

Appendix 6.4-C

Ajax Project Water Balance Model

AJAX PROJECT

**Environmental Assessment Certificate Application / Environmental Impact Statement
for a Comprehensive Study**



AJAX PROJECT WATER BALANCE MODEL

FINAL – REV B

PROJECT NO.: 11125-007

AUGUST 21, 2015



KGHM AJAX MINING INC.

AJAX PROJECT

WATER BALANCE MODEL

REV B

PROJECT NO.:	1125-009	DISTRIBUTION:	
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Suite 800 - 1045 Howe Street
Vancouver, BC Canada V6Z 2A9
Telephone (604) 684-5900
Fax (604) 684-5909

August 21, 2015
Project No.: 1125-007

Nettie Ore
KGHM Ajax Mining Inc.
200-124 Seymour Street
Kamloops, BC V2C 2E1

Dear Ms. Ore,

Re: Ajax Project, Water Balance Model – Rev B

Please find attached a copy of the above-referenced report dated August 21, 2015. We appreciate the opportunity to work on this project and look forward to our continued involvement. Should you have any questions or comments, please do not hesitate to contact the undersigned.

Yours sincerely,

BGC ENGINEERING INC.
per:

Hamish Weatherly, M.Sc., P.Geo.
Principal Hydrologist

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GLOSSARY AND ABBREVIATIONS

Terminology used in this document is defined where it is first used. The following list will assist readers who may choose to review only portions of the document.

the Project	the Ajax Project
AIR	Application Information Requirements
BC	British Columbia
EA	Environmental Assessment
EAO	Environmental Assessment Office
EC	Environment Canada
EIS	Environmental Impact Statement
EMRSF	East Mine Rock Storage Facility
FLNRO	BC Ministry of Forests, Lands, and Natural Resource Operations
IPMRSF	In-Pit Mine Rock Storage Facility
KAM	KGHM Ajax Mining Inc. (the Proponent)
KGHM	KGHM Polska Miedz S.A.
KP	Knight Piésold
LOM	Life of mine
LSA	Local study area
m	Metre
MRSF	Mine Rock Storage Facility
PCDP	Peterson Creek Downstream Pond
RSA	Regional study area
SMRSF	South Mine Rock Storage Facility
STP	Sewage Treatment Plant
SSN	Stk'emlupsemc te Secwepemc Nation
t/d	Tonnes per day
t	Tonne

TSF	Tailings Storage Facility
WBM	Water balance model
WMRSF	West Mine Rock Storage Facility
WMP	Water Management Plan
WSC	Water Survey of Canada

1.0 INTRODUCTION

BGC Engineering Inc. (BGC) was retained by KGHM Ajax Mining Inc. (KAM) to construct a site-wide water balance model (WBM) for the Ajax Project (the Project) near Kamloops, British Columbia. The objective of the WBM is to evaluate the potential effects of the Project on surface water hydrology (specifically water quantity) during Construction, Operation, Decommissioning and Closure, and Post Closure. The model is focused on the local study area (LSA) for the Project, as laid out in the Application Information Requirements (AIR) and Environmental Impact Statement (EIS) guidelines (EAO, 2015). This report will support the provincial Application for an Environmental Assessment (EA) Certificate and the federal EIS for the Project, to be submitted in 2015.

The Project, located at latitude 50°36.6' N and longitude 120°24.0' W, includes a tailings storage facility (TSF), an open pit, several mine rock storage facilities (MRSFs), a number of water management ponds, and a plant site (Drawing 01). These facilities are all located within the Peterson Creek watershed about 7 km southwest of downtown Kamloops in the south-central interior of British Columbia. The Project will be an open pit copper and gold mine processing 65,000 tonnes per day (t/d) through a concentrator. This report provides details on the site-wide WBM developed for the Project by BGC.

1.1. Scope of Work

The purpose of this report is to present the pre-construction and pre-mining hydrologic setting of the Ajax Project and compare it to expected conditions during all phases of the mine life. This comparison allows for an evaluation of mine infrastructure effects on the Peterson Creek hydrologic regime, including surface water and groundwater effects within the Project area and any effects on downstream water bodies. The report is based on a review and compilation of results from climate, hydrology and hydrogeology investigations conducted by BGC and others on behalf of KAM, as well as on compiled, publicly available data for the region.

The scope of this assessment was completed in accordance with the Application Information Requirements / Environmental Impact Statement Guidelines (AIR/EISG) for the Ajax Project as outlined in EAO (2015). This report describes the WBM for the Project including the design basis, assumptions, data sources and results for all phases of the mine life. The scope of work consisted of the following tasks and deliverables:

- Complete a site visit to assess existing hydrological conditions at the site;
- Compile and review available climate, surface water, and spatial data;
- Develop and calibrate a WBM for existing conditions using available data;
- Use the calibrated WBM to predict hydrologic effects during Construction, Operation, Decommissioning and Closure, and Post Closure; and
- Document the WBM and the predictive analyses.

A comprehensive review and assessment of available climate and streamflow data is provided separately in Knight Piésold (2013 and 2015b). As part of concurrent EA work, BGC is also assessing hydrogeological conditions for the project, including estimated groundwater inflows to the open pit and seepage flows from the TSF. A description of the Project area geological and hydrogeological setting is provided in BGC (2015a). The hydrogeological modeling study results are documented in BGC (2015b). BGC has previously worked on earlier iterations of the proposed mine, as documented in BGC, 2011, 2013a, 2013b, 2013c and 2013d.

1.2. Project Description

KAM proposes to develop the Project, an open pit copper-gold mine at the historic Afton Mining Camp, south of the City of Kamloops, British Columbia (BC). The Project is located in the South-Central Interior of British Columbia, southeast of the junction of the Trans-Canada Highway No. 1 and the Coquihalla Highway (No. 5), within the Thompson Nicola Regional District.

The Project lies in the traditional territory of the Secwepemc Nation. Within the Secwepemc Nation, the Tk'emlúps te Secwepemc and the Skeetchestn Indian Band are the Aboriginal groups in closest proximity to the Project. In a cooperative effort, the Tk'emlúps te Secwepemc and Skeetchestn Indian Bands have formed the Stk'emlupsemc te Secwepemc Nation (SSN), as a division of the greater Secwepemc Nation. The Ashcroft Indian Band and Lower Nicola Indian Band, whose members are part of the Nlaka'pamux Nation also assert their Aboriginal rights to the Project area- an area of common interest with the SSN.

The Ajax property includes three historic pits: the Ajax West East Pit, the Ajax West West Pit, and the Ajax East Pit. These pits were formerly mined in the 1980s and 1990s. Key Project facilities include the Tailings Storage Facility (TSF), which is planned as a conventional tailings storage facility; water management ponds; an Open Pit; Peterson Creek diversion; the Tailings Embankments, which will be constructed using mine rock; and four mine rock storage facilities (MRSFs). The four MRSFs include the:

- the South Mine Rock Storage Facility (SMRSF);
- East Mine Rock Storage Facility (EMRSF);
- West Mine Rock Storage Facility (WMRSF); and
- the In-Pit Mine Rock Storage Facility (IPMRSF).

Several facilities that will be part of the Operation phase but not remain after project closure include the:

- plant facilities and administration buildings;
- reclamation stockpiles;
- explosives facility;
- truck stop and fuel storage;
- power lines;
- haul roads; and

- some onsite roads.

Some of the on-site roads will remain during Post Closure to support the Sugarloaf Ranch operation. The mine plan for the Project assumes an operation based on a mill throughput of 65,000 tonnes of ore per day from the Ajax Pit with up to a 23 year mine life. The Construction phase of the Project will be approximately two and a half years, and following the 23 year operation the Decommissioning and Closure phase is expected to take up to 5 years. Over the mine life the Project will produce approximately 140 million pounds of copper and 130,000 ounces of gold annually in concentrate that is shipped by truck to the Port of Vancouver.

Water will be required for use as make-up water for the process plant, potable water, explosives mixing, fire protection, the truck shop, dust control, etc. Water will be obtained from a variety of fresh, contact, and recycled water sources. All water collected, recycled, or used on the project will require containment or storage in man-made structures. An overview of the water management plan (WMP) for the Project is provided in Section 2.4.

1.3. Regional and Local Study Area

The effects to aquatic resources considered in the Application/EIS will focus on water quantity, water quality, and aquatic life. The Project effects on these components are defined according to two scales, the regional study area (RSA) and the local study area (LSA) (Drawing 02). The RSA for surface hydrology effects is defined by the Peterson Creek watershed to its confluence with the South Thompson River, a watershed area of 130 km². The surface hydrology LSA includes all drainage basins that could be affected by mine surface disturbances and as such, covers a smaller area within the RSA. The LSA is basically the central one-third of the Peterson Creek watershed RSA.

The focus of the WBM is the LSA and the Project effects considered for the purposes of this hydrologic assessment include:

- changes in groundwater recharge and/or discharge rates and distribution; and
- changes in baseflow and surface flow to Peterson Creek and its tributaries.

Given the Project layout, effects on groundwater and surface water systems at the Project site are focused on Jacko Lake and downstream reaches of Peterson Creek (Lower). As per the Application Information Requirements (AIR) for the Project, the hydrologic assessment will:

- Identify and analyze potential effects associated with the Project using a site-wide WBM. The model will include effects of Construction, Operation, Decommissioning and Closure, and Post Closure activities.
- Describe the seepage from the MRSFs and TSF (acid generation, seepage, water quality, etc.).
- Describe measures the Proponent (i.e., KAM) has identified they will undertake to mitigate the potential adverse effects.

This report is focused on the former two requirements listed above. Project activities that could affect the hydrological regime include:

- site clearing and grading;
- soil salvage and topsoil storage;
- mining and excavation;
- water management;
- explosives storage and use;
- water required for dust control;
- water withdrawal from Kamloops Lake;
- Peterson Creek diversion around the Open Pit;
- partial infilling of the northeast arm of Jacko Lake;
- Open Pit development;
- TSF development
- ore stockpiling;
- stockpiling of rock from the Open Pit in MRSFs; and
- civil structures, including road construction.

Specifically, this report describes:

- the development of the site-wide WBM for the Project. The WBM depicts water movements within the Project area, including inflows and outflows from water management infrastructure, water withdrawal requirements, and reuse and reclaim water requirements for mine processes;
- expected changes to surface hydrology resulting from infrastructure development and freshwater withdrawal requirements for the Project;
- inflows to the Open Pit, from the TSF and MRSFs, runoff from undisturbed and disturbed areas and stream base flow analyses, which have been used to assess surface and groundwater interactions with mine facilities (done in conjunction with the groundwater quantity assessment); and
- pit lake water balance, which estimates the filling rate of the Open Pit and the potential for it to behave as a long-term hydraulic sink following mine closure.

The Application/EIS also identifies strategies to minimize and mitigate the effects of Project development on the regional hydrological regime, including extreme events (such as the 100-year dry and wet precipitation scenarios) and on water supplies and water license holders. Those strategies are discussed under the Water Management Plan developed for the Project.

Other (non-KAM) projects or activities that may affect surface water quantity include authorized withdrawals for surface and groundwater sources for drinking water, agriculture, commercial and industrial use. These authorized withdrawals are described here-in, as they have effects on existing surface water quantity, with respect to both annual flow volumes and seasonal distribution of flow.

1.4. Report Structure

This report is structured as follows:

- Section 2 describes the physiography and climate of the Project site. An overview of the Water Management Plan (WMP) is also included. Additional details of the WMP for the Project can be referenced in Section 11.7 of the EA application.
- Section 3 describes existing water licenses in the Peterson Creek watershed and management of flow releases from Jacko Lake.
- Section 4 describes the site-wide WBM nodes, which define the internal water balance of the mine site for water management purposes. Flows are also predicted at modeling nodes (corresponding to physical locations) downstream of the Project area on Peterson Creek. Section 4 provides a description of these assessment locations, which coincide with streamflow and water quality stations. The water quantity predictions derived from the WBM will be used to predict water quality at the assessment locations on Peterson Creek.
- Section 5 provides an overview of the WBM model and how it is used to predict runoff from undisturbed ground in the RSA and LSA. Model calibration results from observed streamflows on Peterson Creek (Upper) are also provided.
- Section 6 describes the runoff calculations used in the WBM for each of the land types in the Project area, including undisturbed ground, bare and reclaimed mine rock, the open pit, inactive and active tailings beach, and lake/pond surfaces.
- Section 7 describes the various inputs and assumptions used in the WBM. Examples include: water requirements for the process plant, the assumed settled dry density of the tailings, and estimated groundwater inflows to the open pit.
- Section 8 provides the WBM results calibrated to existing conditions at the various assessment locations, and then used in predictive mode to account for Construction, Operation, Decommissioning and Closure, and Post Closure effects on the hydrologic regime.

2.0 PHYSIOGRAPHY AND CLIMATE

2.1. Regional Study Area

The RSA is the Peterson Creek watershed, occupying an area of approximately 130 km² and extending from its headwaters to its confluence with the Thompson River. The RSA, which is situated within the Thompson Plateau physiographic region, is located in the Interior Plateaus and Highlands Groundwater Region of British Columbia. The Thompson Plateau is bound on the north by the Fraser Plateau, on the east by the Okanagan and Shuswap Highlands and on the west and south by the Cascade Mountains. The main population centres within the Thompson River Plateau include Kamloops, Kelowna, Penticton, Princeton, Merritt and Cache Creek.

Holland (1964) described the Thompson River Plateau as a gently rolling upland of low relief, generally between 1,200 m and 1,500 m elevation. The plateau covers an area of approximately 28,500 km² and represents the late Tertiary erosion surface that has been dissected by three major rivers, i.e., Thompson, Similkameen and Okanagan and their tributaries. Other major hydrologic features include Kamloops Lake and Okanagan Lake (Zubel, 2001).

The RSA is located within the South Thompson River watershed. The South Thompson River and North Thompson River converge at Kamloops to form the Thompson River, which is the largest tributary of the Fraser River. The Thompson River flows approximately 15 km westward from this confluence into Kamloops Lake (a locally enlarged reach of the river). The Thompson River drains an area of 56,000 km² from Greenstone Mountain to Kamloops Lake, carrying runoff from the Columbia and Monashee mountains (Knight Piésold, 2011). Kamloops Lake has a catchment area of 29,050 km², a surface area of 48 km² and is approximately 30 km long (Knight Piésold, 2011). From Kamloops Lake, the Thompson River continues to flow westward to Ashcroft, then southwest to the confluence with the Fraser River near Lytton, BC.

The main topographic feature of the RSA is the broad east-west and north-south Peterson Creek watershed, which is discussed in further detail below.

2.2. Local Study Area

The LSA is a sub-basin within the overall Peterson Creek watershed as shown on Drawing 02. The LSA occupies the central one-third of the RSA, and the Project is located entirely within the LSA, in an area of moderate relief. Elevations in the Peterson Creek watershed range from 800 m to 1,500 m asl. The LSA is characterized by rolling grasslands with timber at higher elevations. Forested areas consist mainly of Douglas-fir, Lodgepole pine and Ponderosa pine. At lower elevations, vegetation typically consists of bunchgrass, sagebrush and prickly pear cacti (Keystone, 2008).

Geomorphic landforms within the LSA reflect the glacial history of the region. Prominent depositional and erosional features that have resulted from glacial recession include south and

southeasterly trending drumlins, successions of melt water channels on sloping surfaces, and kettles. Sugarloaf Hill is a prominent bedrock landform in the LSA and has an elevation of 1130 m asl.

Peterson Creek originates at the Chuwels Mountain and flows north through a wide valley to Jacko Lake. This portion of the creek is referred to as Peterson Creek (Upper). Jacko Lake drains an area of approximately 41 km², about half of which is located above an elevation of 1200 m asl. Historical records indicate that Jacko Lake has been managed for human use since the early 1900s, when the outlet to Peterson Creek was raised to impound water for irrigation. This earthfill dam has since been raised on several occasions and is currently about 3 m high, impounding a volume of about 4.2 Mm³ (Frontier, 2014).

At higher water levels, flow discharge through a spillway located adjacent to the dam. But below elevation 892.0 m asl, the spillway invert, flows are released through a low-level outlet to support downstream water licenses (see Section 3.0). The outlet consists of a 17 m long concrete culvert with a sluice gate at its inlet (BCMOE, 1980). The pipe discharges immediately downstream of the dam and flows into a small concrete weir structure located approximately 30 m downstream of the dam, which overflows into the natural Peterson Creek channel. Jacko Lake is an important water body for recreational fisheries and has been stocked with rainbow trout.

The portion of the creek downstream of Jacko Lake is referred to as Peterson Creek (Lower). Downstream of Jacko Lake, the creek flows east through Knutsford and north again through downtown Kamloops ending at the confluence with the South Thompson River. Within the downtown core of Kamloops, the majority of Peterson Creek (Lower) is contained within culverts and channeled through concrete waterways to its confluence with the South Thompson River (City of Kamloops 2001). Peterson Creek (Upper and Lower) has a mainstem length of approximately 40 km and drains a watershed area of approximately 130 km².

Significant tributaries of Peterson Creek (Lower), from west to east, include Keynes Creek, Humphrey Creek, and Davidson Brook. Keynes Creek discharges into Peterson Creek (Lower) from the south immediately downstream of Jacko Lake. Keynes Creek drains an area of 11.4 km² and the proposed TSF for the Project is located in this tributary watershed.

Humphrey Creek is located to the immediate east of Keynes Creek, and also flows from south to north. Humphrey Creek originates from Edith Lake, flowing north over a distance of approximately 2.5 km to the confluence of Peterson Creek (Lower) draining an area of approximately 5.8 km². Edith Lake is similar to Jacko Lake in that it is stocked with fish and has a dam, which was originally constructed to support downstream water licenses on Peterson Creek (Lower). The lake is a popular destination for recreational fishing, particularly during the winter for ice fishing. Moving further to the east, Davidson Brook discharges into Peterson Creek (Lower) in the vicinity of Knutsford. This tributary flows from south to north and has a watershed area of approximately 6.2 km².

Drainages on the north side of Peterson Creek (Lower) are best described as disrupted, with numerous shallow ponds, some of which are ephemeral containing alkaline water and bordered with saline soils and mineral deposits.

Water storage and irrigation licenses have been present throughout the region since at least 1877 for Jacko Lake and Peterson Creek. Water licenses are described in more detail in Section 3.0.

2.3. Climate

The climate of the Ajax mine site is typical of the dry BC Interior with generally low total precipitation, high evaporation, and correspondingly low streamflow rates. Lying within the rain shadow of the Coast Mountains, this area has a semi-arid steppe climate characterized by generally cool dry winters and hot, dry summers, with low humidity. Convective storms are frequent in the summer months, and as a result precipitation is generally highest in June and July (Knight Piésold, 2013).

Meteorological data have been collected at the site since August 2010 and include records of temperature, relative humidity, precipitation, and wind speed and direction. Mean annual precipitation for the site has been evaluated by Knight Piésold (2013, 2015b) who analyzed active and inactive regional climate stations throughout the area, several of which have two decades or more of data. Based on this analysis, Knight Piésold (2015b) estimated average annual precipitation for the site at 336 mm, distributed as summarized in Table 2-1. This annual precipitation applies to an elevation of 950 m. Approximately 30% of the annual precipitation is estimated to occur as snow.

Table 2-1. Average monthly climate data for Ajax (Knight Piésold, 2015b).

Month	Average Temperature (°C)	Average Rainfall (mm)	Snow Water Equivalent (mm)	Average Precipitation (mm)	PET (mm)
January	-4.5	2.3	21.1	23.4	0
February	-2.4	2.9	11.6	14.5	1
March	1.5	4.2	7.7	11.9	12
April	6.5	16.3	2.8	19.2	40
May	11.1	32.8	0.0	32.8	77
June	14.7	43.4	0.0	43.4	103
July	18.7	42.4	0.0	42.4	130
August	17.8	32.0	0.0	32.0	114
September	12.9	35.8	0.0	35.8	71
October	5.6	13.2	2.3	15.5	28
November	-0.1	5.6	22.4	28.0	3
December	-4.9	3.7	33.3	37.0	0
Average/Total	6.4	235	101	336	579

Annual potential evapotranspiration (PET) has been estimated by Knight Piésold (2015b) at 579 mm; monthly values are shown on Table 2-1. In addition, sublimation between November and February has been estimated at 28 mm (KP, 2015b). Wet (i.e., above average) and dry (i.e., below average) annual precipitation for various return periods is summarized in Table 2-2.

Table 2-2. Wet and dry year annual precipitation at Ajax (Knight Piésold, 2015b).

Return Period (years)	Precipitation (mm)	
	Dry	Wet
10	259	413
20	238	434
50	213	459
100	197	475
200	182	490

The nearest active manual snow survey station is the Highland Valley station (ID No. 1C09A), which is operated by the Ministry of Forest, Lands and Natural Resource Operations (FLNRO). This station is located 40 km southwest of the study area at an elevation of 1475 m and has been in operation since 1966. Long-term normals for this station show a majority of the snowpack melting in April and May. The normal snowwater equivalence on April 1 is 83 mm compared to 20 mm on May 1 and 3 mm on May 15. In most years, the snowpack has completely melted by the end of May.

2.4. Water Management Plan – Overview

This report should be read in conjunction with the WMP prepared for the Project, which is provided in Section 11.7 of the EA application. The management of water as simulated in the WBM is consistent with this plan. This section provides a brief overview of the WMP.

Contact water for the site will be generated from the various MRSFs, the Open Pit and the TSF. A majority of this contact water is expected to be collected at a number of water management ponds around the site (Drawing 01), including:

- North Embankment Pond 1 and 2 – collect runoff from TSF seepage and a portion of the West MRSF (WMRSF);
- South and Southeast Embankment Ponds – collect runoff from the embankments, TSF seepage and undisturbed areas located up gradient;
- SMRSF Pond – collects seepage and surface runoff from the southeast portion of the South MRSF (SMRSF);
- EMRSF Pond – collects seepage and surface runoff from the East MRSF (EMRSF);
- the Plant Site Pond; and
- Central Pond – all of the above ponds are pumped to the Central Pond (with the exception of the Plant Site Pond), which also receives runoff from a portion of the WMRSF and SMRSF. Groundwater inflows and surface runoff into the Open Pit is also collected in the pit floor sump and pumped to the Central Pond.

Runoff to the Central Pond will be used as a source of water for the process plant, which will also receive water from TSF reclaim and make-up water from Kamloops Lake. The TSF will be operated as a conventional tailings facility, receiving flotation tailings from the process plant. Inputs to the TSF include:

- direct precipitation and catchment runoff;
- water in the thickened tailings slurry; and
- water collected in the South and Southeast Embankment Ponds.

Water collected in the TSF will be managed by the reclaim water system that provides water to the process. Due to high evaporative losses, low runoff volumes within the site and void losses to tailings, the Project will operate with a water deficit. Therefore, make-up water for the process plant will be required from Kamloops Lake.

Fresh (non-contact) water from Kamloops Lake will also be required for reagent preparation, gland seals, potable uses, dust control, the truck shop, explosives mixing, and firefighting. Fresh water will be pumped from Kamloops Lake and stored in a fresh/fire water tank. From this tank, fresh water will be distributed to different applications.

At closure, a reclamation cover will be placed over the MRSFs and the TSF. Active management of the Open Pit is not anticipated to be required for Post Closure and this facility will be allowed to slowly fill due to the influx of groundwater inflows, surface runoff and direct

precipitation. A majority of the TSF pond volume at the end of Operation will also be pumped into the Open Pit during the Decommissioning and Closure phase.

Figures 2-1, 2-2, 2-3, and 2-4 show schematics of the water management strategy during Construction, Operation, Decommissioning and Closure, and Post Closure.

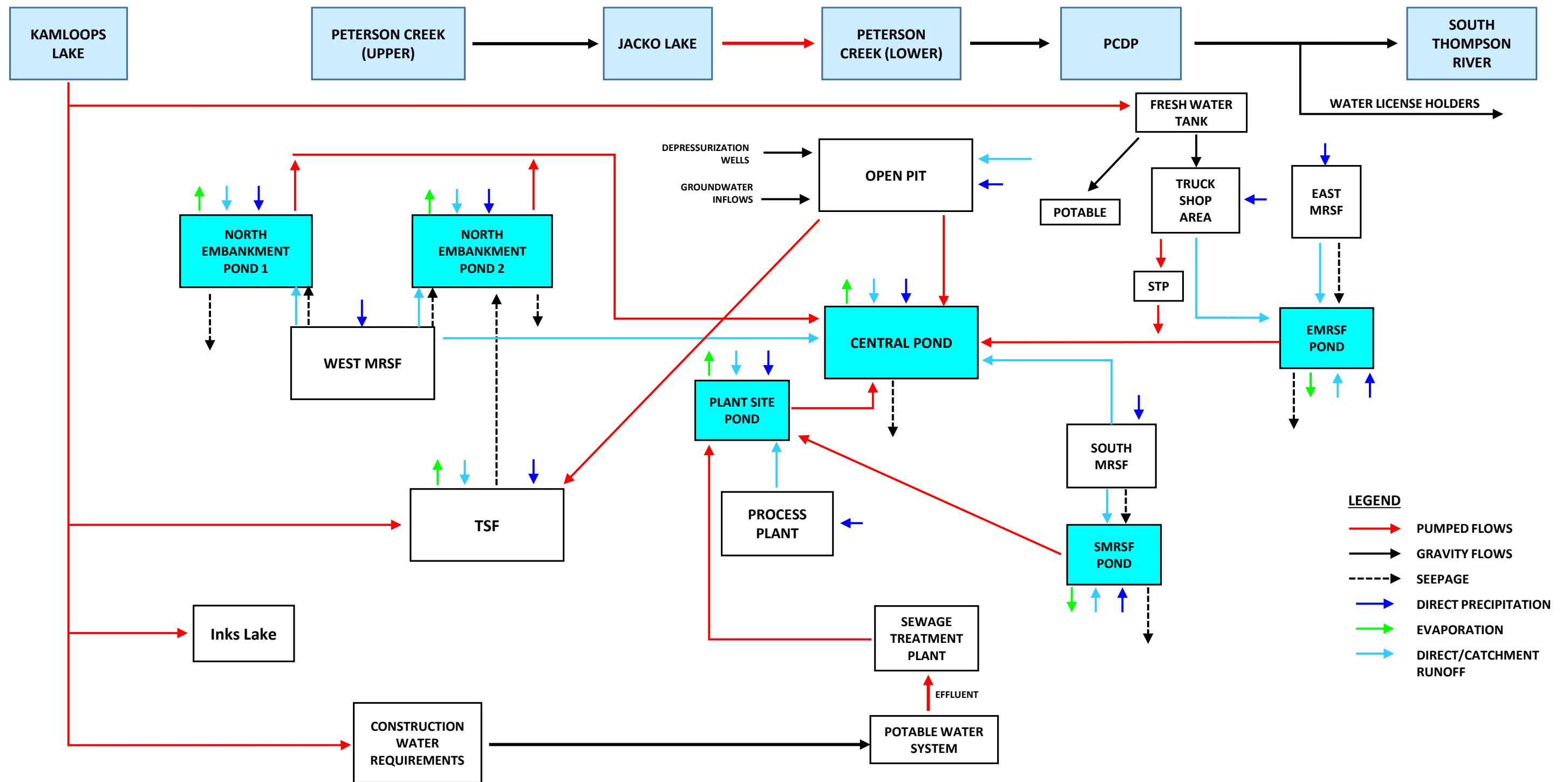


Figure 2-1. Water management strategy flow diagram – Construction.

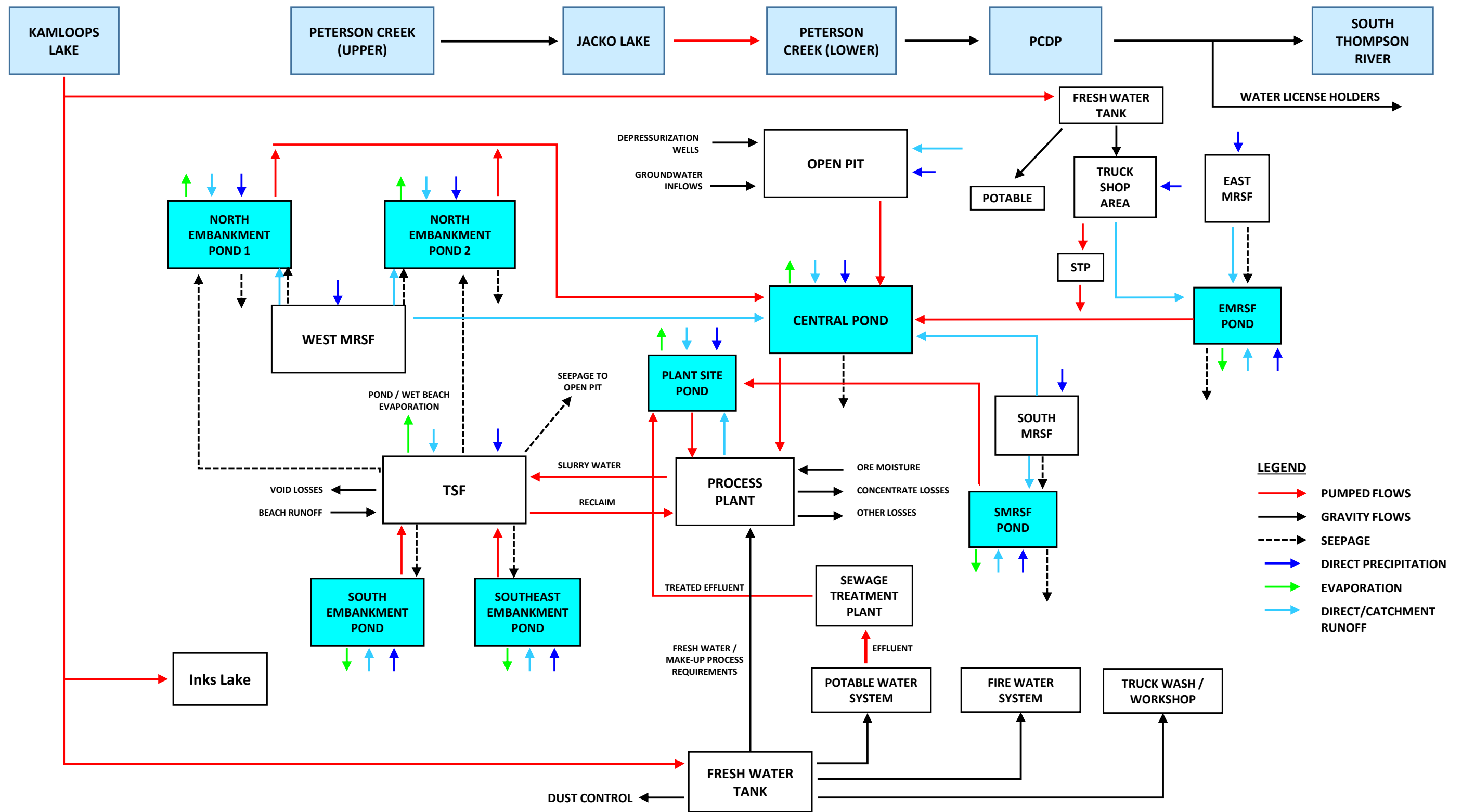


Figure 2-2. Water management strategy flow diagram – Operation.

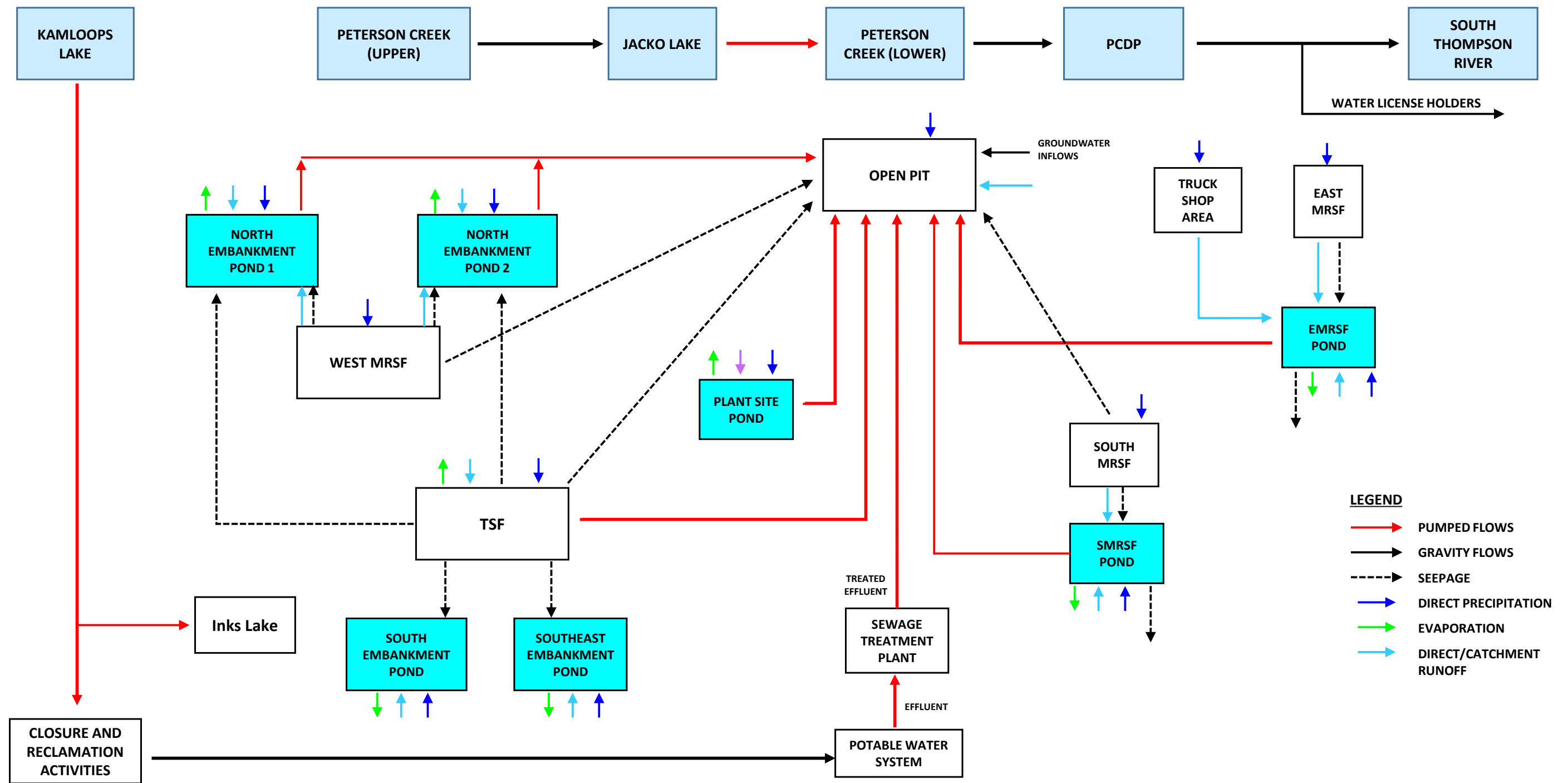


Figure 2-3. Water management strategy flow diagram – Decommissioning and Closure.

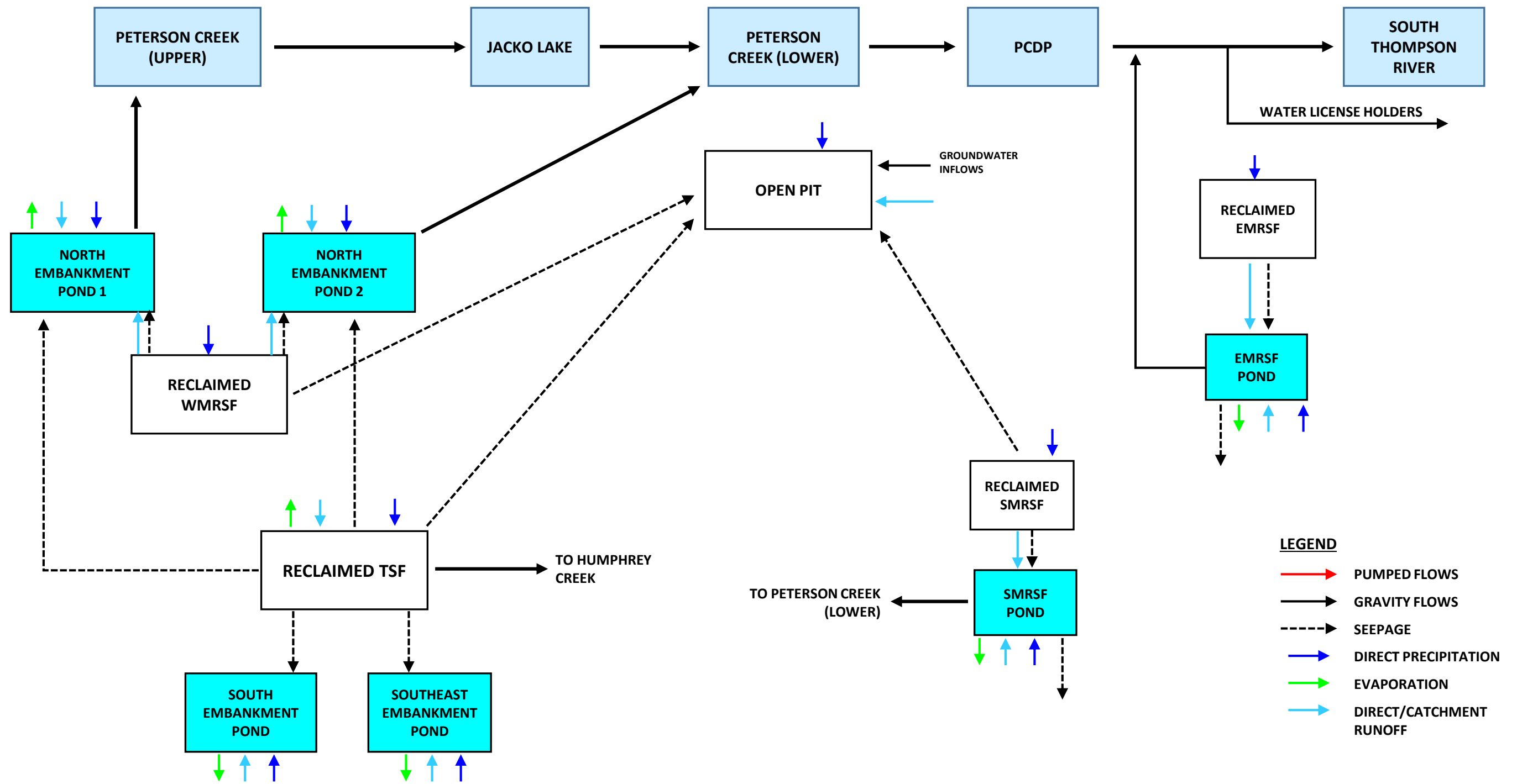


Figure 2-4. Water management strategy flow diagram – Post Closure.

3.0 HYDROLOGIC CONDITIONS AND EXISTING WATER USES

3.1. Jacko Lake

Historical records indicate that Jacko Lake has been managed since the early 1900s, when the outlet to Peterson Creek was raised to impound water for irrigation. Water licenses entitling users to the water in Jacko Lake and Peterson Creek date back to at least 1877 and the elevation of Jacko Lake has been raised on several occasions for this purpose.

A survey dating from 1913 shows a dam on the southeast arm of Jacko Lake, which is the outflow to Peterson Creek. The dam was built to store water and offer flood control for Kamloops. The Jacko Lake dam has been modified and rebuilt over the course of the twentieth century, which has, in turn, affected the size and shape of the lake and its water levels. Bathymetric mapping from 1950 shows a lake with a perimeter of 3.7 km, surface area of 40 ha and volume of approximately 3.6 Mm³.

In the 1970s, the lake area and level were increased. Jacko Lake was raised by about 1 m for improved water storage for licence holders and the lake area was increased to 47 ha. Two additional arms were created (the northeast and southeast arms) due to the raised water level and the west arms of the lake were expanded. A 1978 survey shows Jacko Lake with a perimeter of 4.9 km, surface area of 47 ha, and a volume of approximately 4.0 Mm³.

The outlet channel in the southeast arm was dredged to remove silt accumulations and the dam was raised 1 m in the fall of 1990 to double the amount of live storage for irrigation (Price 1991). The increased storage was allocated to the Ministry of Environment for fish conservation. In wet years most of the licensed water abstraction requirements can be met; however, in dry years the quantity of water is often much less than licensed (Price 1991).

A bathymetric survey of Jacko Lake was most recently completed by Frontier Geoscience in 2014. That survey found a maximum water depth of 24 m and a volume of 4.2 Mm³ at the invert of the spillway outlet (i.e., 892.0 m asl).

3.2. Water Licenses

The following section provides a review of water licenses located within the Peterson Creek watershed. However, there is no way to confirm how much of the licensed amount is actually removed from the creek in any given year.

3.2.1. Jacko Lake and Peterson Creek (Lower)

While Jacko Lake was originally modified for irrigation purposes, it is now an important water body for recreational fisheries and has been stocked for this purpose. There are a number of water storage licenses on Jacko Lake to support downstream irrigation, as well as a conservation license held by FLNRO for fish habitat. These licenses are summarized in Table 3-1 and Drawing 03.

Table 3-1. Jacko Lake and Peterson Creek water licenses.

