Atlantic Gold

Appendix F.6

Groundwater Flow and Solute Transport Modelling to Evaluate Disposal of Beaver Dam Tailings in Touquoy Open Pit - Beaver Dam Gold Project - April 12,.2021

Completed for the Updated 2021 Beaver Dam Mine EIS

Groundwater Flow and Solute Transport Modelling to Evaluate Disposal of Tailings in Touquoy Open Pit

FINAL REPORT

April 12, 2021

Prepared for:

Atlantic Mining NS Inc.
409 Billybell Way, Mooseland
Middle Musquodoboit, NS B0X 1X0

Prepared by:

Stantec Consulting Ltd.
845 Prospect Street
Fredericton, NB E3B 2T7

Sign-off Sheet

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Jonathan Keizer, M.Sc.E., P.Eng.

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Executive Summary

A three-dimensional steady-state groundwater flow model and solute transport model was constructed using MODFLOW to simulate current groundwater conditions in the Study Area, baseline conditions (i.e., when tailings disposal operations begin at the Touquoy mine site), changes to groundwater inflows during operations (i.e., while tailings are deposited in the Touquoy pit), and to evaluate potential changes to water quality in the receiving environment due to the subaqueous disposal of tailings in the Touquoy pit post-closure (i.e., when the pit is full). The model was prepared using a conceptual model and hydrostratigraphic framework developed from regional and site-specific data, and assumed homogeneous properties within the units. A good calibration of model parameters was obtained, as evaluated by comparing simulated and observed groundwater levels and estimated baseflow. The parameter values for hydraulic conductivity are similar to those obtained from other analyses of field observations. The modelling was also conducted incorporating comments received from NRCan, NSE, and DFO on the proposed workplan provided to these agencies prior to completing the model.

At baseline, the open pit will be fully dewatered, and is simulated to intercept groundwater seepage at a rate of 768 m^3/d. The extent of the corresponding drawdown cone, as delineated by the 0.5 m drawdown contour, extends approximately 600 m south of the site and about 50 m west of the site toward Moose River. The inflow to the open pit decreases as it is filled with tailings and water during Beaver Dam operations, until the open pit stage reaches the maximum level of 108 m relative to CGVD2013. At this stage, the groundwater seepage decreases to 373 m^3/d, and the corresponding drawdown cone is about the same as the baseline condition. Groundwater baseflow to Moose River is reduced by less than 1% in all cases.

Upon the filling of the open pit to its ultimate lake stage at 108 m CGVD2013, groundwater flow is anticipated to flow from the pit to Moose River through the glacial till and weathered fractured bedrock. Solute transport in this case is dominated by advection (movement with the flow of groundwater). Solute transport modelling using the calibrated model simulates a slow migration of solutes to Moose River, with concentrations approaching a steady state after about 100 years of travel. Mass loadings for various parameters of concern are simulated by the model for inclusion in a surface water mixing model of Moose River (Stantec 2021).

The presence of preferential pathways, such as fractures and faults not characterized in previous field assessment, were assessed with sensitivity analyses in the model to predict the potential migration of solutes from pit into the receiving environment. The results of the sensitivity analyses indicated that should the faults have higher hydraulic conductivity, solute transport to Moose River would occur more quickly. The potential for higher permeability faults should be considered in the development of management, mitigation and contingency plans.

Abbreviations

AMNS	Atlantic Mining NS Inc.
CGVD2013	Canadian Geodetic Vertical Datum 2013
°C	degrees Celsius
cm	centimetres
g/d	grams per day
K_H	horizontal hydraulic conductivity
K_V/K_H	anisotropy ratio
km	kilometres
km^2	square kilometres
M	metres
m/s	metres per second
m^3/d	cubic metres per day
m^3/s	cubic metres per second
mg/L	milligrams per litre
mm	millimetres
mm/yr	millimetres per year

NSDL&F	Nova Scotia Department of Lands and Forestry
RMS	root mean squared
RSS	residual sum of squares

1.0 INTRODUCTION

The Moose River consolidated project comprises the Beaver Dam, Fifteen Mile Stream, Cochrane Hill, and Touquoy gold deposits. Atlantic Mining NS Inc. (AMNS) are proposing the construction, operation, decommissioning, and closure of an open pit gold mine and associated ancillary activities as the Beaver Dam Gold Project (the Project) as a satellite deposit to the Touquoy Gold project. Ore removed from the open pit at Beaver Dam will be transported approximately 57 km to the Touquoy mill for processing. Tailings from the processing of the Beaver Dam ore are proposed to be disposed of in the exhausted Touquoy open pit developed for the Touquoy Gold Project.

AMNS retained Stantec Consulting Ltd. (Stantec) to conduct an assessment of the disposal of tailings from the processing of the Beaver Dam ore into the open pit at Touquoy. Stantec constructed a groundwater flow and solute transport model to assist in the evaluation of the potential changes to water quality in the receiving environment that are likely to result from this activity. The groundwater flow and solute transport model would also allow for the future assessment of potential mitigation measures that could be implemented to minimize the potential release of contaminants.

1.1 STUDY OBJECTIVES

This study was conducted to assess the environmental effects associated with the disposal of tailings from Beaver Dam ore into the open pit developed for the Touquoy Gold Project. A groundwater flow and solute transport model has been developed to:

- Evaluate the dewatering rate from the Touquoy open pit and changes in groundwater flow conditions and discharges when it is fully dewatered which will be used as the baseline conditions to assess impacts
- Evaluate the groundwater seepage rates to the Touquoy open pit as it is filled with Beaver Dam tailings
- Identify areas where water in contact with the Beaver Dam tailings disposed in the Touquoy open pit is discharged to the receiving environment, and the potential for surface and groundwater interactions
- Predict the potential impacts of discharging groundwater from the Touquoy open pit to the receiving environment

This report forms part of the supporting documentation for the environmental impact study completed for the Beaver Dam Gold Project. The documentation and modelling were conducted following the guidelines prepared by Wels et al. (2012). The documentation and modelling also incorporates comments received from NRCan, NSE, and DFO on the proposed modelling workplan provided to these agencies prior to completing the model. However, some of the comments received are more relevant to a discussion of the effects of dewatering of the Touquoy pit, and will be addressed under separate cover. A concordance table of the comments received, and the responses is provided in Appendix A of this report.

1.2 STUDY AREA

The study area was defined to incorporate natural hydrogeological boundaries around the Touquoy mine site. The subwatershed boundaries for Moose River and Scraggy Lake were selected, as shown on Figure 1.1.

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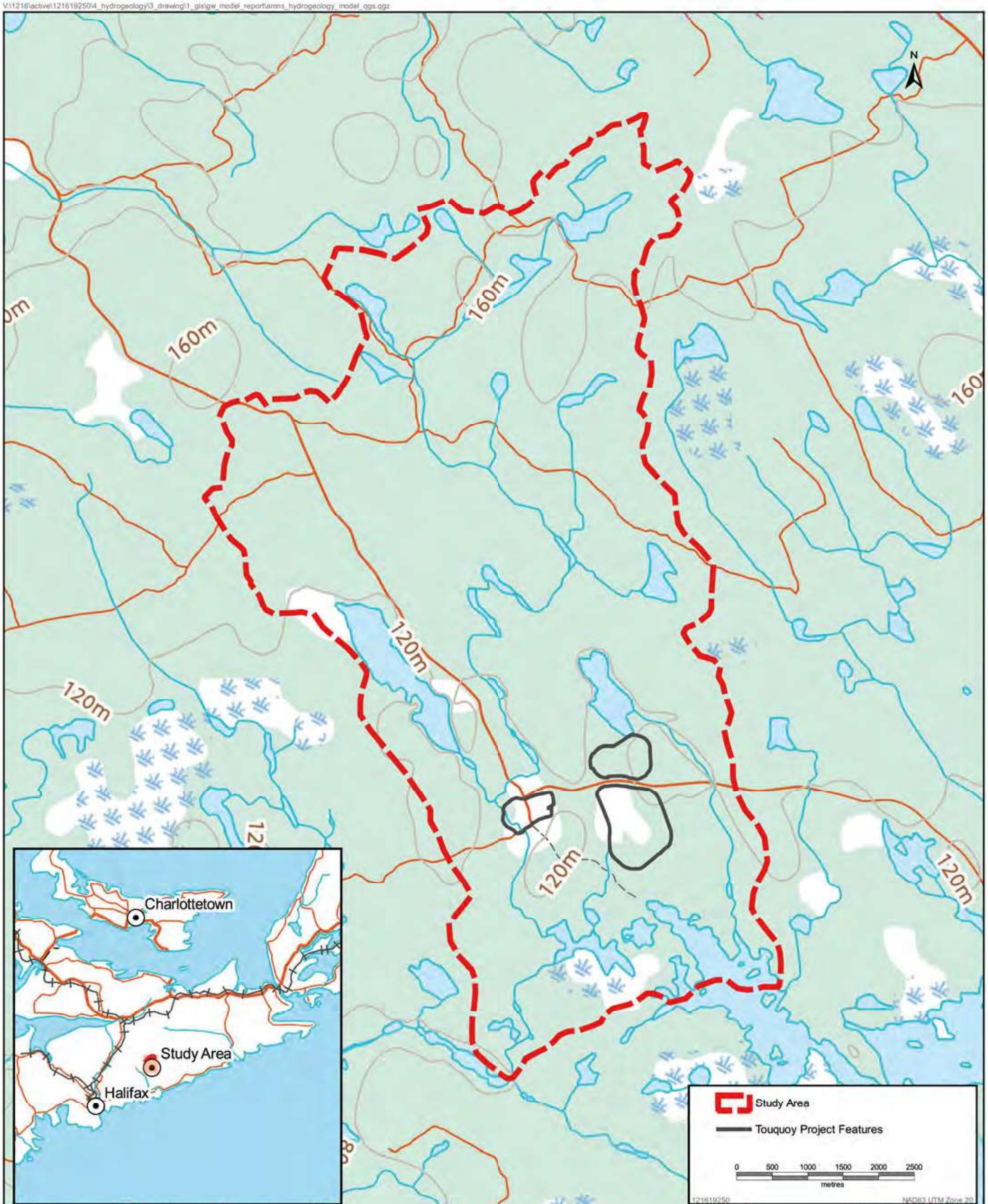

Sources: Base Data - Natural Resources Canada, GeoNova, Atlantic Mining NS Inc.

Study Area

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Figure 1.1

2.0 BACKGROUND

2.1 PROJECT AREA DESCRIPTION AND SURROUNDING LAND USES

The Touquoy processing and tailings management facility is a fully permitted and approved facility currently operating as part of the Touquoy Gold Mine Project in Moose River, Halifax County, Nova Scotia. It is located on land owned by AMNS and Nova Scotia Department of Lands and Forestry (NSDL&F), and centered at 504599 E and 4981255 N (UTM Zone 20 NAD 83 CSRS). Access to Crown land for the construction of the Touquoy Project has been granted through a Crown Land Lease Agreement with NSDL&F (Lease No. 2794371 and Petition No. 37668).

The areas surrounding the Touquoy mine site is zoned mixed use under the Musquodoboit Valley and Dutch Settlement Land Use By-law. The Touquoy mine site location is shown on Figure 2.1.

Groundwater users in the area include Camp Kidston, located 3.5 kilometres (km) northeast of the Touquoy mine site, and permanent residences located approximately 5.8 km to the north of the open pit along Caribou Road.

2.2 CLIMATE

Project site climatic and hydrologic conditions are required for the water balance analysis completed at part of this study. Baseline climate and hydrology conditions at the Touquoy mine site and relevant data required for water balance analysis are presented in this section.

The Middle Musquodoboit climate station operated by Environment and Climate Change Canada (ECCC; Station ID 8203535), was used to characterize the climatic conditions at the mine site. This station is located approximately 20 km northwest of the mine site, and reports data collected between 1961 and 2011.

The climate for the mine site is characterized as continental with temperature extremes moderated by the ocean. Temperatures typically drop below zero between the months of December through March each year. Precipitation is well distributed throughout the year. July and August are the driest months on average.

As presented in Table 2.1, the climate normal precipitation is approximately 1361.1 millimetres (mm) and the average snowfall of 172.2 centimetres (cm), based on a period of record 1981-2010 (climate normal period, Environment Canada 2015a). The extreme one-day precipitation amount of 173 mm for the period of record of the selected climate station occurred in 1961. Average annual lake evaporation is 515 mm for the mine site area based on average lake evaporation at the Truro climate station (Environment Canada 2015b). Corresponding monthly evaporation rates are presented in Table 2.1.

