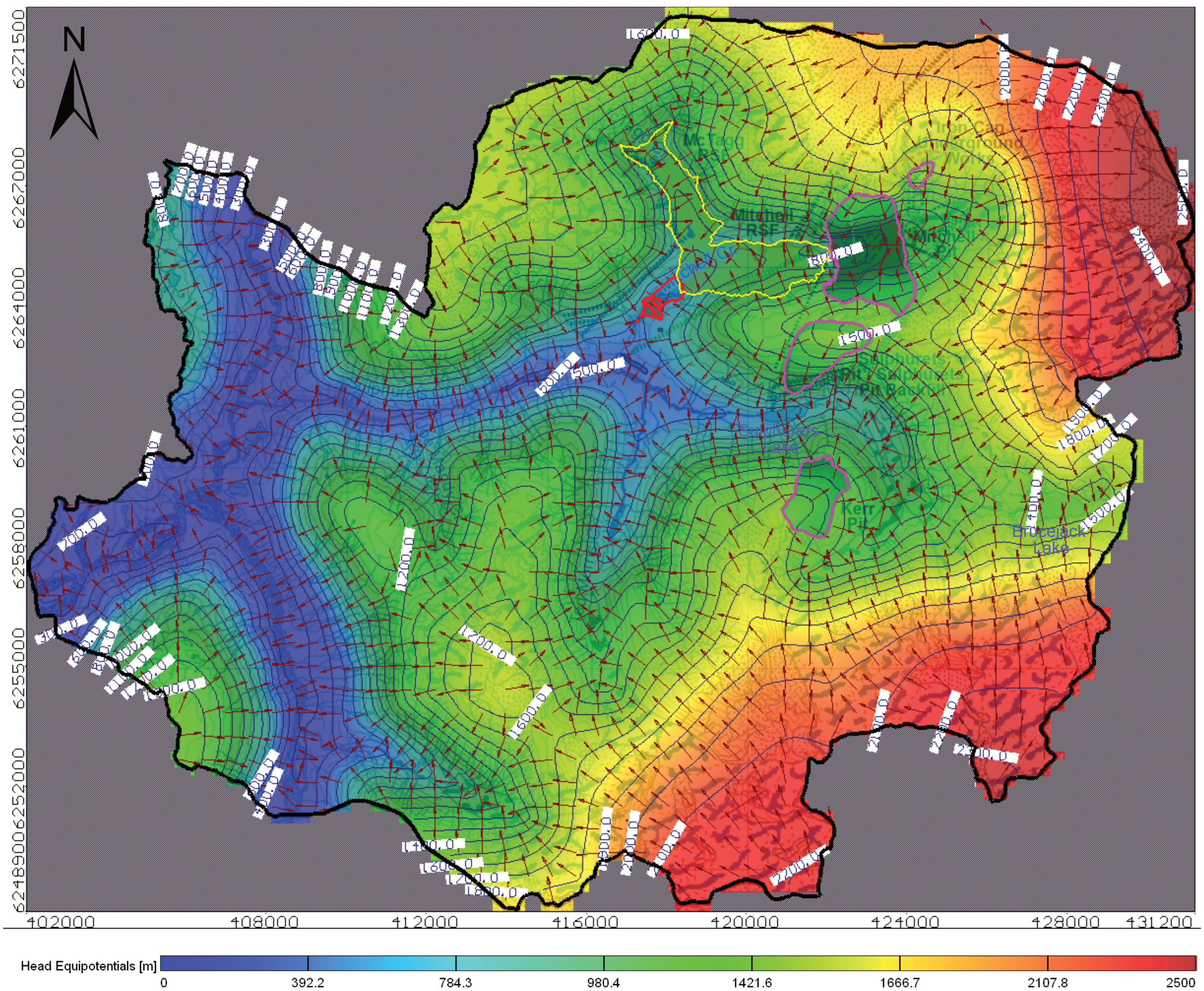
11.7.3.1 Mine Site Local Study Area

Baseline (pre-mining) and predicted base case groundwater levels for the Mine Site LSA are presented in Figures 11.7-1 and 11.7-2, respectively. Predicted flow path lines for the base case at end of operation and post-closure are presented in Figures 11.7-3 and 11.7-4, respectively. Flow path lines generated by sensitivity (worst-case) simulations (upper and lower cases, wet-year and dry-year scenarios) at end of operation and post-closure are presented in Figures 11.7-5, and 11.7-6, respectively. The additional sensitivity simulations of the Mine Site post-closure model demonstrate similar flow patterns as those in the base case, 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.

11.7.3.1.1 Pits and Block Caves

Dewatering will result in radial-inward groundwater flow to open pits and block caves, with water level declines in the nearby groundwater environment. Maintenance of seepage collection and water level management during post-closure will sustain the groundwater sink effect in the Mitchell Pit and Block Cave, the Sulphurets Pit and waste rock backfill, and the Kerr Pit. No water level management is planned at the Iron Cap Block Cave Mine during post-closure; therefore, no residual effect is expected at this time.

Water levels surrounding the pits and block caves will be depressed during the operation phase. The water levels to the west of the Mitchell-Sulphurets confluence were predicted to have no detectable changes. Depression of the phreatic surface has been predicted to reach as much as 1 km to the east of the mines in the upper Sulphurets and Mitchell Valleys.



Legend
- Head Contour
- Flow Direction
- 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
- Pit & Block Cave
- Rock Storage Facility
- Water Storage Facility

Figure 11.7-1

Baseline Groundwater Levels and Flow Directions in the Mine Site

Similar effects on water levels are predicted post-closure. The phreatic surface is predicted to recover somewhat (relative to the operation phase) along the Mitchell Valley downstream of the Mitchell Pit. A recovery of water levels is predicted around the Iron Cap Block Cave Mine, but not to pre-mining conditions. No change in water levels along the base of the Mitchell Valley up-gradient to the east of the Mitchell Pit is predicted. No detectable change in water levels (relative to the operation phase) is predicted near the Sulphurets and Kerr pits, or along the Sulphurets Valley.

All sensitivity (worst-case) scenarios indicate behaviour of the Mitchell Pit as a groundwater sink throughout operation and post-closure. Results for the Iron Cap Block Cave Mine are consistent among the base and worst cases. The wet, dry, and lower cases indicate behaviour of the Kerr and Sulphurets pits as groundwater sinks throughout operation and post-closure. The upper case results indicate a component of flow entering the Kerr and Sulphurets pits could potentially discharge towards Sulphurets Creek.

11.7.3.1.2 Mitchell and McTagg Rock Storage Facilities

Groundwater levels are predicted to rise beneath the Mitchell and McTagg RSFs. A groundwater divide is predicted to develop towards the eastern end of the Mitchell RSF, with flow reporting into the Mitchell Pit in locales east of the divide. All other flow beneath the Mitchell and McTagg RSFs is predicted to report to the WSF pond, which is down the natural valley slope. The groundwater divide is predicted to disappear at post-closure, with development of a lake in the Mitchell Pit. All groundwater beneath the Mitchell and McTagg RSFs is predicted to report to the WSF pond post-closure. The sensitivity (worst-case) scenarios indicate flow patterns within the RSFs are consistent with the base case.

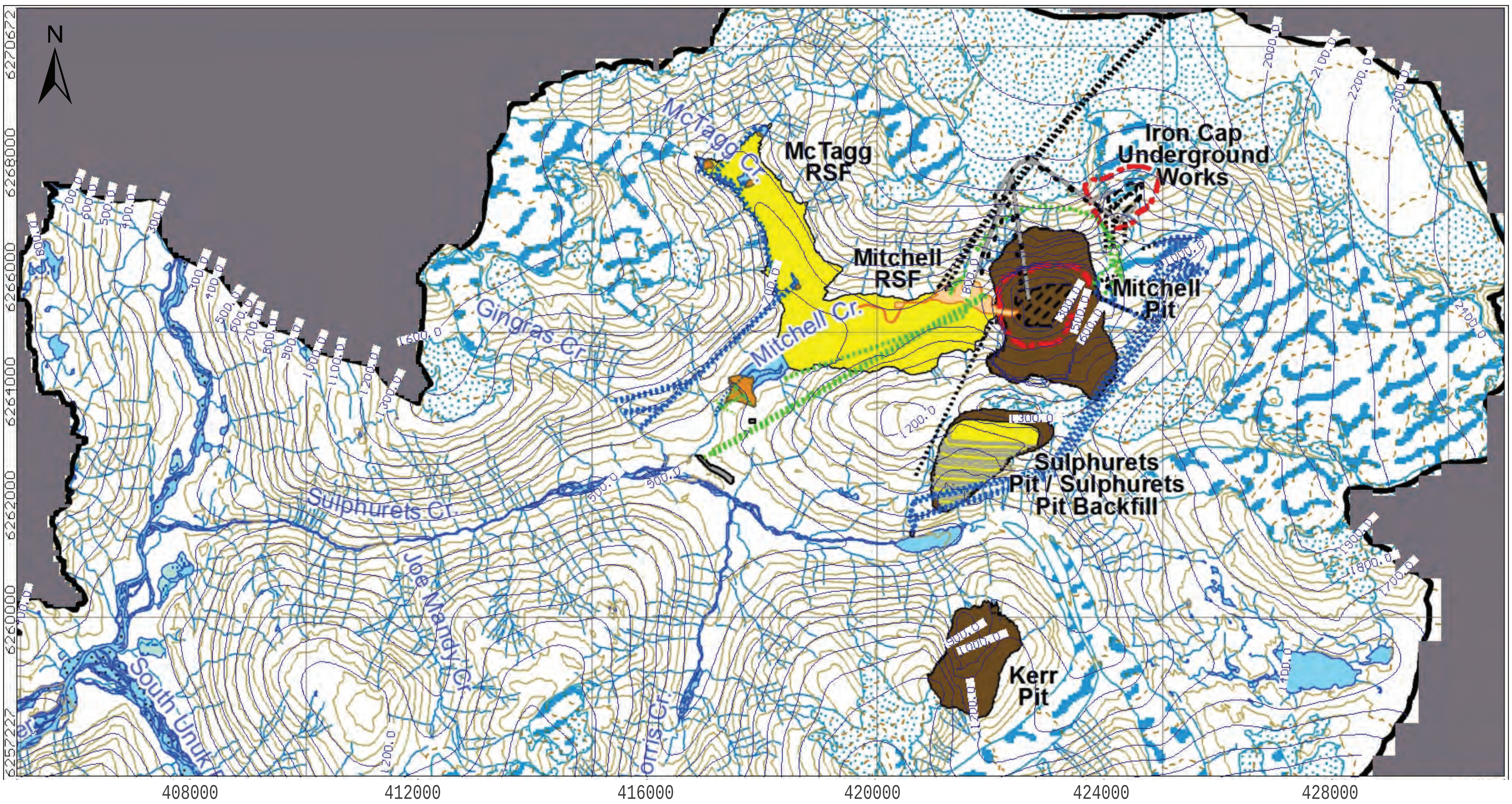
11.7.3.1.3 Water Storage Facility

Elevated water levels in the WSF pond will result in radial-outward hydraulic gradients, including a strong hydraulic gradient beneath the WSD. However, seepage control measures included in the WSF design are predicted to eliminate groundwater discharges from the Mitchell Valley up-gradient of the WSD, and no contact groundwater is predicted to discharge into the downstream Mitchell Creek under the seepage collection dam (Table 11.7-2). Base and sensitivity (worst case) flow path lines, which represent advective flow migration pathways, indicate that seepage from the WSF will be captured by the seepage mitigation and collection system. The upper-case results show flow passing around the south abutment, then reporting to the seepage recovery pond. The pond and seepage control mechanisms will be sustained into the far future; therefore, resulting changes in flow patterns will be permanent.

11.7.3.1.4 Combined Effects of all Project Components on Stream Base Flows in the Mine Site Local Study Area

Groundwater flow rates are predicted to substantially reduce in Mitchell Creek after pit dewatering becomes active and seepage control mechanisms are in place (Table 11.7-3). Base case and sensitivity (worst case) results indicate base flow will be substantially reduced in Mitchell Creek due to the dewatering of the upgradient Mitchell Pit and Iron Cap Block Cave Mine, the storage of waste rocks in Mitchell and McTagg valleys, and the Water Storage Facility and associated seepage mitigation system. No significant reductions in base flow are predicted for Sulphurets Lake or Sulphurets, Gingras, Ted Morris, and Joe Mandy creeks. Total base flow at the Unuk River confluence is predicted to decrease by 48%, due principally to the loss of base flow in Mitchell and McTagg creeks.