Name	License	Purpose	Volume	Unit	Licensee
Jacko Lake					
Peterson Creek	C045895	Storage-Non Power	5,181	m ³	White
Peterson Creek	C045898	Storage-Non Power	82,520	m ³	Frolek Enterprises Ltd.
Peterson Creek	C132063	Conservation Storage	432,335	m ³	FLNRO, Fish & Wildlife
Peterson Creek	C132064	Storage-Non Power	41,260	m ³	Frolek Enterprises Ltd.
Peterson Creek	C132065	Storage-Non Power	19,797	m ³	Hubbard
Peterson Creek	F019450	Storage-Non Power	9,621	m ³	Paravantes
Peterson Creek	F019453	Storage-Non Power	255,824	m ³	R 450 Holdings Ltd.
Peterson Creek	F021539	Storage-Non Power	38,485	m ³	Heron
Peterson Creek	F065641	Storage-Non Power	39,595	m ³	Hubbard
Total licensed storage volume			924,618	m³	
Peterson Creek below Jacko Lake					
Peterson Creek	C118287	irrigation	176,585	m ³ /yr	Thomson
Peterson Creek	C118288	domestic	2,273	m ³ /day	Prehara
Peterson Creek	C118288	irrigation	6,476	m ³ /yr	Prehara
Peterson Creek	C118289	domestic	2,273	m ³ /day	Shannon
Peterson Creek	C118289	irrigation	6,476	m ³ /yr	Shannon
Peterson Creek	C061554	domestic	2,273	m ³ /day	Styles
Peterson Creek	C045894	irrigation	5,181	m ³ /yr	White
Peterson Creek	C045896	irrigation	5,181	m ³ /yr	White
Peterson Creek	C045893	irrigation	82,520	m ³ /yr	Frolek Enterprises Ltd.
Peterson Creek	C045886	irrigation	82,520	m ³ /yr	Frolek Enterprises Ltd.
Peterson Creek	C130927	stockwatering	2,273	m ³ /day	R 450 Holdings Ltd.
Peterson Creek	C130927	irrigation	255,824	m ³ /yr	R 450 Holdings Ltd.
Peterson Creek	C130930	irrigation	255,824	m ³ /yr	R 450 Holdings Ltd.
Peterson Creek	F049860	irrigation	38,485	m ³ /yr	Heron
Peterson Creek	F049859	irrigation	38,485	m ³ /yr	Heron
Peterson Creek	F065640	irrigation	39,595	m ³ /yr	Hubbard
Peterson Creek	F065638	irrigation	39,595	m ³ /yr	Hubbard
Peterson Creek	C035096	irrigation	9,621	m ³ /yr	Paravantes
Peterson Creek	C036058	irrigation	9,621	m ³ /yr	Paravantes
Peterson Creek	C035096	domestic	4,546	m ³ /day	Paravantes
Peterson Creek	C035560	domestic	4,546	m ³ /day	Paravantes
Peterson Creek	C035561	Storage-Non Power	1,233	m ³	Paravantes
Licensed annual irrigation volume			620,763	m³	
Licensed annual abstraction volume			627,400	m³	

Note: Rows shaded in light blue have irrigation licenses supported by Jacko Lake storage. Rows shaded in light red are supported by supplementary storage licenses on Edith Lake (and associated diversion licenses on Anderson Creek) (Table 2-3). Rows shaded in light orange are supplementary licenses supported by Anderson Creek diversions (Table 2-4). Baseflow licenses are shaded in light green.

Each of the storage licenses on Jacko Lake have either a supplementary storage and diversion license on Edith Lake (see Table 3-3) or a diversion license on Anderson Creek (see Table 3-4). The licensed storage volume on Jacko Lake, 0.92 Mm³, represents about 22% of the total lake volume at elevation 892.0 m asl and an approximate lake height of 2 m.

3.2.2. Peterson Creek (Upper)

There are also a number of water licenses located upstream of Jacko Lake, as summarized in Table 3-2 below. Based on this table, up to 530,000 m³ could be pumped from Peterson Creek on an annual basis for irrigation purposes.

Table 3-2. Surface water licenses on Peterson Creek above Jacko Lake.

Timber Lake	F005895	Storage-Non Power	30,837	m ³	Michell
Timber Lake	F021236	Storage-Non Power	72,775	m ³	Michell
Jacko Creek	F021235	Irrigation	103,612	m ³ /yr	Michell
Peterson Creek	C130603	Irrigation	133,216	m ³ /yr	Lipewich
Peterson Creek	F006060	Domestic	2.273	m ³ /day	Lipewich
Peterson Creek	F006060	Irrigation	44,405	m ³ /yr	Lipewich
Peterson Creek	F006009	Incidental - Domestic	4.546	m ³ /day	Michell
Peterson Creek	F006009	Irrigation	249,163	m ³ /yr	Michell
Total Licensed storage volume			103,612	m³	
Licensed annual irrigation volume			530,396	m³	
Licensed annual volume (irrigation + domestic)			533,760	m³	

Note: the storage volume in Timber Lake is used to support irrigation practices throughout the summer, as described below.

The use of Peterson Creek water above Jacko Lake is complex. Sugarloaf Ranches divert streamflows directly into their fields rather than taking irrigation water from a dammed lake or directly from the river. Diversions of Peterson Creek typically start the third week of May and last for two weeks. During this short time frame, Peterson Creek flows are diverted into ditches at the upslope end of agricultural fields and then allowed to flood out onto the fields. This practice provides enough moisture to the soils to grow a hay crop. Some percentage of this agricultural return flow re-enters Peterson Creek downstream, but the delay in return, and the short time of diversion, suggests this flow need not be quantified independently. These diversion ditches are delineated on Drawing 03.

The other licensee on Peterson Creek, Michell, is able to irrigate his fields through the summer with a gravity-feed system from Timber Lake. Timber Lake, located just west of Highway #5, is dammed and Michell has a storage license of about 104,000 m³ on the lake along with an associated irrigation license for the same amount. According to FLNRO records, the Timber Lake Dam has a height of 4 m.

3.2.3. Keynes Creek

There are a few water licenses in the upper watershed of Keynes Creek, as summarized in Table 3-3 and illustrated on Drawing 03. The use of this water for irrigation is aided by two small dams located on Smith Slough and a third dam on Keynes Creek. The Smith Slough Dam is 2 m high with a crest length of 16 m, while the Smith Slough Saddle Dam is 1 m high with a crest length of 60 m. Little Pond Dam on Keynes Creek is 5.5 m high with a crest length of 30 m. All three dams have a dam crest elevation of 1040 m asl, according to FLNRO records.

Table 3-3. Keynes Creek water licenses.

Name	License	Purpose	Volume	Unit	Licensee
Smith Slough	C102915	stockwatering	9.092	m ³ /day	Little
Smith Slough	C102915	storage	30,837	m ³	Little
Smith Slough	C102915	irrigation	27,507	m ³ /yr	Little
Keynes Creek	C102915	storage	30,837	m ³	Little
Keynes Creek	C102915	irrigation	27,507	m ³ /yr	Little
Keynes Creek	C102915	stockwatering	9.092	m ³ /day	Little
Total Licensed storage volume			61,674	m³	
Licensed annual irrigation volume			55,013	m³	
Licensed annual abstraction volume			61,650	m³	

3.2.4. Edith Lake

Reservoir storage in the Peterson Creek watershed is also supplemented by Edith Lake, which is located in the upper reaches of Humphrey Creek. Some of the licensees on Jacko Lake have complementary licenses on Edith Lake that would be available to supplement flows in Peterson Creek (Lower) during very dry years. Edith Lake is similar to Jacko Lake in that it is stocked with fish and has a dam (Figure 3-1). According to FLNRO records, the dam is an earthfill structure with:

- crest elevation = 1023.2 m
- dam height = 3.3 m
- crest length = 60 m.

Edith Lake has a local watershed area of 185 ha compared to a lake area of about 25 ha. The resulting ratio of 7.5 indicates that the lake has a severe water deficit, as evaporative losses from the lake surface far exceed inflows. However, there is a channel diversion that connects Anderson Creek (the watershed to the immediate south) to Edith Lake. The diversion into Edith Lake is supposed to capture all flow that arrives at the diversion point between October 1 and March 31 every year. Also all freshet flows in excess of that needed for licenses downstream on Anderson Creek should be diverted into Edith Lake. According to BC Rivers

Consulting (2011), there was reportedly zero diversion into Edith Lake for at least a decade prior to 2011, although excess freshet runoff was diverted into the lake in 2011, 2014 and 2015.



Figure 3-1. Edith Lake Dam crest. BGC photograph of June 18, 2015.

Water licenses on Edith Lake and the Anderson Creek diversion are summarized below. All of the Edith lake licenses are supported by diversion licenses on Anderson Creek (Drawing 03). Edith Lake is a popular destination for recreational fishing, particularly during the winter for ice fishing.

Table 3-4. Edith Lake water licenses.

Name	License	Purpose	Volume	Unit	Licensee
Humphrey Creek	3005220 ¹	Conservation Storage	740,089	m ³	FLNRO, Fish & Wildlife
Humphrey Creek	C045887	Storage-Non Power	82,520	m ³	Frolek Enterprises Ltd.
Humphrey Creek	C130933	Storage-Non Power	61,797	m ³	R 450 Holdings Ltd.
Humphrey Creek	C130934	Conservation Storage	194,027	m ³	FLNRO, Fish & Wildlife
Humphrey Creek	C132033	Conservation Storage	5,181	m ³	FLNRO, Fish & Wildlife
Humphrey Creek	F007307	Storage-Non Power	98,678	m ³	KGHM Ajax Mining Inc.
Humphrey Creek	F007308	Storage-Non Power	61,674	m ³	KGHM Ajax Mining Inc.
Humphrey Creek	F019451	Storage-Non Power	9,621	m ³	Paravantes
Humphrey Creek	F021540	Conservation Storage	38,485	m ³	FLNRO, Fish & Wildlife
Humphrey Creek	F132035	Conservation Storage	39,595	m ³	FLNRO, Fish & Wildlife
Total licensed storage volume			1,331,667	m³	

¹ Active application.

Rows shaded in grey are complementary licenses to those on Jacko Lake (Table 3-1).

Table 3-5. Anderson Creek diversion water licenses.

Name	License	Purpose	Volume	Unit	Licensee
Water Licenses Upstream of Edith Lake					
Anderson Creek	C036058	Irrigation	9,621	m ³ /yr	Paravantes
Anderson Creek	C045886	Irrigation	82,520	m ³ /yr	Frolek Enterprises Ltd.
Anderson Creek	C045896	Irrigation	5,181	m ³ /yr	White
Anderson Creek	C130930	Irrigation	255,824	m ³ /yr	R 450 Holdings Ltd.
Anderson Creek	F007306	Irrigation	98,678	m ³ /yr	KGHM Ajax Mining Inc.
Anderson Creek	F049859	Irrigation	38,485	m ³ /yr	Heron
Anderson Creek	F065638	Irrigation	39,595	m ³ /yr	Hubbard
Total Licensed storage volume			1,269,993	m³	
Licensed annual irrigation volume			529,903	m³	

All of these licenses are supportive to storage and irrigation licenses on Jacko Lake/Peterson Creek (Lower) or Humphrey Creek.

The water licenses of Table 3-5 are supplementary diversion licenses to support the storage and irrigation licenses on Edith Lake and Peterson Creek (Lower) (see Table 3-1).

Further downstream on Humphrey Creek, KAM also holds license F007306 that allows for the use of 80 acre-ft (98,678 m³) of water for irrigation between April 1 and September 30. This license is complementary to storage license F007307 on Edith Lake and the associated diversion license on Anderson Creek.

According to a local resident, Mr. Ciacone, 2014 was the first time in twenty-five years when streamflows were observed near the mouth of Humphrey Creek. Prior to that time, water levels in the lake had not approached the spillway invert for a couple of decades (Figure 3-2). In a telephone conversation with BGC, Mr. Ciacone observed that FLNRO recently deepened the spillway outlet (i.e., outflows occur at lower lake elevations) and more streamflows are being allowed to be diverted from Anderson Creek into Edith Lake following channel improvements at the diversion location. These actions are likely responsible for the recent observations of streamflow, which include the spring of 2015.



Figure 3-2. Upstream view of Edith Lake at outlet. BGC photograph of June 18, 2015.

3.2.5. Davidson Brook

Moving further downstream on Peterson Creek (Lower), Davidson Brook enters the creek from the south. Water licenses on this tributary are summarized in Table 3-6 below. Some of these licenses are supported by Anderson Creek diversions (Drawing 03). Two dams are located on this tributary: Humphrey Pond Dam and Blair Pond.

Table 3-6. Davidson Brook water licenses.

Name	License	Purpose	Volume	Unit	Licensee
Howard Pond	C115069	Irrigation	39,471	m ³ /yr	Half Circle Ranch
Howard Pond	C115069	Stockwatering	4,546	m ³ /day	Half Circle Ranch
Howard Pond	C115069	Storage-Non Power	39,471	m ³	Half Circle Ranch
Howard Pond	C115070	Irrigation	9,868	m ³ /yr	Blair
Howard Pond	C115070	Stockwatering	4,546	m ³ /day	Blair
Howard Pond	C115070	Storage-Non Power	9,868	m ³	Blair
Davidson Brook	C109341	Irrigation	66,608	m ³ /yr	Half Circle Ranch
Davidson Brook	C109341	Stockwatering	9,092	m ³ /day	Half Circle Ranch
Davidson Brook	C109341	Storage-Non Power	66,608	m ³	Half Circle Ranch
Davidson Brook	C130564	Conserv.-Stored Water	30,837	m ³	Half Circle Ranch
Total Licensed storage volume			146,784	m³	
Licensed annual irrigation volume			115,947	m³	
Licensed annual abstraction volume			122,584	m³	
Water Licenses on Howard Pond that are supported by Anderson Creek Water Licenses					
Howard Pond	C115106	Irrigation	16,652	m ³ /yr	Blair
Howard Pond	C115107	Irrigation	11,101	m ³ /yr	Half Circle Ranch

3.2.6. Separation Lake

The most downstream major tributary of Peterson Creek is the Separation Lake area. Water licenses in this area are summarized in Table 3-7. As with the other tributaries, some of these licenses are supported by Anderson Creek diversions. Dams include Upper Separation Lake Dam, West Slough Dam, and East Slough Dam (Drawing 03).

Table 3-7. Separation Lake water licenses.

Name	License	Purpose	Volume	Unit	Licensee
Bucking Raft Lake	C117813	Stockwatering	31.823	m ³ /day	Deleeuw Ranch Ltd.
Coke Slough	C050962	Irrigation	1,850	m ³ /yr	Carroll
Dinah Spring	C030302	Stockwatering	22.730	m ³ /day	Frolek Cattle Co. Ltd.
Upper Separation Lake	C114398	Irrigation	14,802	m ³ /yr	Sunny Hills Ranch Ltd.
Upper Separation Lake	C114398	Stockwatering	4.546	m ³ /day	Sunny Hills Ranch Ltd.
Upper Separation Lake	C114398	Storage-Non Power	14,802	m ³	Sunny Hills Ranch Ltd.
Kuttai Spring	F009887	Domestic	2.273	m ³ /day	Frolek Ranch & Sawmills Ltd.
West Slough	C131014	Conserv.-Stored Water	12,335	m ³	Sunny Hills Ranch Ltd.
West Slough	C131015	Conserv.-Stored Water	12,335	m ³	Sunny Hills Ranch Ltd. C/O Separation LA
West Slough	C131018	Conserv.-Stored Water	12,335	m ³	Sunny Hills Ranch Ltd.
West Slough	C131019	Conserv.-Stored Water	12,335	m ³	Sunny Hills Ranch Ltd.
East Slough	C131014	Conserv.-Stored Water	12,335	m ³	Sunny Hills Ranch Ltd.
East Slough	C131015	Conserv.-Stored Water	12,335	m ³	Sunny Hills Ranch Ltd. C/O Separation LA
East Slough	C131018	Conserv.-Stored Water	12,335	m ³	Sunny Hills Ranch Ltd.
East Slough	C131019	Conserv.-Stored Water	12,335	m ³	Sunny Hills Ranch Ltd.
Separation Lake	C116977	Domestic	4.546	m ³ /day	Sunny Hills Ranch Ltd.
Separation Lake	C116977	Irrigation	139,383	m ³ /yr	Sunny Hills Ranch Ltd.
Total Licensed storage volume			113,480	m³	
Licensed annual irrigation volume			156,035	m³	
Licensed annual abstraction volume			180,095	m³	
Water Licenses in Separation Lake Watershed that are supported by Anderson Creek Water Licenses					
West Slough	C024354	Storage-Non Power	120,881	m ³	Sunny Hills Ranch Ltd.
West Slough	F016529	Irrigation	240,529	m ³ /yr	Sunny Hills Ranch Ltd.
East Slough	C024354	Storage-Non Power	120,881	m ³	Sunny Hills Ranch Ltd.
East Slough	F016529	Irrigation	240,529	m ³ /yr	Sunny Hills Ranch Ltd.
Separation Lake	F016529	Irrigation	240,529	m ³ /yr	Sunny Hills Ranch Ltd.

3.3. Water License Management

Because of the many water licenses on Peterson Creek, procedures are in place to fairly distribute the available water in any year to all licensees in order of priority. This allocation of water is administered by a province-appointed water bailiff. There are four categories of licensed water in Peterson Creek and these licenses have the following priority (BC Rivers Consulting, 2011):

1. Baseflow licenses downstream of Jacko Lake;
2. Irrigation and related storage licenses downstream of and in Jacko Lake;
3. Baseflow licenses upstream of Jacko Lake; and
4. The conservation storage license in Jacko Lake.

Because of the many licenses on Peterson Creek, the water bailiff is tasked with opening and closing the sluice gate that controls outflows from Jacko Lake when water levels are below the elevation of the spillway outlet (Figure 3-3). The invert of the sluice gate is 2.6 m lower than the spillway invert (BC Rivers Consulting, 2011).



Figure 3-3. Jacko Lake outflow control structure.

BC Rivers Consulting (2011) was retained by the Province to develop storage release rules for Jacko Lake. A summary of these storage rules is provided below.

Table 3-8. Jacko Lake storage release rules (from Table 4 of BC Rivers Consulting, 2011).

No release from Jacko Lake storage below a lake level of 1.36 m above the sluice invert (1.24 m below the spillway invert elevation)*.
Jacko Lake gate remains closed from October 1 to March 31.
First priority release from Jacko Lake each spring is for the three baseflow licenses downstream of Jacko Lake
Maximum daily flow rate is 38 L/s; max duration is 70 consecutive days from start of irrigation
Baseflow flow release cannot exceed the daily Jacko Lake inflow rate.
Any licenses not being exercised will reduce the maximum daily flow rate accordingly.
Second priority release from Jacko Lake is for all the storage-supported licenses downstream of Jacko Lake
Maximum daily flow rate is 70 L/s; duration is 100 days from start of irrigation
Any licenses not being exercised will reduce the maximum daily flow rate accordingly.
Maximum duration of 100 days of storage release is reduced by the duration of spilling minus 2 days
Any supplemental release from Edith lake will reduce the maximum daily release from Jacko Lake in kind
Third priority use of Peterson Creek flow is for baseflow licenses upstream of Jacko Lake
Maximum daily flow rate is 71 L/s; maximum duration is 70 days from start of irrigation
Any licenses not being exercised will reduce the maximum daily flow rate accordingly.
These licenses can only be exercised when first and second priority licensed demand has been met. Only exception to this is written authorization from Allocation Section Head to divert flow.
Fourth priority conservation storage license in Jacko Lake is automatically met if all the above rules are followed.

* This stipulation recognizes the fact that all the additional water stored in Jacko Lake since the dam crest and spillway were raised 1 m in 1989 is licensed to MFLNRO and that lake evaporation from July through September averages 0.15 m or more. This evaporation loss is shared equally between the MFLNRO storage volume and the irrigation storage volume.

The effect of the flow regulation on Jacko Lake is illustrated by the 2014 hydrographs for the lake spillway (JACLAKE), the low level outlet (JACSEEP), and PETER (Figure 3-4). From the beginning of May to early July, water levels were high enough such that spillway overflow was sufficient to honor downstream water licenses. This high flow period was followed by a pair of two to three week periods where flows were released via JACSEEP to accommodate the storage-supported licenses downstream of Jacko Lake. Figure 3-4 shows how releases through JACSEEP control flow at PETER.

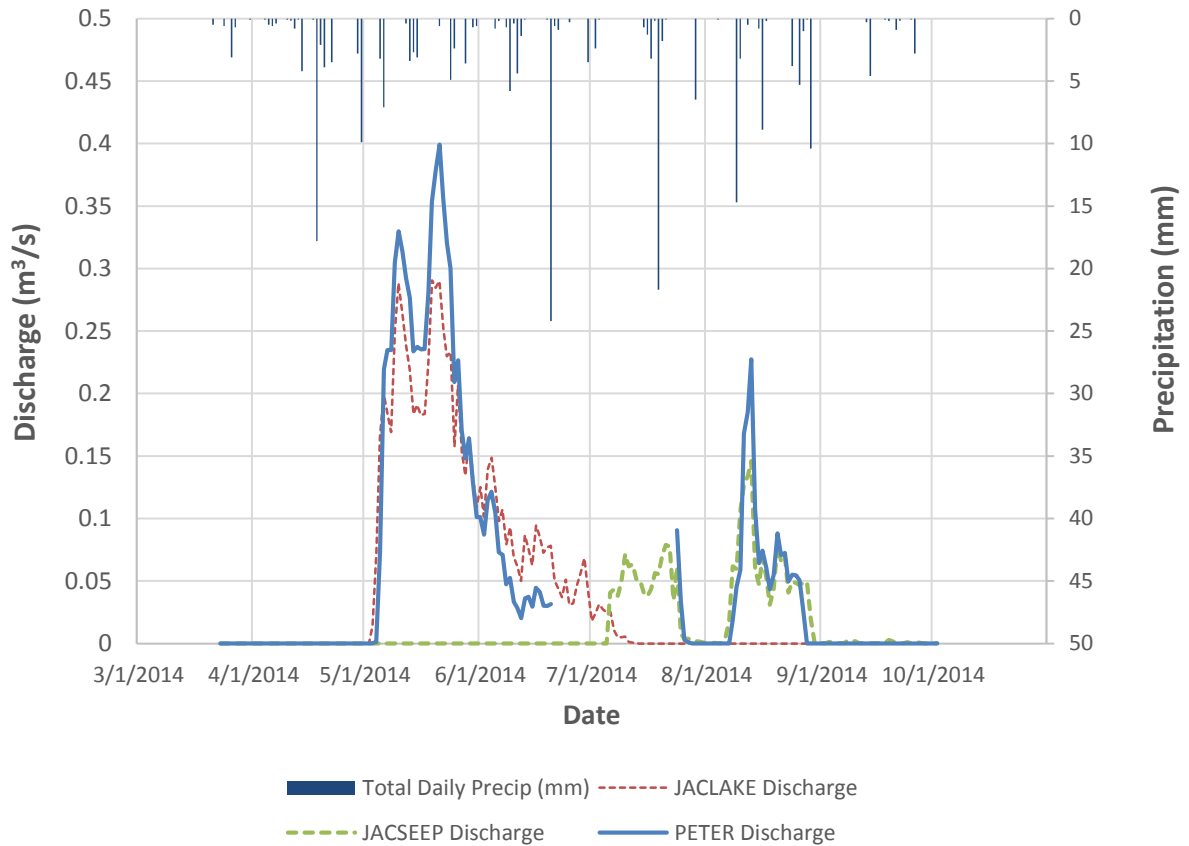


Figure 3-4. 2014 hydrographs for JACLAKE, JACSEEP and PETER (after BGC, 2015c).

3.4. Water Survey of Canada

The Water Survey of Canada (WSC) historically operated a hydrometric station on Peterson Creek. This station, Peterson Creek above Jacko Creek (08LE102), was operated from 1981 to 1986. Flow was measured seasonally at this station, typically from April 1 to September 30. Monthly runoff depths during this period are summarized in Table 3-9. The reported drainage area for this station is 21.2 km².

Table 3-9. Monthly runoff for Peterson Creek above Jacko Creek (1981 to 1986).

Month	1981 (mm)	1982 (mm)	1983 (mm)	1984 (mm)	1985 (mm)	1986 (mm)	Average (mm)
April	-	1.6	5.4	3.1	1.9	2.2	2.9
May	15.3	20.9	19.3	11.7	18.2	15.3	16.8
June	6.4	10.7	5.2	32.7	10.5	8.0	12.3
July	1.8	6.8	1.1	2.5	0.0	5.5	3.0
August	0.3	1.0	0.0	0.0	0.0	1.0	0.4
September	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	23.8	41.0	31.0	50.0	30.6	32.0	35.4

It is not clear whether station 08LE102 was located upstream of where irrigation water was initially removed. The published co-ordinates for this station place it off of the stream network in a field (Drawing 03). However, BGC suspects that the station would have been placed upstream of the irrigation diversion. The WSC was contacted to clarify the matter, but the technician responsible for that station could not recall whether irrigation water was removed from upstream of the gauge.

4.0 MODELLING NODES

4.1. Overview

The site-wide WBM is used to predict flows at a number of modeling nodes, termed assessment locations, downstream of the Project area on Peterson Creek. These assessment locations coincide with water quality stations and in some cases with hydrometric stations. Table 4-1 presents the modeling assessment locations and the corresponding surface water stations along with the contributing watershed area to each location. Locations are shown on Drawing 04.

Table 4-1. Watershed areas for assessment locations.

Location	Hydrometric Station	Watershed Area (km ²)
Jacko Lake	JACLAKE	40.9
PC08	JACSEEP	40.9
PC03+	PETER	57.8
PC02.5		69.9
PC02.3		71.7
PC02		106.4

+ The actual watershed area is 60 km², but 2.2 km² reports to the existing open pits, which do not discharge to Peterson Creek (Lower).

Modeling monthly streamflows at these locations is influenced by the presence and regulation of flows from Jacko Lake. The surface water licenses on Peterson Creek and its tributaries are shown on Drawing 03. In addition, some of the tributaries have closed basins with no obvious surface outlet and thus presumably contribute little to no runoff to downstream reaches. There are a number of earthfill dams of varying sizes within the study area (Drawing 04).

This section provides a discussion of the modeling nodes used in this study. Water quantity predictions from the WBM will ultimately be used to predict water quality at the various assessment locations. The modelling assessment locations are described in this section. These are Jacko Lake, PC08, PC03, PC02.5, PC02.3, and PC02.

4.2. Jacko Lake

A drainage area of 40.9 km² reports to the outlet of Jacko Lake, about half of which is located above an elevation of 1200 m (Drawing 04). The Project, primarily the TSF, will have a minor effect on the watershed area reporting to the lake, but most of the mine facilities are located down gradient of the lake. A small portion of the WMRSF is also located in the Jacko Lake watershed (about 50 ha), as well as North Embankment Pond 1. In addition, the Open Pit will take part of the northeast arm of Jacko Lake (Drawing 01).

The current water management plan (WMP) for the Project is that during Operation, water levels in Jacko Lake will be controlled by pumping water around the project infrastructure to the north and discharging the water back into Peterson Creek (Lower) downstream of the Central Pond. A little further downstream, a second dam will be constructed on Peterson Creek (Lower) immediately downstream of the confluence with Humphrey Creek (Drawing 01). This impoundment is referred to as the Peterson Creek Downstream Pond (PCDP). Flows would then be released from this second dam to meet the downstream storage-supported water license requirements.

There are a total of five modeling nodes downstream of Jacko Lake. Each of these nodes and assumed runoff areas are described below.

4.3. Station PC08

Water quality is monitored at PC08, located immediately downstream of Jacko Lake. Runoff sources to this station include spillway flows and regulated flow releases from Jacko Lake (Figure 3-3).

4.4. Station PC03

The watershed area upstream of station PC03 is approximately 57.8 km². On the north side of Peterson Creek (Lower), the existing watershed area that reports to the creek is about 3.1 km². However, by the end of mining operations, this area will be reduced to 40 ha due to an expanding Open Pit. On the south side, Keynes Creek with an area of approximately 11.4 km² discharges into Peterson Creek (Lower).

Drawing 05 shows the location where a hydrometric station was installed near the mouth of Keynes Creek in 2014 to monitor streamflows out of this watershed (BGC, 2015c). Almost no surface flow was recorded in 2014 (Figure 4-1), which is consistent with the poorly defined channel at this location (Figure 4-2).

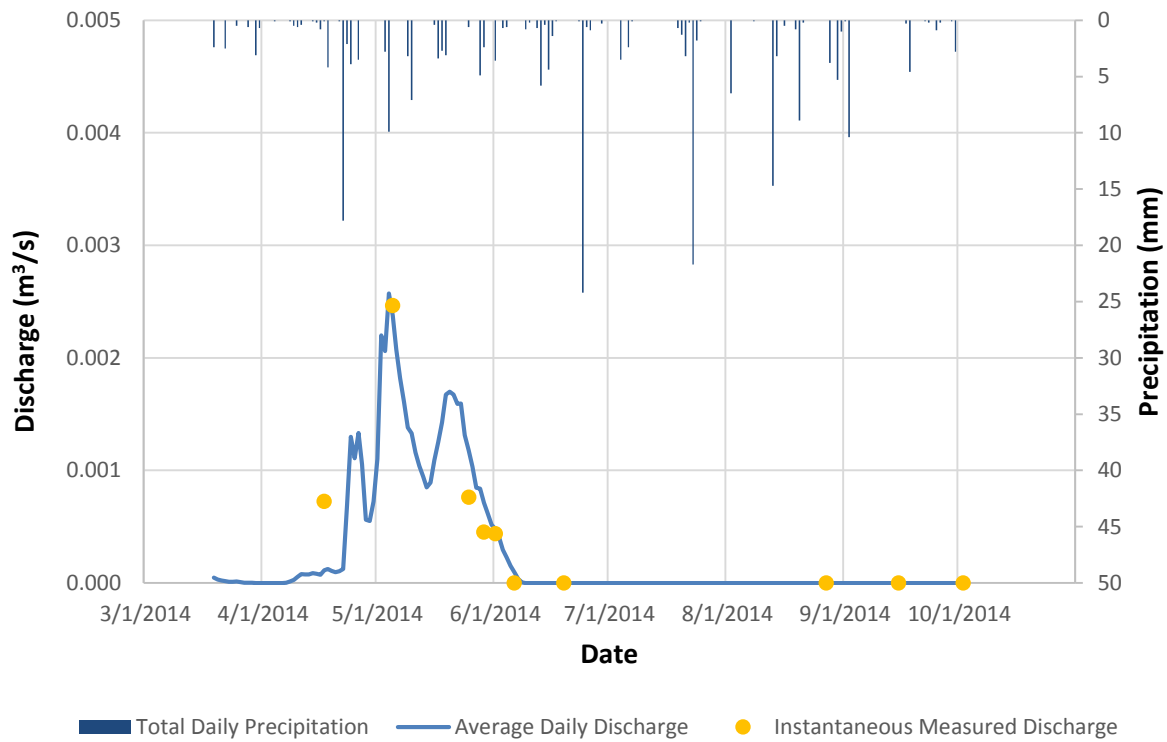


Figure 4-1. 2014 Keynes Creek hydrograph (after BGC, 2015c).



Figure 4-2. KEYNES hydrometric station and staff gauge on May 25, 2014. Note the poorly defined channel and abundance of large woody debris and organic matter.

The lack of surface flow out of the Keynes Creek watershed is a function of the upstream water licenses and evaporative losses from lakes. Additional details are provided in Section 7.9.

On the south side of Peterson Creek, the contributing watershed area is about 195 ha. However, about 30% of this area is occupied by historically reclaimed mine rock, which supports vegetation. Runoff from the reclaimed mine rock is captured by a perimeter ditch that discharges to one of two collection ponds (Drawing 06). These ponds were dry during a BGC site visit in mid-July 2012 (Figure 4-3).

4.5. Station PC02.5

The watershed area upstream of station PC02.5 is approximately 69.9 km². Between PC03 and PC02.5, an additional watershed area of 1210 ha reports to Peterson Creek. This area includes Humphrey Creek (580 ha) and a northern tributary (176 ha), which will be partially covered (76 ha) by the EMRSF. Edith Lake is located in the upper reaches of Humphrey Creek.

This reach of Peterson Creek (Lower) includes the PCDP, which will be used as an impoundment for water pumped from Jacko Lake. Water will be released from this pond to meet the downstream storage-supported water license requirements.

4.6. Station PC02.3

The watershed area upstream of station PC02.3 is approximately 71.7 km². An additional watershed area of 180 ha reports to Peterson Creek (Lower) between PC02.5 and PC02.3. Most of this watershed is a northern tributary (172 ha) that will be partially covered by the EMRSF.

4.7. Station PC02

The watershed area upstream of station PC02 is approximately 106.4 km². Downstream of PC02.3, an additional watershed area of 1230 ha discharges into Peterson Creek (Lower). About half of this area is from Davidson Brook (Drawing 04), which has a drainage area of approximately 620 ha. A number of water licenses are situated in this tributary, as summarized in Section 3.

On the east side of Highway #5A, a watershed area of 2240 ha (Separation Lake) may contribute surface runoff to Peterson Creek (Drawing 04). However, this area is quite flat and there are a number of water licenses in the watershed, as summarized in Table 3-7.

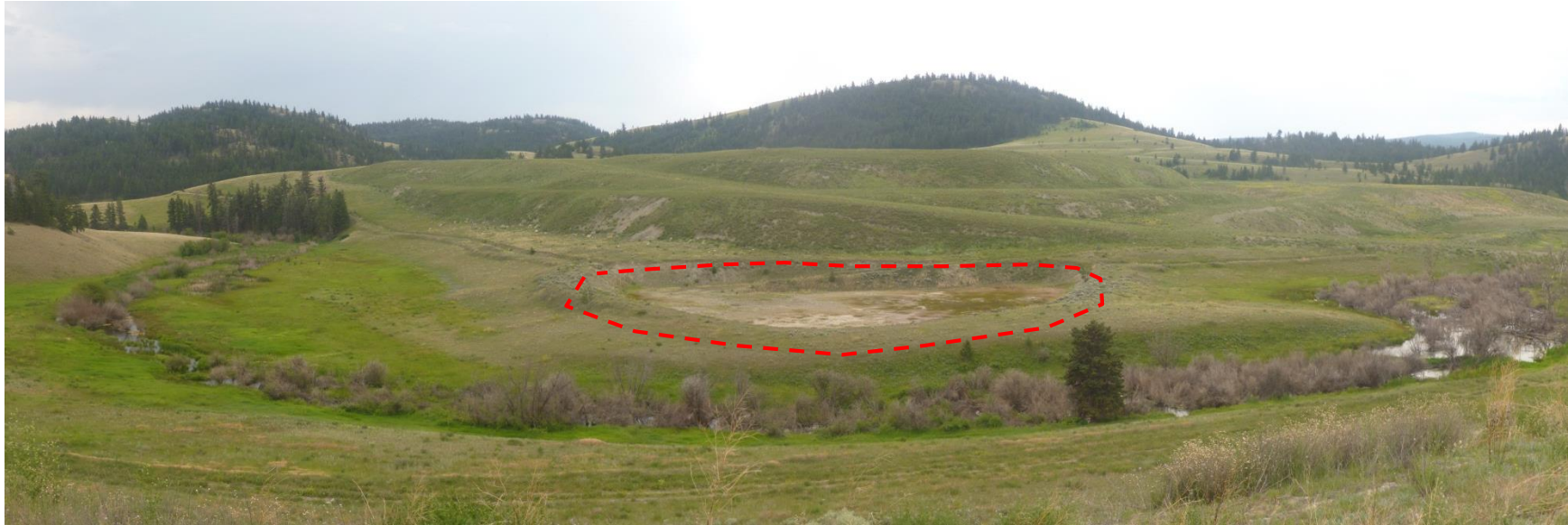


Figure 4-3. Looking south toward historically reclaimed mine rock and collection pond (dashed line). Peterson Creek (Lower) is visible in the foreground – the standing water in the creek is the result of beaver activity. BGC photograph of July 17, 2012.

5.0 WATER BALANCE MODEL – OVERVIEW AND CALIBRATION

5.1. Background

The WBM is set-up in MSEXcel™ to facilitate its review and use by others. One of the primary uses of the model is as a predictive tool to estimate runoff quantities at various nodes both within the mine site and down gradient. These monthly runoff estimates will then be used with mass loadings to estimate water quality at various assessment locations.

The WBM has a monthly timestep. The model is sufficiently discretized in time to support seasonal water management requirements for the site and potential effects on streamflows, including baseflows. However, the model is not suitable for short-term predictions, such as the effects of mine infrastructure on peak flows. A portion of the background data for the water balance has already been assessed by others including:

- water management strategies for the Project;
- compilation of a climate dataset for the Project, including precipitation, potential evaporation and temperature (Knight Piésold, 2013, 2015b);
- precipitation frequency analysis (Knight Piésold, 2015b);
- process plant water balance model (Fluor, 2015); and
- assumed tailings densities (Knight Piésold, 2015a).

The above data are used as inputs to the WBM. The WBM currently assesses existing conditions, Construction (2.5 years), Operation (23 years), Decommissioning and Closure (5 years), and Post Closure. Closure represents the time to construct various covers and reclaim the final landform. Post Closure, including pit lake filling, extends beyond closure for an indefinite amount of time.

5.2. Monthly Water Balance Models

There are a large number of watershed models presently available for predicting streamflow from climatic inputs and land surface characteristics as evidenced by the 72 models reviewed in Singh and Woolhiser (2002). These models are principally constructed on a daily or hourly basis, but can be used on an annual, monthly, or weekly basis. The degree of model complexity varies widely, but most have well in excess of 3 to 5 model parameters and many have more than 10 to 20 parameters. Most of these models are theoretical in that they are physically based (white-box models).

While these physically based models can provide a high resolution of streamflow forecasting, they are data intensive and complicated. Many of these models took years to develop and calibration can take on the order of weeks (Limbrunner et al., 2002). All of the models listed in Singh and Woolhiser (2002) above are far too complex to be incorporated into an Excel spreadsheet, particularly one that must be both transparent, transportable and easy to use.

In contrast, monthly water balance models have found widespread use to simulate and forecast monthly runoff in a watershed. The inter-relation between rainfall, evapotranspiration (ET) and runoff on a monthly scale appears to be very close because of the mutual effects and continuous feedback of water movements in the soil-plant-atmosphere continuum (Xiong and Guo, 1999). Hence, if most of the rainfall can be converted into streamflow or water vapour within a month, then it is no longer necessary to distinguish between the runoff generating and routing processes. Monthly water balance models should therefore take a simpler form and use a smaller number of parameters than daily hydrologic models (Xiong and Guo, 1999).

Despite increased computing power and increasingly sophisticated physically-based models, there is an increasing use (and development) of monthly water balance models to address a range of hydrological problems (Xu and Singh, 1998). These monthly models range in complexity but most have 2 to 5 parameters that require calibration. Monthly hydrologic models can be classified as conceptual (grey-box models) where the equations consider the physical processes in a highly simplified manner. A black-box model is one that is purely empirical.

Monthly water balance models were first developed in the 1940s by Thornthwaite (1947) and later revised by Thornthwaite and Mather (1955, 1957). The empirical Thornthwaite model uses two parameters: the soil moisture capacity and the fraction of surplus water that remains in the soil (which is a function of the depth and texture of the soil, basin morphology, and the nature of the groundwater system). Palmer's (1965) P-model was developed shortly after for agricultural purposes. The model divides the soil into two layers, where moisture cannot be removed from (or recharged to) the lower layer until all the available moisture has been removed from (replenished in) the upper layer. In 1981 Thomas proposed a four-parameter "abcd" model, which has been widely applied. Alley (1984) provides a comprehensive review of all three models and introduces variants of the Thornthwaite models. Alley (1984) concluded that prediction errors are relatively similar among the models, but simulated variables, such as soil moisture storage, differ substantially between models.

More recent parsimonious models have been developed by Vandewiele et al. (1992), Maklouf and Michel (1994), and Xiong and Guo (1999). The Vandewiele et al. (1992) model has been successfully applied in a variety of climatic settings, including northern latitudes (Xu et al., 1996). BGC has validated this model (with weekly and monthly timesteps) at a number of mine sites with similar climatic and hydrological conditions when predicting runoff from undisturbed ground.

After consideration of the calibration dataset, the Vandewiele et al. (1992) model was considered to be suitable for modeling monthly runoff at Ajax. Details of the model are provided below.

5.3. Vandewiele et al. Model Structure

In the Vandewiele et al. monthly model, monthly precipitation P_t and potential evapotranspiration E_t are the inputs; whereas monthly runoff Q_t is the output (t is time in months). The storage or soil moisture content (S) at the end of month t summarizes the hydrologic memory of the watershed, and the water balance is written as:

$$S_t = S_{t-1} + P_t - R_t - Q_t \quad (\text{Eq. 5-1})$$

where R_t is actual evapotranspiration. All quantities are expressed in millimeters depth. Actual evapotranspiration is computed from monthly potential evapotranspiration (E_t) and from the water available W_t for evapotranspiration during month t . The water available for evapotranspiration is calculated using the following equation:

$$W_t = P_t + S_{t-1} \quad (\text{Eq. 5-2})$$

where S_{t-1} is the soil storage at the beginning of month t . Two possible actual evapotranspiration equations are defined by Vandewiele et al.:

$$R_t = \min \left[E_t \left(1 - a_1^{\frac{W_t}{E_t}} \right), W_t \right] \quad (\text{Eq. 5-3})$$

$$R_t = \min [W_t (1 - a_1^{E_t}), E_t] \quad (\text{Eq. 5-4})$$

where a_1 is a positive parameter, which is characteristic of the watershed being studied. This parameter is constrained by $0 \leq a_1 \leq 1$. The equations are structured such that actual evapotranspiration increases with E_t and W_t .