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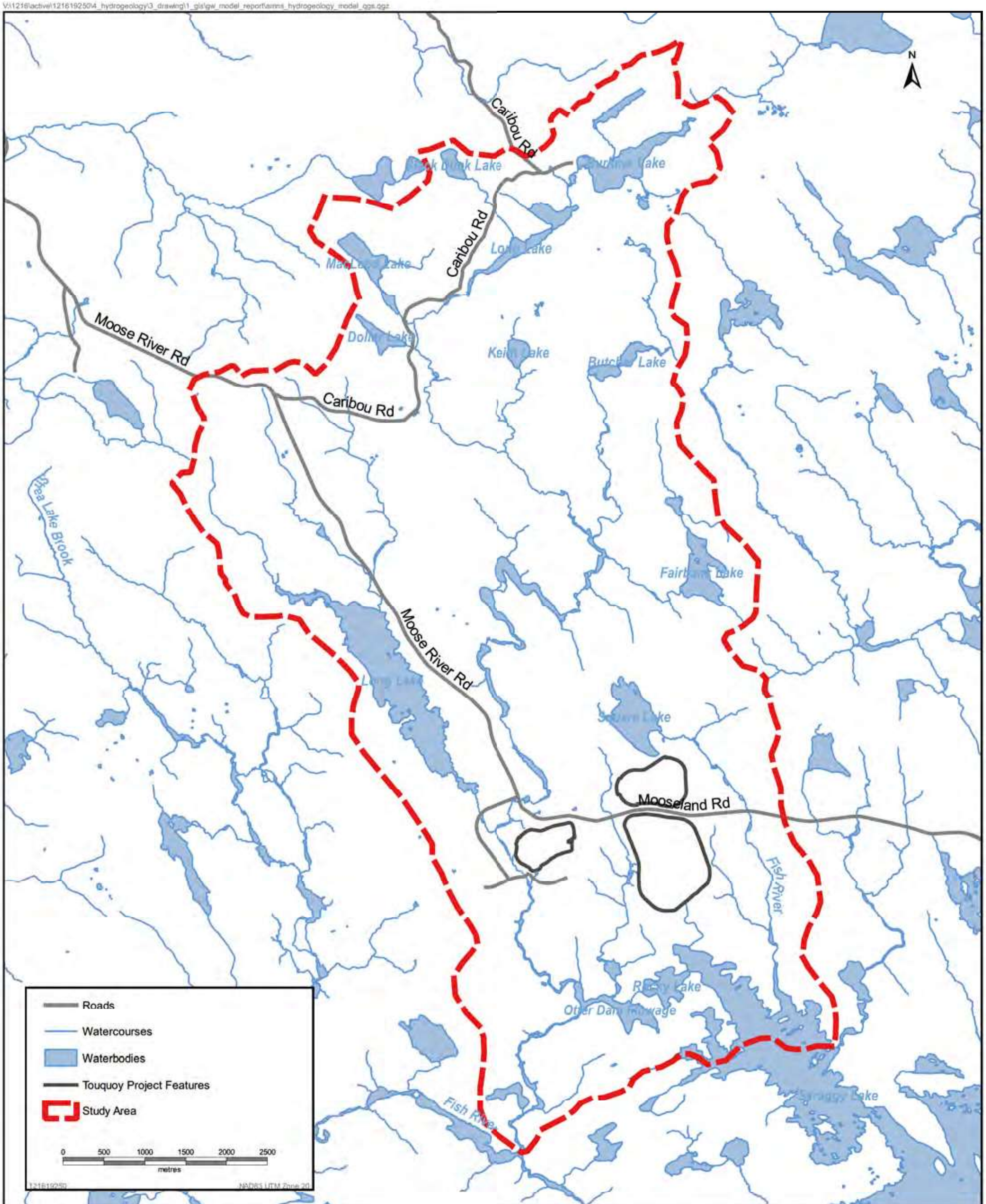

Sources: Base Data - GeoNova, Atlantic Mining NS Inc.

Touquoy Mine Site Location Plan

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Figure 2.1

Table 2.1 Representative Climate Values for the Mine Site

Climate Normal for the 30-year period (1981-2010) at Middle Musquodoboit Climate Station													
Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temperature (°C)	-6.2	-5.2	-1.3	4.4	9.9	14.8	18.5	18.4	14.2	8.5	3.5	-2.4	6.4
Rainfall (mm)	80.4	62.1	92.8	99.5	104.9	99.8	103.8	91.9	110.7	116.7	128.6	97.2	1188.3
Snowfall (cm)	49.4	41.3	31.4	9.5	0.5	0.0	0.0	0.0	0.0	0.0	8.2	31.9	172.2
Precipitation (mm)	129.8	103.4	124.2	109.0	105.4	99.8	103.8	91.9	110.7	116.7	136.8	129.1	1361.1
Snow Depth (cm)	40	67	64	22	6	1	0	0	0	0	25	28	21.1
Monthly Lake Evaporation at Truro Climate Station for 30 year period (1981-2010)													
Lake Evaporation (mm/day)	0	0	0	0	89.9	102	117.8	96.1	69	40.3	0	0	515.1

2.3 PHYSIOGRAPHY, TOPOGRAPHY, AND DRAINAGE

The Project is located within the Atlantic Maritime Ecozone and the South-Central Nova Scotia Uplands Ecoregion (Environment Canada undated). This ecoregion is classified as having an Atlantic high cool temperature ecoclimate. This mixed wood forest region is composed of intermediate to tall, closed stands of red and white spruce, balsam fir, yellow birch, and eastern hemlock. Yellow birch, beech, and red and sugar maple can be found at higher elevations. Eastern white pine is found on sandy areas. The ecoregion has extensive wetland and rock barrens, which support stunted black spruce, larch, and heath.

The topography of the area is presented on Figure 2.2. The elevation varies from a high of about 189.6 metres (m) relative to the Canadian Geodetic Vertical Datum of 2013 (CGVD2013) in the north of the study area, to a low of about 81.6 m CGVD2013 in the southwest of the study area at the outlet of Moose River at Fish River. The topography in the study area is undulating, with several drumlins covering the land, as discussed in Section 2.4, and shown on Figure 2.3.

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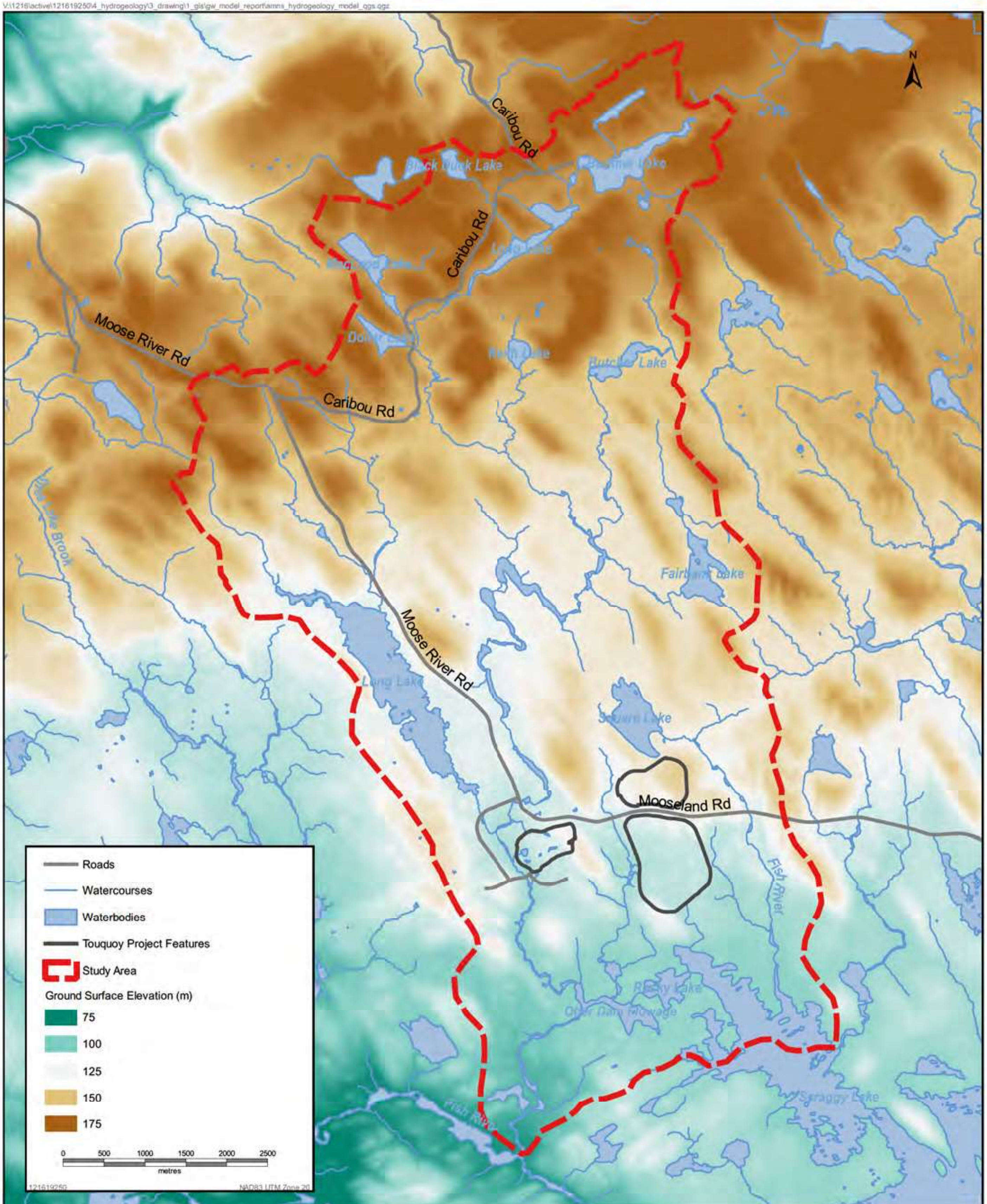

Sources: Base Data - GeoNova, Atlantic Mining NS Inc.

Touquoy Mine Site Topography

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Beaver Dam Gold Project

Figure 2.2

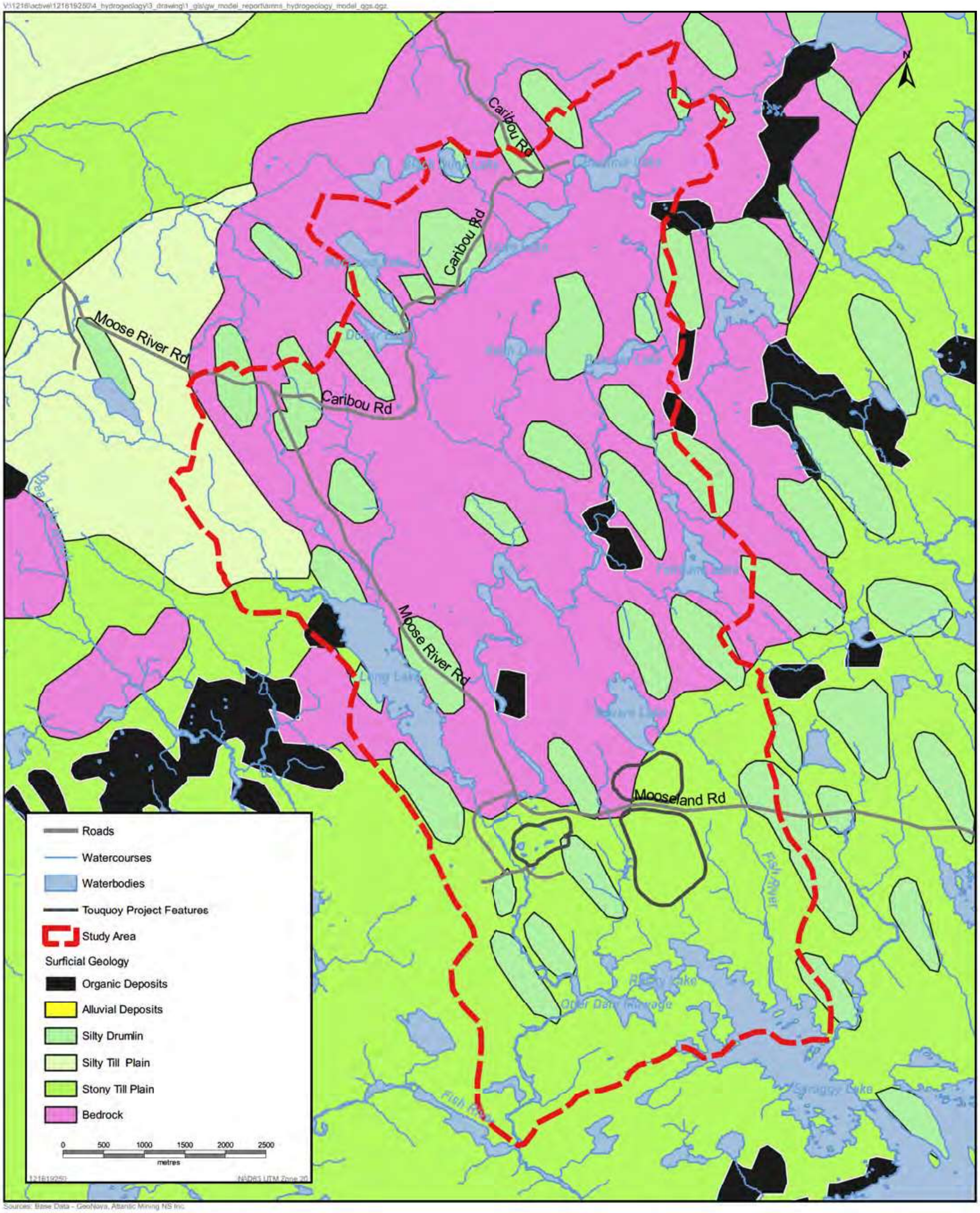
2.4 REGIONAL GEOLOGICAL CONTEXT

2.4.1 Overburden Geology

The regional surficial geology of Nova Scotia has been mapped by the Nova Scotia Department of Natural Resources (Stea et al. 1992) and consists of a veneer of stony till overlying bedrock in the south of the study area, or as exposed bedrock in the north of the study area, as shown on Figure 2-3. Organic deposits were observed in low lying areas and areas associated with wetlands. Silty drumlins are noted throughout the study are, as shown on Figure 2.3.