End of Operation



Legend

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

Post-closure

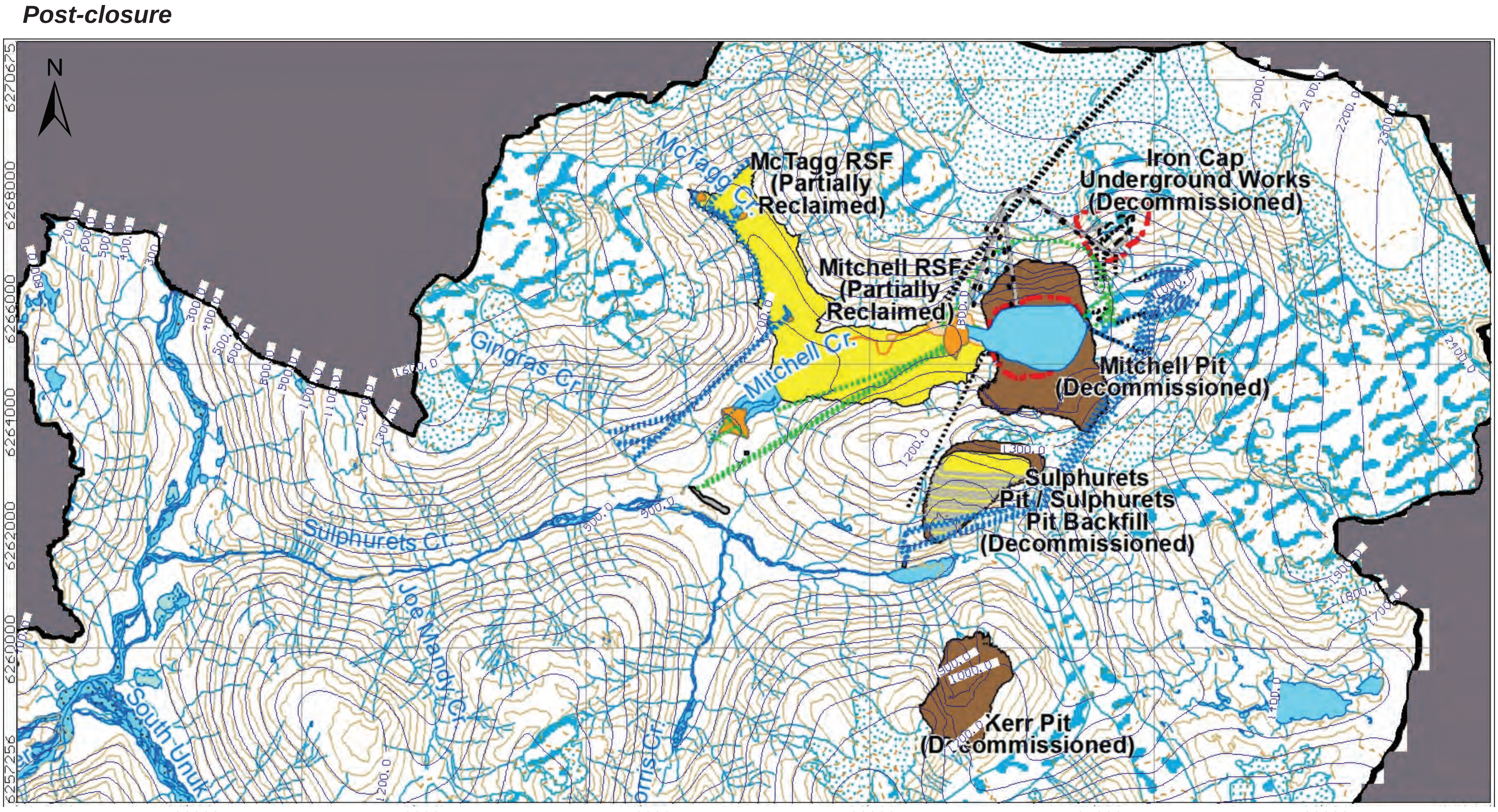
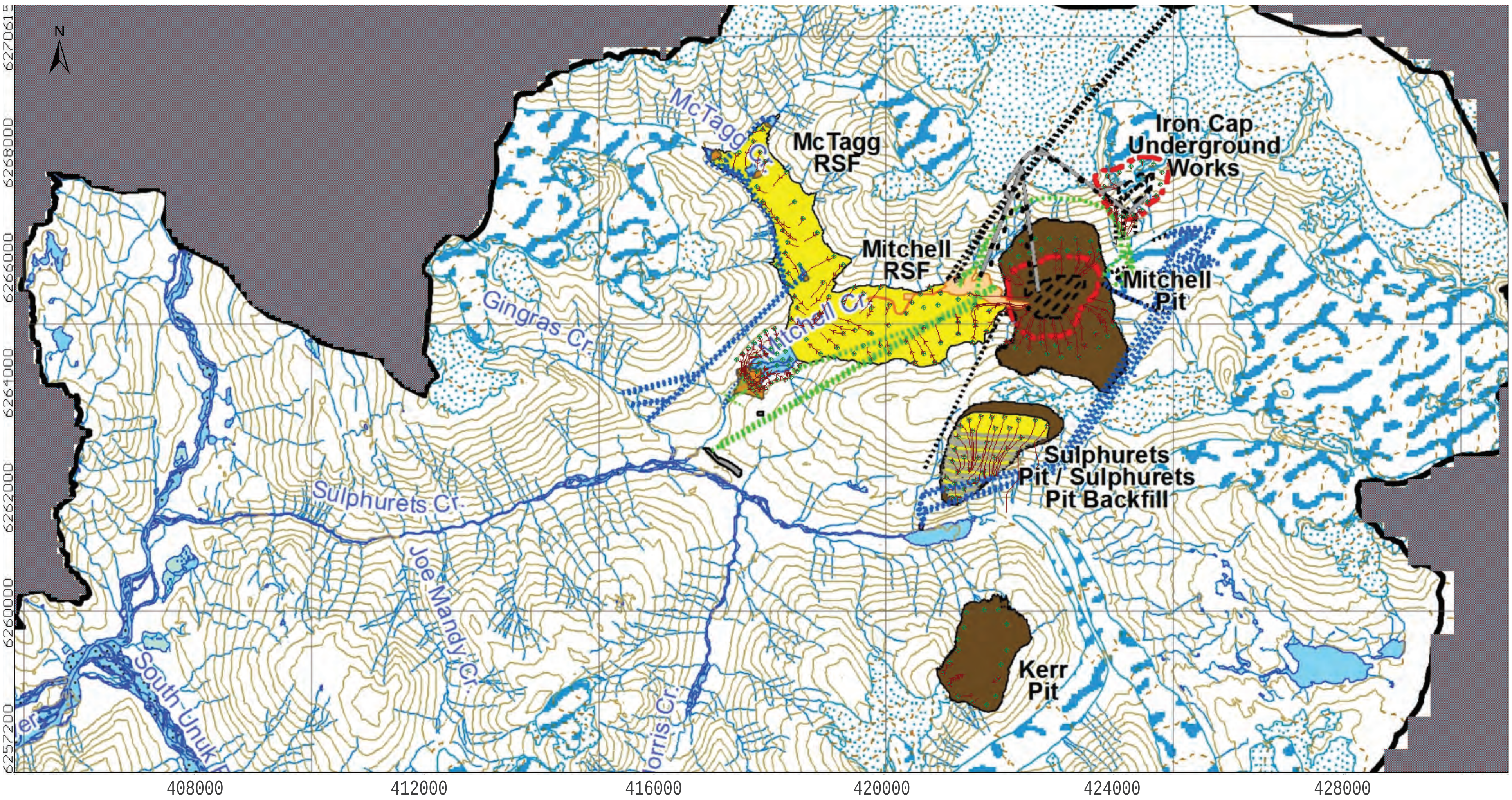
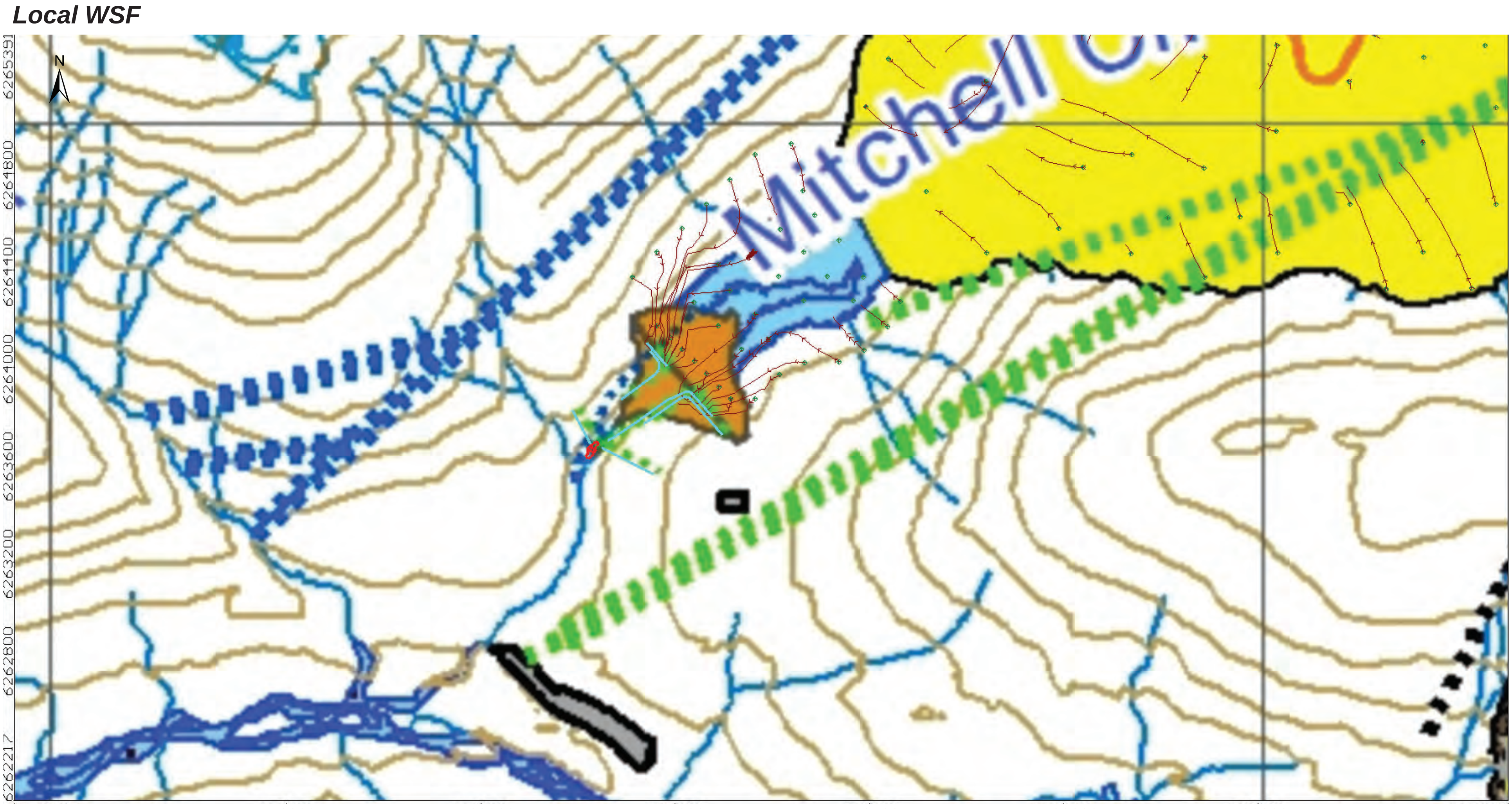


Figure 11.7-2

Predicted Groundwater Levels in the Mine Site (Base Case)



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

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Predicted Flow Path Lines in the Mine Site at End of Operation (Base Case)

Figure 11.7-3

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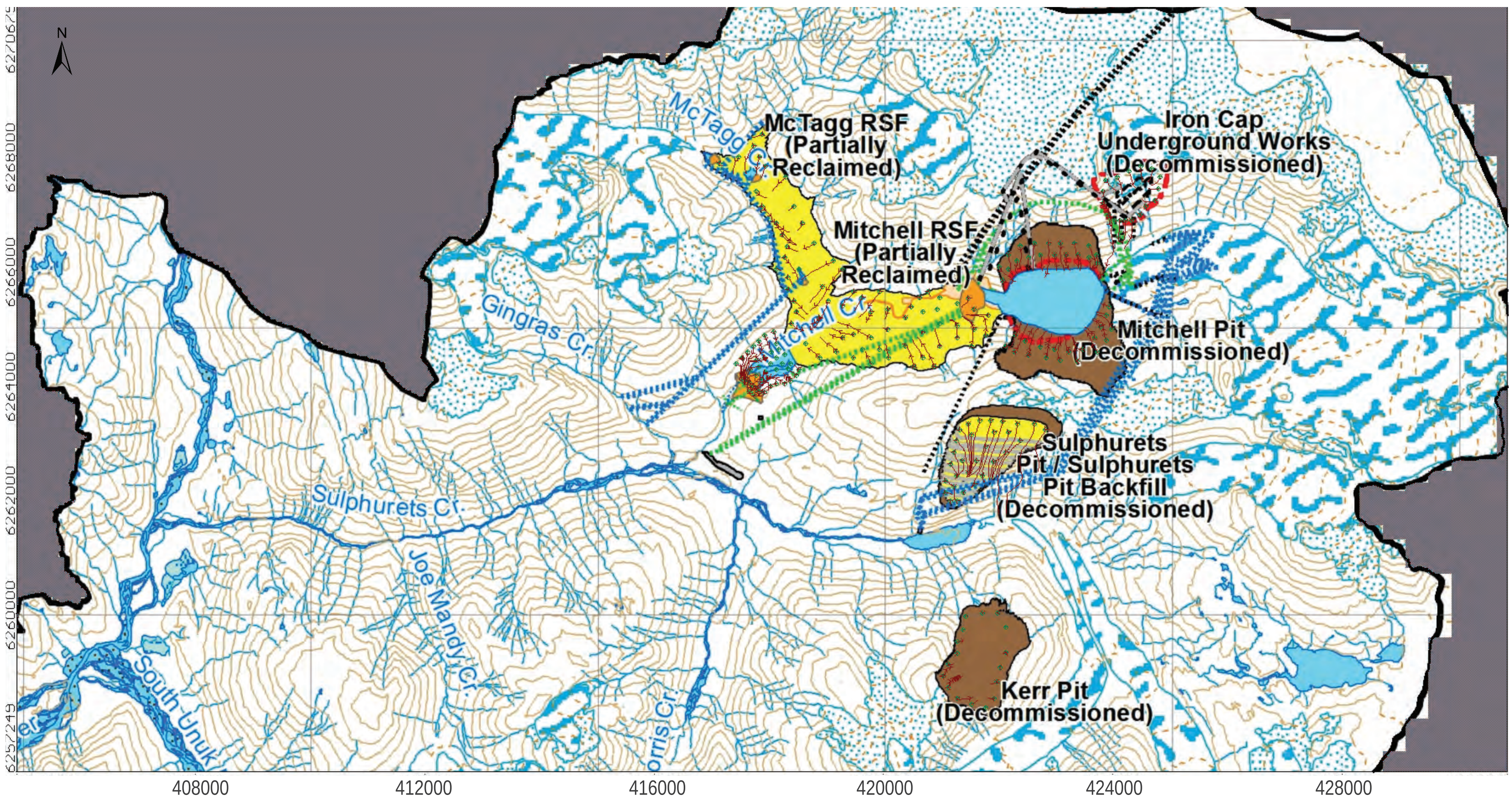
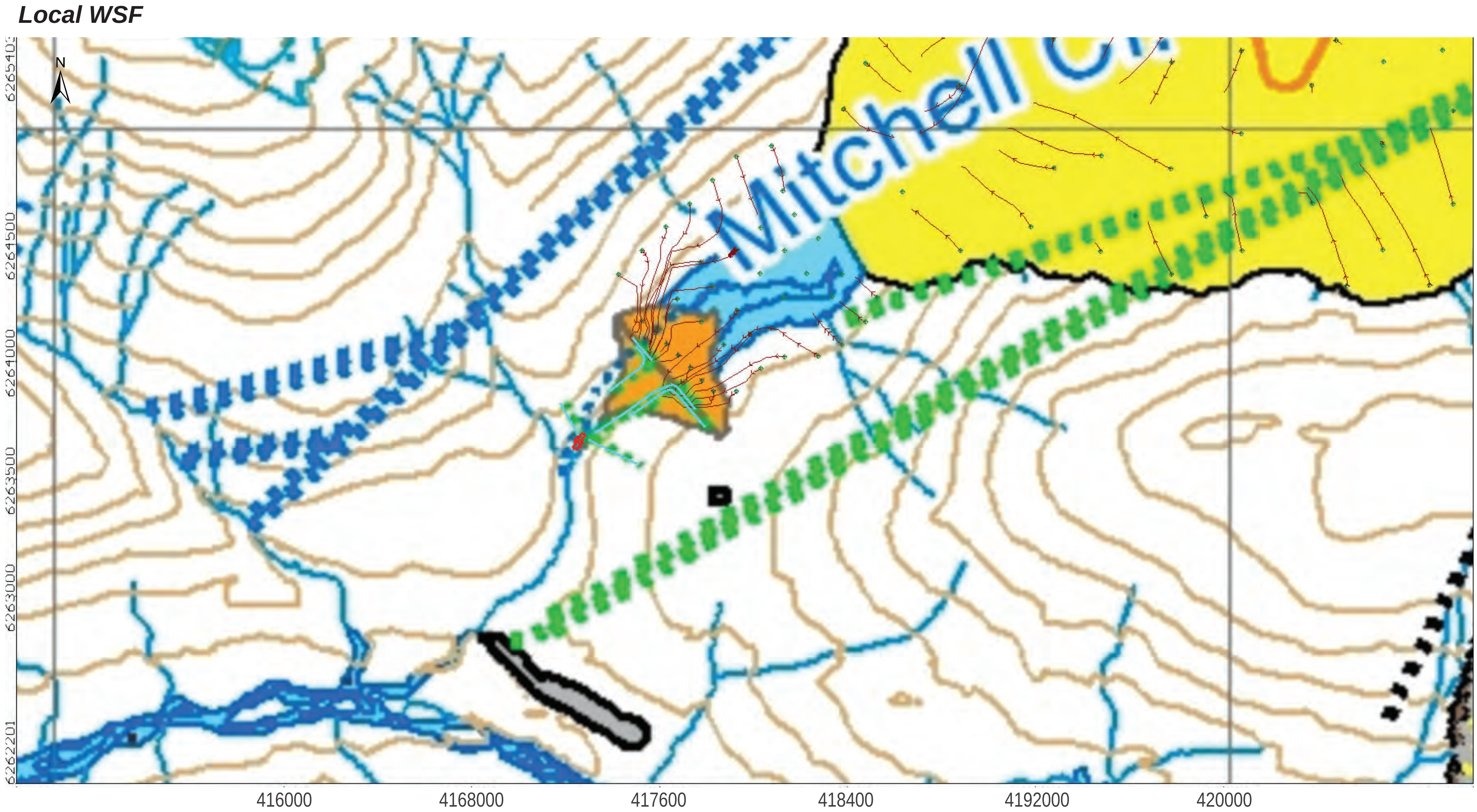