Stream discharge Q_t is divided into slow runoff Q_s and fast runoff Q_f . These terms are roughly analogous to baseflow from groundwater flow (slow runoff), and overland flow and interflow in the unsaturated zone (fast runoff). These two runoff components are computed as follows:

$$Q_s = a_2 (S_{t-1})^{b_1} \quad (\text{Eq. 5-5})$$

$$Q_f = a_3 (S_{t-1})^{b_2} \left[P_t - E_t \left(1 - \exp \left(\frac{-P_t}{E_t} \right) \right) \right] \quad (\text{Eq. 5-6})$$

where a_2 , a_3 , b_1 and b_2 are positive valued parameters. Slow runoff depends on storage in the catchment in the previous month as shallow groundwater contribution to streamflow is typically on the order of weeks or longer from initial infiltration. The equation for fast runoff is structured such that greater storage in the previous month (S_{t-1}) causes a greater percentage of the active rainfall to runoff rapidly. This is analogous to the effect of Antecedent Moisture Content effects of initial abstraction in the widely used US Soil Conservation Service runoff model.

The model parameter couples (a_2, b_1) and (a_3, b_2) are highly correlated, and therefore the values of b_1 and b_2 are restricted to $\frac{1}{2}$, 1 or 2. While there are a number of possible model variants (two choices for evaporation, and multiple choices for b_1 and b_2), the model is relatively easy to set-up and calibrate. Model calibration to the site is discussed in Section 5.4.

The model can easily be set-up to accommodate a snowpack and snowmelt. The snowpack water balance is described by the following equation:

$$S_k = S_{k-1} + Snow_k - E_k - M_k \quad (\text{Eq. 5-7})$$

where S_k = snowpack storage for month k , $Snow_k$ = snowfall, E_k = sublimation, and M_k = snowmelt. The fast component of runoff quickly drops off to zero as the snowpack starts to develop and all of the creek flow is then supplied by groundwater. Figure 5-1 is a schematic that shows the contribution of snowmelt and rainfall to creek flows.

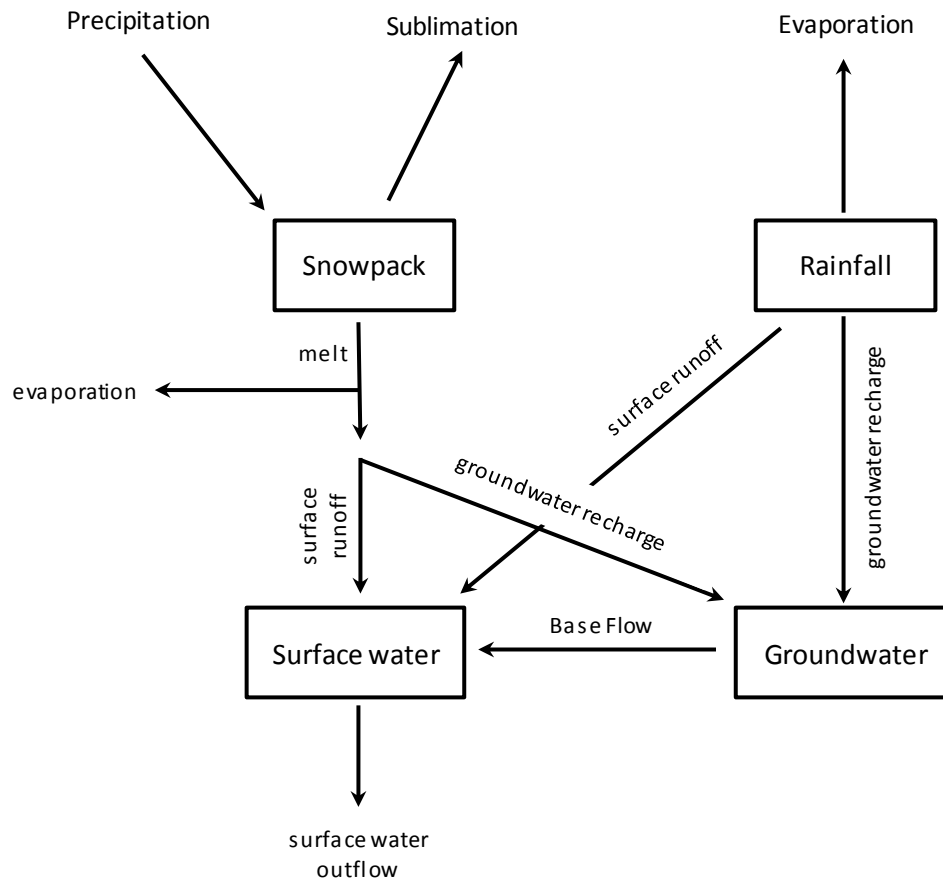


Figure 5-1. Water balance schematic for undisturbed ground.

5.4. Peterson Creek Calibration

Collection of streamflow data from site commenced in 2008. Knight Piésold (2013) collected seasonal hydrographs (2008-2011) at several locations on Peterson Creek including stations JACINF, JACLAKE, JACSEEP, and PETER (Drawing 05). Monitoring of these stations recommenced in 2014 (BGC, 2015c). Of these four stations, JACINF is most representative of existing, unregulated runoff conditions. JACINF is located on Peterson Creek upstream of Jacko Lake at the culvert crossing of Lac Le Jeune Road. The Water Survey of Canada (WSC) also operated a hydrometric station on Peterson Creek (#08LE102, about 1.6 km southwest of JACINF) from 1981 to 1986 (Drawing 03).

JACLAKE measures water levels and flows through the Jacko Lake spillway, but the spillway is often dry as lake levels are regulated by a low level outlet control gate. JACSEEP is located immediately downstream of Jacko Lake and measures flow released from the low level outlet. Knight Piésold (2013) have been unable to develop a hydrograph for this station, as the V-notch weir, which is the control for this gauging site, is regularly blocked by vegetation and debris. The control section above the weir also experienced occasional backwater, due to a constriction in a pair of culverts located downstream. These culverts were replaced by KAM in 2014, eliminating the backwater effect.

PETER is located further downstream on Peterson Creek (Lower) at the crossing of Goose Lake Road. Figure 3-4 shows the 2014 hydrograph at this station, which reflects the operation of the low level outlet at Jacko Lake. To complicate matters, a beaver dam was constructed upstream of PETER in early 2012, leading to flow back-up and development of a pond, which altered the natural flow patterns in the channel (Knight Piésold, 2013).

5.4.1. Knight Piésold Synthetic Dataset

For the purpose of gaining an understanding of long-term flow patterns in the Project area, Knight Piésold (2013) developed a long-term synthetic flow series for the JACINF gauge. This site was selected in preference to the other gauge sites because its record represents unregulated flow that can be correlated to regional flow records. Flows at the other gauge sites are subject to influence by lake outlet operation and beaver dam activity.

To generate the synthetic dataset, Knight Piésold (2013) correlated the JACINF daily streamflow data with concurrent data from a number of regional WSC hydrometric stations. That analysis indicated that data from station 08LF027 (Deadman River at Criss Creek) provided the strongest and most consistent correlation. Ranked regression analysis (also known as frequency paired analysis) was used to generate a synthetic long-term streamflow record for JACINF using monthly derived relations between the long-term streamflow data from 08LF027 (1962-2001) and the short-term streamflow data at JACINF (2008-2011). The resultant synthetic dataset covers the period 1962-2011. Mean annual flow for this period is $0.025 \text{ m}^3/\text{s}$, which represents an annual runoff of 26 mm based on a drainage area of 31.1 km^2 .

Approximately 70% of the annual flow occurs in May and June in response to snowmelt and 95% of the annual flow occurs in the April to July period. This flow distribution is generally consistent with the regional flow patterns.

5.4.2. Calibration

The Vandewiele et al. (1992) model was calibrated to the average unit (i.e., millimeters of runoff) synthetic flows provided by Knight Piésold (2013) for JACINF. Model inputs included monthly precipitation data from the Kamloops Airport¹ climate station (1962-2011) and the monthly evaporation values are summarized in Table 2-1. The calibration was conducted by elevation band, as precipitation in the area increases with elevation (see Figure 2-7 of KP, 2013). A precipitation gradient of approximately 4.8% per 100 m was employed (KP, 2015b) and the JACINF watershed was delineated into three elevation bands: 900 m to 1200 m, 1200 m to 1500 m, and > 1500 m. Average annual precipitation for each of these elevation bands is assumed to be 352 mm, 401 mm, and 425 mm, while the percentage watershed area for each of the elevation bands is measured at 40%, 47%, and 13%, respectively.

Potential Evaporation

Potential evaporation was also assumed to vary by elevation band relative to the base case values shown in Table 2-1. Monthly evaporation was adjusted for each of the elevation bands using the following percentages:

- 600 m to 900 m = +3%
- 900 m to 1200 m = -3%
- 1200 m to 1500 m = -10%
- > 1500 m = -16%

These evaporation adjustments were calculated using the Thornthwaite temperature-based method, which was employed by Knight Piésold (2013, 2015b) to generate the values shown in Table 2-1. A temperature lapse rate of -0.5°C per 100 m was employed for the calculations.

Snow Accumulation and Melt

The calibration assumed that snow accumulates from November to March (with sublimation losses tracked) and melting of the snowpack has the distribution summarized in Table 5-1.

¹ This station (#1163780) is maintained by Environment Canada. Precipitation data from this station were scaled to the Ajax site to provide an average annual precipitation of 310 mm.

Table 5-1. Average snowmelt distribution by elevation band.

Month	900 m – 1200 m		1200 m – 1500 m		> 1500 m	
	Avg. Temp (°C)	Potential Snowmelt (mm)	Avg. Temp (°C)	Potential Snowmelt (mm)	Avg. Temp (°C)	Potential Snowmelt (mm)
March	-2.4	0	-3.9	0	-5.4	0
April	7.3	110	5.8	52	4.3	39
May	9.2	143	7.7	72	6.2	58
June	13.8	207	12.3	111	10.8	97

The snowmelt distribution listed in Table 5-1 are average values based on the calibration process and resulted in the best fit to the synthetic dataset. A simplified, temperature-based approach was used to estimate snowmelt (Hock, 2003). Snowmelt is also a function of wind speed and radiation, but temperature-based methods can also yield a reasonable approximation of snowmelt. For months with $T > 0^{\circ}\text{C}$, potential snowmelt, M_{pot} , is calculated as:

$$M_{pot} = k_m \cdot T \cdot n_d \quad (\text{Eq. 5-8})$$

where k_m is a degree-day factor ($\text{mm}/^{\circ}\text{C}/\text{day}$), T is the average monthly temperature, and n_d is the number of months in a given month. The degree-day factor is a function of land cover and was set to $0.5 \text{ mm}/^{\circ}\text{C}/\text{day}$ for the lowest elevation band and $0.3 \text{ mm}/^{\circ}\text{C}/\text{day}$ for the two higher elevation bands.

The calibration also assumed that the parameters in the Vandewiele et al. model were not elevation sensitive, so the same parameters were used for each elevation band. This assumption results in greater runoff per unit area with increasing elevation, which corresponds to steeper topography as elevation increases.

Baseflows and Conceptual Flow Model

Streamflows measured at JACINF represent surface and near surface (interflow) runoff only. Groundwater is measured at a depth of approximately 15 m below the ground surface in groundwater well (MW11-08S) located immediately downstream of JACINF (Drawing 07). This information indicates that there is no groundwater baseflow discharging to the JACINF gauge. Therefore, the calibration to the JACINF synthetic hydrograph dataset included only the fast component of the Vandewiele et al. model; recharge was added as a separate term to represent baseflows.

The conceptual model of runoff reaching the JACINF station is a shallow zone of moderately permeable overburden at the surface that becomes saturated during spring melt and contributes rapid runoff to the local stream network. A portion of the snow melt also infiltrates to depth eventually reaching the groundwater table as recharge. Infiltration to the groundwater

table is conceptualized as a slow process due to the low hydraulic conductivity of the relatively fine-grained till and/or bedrock that underlies a majority of the area. As a result of low infiltration rates through the till, recharge and hence baseflows² are not expected to fluctuate significantly either on a seasonal or annual basis. As the spring melt passes, a majority of subsequent rainfall does not contribute to either surface runoff or recharge due to high temperatures, high potential evapotranspiration rates and relatively low rainfall (relative to potential evapotranspiration).

This conceptual model of slow infiltration and constant groundwater flows is consistent with groundwater levels measured around site. Figure 5-2 shows groundwater elevations measured at monitoring wells MW11-08 and MW11-04, which are located southwest and north of Jacko Lake respectively (Drawing 07). Groundwater levels at these two stations are shown to display minimal fluctuations on an annual basis.

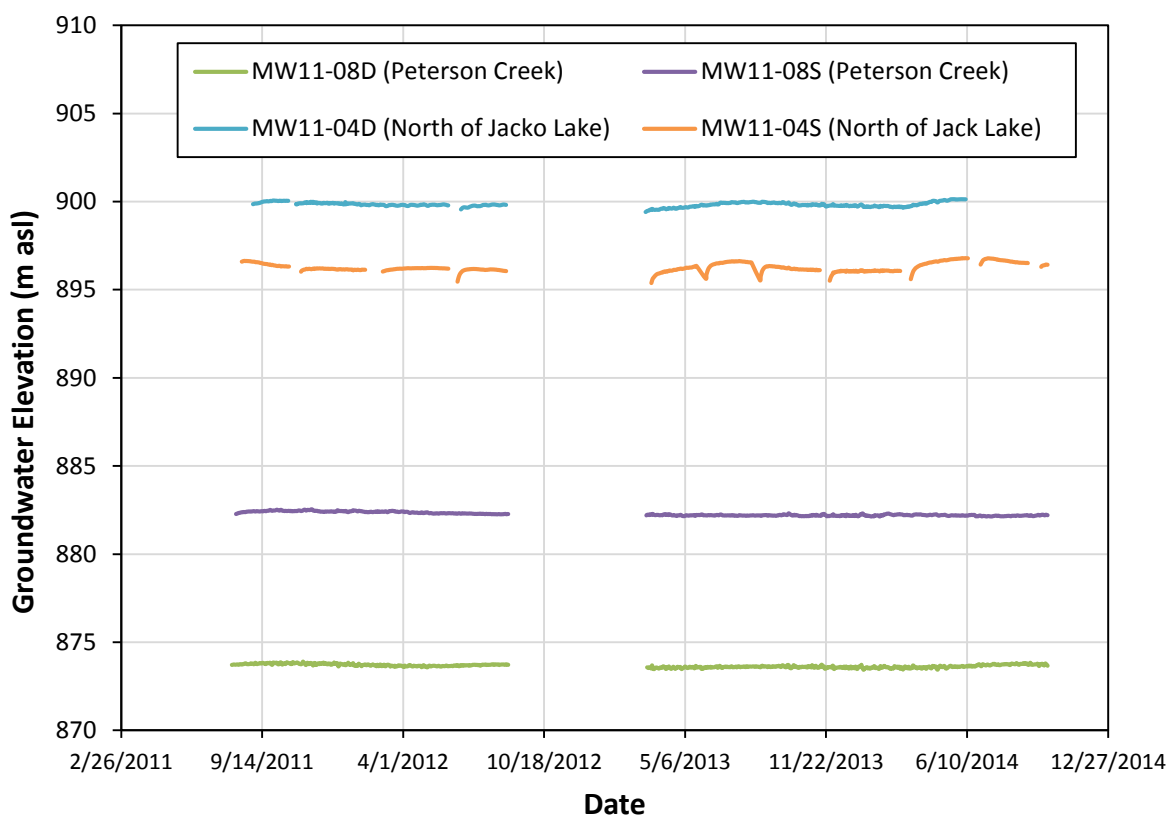


Figure 5-2. Groundwater elevations at monitoring wells MW11-04 and MW11-08.

² Of note is that baseflows only occur where the groundwater elevation is greater than the stream bed elevation. Peterson Creek (Lower) is characterized by both gaining and losing reaches (see BGC, 2015b), as such baseflows are not observed year round along the entire creek length.

Results

Rather than attempting to model on a month-to-month basis for a number of years, the calibration focused on providing the best fit on an annual and monthly basis for the average flows. Results of the calibration are shown in Figure 5-3. In general, the modelled and synthetic hydrograph data show a very good fit for most of the months. An overall goodness of fit can be calculated using the Nash-Sutcliffe (1970) efficiency criterion and the relative error (RE) of the volumetric fit between the observed runoff series and simulated series. The value of RE is expected to be close to zero for a good simulation of the total volume of the observed runoff series. The average monthly simulations resulted in an $r^2 = 92\%$ and $RE = 1.6\%$.

Table 5-2. Average monthly runoff for Peterson Creek gauge JACINF – synthetic and simulated (1963-2008).

Month	Undisturbed Runoff (mm)		difference
	Synthetic Dataset (KP)	Simulated Dataset (BGC)	
January	0.05	0.00	
February	0.06	0.00	
March	1.5	0.8	-43%
April	3.3	3.1	-5%
May	11.3	10.8	-4%
June	6.6	8.7	32%
July	2.4	1.9	-20%
August	0.45	0.31	-32%
September	0.19	0.23	21%
October	0.10	0.23	134%
November	0.10	0.00	
December	0.00	0.00	
Total	25.7	26.1	1.6%

The model provides an excellent prediction during the peak snowmelt month (May), while other months are overpredicted or underpredicted. For the EA assessment, the WBM will be run in a deterministic mode, where a range of precipitation conditions are evaluated for water quantity and water quality prediction purposes (see Section 8.4). Therefore, a range of flows will be modelled for all months.

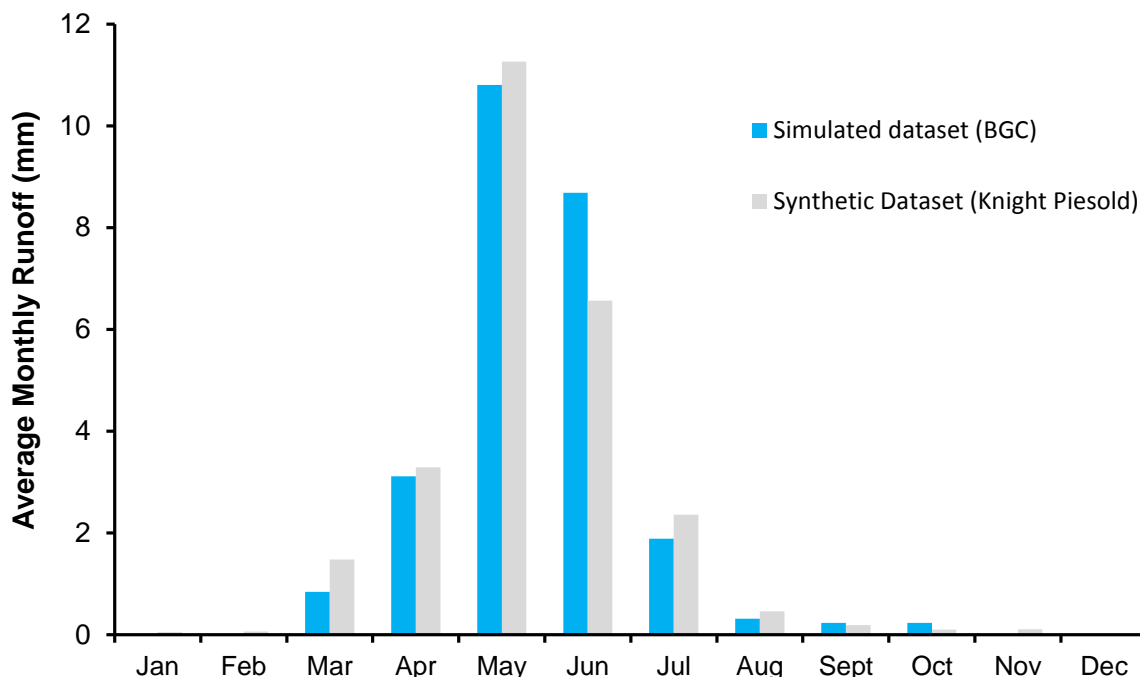


Figure 5-3. Average monthly runoff for Peterson Creek gauge JACINF – synthetic and simulated (1963-2008).

5.4.3. Model Validation

The adopted calibration parameters were then validated by simulating streamflows at JACINF for 2014. Monthly precipitation data from Kamloops were input to the model and upscaled for the various elevations bands. Using these data, the snowpack at the end of February for the lowest elevation band (900 m to 1200 m) is predicted to be 70 mm in the WBM, once sublimation losses are factored in. In comparison, a snowpack survey at the end of February measured an average snow water equivalence of 66 mm for the lowest elevation band (BGC, 2015c). Similarly, for the highest elevation band (> 1500 m), the snowpack at the end of March is predicted to be 118 mm, compared to a measured value of 129 mm. Thus, the orographic factors applied in the model and sublimation losses appear to be reasonable.

Figure 5-4 shows the daily hydrograph for station JACINF. Data are shown to be missing from late June to late July, but it is reasonable to assume that streamflow values during this period can be estimated with a linear interpolation. Figure 5-5 shows the results of the model validation. In general, there is good agreement between the simulated and observed monthly values, with the pattern of spring runoff replicated. The simulation resulted in an $r^2 = 94\%$ and RE = 7.2% (observed runoff = 31.0 mm versus simulated runoff = 33.2 mm).

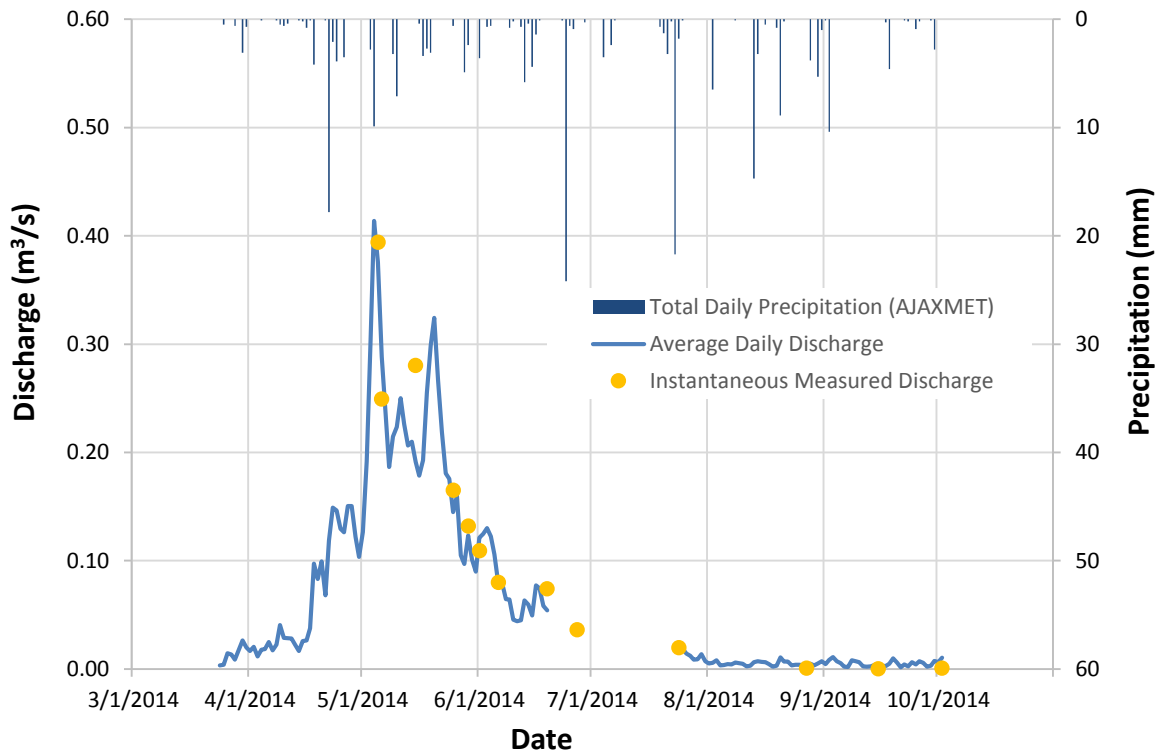


Figure 5-4. 2014 stream hydrograph for Peterson Creek gauge JACINF (after BGC, 2015c).

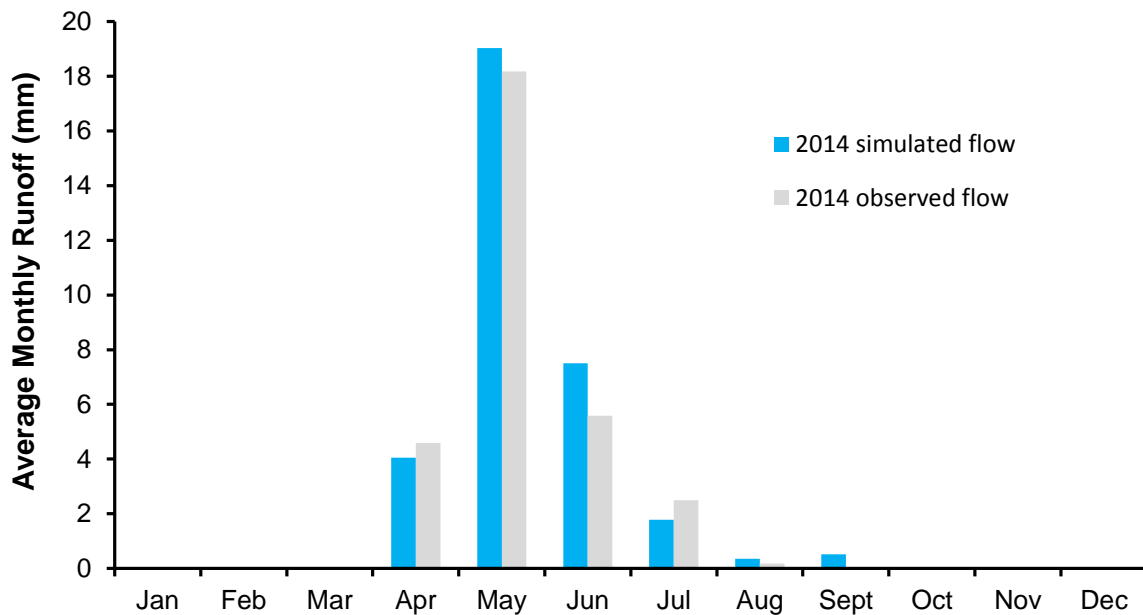


Figure 5-5. 2014 average monthly runoff for Peterson Creek gauge JACINF –observed and simulated.

5.4.4. Recharge

Recharge has been estimated by BGC (2015b) for various elevation bands, as summarized in Table 5-3.

Table 5-3. Estimated annual recharge (BGC, 2015b).

Recharge Zone	Elevation (m asl)	Recharge (mm a⁻¹)
Bunchgrass	<400 - 900	0.5
Bunchgrass – Enhanced Recharge	600 - 900	4.9
Ponderosa Pine	600 - 900	4.9
Interior Douglas Fir	900 - 1400	8.4
Montane Spruce	1400 – 1600	9.9
Engelman Spruce – Subalpine Fir	>1600	10.6

The recharge values of Table 5-3 are calibrated values adopted for the groundwater model, but do not represent net recharge that ends up reporting to Peterson Creek. Groundwater discharge zones and an evapotranspiration extinction depth of 5.5 m results in some of this recharge being lost to evaporation. The net recharge applied in the WBM for around the mine site is 3 mm and 4 mm at higher elevations, which is consistent with chloride mass balance results (BGC, 2015a).

5.4.5. Total Runoff

The estimated recharge values were added to the runoff estimates of Table 5-2 to generate total flows for the various elevation bands. Average monthly runoff depths for the various elevation bands are summarized in Table 5-4 based on a precipitation dataset for the period 1896-2011 (see Section 6.1). The 950 m elevation band represents runoff conditions for the various mine facilities (e.g., Open Pit, TSF).

Table 5-4. Average estimated monthly runoff for various elevation bands.

Elevation Band	Runoff Depth (mm)				
	600 - 900 m	950 m	900 - 1200 m	1200 - 1500 m	> 1500 m
January	0.2	0.3	0.3	0.3	0.3
February	0.3	0.3	0.3	0.3	0.3
March	2.9	2.3	2.1	0.4	0.3
April	6.4	6.5	6.6	1.6	1.0
May	3.9	7.9	11.2	18.0	15.7
June	1.7	2.9	3.9	17.5	31.2
July	0.6	0.9	1.2	3.0	7.9
August	0.4	0.5	0.7	1.3	2.8
September	0.3	0.5	0.6	1.0	1.7
October	0.5	0.6	0.8	0.3	0.3
November	0.2	0.2	0.3	0.3	0.3
December	0.2	0.3	0.3	0.3	0.3
Total	17.6	23.1	28.4	44.5	62.3

The runoff depths of Table 5-4 assume that all groundwater recharge reports to surface water in the catchment above the assessment location being evaluated. However, the groundwater modelling and monitoring wells generally indicates that groundwater flow is at depth along the tributary streams and discharges only at lower elevations along Peterson Creek (Lower) (BGC, 2015b). Peterson Creek (Lower) also has losing and gaining reaches, so baseflows are not observed consistently along its length (see Drawing 03 of BGC, 2015b).

Simulated annual runoff at JACINF for the period 1963-2011 is shown in Figure 5-6. Simulated annual runoff for JACINF, Peterson Creek (1963-2011). Of note is calendar year 1997 where the annual runoff is more than double the next highest year. This result is consistent with the occurrence of a number of floods in BC in that year.

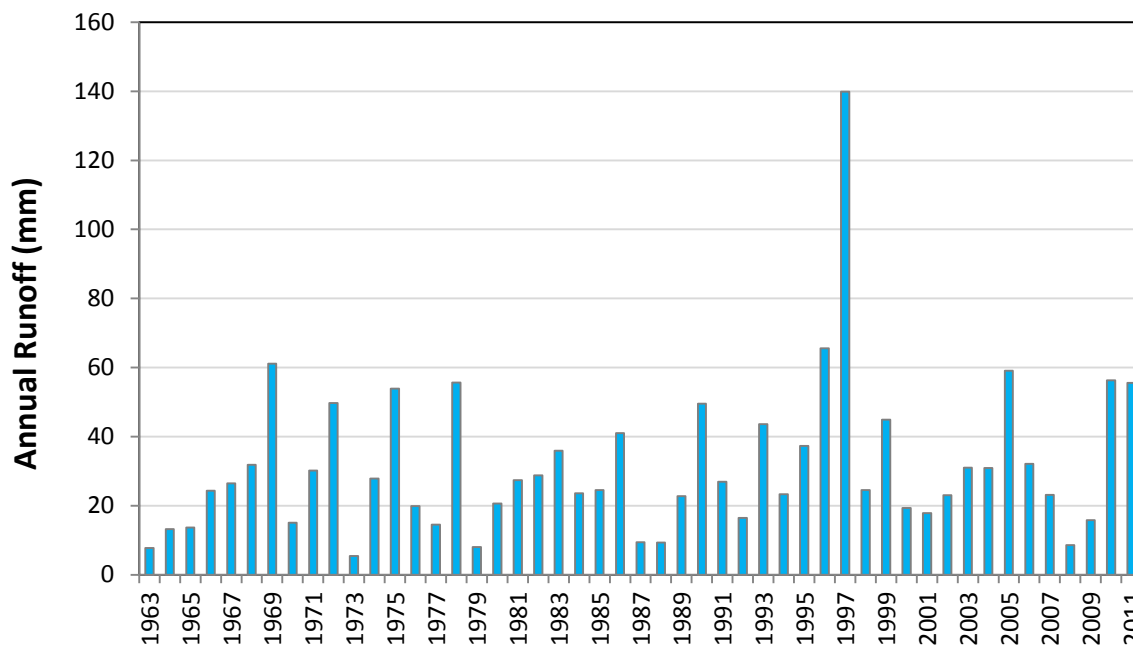


Figure 5-6. Simulated annual runoff for JACINF, Peterson Creek (1963-2011).

5.4.6. Irrigation

The measured streamflows at JACINF do not represent undisturbed conditions due to existing surface licenses. Based on Table 3-2, up to 530,000 m³ could be pumped from Peterson Creek above Jacko Lake on an annual basis for irrigation purposes. This volume represents about two-thirds of the annual simulated flow in Peterson Creek at JACINF.

There is no way to confirm how much of the licensed amount is actually removed from the creek in any given year. However, the maximum diversion rate from Peterson Creek is only 71 L/s and these irrigation licenses have only third priority to water. If flows are only diverted for approximately three weeks during the spring freshet, the maximum diverted volume would be about 130,000 m³ compared to the licensed amount of 426,000 m³ (discounting the 104,000 m³ on Timber Lake and Jacko Creek.)

In light of the above, the streamflows recorded at JACINF reflect upstream irrigation practices; but there is no way to quantify how much runoff is diverted on an annual basis or whether this diversion volume varies significantly from year to year. The synthetic dataset of Knight Piésold (2013) and the runoff estimates of Table 5-2 are therefore best regarded as values that account for current upstream irrigation and domestic water use practices. As such, this model should not be used for other areas where there may not be irrigation diversions. Modifications to the model parameters would be required to account for increased runoff.

Recorded flows at JACINF reflecting upstream irrigation practices is consistent with the Peterson Creek WSC station, which was operational in the 1980s. These data indicate an average annual runoff of 35 mm at the WSC station (Table 3-9) versus the long-term estimate

of 26 mm at JACINF (Knight Piésold, 2013). The 1982-1986 period was characterized by only slightly above average precipitation at Kamloops Airport (+6%). The extra 7 mm of runoff (33 mm, which factors in the 6% extra precipitation, minus 26 mm) represents a volume of water of about 220,000 m³ that would report to Jacko Lake in the absence of irrigation. This volume estimate is roughly consistent with an estimated diversion volume of 130,000 m³ on Peterson Creek and licensed diversion of 104,000 m³ on Timber Lake and Jacko Creek. Therefore, it appears that irrigation practices upstream use on the order of 200,000 m³ to 250,000 m³ on an annual basis.

5.5. Cherry Creek

The WSC also operated a hydrometric station on Cherry Creek (#08LF086) from the end of October 1980 to the end of March 1996 (Drawing 08). An average hydrograph for the period from 1981 to 1995 for this station is shown in Figure 5-7. Cherry Creek has a watershed area of 123 km² at the hydrometric station³. Watershed areas for different elevation bands are summarized below.

Table 5-5. Watershed area by elevation band at WSC station 08LF086.

Elevation Band	Area (km²)	% of watershed
600 m to 900 m	35.9	29
900 m to 1200 m	24.6	20
1200 m to 1500 m	34.3	28
> 1500 m	28.0	23
Total	122.8	

³ The WSC report a drainage area of 143 km² for this station, but analysis of available GeoBase contour data indicates that the WSC estimate is inaccurate.

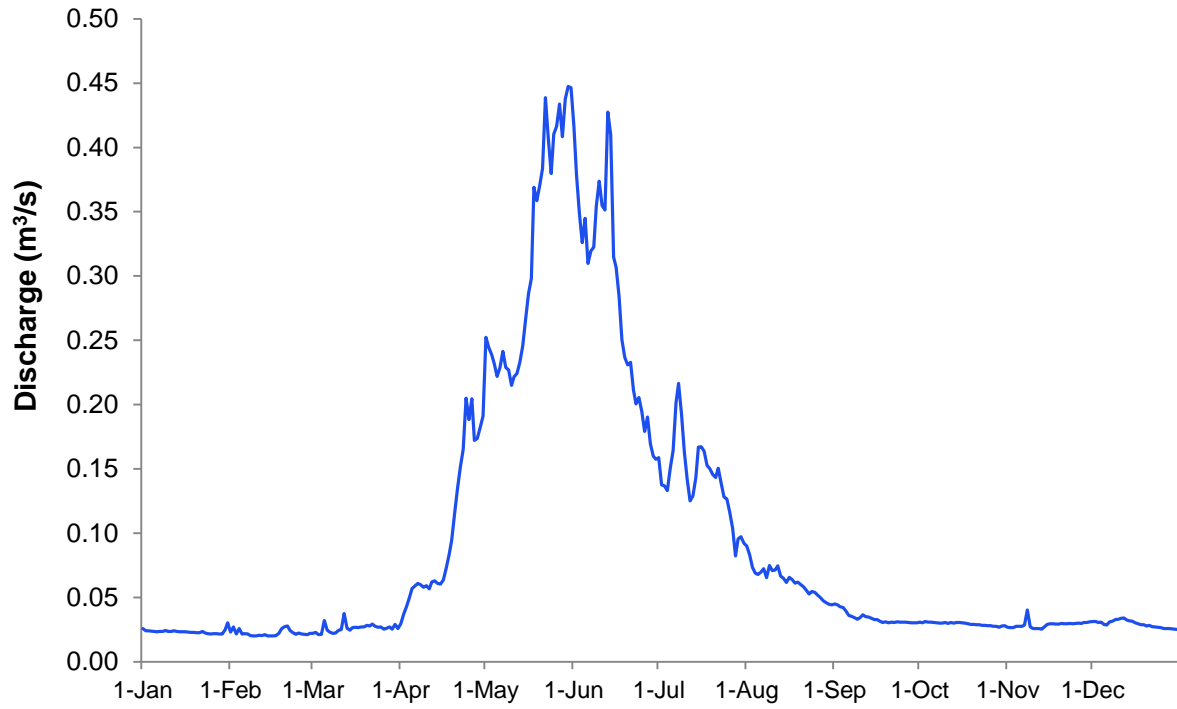


Figure 5-7. Cherry Creek (#08LF086) average hydrograph (1981-1995).

Average monthly runoff at the Cherry Creek station is summarized below in Table 5-6. Using the same calibration parameters developed for JACINF, the overall fit is very good.

Table 5-6. Average monthly runoff for Cherry Creek (1981-1995).

Month	Runoff (mm)
January	0.5
February	0.4
March	0.6
April	2.1
May	6.9
June	6.0
July	3.1
August	1.4
September	0.7
October	0.6
November	0.6
December	0.6
Total	23.6

Of note in Table 5-6 is that the observed fall and winter streamflow data (October-March) show a relatively consistent runoff depth of 0.6 mm. This observation is consistent with the conceptual runoff model of slow infiltration rates causing relatively constant baseflow on a seasonal basis. Also, assuming a monthly baseflow of 0.6 mm, correspond to an annual baseflow on the order of 7.2 mm, which is consistent with BGC recharge estimates (Table 5-3).

The average annual runoff depth of 23.6 mm predicted for Cherry Creek are influenced by upstream irrigation activities and water licenses, rendering it a poor calibration target. Similar to Peterson Creek, there are a number of existing licenses on Alkali Creek and Cherry Creek above the WSC station. A majority of these licenses are for storage and irrigation. Based on these licenses, approximately 1.2 Mm³ of water is allocated to irrigation on an annual basis upstream of gauge 08LF086. This licensed amount represents 40% of the average annual runoff recorded at the Cherry Creek gauge (2.9 Mm³) between 1981 and 1995. What these data do suggest is that runoff recorded at 08LF086 is not representative of undisturbed hydrologic conditions. No data exists as to which licenses are exercised on an annual basis and to what extent.

The licenses also include dam storage on a number of lakes with controlled outlets. BGC is not aware of any reports that document how these outlets are operated or water level or flow data related to their operation.

6.0 RUNOFF CALCULATIONS

The WBM developed by BGC tracks average monthly runoff volumes and rates for the following facilities:

- undisturbed ground within the Peterson Creek watershed and its tributaries;
- WMRSF, EMRSF and SMRSF;
- stockpiles;
- the Open Pit; and
- the TSF.

Runoff volumes and patterns for each of these areas are unique and are calculated separately. The following sections describe how flow contributions from the various ground surfaces were estimated. A schematic for the WBM is provided in Figure 6-1.

6.1. Undisturbed Ground

Average monthly runoff from undisturbed ground from the calibrated model is summarized in Table 5-4 for the various elevation bands. Results for the 950 m elevation band are used to model sub-watersheds in the LSA. The simulated runoff depths from the upstream areas have been calibrated to flows that include upstream water use and thus are not entirely reflective of undisturbed conditions. This is deemed acceptable because the present existing, “disturbed” conditions are likely to represent Post Closure conditions, because new licenses are not expected to be issued.

A potential issue is the runoff estimate for the 950 m elevation band, which is used in the WBM to predict runoff for other tributaries that surround the proposed mine site and may be underestimated. The annual runoff estimate for this elevation band is 23 mm (Table 5-4). As described below, however, water balance calculations for endorheic basins in the lower Peterson Creek watershed indicate that an annual runoff of about 23 mm may be an over-estimate.

There are a number of endorheic basins in the Project area. An endorheic basin, also called a terminal or closed basin, is a closed drainage basin that retains water and allows no surface outflow to other external bodies of water, such as a river, but converges instead into lakes or swamps, permanent or seasonal, that equilibrate through evaporation. The lakes or seasonal ponds are interpreted to represent discharge zones where runoff accumulates and the footprint of the ponds is sufficient such that evaporative losses exceed runoff inputs.