2.4.2 Bedrock Geology

The geology in central Nova Scotia, including the area around the Touquoy mine site, is composed dominantly by Cambrian to Ordovician age greywackes and argillites of the Meguma Group, as shown on Figure 2.4 from the geological maps presented in Ausenco (2015). At the Touquoy mine site and the southern portion of the study area, the underlying bedrock is composed of the Moose River, Tangier and Moose River, and Taylor's Head members of the Goldenville Formation. Bedrock in northern portions of the study area consists of the Cunard and Beaverbank members of the Halifax Formation. These formations have undergone significant alteration by a series of northeast-trending, tightly-folded anticlines and synclines, and are further altered by a number of northwest trending faults, as shown on Figure 2.4. The Moose River member is composed dominantly of argillite, while the other members of the Goldenville Formation are dominantly greywacke.



Touquoy Mine Site Surficial Geology

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Figure 2.3

3.0 CONCEPTUAL MODEL

3.1 MODELLING APPROACH

The development of a conceptual model is the fundamental first step in the preparation of a numerical groundwater model. The conceptual model combines the available hydrologic and hydrogeologic data from a site, and allows for the interpretation of the hydrostratigraphy and boundary conditions so they can be entered into a numerical groundwater flow model. The general approach used to develop the conceptual and numerical model was to add complexity as warranted by the available data to achieve the objectives of the numerical modelling (see Section 1.1).

3.2 CONCEPTUAL MODEL BOUNDARIES

The conceptual model boundaries were defined to coincide with or extend beyond the proposed limits for the groundwater flow model. Natural hydrologic and hydrogeologic boundaries such as watershed boundaries and surface water bodies were used to define the lateral extent of the conceptual model. The boundaries of the conceptual model correspond with the extent of the study area illustrated on Figure 2.1. The boundaries coincide with watershed boundaries for Moose River, Square Lake and the northern arm of Scraggy Lake. The limits of the conceptual model were constrained vertically by ground surface topography and extended several hundred meters to below the base of the open pit.

3.3 HYDROSTRATIGRAPHY

Previous work by Conestoga-Rovers & Associates (CRA 2007a, 2007b) and Peter Clifton & Associates (PCA 2007) identified three hydrostratigraphic units based on lithology and hydraulic properties: glacial till, weathered fractured bedrock, and competent fractured bedrock. These hydrostratigraphic units were further subdivided into zones based on the surficial geology in the overburden shown on Figure 2.3. The weathered fractured bedrock and competent fractured bedrock were further subdivided to include the bedrock units identified on Figure 2.4.

3.3.1 Overburden Hydrostratigraphic Units

The overburden hydrostratigraphic units include:

- Stony Till
- Silt Till
- Organics
- Silty Drumlin

The stony till is the dominant overburden unit, consisting of cobbly silt-sand grading to sand is assumed to be approximately 4 m thick on average across the study area. The silt till is present in the northwestern portion of the study area, however no specific testing of this unit has been performed, so it is assumed to have similar hydraulic conductivity as the stony till unit. The hydraulic conductivity of the till is estimated to range from 3×10^{-7} to 1×10^{-5} metres per second (m/s), based on estimates from shallow test pits at the western end of the pit (PCA 2007) and slug tests conducted on monitoring wells installed at the Touquoy Mine Site (GHD Limited 2016a,b; Stantec 2019).

3.3.2 Bedrock Hydrostratigraphic Units

Ten bedrock hydrostratigraphic units were identified in the Touquoy Mine Site study area. These are based on the five stratigraphic members (Cunard, Beaverbank, Taylor's Head, Tangier and Moose River, and Moose River) presented on Figure 2.4, each subdivided into a weathered fractured bedrock unit, and a competent fractured bedrock unit.

Weathered fractured bedrock consisting of Meguma Group sandstones and mudstones that has undergone alterations due to weathering and is more permeable than the underlying bedrock. This unit is assumed to be 10 m thick based on the distribution of hydraulic conductivity estimates from packer testing conducted within the footprint of the proposed Touquoy pit.

Competent fractured bedrock consisting of Meguma Group sandstones and mudstones that have not undergone alterations due to weathering. This unit was assumed to extend from the base of the weathered fractured bedrock to below the extent of the open pit.

Hydraulic conductivity testing of greywacke and argillite observed at the Touquoy Mine Site did not identify distinct hydraulic differences between these units, although weathered fractured bedrock was observed to be more permeable than the deeper, more competent bedrock. The variability of hydraulic conductivity estimates in bedrock units is shown on Figure 3.1. Hydraulic conductivity estimates in weathered fractured bedrock range between 4×10^{-9} m/s and 4×10^{-4} m/s. Fewer measurements are available in the competent fractured bedrock, where the hydraulic conductivity ranges between 4×10^{-10} m/s and 1×10^{-7} m/s.

Faults in the bedrock were not specifically tested to assess the hydraulic conductivity at the Touquoy Mine Site. However, regular observations of the faults exposed in the Touquoy open pit have identified some discrete seepage at these faults. The total flow from these exposed faults are generally very low. The faults with seepage were located on pit walls that were generally located away from Moose River, and do not suggest a strong connection with the river.

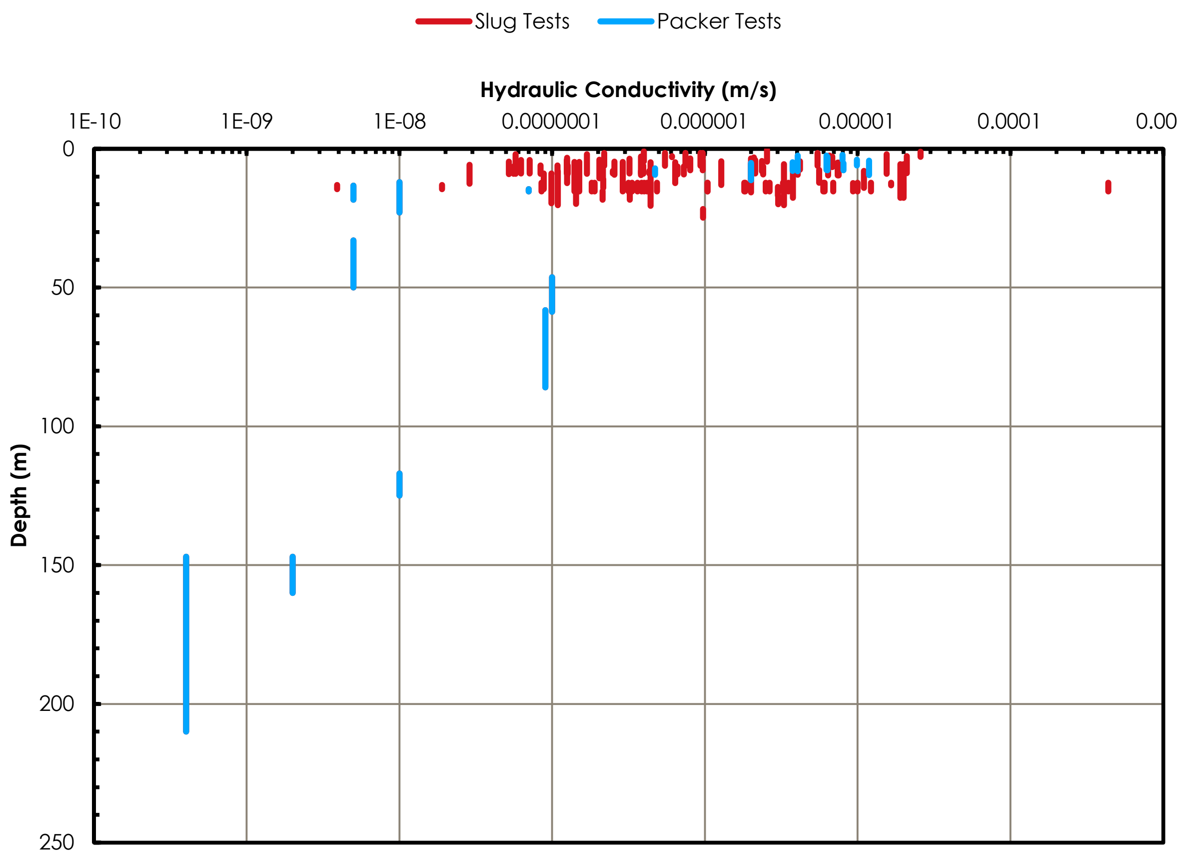


Figure 3.1 Hydraulic Conductivity Estimates in Bedrock

4.0 MODEL CONSTRUCTION AND CALIBRATION

MODFLOW was chosen as the numerical groundwater-software application for this evaluation because it is considered an international standard for simulating and predicting groundwater flow. The MODFLOW-NWT (Niswonger et al. 2012) numerical groundwater flow code was used to simulate the hydrogeologic conditions in the study area. The MODFLOW-NWT code was selected as it is able to efficiently solve the saturated groundwater flow equations under complex hydrogeological conditions without encountering numerical difficulties associated with drying out of model cells that are commonly encountered in dewatering scenarios.

MT3D-USGS (Bedekar et al. 2016) was chosen as the numerical solute transport model. MT3D-USGS is a modular three-dimensional multispecies transport code for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems.

Groundwater Vistas version 7 (Environmental Simulations International 2018) was chosen as the graphical user interface with MODFLOW-NWT and MT3D-USGS. Groundwater Vistas is a pre- and post-processor for MODFLOW-NWT and MT3D-USGS models and other technologies for sensitivity analysis and model calibration.

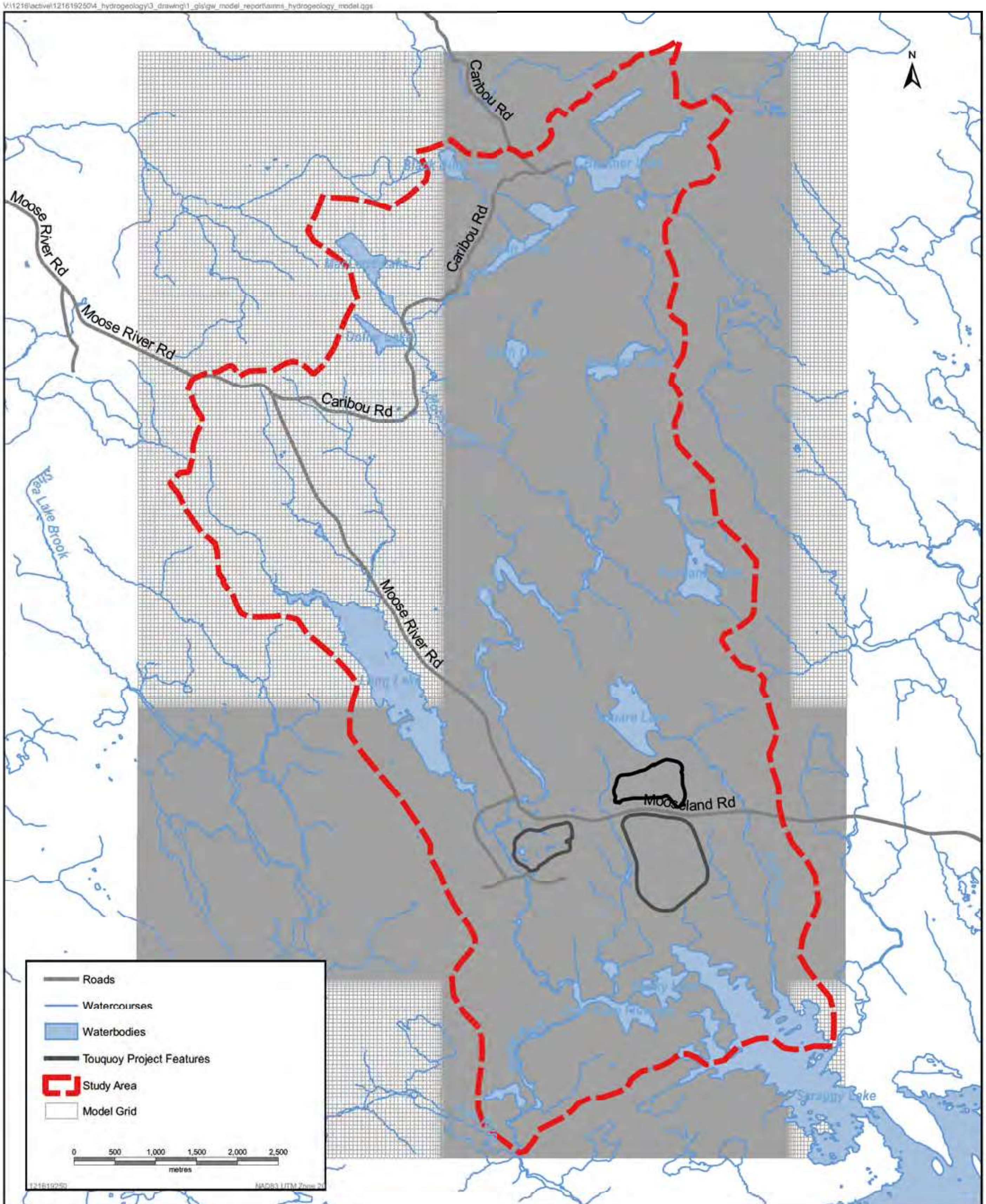
4.1 MODEL DOMAIN

The model grid was constructed to cover the Study Area, as shown on Figure 4.1. The grid is composed of 624 rows and 562 columns for a total area of 117.6 square kilometres (km^2). Cells outside the Study Area are designated “inactive.” The total active area of the model is approximately 58.2 km^2.