Local WSF



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 & Pit Lake
- Rock Storage Facility
- Underground Footprint
- Water Treatment Plant
- Ore Preparation Complex
- Glacier
- Icefield
- Creek/River/Lake
- Inactive Cells

Figure 11.7-4

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Predicted Flow Path Lines in the Mine Site Post-closure (Base Case)

Figure 11.7-4

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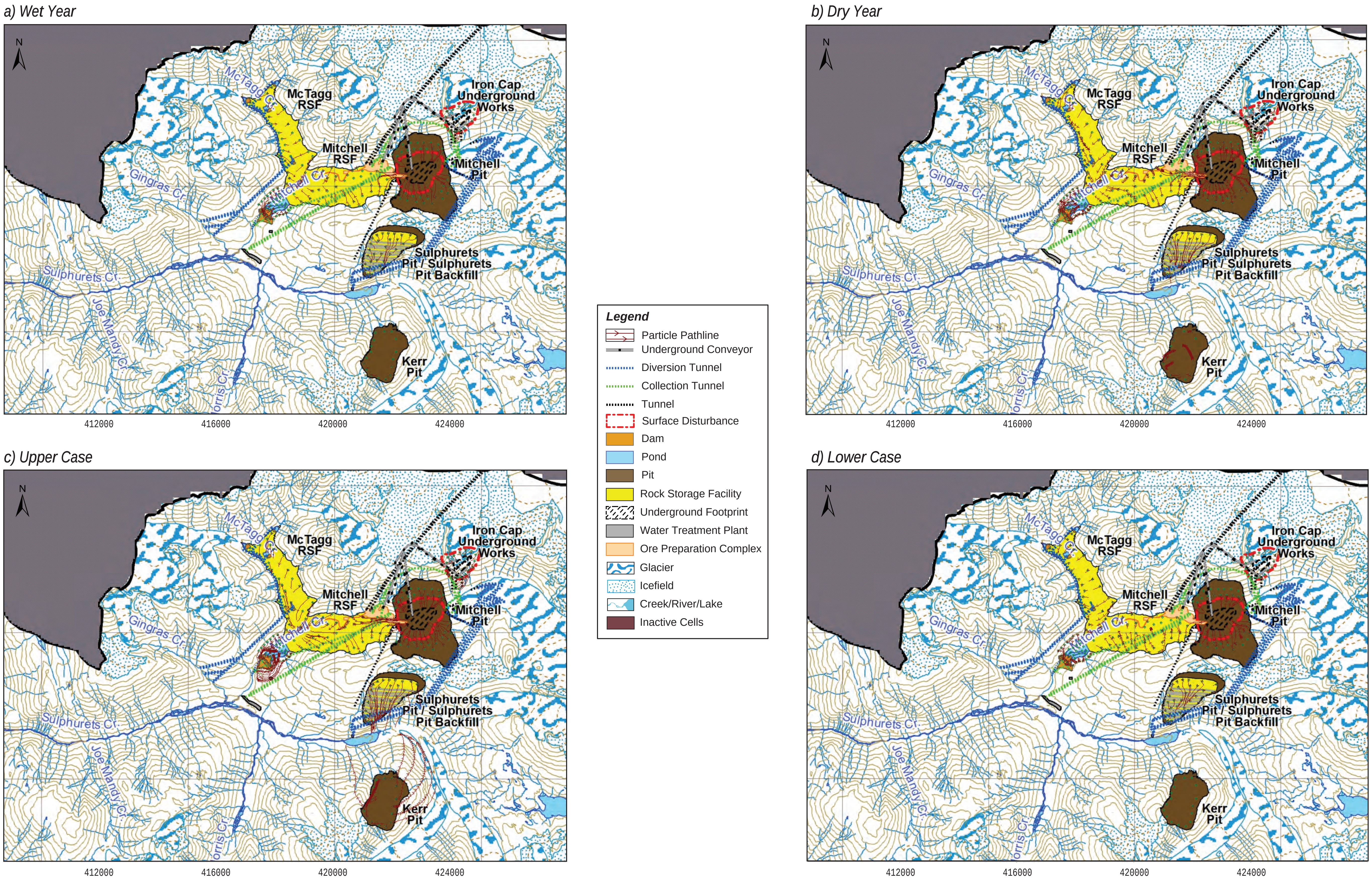

Note: Each mark on pathlines represents flow distance in 10 years.

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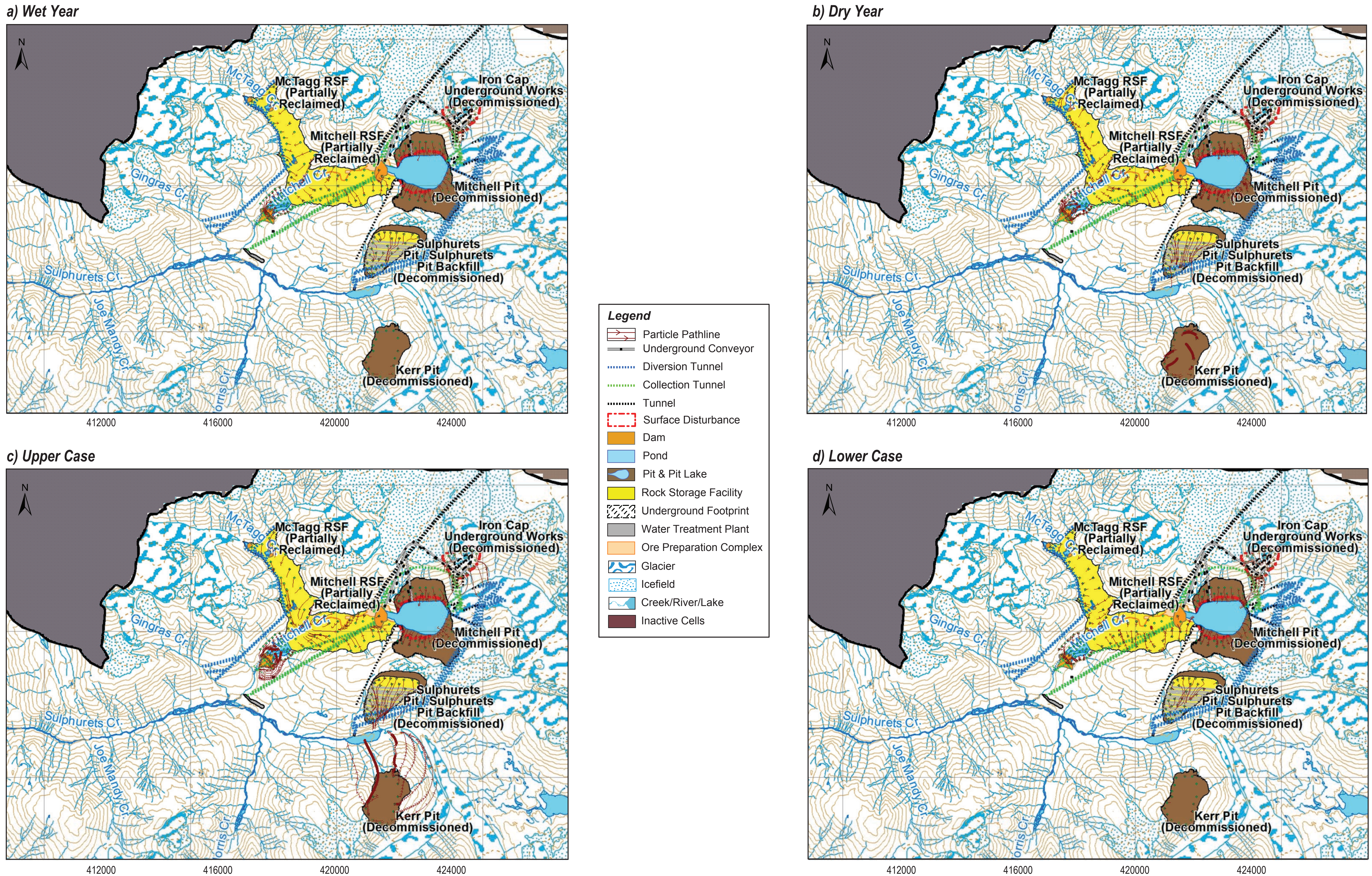
Figure 11.7-5

End of Operation Flow Path Lines in the Mine Site for Worst Case Scenarios



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

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Figure 11.7-6

Post-closure Flow Path Lines in the Mine Site for Worst Case Scenarios

Table 11.7-2. Simulated Flow Rates beneath the Water Storage Dam and Reporting to the Mitchell Creek Down-gradient

	End of Operation		Post-closure	
	m³/day	L/s	m³/day	L/s
Base Case				
Seepage under the WSD	2,755.3	31.9	2,755.3	31.9
Contact Water in Downstream Mitchell Creek under Seepage Dam	0.0	0.0	0.0	0.0
Upper Case – Higher Hydraulic Conductivity				
Seepage under the WSD	15,337.7	177.5	15,337.7	177.5
Contact Water in Downstream Mitchell Creek under Seepage Dam	0.0	0.0	0.0	0.0
Lower Case – Lower Hydraulic Conductivity				
Seepage under the WSD	651.3	7.5	651.4	7.5
Contact Water in Downstream Mitchell Creek under Seepage Dam	0.0	0.0	0.0	0.0
Wet Year – More Recharge				
Seepage under the WSD	2,785.6	32.2	2,785.6	32.2
Contact Water in Downstream Mitchell Creek under Seepage Dam	0.0	0.0	0.0	0.0
Dry Year – Less Recharge				
Seepage under the WSD	2,750.7	31.8	2,750.7	31.8
Contact Water in Downstream Mitchell Creek under Seepage Dam	0.0	0.0	0.0	0.0

The reduction in base flow predicted at the downstream end of Sulphurets Creek is expected to be compensated by diverted glacier melt water in the Mitchell Diversion Tunnels and McTagg Twinned Diversion Tunnels, and by discharge of treated water from the WSF and Water Treatment Plant. Effects on surface water quantity are discussed in Chapter 13.