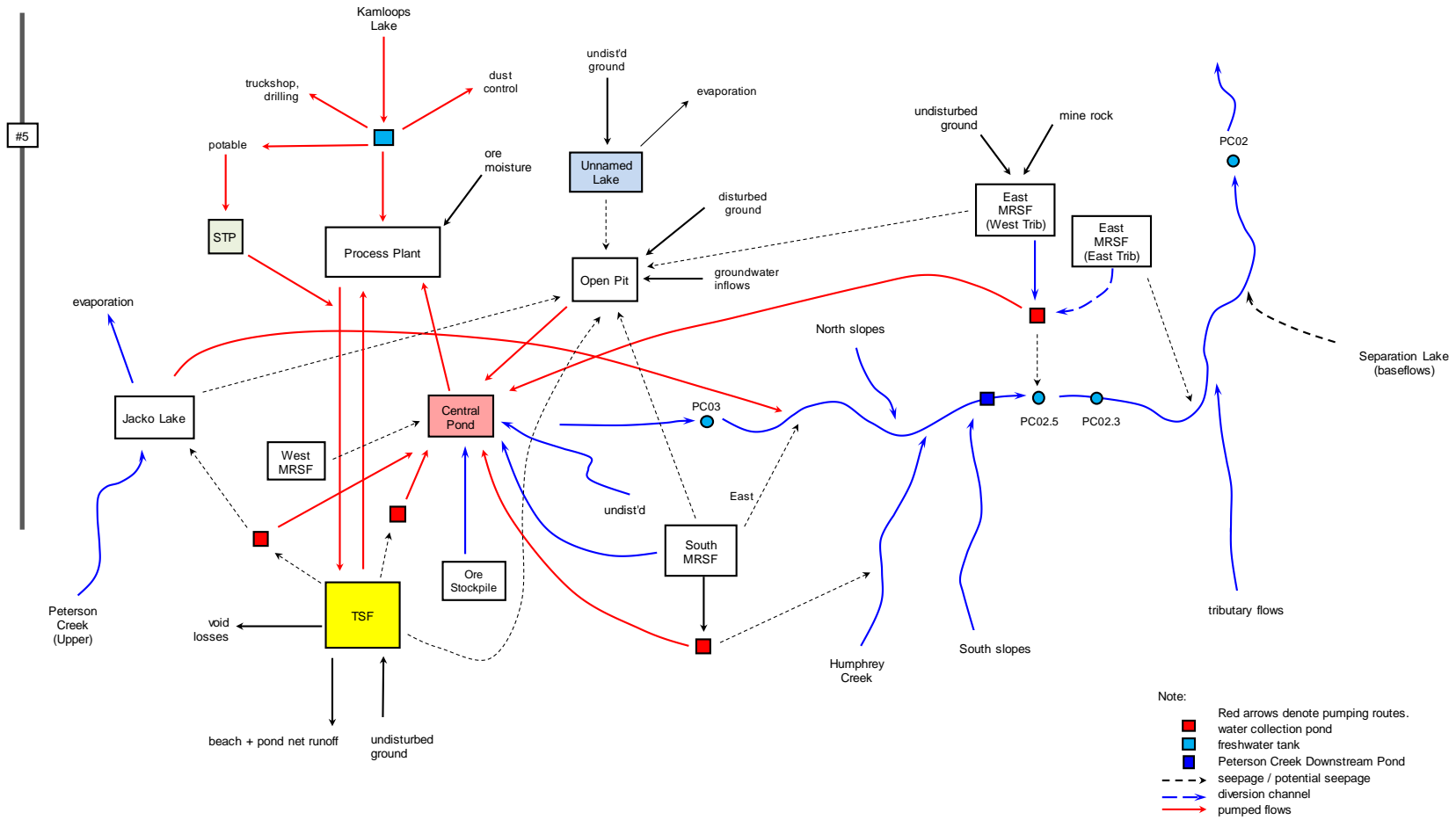


Figure 6-1. Ajax water balance schematic.

Examples of endorheic basins at site are delineated on Drawing 09 and include Inks Lake (Figure 6-2) and Nelson Lake (Figure 6-3). Water may infiltrate through these lakes and recharge the groundwater flow system; however, surface flows are assumed to be captured. Table 6-1 summarizes the pond/lake areas for these two endorheic basins relative to the total watershed area.

Table 6-1. Endorheic basins at Ajax.

Watershed	Total Area (ha)	Lake/Pond Area (ha)	Ratio
Inks Lake	300	12.1	25
Nelson Lake	60	2.4	24
Wallender Lake	260	7.3	35
Unnamed Lake (north of open pit)	133	5.0	26



Figure 6-2. View of Inks Lake looking northwest. BGC photograph of July 17, 2012.



Figure 6-3. View of Nelson Lake looking north. BGC photograph of July 17, 2012.

Inks Lake and Nelson Lake have basin/lake ratios of 25 and 24 respectively. Two additional watersheds are summarized in Table 6-1: Wallender Lake and a small, un-named lake located immediately north of the existing pit. At the un-named lake, a review of historical air photographs from 1974 indicates that the lake used to drain naturally to the south with eventual discharge to Peterson Creek (Drawing 10). However, development of the existing Ajax open pit intercepted the lower reaches of this drainage, while mine rock was deposited within the drainage immediately downstream of the lake. As a result, the lake has increased in size. It is assumed that when lake levels are high enough, lake water seeps through the mine rock and reports to the existing open pit.

From a topographic perspective, the watershed for Wallender Lake would also appear to be an endorheic basin; however, the basin/lake ratio is larger than one would expect for a closed basin. A review of recent aerial imagery shows a subsurface flow path that may extend from the south end of the lake in a southwest direction toward Inks Lake (Drawing 11). This subsurface flow path is obvious in the field on the west side of the Lac Le Jeune Highway, manifesting itself as a line of greener vegetation in the lower lying areas. Two seasonal ponds are located along this flow path, and groundwater is likely flowing south from Wallender Lake in this area before discharging into Inks Lake.

Four additional endorheic basins evaluated by BGC, and not summarized in Table 6-1, have basin/lake ratios of between 23 and 27. It is therefore concluded that lakes or seasonal ponds can form at the topographic low of a closed basin where the basin area is less than about 23 to 27 times that of the maximum lake surface area.

Annual evaporation and sublimation (613 mm) exceeds annual precipitation (336 mm), for a net deficit of -277 mm acting on standing surface water bodies. Assuming an average basin/lake ratio of 25, the implication is then that average annual runoff from undisturbed

ground in these endorheic basins is on the order of 11 mm. If groundwater flows bypass these endorheic lakes and report elsewhere, average annual runoff from these basins may be on the order of 16 mm (assuming 5 mm of recharge as per Table 5-3). In contrast, average annual runoff (including groundwater recharge) in the mine site area is estimated at about 23 mm (Table 5-4). For the purposes of the EA, the higher runoff estimate of 23 mm has been adopted, as it results in a more conservative estimate of potential hydrologic impacts as a result of Project activities.

6.2. Mine Rock Storage Facilities

Flow contributions from the WMRSF, SMRSF and EMRS were estimated using HYDRUS-1D (Šimůnek et al., 2012), which simulates one-dimensional movement of water and solutes through variably saturated media. The computer code numerically solves the Richards equation for flow in the unsaturated zone. Required climatic inputs to the model include daily temperature, precipitation and potential evaporation. Additional details of this modelling are provided in Appendix A. The results of this modelling indicate that for bare mine rock, the average annual infiltration is on the order of 44 mm, which is about 2 times greater than runoff from undisturbed ground.

For the MRSFs, it is assumed that a proportion of the infiltrating water is taken up by void losses as the mine rock “wets” up. The initial delivered volumetric water content of the mine rock has been estimated at 6.0% (e.g., according to Schafer and Associates (1994), freshly shot rock at the Golden Sunlight Mine typically has less than 6% water at the time of emplacement on the pile). The mine rock field capacity is estimated to be 9.0% (see Appendix A). Although the water content and soil suction relationship is actually a continuum, it is still useful to think of the concept of field capacity as the threshold moisture content at which water can be held against gravity (i.e., will not drain). Therefore at the initial moisture content of 6.0% there is no drainage. Before drainage can begin, the entire mine rock column must be brought to the threshold (or residual) moisture content of 9.0% (the field capacity). The WBM tracks the monthly deposition of mine rock and its moisture content. Seepage outflow from the base of the mine rock is assumed not to occur until the average moisture content of the entire mine rock pile exceeds 9%. In practice, the mine rock mass will be highly variable, with some zones exhibiting a more rapid advance of the wetting front than others. In addition, runoff over trafficked surfaces will tend to redistribute and concentrate recharge in localized areas (these areas will change over time as the facility is developed). Therefore, predictions of seepage from the MRSF are approximate only.

The WBM also assumes that 10% of the water that infiltrates into the MRSF will pass through the facility along preferential flow paths (macro flow) while the remainder will go into storage as moisture, if the mine rock is not yet at field capacity. This assumption is based on empirical evidence from mine rock facilities, where observed discharges can be attributed to these preferential flow paths (Smith et al., 1995). Of this 10% of macro flow, 20% is assumed to infiltrate into the underlying soils and report as baseflow, while the remaining 80% is assumed

to report to the water management pond (where applicable). This flow split can be adjusted in the WBM and thus can be used to evaluate sensitivity of the water quality predictions. A schematic of this conceptual flow through the bare mine rock is provided in Figure 6-4.

The WBM further assumes that prior to the mine rock reaching field capacity, the percentage of macro flow increases from 10% to 60% by Year 200 of the closure period. This increase was modelled to prevent the unrealistic scenario developing where seepage is predicted to increase from 10% of the infiltration water to 100% within the period of one year.

Closure covers placed over the MRSFs will reduce infiltration, and therefore seepage. HYDRUS modelling indicates that annual infiltration into the mine rock is only reduced by a small amount when only a nominal reclamation cover is placed over the mine rock. This infiltration value is reduced to 8 mm assuming a 0.3 m thick, compacted low permeability till cover is placed between the mine rock and the closure cover.

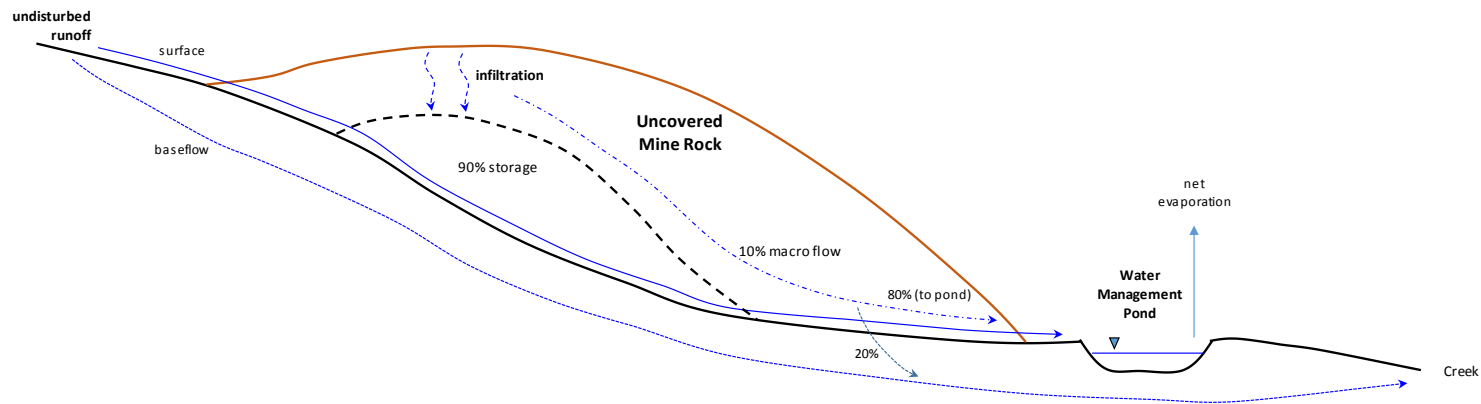
Conceptual flow through the MRSF during the Closure/Post Closure period is summarized in Figure 6-5. Note that this schematic shows the mine rock at the threshold moisture content of 9.0%.

6.3. Ore Stockpile

Runoff from the ore stockpile is calculated in the same fashion as for the MRSFs. Any runoff from this facility is assumed to drain to the Central Pond or the Open Pit.

6.4. Overburden and Top Soil Stockpiles

A number of overburden and top soil stockpiles will be developed around the mine site. The most prominent of these facilities will be placed on top of the EMRSF (Drawing 01). Runoff from these stockpiles is assumed to be the same as that for undisturbed ground. The stockpiles will be removed at closure for reclamation activities, but some of the material will be used to cover the EMRSF.



Note:

Undisturbed runoff refers to runoff (surface flows and groundwater/base flows) from undisturbed, vegetated areas upslope of the mine rock. This runoff is calculated using the a calibrated V'andewiele et al. (1992) model.

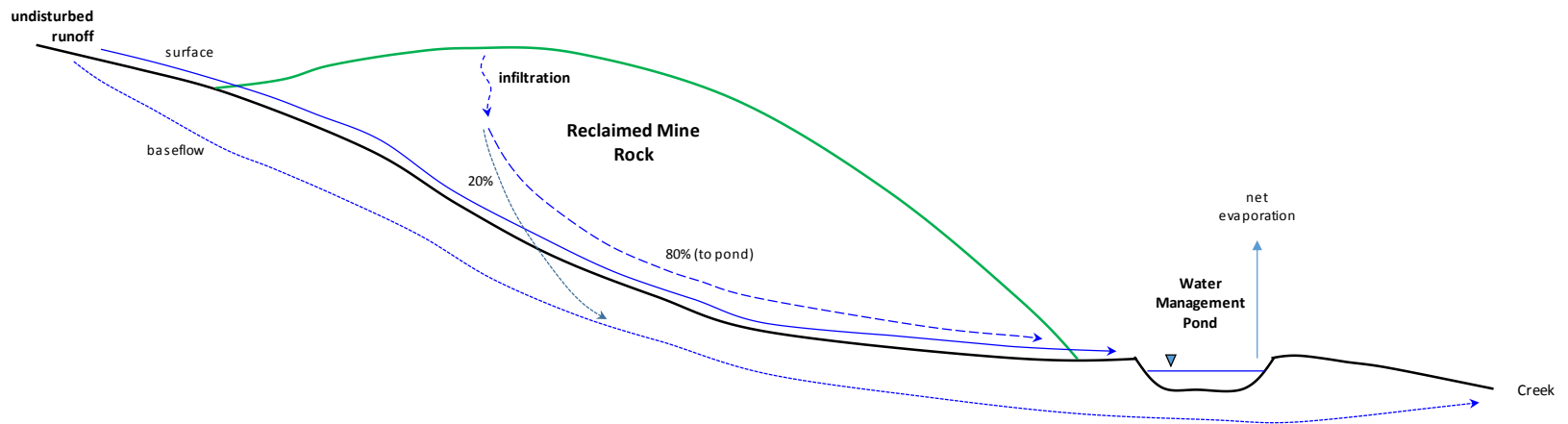
The surface runoff component is assumed to flow through the mine rock underdrain and report to the water management pond. The baseflow component is assumed to bypass the pond, although seasonally, particularly with time, it may report to the water management pond.

A portion of the available water (snowmelt + rainfall) infiltrates into the waste rock, with the remainder evaporating.

Of the infiltration water, 10% follows preferential flow paths and reports to the water management pond rapidly (i.e. macro flow).

The remaining 90% goes to fill void space in the mine rock storage. Once the volumetric water content of the mine rock voids reaches 9%, all of the infiltrating water is assumed to report to the base of the MRSF (i.e. matrix flow).

Figure 6-4. Conceptual model of flow through the mine rock storage facilities during Operation.



Note:

This schematic assumes that the volumetric water content of the waste rock voids has reached 9%. At that point, 80% of the infiltration water is assumed to report to the underdrain of the mine rock and discharge to the water management pond. The remaining 20% would infiltrate the soils below the mine rock and report to the water table, joining the undisturbed baseflow, both of which then bypass the water management pond.

Figure 6-5. Conceptual model of flow through the mine rock storage facilities during Closure/Post Closure.

6.5. Open Pit

Incident rainfall and snowmelt from within the Open Pit footprint will have minimal evaporative losses. Based on BGC's experience at other mine sites in similar climatic conditions, runoff from the pit footprint is calculated as available water (snowmelt + rainfall) minus 35% of potential evaporation. It is also assumed that 30% of the snow falling within the pit footprint is removed with mine rock or ore during mining.

Figure 6-6 summarizes runoff components to the Open Pit during Operation. In addition to runoff from up gradient undisturbed ground and precipitation within the pit footprint, groundwater seepage reports from several sources:

- seepage from the un-named lake located up gradient (Drawing 10);
- groundwater inflows from depressurization of the surrounding bedrock as the Open Pit is developed; and
- seepage flows from Jacko Lake.

These latter sources are discussed in more detail in Section 7.3.

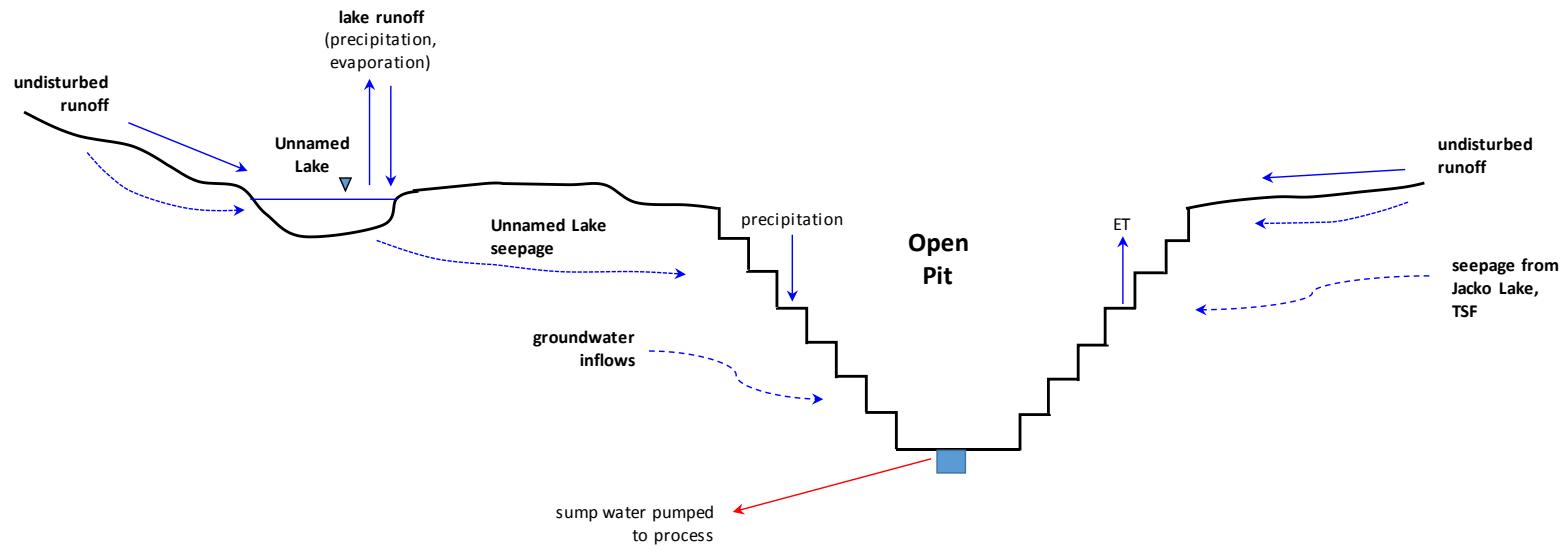
6.6. Tailings

Ground surfaces within the TSF footprint include active tailings, inactive tailings and pond surfaces. Details of the TSF design are provided in Norwest, 2015. Based on BGC's experience at other mine sites in similar climatic conditions, runoff from each of these surfaces is calculated as follows:

- active tailings = available water minus 100% of potential evaporation (PE)
 - also active tailings is assumed to occupy 25% of the exposed beach area
- inactive tailings = available water minus 65% of PE
- pond = available water minus 100% of PE.

Figure 6-7 summarizes runoff components into the TSF during Operation. As well as runoff to the beach and pond surfaces, the WBM assumes that the surface runoff component from up gradient undisturbed ground will report to the TSF pond, while the baseflow component will report as groundwater recharge underneath the facility. The beach and pond areas are updated each timestep, and are calculated based on a volume-area curve developed for the facility.

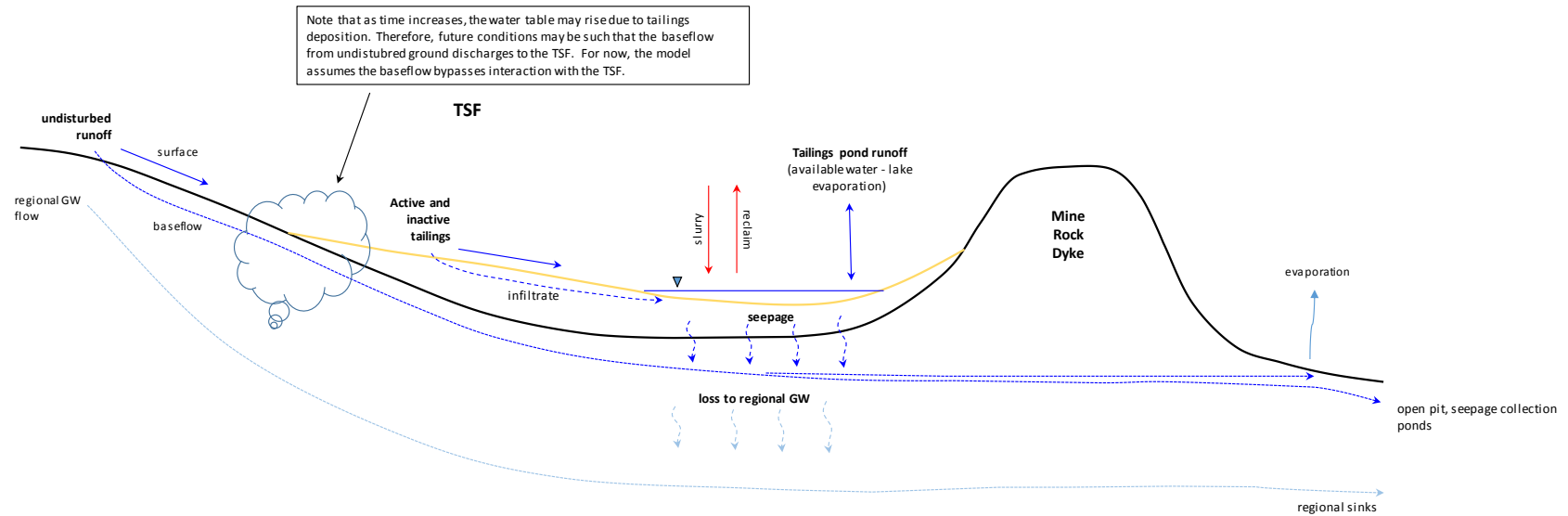
The WBM also tracks seepage out of the TSF: these seepage rates are informed by the groundwater modelling work conducted by BGC (2015b). This seepage is discussed in more detail in Section 7.3.



Note:

Disturbed runoff is direct precipitation within the pit footprint and is calculated as available water (snowmelt + rainfall) minus a percentage (35%) of PE (potential evaporation). Groundwater inflows are derived from the BGC hydrogeologic model and refer to groundwater inflows driven by advancement of the open pit and the accompanying drawdown of the water table. Undisturbed runoff refers to runoff (surface flows and groundwater/base flows) from undisturbed, vegetated areas upslope of the open pit that discharges into the pit directly. This runoff is calculated using a calibrated version of the Vandewiele et al. (1992) model. The Unnamed Lake is located upgradient of the Open Pit and is a lake that used to drain to Peterson Creek through an ephemeral creek. The creek outlet was blocked with mine rock as part of the past mining. Some seepage from this pond and through the historic waste rock is expected during mining. Lake runoff is equal to available water (snowmelt + rainfall) minus 100% of PE. During summer months, PE typically exceeds rainfall.

Figure 6-6. Conceptual model of runoff to the Open Pit during Operation.



Note:

Pond runoff is equal to available water (snowmelt + rainfall) minus 100% of PE. During summer months, this value is negative as PE typically exceeds rainfall. For runoff from the mine rock dyke, see Figure 5-2. Seepage from the tailings will combine with baseflow from the undisturbed ground. This water will primarily discharge to the surface and evaporate or report to the open pit. These seepage flows are calculated as per the groundwater model, as are their discharge locations.

Figure 6-7. Conceptual model of TFS flows during Operation.

7.0 WATER BALANCE MODEL INPUTS AND ASSUMPTIONS

This section provides an overview of various inputs to the WBM.

7.1. Precipitation Inputs

Precipitation inputs to the WBM include both a deterministic dataset and the ability for the user to enter a specific return period for a given year.

7.1.1. Deterministic

A monthly precipitation dataset for the period 1896-2011 is used as an initial input to the WBM. The model allows the user to enter any year between 1897 and 1985. The year chosen then represents the first year of simulation (Year -1) with subsequent calendar years following in sequence. For example, if the year 1970 is chosen, then Year -1 of the simulation is 1970, Year 1 is 1971, Year 2 is 1972, etc. This approach represents a deterministic analysis of site runoff and provides a robust representation of possible precipitation and runoff trends expected at site. Runoff rates and pond volumes for the various mine facilities can be calculated based on the deterministic dataset and used to develop water management strategies for the Operation phase.

The deterministic model is advantageous in that it accounts for the possibility for several years of above average or below average precipitation to occur in sequence. WBM results can then be evaluated for such sequences, which represent previously observed climate conditions rather than theoretical conditions. Figure 7-1 shows assumed annual precipitation at Ajax for the 1897-2011 period based on scaled (i.e., elevation adjusted) precipitation data from Kamloops Airport⁴.

⁴ Whereby average annual precipitation data at the airport is 244 mm for the period 1897-2011 compared to 336 mm at the Project site.

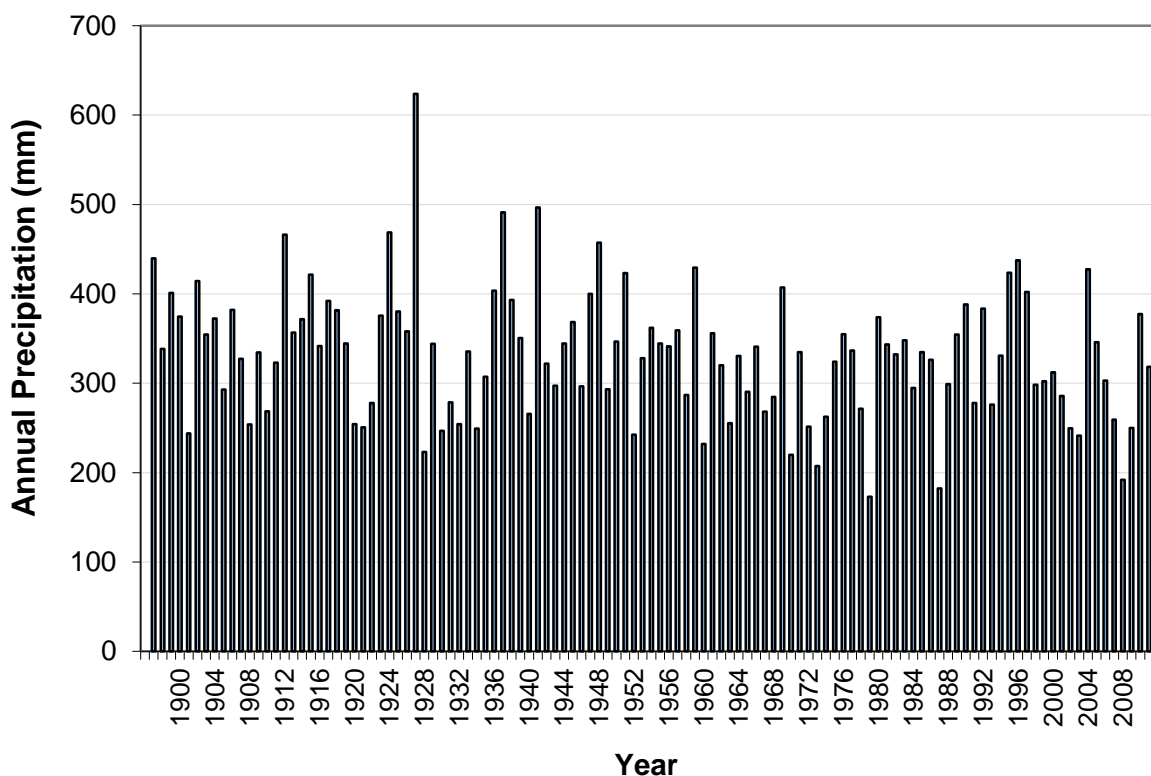


Figure 7-1. Estimated annual precipitation at Ajax (1897-2011).

Users of the deterministic model should be reminded that the projected monthly and annual precipitation amounts over the 115-year time scale of the model do not represent a prediction of precipitation in real time, and are intended only to represent the expected range of variation of the WBM elements. Deviations from the projected values in any given month or year will likely be observed during the course of the project.

7.1.2. Specific Return Period

The WBM has also been set-up to evaluate specific runoff conditions. For example, the default case is for each year of the mine life to have average runoff conditions (i.e., annual precipitation = 336 mm at the mine site). The model is also used to evaluate dry and wet years for a given year by changing the default precipitation. This flexibility allows the user to evaluate a broad range of potential conditions.

7.2. Process Parameters

An average mill throughput of 65,000 t/d is planned for the mine. The ore will be processed at the mill with the resultant tailings sent as thickened slurry to the TSF.

Table 7-1. Process plant assumptions for 65,000 t/d (Fluor, 2015; Norwest, 2015).

Process Plant Inflows	
Ore initial moisture content ¹	4.5% (by weight)
	123 m ³ /h
Total process requirement	1,806 m ³ /h
Process Plant Outflows	
Tailings slurry % solids	60%
Tailings slurry water	1,806 m ³ /h
Ore concentrate	0.01 m ³ /h

Within the process, fresh (non-contact) water will be required for reagent preparation, gland seals and wash water. Recycled water (contact water) will be used to partially make up the water consumed in process (e.g., evaporative losses on the tailings beach and void losses within the tailings deposits). However, because this site is in water deficit, contact water is not expected to make up the entire volume consumed in process. The remaining deficit will be made up through fresh water supply from Kamloops Lake.

7.3. TSF

7.3.1. Operation

The TSF will ultimately occupy much of the Keynes Creek watershed (Drawing 12). Tailings containment will be provided by four embankments: the North Embankment, the East Embankment, the South Embankment, and the Southeast Embankment. The various components of runoff to the facility are as shown on Figure 6-7. A supernatant pond will be maintained throughout Operation to allow for reclaim to the process plant. Depositional planning by Norwest (2015) indicates that the required pond volume is 2.1 Mm³, which represents three months supply of make-up water to the process plant. The WBM assumes that this pond volume is developed during the final year of construction (Year -1) by pumping water from Kamloops Lake at an average rate of 1505 m³/h for a period of 2 months. The WBM assumes that a minimum pond volume of 2.1 Mm³ is required at all times, which provides a limit on the amount of reclaim water being used in process. Thus, reclaim rates are higher during periods of runoff (e.g., spring melt) and lower during periods of negligible runoff (late summer and winter). The amount of reclaim is also constrained by capillary sequestration of water in the deposited tailings (i.e., void losses).

7.3.2. Tailings Settled Density

The initial loss of water to tailings voids is calculated as follows:

$$initial\ void\ loss = \left[\frac{1}{\rho} - \frac{1}{SG} \right] \cdot tailings\ tonnage$$

where ρ = the settled dry density of tailings and SG = specific gravity.

The WBM assumes that when the thickened tailings is initially deposited in the TSF the settled dry density is 1.2 t/m³. The model also accounts for the slow release of water from void space as the tailings consolidate. Consolidation modelling of the deposited tailings as a function of mine life has been conducted by Knight Piésold (2015a) and is summarized in Table 7-2. Results shown are for a tailings slurry of 65% solids by weight.

Table 7-2. Tailings consolidation results (Knight Piésold, 2015a).

	Year	Settled Dry Density (t/m ³)		Year	Settled Dry Density (t/m ³)
Operation	1	1.38	Closure and Post Closure	21.17	1.45
	2	1.40		22.17	1.46
	3	1.40		23.17	1.46
	4	1.40		24.17	1.46
	5	1.41		25.17	1.46
	10	1.43		30.17	1.47
	15	1.44		40.17	1.48
	20	1.45		50.17	1.49
	20.17	1.45		70.17	1.50

Note: the consolidation modelling conducted by Knight Piésold (2015a) assumed a mine life of 21 years, which has since been revised to 23 years.

7.3.3. Seepage

Each TSF embankment has a corresponding seepage/surface runoff collection pond, except for the East Embankment for which seepage is directed toward the Central Pond and Open Pit. As well as capturing TSF seepage, these ponds also collect seepage and runoff from the corresponding MRSFs and catchment runoff.

Seepage and runoff from the North Embankment is collected at North Embankment Ponds 1 and 2 (Drawing 12). The WBM assumes that any runoff collected at these ponds is pumped to the Central Pond for use in process.

Seepage and embankment runoff from the South and Southeast Embankments will be collected at their water management ponds. Given the small contributing watershed area to these ponds, the WBM assumes that static ponds develop whereby runoff to the ponds is at an equilibrium with evaporative losses, although pumps are provided for in the WMP so that any water accumulating in these ponds can be pumped to the TSF.

Groundwater modelling by BGC indicates that a majority of TSF seepage is predicted to discharge to the surface down gradient of the facility and evaporate before reaching a watercourse. TSF seepage is not predicted to report to North Embankment Pond 2, given its shallow depth and proximity to the Open Pit. Small seepage volumes are also estimated to report to North Embankment Pond 1, and the South and Southeast Embankment Ponds. The remaining seepage is predicted to report to the Open Pit. Annual TSF seepage estimates are summarized in Table 7-3 and Table 7-4 for various scenarios.

Table 7-3. TSF seepage estimates for base case and high K scenario (BGC, 2015b).

Year	Base Case (m ³ /day)						High K (m ³ /day)					
	Total	Jacko Lake	North Embank't Pond 1	Open Pit	South Embank't Pond	Southeast Embank't Pond	Total	Jacko Lake	North Embank't Pond 1	Open Pit	South Embank't Pond	Southeast Embank't Pond
-1	720	0	0	0	0	0	1,190	0	0	0	0	0
1	941	0	0	0	0	0	2,024	0	0	1,584	0	0
2	1,385	0	0	958	0	0	3,366	0	0	2,633	0	0
3	1,031	0	0	872	0	0	2,418	0	0	1,747	0	0
4	881	0	0	628	0	0	1,904	0	0	1,187	0	0
5	2,796	0	0	1,934	0	0	6,077	0	0	3,534	0	0
6	1,916	0	0	806	0	0	4,013	0	0	1,717	0	0
7	1,570	0	0	649	0	0	3,125	0	0	1,378	0	0
8	1,371	0	0	948	0	0	2,644	0	0	2,068	0	0
9	1,218	0	0	755	0	0	2,393	0	0	1,343	0	0
10	3,911	0	0	1,198	1	0	8,249	0	0	2,119	2	0
11	2,507	0	0	614	1	0	5,692	0	0	1,411	5	0
12	2,050	0	0	529	2	0	4,691	0	0	1,287	6	0
13	1,833	0	0	477	2	0	4,077	0	0	1,222	7	0
14	1,662	0	0	441	2	0	3,731	0	0	1,172	8	0
15	1,521	0	0	1,052	2	0	3,503	0	0	2,075	9	0
16	1,401	0	0	538	2	0	3,328	0	0	1,493	9	0
17	1,292	0	0	486	2	0	3,181	0	0	1,395	9	0
18	1,205	0	0	454	2	0	3,052	0	0	1,332	10	0
19	1,136	0	0	431	2	0	2,937	0	0	1,291	10	0
20	4,949	0	0	843	3	0	12,109	0	0	2,140	152	0
21	3,398	0	0	565	4	0	8,985	0	0	1,736	263	0
22	2,696	0	0	519	16	0	6,939	0	0	1,630	325	0
23	2,542	0	0	493	21	0	6,186	0	0	1,567	360	0
closure	1,602	0	0.45	1,108	78	4	7,934	0	68	6,207	403	30

Table 7-4. TSF seepage estimates for low K and high TSF conductance scenarios (BGC, 2015b).

Year	Low K (m ³ /day)						High Conductance (m ³ /day)					
	Total	Jacko Lake	North Embank't Pond 2	Open Pit	South Embank't Pond	Southeast Embank't Pond	Total	Jacko Lake	North Embank't Pond 1	Open Pit	South Embank't Pond	Southeast Embank't Pond
-1	242	0	0	0	0	0	746	0	0	0	0	0
1	363	0	0	38	0	0	967	0	0	0	0	0
2	493	0	0	51	0	0	1,447	0	0	1,007	0	0
3	388	0	0	40	0	0	1,056	0	0	735	0	0
4	330	0	0	34	0	0	894	0	0	622	0	0
5	934	0	0	97	0	0	2,889	0	0	2,011	0	0
6	760	0	0	79	0	0	1,942	0	0	827	0	0
7	636	0	0	66	0	0	1,584	0	0	666	0	0
8	556	0	0	58	0	0	1,375	0	0	957	0	0
9	499	0	0	52	0	0	1,221	0	0	850	0	0
10	1,459	0	0	151	0	0	4,007	0	0	1,228	0	0
11	1,235	0	0	128	0	0	2,519	0	0	630	0	0
12	1,002	0	0	104	0	0	2,056	0	0	542	0	0
13	853	0	0	88	0	0	1,827	0	0	489	0	0
14	759	0	0	79	0	0	1,656	0	0	452	0	0
15	693	0	0	72	0	0	1,513	0	0	1,371	0	0
16	645	0	0	67	0	0	1,389	0	0	551	0	0
17	608	0	0	63	0	0	1,278	0	0	498	0	0
18	577	0	0	60	0	0	1,195	0	0	465	0	0
19	547	0	0	57	0	0	1,126	0	0	444	0	0
20	1,988	0	0	206	0	0	5,090	0	0	863	0	0
21	1,698	0	0	176	0	0	3,406	0	0	567	0	0
22	1,462	0	0	152	0	0	2,688	0	0	531	0	0
23	1,273	0	0	132	0	0	2,555	0	0	503	0	0
closure	357	0	47	37	14	0.4	1,816	0	0	1,264	83	5

7.4. Pit Inflows

Groundwater inflows to the pit have been estimated by BGC (2015b) and are summarized in Table 7-5. Three sets of results have been reported: a base case hydraulic conductivity (K), a high K (5x) case, and a low K (5x) case. Also summarized in Table 7-5 are estimated seepage rates from Jacko Lake into the Open Pit through the life of mine (LOM).

Table 7-5. Estimated groundwater inflows and Jacko lake seepage flows to the Open Pit (BGC, 2015b).

Mine Year	Pit Inflows (m ³ /d)			Seepage from Jacko Lake (m ³ /d)		
	Base Case	High K	Low K	Base Case	High K	Low K
-1	57	267	15	0	0	0
1	57	265	15	0	0	0
2	4,416	6,446	3,595	62	162	18
3	1,286	2,242	649	90	207	30
4	926	1,523	464	106	231	38
5	3,126	4,534	2,392	116	251	44
6	1,189	2,203	597	122	260	49
7	957	1,767	520	127	264	52
8	3,984	3,747	3,843	129	267	53
9	1,113	1,723	761	131	270	55
10	1,765	2,718	1,413	132	272	56
11	905	1,810	569	133	273	56
12	780	1,651	502	134	275	57
13	703	1,567	465	135	277	57
14	649	1,504	426	135	278	58
15	1,971	2,662	1,906	136	280	58
16	794	1,916	449	136	282	58
17	716	1,790	409	136	284	59
18	669	1,709	387	136	286	59
19	635	1,656	365	137	288	59
20	1,243	2,746	816	137	289	59
21	833	2,227	396	137	291	59
22	766	2,092	373	137	293	59
23	727	2,011	356	137	294	60

During the closure period, groundwater inflow and lake seepage rates are a function of the water level in the Open Pit, as summarized in Table 7-6. The Open Pit would only spill if the water level reached elevation 884 m. A volume elevation curve for the Open Pit, which is partially backfilled with mine rock during Operation, is provided in Figure 7-2.

Table 7-6. Groundwater inflows and Jacko Lake seepage flows into the Open Pit during Closure and Post Closure.

Lake Elevation (m)	Groundwater Inflow (m ³ /h)	Jacko Lake seepage (m ³ /h)
435	21	5.6
500	20	5.6
550	18	5.6
600	17	5.6
880	7	4.8

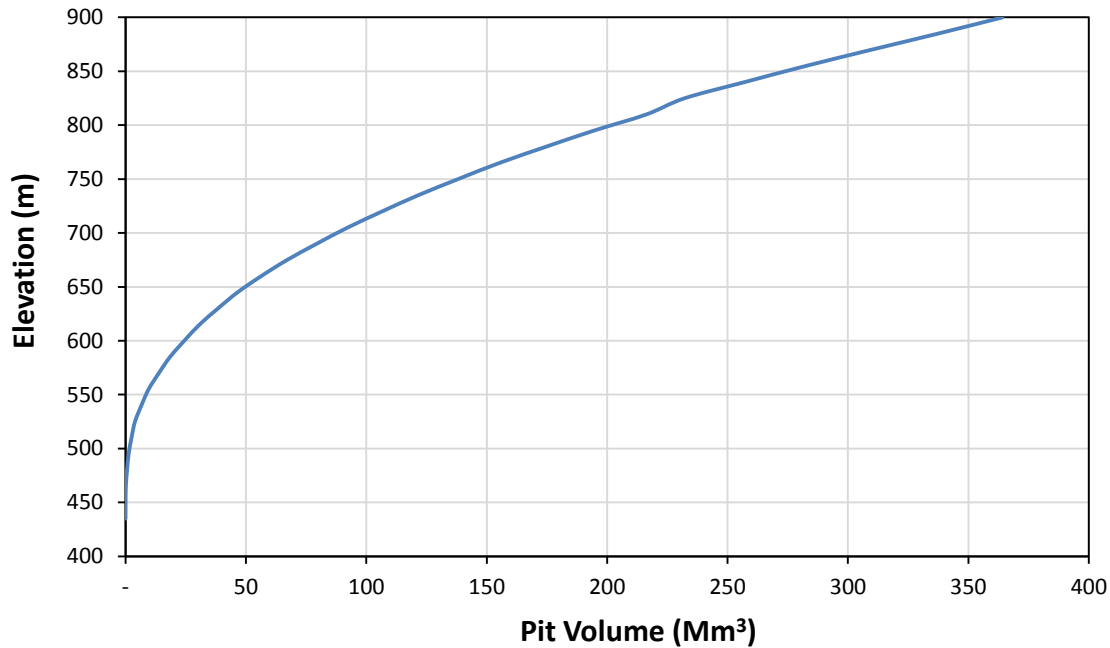


Figure 7-2. Volume-elevation curve for partially backfilled Open Pit.