A uniform row and column spacing of 50 m was initially applied across the domain. The grid was refined to 5 m spacing (columns and rows) around the Touquoy open pit and Moose River. This refinement extends across the whole model domain and to all layers.

The model was discretized into ten model layers using the hydrostratigraphic units presented in Figure 4.2. Competent fractured bedrock is divided into eight 20-m-thick layers (Layers 3 through 10) based on the pit bench design and two additional layers below the proposed pit floor, as shown on Figure 4.2.

A cross-section showing the conceptual relationship between Moose River, the open pit, and overburden and weathered bedrock thicknesses is shown on Figure 4.3. As shown on Figure 4.3, Moose River is interpreted to occur within the overburden materials, which are 4 to 6 m thick. Moose River is approximately 0.6 m deep, and 13.5 m wide, based on aquatic habitat surveys conducted in this area.



Sources: Base Data - GeoNova, Atlantic Mining NS Inc.

Study Area and Model Grid

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Figure 4.1

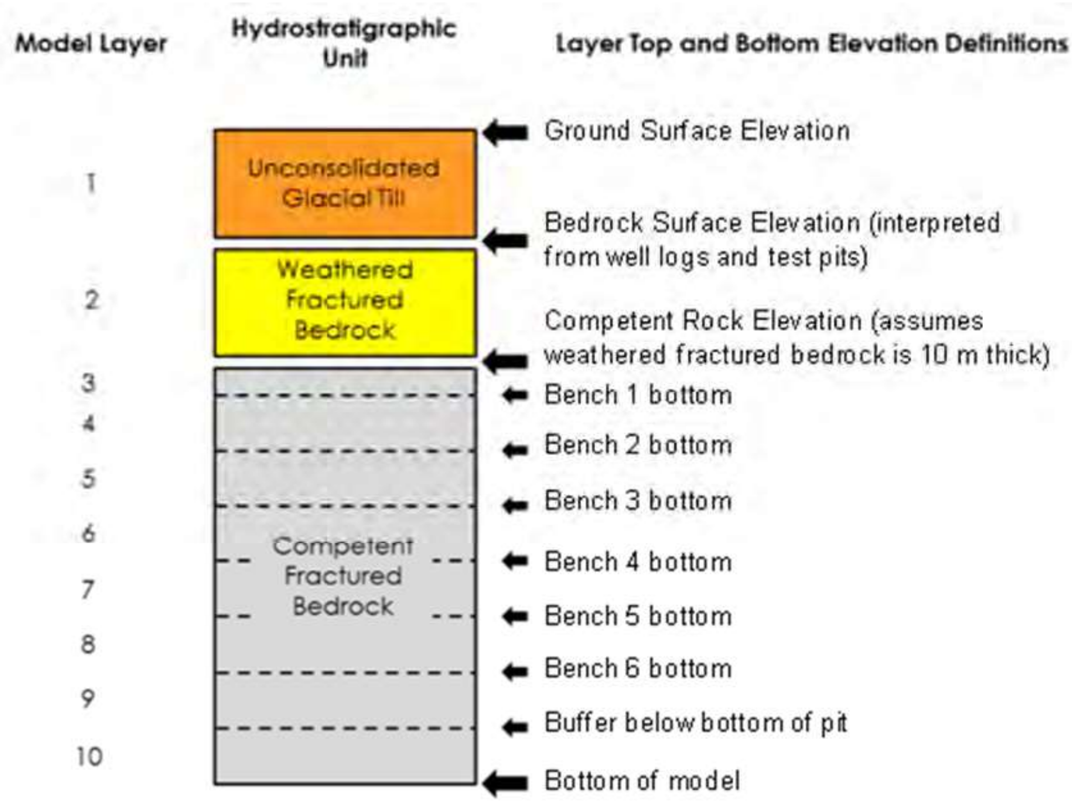

Figure 4.2 Model layer top and bottom elevation definitions and hydrostratigraphy

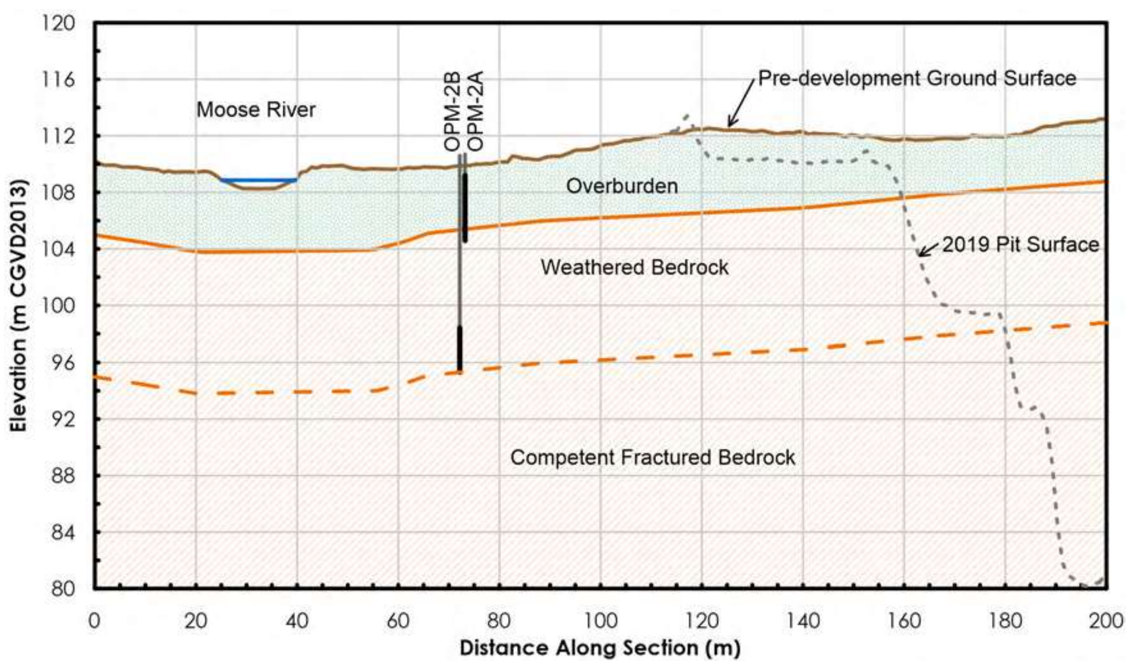

Figure 4.3 Cross-section between Moose River and Open Pit at OPM-2A/B

4.2 DISTRIBUTION OF HYDROGEOLOGICAL PARAMETERS

The hydraulic conductivity, porosity, and recharge rate were assigned in the model based on the hydrostratigraphic units as defined in the conceptual model. The geometric mean hydraulic conductivity values for each unit determined from the field testing programs were used in the initial model set-up, and the hydrostratigraphic units were assumed to be uniform and isotropic. The bulk hydraulic conductivity of the isotropic bedrock hydrostratigraphic units are interpreted to include the fractures and faults described in Section 3.3.2.

4.3 BOUNDARY CONDITIONS

4.3.1 Model Boundary

The model limits were assigned based on local watershed boundaries but were extended into neighbouring watersheds based on anticipated effects from the presence of the open pit. The model was extended to natural hydrologic/hydrogeologic boundaries, including watershed boundaries (assumed to be coincident with groundwater flow divides) or surface water features (also assumed to be coincident with groundwater flow divides). The model domain limits are presented on Figure 2.1.

Surface elevations were derived from the LiDAR-derived digital elevation model (DEM) data obtained from GeoNova (2020). The bedrock surface was derived from on-site boreholes and test pits, and from the Nova Scotia drill hole database (Nova Scotia Department of Natural Resources 2016) for off-site exploration boreholes. A minimum overburden thickness of 1 m was assigned in the model.

4.3.2 Recharge and Evapotranspiration

The type of soil and vegetation present at surface is an important factor in determining whether precipitation will become runoff or groundwater recharge. Recharge rates were assigned based on the hydrostratigraphic units exposed at the top of the model domain and consideration of the surficial geology mapping for the area. The groundwater recharge rate was adjusted for each of these major groups during the model calibration process. However, at the end of calibration, the recharge was found to be relatively uniform, so a uniform recharge rate was specified for the entire model domain. Recharge rates were specified for average annual and average summer conditions.

Evapotranspiration was also assigned to the model domain, using a uniform rate representing average annual and average summer conditions. An extinction depth of 1 m was specified for the evapotranspiration rates. Evapotranspiration was adjusted with the recharge rate during the model calibration.

4.3.3 Lakes

Several lakes and watercourses are located within the model domain. Lakes were assigned as boundary conditions in the model using a head-dependent flux boundary (i.e., general head boundary), as shown on Figure 4.4. This type of boundary conditions determines the flow rate between the boundary condition and the aquifer based on the head assigned to the boundary condition. The vertical extent of the lakes was determined using available bathymetric data collected at the lakes, and the reference head for each cell was obtained from the digital elevation model.

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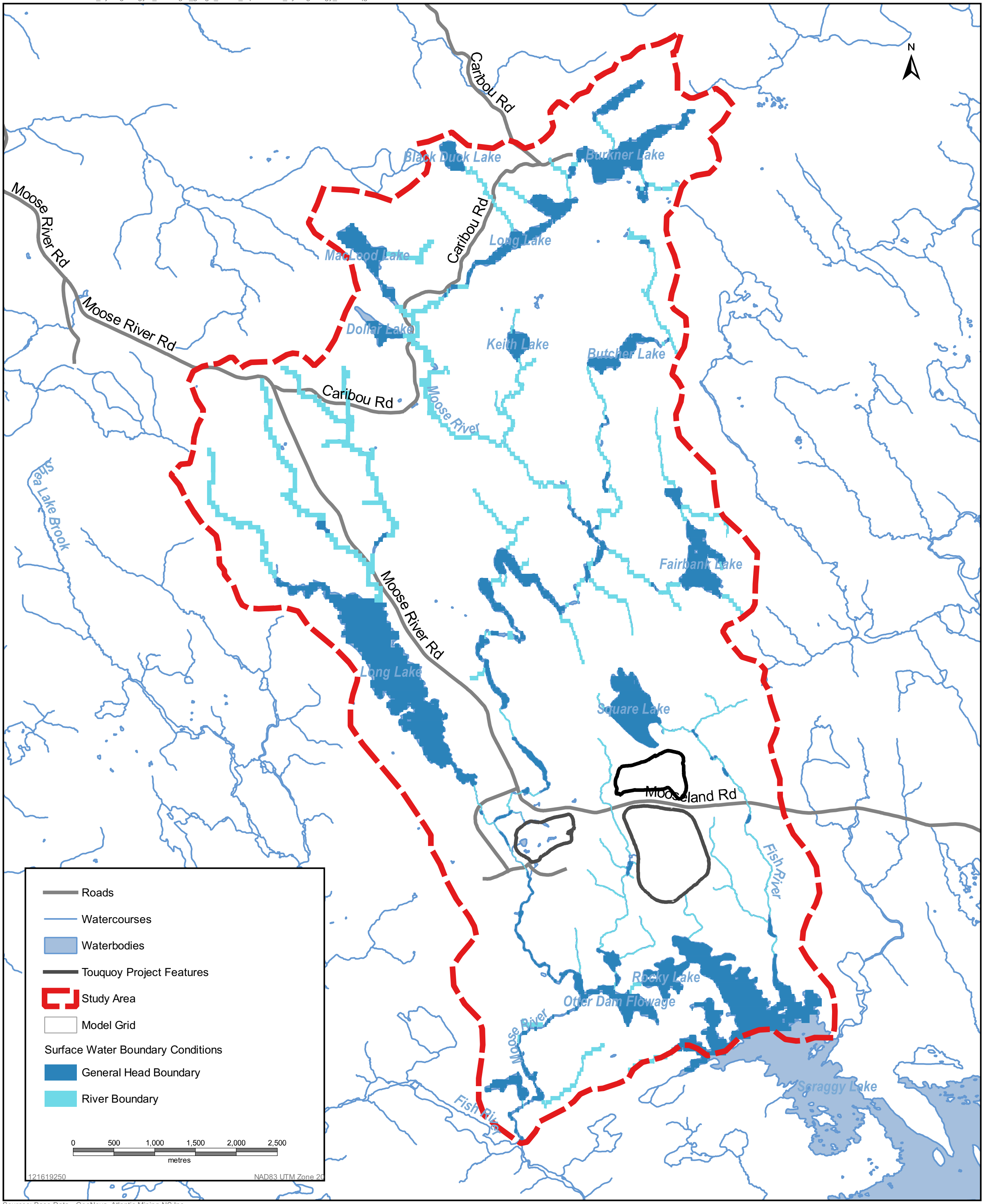

Sources: Base Data - GeoNova, Atlantic Mining NS Inc.

Surface Water Boundary Conditions

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Figure 4.4

The interaction between the surface water in the lakes and the groundwater in the underlying aquifers is defined by a “conductance” term. This term represents the presence of a layer of sediment on the lakebed or streambed that can affect the rate of water transferred between the lake or watercourse and the underlying model layer. The conductance term was used as a calibration parameter.