11.7.3.2 Processing and Tailing Management Area Local Study Area

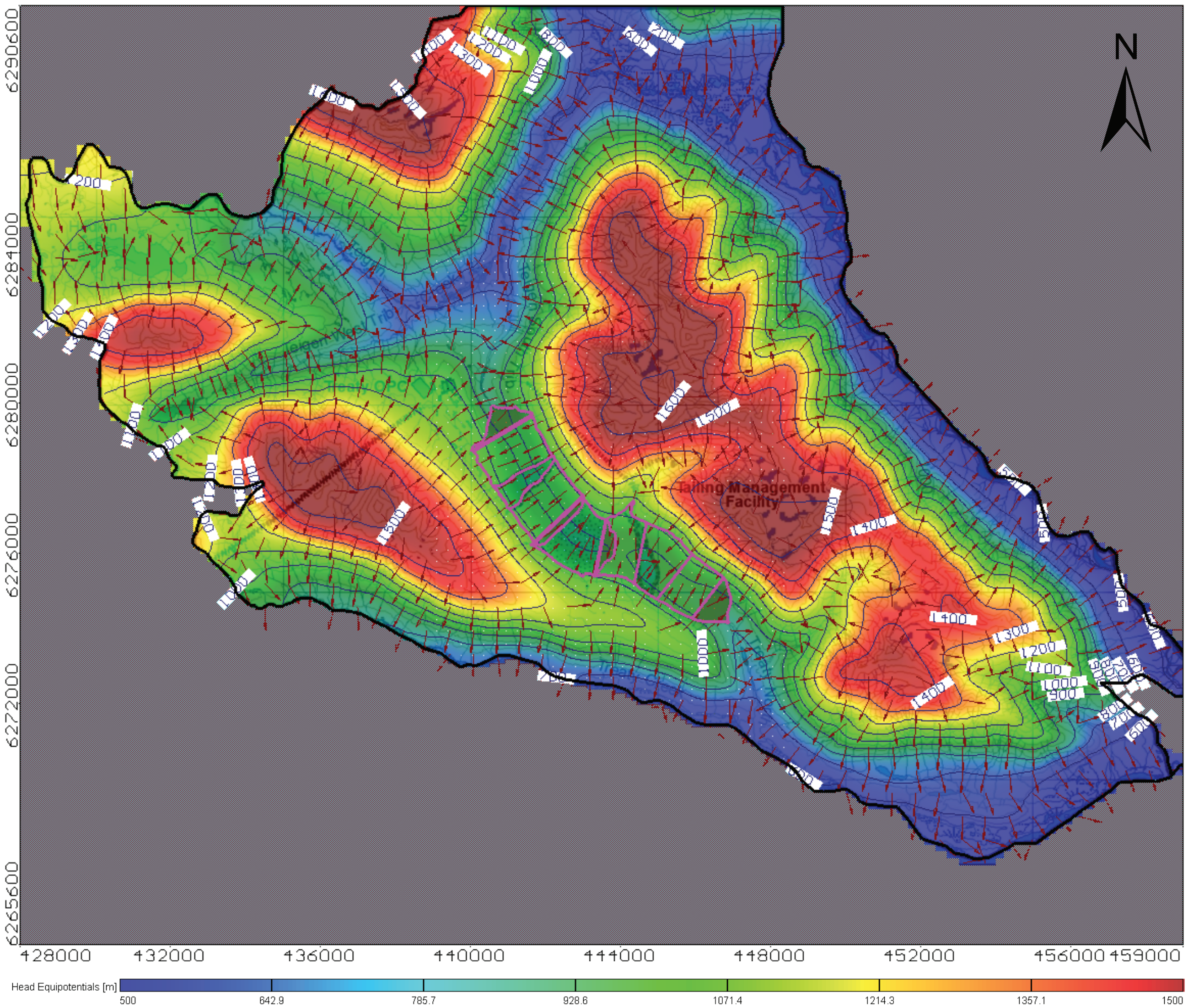
Baseline (pre-mining) and predicted base-case groundwater levels for the PTMA LSA (end of TMF stage 1, end of operation, post-closure) are presented in Figures 11.7-7 and 11.7-8, respectively. Predicted flow path-lines for base case at end of TMF stage 1, end of operation, and post-closure are presented in Figure 11.7-9. Flow path-lines generated by sensitivity (worst-case) scenarios at end of operation, the time at which effects on groundwater quantity are greatest in the PTMA, are presented in Figure 11.7-10.

Elevated water levels in the TMF cells will result in local water table mounding and radial-outward hydraulic gradients, including strong hydraulic gradients beneath the North Cell, Saddle (TMF stage 1), and southeast (TMF stage 3, 4, and 5) dams. However, seepage control measures included in the TMF design are predicted to considerably reduce groundwater discharges from the TMF (Table 11.7-4). Capture of seepage at the seepage recovery ponds (North Cell, Saddle, and southeast) is predicted. Sensitivity (worst-case) scenario simulation results also indicate capture of seepage leaving the TMF cells. The flow pathline results from the additional sensitivity simulations of the PTMA post-closure model, but with one order of magnitude higher permeability of the tailing or with one order of magnitude lower effective porosities of the bedrock, which indicates that the seepage from the TMF will be captured, as in the base case. The results from the simulation of the post-closure model but using general head boundaries (instead of the constant head boundaries) to represent the tailing cells, together with the one order of magnitude higher tailing K values, also verify that the seepage from the TMF is captured.

Table 11.7-3. Simulated Stream Base Flows Down-gradient of Project Components that Interact with Groundwater Quantity: Mine Site

		Base Case		Upper Case (*Higher K*)		Lower Case (*Lower K*)		Wet Year (*More Recharge*)		Dry Year (*Less Recharge*)	
Base flow to Creeks (m^3/s)	**Baseline Pre-mining**	**End of Operation**	**Post-closure**	**End of Operation**	**Post-closure**	**End of Operation**	**Post-closure**	**End of Operation**	**Post-closure**	**End of Operation**	**Post-closure**
Mitchell-McTagg Creeks to Mitchell/ Sulphurets Confluence	0.29	0.01	0.01	0.05	0.05	0.004	0.004	0.01	0.01	0.01	0.01
Sulphurets Creek Upper Reach	0.03	0.03	0.03	0.08	0.08	0.01	0.01	0.05	0.05	0.02	0.02
Sulphurets Creek Lower Reach	0.10	0.10	0.10	0.24	0.24	0.04	0.04	0.14	0.14	0.07	0.07
Sulphurets Lake	0.006	0.005	0.005	0.01	0.01	0.002	0.002	0.01	0.01	0.004	0.004
Ted Morris Creek	0.07	0.07	0.07	0.17	0.17	0.03	0.03	0.11	0.11	0.04	0.04
Joe Mandy Creek	0.04	0.04	0.04	0.06	0.06	0.02	0.02	0.06	0.06	0.02	0.02
Gingras Creek	0.04	0.04	0.04	0.04	0.04	0.02	0.02	0.07	0.07	0.02	0.02
Total Base Flow of Sulphurets Creek Outlet at Unuk River	0.58	0.30	0.30	0.65	0.65	0.12	0.12	0.46	0.45	0.19	0.19

K = hydraulic conductivity



Legend

Head Contour	Tailing Management Facility
Flow Direction	Seepage Collection Dam & Pond
Plant Site	Conveyor Tunnel
Tailing Dam	Diversion Tunnel
Tailing Pond	Glacier
TMF North Cell	Creek/River/Lake
TMF South Cell	Wetland
CIL Cell	Inactive Cells

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Baseline Water Levels and Flow Directions in the Processing and Tailing Management Area

Figure 11.7-7

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Table 11.7-4. Simulated Stream Base Flows Down-gradient of Project Components that Interact with Groundwater Quantity: Processing and Tailing Management Area

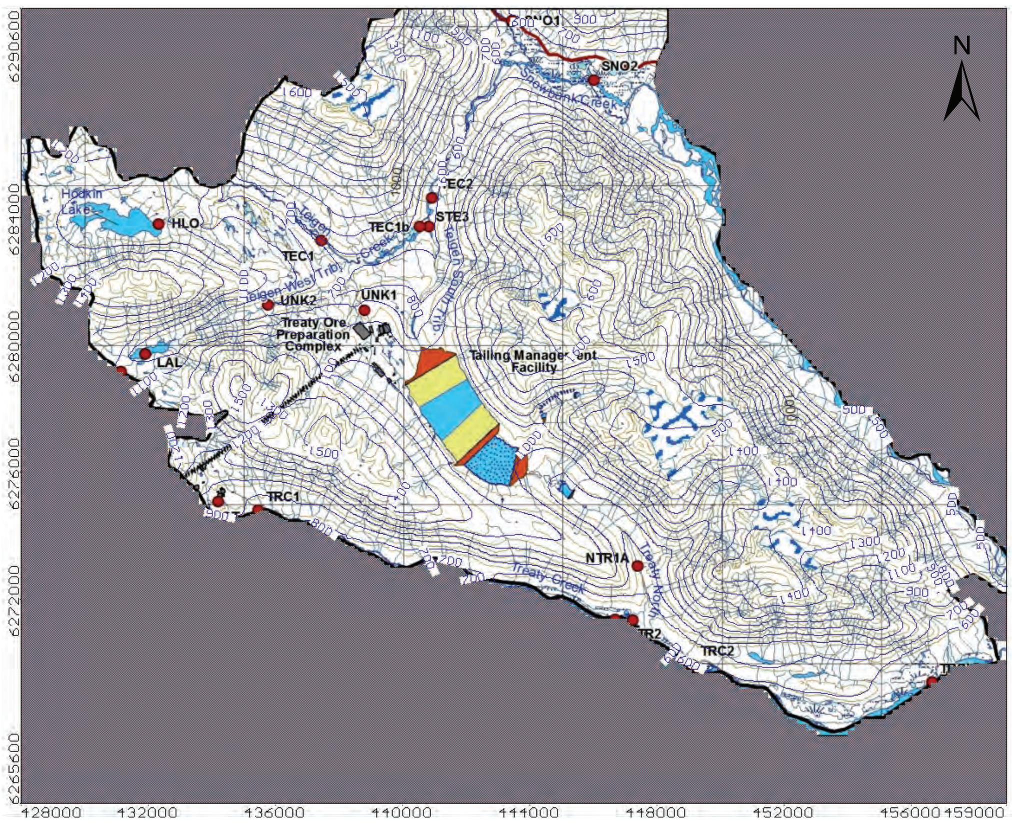
Groundwater Flows	Operation Year 25		Operation Year 51.5		Post-closure	
	L/s	% Change	L/s	% Change	L/s	% Change
Base flow into South Teigen Tributary						
Pre-mining	156.6		156.6		156.6	
Base Case	36.0	-77	35.6	-77	35.6	-77
Base flow into North Treaty Tributary						
Pre-mining	73.7		73.7		73.7	
Base Case	68.2	-7.4	16.4	-78	16.4	-78
Base flow into Teigen Main Creek						
Pre-mining	359.6		359.6		359.6	
Base Case	355.5	-1.1	355.5	-1.2	355.5	-1.2
Base flow into Treaty Main Creek						
Pre-mining	432.8		432.8		432.8	
Base Case	430.5	-0.5	431.7	-0.3	431.7	-0.3

Pre-mining base flows are those estimated in the calibrated model without integration of Project components, thereby representing baseline conditions. Shallow groundwater flow rates are predicted to reduce in the South Teigen and North Treaty Valleys after TMF seepage control mechanisms become active. Base flow reductions of 77 and 78% are predicted in the South Teigen and North Treaty Creeks, respectively. Base flow reductions at the parent catchment scale are predicted to be negligible (1% or less). Reductions in base flow reflect reductions in shallow groundwater flow.

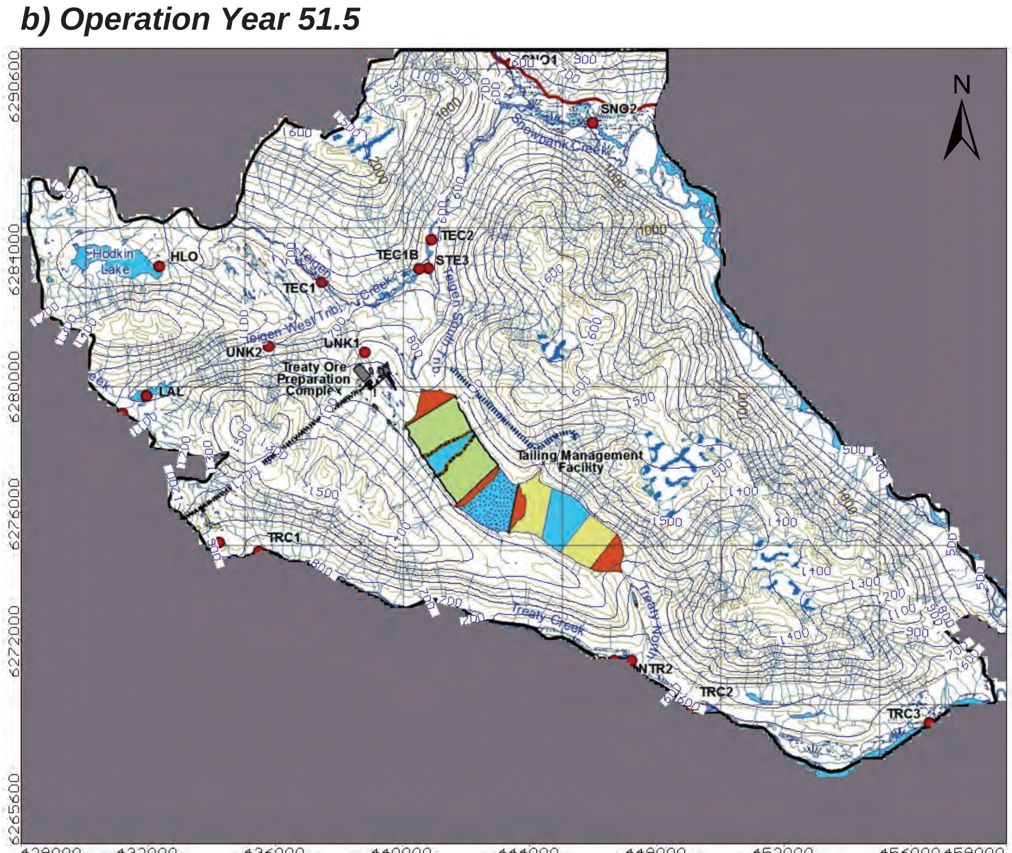
The reduction in base flow in the South Teigen Tributary is expected to be compensated by diversion of snow and ice melt through the East Catchment Diversion Tunnel and the network of diversion ditches. Discharge of water from tailing cells when the water quality meets the requirements during the post-closure phase will also compensate for effects on surface water quantity. Effects on surface water quantity are discussed in Chapter 13.