7.5. Mine Rock Storage Facilities

There are three MRSFs within the Project: the WMRSF, the SMRSF, and the EMRSF. Each of these facilities is discussed in more detail below. Runoff calculations for the mine rock are discussed in Section 6.2.

7.5.1. West MRSF

Based on watershed areas, the WMRSF can be divided into three zones: a west, central and east portion. For the west portion, the WBM assumes that seepage flow from the MRSF either reports to the North Embankment Pond 1 or to Peterson Creek (Lower)/Jacko Lake. This water management pond also receives runoff from TSF seepage and surface flows from undisturbed

ground within the seepage pond catchment. Baseflows from the undisturbed ground are assumed to report to Peterson Creek (Lower).

For the central portion, the WBM assumes that seepage flow from the MRSF either reports to North Embankment Pond 2 or to the Open Pit. This seepage pond also receives surface flows from undisturbed ground within the seepage pond catchment. TSF seepage is not predicted to report to this pond.

For the east portion, the WBM assumes that seepage flow from the MRSF either reports to the Central Pond or to the Open Pit.

At Post Closure, the WBM assumes that water collected in the seepage ponds is released to the environment, with the surface area of the ponds allowing for the maximization of evaporation losses (i.e., Peterson Creek (Upper and Lower)). The Central Pond is not maintained through closure, so any seepage flows from the MRSF either report to the Open Pit or Peterson Creek (Lower) (either as surface runoff or to the underlying Peterson Creek aquifer).

7.5.2. South MRSF

The SMRSF straddles three watershed boundaries, as illustrated in Drawing 13. Therefore, this MRSF is treated as three separate zones in the WBM: west, east and south.

- Seepage from the west portion is assumed to report either to the Central Pond or the Open Pit.
- Seepage from the east portion is assumed to report either to the Central Pond (near surface flows would be intercepted by the plant site area or conveyor and recycled within the process) or to Peterson Creek (Lower).
- Seepage from the south portion either reports to the downstream water management pond or Humphrey Creek. Flows captured in the SMRSF Pond are pumped to the Plant Site Pond.

At closure, the SMRSF Pond will be operated as an evaporative pond to limit potential surface runoff to Humphrey Creek. The Central Pond is not maintained through closure, at least in its operations form, so any seepage flows from the east and west portions of the SMRSF report either to Peterson Creek (Lower) and aquifer or the Open Pit.

7.5.3. East MRSF

The EMRSF straddles two small tributaries of Peterson Creek (Lower) (Drawing 14). The west tributary has a watershed area of 176 ha, while the east tributary has a watershed area of 172 ha. Groundwater modelling indicates that a majority of groundwater flow in the west tributary will report to the Open Pit (BGC, 2015b). This flow includes baseflow from the undisturbed ground in the watershed and seepage flow from the MRSF that reports to the groundwater table. Surface runoff from undisturbed areas and the remaining MRSF seepage flow is assumed to report to the downstream EMRSF Pond. Runoff reporting to this pond is then

pumped to the Central Pond. Groundwater flows not captured by the Open Pit will report to Peterson Creek (Lower) and aquifer.

The east tributary does not have its own water management pond. Rather, near surface flows in this catchment will be captured by a collection ditch and diverted to the EMRSF Pond. The WBM assumes that near surface seepage flows from the MRSF and surface runoff from the undisturbed ground will be intercepted by the ditch. Deeper groundwater flows will bypass this ditch and report to Peterson Creek (Lower).

At closure, the EMSRF Pond will be operated as an evaporative pond to limit potential surface runoff to Peterson Creek (Lower).

7.6. Central Pond

In the WBM, the Central Pond is assumed to receive runoff from the following sources:

- catchment runoff from undisturbed ground not effected by mine facilities;
- the EMRSF Pond;
- the SMRSF Pond;
- North Embankment Pond 1 and 2;
- seepage/runoff from the north portion of the SMRSF;
- seepage/runoff from the east portion of the WMSRF; and
- seepage/runoff from the ore stockpile.

The Central Pond will also receive flow from pit dewatering. The Central Pond will be decommissioned at closure or reconfigured.

7.7. Additional Fresh Water Uses

Apart from make-up water for process, additional fresh water is required for (Fluor, 2015):

- drilling (1.5 m³/h);
- explosives mixing (0.4 m³/h);
- dust control (peak demand of 201 m³/h);
- the truck shop (12.5 m³/h); and
- potable water (3.6 m³/h).

Potable water (for personal consumption, showers, washrooms, laundry facilities and janitorial services) will be used at two separate locations: the truck shop and the Plant Site. Before use, all potable water will be treated at an on-site treatment plant. Potable water losses are estimated at 0.7 m³/h with the remainder being sent to one of two STPs. Effluent from the STP at the truck shop will be pumped to the Central Pond in the EMRSF Pond pipeline. Effluent from the Plant Site STP will be pumped to the Plant Site Pond. Sewage sludge generated from the STPs will be transported offsite for disposal at a licensed facility.

While the peak water demand for dust control is 201 m³/h, the WBM assumes an average usage rate of 40 m³/h for the May to October period.

7.8. Runoff Calculations

Runoff calculations for the various land types at the project site are discussed in Section 6.0. The table below provides a summary of runoff calculations assumed for the WBM under average precipitation conditions.

Table 7-7. Summary of runoff calculations.

Ground Type	Method	Average Annual Runoff (mm)
<i>Undisturbed ground</i>		
600 m to 900 m elevation	calibrated Vandewiele et al. (1992) model	17
920 m (i.e., mine site)		23
900 m to 1200 m elevation		28
1200 m to 1500 m elevation		44
> 1500 m elevation		62
MRSF (bare rock)	HYDRUS-1D	44 ¹
Stockpiles	HYDRUS-1D	44 ¹
MRSF (reclamation + till cover) - infiltration	HYDRUS-1D	8 ¹
Open Pit	Runoff = available water (snowmelt (snow*0.7 + rain) – 30%PE)	87
Active Tailings	Runoff = available water – 100%PE	-279
Inactive Tailings	Runoff = available water – 65%PE	43
Pond/Lake	Runoff = available water – 100%PE	-279

¹ Infiltration into mine rock

7.9. Additional Assumptions

A number of assumptions have been made for the existing conditions and Operation WBMs.

7.9.1. Keynes Creek

Figure 4-1 illustrates that almost no surface runoff reaches the mouth of Keynes Creek, despite it having a watershed area of 11.4 km². The lack of surface flow out of this watershed is explained by the existing water licenses and a number of lakes in the watershed, which provide a sink for surface runoff where high evaporative losses can occur. For example, Goose Lake has a watershed area of 335 ha compared to a lake surface area of 9 ha (Figure 7-3). Some runoff does exit this lake, as the watershed to lake area ratio is about 37 (see Section 6.1). However, the alkaline nature of the lake indicates that evaporative losses are significant.

About 1.2 km downstream of Goose Lake, a man-made lake has been created as Keynes Creek flows through a culvert under a road (Figure 7-4). This lake covers an area of about 7 ha when full, although aerial imagery indicates the lake can be relatively dry at times. Presumably, this impoundment was created to provide a source of water for irrigation or stockwatering. Downstream of this lake, the valley bottom of Keynes Creek is covered in grasses (Figure 7-5).

About 1 km south of this location, there are an additional two man-made lakes that are coincident with the water licenses of Keynes Creek (Drawing 03). These lakes cover an area of about 5.5 ha and above these impoundments (in the southwest corner of the watershed) there are two small natural lakes with a combined surface area of 4 ha.



Figure 7-3. North view of Goose Lake. BGC photograph of September 14, 2014.



Figure 7-4. Road crossing of Keynes Creek downstream of Goose Lake, which has created a small man-made lake. BGC photograph of September 14, 2014.



Figure 7-5. Upstream (south) view of Keynes Creek, downstream of the impoundment of Figure 7-4. BGC photograph of September 14, 2014.

The watershed area upstream of the most downstream impoundment is about 10.4 km². Assuming that baseflows bypass these ponds at depth, which is the conceptual flow model for tributary runoff, then the average annual surface runoff is on the order of 21 mm or 140,000 m³. This runoff volume is approximately balanced by the licensed abstraction volume (60,000 m³) and potential evaporative losses from the various lake surfaces (75,000 m³). Therefore, it is not unexpected that almost no surface runoff reports to the mouth of Keynes Creek under existing conditions.

The existing conditions WBM assumes that the baseflow component of runoff for the entire Keynes Creek watershed reports to Peterson Creek (Lower), but that only the lower portion of the watershed (0.9 km²) contributes surface runoff to the creek. This assumption is consistent with observations at groundwater wells BGC14-002D/S, which show groundwater levels about 7 m below the surface. These wells are located along Keynes Creek near the KEYNES hydrometric station.

7.9.2. Jacko Lake

Section 3.0 provides a summary of the water licenses on Jacko Lake and how water is allocated for downstream use. The WBM currently assumes that the storage-supported irrigation volume of 492,283 m³ is released from the lake in July and August via the low level outlet.

7.9.3. Edith Lake

The WBM currently assumes that the Edith Lake watershed does not contribute runoff to Peterson Creek. This assumption should be revisited for permitting, as recent changes in the management of Edith Lake and the Anderson Creek diversion have allowed for increased flows in Peterson Creek (Lower) in the last several years.

7.9.4. Subsurface Flows

Downstream of Jacko Lake, Peterson Creek flows within a valley that is composed of a thick sequence of glaciofluvial sediments (the Peterson Creek Aquifer). Because these sediments have a relatively high hydraulic conductivity, a 1,000 m portion of the Peterson Creek channel immediately downstream of Jacko Lake was lined with comparatively impervious till in 1990 (Price, 1991). The lining was installed to help mitigate water losses due to seepage and evapotranspiration.

Groundwater modelling by BGC (2015b) indicates that there are a number of gaining and losing reaches along Peterson Creek (Lower). However, the WBM does not differentiate between these reaches. It is assumed that Peterson Creek (Lower) is a gaining reach along its entire length.

7.9.5. Davidson Brook

It is assumed that all licenses on Davidson Brook are currently active. Using the WBM, annual surface runoff on the order of 130,000 m³ is predicted to occur from Davidson Brook of which about 90% (120,000 m³) is a licensed abstraction volume (see Table 3-6). Therefore, the WBM assumes that only 10% of the Davidson Brook watershed provides surface runoff to Peterson Creek (Lower), but that the entire watershed area provides baseflow to the creek.

7.9.6. Separation Lake

The estimated annual runoff to the Separation Lake watershed is 19 mm, of which 3 mm is assumed to be recharge. Therefore, the average surface runoff volume to this sub-watershed is about 360,000 m³. However, there are also a number of lakes in the sub-watershed that cover an area of about 68 ha. Evaporative losses are therefore about 180,000 m³, while the licensed irrigation and stockwatering volume is approximately 180,000 m³ (Table 3-7). As the evaporative losses and licensed irrigation volumes approximately equal the estimated surface runoff volume, the WBM assumes no surface outflow from the Separation Lake sub-watershed.

However, it is assumed that recharge (3 mm) bypasses the surface drainages and lakes, and instead discharges to Peterson Creek (Lower).

7.10. Areas

Watershed areas reporting to the various assessment locations for existing conditions and Operation are summarized below.

Table 7-8. Watershed areas assumed for assessment locations.

Node	Watershed Area (km ²)		Change in Area	
	Existing	Operation	(km ²)	(%)
Jacko Lake	40.9	40.1	-0.8	-2.0%
PC02.5	55.7	47.0	-10.1	-18.0%
PC02	66.0	55.8	-11.4	-17.3%

Note: the reported watershed areas for PC02.5 and PC02 do not account for the Separation Lake basin or a majority of the Keynes Creek basin, as discussed in Section 7.9.

The reduction in watershed area for the downstream nodes is a function of:

- the growing footprint of the Open Pit,
- the various water management ponds, where runoff will be intercepted (Central Pond, the EMRSF Pond, the SMRSF Pond, and North Embankment Ponds 1 and 2).

The reductions in watershed area and flows for the various modeling nodes are described in the following sections.

Jacko Lake

The current drainage area of the Jacko Lake watershed is 4090 ha. This area will be reduced by about 80 ha following construction of the WMRSF and the downstream North Embankment Pond 1 and a minor expansion of the Open Pit into Jacko Lake, a reduction of about 2%. Flows into the lake will also be slightly reduced as a result of a progressive drawdown of the bedrock groundwater table around the Open Pit, as the pit is excavated downward. Groundwater simulations indicate that small volumes of water will seep into the Open Pit from Jacko Lake through bedrock (on the order of 5 m³/h).

Peterson Creek

Moving downstream, the watershed area of Peterson Creek will be reduced by 334 ha due to the expansion of the Open Pit. The Open Pit will ultimately occupy a footprint of 237 ha and also intercept an area of 97 ha of undisturbed ground, which will drain into the Open Pit. Further watershed reductions result from the construction of the various water collection ponds:

- 70 ha reports to North Embankment Pond 2
- 338 ha reports to the Central Pond

- 110 ha to the SMRSF Pond
- 314 ha to the EMRSF Pond

The total reduction in area is then approximately 1140 ha. Assessment location PC02 is downstream of the LSA on Peterson Creek. The total existing watershed area at this location is 66 km². By the end of Operation, this area will be reduced by 17%.

8.0 WATER BALANCE MODEL RESULTS

8.1. Introduction

This section presents WBM results on an annual and monthly basis for existing conditions, Construction, Operation, and Post Closure. The intent is to quantify the potential effects that the Project will have on surface water quantity. Effects to surface water quantity could potentially occur during all phases of the Project. Results are primarily provided for the various assessment locations on Peterson Creek including: Jacko Lake, PC03, PC02.5 and PC02. Potential effects to Kamloops Lake, as a result of using the lake as a source of make-up water, are also quantified.

The base case scenario being evaluated is average precipitation conditions, but a number of sensitivity simulations have also been evaluated, as part of the water quality modelling. The sensitivity scenarios being evaluated are summarized below in Table 8-1.

Table 8-1. Sensitivity scenarios to assess effects on surface water quantity.

Group No.	Sensitivity Scenario	Precipitation ¹	MRSF Infiltration ²	Hydraulic Conductivity ³	TSF Conductance ⁴	Pond Seepage Bypass ⁵
0	Base case	Average	Base	Base	Base	Base
1	Climate Inputs					
	1	Variable climate	Base	Base	Base	Base
2	MRSFs					
	1	Average	2x higher	Base	Base	Base
3	Groundwater Assumptions					
	1	Average	Base	5x higher	Base	Base
	2	Average	Base	5x lower	Base	Base
	3	Average	Base	Base	10x higher	Base
	4	Average	Base	Base	Base	2x higher

¹ Average annual precipitation for the mine site is 336 mm. Variable climate conditions include stepping the WBM through the historic climate record (1897-2011) in 5 year increments.

² Unsaturated flow modelling predicts that 8 mm of water infiltrates the engineered cover on an annual basis at Post Closure.

³ Increasing and decreasing the hydraulic conductivity by a factor of 5 based on groundwater modelling results. These two scenarios result in an increase/decrease in groundwater flows.

⁴ Increasing the TSF conductance by a factor of 10 increases the TSF seepage estimates.

⁵ The base case assumption is that 20% of the macro flow in the MRSFs reports to the groundwater table and bypasses the downstream water management pond.

8.2. Base Case Simulation

Water balance schematics for the Project for existing conditions, Operation, and Post Closure (Year 100 of closure) are shown in Figures 8-1 to 8-3. Values shown are annual average flows (m^3/h). A reduction in Peterson Creek (Lower) flows relative to existing conditions is observed in all scenarios. By the end of Operation, an average annual flow of $188 \text{ m}^3/\text{h}$ is estimated at assessment location modelling node PC02, which represents an average decrease of 18% below existing conditions ($230 \text{ m}^3/\text{h}$). This decrease in flow is a result of the footprint of the Open Pit and the various management ponds, which intercept runoff from the West, South and East MRSFs. By year 100 of Closure, an annual average flow of $215 \text{ m}^3/\text{h}$ is estimated at PC02, a reduction of 7% compared to existing conditions. A recovery in flow relative to Operation is a result of TSF and MRSF reclamation.

Estimated average monthly changes in flow at various locations in the Peterson Creek (Lower) watershed under existing conditions, Construction, Operation (Year 23), and at Year 100 of Closure are summarized in Table 8-1 and Table 8-2. These changes assume average precipitation conditions. Results are also shown graphically in Figure 8-4 and Figure 8-5 for assessment locations PC03 and PC02.

Note: Rates are in m³/h.

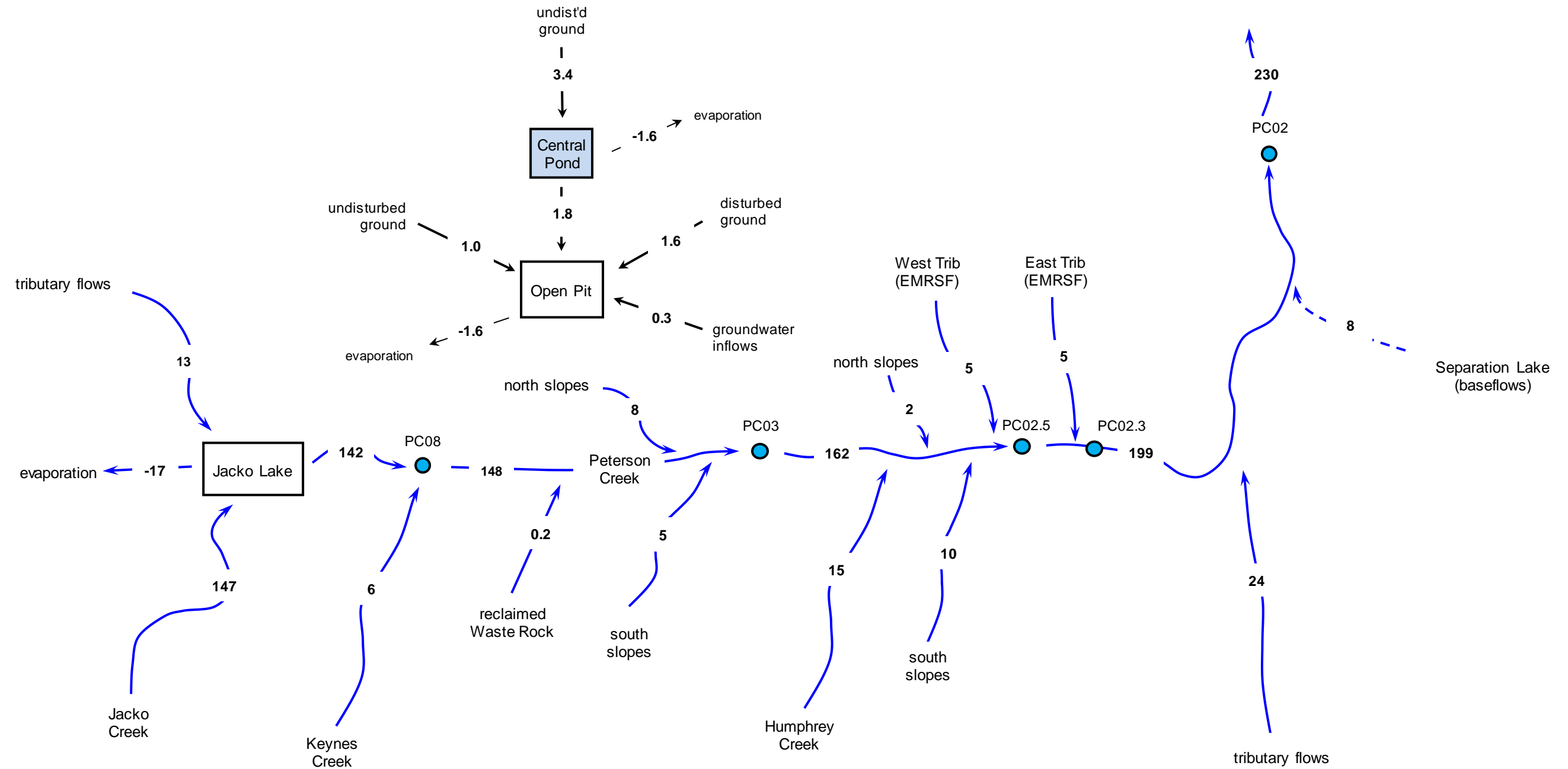
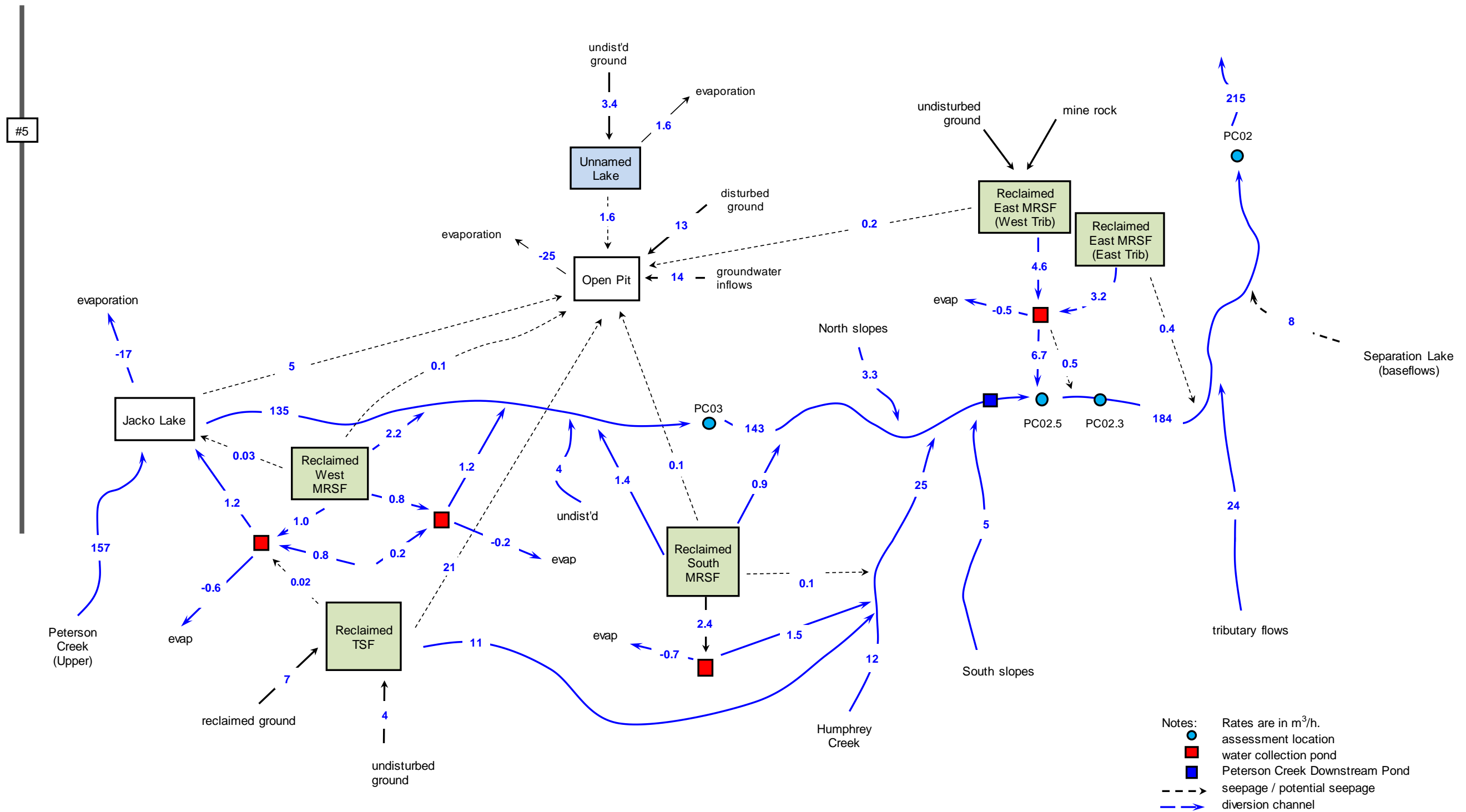


Figure 8-1. Ajax Project annual average water balance model schematic for existing conditions.



Please note that surface runoff from reclaimed MRSF's includes infiltration through the cover materials, but which reports as macro flow to the stream network.

Figure 8-3. Ajax Project average annual water balance model schematic for Year 100 of closure.

Table 8-2. Average monthly streamflow in Peterson Creek (Jacko Lake and PC03) for existing conditions, Construction, Operation and Closure.

Month	Jacko Lake Outflow (m ³ /h)				PC03 (m ³ /h)			
	Existing	Construction	Ops (Year 23)	Closure (Year 100)	Existing	Construction	Ops (Year 23)	Closure (Year 100)
January	0	0	0	0	6	0	0	0
February	0	0	0	0	6	0	0	0
March	0	0	0	0	22	0	0	9
April	0	0	0	0	58	0	0	28
May	530	509	443	453	598	0	0	487
June	586	582	576	571	615	0	0	590
July	289	289	289	289	300	0	0	294
August	289	289	289	289	297	0	0	290
September	0	0	0	0	8	0	0	1
October	0	0	0	0	9	0	0	2
November	0	0	0	0	6	0	0	0
December	0	0	0	0	6	0	0	0
Average	142	140	134	135	162	0	0	143

Table 8-3. Average monthly streamflow in Peterson Creek (PC02.5 and PC02) for existing conditions, Construction, Operation and Closure.

Month	Peterson Creek (Lower) PC02.5 (m ³ /h)				Peterson Creek (Lower) PC02 (m ³ /h)			
	Existing	Construction	Ops (Year 23)	Closure (Year 100)	Existing	Construction	Ops (Year 23)	Closure (Year 100)
January	10	4	3	3	23	17	16	16
February	11	4	4	4	25	18	17	17
March	59	28	25	47	100	69	62	92
April	166	89	78	156	268	191	170	275
May	727	606	527	631	845	725	634	767
June	664	616	605	638	714	667	651	694
July	314	294	292	301	335	315	312	322
August	305	289	288	291	321	305	304	306
September	16	4	3	5	32	20	19	21
October	19	8	6	10	37	26	24	28
November	10	4	3	3	23	17	16	16
December	10	4	3	3	23	17	16	16
Average	194	164	154	175	230	200	188	215

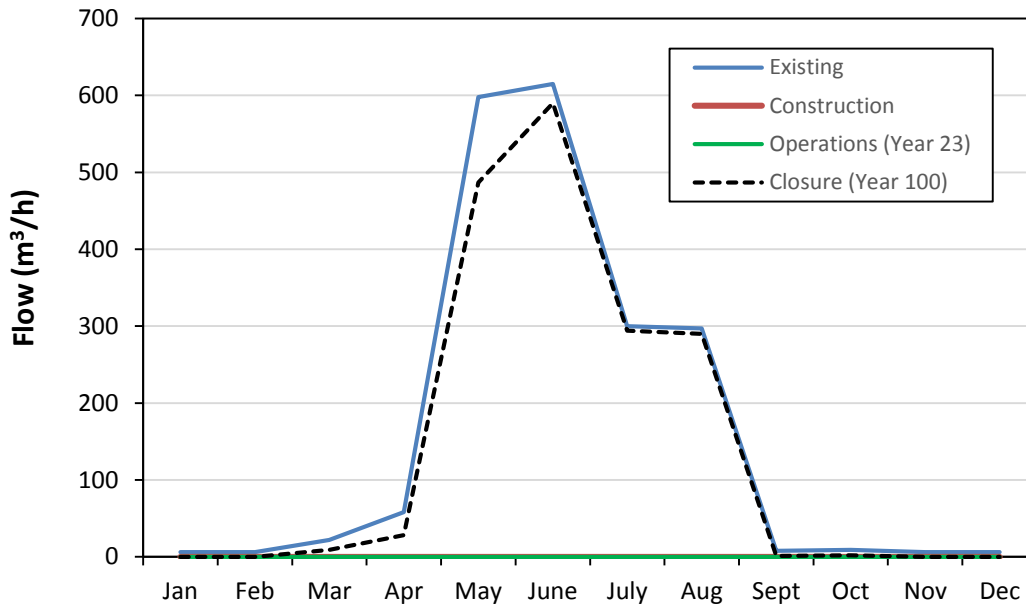


Figure 8-4. Simulated monthly flows at Peterson Creek (Lower) – PC03 for various phases of mine life under average precipitation conditions. Note that there is no flow at PC03 for Construction and Operation.

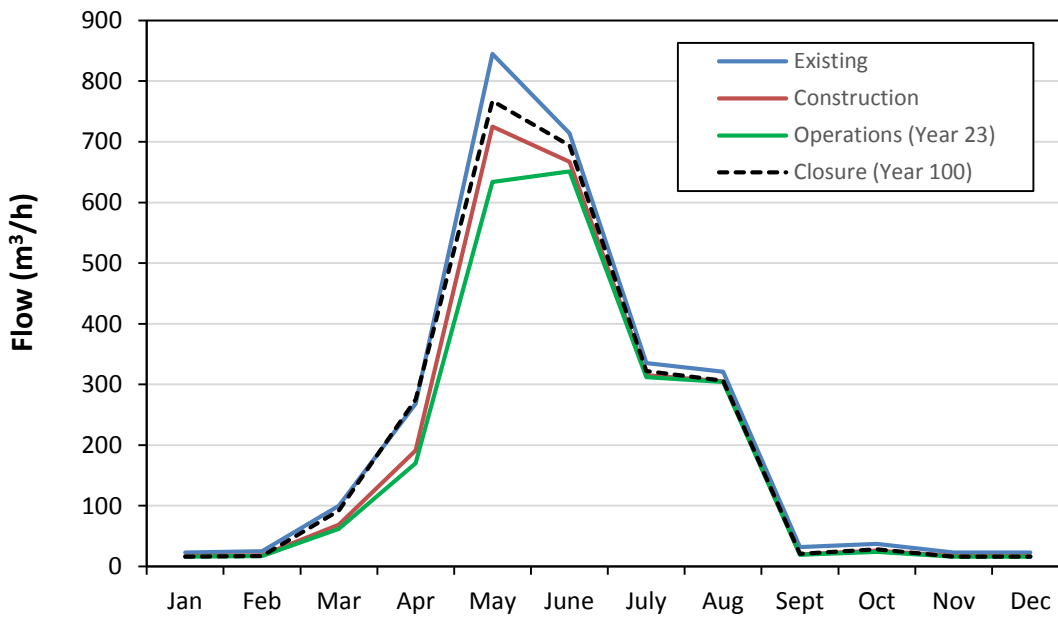


Figure 8-5. Simulated monthly flows at Peterson Creek (Lower) – PC02 for various phases of mine life under average precipitation conditions.

8.3. Effects on Kamloops Lake

The make-up intake on Kamloops Lake will have a maximum capacity of 1,505 m³/h reporting to the mine site. Table 8-4 summarizes the estimated monthly average use of Kamloops Lake as a source of make-up water over the LOM. A majority of this water is required as a source of make-up water for the process plant to slurry tailings to the TSF. Water make-up requirements are the greatest in the summer months, when evaporative losses are at a maximum

Table 8-4. Average monthly use of Kamloops Lake over the LOM.

Month	Kamloops Lake (m³/h)
January	765
February	813
March	846
April	298
May	932
June	1,107
July	1,276
August	1,251
September	993
October	883
November	815
December	811
Average	901

Potential effects on Kamloops Lake can be evaluated by comparing the maximum flow rate to average monthly inflows to the lake. The Water Survey of Canada (WSC) monitors water levels on the Thompson River at Kamloops (#08LF023). The watershed area at this station is 37,800 km². Flow data are available from two downstream hydrometric stations on the Thompson River, Savona and Walhachin, as summarized below.

Table 8-5. Thompson River WSC stations.

Station	ID	Area (km ²)	Flow	Level	Period of Record
Thompson River at Kamloops	08LF023	37,800	x	✓	1915-present
Thompson River near Savona	08LF033	39,100	✓	x	1926-1932, 1960-1966
Thompson River near Walhachin	08LF043	40,900	✓	x	1933-1948

The stations at Savona and Walhachin are representative of outflows from Kamloops Lake. Savona is located right at the lake outlet, while Walhachin is located only 12 km downstream. Both these stations are discontinued, but Table 8-6 summarizes monthly average flow at both these stations and compares these flows to the maximum pumping of 1,505 m³/h at the water intake plus the licensed withdrawal for the adjacent New Afton Mine (the mines would have a common abstraction point). New Afton is currently licensed to draw an annual volume of 1.218 Mm³ (139 m³/h) from Kamloops Lake, but has recently applied to increase this annual withdraw to 1.324 Mm³ (151 m³/h). Therefore, Table 8-6 compares average monthly flows on the Thompson River to the total abstraction volume of 1805 m³/h.

Table 8-6. Thompson River average monthly flow.

Month	Thompson R. near Savona			Thompson R. near Walhachin		
	(m ³ /s)	(m ³ /h)	1805 m ³ /h as %	(m ³ /s)	(m ³ /h)	1805 m ³ /h as %
January	206	742,000	0.24%	198	712,000	0.25%
February	188	678,000	0.27%	173	624,000	0.29%
March	182	655,000	0.28%	171	616,000	0.29%
April	307	1,104,000	0.16%	303	1,092,000	0.17%
May	1,096	3,947,000	0.05%	1,283	4,620,000	0.04%
June	2,168	7,806,000	0.02%	2,076	7,474,000	0.02%
July	1,573	5,662,000	0.03%	1,495	5,383,000	0.03%
August	926	3,334,000	0.05%	830	2,987,000	0.06%
September	597	2,150,000	0.08%	525	1,890,000	0.10%
October	500	1,799,000	0.10%	405	1,457,000	0.12%
November	392	1,412,000	0.13%	346	1,245,000	0.14%
December	267	962,000	0.19%	255	918,000	0.20%

This table shows that the 1,805 m³/h allotment from Kamloops Lake constitutes a minor component of the average flow through the lake (< 0.3%). This evaluation was also conducted using 10-year return period low flows for each month at the Savona station.

Table 8-7. Thompson River 10-year return period monthly low flows.

Month	Thompson R. near Savona		
	(m ³ /s)	(m ³ /h)	1805 m ³ /h as %
January	128	460,800	0.39%
February	133	478,800	0.38%
March	130	468,000	0.39%
April	240	864,000	0.21%
May	277	997,200	0.18%
June	1,275	4,590,000	0.04%
July	955	3,438,000	0.05%
August	579	2,084,400	0.09%
September	336	1,209,600	0.15%
October	252	907,200	0.20%
November	200	720,000	0.25%
December	152	547,200	0.33%

8.4. Sensitivity Runs

A majority of the sensitivity runs have an insignificant effect on surface water quantity, and as such results are not shown for these runs. The exception is the variable climate condition run, which involves stepping through the historic climate record (1897-2011) in 5 year increments. This run allows a full range of climate conditions to be evaluated at all stages of mine life, including extreme wet and dry years and a series of years with above average or below average precipitation (Figure 7-1). To illustrate the range of runoff conditions that this sensitivity run assesses, the following extreme conditions were modelled:

- a 100-year dry year (197 mm) with the preceding year having average runoff; and
- a 100-year wet year (475 mm) with the preceding year having average runoff.

Results are shown in Table 8-8 and Table 8-9. Figure 8-6 shows monthly differences in flow at PC02 under existing conditions for the three precipitation scenarios. Of note is that there is no surface flow at PC03 during Operation due to the Peterson Creek diversion.

Table 8-8. Average monthly streamflow in Peterson Creek for existing conditions and Operation for a 100-year dry year.

Month	Jacko Lake Outflow (m ³ /h)		PC03 (m ³ /h)		PC02.5 (m ³ /h)		PC02 (m ³ /h)	
	Existing	Ops (Year 23)	Existing	Ops (Year 23)	Existing	Ops (Year 23)	Existing	Ops (Year 23)
January	0	0	6	0	10	3	23	16
February	0	0	6	0	10	3	23	16
March	0	0	6	0	10	6	23	18
April	0	0	34	0	93	39	153	94
May	0	0	7	0	14	0	28	14
June	0	0	6	0	10	0	23	13
July	289	289	295	0	299	279	312	291
August	289	289	295	0	299	284	312	297
September	0	0	6	0	10	0	23	13
October	0	0	6	0	10	0	23	13
November	0	0	6	0	10	3	23	15
December	0	0	6	0	10	3	23	16
Average	49	49	58	0	66	53	83	69

Table 8-9. Average monthly streamflow in Peterson Creek for existing conditions and Operation for a 100-year wet year.

Month	Jacko Lake Outflow (m ³ /h)		PC03 (m ³ /h)		PC02.5 (m ³ /h)		PC02 (m ³ /h)	
	Existing	Ops (Year 23)	Existing	Ops (Year 23)	Existing	Ops (Year 23)	Existing	Ops (Year 23)
January	0	0	6	0	10	3	23	16
February	0	0	6	0	10	3	23	16
March	0	0	7	0	13	6	28	20
April	141	81	371	0	828	398	1226	753
May	2957	2,841	3467	0	4485	3,535	5361	4,315
June	2312	2,297	2354	0	2430	2,343	2504	2,410
July	289	289	296	0	303	285	318	299
August	289	289	295	0	299	287	312	300
September	0	0	9	0	19	4	36	21
October	0	0	8	0	17	6	34	22
November	0	0	6	0	10	3	23	16
December	0	0	6	0	10	3	23	16
Average	502	486	573	0	707	577	831	688

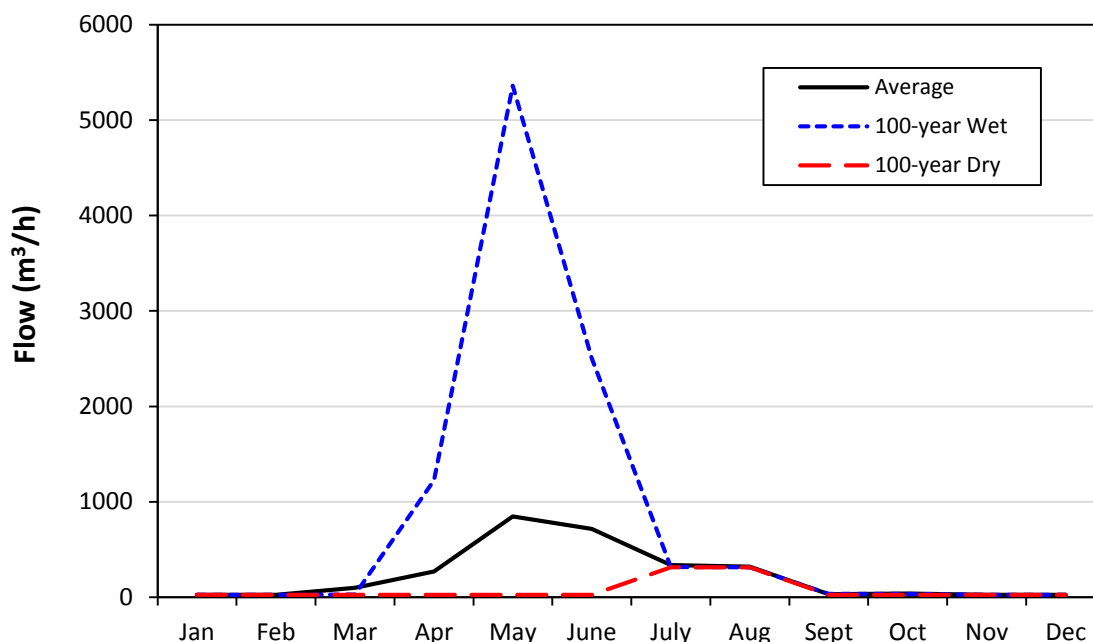


Figure 8-6. Average monthly flows at PC02 under existing conditions for the three precipitation scenarios.

8.5. Closure and Post Closure

During the Decommissioning and Closure period, reclamation covers will be placed over the MRSFs and TSF. The TSF will be covered and contoured such that surface runoff is to the east, with discharge into the Humphrey Creek watershed. Reclamation of the TSF will commence once the supernatant pond water remaining at the end of Operation is pumped over to the Open Pit.

Runoff from the MRSFs will continue to report to the water management ponds, but as opposed to Operation where the runoff will be pumped to the Central Pond, the ponds will be allowed to fill and spill to the environment provided water quality criteria are met. By maintaining a full pond, evaporation losses will be maximized. Infiltration into the mine rock will also be minimized by the placement of a compacted till cover.

By Year 100 of closure, an average annual flow of 215 m³/h has been estimated at assessment location PC02, which represents an average annual decrease of 7% from existing conditions (230 m³/h). Streamflows are higher than at the end of Operation due to increased runoff from the reclaimed TSF and MRSFs.

8.5.1. Open Pit

The Open Pit will gradually fill during the closure period. Inputs to the pit include:

- the supernatant TSF pond volume at the end of Operation;

- incident precipitation within the ultimate pit footprint of 237 ha (snowmelt + rainfall);
- runoff from a small undisturbed area (97 ha) located up gradient of the pit;
- minor seepage inflows from Jacko Lake, the TSF, and the South and West MRSFs.