4.3.4 Watercourses

Watercourses in the groundwater model are assigned to Layer 1 using the River package. The river package allows water to exit the groundwater system when the head in the aquifer is greater than the assigned head (stage) of the river, and allows water to enter the groundwater system with the head in the aquifer is lower than the assigned stage of the river. The rivers were divided into two types within the model, based on river width estimates obtained from satellite imagery. River cells define most stream and river reaches in the domain, and with the exception of Moose River, were assigned an assumed width of up to 3 m and depth of 0.3 m.

Moose River was represented using a combination of river cells and general head boundary cells. The river cells define run and shallow pool reaches of Moose River, and were assigned widths of 8 m and depths of 1 m, except in the area of the Touquoy open pit where additional information on stream width and depth were collected from field observations. Larger and deeper pool areas in Moose river ware represented using a general head boundary condition, based on mapping provided in the Nova Scotia Hydrographic Network (Province of Nova Scotia 2020). The widths for these areas were determined from the mapped extent of the river reaches, and the depths based on a minimum depth of 1 m, or based on field observations of stream depths under average annual or average summer conditions.

The riverbed conductance term was also assigned to the river cells and was used as a calibration parameter. The default conductance term was assigned based on the hydraulic conductivity of the underlying overburden material.

4.3.5 Touquoy Open Pit

The extent of the Touquoy open pit in August 2019 was assigned to the model for the calibration to average annual and average summer conditions observed in 2019. A 3D surface representing the pit shell that was provided by AMNS for inclusion in the model.

Model cells that were intersected by the walls or floor of the open pit were identified and assigned as a seepage face boundary condition in the model using the MODFLOW DRAIN package. The conductance of the DRAIN cells was specified based on the hydraulic conductivity in the cells multiplied by the width, length and thickness of the cell. Blasting effects on the hydraulic conductivity of the bedrock were assumed to be localized to the first 5 m of the exposed bedrock face, coinciding with the width of the drain cells, and were incorporated as part of the conductance value for the drains. The conductance was adjusted during the model calibration to match average summer and average annual pit inflow rates.

4.4 CALIBRATION

4.4.1 Calibration Methodology

The groundwater model was calibrated to known conditions at the Touquoy open pit in 2019. Model calibration was conducted using an iterative approach under steady-state conditions representing average annual and average summer flow conditions. This involved a process where a flow simulation was carried out, the resulting groundwater levels and baseflow rates to watercourses were compared to measured values, and the model input parameters were re-adjusted to achieve better agreement with observed (field measured) conditions and the overall interpreted groundwater flow directions. The process of model calibration involves the adjustment of model parameter values to match field-measured values within a pre-established range of error. A hybrid calibration approach was used that combined automated parameter estimation, facilitated using the Parameter Estimation (PEST) code (Doherty 2018), together with professional judgement and interpretation of the calibration results.

The calibration was completed using the following steps:

1. Prepare model files and input parameters
2. Run PEST to estimate parameter values that provide the best average fit to the observations
3. Review the model results
4. Adjust insensitive parameters from the PEST calibration (if any can be identified)
5. Repeat steps 2 through 4 until the model is determined to be adequately calibrated within acceptable ranges of error

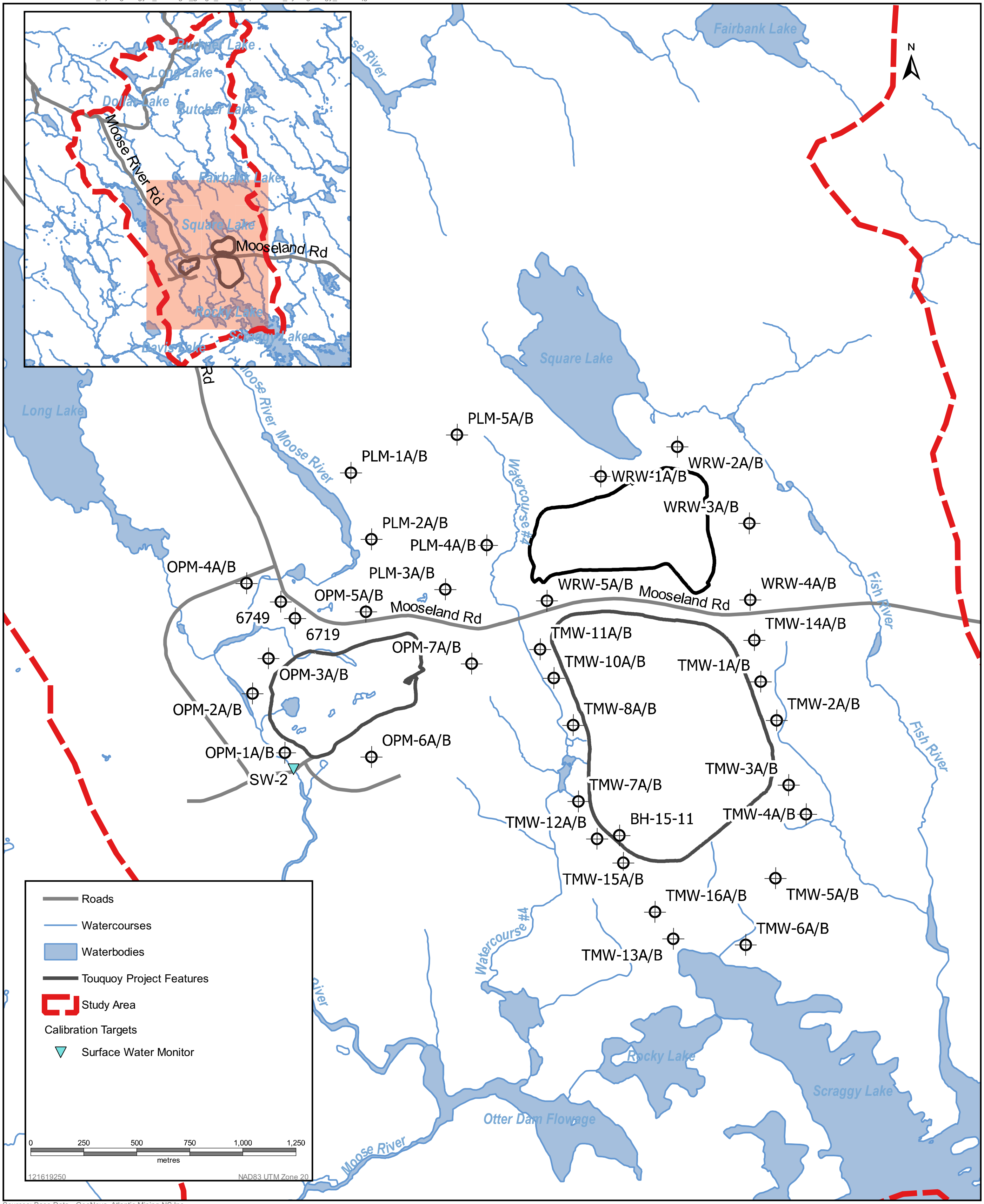
Several parameters were adjusted during the calibration of the model, including:

- Horizontal hydraulic conductivity
- Vertical hydraulic conductivity
- Recharge
- Evapotranspiration
- Riverbed and lake bed conductance

These parameters were adjusted automatically using PEST over the ranges determined from field observations or literature values. A total of 38 parameters were adjusted during the calibration process.

4.4.2 Calibration to Water Levels

Model calibration was assessed by comparing model simulated water levels to observations collected from water level data collected from onsite monitoring wells (Stantec 2020). The water level target at each location was calculated as the average annual and average summer water level observed during 2019 for each location. Water well records had only one water level measurement from the time of completion and were considered the least reliable measurements in the calibration process. Water level observations from onsite wells were considered the most reliable as they have a longer period of record under current land use conditions and varying climatic conditions and provide an average water level appropriate for calibration of a steady state groundwater flow model. The calculated water level targets are presented in Table 4.1 for average annual conditions, and in Table 4.2 for average summer conditions. The locations of the 66 monitoring wells (in 33 well nests) used for water level targets are shown on Figure 4.5.



Sources: Base Data - GeoNova, Atlantic Mining NS Inc.

Location of Calibration Targets

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Figure 4.5

Table 4.1 Water Level Calibration Residuals and Statistics for Average Annual 2019 Conditions

Location	Average Annual Target Water Level (m CGVD2013)	Simulated Average Annual Water Level (m CGVD2013)	Residual (m)	Target Type
PLM-1A	131.302	132.092	-0.790	Monitoring Well
PLM-1B	128.546	130.726	-2.179	Monitoring Well
PLM-2A	119.447	117.855	1.592	Monitoring Well
PLM-2B	118.791	118.279	0.512	Monitoring Well
PLM-3A	129.148	128.380	0.769	Monitoring Well
PLM-3B	125.498	126.945	-1.447	Monitoring Well
PLM-4A	125.487	124.084	1.403	Monitoring Well
PLM-4B	124.509	124.720	-0.210	Monitoring Well
PLM-5A	126.076	127.842	-1.765	Monitoring Well
PLM-5B	126.098	128.038	-1.940	Monitoring Well
WRW-1A	131.132	129.074	2.058	Monitoring Well
WRW-1B	130.796	129.099	1.698	Monitoring Well
WRW-2A	133.852	129.600	4.253	Monitoring Well
WRW-2B	133.302	130.596	2.706	Monitoring Well
WRW-3A	124.903	128.020	-3.118	Monitoring Well
WRW-3B	125.840	128.407	-2.568	Monitoring Well
WRW-4A	129.504	127.155	2.349	Monitoring Well
WRW-4B	125.834	126.883	-1.050	Monitoring Well
WRW-5A	120.117	119.702	0.415	Monitoring Well
WRW-5B	120.027	119.562	0.465	Monitoring Well
OPM-1A	107.246	107.367	-0.121	Monitoring Well
OPM-1B	106.788	107.338	-0.550	Monitoring Well
OPM-2A	109.074	108.926	0.148	Monitoring Well
OPM-2B	102.597	104.701	-2.103	Monitoring Well
OPM-3A	114.914	114.155	0.759	Monitoring Well
OPM-3B	114.825	114.157	0.668	Monitoring Well
OPM-4A	113.140	113.795	-0.655	Monitoring Well
OPM-4B	113.315	113.800	-0.485	Monitoring Well
OPM-5A	117.556	117.508	0.047	Monitoring Well
OPM-5B	118.055	117.390	0.665	Monitoring Well
OPM-6A	114.514	113.728	0.787	Monitoring Well
OPM-6B	114.678	113.581	1.097	Monitoring Well

Table 4.1 Water Level Calibration Residuals and Statistics for Average Annual 2019 Conditions

Location	Average Annual Target Water Level (m CGVD2013)	Simulated Average Annual Water Level (m CGVD2013)	Residual (m)	Target Type
OPM-7A	115.464	118.117	-2.653	Monitoring Well
OPM-7B	115.525	118.097	-2.572	Monitoring Well
TMW-1A	115.550	114.455	1.096	Monitoring Well
TMW-1B	115.570	114.517	1.053	Monitoring Well
TMW-2A	113.753	112.612	1.141	Monitoring Well
TMW-2B	113.538	112.687	0.851	Monitoring Well
TMW-3A	108.800	109.862	-1.061	Monitoring Well
TMW-3B	108.707	109.865	-1.158	Monitoring Well
TMW-4A	107.399	108.198	-0.800	Monitoring Well
TMW-4B	107.514	108.199	-0.685	Monitoring Well
TMW-5A	107.346	109.007	-1.661	Monitoring Well
TMW-5B	107.406	108.973	-1.568	Monitoring Well
TMW-6A	105.002	105.721	-0.719	Monitoring Well
TMW-6B	104.849	105.668	-0.819	Monitoring Well
TMW-7A	108.226	109.417	-1.191	Monitoring Well
TMW-7B	107.879	109.475	-1.596	Monitoring Well
TMW-8A	108.472	109.213	-0.741	Monitoring Well
TMW-8B	108.516	109.395	-0.879	Monitoring Well
TMW-9A	110.780	111.951	-1.171	Monitoring Well
TMW-9B	110.881	112.086	-1.205	Monitoring Well
TMW-10A	114.339	113.942	0.397	Monitoring Well
TMW-10B	114.301	114.056	0.245	Monitoring Well
TMW-11A	113.739	115.643	-1.905	Monitoring Well
TMW-11B	112.419	115.785	-3.367	Monitoring Well
TMW-12A	113.809	112.737	1.073	Monitoring Well
TMW-12B	115.664	113.145	2.519	Monitoring Well
TMW-13A	109.399	109.047	0.352	Monitoring Well
TMW-13B	106.698	107.807	-1.109	Monitoring Well
TMW-14A	121.484	118.793	2.691	Monitoring Well
TMW-14B	121.084	118.959	2.125	Monitoring Well
TMW-15A	120.942	118.185	2.757	Monitoring Well
TMW-15B	119.068	117.870	1.198	Monitoring Well

Table 4.1 Water Level Calibration Residuals and Statistics for Average Annual 2019 Conditions