Base flow estimates were computed for sensitivity (worst-case) scenarios (Table 11.7-5). The results show the potential ranges of the base flow estimates, which arise due to uncertainties associated with the permeability of the geological materials (upper and lower cases) and variation of recharge (wet and dry climate scenarios). The wet year (more recharge) and upper-case (higher permeability) scenarios result in higher base flow estimates; the dry year (less recharge) and lower-case (lower permeability) scenarios result in lower base-flow estimates. Uncertainty in the hydraulic conductivity estimates likely trend towards the upper-case simulations. Hydraulic conductivity estimates are derived from single well response tests, which tend to underestimate the bulk hydraulic conductivities for larger scales (Neuman 1990).

a) Operation Year 25



b) Operation Year 51.5



Legend

- Head Contour
- Surface Water Quality Monitoring Station
- Plant Site
- Tailing Dam
- Tailing Pond
- Tailing Cells
- CIL Cell
- Seepage Collection Dam and Pond
- Conveyor Tunnel
- Diversion Tunnel
- Glacier
- Creek/River/Lake
- Wetland
- Inactive Cells

c) Post-closure

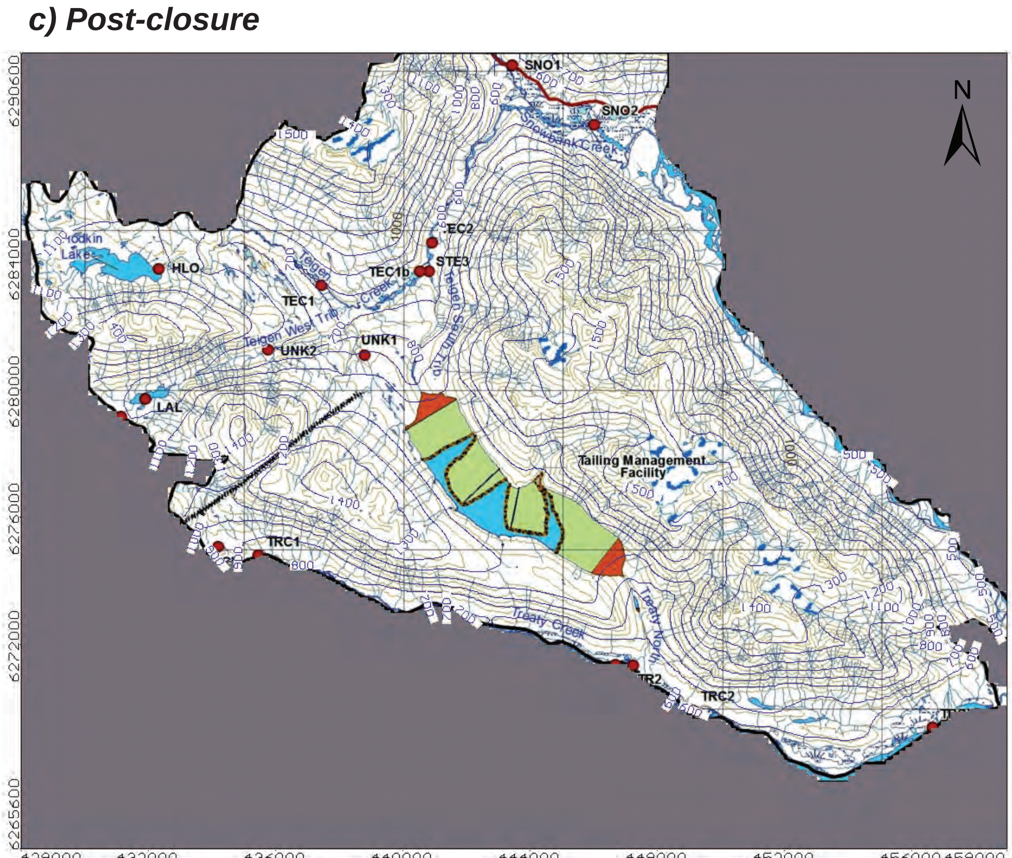


Figure 11.7-8

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Predicted Water Levels in the Processing and Tailing Management Area at Operation and Post-closure (Base Case)

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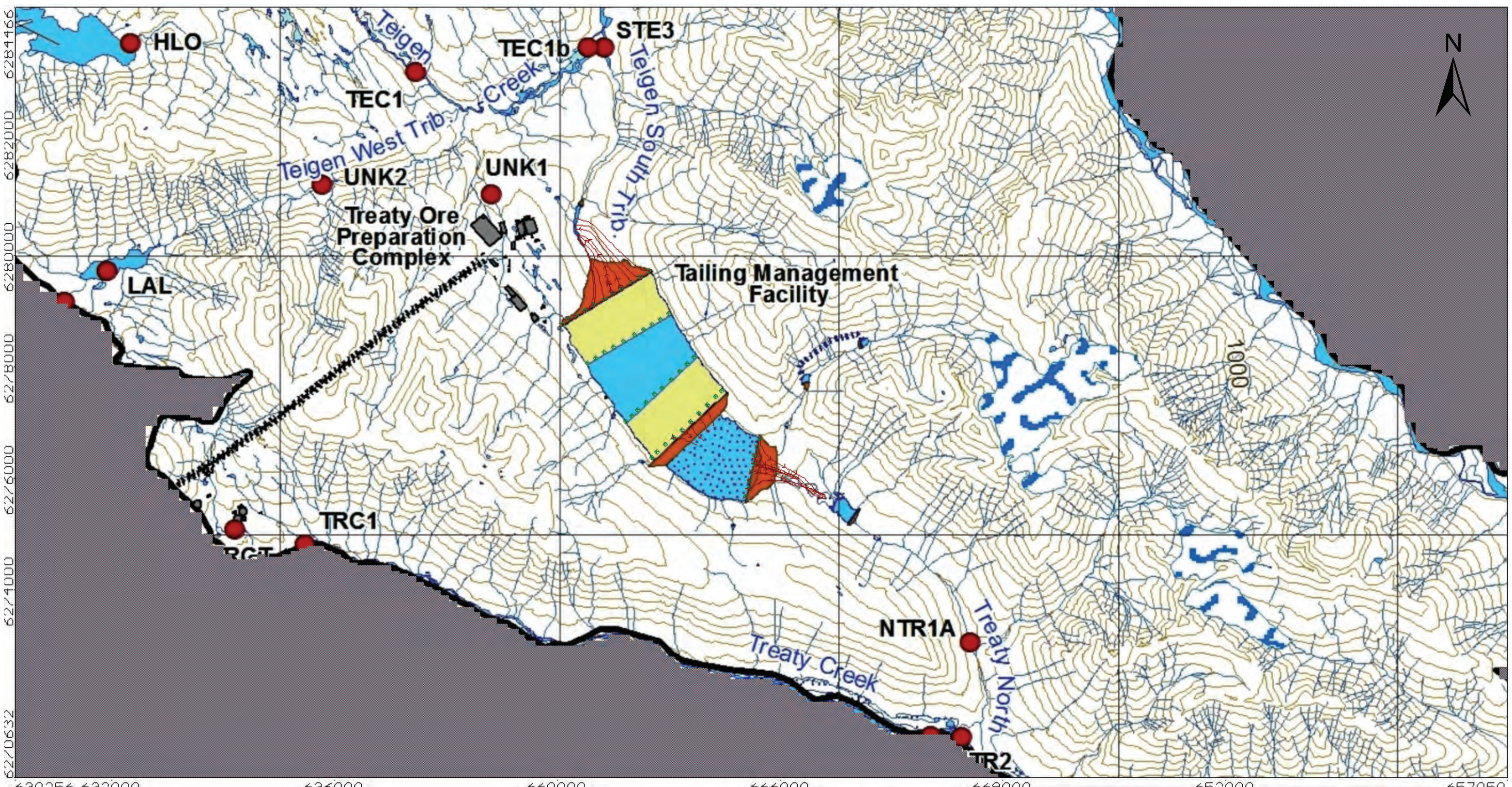
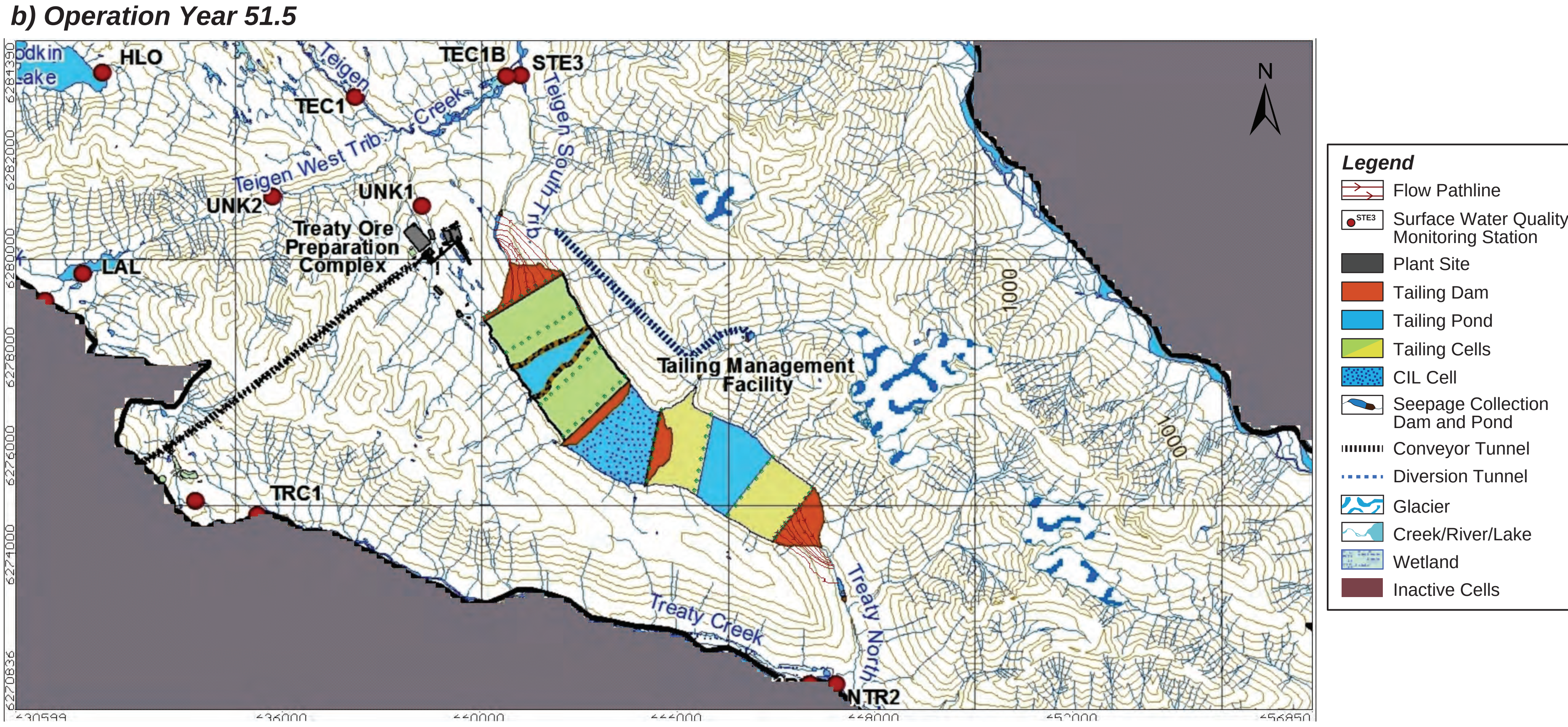
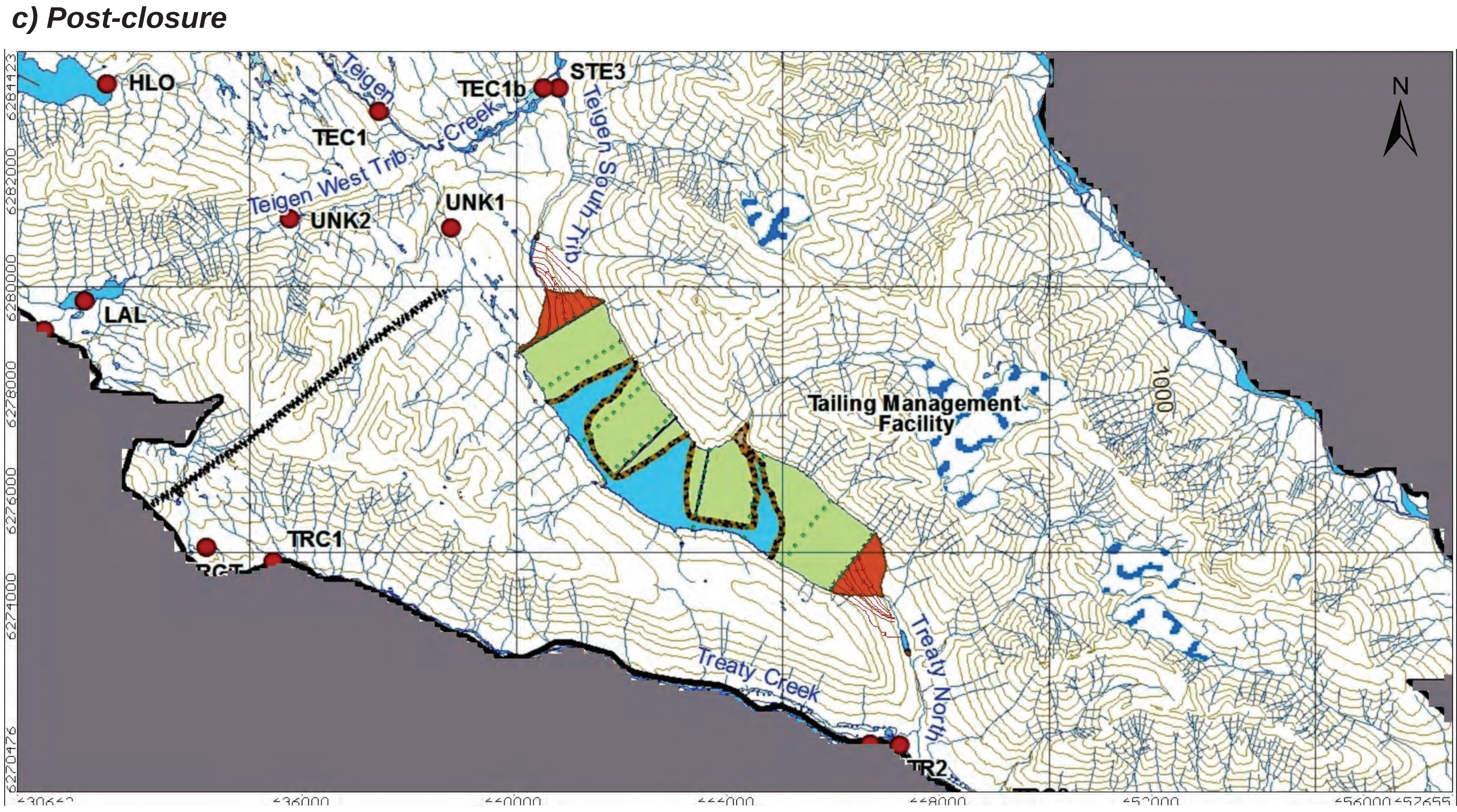
a) Operation Year 25



b) Operation Year 51.5



c) Post-closure



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

Figure 11.7-9

Predicted Flow Paths Leaving the Tailing Management Facility at Operation and Post-closure (Base Case)