Figure 8-7 shows the resulting pit lake filling curve based on the assumptions above. After about 300 years and assuming average runoff conditions, the pit lake reaches a relatively static elevation of about 760 m, approximately 124 m below the natural spillway elevation of 884 m on the pit perimeter. If this ultimate elevation creates a depression in the groundwater table, the Open Pit may behave as a long-term sink for groundwater in the LSA, causing bedrock groundwater to flow towards the pit from areas outside of the pit crest. The sink will be a terminal groundwater “sink” in perpetuity – strongest near the end of the operational period, when pit dewatering causes bedrock groundwater in the mine area to flow towards the Open Pit.

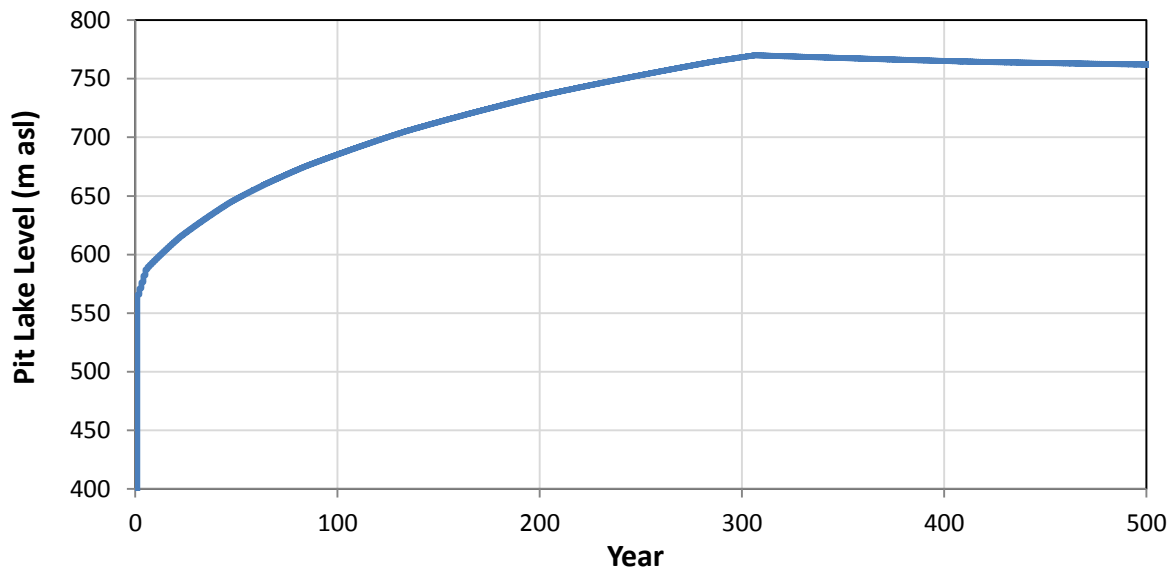


Figure 8-7. Pit lake filling curve at closure.

8.5.2. TSF

Seepage from the TSF continues through the Decommissioning and Closure and Post Closure phases, resulting in drain down of the tailings. The WBM indicates that it takes several hundred years for the tailings column to reach a generally unsaturated state.

8.6. Climate Change

Using the ClimateBC model, changes in temperature and precipitation at the mine site were predicted for 2085 and compared to 1981-2000 climate normals. The ClimateBC model is a program created by the University of British Columbia and is used to generate high resolution spatial climate data (annual, seasonal and monthly) for historical and future periods in British

Columbia. This program was developed at the Centre for Forest Conservation Genetics, Department of Forest and Conservation Sciences, University of British Columbia (<http://cfcg.forestry.ubc.ca/projects/climate-data/climatebcwna/>).

The program generates monthly data for various reference periods, and calculate seasonal and annual climate variables for specific locations based on latitude, longitude and elevation. The program also downscales and integrates historical (1901-2013) and future climate data sets (2020s, 2050s and 2080s) generated by various global circulation models (GCMs) from IPCC AR5. The output includes both directly calculated and derived climate variables. Methodologies are described in Wang et al. (2012).

Using the ClimateBC model, temperature and precipitation for the 1981-2010 period was compared to 2085 conditions. For the latter, results from sixteen GCMs were averaged for the greenhouse gas emission scenario RCP 4.5 to predict future climate conditions at the mine site. Emission scenario RCP 4.5 assumes that anthropogenic greenhouse gas emissions peak around 2040 and then decline.

Figure 8-8 shows the predicted increase in maximum, minimum and average temperatures in 2085 compared to the climate normals (1981-2010). July is expected to have the highest temperature increase for the 2085 predictions, with an increase of 3°C to 4.0°C, while January is predicted to have the lowest increase in maximum temperature of 1.0°C. Temperature predictions for 2085 suggest seasonal mean maximum temperatures could increase by an average of 1.8°C during the Winter, 3.1°C during the Spring, 3.8°C during the Summer and 2.4°C during the Autumn months compared to the seasonal mean maximum temperatures for the climate normal (1981-2010).

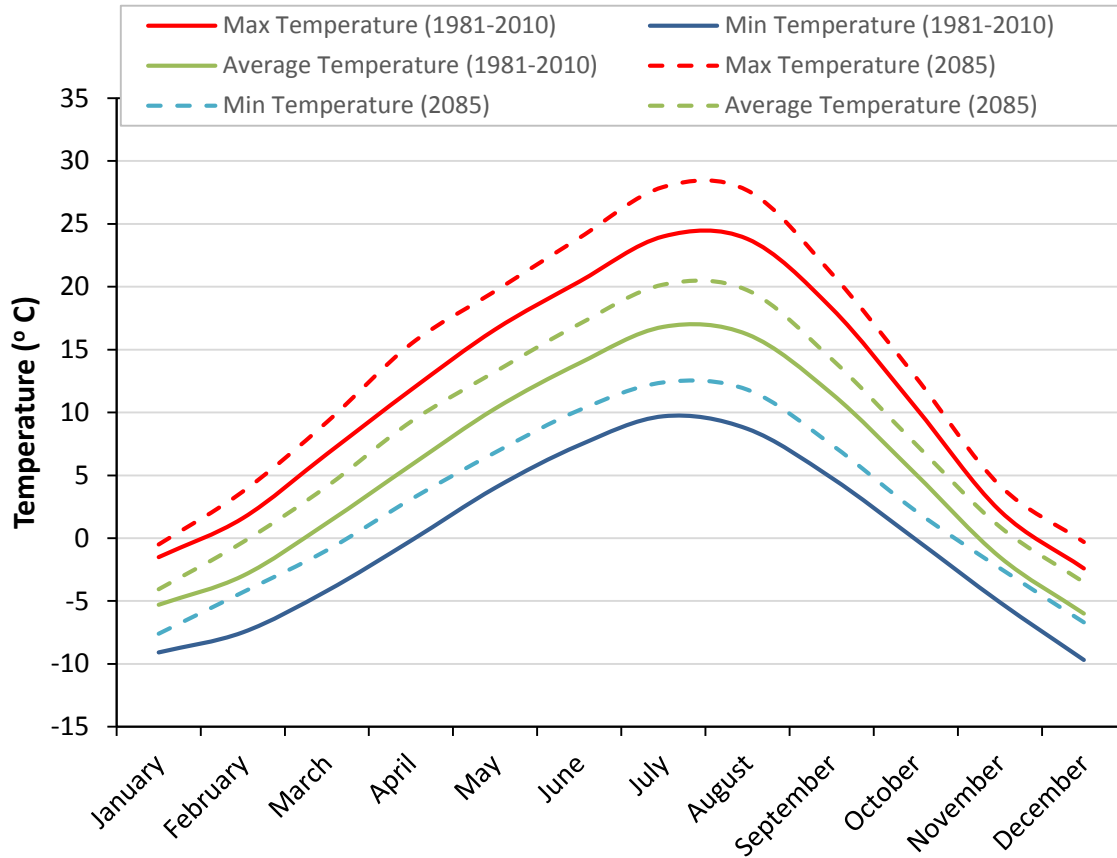


Figure 8-8. ClimateBC results showing estimated seasonal normal temperatures (1981-2010) and predicted monthly temperatures in 2085.

Predicted monthly changes in precipitation between the climate normal and 2085 are shown in Table 8-10 and Figure 8-9. June and July predictions show the most significant decrease in precipitation, 10.6 mm in July, while the most significant increase in predicted precipitation, 13.4 mm, is expected in December.

In general, the predicted increase in temperature suggests higher evapotranspiration losses in the summer, less precipitation in the form of snow, and an earlier onset of snowmelt. Combined these factors could result in a decrease in annual runoff at the mine site, which is strongly dependent on snow accumulation and snowmelt. Conversely, winter precipitation is expected to increase slightly, which could partially offset a potential reduction in runoff.

Table 8-10. Predicted monthly changes in precipitation between climate normals (1981-2010) and 2085.

Month	Monthly Change in Precipitation between Normal (1981-2010) and 2085 (mm)
January	6.1
February	4.3
March	-1.6
April	2.6
May	-1.4
June	-8.1
July	-10.6
August	-4.6
September	-4.3
October	-0.8
November	1.4
December	13.4
Total	-3.6

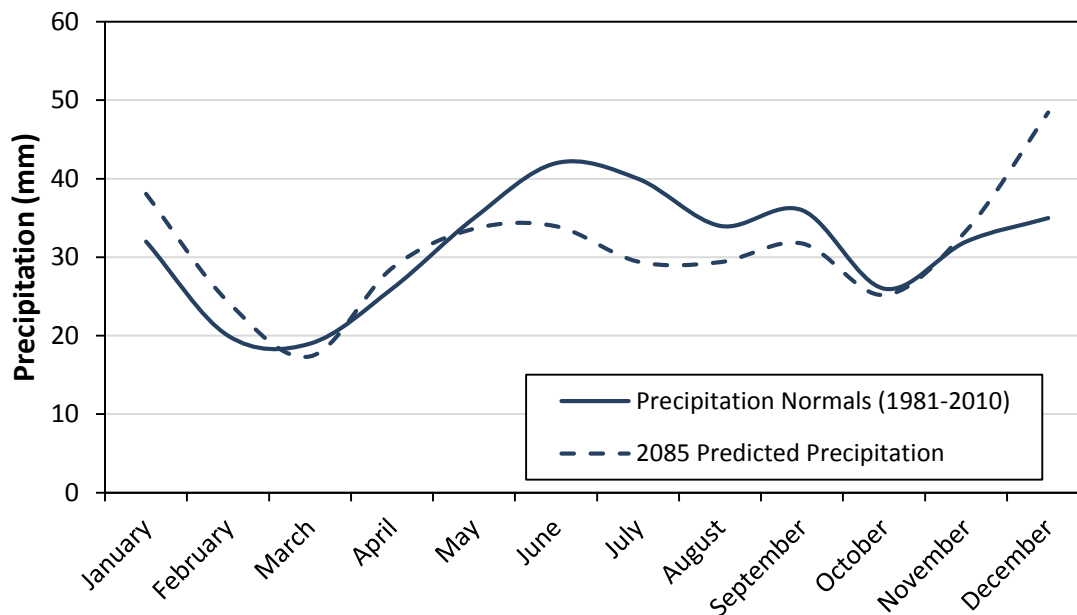


Figure 8-9. ClimateBC results showing seasonal normal temperatures (1981-2010) and predicted seasonal temperatures in 2085.

9.0 LOW FLOWS

9.1. Trend Analysis

One of the requirements of the AIR is the completion of a trend analysis to determine if low flows are increasing or decreasing over time. As noted in Section 5.4 and BGC (2015c), there are insufficient streamflow data at site to conduct a trend analysis. Moreover, subsurface conditions are such that low streamflows do not report to surface at these site stations. This was one of the primary drivers for the installation of hydrometric station PC02.1 in June 2015 (Drawing 05).

Station PC02.1 is located the furthest downstream on Peterson Creek and it receives contributing flows from all the other Project gauging stations. This station was installed in June 2015 with the intent of monitoring baseflows in Peterson Creek (Lower) during periods when Jacko Lake is not spilling or flows are being released from the low level outlet. During periods of low flow, there is typically no surface flow at PETER, due to flow through the subsurface aquifer. However, station PC02.1 is located within a zone of groundwater discharge and it is expected that baseflows can be monitored here.

As such, a trend analysis was conducted using regional WSC stations. As part of the baseline analysis, Knight Piésold (2013) correlated the JACINF daily streamflow data with concurrent data from a number of regional WSC hydrometric stations. These station locations are shown in Drawing 15, while station information is provided in Table 9-1.

Four of these stations were selected for trend analysis. These are:

- Salmon River above Salmon Lake (08LE075);
- Criss Creek near Savona (08LF007);
- Deadman River above Criss Creek (08LF027); and
- Cuichon Creek above Tunkwa Lake Diversion (08LG056).

Two of these stations (Deadman River and Salmon River) show a statistical increasing trend for the annual 7-day low flow (Q7), while the other two stations do not (Cuichon Creek and Criss Creek). Annual 7-day low flows for these stations are shown in Figures 9-1 to 9-4 for the period of record. Linear trend lines are shown by the dashed lines. The trend observed at the Deadman River and Salmon River is significant at the 95th percentile.

These results suggest that an increasing trend in low flows could also be occurring on Peterson Creek, although the trend is not observed at all regional stations. It should also be recognized that regulation of Peterson Creek flows at Jacko Lake complicates any such trend or interpretation thereof.

Table 9-1. Regional hydrometric stations (Knight Piésold, 2013).

ID	Station Name	Period of Record	Lat	Long	Distance from Site (km)	Drainage Area (km²)	Median Elevation (m)	Mean Annual Runoff (mm)
08LE075	Salmon River Above Salmon Lake	1965 – 2002	50.288	-119.956	57	143	1350	165
08LF007	Criss Creek near Savona	1912 – present	50.883	-120.965	41	479	1190	110
08LF027	Deadman River at Criss Creek	1913 – present	50.901	-120.974	42	878	1190	41
08LG041	Guichon Creek at Outlet of Merrit Lake	1933 – present	50.362	-120.809	38	871	1369	26
08LG049	Nicola River above Nicola Lake	1915 – present	50.197	-120.408	52	1,500	1230	87
08LG056	Guichon Creek Above Tunkwa Lake Diversion	1967 - present	50.608	-120.911	27	78	1340	56

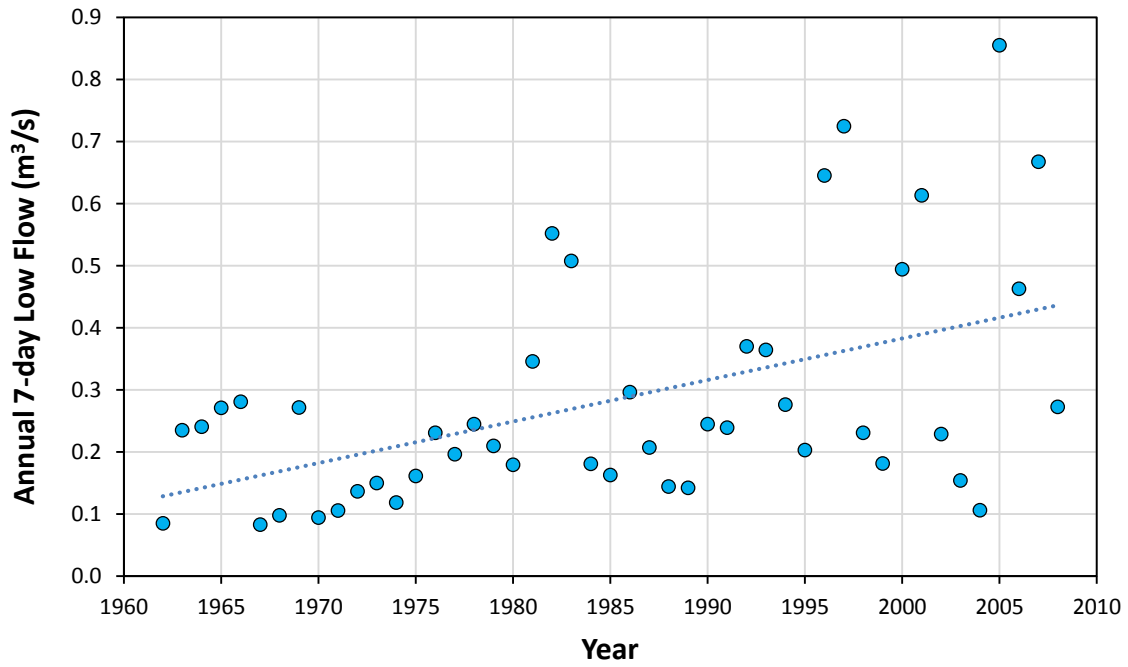


Figure 9-1. Annual 7-day low flows at WSC station Deadman River.

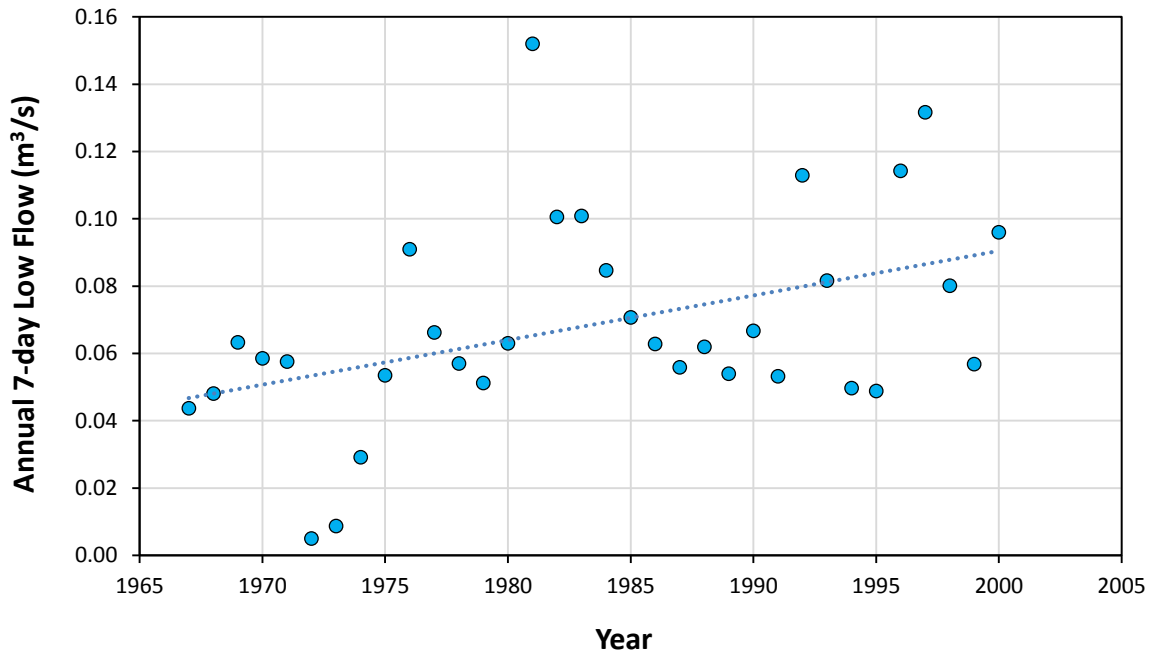


Figure 9-2. Annual 7-day low flows at WSC station Salmon River.

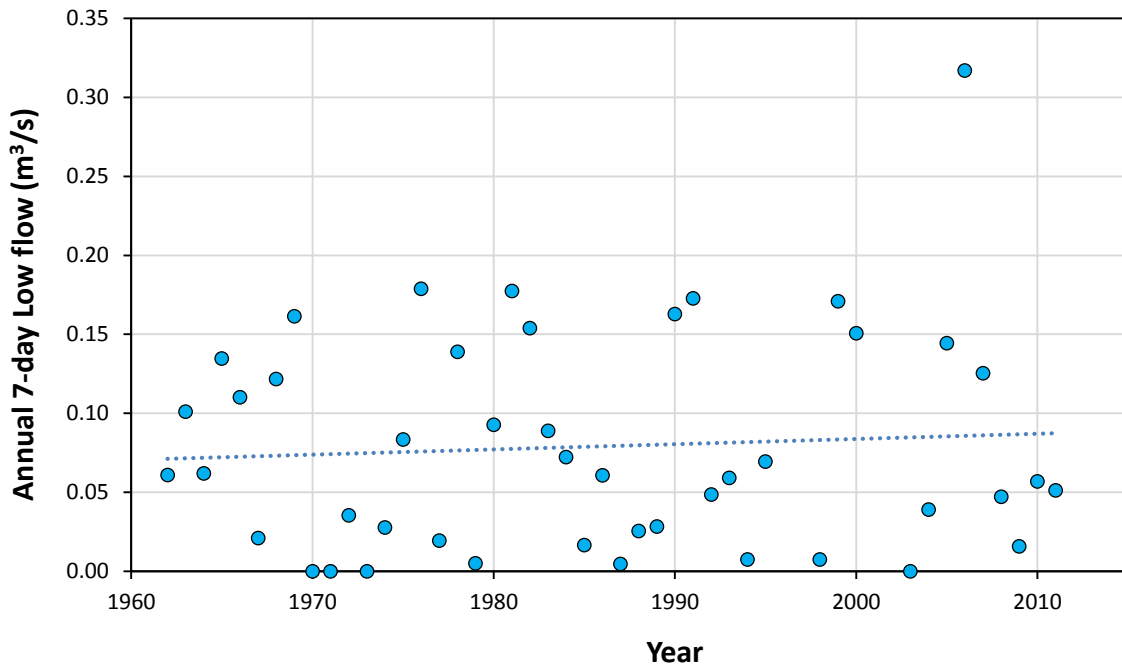


Figure 9-3. Annual 7-day low flows at WSC station Criss Creek.

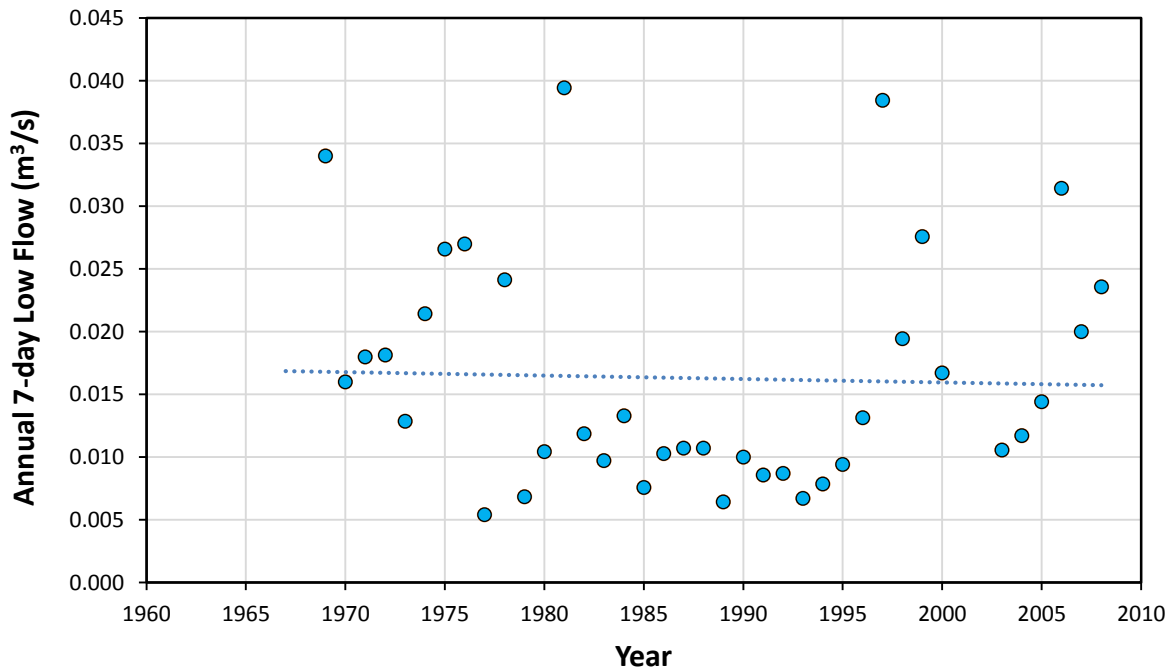


Figure 9-4. Annual 7-day low flows at WSC station Guichon Creek.

9.2. Regional Frequency Analysis

A regional frequency analysis of annual 7-day low flows was also conducted for application to Peterson Creek (Lower). The regional analysis was completed using the Criss Creek and Deadman River WSC stations, as well as the WSC station on Cherry Creek (see Section 5.5 and Drawing 08). Inclusion of the Guichon Creek and Salmon River stations resulted in low flow estimates for Peterson Creek, which were judged to be significantly over-estimated. Results of the low flow analysis are summarized in Table 9-2 below for return periods of 2, 5, 10 and 20 years. A power relation of the form $Q_7 = 10^b A^m$ (where A = drainage area) was used for derivation of the regional relation.

Table 9-2. Regional 7-day low flow frequency analysis.

Station	Area (km ²)	7Q2 (L/s)	7Q5 (L/s)	7Q10 (L/s)	7Q20 (L/s)
Criss Creek near Savona	490	53	17	8	4
Deadman River above Criss Creek	862	220	126	103	93
Cherry Creek below Pendleton Creek	143	11	8	8	7
m	-	1.60	1.39	1.19	1.13
b	-	-5.46	-5.18	-4.82	-4.80
r ²	-	0.97	0.80	0.55	0.38
Peterson Creek (Lower) – PC02	106	6.2	4.2	4.0	3.1

The validity of applying this regional relation to Peterson Creek (Lower) can be questioned given the upstream regulation at Jacko Lake. An alternative approach would be to pro-rate the Cherry Creek results to Peterson Creek by drainage area given their close proximity and recognizing that Cherry Creek is also highly regulated, although the dataset at Cherry Creek is limited (n=15) and the source of regulation is further removed than at Peterson Creek (Lower).

10.0 CLOSURE

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Yours sincerely,

BGC ENGINEERING INC.
per:

Hamish Weatherly, M.Sc., P.Geo.
Principal Hydrologist

Reviewed by:

Trevor Crozier, M.Sc., P.Eng.
Principal Hydrogeologist

HW/TC/ma

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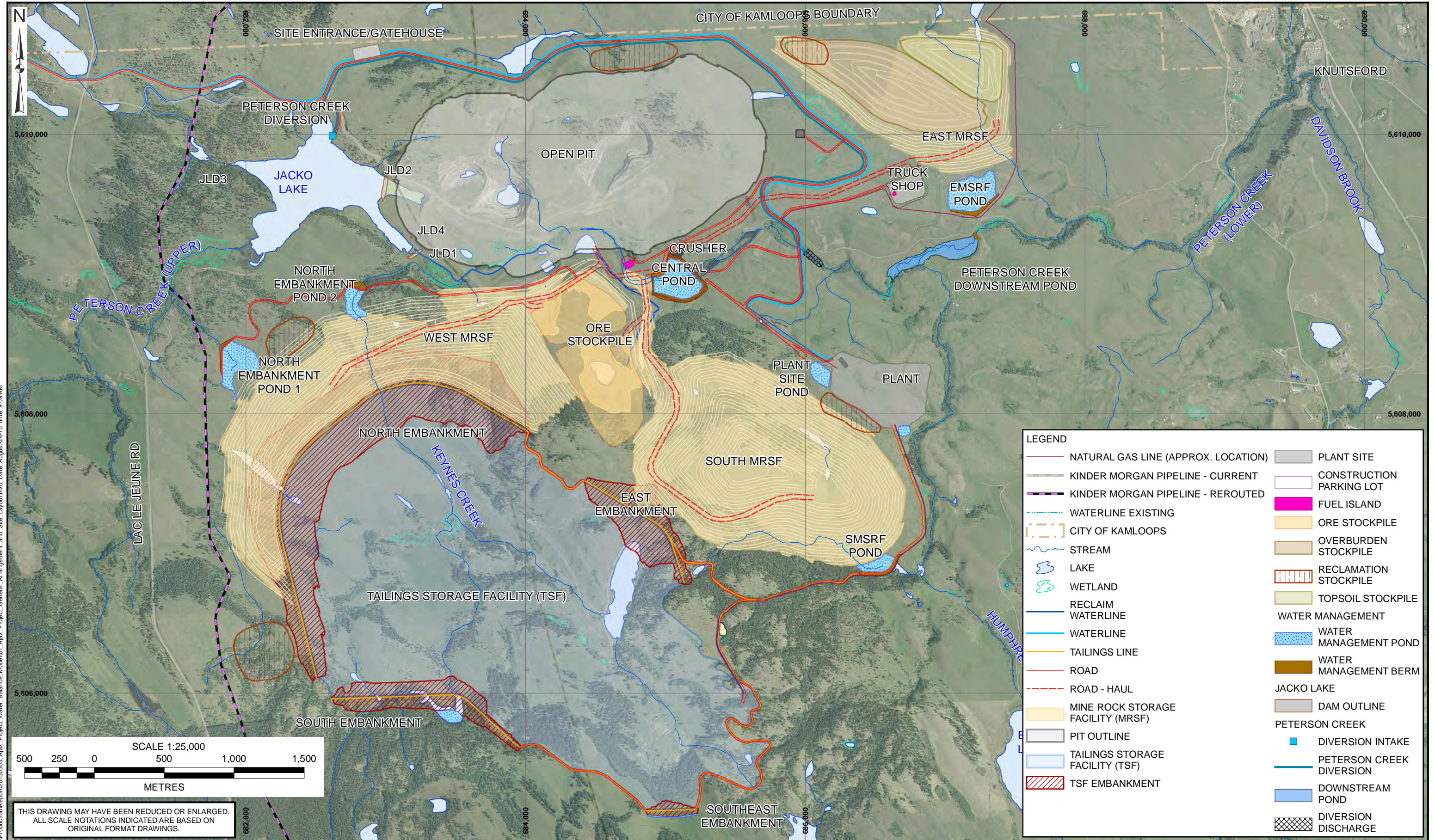
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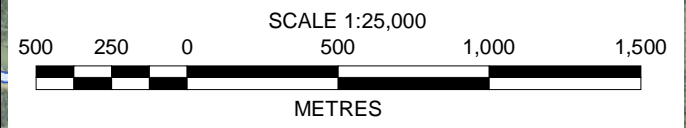
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DRAWINGS



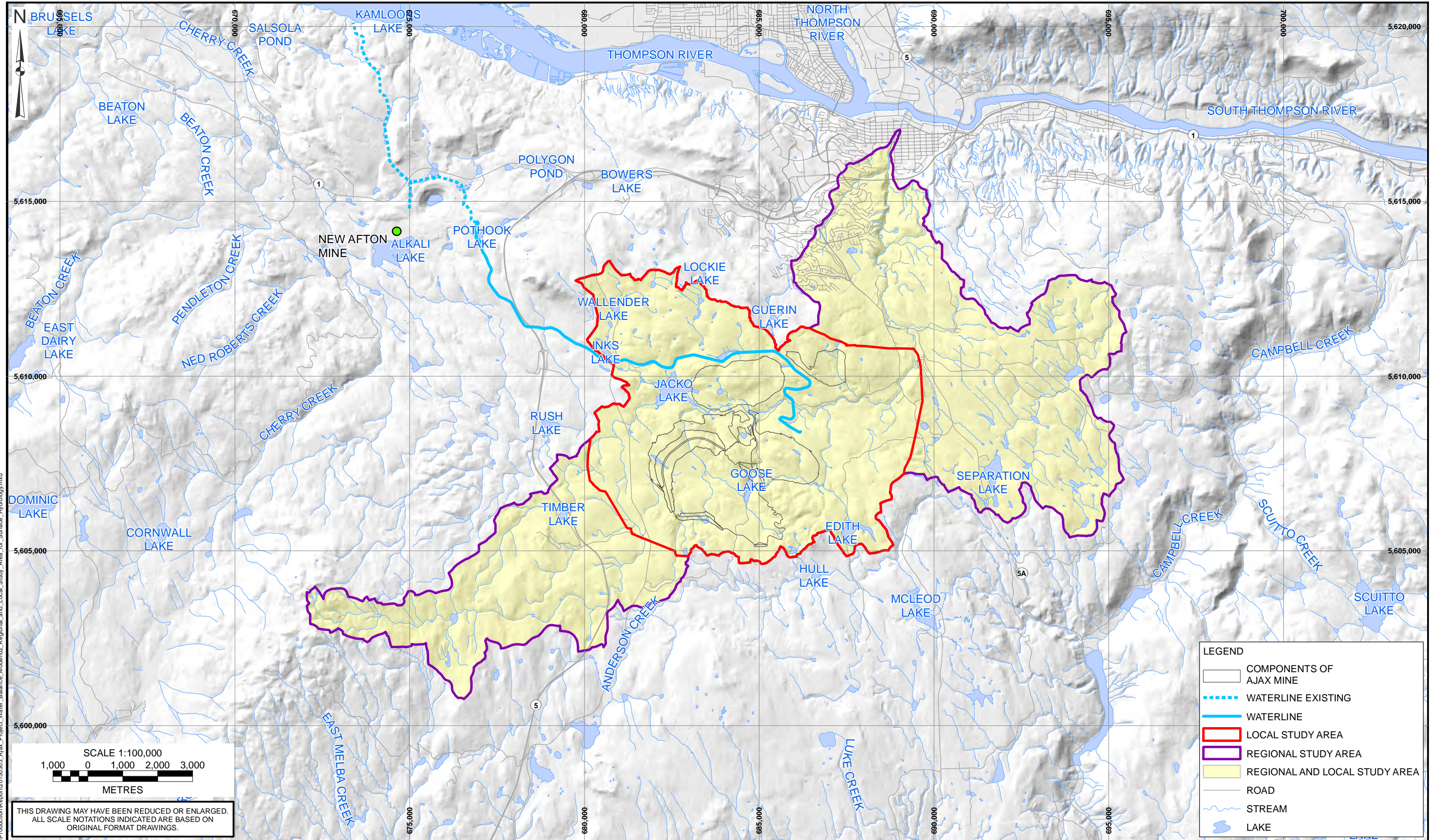
LEGEND	
	NATURAL GAS LINE (APPROX. LOCATION)
	KINDER MORGAN PIPELINE - CURRENT
	KINDER MORGAN PIPELINE - REROUTED
	WATERLINE EXISTING
	CITY OF KAMLOOPS
	STREAM
	LAKE
	WETLAND
	RECLAIM WATERLINE
	WATERLINE
	TAILINGS LINE
	ROAD
	ROAD - HAUL
	MINE ROCK STORAGE FACILITY (MRSF)
	PIT OUTLINE
	TAILINGS STORAGE FACILITY (TSF)
	TSF EMBANKMENT
	PLANT SITE
	CONSTRUCTION PARKING LOT
	FUEL ISLAND
	ORE STOCKPILE
	OVERBURDEN STOCKPILE
	RECLAMATION STOCKPILE
	TOPSOIL STOCKPILE
	WATER MANAGEMENT
	WATER MANAGEMENT POND
	WATER MANAGEMENT BERM
	JACKO LAKE
	DAM OUTLINE
	PETERSON CREEK
	DIVERSION INTAKE
	PETERSON CREEK DIVERSION
	DOWNSTREAM POND
	DIVERSION DISCHARGE



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		<p>DATE: AUG 2015</p>		<p>TITLE: AJAX PROJECT GENERAL ARRANGEMENT AND SITE LAYOUT</p>
		<p>DRAWN: MIB</p>		<p>PROJECT No.: 1125007</p>
		<p>CHECKED: HW</p>		<p>01</p>
<p>APPROVED: TWC</p>	<p>CLIENT: KGHM AJAX MINING INC.</p>			

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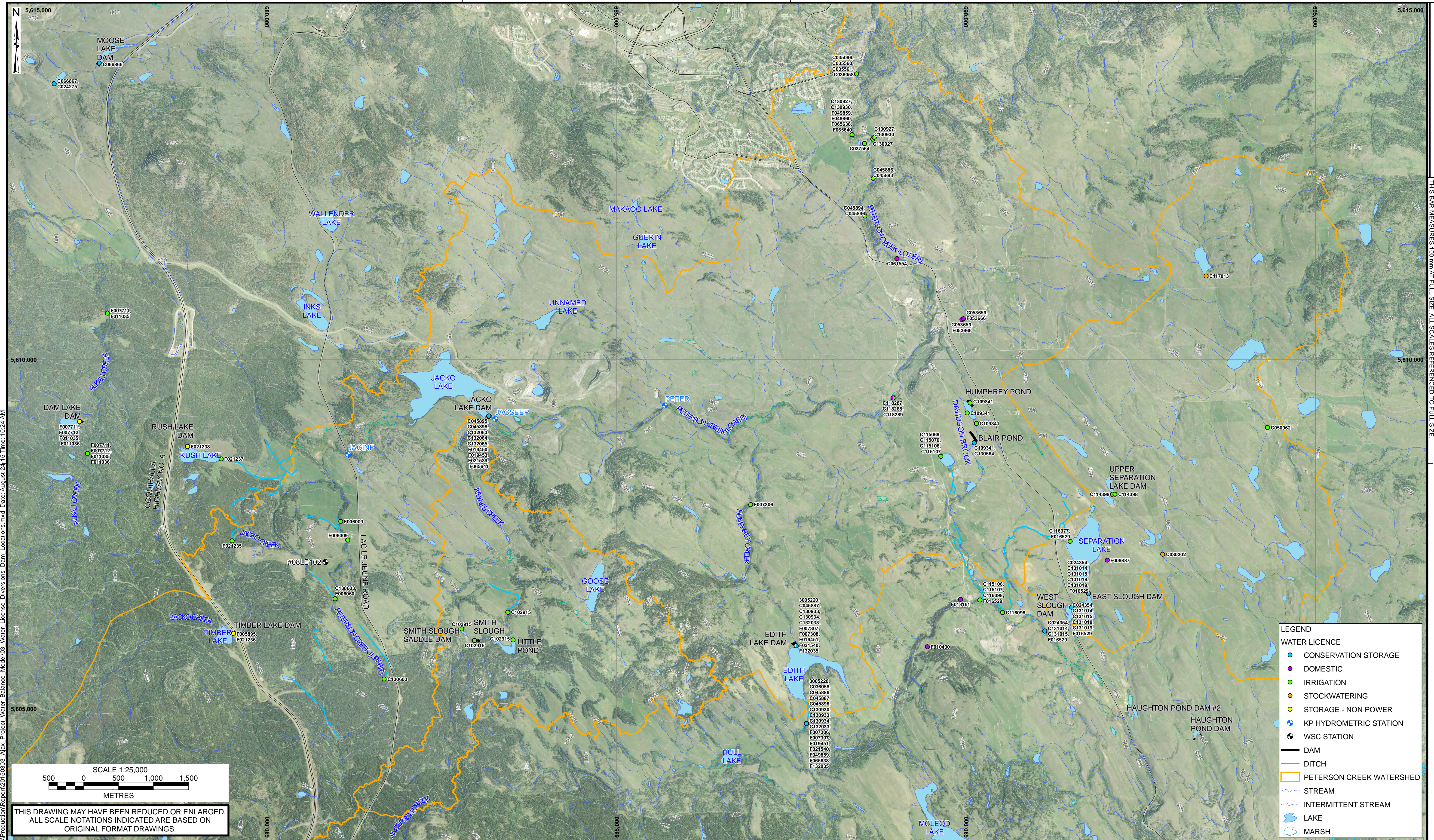
BGC ENGINEERING INC.
 AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
 KGHM AJAX MINING INC.

LEGEND

- COMPONENTS OF AJAX MINE
- WATERLINE EXISTING
- WATERLINE
- LOCAL STUDY AREA
- REGIONAL STUDY AREA
- REGIONAL AND LOCAL STUDY AREA
- ROAD
- STREAM
- LAKE

PROJECT: AJAX PROJECT - WATER BALANCE MODEL	
TITLE: REGIONAL AND LOCAL STUDY AREA	
PROJECT No.:	DWG No.:
1125007	02



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THIS BAR MEASURES 100 mm AT FULL SIZE. ALL SCALES REFERENCED TO FULL SIZE.



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 3. BASE TOPOGRAPHIC DATA BASED ON CONTOURS COMPILED FROM KAM, TRIM AND GEOBASE, DATED MAY 2012. CONTOUR INTERVAL IS 20 m.
 4. PROJECTION IS NAD 1983 UTM ZONE 10N.
 5. WATER LICENCE POINTS FROM DATA BC.
 6. WATER COMPILED FROM KGHM, CITY OF KAMLOOPS AND NATIONAL HYDRO NETWORK INFORMATION.
 7. ORTHOPHOTO PROVIDED BY KAM FROM EAGLE MAPPING AERIAL PHOTOGRAPHY DATED JUNE 26, 2006, PUBLISHED SEPTEMBER 29, 2006.