Location	Average Annual Target Water Level (m CGVD2013)	Simulated Average Annual Water Level (m CGVD2013)	Residual (m)	Target Type
TMW-16A	115.719	116.260	-0.541	Monitoring Well
TMW-16B	115.409	115.211	0.198	Monitoring Well
Residual Statistics				
Number of Wells			66	
Sum of Squared Error (m²)			166	
Mean Error (m)			-0.095	
Absolute Mean Error (m)			1.310	
Root Mean Squared Error (m)			1.584	
Normalized Mean Squared Error (%)			5.1	

Table 4.2 Water Level Calibration Residuals and Statistics for Average Summer 2019 Conditions

Location	Average Annual Target Water Level (m CGVD2013)	Simulated Average Annual Water Level (m CGVD2013)	Residual (m)	Target Type
PLM-1A	130.521	131.932	-1.410	Monitoring Well
PLM-1B	128.246	130.235	-1.989	Monitoring Well
PLM-2A	119.042	117.036	2.006	Monitoring Well
PLM-2B	118.386	117.634	0.752	Monitoring Well
PLM-3A	128.184	126.478	1.706	Monitoring Well
PLM-3B	124.506	124.605	-0.099	Monitoring Well
PLM-4A	124.427	123.834	0.593	Monitoring Well
PLM-4B	124.089	123.952	0.136	Monitoring Well
PLM-5A	125.976	126.173	-0.197	Monitoring Well
PLM-5B	126.061	126.514	-0.454	Monitoring Well
WRW-1A	130.895	128.802	2.093	Monitoring Well
WRW-1B	130.433	128.850	1.583	Monitoring Well
WRW-2A	133.460	129.100	4.360	Monitoring Well
WRW-2B	132.779	130.212	2.566	Monitoring Well
WRW-3A	124.951	125.874	-0.924	Monitoring Well
WRW-3B	125.735	126.567	-0.831	Monitoring Well

Table 4.2 Water Level Calibration Residuals and Statistics for Average Summer 2019 Conditions

Location	Average Annual Target Water Level (m CGVD2013)	Simulated Average Annual Water Level (m CGVD2013)	Residual (m)	Target Type
WRW-4A	128.501	126.496	2.005	Monitoring Well
WRW-4B	125.349	126.198	-0.849	Monitoring Well
WRW-5A	119.922	119.259	0.662	Monitoring Well
WRW-5B	119.860	119.115	0.745	Monitoring Well
OPM-1A	105.899	107.078	-1.179	Monitoring Well
OPM-1B	105.269	106.758	-1.489	Monitoring Well
OPM-2A	106.478	108.161	-1.684	Monitoring Well
OPM-2B	100.230	103.165	-2.935	Monitoring Well
OPM-3A	113.724	113.148	0.576	Monitoring Well
OPM-3B	113.666	113.151	0.515	Monitoring Well
OPM-4A	112.877	113.303	-0.425	Monitoring Well
OPM-4B	112.909	113.302	-0.393	Monitoring Well
OPM-5A	116.076	116.422	-0.345	Monitoring Well
OPM-5B	117.823	116.399	1.424	Monitoring Well
OPM-6A	113.607	112.119	1.488	Monitoring Well
OPM-6B	113.765	111.932	1.833	Monitoring Well
OPM-7A	114.872	116.288	-1.416	Monitoring Well
OPM-7B	114.939	116.305	-1.366	Monitoring Well
TMW-1A	114.788	113.488	1.300	Monitoring Well
TMW-1B	114.751	113.574	1.177	Monitoring Well
TMW-2A	113.343	112.339	1.003	Monitoring Well
TMW-2B	113.180	112.368	0.812	Monitoring Well
TMW-3A	108.279	109.193	-0.914	Monitoring Well
TMW-3B	108.124	109.207	-1.083	Monitoring Well
TMW-4A	107.157	107.810	-0.653	Monitoring Well
TMW-4B	107.278	107.820	-0.542	Monitoring Well
TMW-5A	107.331	108.224	-0.893	Monitoring Well
TMW-5B	107.343	108.201	-0.858	Monitoring Well
TMW-6A	104.354	105.397	-1.042	Monitoring Well
TMW-6B	104.142	105.367	-1.225	Monitoring Well
TMW-7A	107.961	108.995	-1.035	Monitoring Well
TMW-7B	107.879	109.025	-1.146	Monitoring Well

Table 4.2 Water Level Calibration Residuals and Statistics for Average Summer 2019 Conditions

Location	Average Annual Target Water Level (m CGVD2013)	Simulated Average Annual Water Level (m CGVD2013)	Residual (m)	Target Type
TMW-8A	108.415	108.823	-0.407	Monitoring Well
TMW-8B	108.420	108.989	-0.569	Monitoring Well
TMW-9A	110.335	111.594	-1.258	Monitoring Well
TMW-9B	110.659	111.692	-1.032	Monitoring Well
TMW-10A	114.122	113.489	0.634	Monitoring Well
TMW-10B	114.090	113.600	0.490	Monitoring Well
TMW-11A	113.419	115.344	-1.925	Monitoring Well
TMW-11B	112.131	115.479	-3.349	Monitoring Well
TMW-12A	113.345	112.069	1.276	Monitoring Well
TMW-12B	115.664	112.446	3.218	Monitoring Well
TMW-13A	108.720	108.755	-0.035	Monitoring Well
TMW-13B	106.520	107.356	-0.836	Monitoring Well
TMW-14A	120.974	118.035	2.940	Monitoring Well
TMW-14B	120.596	117.797	2.799	Monitoring Well
TMW-15A	120.739	117.870	2.869	Monitoring Well
TMW-15B	118.999	117.324	1.675	Monitoring Well
TMW-16A	115.535	115.904	-0.369	Monitoring Well
TMW-16B	115.272	114.759	0.512	Monitoring Well
Residual Statistics				
Number of Wells			66	
Sum of Squared Error (m^2)			155	
Mean Error (m)			0.130	
Absolute Mean Error (m)			1.256	
Root Mean Squared Error (m)			1.531	
Normalized Mean Squared Error (%)			4.6	

A plot of the simulated (modelled) versus observed (measured) groundwater levels is shown in Figure 4.6. A line of best fit (e.g., a line having a slope of 1.0) is shown for comparison. Simulated groundwater levels that match the observed groundwater levels exactly will fall on this line. As shown on Figure 4.6 and in Table 4.1, there is generally good agreement with the automated and manual water level targets.

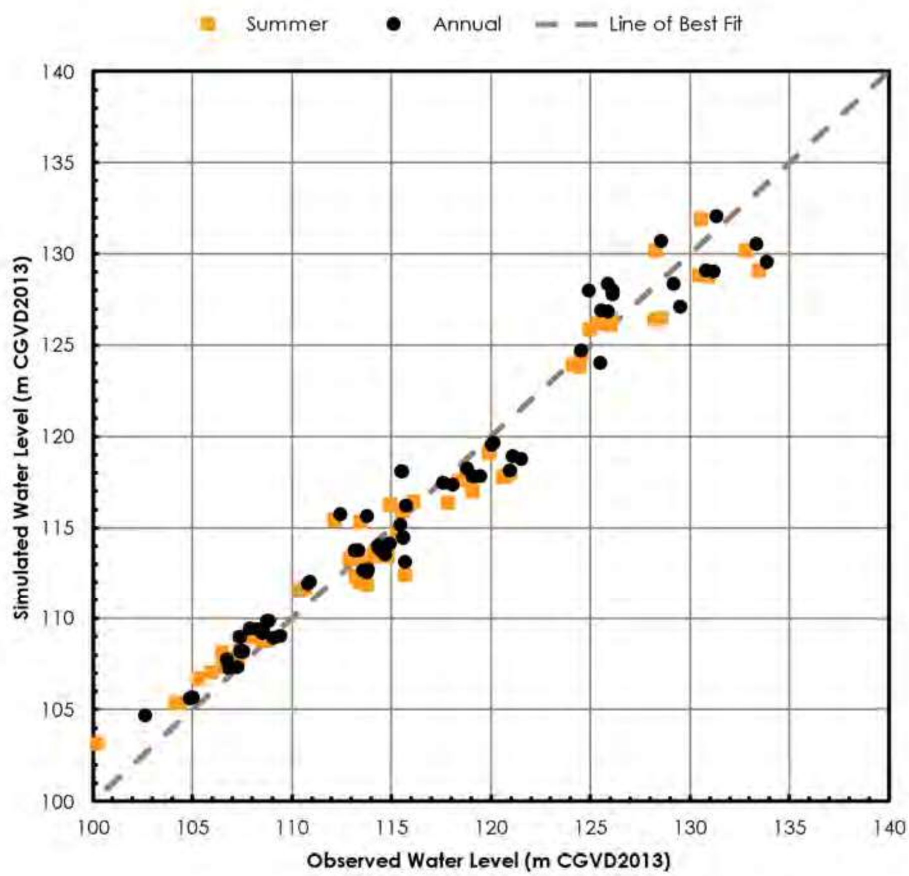


Figure 4.6 Scatterplot Showing the Match of Observed and Simulated Water Levels for Average Annual and Average Summer 2019 Conditions

The statistical measures of the calibration to the water level data are reported in Table 4.1 for average annual conditions, and in Table 4.2 for average summer conditions. These measures include the standard error of the estimate and the root mean squared (RMS) error. In evaluating the fit between the observed and the simulated water levels, the RMS error is usually regarded as the best measure (Anderson and Woessner 1991). The RMS error is essentially a standard deviation calculated as the average of the squared differences between the measured and the simulated water levels. If the ratio of the RMS error to the total water level differential over the model area is small (e.g., less than 10%; Spitz and Moreno 1996), then the errors are only a small part of the overall hydraulic response of the model. In this simulation, the ratio of the RMS errors to the total water level differential (5.2% for average annual and 4.6% for average summer conditions) are less than the recommended 10% threshold.

4.4.3 Calibration to Groundwater Flow Rates

Model calibration was assessed by comparing model simulated groundwater baseflow rates to Moose River, and groundwater inflow rates to the Touquoy open pit for average annual and average summer conditions. Baseflow in Moose River was estimated at SW-2 (see Figure 4.5) using a recursive filtering algorithm (Arnold et al. 1995) to determine baseflow indices for the observed summer and annual river flow rates at SW-2. The baseflow indices and associated baseflow rates are provided on Table 4.3.

Table 4.3 Baseflow Targets in Moose River

Baseflow Period	Baseflow Index	Baseflow Rate (m^3/d)
2019	0.29	28,814
Summer 2019 (July-September)	0.52	9,848

Groundwater inflow rates to the open pits were calculated based on the observed pit dewatering rates at the Touquoy open pit. Groundwater inflow rates for the summer months (i.e., July to September 2019) were estimated based on the dewatering rates, and are presented on Table 4.4. Groundwater inflow rates for the annual conditions were corrected to account for direct precipitation on the open pit.

Table 4.4 Groundwater Inflow Targets to Touquoy Open Pit

Period	Groundwater Inflow Rate (m^3/d)
2019	719
Summer 2019 (July-September)	355

The match of the groundwater flow targets in Moose River and to the Touquoy open pit are presented on Table 4.5. As shown on the table, the groundwater baseflow rates to Moose River are slightly (2%) underpredicted for the average annual condition, but slightly (5%) overpredicted for the summer baseflow period. The average annual pit inflow rates were underpredicted by 3% for the annual conditions, and were overpredicted by 13% for the summer conditions. These are considered good matches the complete set of flow targets and water levels.

Table 4.5 Calibrated Groundwater Inflow Rates

Flow Target	Target Rate (m^3/d)	Simulated Rate (m^3/d)
Moose River Baseflow 2019 (Annual)	28,814	29,346
Moose River Baseflow Summer 2019 (July-September)	9,848	9,386
Pit Inflow 2019 (Annual)	719	700
Pit Inflow Summer 2019	355	402

4.4.4 Calibrated Model Parameters

The values of the hydrogeologic parameters that were determined from the calibration process are presented in Table 4.6. The hydraulic conductivity values for the various hydrostratigraphic units generated by the model are within the ranges expected for the materials based on measured and literature values.