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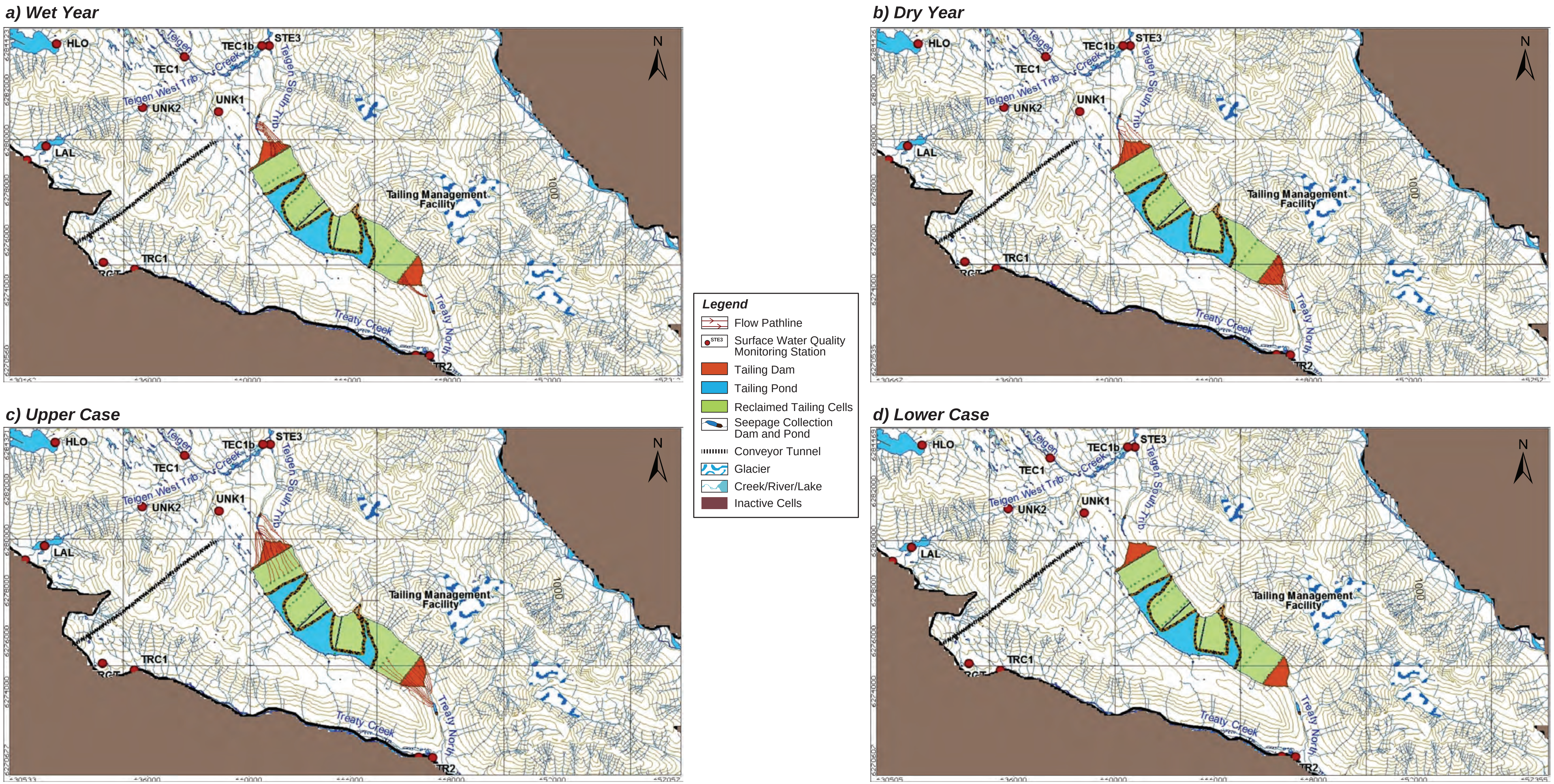

Note: Each mark on pathlines represents flow distance in 10 years.

Figure 11.7-10

Flow Paths Leaving the Tailing Management Facility for Worst Case Scenarios (Post-closure)

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Table 11.7-5. Processing and Tailing Management Area Flow Model Sensitivity Analysis: Worst-case Scenario Results for Stream Base Flows

Groundwater Flows	Operation Year 25 (L/s)	Operation Year 51.5 (L/s)	Post-closure (L/s)
Base flow into South Teigen Tributary			
Base Case	36.0	35.6	35.6
Upper Case – *K × 5*	93.2	91.9	91.9
Lower Case – *K / 5*	21.0	20.9	20.9
Wet Year – *Recharge × 2*	56.3	55.5	55.5
Dry Year – *Recharge × 0.5*	26.7	26.2	26.2
Base flow into North Treaty Tributary			
Base Case	68.2	16.4	16.4
Upper Case – *K × 5*	111.1	25.8	25.8
Lower Case – *K / 5*	37.3	9.4	9.4
Wet Year – *Recharge × 2*	103.2	22.3	22.3
Dry Year – *Recharge × 0.5*	51.0	14.1	14.1
Base flow into Teigen Main Creek			
Base Case	355.5	355.5	355.5
Upper Case – *K × 5*	611.0	610.9	610.9
Lower Case – *K / 5*	197.8	197.8	197.8
Wet Year – *Recharge × 2*	567.1	567.1	567.1
Dry Year – *Recharge × 0.5*	233.8	233.7	233.7
Base flow into Treaty Main Creek			
Base Case	430.5	431.7	431.7
Upper Case – *K × 5*	906.2	909.5	909.5
Lower Case – *K / 5*	174.5	174.9	174.9
Wet Year – *Recharge × 2*	532.8	533.7	533.7
Dry Year – *Recharge × 0.5*	377.3	378.6	378.6

11.7.3.3 Tunnels and Submerged Mine Works

Tunnels have been included in the modelling exercises (both Mine Site and PTMA), assuming no concrete liners will be installed. Flow rates entering the tunnels due to seepage from the groundwater environment have been calculated (refer to Appendix 11-E). Radial inward flow has been predicted to occur. However, effects are predicted to be localized, with negligible depressurization of the medium and only localized changes to flow patterns. Actual effects are expected to be much reduced relative to model predictions, with construction of concrete liners where considerable seepage occurs.

Decommissioned tunnels and submerged mine works (e.g., Iron Cap Block Cave Mine) will act as flow conduits. Simulations have shown negligible changes in flow patterns and groundwater levels around decommissioned submerged works.

11.7.4 Identified Residual Effects

Residual effects on groundwater quantity have been identified, arising from the combined effects of alteration of boundary conditions and alteration of permeability. Reductions in water levels and groundwater sinks have been predicted to result from mine dewatering, constituting residual effects. Increases in water levels and seepage controls associated with the TMF and WSF will have residual effects. Water-level mounding beneath the Mitchell and McTagg RSF is a residual effect. The controlled low water in the Sulphurets Pit backfill RSF is a residual effect.

Tunnels and submerged decommissioned works are not interpreted to result in residual effects on groundwater quantity.

11.8 Significance of Residual Effects for Groundwater Quantity

11.8.1 Residual Effect Descriptors for Groundwater Quantity

Residual effect descriptors for groundwater quantity (summarized in Table 11.8-1) are focused on changes in groundwater levels and flow rates relative to baseline conditions. They are used as criteria in the determination of significance.

Magnitude – The magnitude of an effect accounts for the amounts that water levels and flow patterns diverge from baseline conditions. Variability in the baseline data sets for groundwater levels is used as a benchmark to define magnitude as low, medium, or high. Flow rates are compared at down-gradient points of interest to the results of the calibrated pre-mining models. Flow directions are compared qualitatively with the results of the calibrated pre-mining models.

Geographic Extent – Geographic extent varies from the Project area footprint (local) to inter-provincial (beyond regional). The extent descriptor also accounts for the catchment basin context, whereby a landscape-scale effect is limited to the immediate catchment that the effect has at its source, and a regional-scale effect extends into downstream parent watersheds.

Duration – The duration criterion has been established with options 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).

Reversibility – Reversibility gauges the potential for flow patterns and water levels to return to baseline conditions, and how long this would take. Whether there is a plan to reverse an effect is also taken into account. For example, seepage controls are included in certain mine components to minimize migration of contact water, and the mine plan does not include provisions to reverse the effect these controls have on groundwater flow patterns.

Context – For the groundwater effects assessments, the context criterion for resilience 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 drinking water (BC MOE 2010).

Table 11.8-1. Definitions of Significance Criteria for Groundwater Quantity Residual Effects

Timing *What phase of the Project is the effect associated with?*	**Magnitude** *(negligible, low, medium, high)*	**Geographic Extent** *(local, landscape, regional, beyond regional)*	**Duration** *(short-term, medium-term, long-term, far future)*	**Frequency** *(once, sporadic, regular, continuous)*	**Reversibility** *(reversible short-term, reversible long-term, or irreversible)*	**Context** *(ecological resilience and/or unique attributes) (low, neutral, high)*	**Probability** *(low, medium, high)*	**Confidence** *(low, medium, high)*	**Significance** *(Not Significant: minor, moderate; Significant: major)*	**Follow-Up Monitoring** *(Not required, required)*
Construction	**Negligible.** There is no detectable change from baseline conditions.	**Local.** The effect is limited to the project footprint	**Short term**. The effect lasts up to five years	**Once.** The effect occurs once during any phase of the project.	**Reversible short-term:** An effect that can be reversed relatively quickly. This includes changes in groundwater quantity that are not expected to last more than five years.	**Low**. The affected groundwater is of low value for aquatic life habitat and human consumption, as determined with reference to baseline water quality guidelines for the protection of fresh water aquatic life and raw drinking water (BC MOE 2010). Multiple guideline exceedances.	**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.	**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**
Operations	**Low.** Water level differs from the average value for baseline conditions, but is within the range of natural variation. Seepage rate is within 10% of baseline conditions. Minor changes in flow directions	**Landscape.** The effect extends beyond 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:** An effect that can be reversed after many years. This includes changes in groundwater quantity that are expected to last more than five years, but an eventual reutrn of baseline conditions is expected.	**Neutral.** The affected groundwater is of moderate value for aquatic life habitat and human consumption, as determined with reference to baseline water quality guidelines for the protection of fresh water aquatic life and raw drinking water (BC MOE, 2010) One or two slight guideline exceedances	**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.	**Not Significant (moderate).** Residual effects have medium magnitude, local 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.** Water level differs from the average value for baseline conditions and approaches the limits of natural variation. Seepage rate is within 50% of baseline conditions. Moderate changes in flow directions	**Regional.** The effect extends into a downstream parent drainage basin. The effect may extend across the regional assessment 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.** The effect cannot be reversed. This includes changes in groundwater quantity that are expected to last into perpetuity.	**High.** The affected groundwater is of high value for aquatic life habitat and human consumption, as determined with reference to baseline water quality guidelines for the protection of fresh water aquatic life and raw drinking water (BC MOE, 2010) No guideline exceedances. The affected groundwater 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.	**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.	
Post-closure	**High.** Water level differs from baseline conditions and exceed the range of natural variation. Seepage rate differs from baseline by more than 50%. Considerable changes in flow directions.	**Beyond Regional**: The effect extends beyond the regional study area. Effect may cross provencial or state boundaries	**Far Future:** The effect lasts more than 50 years.	**Continuous.** An effect occurs constantly during any phase of the Project.						

Confidence – The confidence criterion addresses uncertainty in predicted results. This is accomplished through a comparison of base-case (expected) model results with sensitivity (worst-case) scenarios, as well as consideration for calibration statistics. Calibration statistics are a quantitative measure of the fit between field observations and simulation results. A good fit indicates high confidence in the predictions of the base-case simulations. Discrepancies between the expected and sensitivity (possible worst-case) scenarios reflect uncertainty in the predictions. A discrepancy between the base-case and upper- or lower-case scenarios reflects uncertainty embedded in the characterization of the permeability of the subsurface materials. A discrepancy with the wet or dry cases reflects uncertainty in recharge estimates e.g., in wetter and drier climates. The sensitivity (possible worst-case) scenario results are discussed alongside base-case results throughout the significance determination discussions.

11.8.2 Residual Effects Assessment for Groundwater Quantity

The two primary effect pathways (alteration of boundary conditions and alteration of permeability) are sometimes cumulative for individual Project components. For example, the WSF includes a series of grout curtains and seepage collection tunnels (alteration of permeability), an artificial lake in the reservoir (alteration of boundary conditions), and a seepage collection pond (also alteration of boundary conditions). Effects have not been broken down into individual effect components for the purpose of assessing residual effects. Residual effects have been arranged into four categories that combine the two primary effect pathways, based on the source. They include the following:

1. Pits and block cave mine dewatering during operation and subsequent water level management at post-closure.
2. Water level mounding in the Mitchell and McTagg RSF and loss of base flow contributions in Mitchell and McTagg valleys.
3. Controlled low water levels in Sulphurets pit backfill RSF.
4. Development of artificial reservoirs and implementation of associated seepage control mechanisms.

All four categories result in changes to groundwater levels, flow rates, and flow directions. The residual effects assessment includes an individual investigation for each Project component with identified residual effects, as summarized in Table 11.8-2. Components with matching significance criteria for a given effect are grouped together for discussion purposes.

11.8.2.1 Pit and Block Cave Mine Dewatering and Water Level Management

Plans for dewatering during operation and water level management at post-closure vary between the four deposits. They are discussed separately herein.