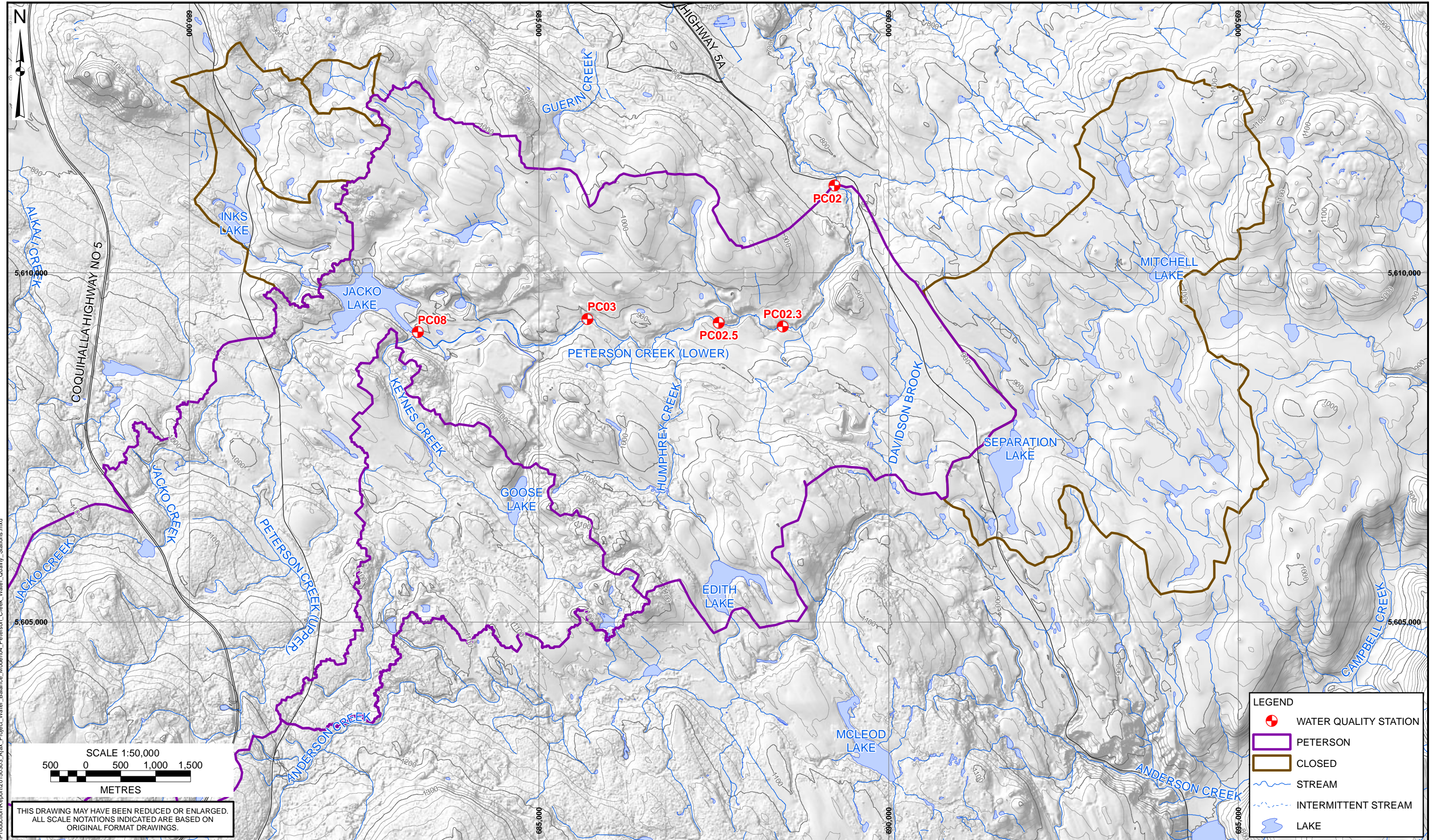
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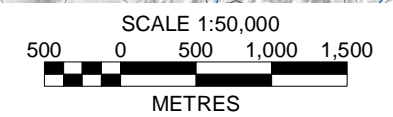
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PROJECT:	AJAX PROJECT - WATER BALANCE MODEL	
TITLE:	WATER LICENSES, DIVERSIONS AND DAM LOCATIONS	
PROJECT No.:	1257007	DWG No.:
		03



LEGEND

- WATER QUALITY STATION
- PETERSON
- CLOSED
- STREAM
- INTERMITTENT STREAM
- LAKE



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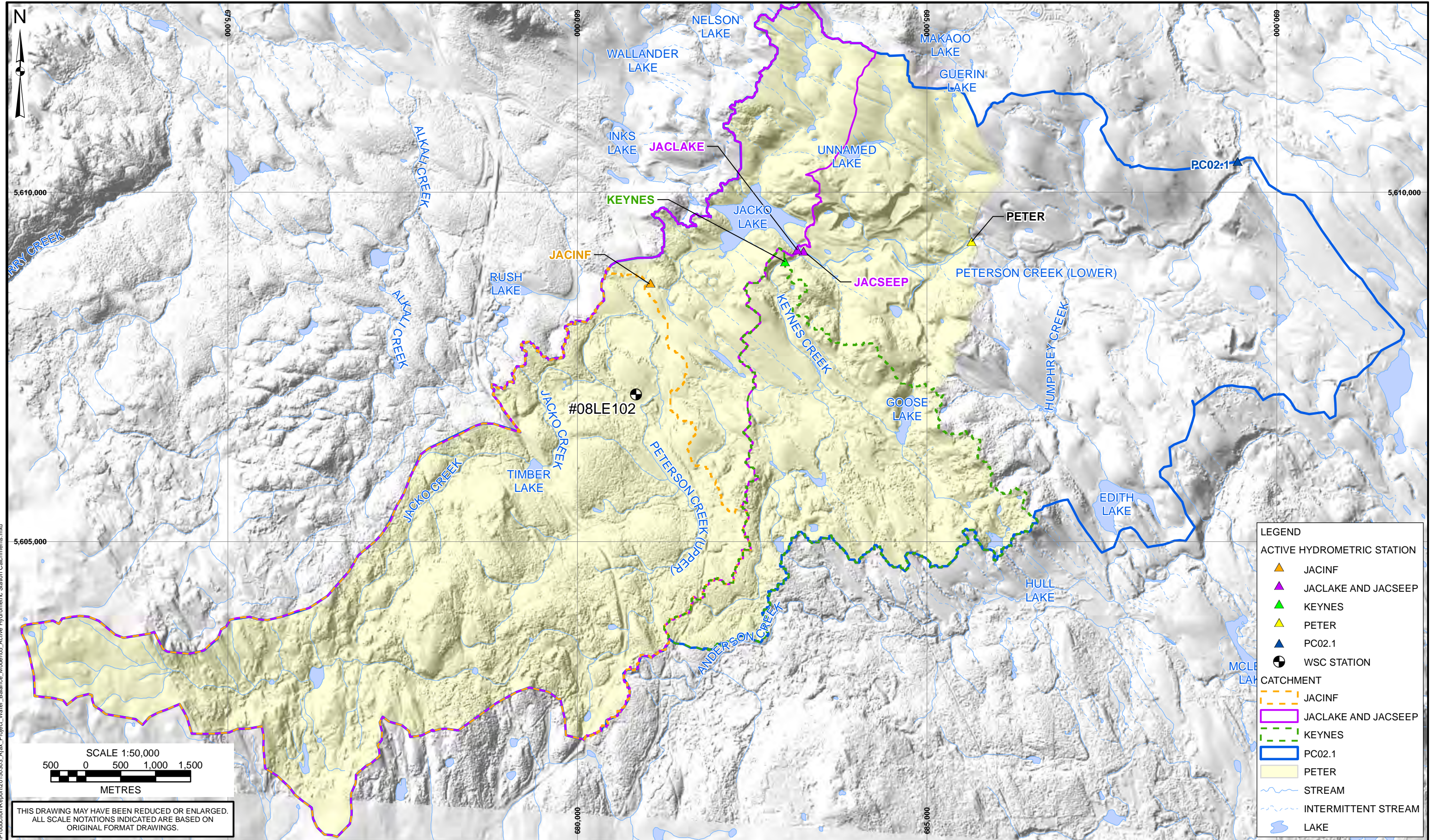
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CLIENT:
KGHM AJAX MINING INC.

PROJECT:	AJAX PROJECT - WATER BALANCE MODEL	
TITLE:	PETERSON CREEK WATER QUALITY STATIONS	
PROJECT No.:	1125007	DWG No.: 04

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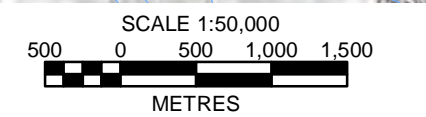
LEGEND

ACTIVE HYDROMETRIC STATION

- ▲ JACINF
- ▲ JACLAKE AND JACSEEP
- ▲ KEYNES
- ▲ PETER
- ▲ PC02.1
- ⊗ WSC STATION

CATCHMENT

- JACINF
- JACLAKE AND JACSEEP
- KEYNES
- PC02.1
- PETER
- STREAM
- - - INTERMITTENT STREAM
- LAKE



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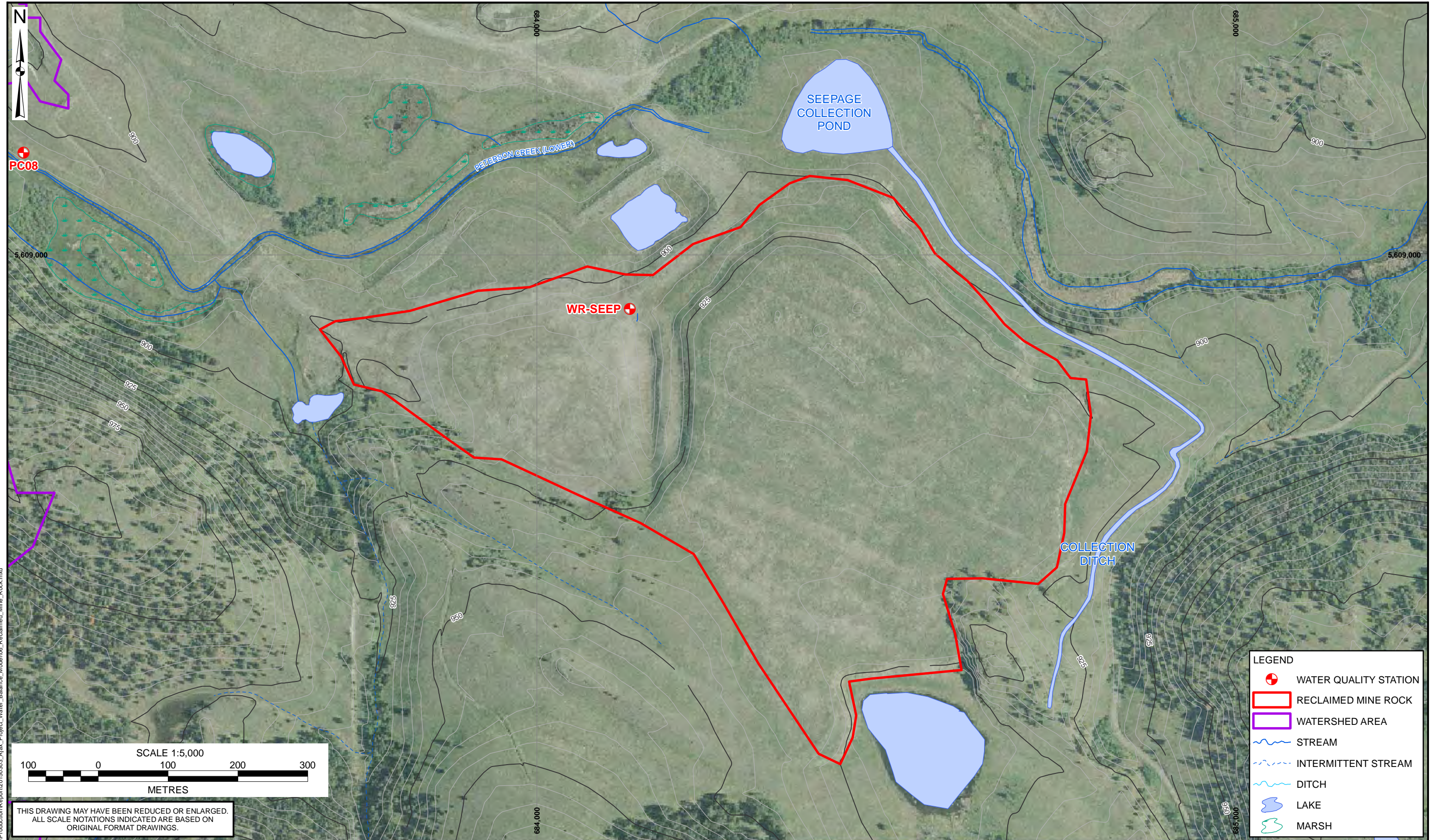
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CHECKED:	HW
APPROVED:	TWC

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CLIENT:
KGHM AJAX MINING INC.

PROJECT: AJAX PROJECT - WATER BALANCE MODEL	
TITLE: ACTIVE HYDROMETRIC STATION CATCHMENTS	
PROJECT No.:	DWG No.:
1125007	05

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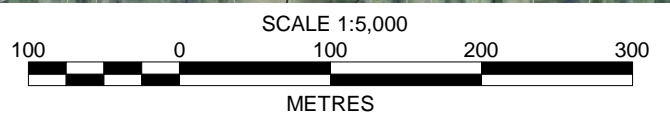
PC08

WR-SEEP

SEEPAGE COLLECTION POND

PETERSON CREEK (LOWER)

COLLECTION DITCH



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LEGEND	
	WATER QUALITY STATION
	RECLAIMED MINE ROCK
	WATERSHED AREA
	STREAM
	INTERMITTENT STREAM
	DITCH
	LAKE
	MARSH

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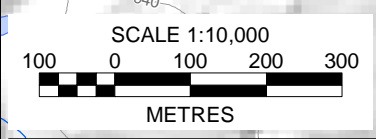
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CLIENT:
 KGHM AJAX MINING INC.

PROJECT:	AJAX PROJECT - WATER BALANCE MODEL	
TITLE:	RECLAIMED MINE ROCK	
PROJECT No.:	1125007	DWG No: 06

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LEGEND	
	GROUNDWATER MONITORING WELL
	GROUNDWATER MONITORING LOCATION WITH VWP
	STREAM
	INTERMITTENT STREAM
	LAKE

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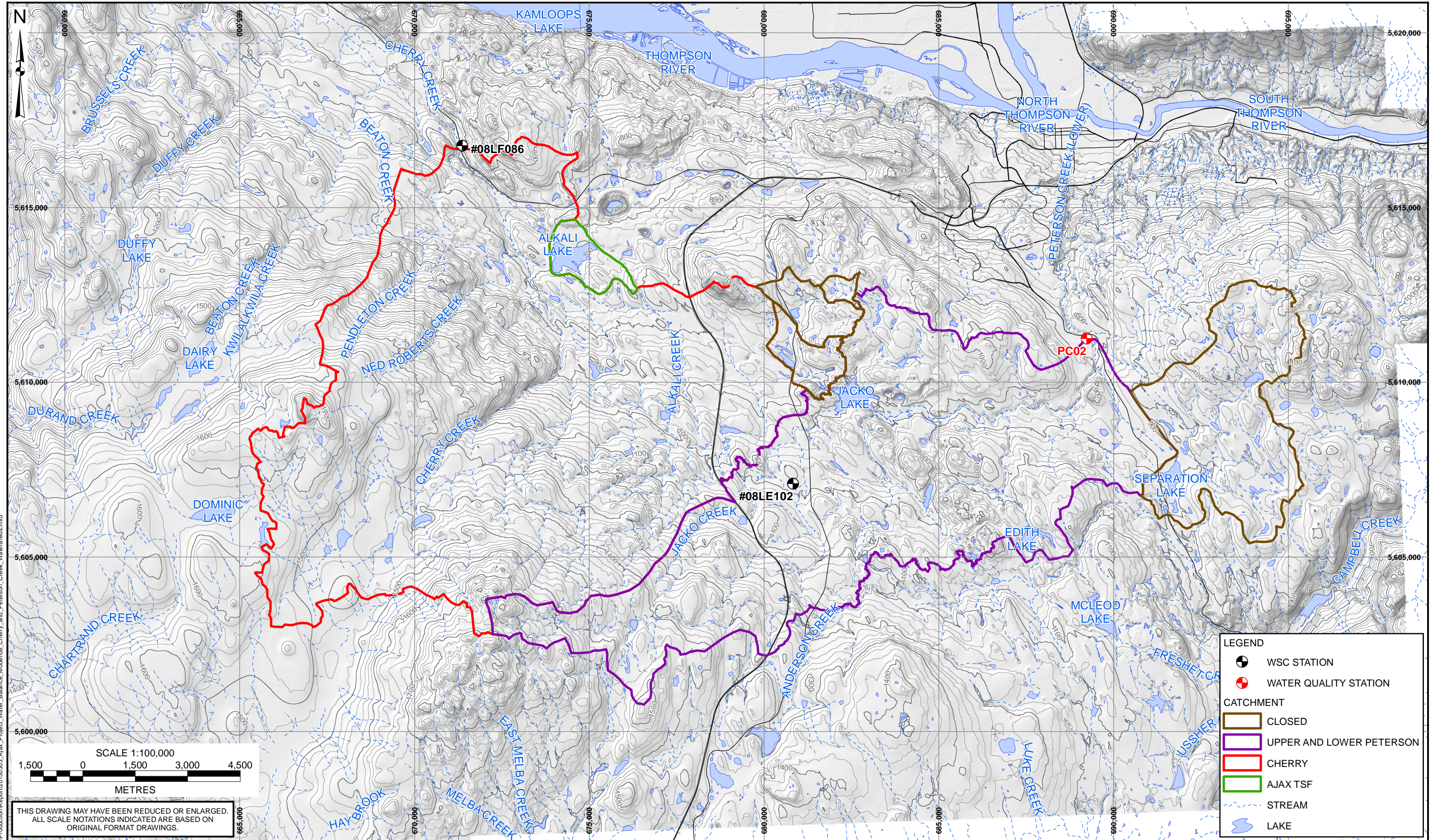
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CLIENT:
KGHM AJAX MINING INC.

PROJECT: AJAX PROJECT - WATER BALANCE MODEL	
TITLE: GROUNDWATER WELLS	
PROJECT No.: 1125007	DWG No.: 07

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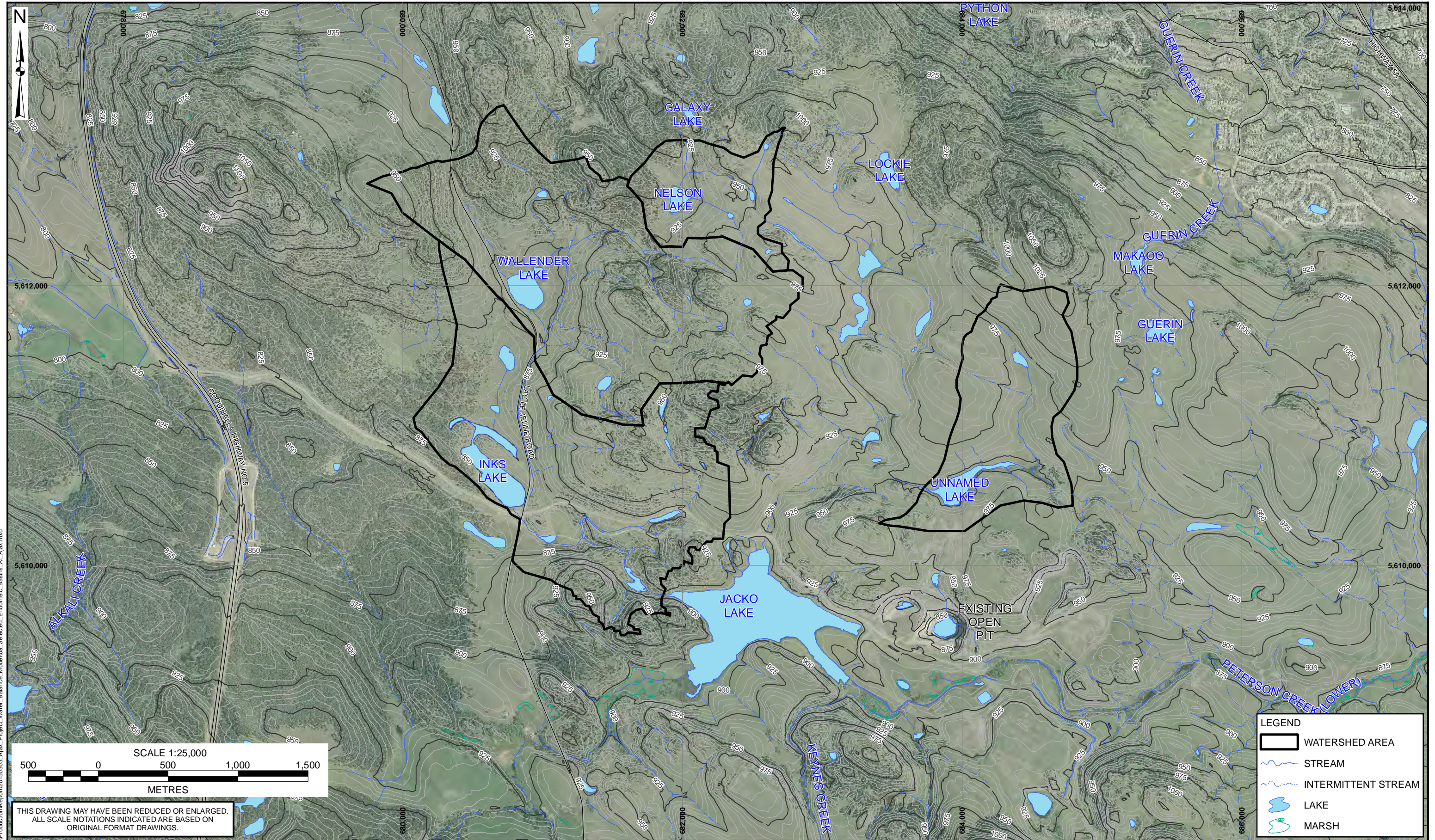
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 AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
 KGHM AJAX MINING INC.

PROJECT: AJAX PROJECT - WATER BALANCE MODEL	
TITLE: CHERRY CREEK AND PETERSON CREEK WATERSHEDS	
PROJECT No.:	DWG No.:
1125007	08



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 6. WATER COMPILED FROM KGHM, CITY OF KAMLOOPS AND NATIONAL HYDRO NETWORK INFORMATION.

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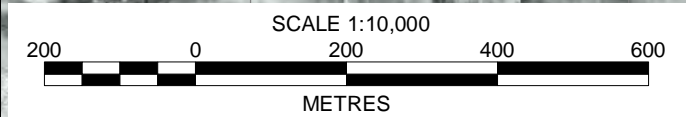
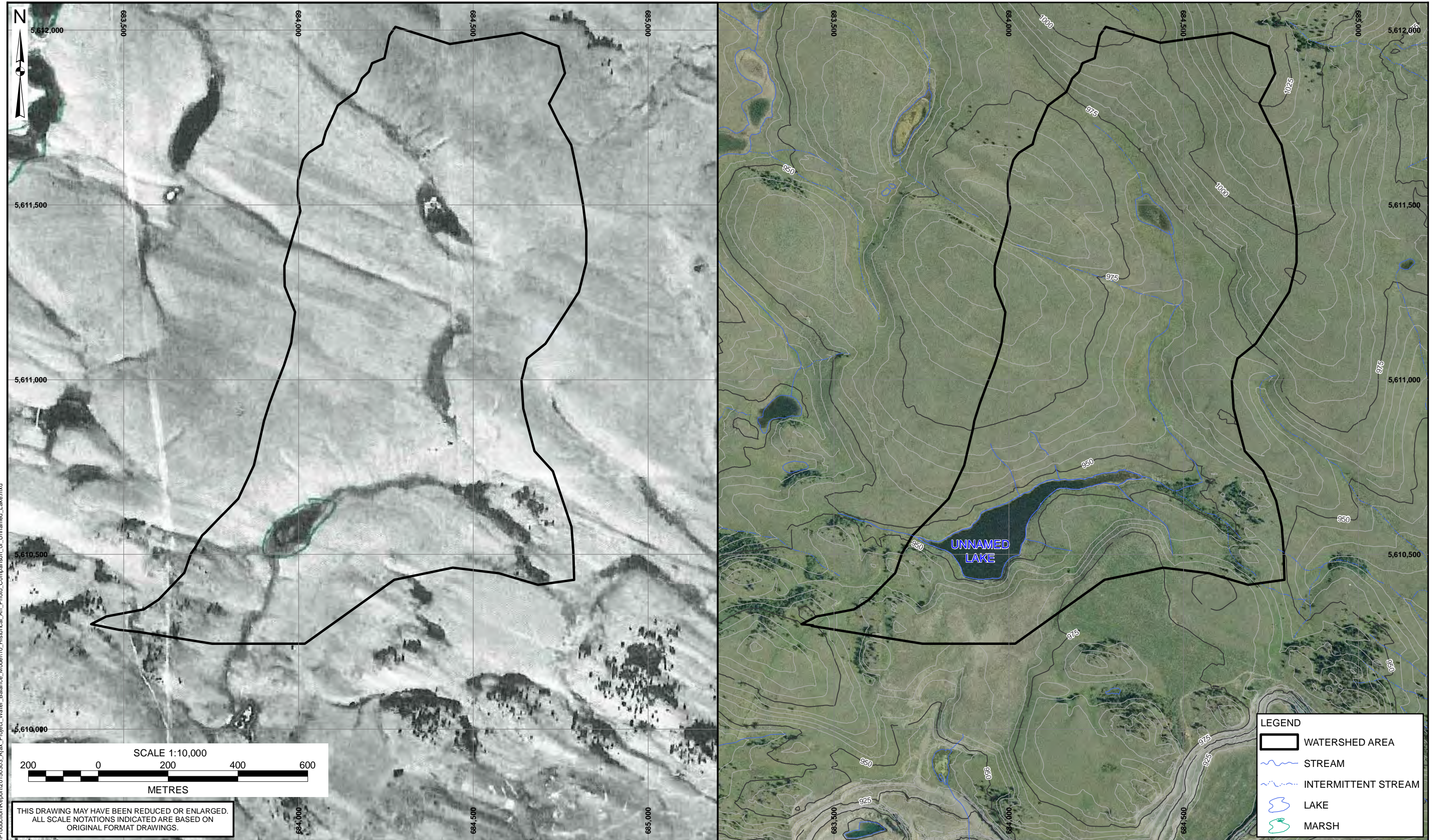
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CLIENT:
KGHM AJAX MINING INC.

PROJECT:	AJAX PROJECT - WATER BALANCE MODEL	
TITLE:	SELECTED ENDORHEIC BASINS AT AJAX	
PROJECT No.:	1125007	DWG No.: 09

LEGEND

- WATERSHED AREA
- ~ STREAM
- - - INTERMITTENT STREAM
- LAKE
- ~ MARSH

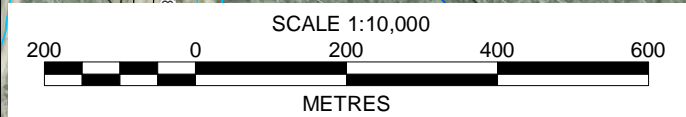
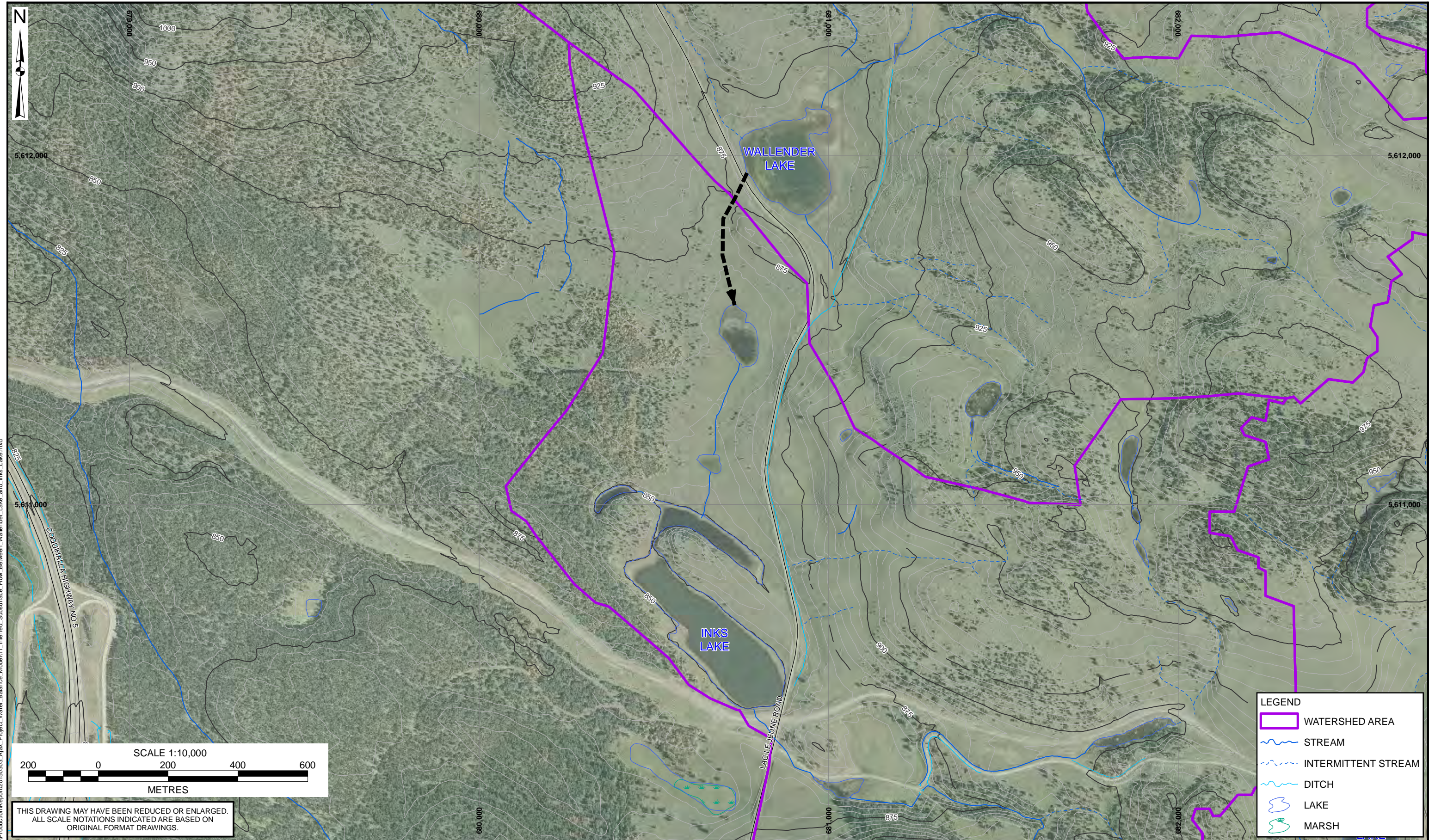


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LEGEND	
	WATERSHED AREA
	STREAM
	INTERMITTENT STREAM
	LAKE
	MARSH

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		<p>TITLE: HISTORICAL AIR PHOTO COMPARISON OF UNNAMED LAKE</p>			
		<p>PROJECT No.: 1125007</p>		<p>DWG No.: 10</p>	

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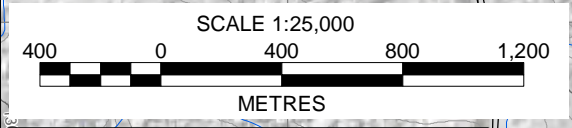
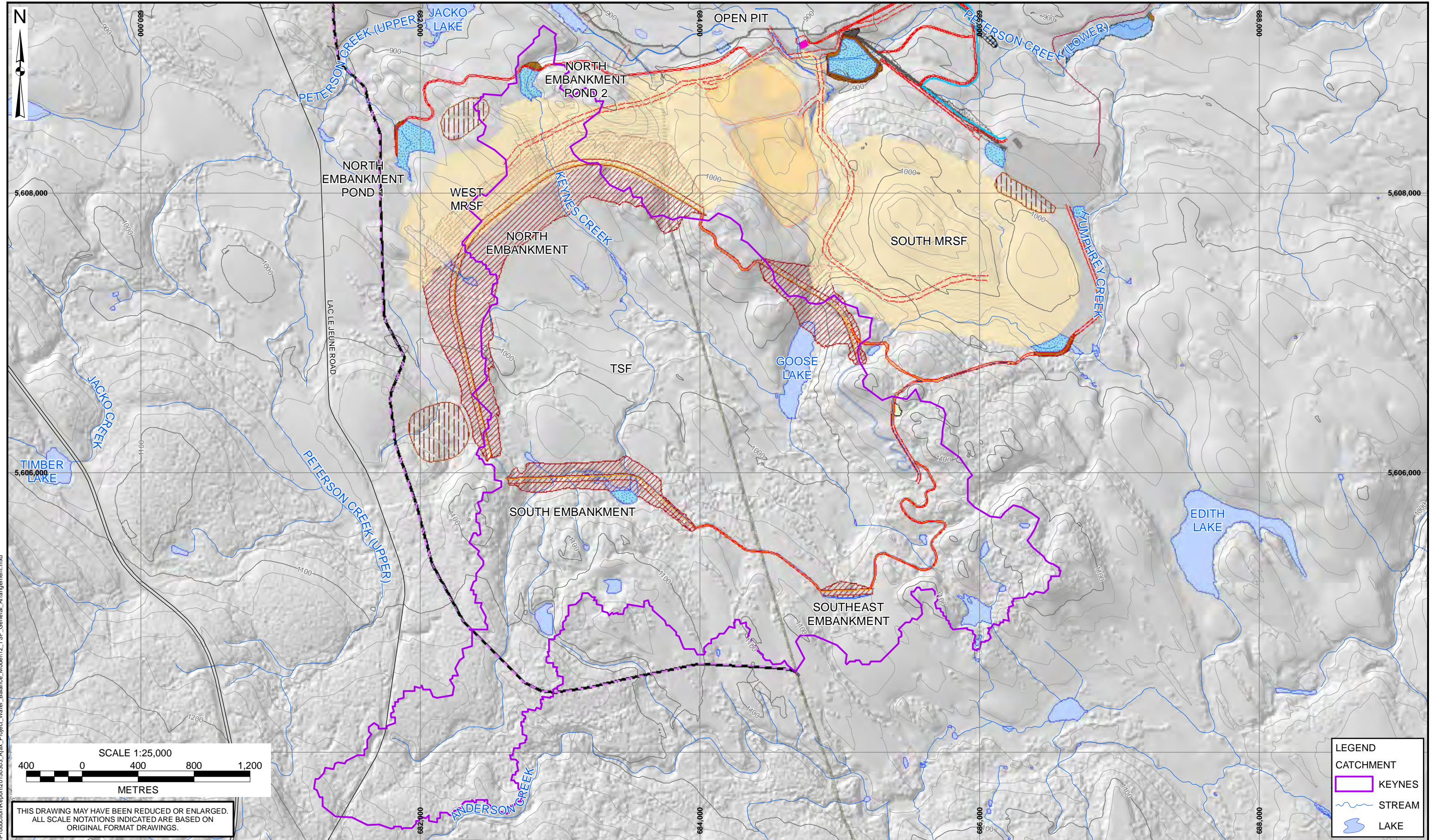


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LEGEND	
	WATERSHED AREA
	STREAM
	INTERMITTENT STREAM
	DITCH
	LAKE
	MARSH

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		DATE:	AUG 2015		TITLE:	INFERRED SUBSURFACE FLOW BETWEEN WALLENDER LAKE AND INKS LAKE		
		DRAWN:	MIB		PROJECT No.:	1125007	DWG No.:	11
		CHECKED:	HW					
		APPROVED:	TWC					

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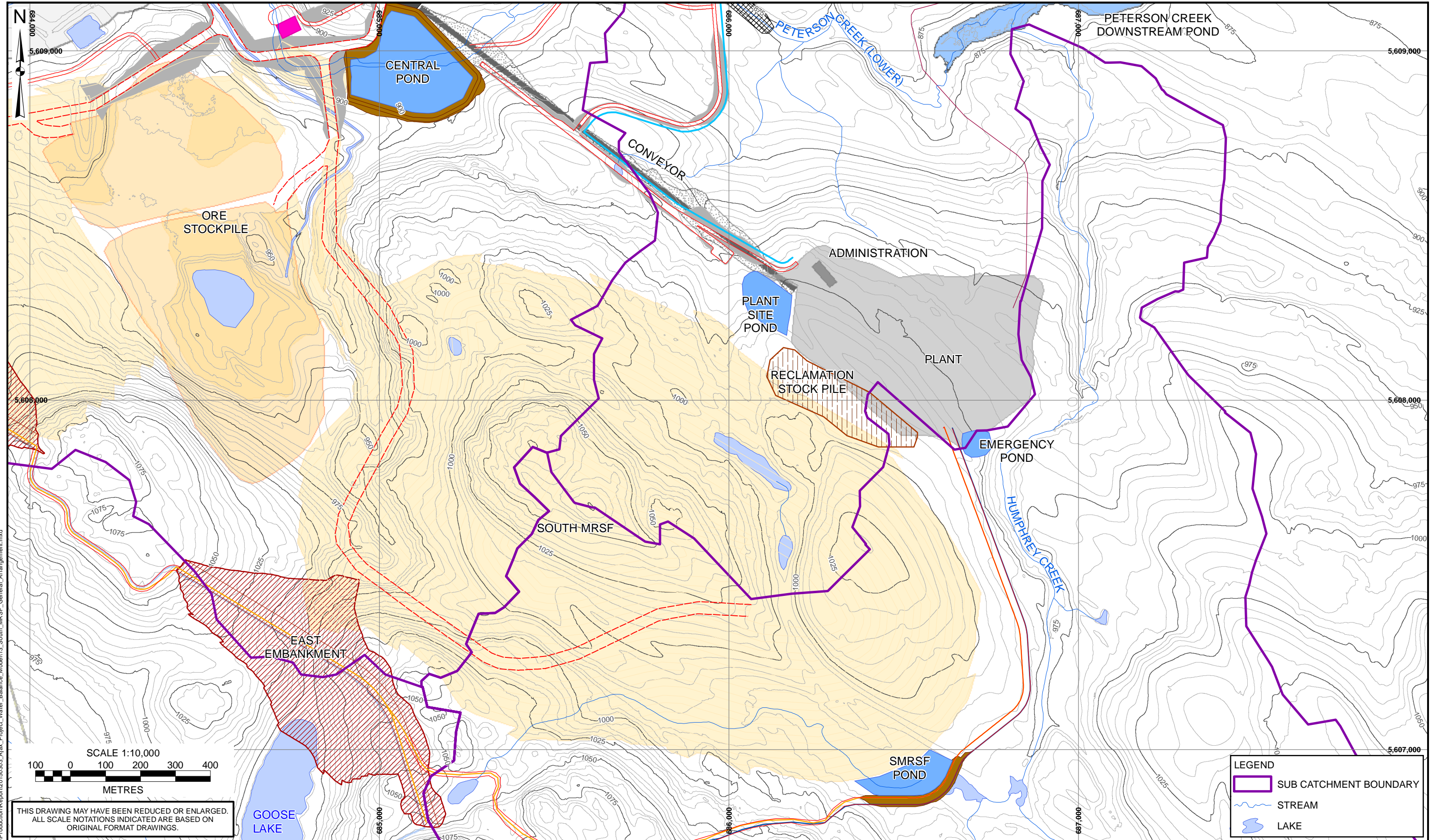
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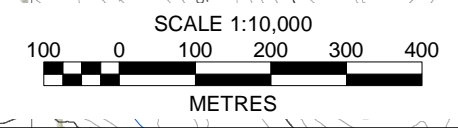
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KGHM AJAX MINING INC.

PROJECT: AJAX PROJECT - WATER BALANCE MODEL	
TITLE: TSF GENERAL ARRANGEMENT	
PROJECT No.:	DWG No.:
1125007	12



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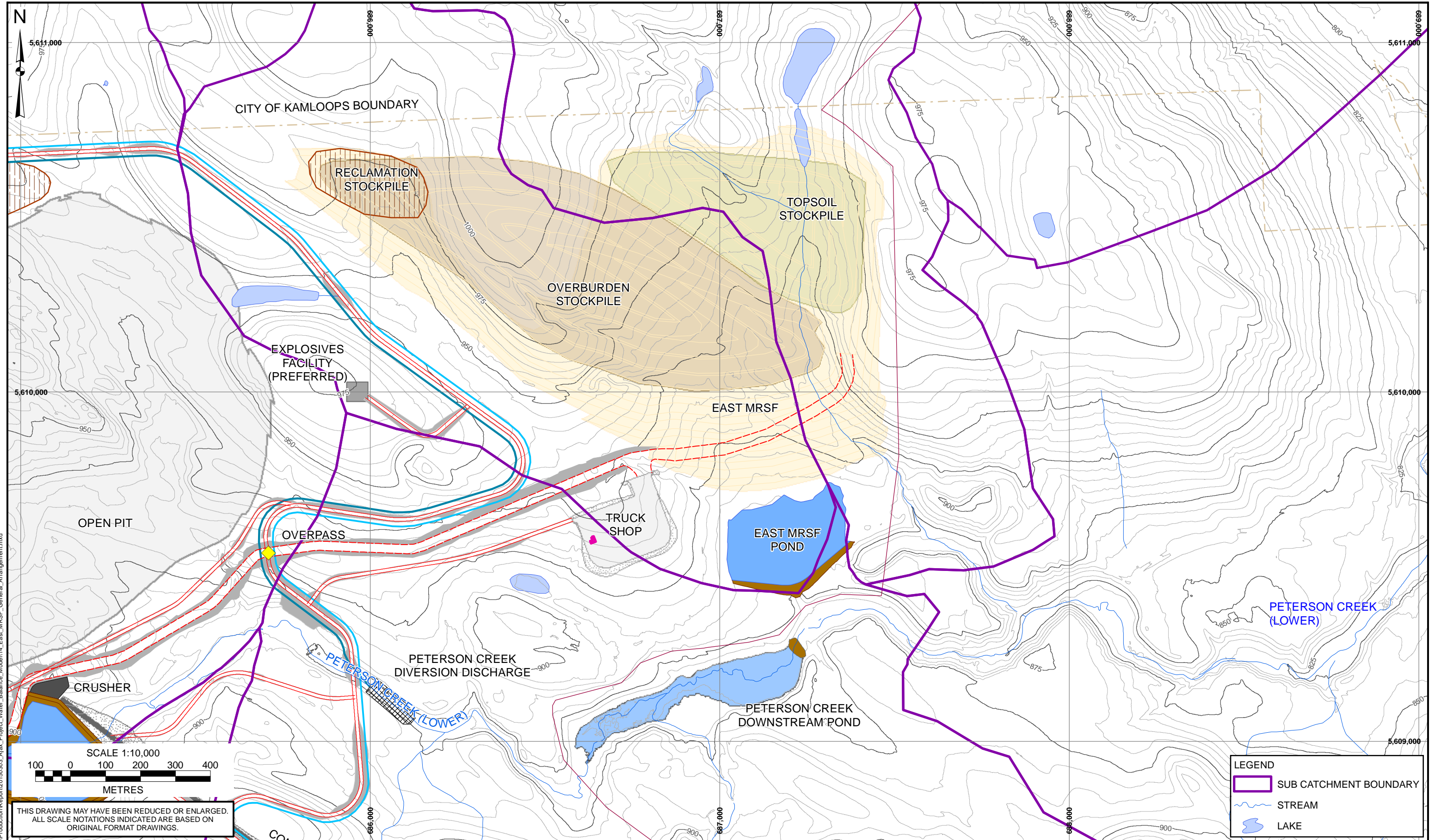
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CLIENT:
KGHM AJAX MINING INC.