Table 4.6 Calibrated Model Parameters

Parameter	Value at End of Calibration	Expected Range	
Groundwater Recharge and Evaporatranspiration (mm/yr)			
Annual Recharge	322	135	405
Summer Recharge	123		
Annual Evapotranspiration	85		
Summer Evapotranspiration	97		
Hydraulic Conductivity (m/s)			
Stony Till Plain	1.0×10^{-4}	1.0×10^{-8}	1.0×10^{-4}
Silt Till Plain	1.0×10^{-4}	1.0×10^{-8}	1.0×10^{-4}
Organics	1.0×10^{-4}	1.0×10^{-8}	1.0×10^{-4}
Drumlin	4.5×10^{-6}	1.0×10^{-8}	1.0×10^{-4}
Weathered Cunard Member	5.6×10^{-8}	3.9×10^{-9}	4.4×10^{-4}
Weathered Beaverbank Member	3.7×10^{-7}	3.9×10^{-9}	4.4×10^{-4}
Weathered Taylor's Head Member	3.7×10^{-7}	3.9×10^{-9}	4.4×10^{-4}
Weathered Tangier & Moose River Members	2.4×10^{-7}	3.9×10^{-9}	4.4×10^{-4}
Weathered Moose River Member	1.3×10^{-8}	3.9×10^{-9}	4.4×10^{-4}
Competent Cunard Member	3.9×10^{-9}	3.9×10^{-9}	4.4×10^{-4}
Competent Beaverbank Member	1.1×10^{-8}	3.9×10^{-9}	4.4×10^{-4}
Competent Taylor's Head Member	6.7×10^{-9}	3.9×10^{-9}	4.4×10^{-4}
Competent Tangier & Moose River Members	4.9×10^{-9}	3.9×10^{-9}	4.4×10^{-4}
Competent Moose River Member	7.4×10^{-9}	3.9×10^{-9}	4.4×10^{-4}
Vertical Anisotropy (K_v/K_h)			
Stony Till Plain	1.0	0.001	5.0
Silt Till Plain	1.0	0.001	5.0

Table 4.6 Calibrated Model Parameters

Parameter	Value at End of Calibration	Expected Range	
Organics	1.0	0.001	5.0
Drumlin	2.0	0.001	5.0
Cunard Member	0.23	0.001	5.0
Beaverbank Member	0.98	0.001	5.0
Taylor's Head Member	4.3	0.001	5.0
Tangier & Moose River Members	0.81	0.001	5.0
Moose River Member	0.30	0.001	5.0
Cunard Member	1.0	0.001	5.0
Beaverbank Member	0.34	0.001	5.0
Taylor's Head Member	1.0	0.001	5.0
Tangier & Moose River Members	0.84	0.001	5.0
Moose River Member	0.53	0.001	5.0

As shown on Table 4.6, the hydraulic conductivity of the overburden units with the exception of the drumlins was at the high-end of the expected range. This may conservatively overestimate the flow into the overburden from groundwater recharge, but provides a reasonable match of water levels in the overburden across the site, and was therefore considered acceptable for this model.

4.4.5 Calibration Uncertainty

An evaluation of the potential uncertainty in the model was conducted by reviewing the relative sensitivity of the parameters adjusted during the calibration to the results of the final calibration. These values were determined using PEST, and are presented on Figure 4.7. The relative sensitivity is provided on a scale from 0 to 1 as a ratio of the sensitivity of the parameter to the calibration of the model, with the sum of the sensitivity values totaling 1. A sensitivity of 0 indicates that varying the parameter does not affect the outcome of the calibration, while a sensitivity approaching 1 indicates that the outcome of the calibration is completely dependent on the value of this parameter.

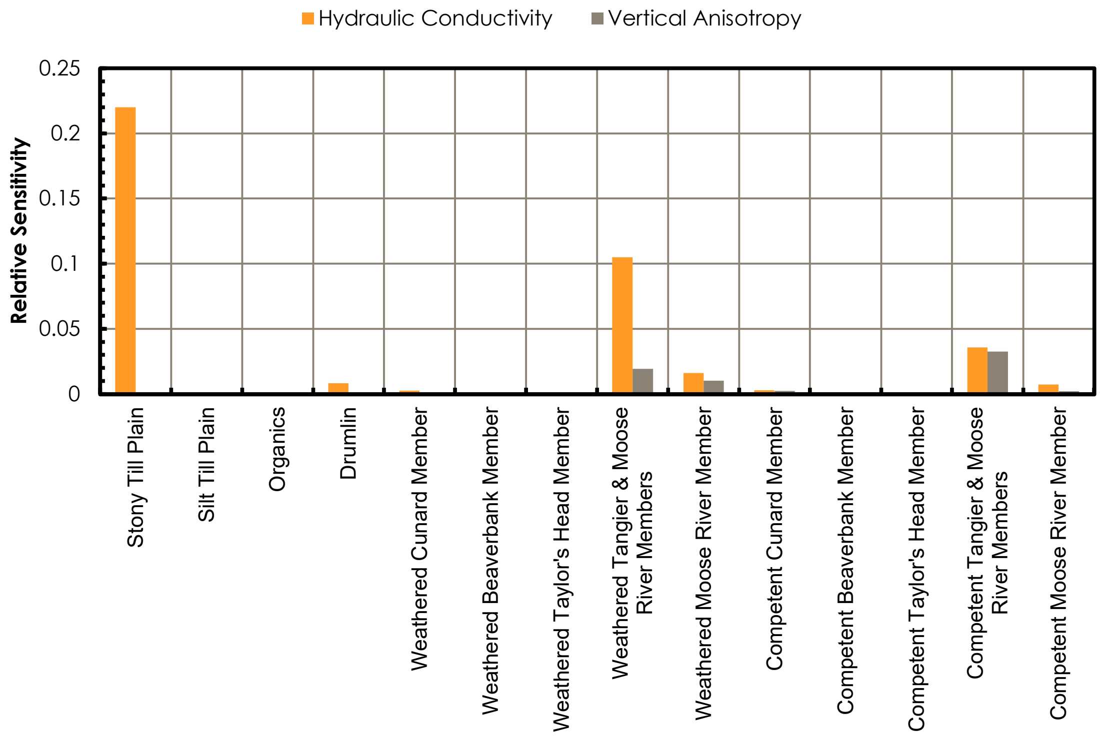
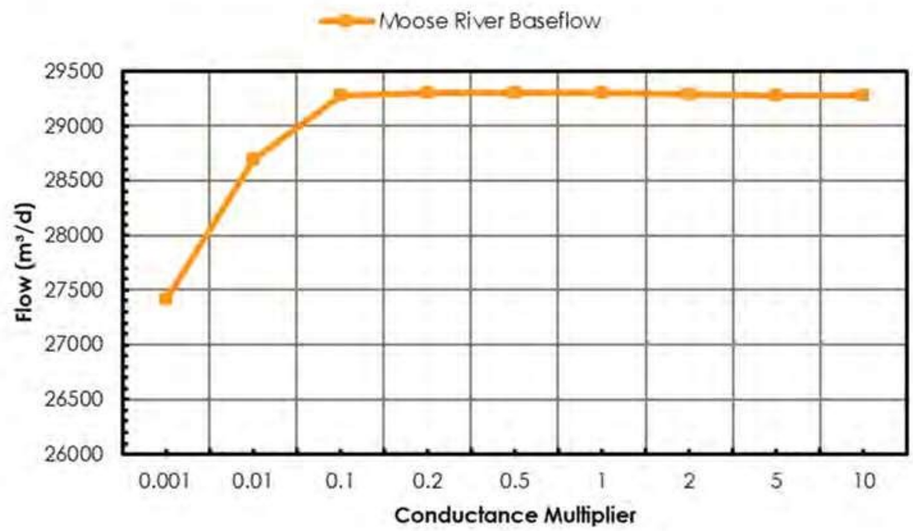


Figure 4.7 Calibration Sensitivity to Parameter Estimates

As shown on Figure 4.7, the model calibration was most sensitive to the hydraulic conductivity within the stony till plain unit (0.23) and the hydraulic conductivity of the weathered Tangier & Moose River Members fractured bedrock units (0.11). While it may be possible to vary the hydraulic conductivity of the shallow bedrock unit, adjusting this parameter away from its calibrated value would also require an alteration to the calibrated recharge rates, which are also sensitive parameters. Therefore, it is not possible to adjust one of these sensitive parameters independently without affecting the calibration of the model. Other parameters varied during the calibration had relatively small effects on the calibration (i.e., the calibration was less sensitive to these parameters over the range adjusted).

4.4.6 Sensitivity to Streambed and Pit Wall Conductance

The sensitivity of the calibrated groundwater baseflow rates to Moose River, and the groundwater inflow rates to the Touquoy open pit to the streambed or pit wall conductance factor were assessed following the calibration. The calibrated conductance factors were multiplied by factors ranging from 0.001 to 10 compared to the baseline conductance rates. The effects of the sensitivities are shown on Figure 4.8. As shown on the figure, the groundwater baseflow rates to Moose River and pit inflow rates do not change significantly from the calibrated rates by increasing the conductance rate by up to a factor of 10, or by decreasing the conductance by a factor of 0.1. Moose River baseflow are observed to decrease when the conductance is decreased by factors below 0.01. This also corresponds to an increase in the pit inflow rates. This is due to the higher groundwater levels that result when the baseflow to Moose River is restricted. The relative stability of the groundwater flow rates when conductance multipliers are greater than 0.1 indicate that the flow to the boundary conditions are controlled more by the hydraulic parameters of the aquifer instead of the conductance assigned to the boundary conditions.



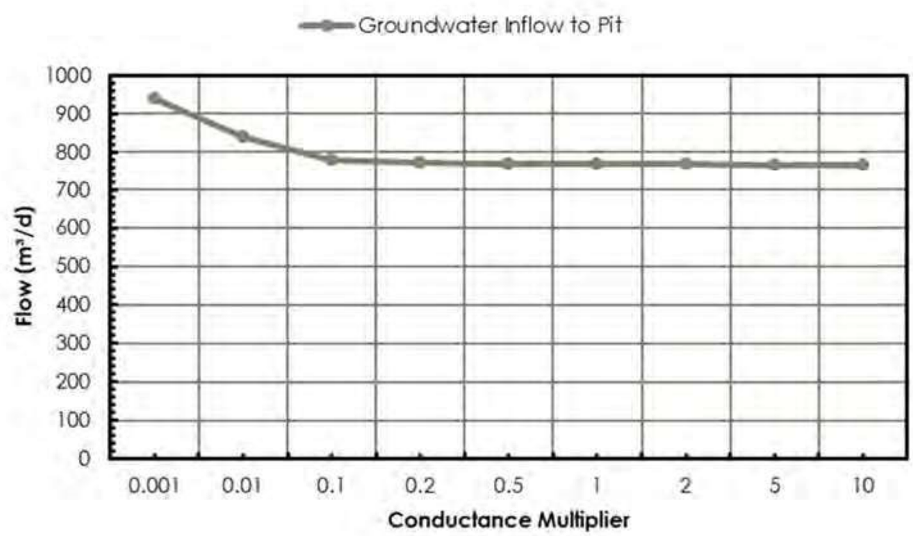


Figure 4.8 Sensitivity of Conductance to Calibrated Groundwater Flow Rates

5.0 MODEL APPLICATIONS

The calibrated groundwater flow model was used to simulate groundwater levels and flow and groundwater discharge to the receiving environment under baseline conditions. The baseline condition is defined as the conditions that will exist prior to disposal of Beaver Dam tailings into the Touquoy open pit (i.e., the conditions associated with the fully dewatered open pit at Touquoy). The baseline model results were then used to compare model predictions for the end of operation (i.e., the completion of placement of Beaver Dam tailings into the Touquoy open pit), during closure (i.e., the filling of the remainder of the Touquoy open pit with water), and after post-closure (i.e., after the Touquoy pit is full of water).

Section 5.1 presents the results from the existing conditions simulation using the calibrated model. Model modifications completed to allow simulation of the other phases of the Beaver Dam project, including baseline conditions when the Touquoy open pit is fully dewatered, operating conditions with the deposition of Beaver Dam tailings into the open pit, and the post-closure phase following the filling of the open pit are discussed in Sections 5.2 to 5.4.

5.1 PRE-DEVELOPMENT CONDITIONS

5.1.1 Model Setup

The calibrated flow model represents the existing conditions for the Touquoy mine site. This model was adjusted to reflect the pre-development conditions to evaluate the relative changes for drawdown comparisons for the Beaver Dam operations at the Touquoy mine site. This was achieved by removing the drain cells boundary condition representing the existing pit conditions used during model calibration. This results in active cells without a specified boundary condition.

5.1.2 Results

The water table elevation under pre-development conditions based on the calibrated groundwater flow model are shown on Figure 5.1. The model provides a good representation of the expected pre-development groundwater flow conditions with groundwater in the area of the open pit flowing from the water table high near east of the existing pit toward Moose River.

The model was used to estimate the groundwater discharge to Moose River and its tributaries upstream of surface water monitoring location SW-2. The net baseflow to Moose River at SW-2 is simulated to be 29,845 m^3/d under average annual conditions, and 9,689 under summer conditions. The baseflow rates are used to quantify changes to groundwater discharge during the baseline, operation and closure phases, as presented in Sections 5.2 to 5.4.