Table 11.8-2. Summary of Residual Effects on Groundwater Quantity

Description of Residual Effect	Project Component (s)	Timing of Effect	Magnitude	Extent	Duration	Frequency	Reversibility	Context	Likelihood of Effects: Probability	Likelihood of Effects: Confidence Level	Significance Determination	Follow-up Monitoring
Alteration of groundwater levels and flow patterns due to mine de-watering and water level management	Mitchell Pit and Block-Cave Mines, Sulphurets and Kerr Pits, subsequent pit lakes	Operations	High	Local	Far future	Continuous	Irreversible	Low	High	High	Not Significant (Moderate)	Not Required
	Iron Cap Block-Cave Mine	Operations	High	Local	Long	Continuous	Reversible long-term	Low	High	High	Not Significant (Minor)	Not Required
Water level mounding in the Mitchell and McTagg RSFs	Mitchell & McTagg Rock Storage Facilities	Operations	Medium	Local	Long	Continuous	Irreversible	Low	High	High	Not Significant (Minor)	Not Required
		Post-closure	Low	Local	Far future	Continuous	Irreversible	Low	High	High	Not Significant (Minor)	Not Required
Alteration of groundwater levels and flow patterns due to artificial reservoirs and implementation of associated seepage control mechanisms	Water Storage Facility	Construction	High	Local	Far future	Continuous	Irreversible	Low	High	High	Not Significant (Moderate)	Required
	Tailings Management Facility	Operations	High	Landscape	Far future	Continuous	Reversible long-term	Neutral	High	High	Not Significant (Moderate)	Required
Overall Residual Effect	All	Post-closure	High	Landscape	Far future	Continuous	Irreversible	Low	High	High	Not Significant (Moderate)	Not Required

11.8.2.1.1 Mitchell Pit and Mitchell Block Cave

Effects on groundwater quantity arising due to water management in the Mitchell Pit and Mitchell Block Cave Mine have been determined to be **not significant (moderate)**. The probability of this effect occurring is high, because dewatering will be necessary to access the Mitchell Pit and Mitchell Block Cave Mine. The resulting groundwater sink during operation extends beyond the footprint of the mine and adjacent components (landscape extents). The magnitude is high because there is a reversal of flow direction. Water levels near the pit decline to well below minimum baseline measurements in the area.

A recovery in water levels is predicted during post-closure. However, the groundwater sink remains in place. Thus, the duration criterion is far future, and the effect is irreversible. Magnitude and extent criteria do not change during post-closure.

The value of groundwater in the Mitchell Valley for aquatic life habitat and human consumption is low due to the poor water quality. Thus, the context is regarded as low.

Sensitivity (worst-case) scenario simulations do not result in any significance determination criteria that differ from the base-case simulation. The predictions were made based on the three-dimensional hydrogeological baseline model. The model was calibrated to water-level measurements taken in a large numbers of installed wells and piezometers over a four year period from 2008 to 2012, as well as to the estimated low-flows in the creeks in the Mine Site (refer to Appendix 11-E for details of the calibration results). Therefore the confidence level of the effect assessment is high.

11.8.2.1.2 Kerr Pit

Water management for the Kerr Pit has been determined to have a **not significant (moderate)** residual effect. The probability of this effect occurring is high, because dewatering will be necessary to access the deposit. The resulting groundwater sink will be sustained, because seepage collection is planned from basal drains at post-closure (duration criterion, far future; reversibility criterion, irreversible). The flow direction reversal and drawdown cone extend beyond the footprint of the pit. The magnitude is high due to flow direction reversal and water level decline that exceed baseline variability considerably.

The value of groundwater in the Sulphurets Valley for aquatic life habitat and human consumption is low due to the borderline water quality (specifics regarding groundwater quality are discussed in Chapter 12). Therefore, the context is regarded as low.

The sensitivity (lower case, wet year, and dry year) scenarios do not result in any significance determination criteria that differ from the base case. Upper-case results indicate a component of flow entering the pit could discharge towards Sulphurets Creek. Discharge towards the valley bottom would provide partial compensation for abstractions arising from de-watering of the pit, and would thus be a reduction in the adverse residual effect on groundwater quantity. Thus, no increase in the severity of residual effects is indicated by sensitivity (worst-case) scenarios. The predictions were made on the basis of the well-calibrated hydrogeological baseline model (as discussed in Section 11.8.2.1.1). The confidence level is thus regarded as high.

11.8.2.1.3 Iron Cap Block Cave Mine

Effects on groundwater quantity arising due to water management at the Iron Cap Block Cave Mine have been determined to be **not significant (minor)** due to a predicted recovery in water levels and flow patterns post-closure. The probability of the effect occurring is high, because dewatering will be necessary to access the deposit during the operation phase. The predicted groundwater sinks will be sustained for two decades during the operation phase, followed by a recovery trending towards baseline water levels and flow patterns (duration criterion, long; reversibility criterion, reversible long-term). The flow direction reversal associated with the drawdown cone extends beyond the footprint of the mine (landscape extent). Magnitude is high due to the decline in water level that exceeds baseline variability considerably.

The value of groundwater in the Mitchell Valley for aquatic life habitat and human consumption is low due to the poor water quality (specifics regarding groundwater quality are discussed in Chapter 12). Thus, the context is regarded as low.

Sensitivity (worst-case) scenarios do not result in any significance determination criteria that differ from the base-case, and the predictions were made on the basis of the well-calibrated hydrogeological baseline model (as discussed in Section 11.8.2.1.1). Therefore, the confidence level is high.

11.8.2.2 Water Level Mounding in the Mitchell and McTagg Rock Storage Facility

Effects on groundwater quantity arising due to water table mounding in the Mitchell and McTagg RSFs have been determined to be **not significant (minor)**. The probability of this effect occurring is high, because water level mounding is a well-understood effect of artificial earth piling. The resulting outward gradient will be confined to the bottom of the Mitchell Valley, as gradients driven by recharge at higher elevations are stronger. The magnitude is moderate during the operation phase (long term), when a flow reversal is predicted in the shallow near the Mitchell Pit. Magnitude is low during the post-closure phase (far future), because flooding of the Mitchell Pit will result in a local return towards the pre-mining down-valley flow regime. The RSF is planned to remain in place permanently; therefore, effects are considered irreversible.

The value of groundwater in the Mitchell Valley for aquatic life habitat and human consumption is low due to the poor water quality. Thus, the context is regarded as low.

Sensitivity (worst-case) scenario simulations do not result in any significance determination criteria that differ from the base-case simulation. Therefore, the confidence level is high.

11.8.2.3 Sulphurets Pit and Backfill Rock Storage Facility

Water management for the Sulphurets Pit and backfill RSF has been determined to result in a **not significant (moderate)** residual effect. The probability of this effect occurring is high, because dewatering will be necessary to access the deposit. The resulting groundwater sink will be sustained, because seepage collection is planned from a basal drain when the pit becomes adapted as a waste rock storage facility (duration criterion, far future; reversibility criterion, irreversible). The basal drain is also predicted to sustain unsaturated conditions throughout the waste rock backfill. The flow direction reversal and drawdown cone extend beyond the footprint of the pit. The magnitude is high, due to flow direction reversal and water level decline that exceed baseline variability considerably.

The value of groundwater in the Sulphurets Valley for aquatic life habitat and human consumption is low due to the borderline water quality (specifics regarding groundwater quality are discussed in Chapter 12). Therefore, the context is regarded as low.

The sensitivity (lower case, wet year, and dry year) scenarios do not result in any significance determination criteria that differ from the base case. Upper-case results indicate that a component of flow entering the pit could discharge towards Sulphurets Creek. Discharge towards the valley bottom would provide partial compensation for abstractions arising from de-watering of the pit, and would thus be a reduction in the adverse residual effect on groundwater quantity. Therefore, no increase in the severity of residual effects is indicated by sensitivity (worst case) scenarios. The predictions were made on the basis of the well-calibrated hydrogeological baseline model (as discussed in Section 11.8.2.1.1). The confidence level is thus regarded as high.

11.8.2.4 Development of Artificial Reservoirs and Implementation of Associated Seepage Control Mechanisms

The WSF and TMF designs will result in residual effects on groundwater quantity because the development of artificial ponds will introduce strong hydraulic gradients.

High magnitudes have been identified for the effects arising from the TMF and WSF. A complexity of flow pattern changes has been predicted around both facilities, along with water level increases that exceed the range of natural variability. Seepage rates in the Mitchell Valley downstream of the WSF will be reduced considerably, as indicated by a reduction in base flow upstream of the confluence with Sulphurets Creek. Seepage rates in the South Teigen and North Treaty Valleys downstream of the TMF will be reduced considerably, as indicated by 80% reductions in base flow.

Frequencies may be regarded as continuous due to the constant interaction between the facilities and the groundwater environment. Additional significance determination criteria are discussed individually for the WSF and TMF below.

11.8.2.4.1 Water Storage Facility

The WSF is expected to be in operation to perpetuity, including maintenance of a managed water level in the reservoir and active seepage collection (duration criterion, far future; reversibility criterion, irreversible). The value of groundwater in the Mitchell Valley for aquatic life habitat and human consumption is low due to the poor water quality. Therefore, the context is regarded as low.

Capture of all seepage beneath the WSF is indicated in results of all sensitivity (worst-case) scenarios. The upper case predicts flow paths that bypass the WSD around the southeast abutment, but still report to seepage interception tunnels further downstream. Very high hydraulic conductivities (up to 10^{-3} m/s) have been used for the upper-case scenario along the band of carbonate rock (possible preferential flow paths) 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.

If seepage control mechanisms were unable to function as intended, the result could be greater seepage rates from the WSF and possibly some contact groundwater discharging into Mitchell Creek downstream. From a groundwater quality standpoint, increased seepage would constitute an increase in the severity of the residual effect (discussed in Chapter 12). However, from a groundwater quantity standpoint, increased seepage would not constitute an increase in the severity of the residual effect. The confidence level is thus regarded as high.

The significance of residual effects on water quantity associated with the WSF design has been determined to be **not significant (moderate).**

11.8.2.4.2 Tailing Management Facility

The Tailing Management Facility Management and Monitoring Plan (Section 26.4) describes the discharge of the TMF when water quality conditions are adequate during operation and post-closure (duration criterion, far future; reversibility criterion, reversible long term). The value of groundwater in the PTMA for aquatic life habitat and human consumption is high due to the potable water quality and downstream fish habitats (specifics regarding groundwater quality are discussed in Chapter 12). However, the groundwater in the PTMA is not regionally unique in its resource potential. Thus, the context is regarded as neutral.

Sensitivity (worst case) scenarios have demonstrated sensitivity of the predictions to uncertainty in the estimated hydraulic conductivities and recharge rates. The model was calibrated to water level measurements taken in a large numbers of installed wells and piezometers over a four year period, as well as to the estimated low-flows in the creeks in the PTMA (refer to Appendix 11-E for details of the calibration results). Therefore, the confidence level of the effect assessment is high.

The significance of residual effects on water quantity associated with the TMF design has been determined to be **not significant (moderate)**.

11.8.2.5 Overall Effect on Groundwater Quantity

Groundwater quantity will be affected by Project development. Residual effects will be **not significant (moderate)** and will be restricted to the immediate catchment basins containing Project component footprints.

Groundwater modelling indicates that water levels and flow patterns will diverge markedly from baseline conditions within and near the pits, block caves, WSF, and TMF. Water levels will increase beneath the Mitchell and McTagg RSF, alongside a temporary flow reversal at the upper end of the Mitchell RSF during the operation phase. Water levels will be controlled to be low locally at the waste rock storage backfilled in Sulphurets Pit.

11.9 Potential Cumulative Effects for Groundwater Quantity

The potential for cumulative effects on groundwater quantity arising due to interaction with other nearby projects and human activities was investigated. All identified Project-specific residual effects were included in the cumulative effects assessment. These include the following:

- mine dewatering and water level management;
- development of contact water lakes and implementation of associated seepage control mechanisms;
- tunnel drainage effects; and
- development of preferential flow pathways due to submergence of excavated mine components.

11.9.1 Scoping of Cumulative Effects

11.9.1.1 Spatial Linkages with other Projects and Human Actions

The major groundwater divides used to delineate the LSA sites were used to assess potential spatial overlap of groundwater quantity impacts arising from other projects. Modelling exercises have shown that extents of effects on flow patterns and water levels sourced at Project components that interact with the groundwater environment will not surpass these boundaries. The following projects and activities are considered to have a potential spatial overlap with effects on groundwater quantity (Figure 11.9-1; Table 11.9-1):

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

11.9.1.2 Temporal Linkages with other Projects and Human Actions

Temporal overlaps of past, present, and future projects and land use activities are identified in Table 11.9-1. All projects and activities that have a spatial overlap with the Project's effects on groundwater quantity also have a potential temporal overlap. These include the following:

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

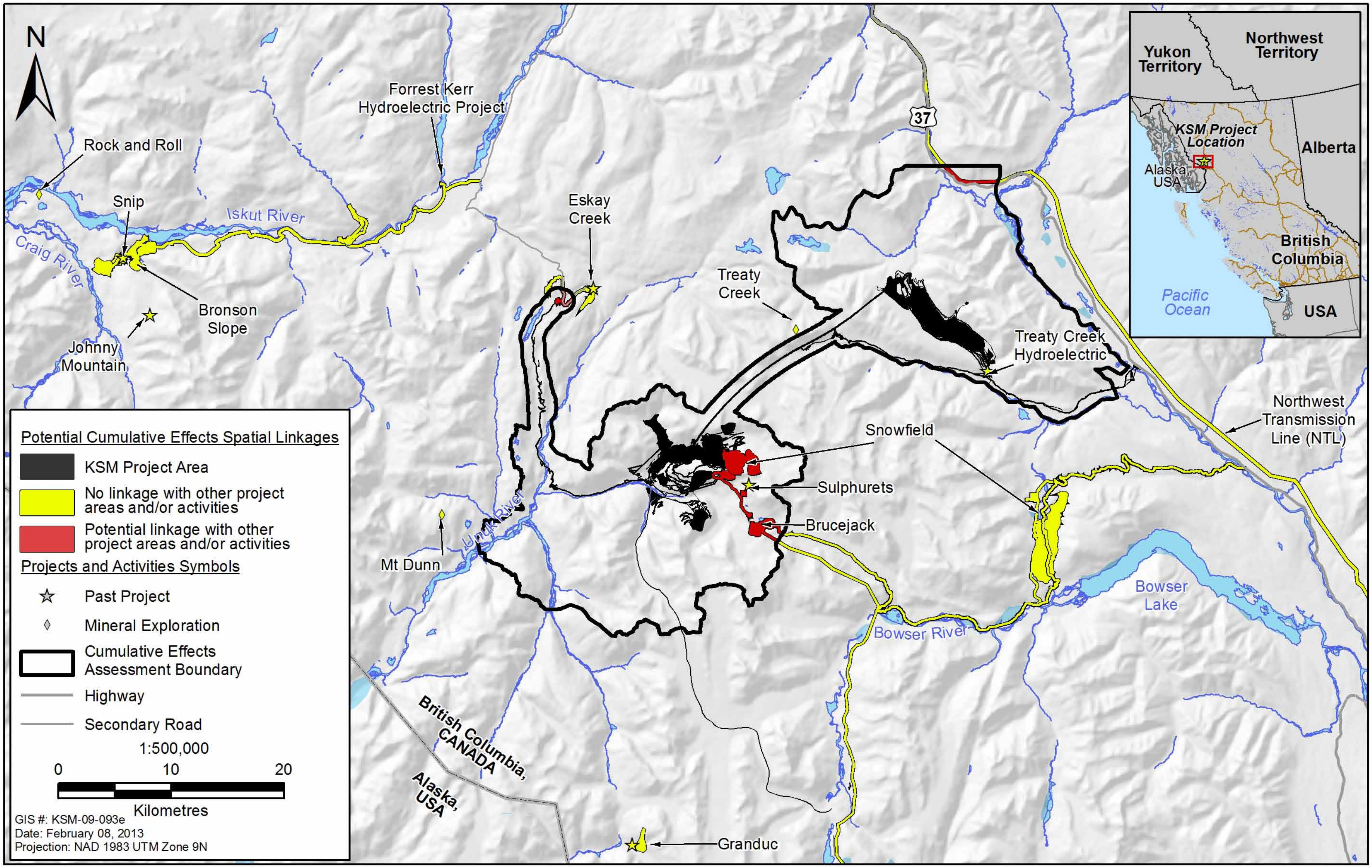

Figure 11.9-1

SEABRIDGE GOLD
KSM PROJECT

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

Figure 11.9-1

Rescan
Engineers & Scientists

Table 11.9-1. Summary of Potential Linkages between the KSM Project and other Human Actions in regards to Groundwater Quantity