PROJECT:	AJAX PROJECT - WATER BALANCE PLAN	
TITLE:	SOUTH MRSF GENERAL ARRANGEMENT	
PROJECT No.:	1125007	DWG No: 13

LEGEND

- SUB CATCHMENT BOUNDARY
- STREAM
- LAKE



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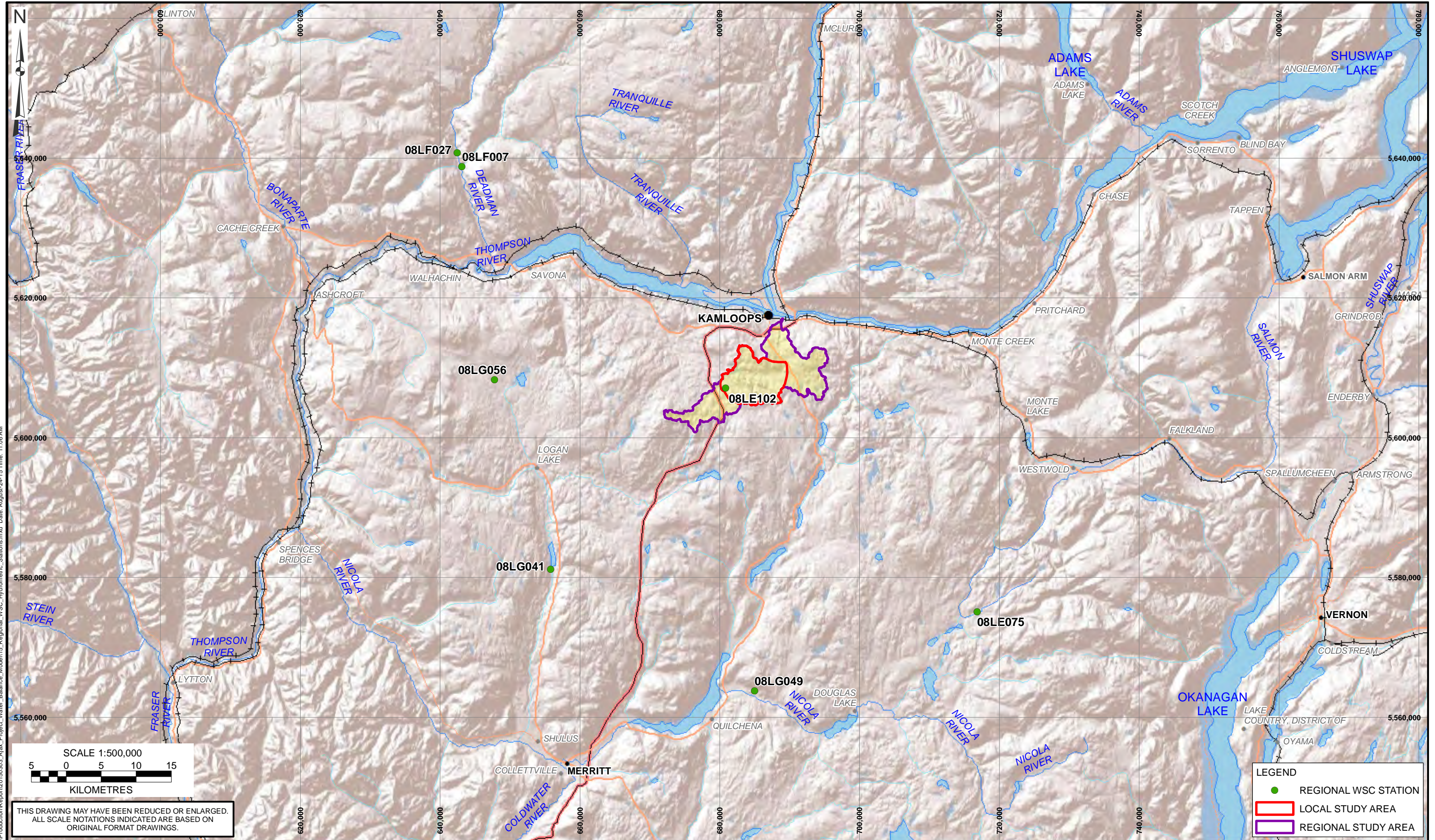
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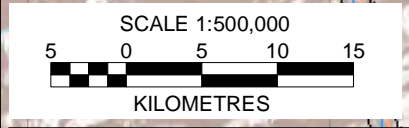
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CLIENT:
KGHM AJAX MINING INC.

PROJECT:	AJAX PROJECT - WATER BALANCE MODEL	
TITLE:	EAST MRSF GENERAL ARRANGEMENT	
PROJECT No.:	1125007	DWG No: 14



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CLIENT:
 KGHM AJAX MINING INC.

PROJECT: AJAX PROJECT - WATER BALANCE MODEL	
TITLE: REGIONAL WSC STATIONS	
PROJECT No.:	DWG No.:
1125007	15

APPENDIX A HYDRUS MODELLING

Project Memorandum

To:	KGHM Ajax Mining Inc.	Doc. No.:	1125-006-M03-2015
Attention:	Nettie Johnson	Project No.:	1125010-02
From:	Elisa Scordo	Date:	July 28, 2015
Subject:	Ajax Project EA – Mine Rock and Tailings Sand Infiltration HYDRUS-1D Modelling		

1.0 INTRODUCTION

KGHM Ajax Mining Inc. (KAM) is currently conducting an Environmental Assessment (EA) for the Ajax Project (the Project) located approximately 7 km south-west of the City of Kamloops, British Columbia. BGC Engineering Inc. (BGC) was retained by KAM to develop a site-wide water balance model (WBM) and groundwater flow model, both of which will form a component of the EA Certificate application for the Project. This memorandum summarizes hydrological modelling work undertaken to estimate the volume of water infiltration that is expected through several proposed mine rock storage facilities (MRSFs) and proposed tailings storage facility (TSF) for various operations scenarios prior to reclamation material placement and revegetation.

1.1. Scope of Work

Mine rock infiltration is a required input for the site-wide WBM and groundwater flow models under development for the Project (BGC, 2015a,b). BGC provided KAM with a proposal dated September 2, 2014, to expand the existing BGC hydrology and hydrogeology scope in order to help quantify the potential effects of the Project on groundwater, surface water and water quality as part of the EA application (BGC, 2014). Within this scope included new modelling work to estimate mine rock infiltration for the Project site using the physically based unsaturated flow model HYDRUS-1D (Šimůnek et al., 2008). The objective for the modelling work is to estimate infiltration into the MRSF and TSF facilities for various operations scenarios as inputs to the WBM under development for the Project.

Additional modelling analyses were requested during a project team meeting on March 17, 2015, to determine the impact of applying a glacial till cover over the mine rock of varying thicknesses (0.3, 0.6 and 1.0 m) on infiltration, along with the impact of compaction on the thin glacial till cover (0.3 m) scenario, the results of which are also summarized in this memorandum.

1.2. Study Areas

A detailed description of the regional study area (RSA) and local study area (LSA) for the hydrology and hydrogeology modelling scopes is provided in BGC (2015a,b). The HYDRUS-1D modelling work is applicable at the LSA scale and evaluates the proposed MSRFs and TSF landforms on site for the operations phase of the Project, prior to reclamation material placement and revegetation.

1.3. Facility Description

The Ajax Project is a proposed open pit copper-gold mine at the historic Afton Mining Camp that includes an open pit, a TSF, MRSFs, a number of water management ponds, and a plant site. The TSF is planned as a conventional tailings storage facility and will contain flotation tailings from the plant site. Tailings containment will be provided by four embankments. Four MRSFs are planned: the South Mine Rock Storage Facility (SMRSF), East Mine Rock Storage Facility (EMRSF), West Mine Rock Storage Facility (WMRSF) and the In-Pit Mine Rock Storage Facility (IPMRSF).

The MRSFs will be constructed over the operating period of the mine and will store mine rock generated from the mining process, some of which is potentially acid-generating (PAG) material. SMRSF is the largest of the four MRSFs and is planned to contain 358 Mt of mine rock and reach a final design elevation of 1,135 masl. At closure, the MSRFs will be contoured and capped with non-potentially acid generating (NPAG) material, overburden and stockpiled reclamation material to support native vegetation as summarized in the Application Information Requirements (AIR) for the Project (EAO, 2015). Following soil placement, the MSRFs will be revegetated with an agricultural and native seed mix to re-establish grazing land and wildlife habitat characteristic of the natural grassland environment (EAO, 2015).

2.0 METHODOLOGY

2.1. HYDRUS-1D

Mine infiltration analyses were conducted using HYDRUS-1D (Version 4.16; Šimůnek et al., 2008), an open-source program which simulates water flow, heat and solute transport for a one-dimensional, variably saturated media. The program numerically solves the Richards equation (Richards, 1931) for saturated-unsaturated flow. This model was selected for the Project site because it has been successfully used in numerous hydrological studies and under various climatic conditions, including semi-arid environments (e.g., Scanlon et al., 2002) and has been applied to predict the effectiveness of engineered covers in minimizing infiltration into underlying mine waste materials (e.g., Fayer et al., 1992).

In the model, surface runoff occurs when the precipitation intensity exceeds the infiltration capacity of the soil. During periods when the air temperature drops below freezing, precipitation comes in the form of snow and accumulates on the soil profile as a snow layer. Snow melt occurs once the air temperature increases above freezing allowing the water to be

available to infiltrate the soil profile. Sublimation from the snow layer is also accounted for using a sublimation constant. Once water infiltrates the soil, it can move up by evaporation or down as a result of gravity or matric-potential gradients. For unsaturated systems, flow is primarily vertical, and therefore a one-dimensional approach was adopted for this assessment. Material types were assumed to be homogeneous and isotropic.

2.2. Modelling Scenarios

Six modelling scenarios were considered for the assessment as discussed below and summarized in Table 2-1. Figure 2-1 provides conceptual illustrations of each scenario. A 30 year climate dataset described in Section 2.3 defined the upper boundary condition of the model while the lower boundary was assumed as free draining. Simulations were run for the entire 30 year climate dataset (1981 to 2011). Further description of all modelling assumptions and the model setup including initial conditions are provided in Sections 2.6 and 2.7.

Scenario 1: Infiltration into uncovered mine rock

The base case scenario considers infiltration into uncovered mine rock at the end of mine operations once the MRSF has reached final design height and prior to reclamation and revegetation. A profile height of 200 m was assumed for the scenario.

Scenarios 2, 3 and 4: Infiltration into mine rock with glacial till cover (uncompacted)

These scenarios consider the effects of varying the thickness of glacial till cover on infiltration as requested during the March 17, 2015 project meeting. The glacial till cover is varied at one of three thicknesses including a 0.3 m cover (Scenario 2), a 0.6 m cover (Scenario 3) and a 1.0 m cover (Scenario 4) directly over mine rock.

Scenario 5: Infiltration into mine rock with glacial till cover (compacted)

This scenario considers the impacts of compaction of the 0.3 m glacial till cover as requested during the March 17, 2015 project meeting. The profile consisted of 0.3 m of compacted glacial till over 0.3 m of loose, uncompacted glacial till for a total package of 0.6 m over mine rock.

Scenario 6: Infiltration into uncovered tailings sand

This scenario considers infiltration into uncovered tailings sand at the end of mine operations once the TSF has reached final design height and prior to reclamation and revegetation. A profile height of 100 m was assumed for the scenario.

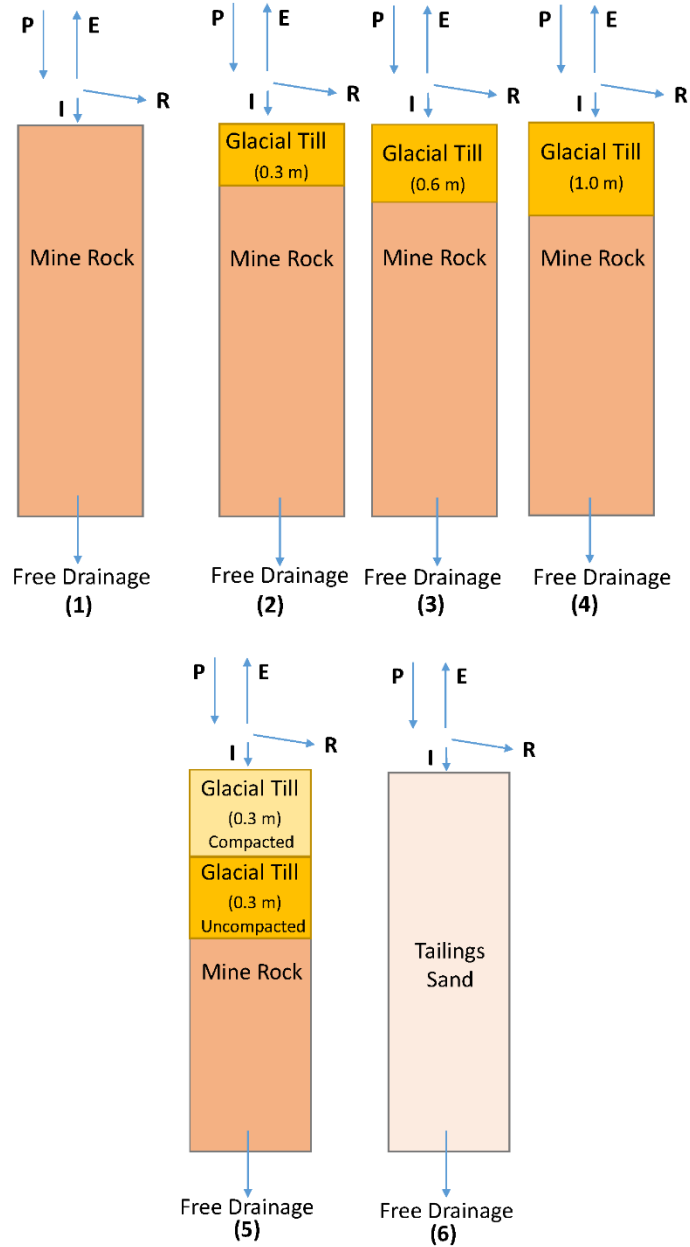


Figure 2-1. Modelling scenarios considered for various configurations of mine rock, tailings sand and glacial till material thicknesses and placement. Where precipitation (P), evaporation or sublimation (E), evapotranspiration (ET), runoff (R), infiltration (I) were modelled fluxes in and out of the covers.

Table 2-1. Summary of HYDRUS-1D scenarios.

Scenario	Description	Profile Material	Profile Depth (m)	Glacial Till Depth (m)	Compaction (Y/N)
1	Uncovered mine rock	Mine Rock	200	0	N
2	0.3 m glacial till cover over mine rock	Mine Rock	200	0.3	N
3	0.6 m till cover over mine rock	Mine Rock	200	0.6	N
4	1.0 m till cover over mine rock	Mine Rock	200	1.0	N
5	0.3 m compacted glacial till over 0.3 m of loose, uncompacted glacial till	Mine Rock	200	0.6	Y
6	Uncovered tailings sand	Tailings Sand	100	0	N

2.3. Climate Data

Climate data were obtained from the Kamloops Airport Environment Canada (EC) climate station (ID#1163780, 350 masl) for the period of 1981 to 2011 including daily precipitation and air temperatures and scaled to the Project to an elevation band of 900 to 1,200 m (Table 2-2, Figure 2-2). Monthly potential evapotranspiration values estimated by Knight Piésold (2014) were divided to generate a daily time-step for input into the model. Knight Piésold (2013, 2014) estimated potential evapotranspiration using the Thornthwaite temperature-based method (Thornthwaite, 1955). Long-term average annual precipitation and potential evapotranspiration is estimated at 336 mm and 585 mm for the Project, and average annual temperature is estimated to be 6.4°C (Knight Piésold, 2014). In this arid-climate, the Project experiences water deficit conditions due to evaporation exceeding precipitation on an annual basis. BGC (2015a) provides additional discussion on the regional and local climatic conditions of the Project.

Table 2-2. Summary of climate inputs for HYDRUS-1D model.

Parameter	Unit	Frequency	Period	Climate Station
Air Temperature	°C	Daily	1981 – 2011	Kamloops Airport EC
Precipitation	Mm	Daily	1981 – 2011	Kamloops Airport EC
Potential evapotranspiration	Mm	Daily ¹	1981 – 2011	Afton BC FLNRO ²

Notes:

- 1: Average monthly values presented in Knight Piésold (2014) were divided to generate a daily time-step.
- 2: Monthly values were estimated using a long-term synthetic temperature series generated from a 25 year dataset (1988 to 2012) from the Afton Climate Station (780 masl) operated by the British Columbia Ministry of Forests, Land and Natural Resources Operations (BC FLNRO).

Maximum and minimum air temperature values were used in the model to accumulate snow at the soil surface. The model assumes that all precipitation is in the form of snow when the air temperature is below -2°C and liquid when the air temperature is above $+2^{\circ}\text{C}$ and that a linear transition exists between these two limiting temperatures (Jarvis, 1994). The existing snow layer (if it exists) melts proportionally to the air temperature when the air temperature is above zero. The thickness of the snowpack is expressed as snow water equivalence (SWE). In addition, sublimation between November and February has been estimated at 28 mm (Knight Piésold, 2014). A sublimation constant was used to reduce the potential evaporation from the snow layer as a heat transport process in the model.



Figure 2-2. Google Earth 2015 imagery of the Ajax Project site and regional stations used for model inputs.

2.4. Material Properties

A description of the physical and hydraulic properties for mine rock, tailing sand and glacial till are described in the following sections. Model scenarios used hydraulic parameters from laboratory testing data and ‘best estimate’ van Genuchten (1980) curve fitting parameters from the literature as described in Section 2.5.

2.4.1. Mine Rock

The material properties of mine rock have a significant impact on the degree of infiltration and preferential flow within the MRSF. The particle size distribution (PSD) of mine rock is a function of the mineral composition of the material but is also influenced by factors such as the mine’s blasting techniques. For the Project, mine material is expected to be blasted to produce a suitable PSD and mineralized material will be blasted to comply with fragmentation

requirements and a specified particle distribution (EAO, 2015). However, information on the target PSD for mine rock material at the site was not available at the time of modelling.

As a result, PSD curves generated for material types contained within seven field bins installed on the site to characterize geochemical conditions were used to represent the material property of the mine rock. PSD curves were generated in June 2007 by Thurber Engineering Ltd., under the direction of Lorax Environmental Services Ltd (Lorax; Figure 2-3). Results from the field bins were provided by Bruce Mattson (Lorax) to BGC on January 21, 2015.

Grain size distributions from representative samples from the field bins comprise 82% gravels, 15% sands and 3% fines (silts and clays) with an average moisture content of 3% (n=7) based on sieve analyses (Figure 2-3). The material properties for the MRSFs were assumed to have a similar PSD as the field bins. PSD curves were used to parameterize the model as described in Section 2.5.

The method of mine rock placement also has an implication on the material properties. MRSFs constructed by end-dumping tend to have a fining-up gradation with finer materials overlaying coarser material that falls to the base of the lift (Fala et al., 2005). Alternatively, MRSFs constructed as a series of lifts (referred to as push-dumping) tend to have a coarse lower zone and a non-uniform upper zone with horizontal traffic surfaces between lifts (Corazao Gallegos, 2007). However, this degree of material heterogeneity was not accounted for in the model. The soil profile is assumed to be homogeneous which could potentially overestimate the degree of infiltration into the MRSF due to reduced compaction from placement and handling techniques.

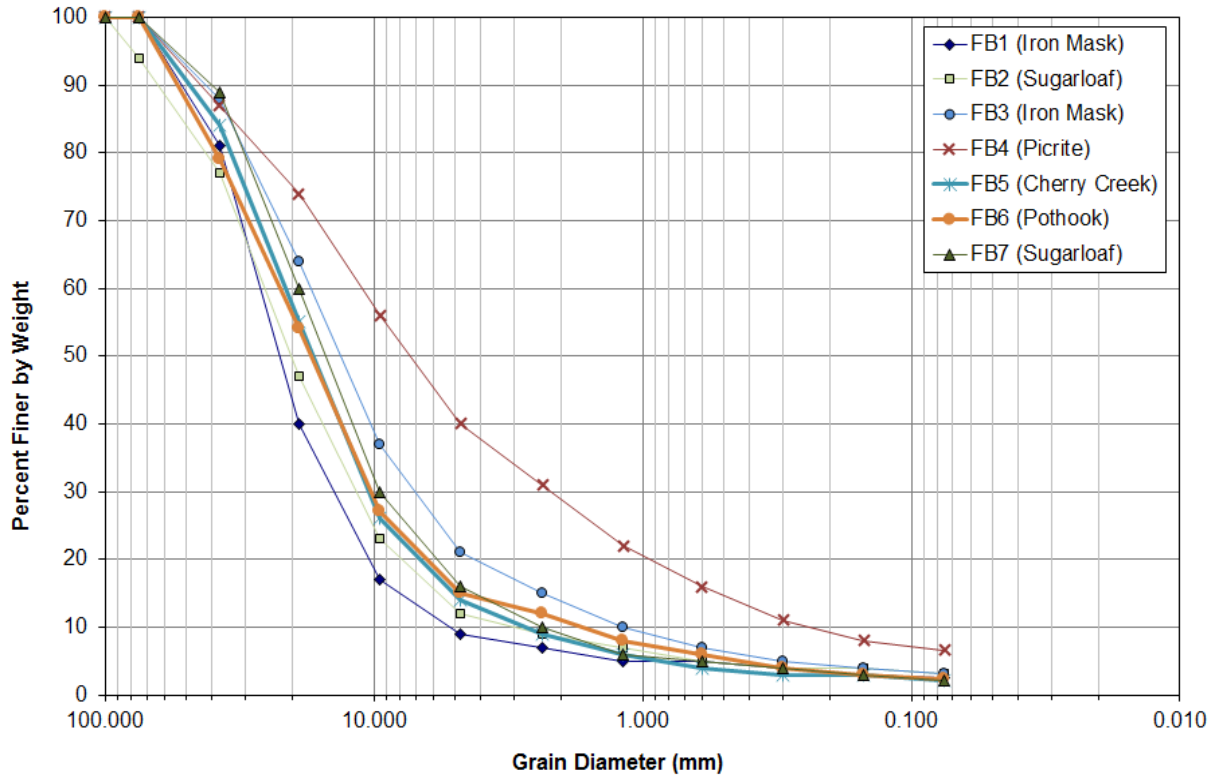


Figure 2-3. Particle size distribution curves for seven field bin (FB) locations. Associated rock units included Iron Mask Hybrid, Sugarloaf Diorite, Cherry Creek, Pothook Phases of the Iron Mask Batholith and Picrite.

2.4.2. Mine Tailings

A geotechnical study conducted for the Ajax tailings materials was used to represent the tailings conditions expected for the Ajax Project (Knight Piésold, 2015). Grain size distributions and material properties were determined for three tailings samples provided by KAM using sieve and hydrometer testing to determine the percent of silt and clays. The Mill Feed 11-21 sample was further processed into the fine and coarse material fraction.

The bulk tailings samples are described as sand and silt with trace clay and comprised of 49% sand, 42% silt and 9% clay. The fine fraction tailing sample is described as clay-silt with trace sands and comprised of 6% sand, 74% silt and 20% clay. While the course fraction tailings sample is described as sand with some fines and comprised of 81% sand and 19% fines (silt and clay). PSD curves for each sample type are provided in Knight Piésold (2015). Results of the sample PSDs are summarized in Table 2-3. Analyses were conducted by the Knight Piésold laboratory in Denver, Colorado. Tailings properties were used to parameterize the model as discussed in Section 2.5.

Table 2-3. Average particle size values for tailings samples.

Tailings Sample	Average Particle Size			
	% Gravel	% Sand	% Silt	% Clay
Bulk Tailings (1,4,5)	0	51	39	10
Bulk Tailings (Mill Feed 6-10)	0	47	43	10
Bulk Tailings (Mill Feed 11-21)	0	49	42	9
Fine Fraction (Mill Feed 11-21)	0	6	74	20
Coarse Fraction (Mill Feed 11-21)	0	81	19	

2.4.3. Glacial Till

Grain size analyses and PSD curves from 42 test pits sampled on site by Knight Piésold in 2014 were used to represent the glacial till. Results of the laboratory testing were provided by Josie Speed (Knight Piésold) to BGC on March 18, 2015. Particle sizes were broken down into the fraction of gravel, sand, silt and clay. The glacial till strata can be described as silty to sandy with gravel, trace clay and trace cobbles. The fines content (particle sizes < 0.075 mm) was noted to vary between 30% and 58%. The natural moisture content on till samples was noted to typically vary within 4% and 14%.

2.5. Material Parameters

Physical parameters such as residual water content (θ_r), saturated water content (θ_s), saturated hydraulic conductivity (K_s), and two van Genuchten shape parameters α and n are required model inputs. Hydraulic parameters are often very time consuming and costly to determine empirically. As a result, properties are often predicted from more easily measured data such as soil texture, bulk density, porosity, organic matter content, soil structure and mineralogy using pseudo-transfer functions (e.g., Twarakavi et al., 2009).

For the model, the van Genuchten parameters were determined using a procedure described in Blackmore et al. (2014). This includes first renormalizing the PSD curves to the material passing through a 4.75 mm sieve and apportioning the renormalized volumes to the fraction of sand (4.75 to 0.42 mm), silt (0.42 to 0.075 mm) and clays (<0.075 mm). Once classified, percentages are then applied to the USDA soil classification triangle and referenced to a table developed by Carsel and Parish (1988) describing typical parameters for 12 soil textural classifications (Table 2-4).

There are several different soil classifications systems available to classify fine grained material. For example, the Canadian Geotechnical Society (2006) classification define sand as 2 mm to 0.06 mm, silt as 0.06 mm to 0.002 mm and clay as smaller than 0.002 mm. The ranges described in Blackmore et al. (2014) were used to classify the particle size results from the field bins because these samples were not subject to hydrometer testing to distinguish between the silt and clay fraction. As a result, material passing through the 0.075 mm sieve size represents the amount of fines (silt and clay) in the sample. This approach is consistent

with Blackmore et al. (2014) in which the 0.075 mm sieve represented the smallest sieve size sample and was therefore used as the upper diameter limit for ‘clay’.

Tailings sand and glacial till samples were subject to hydrometer testing and were therefore classified into soil textural class as a component of the laboratory analysis. Results were directly applied to the USDA soil classification triangle without first normalizing the sample for the fraction of sand-silt-clay. Figure 2-4 and Notes:

*Value is consist with compiled hydraulic conductivity data for mine rock in the New Afton area (Piteau Associates, 2006). A hydraulic conductivity geometric mean of 1×10^{-5} m/s for mine rock was reported from this study.

Table 2-5 summarize the parameters used to represent the soil textural classes describing mine rock, glacial till and tailings sand in the model. Although the bulk tailings samples corresponded to a loam textural class, the tailings material at Ajax was modelled as a silty loam based on the PSD determined from the fine fraction tailings sample (Mill Feed 11-21) as shown in Figure 2-4.

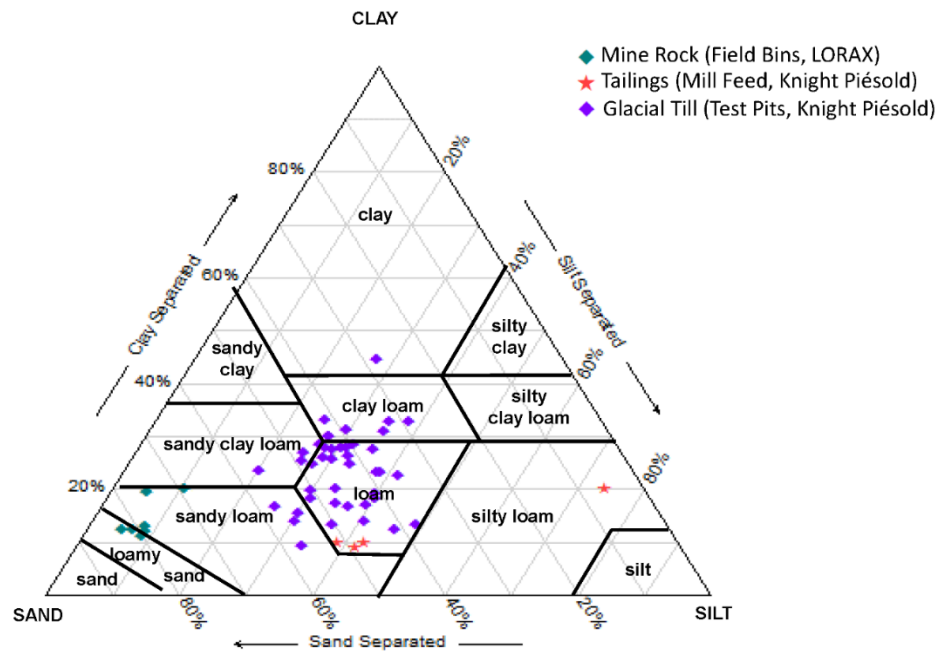


Figure 2-4. USDA soil classifications with percentages from samples assumed to represent mine rock, tailings sand and glacial till textural classes.

Table 2-4. Average values of the van Genuchten parameters for the 12 soil textural types of the USDA classification (from Carsel and Parrish, 1988). Model parameters used to represent mine rock (sandy loam), tailings sand (silty loam) and glacial till (loam) are in bold.

Soil Texture (USDA)	Residual water content, θ_r	Saturated water content, θ_s	van Genuchten Parameters		Saturated conductivity, K_s (cm d ⁻¹)
			α (cm ⁻¹)	N	
Sand	0.045	0.43	0.145	2.68	712.8
Loamy sand	0.057	0.41	0.124	2.28	350.2
Sandy loam	0.065	0.41	0.075	1.89	106.1*
Loam	0.078	0.43	0.036	1.56	24.96
Silt	0.034	0.46	0.016	1.37	6
Silty loam	0.067	0.45	0.02	1.41	10.8
Sandy clay loam	0.100	0.39	0.059	1.48	31.44
Clay loam	0.095	0.41	0.019	1.31	6.24
Silty clay loam	0.089	0.43	0.01	1.23	1.68
Sandy clay	0.100	0.38	0.027	1.23	2.88
Silty clay	0.070	0.36	0.005	1.09	0.48
Clay	0.068	0.38	0.008	1.09	4.80

Notes:

*Value is consist with compiled hydraulic conductivity data for mine rock in the New Afton area (Piteau Associates, 2006). A hydraulic conductivity geometric mean of 1×10^{-5} m/s for mine rock was reported from this study.

Table 2-5. Summary of material type results.

Material Types	No. of Samples	Sample Type	Data Source	Assumed soil texture
Mine Rock	7	Field Bins	Lorax Environmental Services	Sandy loam
Glacial Till	42	Test Pits	Knight Piésold	Loam
Tailings	3	Mill Feed Tailings Samples	Knight Piésold	Silty loam

The impacts of compacting the glacial till (loam) cover was modelled by adjusting the van Genuchten parameters used for the simulation to a bulk density of 1.6 g/cm^3 for a loam soil texture. Loamy soils at a bulk density of $>1.6 \text{ g/cm}^3$ are considered a potential barrier to root growth (Daddow and Warington, 1983). The hydraulic parameters used in the simulation were estimated using the ROSETTA Lite V.1.0 Neural Network Prediction tool in HYDRUS-1D

(Schapp, 1999), the results of which are summarized in Table 2-6. A similar parameterization approach was used in Blackmore et al. (2014) to represent a trafficked surface on the MRSF, the assumption being that the layer would behave more like a fine-grained material with greater susceptibility to ponding and/or slower infiltration.

Table 2-6. Average values of the van Genuchten soil water retention parameters estimated using ROSETTA Lite V.1.0 to model compaction of the glacial till layer.

Residual water content, θ_r	Saturated water content, θ_s	van Genuchten Parameters		Saturated conductivity, K_s (cm d ⁻¹)
		α (cm ⁻¹)	N	
0.058	0.36	0.02	1.34	4.99*

Notes:

*Value is consist with hydraulic conductivity geometric mean of 1×10^{-7} m/s from hydrogeology baseline work conducted at the Project site (BGC, 2015b).

2.6. Model Assumptions

The following assumptions were used to develop the HYDRUS-1D model for the Project site:

- Vertical flow is assumed with no horizontal flow or solute transport for all modelling scenarios. The soil profile is assumed to be free draining.
- No hysteresis and ponding of water on the soil surface was assumed for all scenarios.
- Snowmelt is assumed to occur based on site air temperatures rather than an energy budget approach.
- Initial conditions were assumed to be vertically uniform.
- The mine rock material planned for the MRSFs are assumed to have a similar PSD as the field bins (n=7) consisting of gravel, sand and fines (silt/ clay) corresponding to a sandy loam texture (Figure 2-4).
- The mine rock profiles are assumed to be uniform and represented as one column of mine rock material with homogeneous soil properties.
- A profile height of 200 m and 100 m was assumed for the MRSF and TSF scenarios, respectively.
- The tailings material planned for TSF is assumed to have a similar texture as samples taken from the Ajax Mine site (Table 2-3) corresponding to a silty loam material.
- Test pit samples are assumed to be representative of glacial till properties on site and corresponded to a loam soil texture. A bulk density of 1.6 g/cm³ was assumed to represent compaction of the glacial till layer.

2.7. Model Setup

The model was setup with the following conditions:

- A material profile depth of 200 m was used for all mine rock scenarios. The profile was discretized into 100 elements from the top to the bottom of the pile with a uniform grid block size of approximately 20 m.
- A material profile depth of 100 m was used for all TSF scenarios. The profile was discretized into 100 elements from the top to the bottom of the pile with a uniform grid block size of approximately 10 m.
- A glacial till was included in the soil profile for the scenarios that included glacial till placement resulting in a layered soil profile.
- The depth of the glacial till layer was varied to simulate infiltration for a thick (1.0 m), medium (0.6 m) and thin (0.3 m) cover (Scenarios 2a,b,c). A bulk density of 1.6 g/cm³ was applied to the thin 0.3 m cover to simulate compaction (Scenario 2d).
- Initial conditions in the model were assumed to be either equal to (1) the field capacity for the particular soil type, (2) an initial pressure head (h) of -100 cm or (3) an initial pressure head of $h = -150$ cm. Pressure heads were distributed uniformly throughout the soil profile. Initial water contents are assigned in the modelling based on an analytical solution described in Twarakavi et al. (2009). Setting the initial water content equal to field capacity is considered a reasonable first approximation for the model (Šimůnek, J., pers. comm., 2015).
- Daily climate data for the variables of precipitation, air temperature and potential evapotranspiration defined the upper boundary condition of the model. Simulations were run for the entire 30 year climate dataset (1981 to 2011).
- The lower boundary was assumed as free draining for all scenarios.

HYDRUS-1D modelling results for the scenarios described in Section 2.2. are presented in Section 3.0.

3.0 RESULTS AND SUMMARY

Figure 3-1 presents a summary of the infiltration results for each of the operational and closure modelling scenarios described in Section 2.2. Table 3-1 indicates which results were applied to the EA-level WBM developed for the Project. Results represent the amount of water that is predicted to infiltrate the soil cover and do not represent potential groundwater recharge from the base of the profile.

Results of the study indicated that:

- Infiltration into the uncovered (bare) mine rock (Scenario 1) was estimated at approximately 44 mm, or 13% of annual average precipitation (336 mm) over the 30-year simulation period. A majority of the precipitation that reaches the surface of the MRSF in this scenario either evaporates or infiltrates the soil and is stored as soil water, with less than 2 mm conveyed as surface runoff.

- The placement of an uncompacted glacial till cover over the mine rock in a thickness of 0.3, 0.6 or 1.0 m (Scenarios 2,3,4) reduced the total infiltration into the soil profile and increased the total amount of evaporation and runoff shed from the cover over the simulation period. The placement of 1.0 m of glacial till resulted in the greatest reduction in infiltration to approximately 7 mm, while 0.3 m and 0.6 m of glacial till cover reduced infiltration to approximately 33 mm and 23 mm, respectively.
- Compaction of the 0.3 m glacial till cover to a bulk density of 1.6 g/cm³ over a 0.3 m layer of loose, uncompacted glacial till (Scenario 5) provided a similar infiltration rate as estimated for the 1.0 m thick glacial till cover described above at approximately 8 mm of infiltration.
- Infiltration into the uncovered (bare) tailings sand (Scenario 6) was estimated at approximately 19 mm, or 6% of annual average precipitation (336 mm) over the 30-year simulation period.

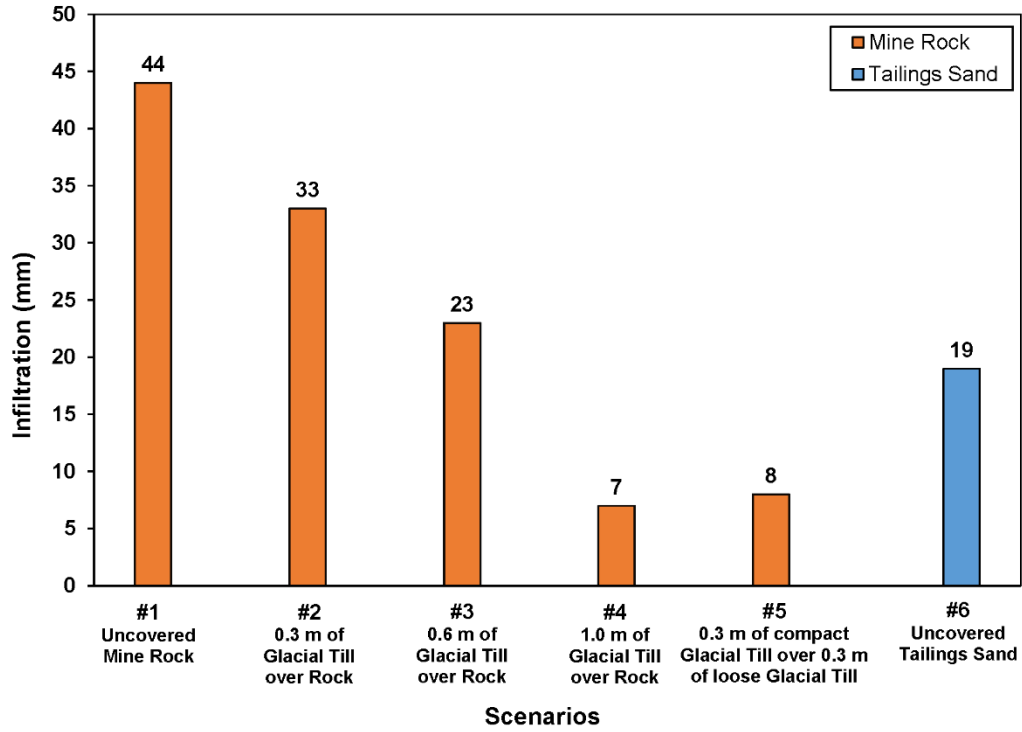


Figure 3-1. Summary of modelled infiltration rates for each operational and pre-reclamation scenario.

Table 3-1. Summary of HYDRUS-1D results for each modelling scenario.

Scenario	Description	Profile Material	Profile Depth (m)	Glacial Till Depth (m)	Compaction (Y/N)	Infiltration (mm)	Infiltration as Percent of Average Precipitation ¹ (%)
1	Uncovered mine rock	Mine Rock	200	0	N	44*	13
2	0.3 m glacial till cover over mine rock	Mine Rock	200	0.3	N	33	10
3	0.6 m till cover over mine rock	Mine Rock	200	0.6	N	23	7
4	1.0 m till cover over mine rock	Mine Rock	200	1.0	N	7	2
5	0.3 m compacted glacial till over 0.3 m of loose, uncompactd glacial till	Mine Rock	200	0.6	Y	8*	2
6	Uncovered tailings sand	Tailings Sand	100	0	N	19	6

Note:

1: Average annual precipitation value of 336 mm (Knight Piésold, 2014)

*Value applied to the EA-level WBM (BGC, 2015a)

4.0 CLOSURE

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Yours sincerely,

BGC ENGINEERING INC.
per:

Elisa Scordo, M.Sc., P.Geo.
Hydrologist

Reviewed by:
Carl Mendoza, Ph.D., P.Eng.(AB, BC), P.Geol. (AB)
Principal Hydrogeological Engineer

CK/CM/ma/cm

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