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 area 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
	NTL (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	Arctos Anthracite Coal Project	NL	NL	NL
	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
	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
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 and Brucejack Projects Exploration Activity	X; KSM and Brucejack Projects Exploration Activity	X; KSM and Brucejack Projects Exploration Activity
	Recreation and Tourism	NL	NL	NL
	Timber Harvesting	NL	NL	NL
	Traffic and Roads	NL	NL	NL

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

11.9.2 Cumulative Effects Assessment for Groundwater Quantity

A summary of possible interactions for each project identified in Section 11.9.1 is presented in Table 11.9-2. Most projects are at a distance at which interactions are not expected, as discussed in Section 11.9.2.1. The proximity of the planned Snowfield Pit to the planned Mitchell Pit is such that potential cumulative effects on groundwater quantity exist, as discussed in Section 11.9.2.2. 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, adjacent waste rock dumps, and a tunnel in the upper Mitchell Valley. The planned pit footprint overlaps with that of the Mitchell Pit. Tailing disposal was planned for the Scott Creek watershed, several basins to the northeast. Potential interactions exist for infrastructure that would be located in the upper Mitchell Valley.

Table 11.9-2. Summary of Projects and Activities with Potential to Interact Cumulatively with expected Project-specific Residual Effects on Groundwater Quantity

Description of KSM Residual Effect	Potential for Cumulative Effect: Relevant Projects and Activities				
	Past Sulphurets Project	**Northwest Transmission Line**	**Brucejack Mine**	**Snowfields Project**	**Mineral and Energy Resource Exploration**
Mine de-watering and water level management	No interaction	No interaction	No interaction	Possible interaction	No interaction
Development of contact water lakes and implementation of associated seepage control mechanisms	No interaction	No interaction	No interaction	No interaction	No interaction
Tunnel drainage effects	No interaction	No interaction	No interaction	No interaction	No interaction
Development of preferential flow pathways due to submergence of excavated mine components	No interaction	No interaction	No interaction	No interaction	No interaction

11.9.2.1 Project-specific Residual Effects on Groundwater Quantity 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 quantity associated with the KSM 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 not expected to interact are discussed individually below, with specific reference to the residual effects identified for the KSM Project.

11.9.2.1.1 Past Sulphurets Project

The Sulphurets Advanced Exploration Project included excavation of underground works near Brucejack Lake for bulk sampling (Price 2005). The remnant submerged shaft may act as a preferential flow pathway for groundwater, thereby affecting flow patterns. Remnants do not include artificial lakes, seepage controls, tunnel drainage effects, or active mine dewatering that could potentially interact with KSM Project-specific effects. Therefore, no interactions of effects on groundwater quantity are expected.

11.9.2.1.2 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 quantity identified for the Brucejack Mine include the following:

- dewatering of the underground mine (Rescan 2012);
- preferential flow through the mine following decommissioning; and
- water level management in Brucejack Lake.

The hydrogeologic setting of the Brucejack Project is very similar to that of the KSM Project. The wet climate and associated high recharge fluxes results in highly localized cones of depression. Back-filling of the underground with waste rock and tailing is expected to reduce preferential flow path effects. The Brucejack underground works are 6 km from the nearest predicted effects sourced at the KSM Project. No interactions of effects on groundwater quantity are expected.

11.9.2.1.3 Northwest Transmission Line

As shown in Figure 11.9-1, only a short section of the NTL is crossing the northeastern corner of the PTMA LSA boundary and is over 10 km away from the TMF footprint. No effects on groundwater quantity are expected for the NTL, as specified in the submitted environmental assessment (Rescan 2010). Therefore, no interactions with the KSM Project are expected. The overall residual effects on groundwater quantity in the PTMA remain unchanged (not significant, moderate) and do not surpass the landscape scale.

11.9.2.1.4 Mineral and Energy Resource Exploration

No interactions are expected for past, present, or future exploration activity. These activities have minimal effects on groundwater quantity. Localized extraction for use in work camps may occur. However, extraction rates would be negligible in comparison to those required for mine dewatering. Drilling activities may briefly interrupt local flow patterns and water levels, but complete recoveries are expected in a timeframe on the scale of days to weeks.

11.9.2.2 Cumulative Effects due to Pit Dewatering for the Planned Snowfield Project

The proximity of the planned Snowfield Pit to the planned Mitchell Pit is such that potential cumulative effects on groundwater quantity exist. No effects assessment data existed for the planned Snowfield Project at the time of writing. To evaluate cumulative residual effects with the KSM Project, the following assumptions have been made:

- infrastructure in the upper Mitchell Valley will be limited to an open pit, waste rock dumps, and a conveyor/transport tunnel;
- decommissioning of the pit will involve development of a pit lake, but also continued water level management and the sustenance of a groundwater sink; and
- all contact water will be transported off site for disposal and/or treatment. No contact WSF will be created in the upper Mitchell Valley.

With consideration for these assumptions, potential cumulative effects arise due to dewatering of the Snowfield Pit only.

11.9.2.2.1 Project-specific Cumulative Effects Mitigations for Interactions with the Planned Snowfield Project

No mitigation measures are planned to minimize cumulative effects on groundwater quantity arising from interactions with the planned Snowfield Project.

11.9.2.2.2 Snowfield Project Mitigation to Address Interactions with the KSM Project

The Snowfield Project is in an early stage of exploration and has not yet entered the BC environmental assessment process. The most recent infrastructure plans, detailed in Wardrop (2010), do not specify mitigation measures to minimize cumulative effects on groundwater quantity arising from interactions with the KSM Project.

11.9.2.2.3 Determination of Potential for Residual Cumulative Effect and Significance

Interacting drawdown cones are expected for the Mitchell Pit, Mitchell Block Cave Mine, and the Snowfield Pit. The principle of superposition is widely used to predict interaction of drawdown cones from multiple sources (Reilly, Franke, and Bennett 1984). However, predictive modelling data do not exist for the Snowfield Project and the assessment is limited to a qualitative discussion. The key point raised by the principle of superposition is that drawdown cones are additive in nature. There is no magnifying effect on extents or magnitudes of water level declines.

Cumulative residual effects at the Mine Site were assessed for interaction of Mitchell and Snowfield mine dewatering drawdown cones (summarized in Table 11.9-3). Groundwater flow modelling predicts that the drawdown cone around the Mitchell Pit and Mitchell Block Cave Mine at maximum extents will not exceed a radius of influence beyond the pit footprint. The combined drawdown cone will be larger, but the radius of influence is not expected to increase in extent beyond pit footprints. Therefore, the Snowfield Project is not expected to increase the scale of extent of the residual effect. The cumulative residual effect remains local in extent.

The magnitude, duration, and reversibility criteria for residual effects associated with the Mitchell Pit dewatering were all determined to be at their maximum respective levels (high magnitude, far-future duration, irreversible). Interaction with the Snowfield Project is not expected to augment these criteria.

Table 11.9-3. Summary of Residual Cumulative Effects on Groundwater Quantity

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	Conf. Level Adjusted for CE				
Alteration of groundwater levels, flow rates and directions due to mine de-watering and water level management	Snowfield Project	Operations	High	High	Local	Local	Far future	Far future	Continuous	Continuous	Irreversible	Irreversible	Low	Low	High	High	High	High	Not Significant (Moderate)	Not Significant (Moderate)	Not Required	Not Required
Overall Effect	All	Post-closure	High	High	Local	Local	Far future	Far future	Continuous	Continuous	Irreversible	Irreversible	Low	Low	High	High	High	High	Not Significant (Moderate)	Not Significant (Moderate)	Required	Required

CE = Cumulative Effect

Context remains low because baseline water quality in the Mitchell Valley is poor. Probability remains high, and the only factor affecting probability for the interaction is uncertainty regarding whether the Snowfield Project will move forward.

Confidence level remains high. The Snowfield Pit would be excavated in the same hydrogeologic setting as the Mitchell Pit.

11.9.2.3 Overall Cumulative Effect on Groundwater Quantity

Interaction of drawdown cones arising from mine dewatering is expected to occur for the Mitchell Pit, Mitchell Block Cave Mine, and Snowfield Pit. The cumulative effect does not augment any significance determination criteria relative to Project-specific residual effects. The residual effects have been determined to be **not significant (moderate)** and restricted to the local catchment basins containing Project components.

11.10 Summary of Assessment of Potential Environmental Effects on Groundwater Quantity

Excavation into the groundwater environment and water management practices will affect groundwater quantity throughout the Project life and beyond, thereby resulting in residual effects. Overall residual effects will be **not significant (moderate)** and restricted to the catchment basins within and immediately adjacent to mine component footprints.

Groundwater modelling indicates that water levels and flow patterns will diverge markedly from baseline conditions within and near the mines (both pits and block caves), RSFs, WSF, and TMF. Flow patterns could change around tunnels, but water levels are not predicted to be affected significantly and groundwater seepage into the tunnels is expected to be small during operation and post-closure.

The planned Snowfield Project includes a pit immediately adjacent to the Mitchell Pit. Dewatering of the two adjacent pits is expected to result in interacting drawdown cones, but the cumulative effect will not be of greater magnitude, and extents will remain localized to the upper Mitchell Valley catchment basin.

Permanent effects are expected for most components that interact with the groundwater environment. The Tailing Management Facility Management and Monitoring Plan (Section 26.4) describes the discharge from cell ponds at some time during post-closure, which would allow a return to near-baseline water levels. Table 11.10-1 provides a summary of all potential and residual effects considered in this assessment.

11.11 Groundwater Quantity Conclusions

Groundwater flow modelling has demonstrated that the KSM Project will affect groundwater quantity within the local mine footprints. Residual effects will occur due to dewatering of pits and block caves during operation, pit lake water level management during post-closure, water level mounding in the Mitchell and McTagg RSFs, and the development of artificial ponds with seepage control mechanisms (WSF and TMF). Groundwater management is planned into the far future in the Mitchell Pit and Mitchell Block Cave Mine, Sulphurets Pit and Backfill RSF, Kerr Pit, WSF, and TMF. Increase in ground elevation along the Mitchell and McTagg valleys due to placement of waste rocks will result in elevation of the water table. Effects resulting from these components will be permanent, with the imposition of water levels and flow patterns that diverge substantially from baseline conditions.

The planned Snowfield Project includes a pit immediately adjacent to the Mitchell Pit. Dewatering of the two adjacent pits is expected to result in interacting drawdown cones, but the cumulative effect will not be of greater magnitude, and extents will remain localized around the pit footprints. There are no other cumulative effects due to other past, present, or reasonably foreseeable future projects or human activities.

Alterations to groundwater flow patterns and water levels will be confined to the immediate catchment basins of the Project footprint. No effects have been predicted in down-gradient parent catchment basins.

Table 11.10-1. Summary of Assessment of Potential Environmental Effects: Groundwater Quantity

Valued Component	Phase of Project	Potential Effect	Key Mitigation Measures	Significance Analysis of Project Residual Effects	Significance Analysis of Cumulative Residual Effects
Groundwater Quantity	Construction through post-closure inclusive	Alteration of groundwater levels, flow rates, and directions due to mine de-watering and water level management.	- Cessation of de-watering	**Not Significant (Moderate):** Irreversible, high-magnitude changes in groundwater levels and flow patterns. Effects confined to the locality of the mine footprint.	**Not Significant (Moderate)**: Interactions are expected with the Snowfield Project, which includes an open pit and waste rock dumps in the upper Mitchell Valley. The overall de-watered zone resulting from the combined drawdown cones of the Mitchell Pit and Block-Cave and the Snowfield Pit will be larger. The cumulative effect does not augment the significance determination relative to project-specific effects.
	Operations through post-closure	Alteration of groundwater levels and patterns due to increase in ground surface elevation.	None	**Not Significant (Minor):** Irreversible, moderate to low magnitude changes in groundwater levels and flow directions along the footprint fo the RSFs.	No interaction with other projects
	Construction through post-closure inclusive	Alteration of groundwater levels, flow rates, and directions due to artificial reservoirs and implementation of associated seepage control mechanisms.	- TMF Monitoring and management plan	**Not Significant (Moderate):** Irreversible, high-magnitude changes in groundwater levels and flow patterns. Effects confined to the locality of the mine footprint. Follow-up monitoring will be conducted.	No interaction with other projects
	Construction through post-closure inclusive	Alteration of groundwater levels, flow rates, and directions due to tunnel drainage effects.	- Tunnel de-commissioning - Concrete liners along high-permeability sections of tunnel walls	No residual effect, as determined by numerical modelling	No interactions with other projects
	Closure and post-closure	Alteration of groundwater levels, flow rates, and directions due to hydraulic connections created by submerged excavated mine components.	- Concrete liners on high-permeability sections of tunnel walls	No residual effect, as determined by numerical modelling	No interactions with other projects

References

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