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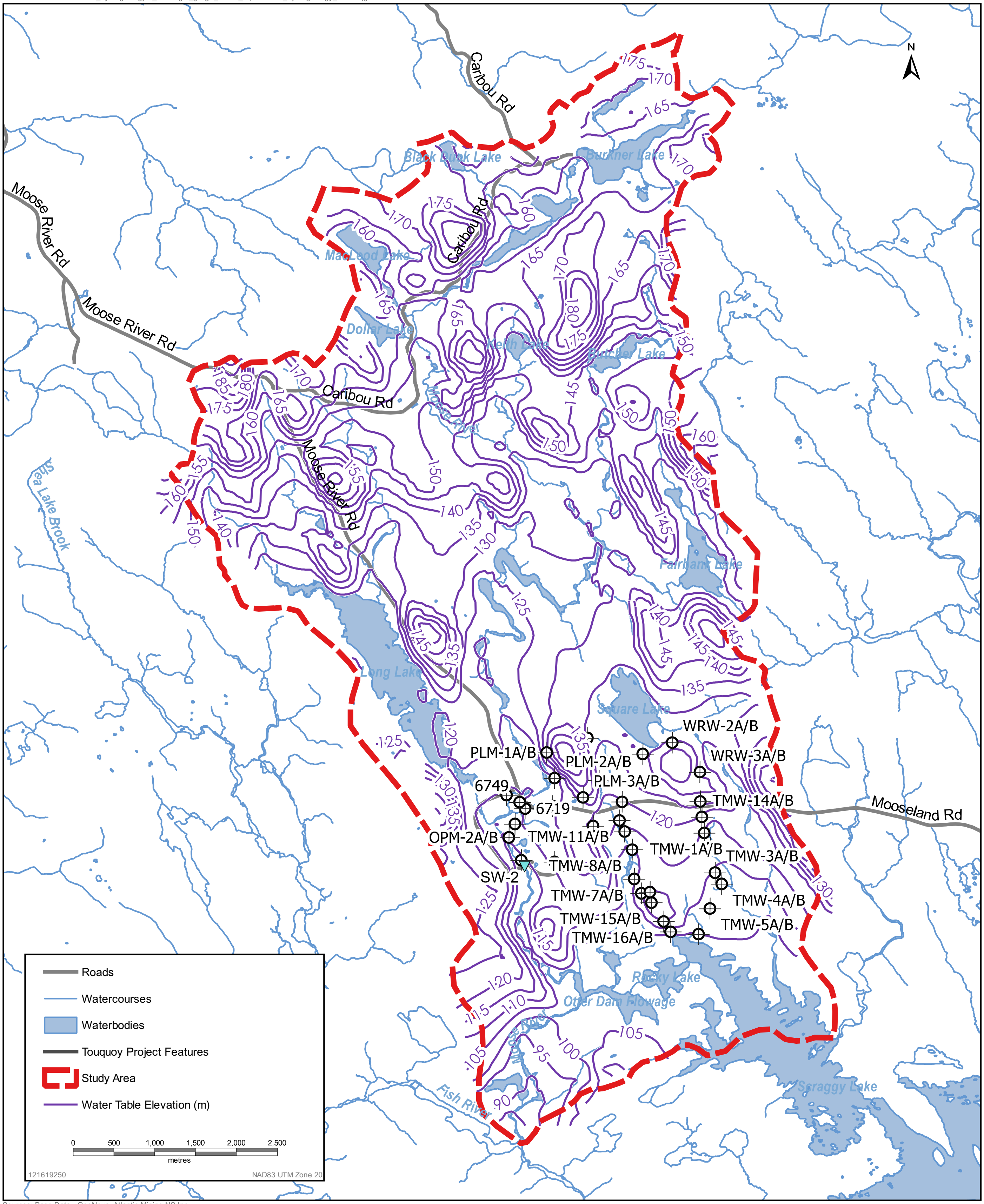


Sources: Base Data - GeoNova, Atlantic Mining NS Inc.

Water Table Elevation Contours under Average Annual Pre-Development Conditions

Stantec

Beaver Dam Gold Project

Figure 5.1

5.2 BASELINE CONDITIONS

5.2.1 Model Setup

Baseline conditions for the operation of the Touquoy open pit as a tailings management area will be the conditions when the Touquoy pit has been fully excavated and completely dewatered. To simulate these conditions, the model drain cells representing the seepage face boundary condition in the model were adapted to reflect the fully developed open pit, which is approximately 95 m deeper than the existing (i.e., August 2019) pit simulated during calibration. This was run for the average annual conditions to estimate the long-term water table position, and to quantify the baseflow to Moose River and pit inflow rates. The average summer conditions were also run to quantify the baseflow to Moose River and pit inflow rates.

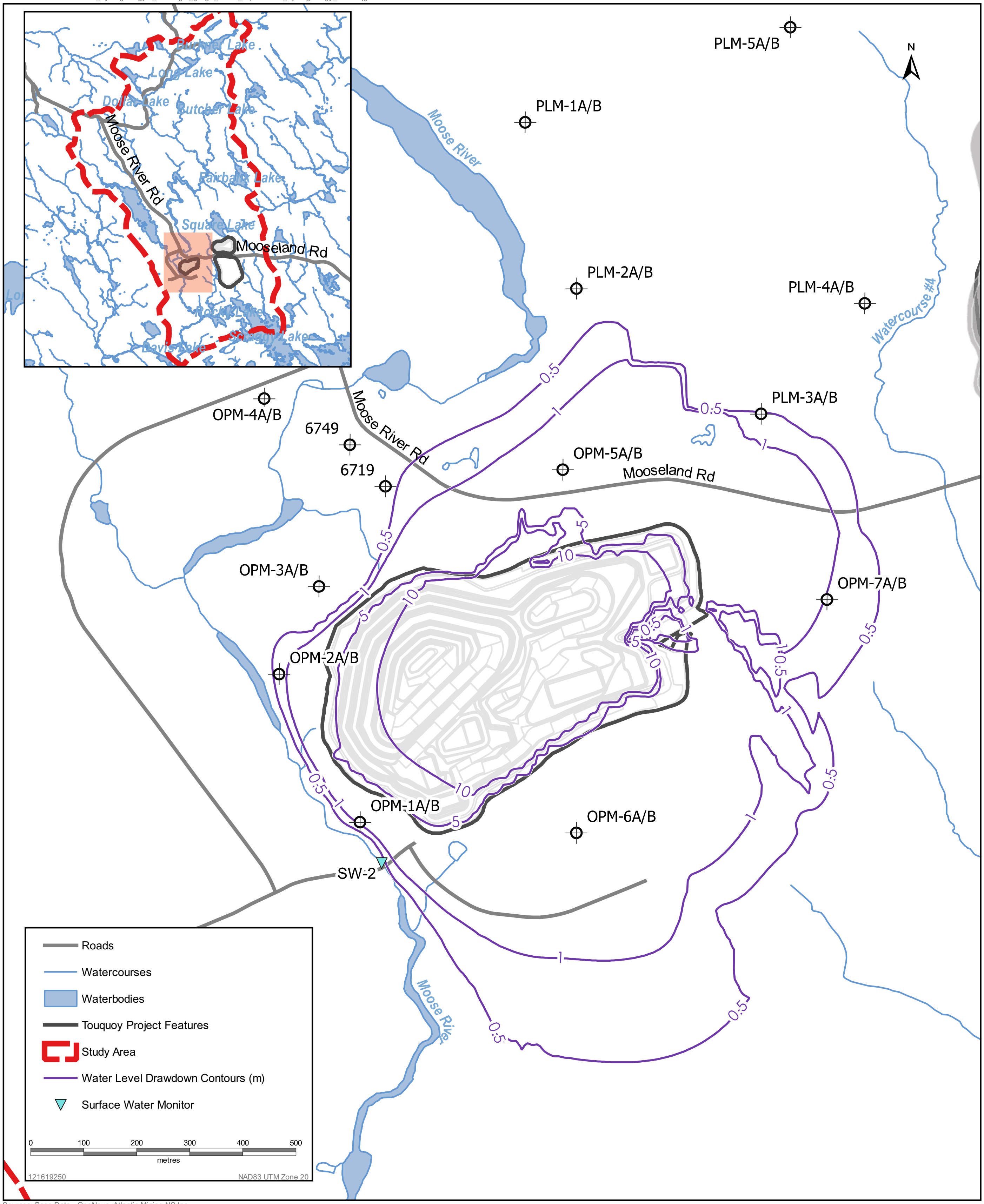
5.2.2 Results

The predicted average annual steady-state groundwater drawdown contours for the average annual baseline conditions are presented on Figure 5.2. The extent of the drawdown cone, as delineated by the 0.5 m drawdown contour, extends approximately 350 m south of the Touquoy pit and about 50 m west of the Touquoy pit toward Moose River.

The pit inflow rates and net baseflow to Moose River at SW-2 are presented on Table 5.1. Compared to the existing conditions, the groundwater inflows to the open pit are anticipated to increase by 68 m^3/d (9.5%) on a mean annual basis, and 42 m^3/d (10.4%) on a summer flow basis. The dewatering of the fully-developed open pit is anticipated to reduce the baseflow in Moose River at SW-2 by 49 m^3/d on a mean annual basis, and 29 m^3/d on a summer flow basis.

Table 5.1 Comparison of Baseline to Existing Groundwater Flows (m^3/d)

Flow Target	Existing (2019) Conditions	Baseline (Full Depth Pit)
Moose River Annual Baseflow	29,346	29,297
Moose River Summer Baseflow	9,386	9,357
Annual Pit Inflow	700	768
Summer Pit Inflow	402	444



Sources: Base Data - GeoNova, Atlantic Mining NS Inc.

Drawdown at Average Annual Baseline Conditions (Fully Dewatered Pit)

Stantec

Beaver Dam Gold Project

Figure 5.2

5.3 OPERATION

5.3.1 Model Setup

The operation of the Touquoy open pit as a tailings management area will result in the deposition of tailings and associated tailings slurry water to the open pit. As the pit fills, the dewatering rate to the open pit will decrease. The groundwater inflow to the open pit after dewatering is terminated was simulated to provide estimated flow rates for use in the water balance model. Groundwater inflow was simulated by adjusting the stage of the DRAIN cells representing the seepage faces described in Section 5.1, and the addition of tailings to layers below those stages. The stage of the water level forming a pit lake was specified at intervals corresponding to the model layer thicknesses over the entire depth of the open pit by conducting several steady-state runs, one for each model stage, based on the mean annual conditions. The placement of tailings in the open pit was assigned using a hydraulic conductivity of 1×10^{-6} m/s. At this value, the flow rates to the open pit are governed by the lower pit wall hydraulic conductivity.

5.3.2 Results

The predicted inflow rates to the Touquoy open pit compared to the pit lake stage associated with the deposition of the Beaver Dam-only scenario are presented on Figure 5.3. As shown on the figure, the inflow rates decrease from 768 m^3/d when the pit stage elevation is at -25 m CGVD2013, to 373 m^3/d at a pit stage of 108 m CGVD2013, at which point the pit lake will overflow to Moose River through a constructed spillway.

The predicted steady-state groundwater drawdown contours for the conditions when the pit is full are presented on Figure 5.4, and the water table contours are presented on Figure 5.5. The extent of the drawdown cone, as delineated by the 0.5 m drawdown contour, extends approximately 350 m south of the site and about 50 m west of the site toward Moose River which is similar to the fully dewatered pit. As presented on Figure 5.3, the groundwater flow to the open pit remains at 373 m^3/d because the 108 m CGVD2013 level is below the natural groundwater elevation within the footprint of the open pit. However, at this elevation, there are both groundwater inflows to, and outflows from, the open pit that are not observed with the fully dewatered open pit where no outflows are observed and the inflow condition dominates.

The net baseflow to Moose River at SW-2 under pit full conditions is simulated to be 29,608 m^3/d. Compared to the existing conditions, the groundwater inflows to the Touquoy pit filled to 108 m CGVD2013 is anticipated to increase the baseflow in Moose River at SW-2 by 249 m^3/d.

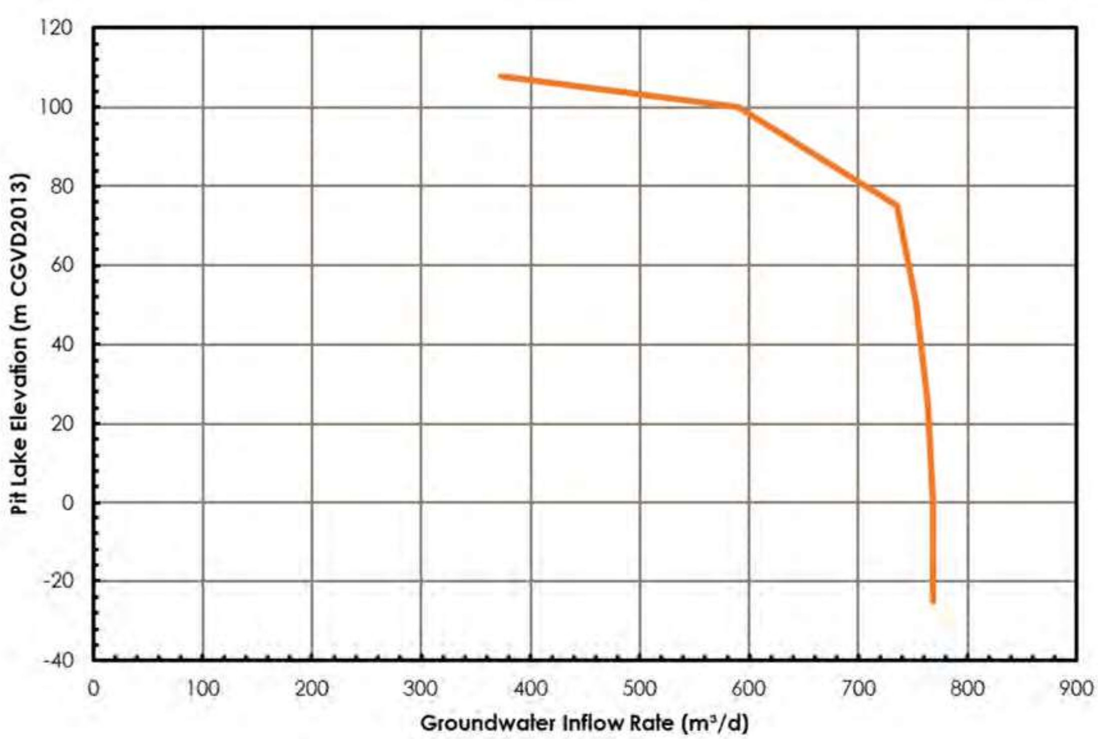
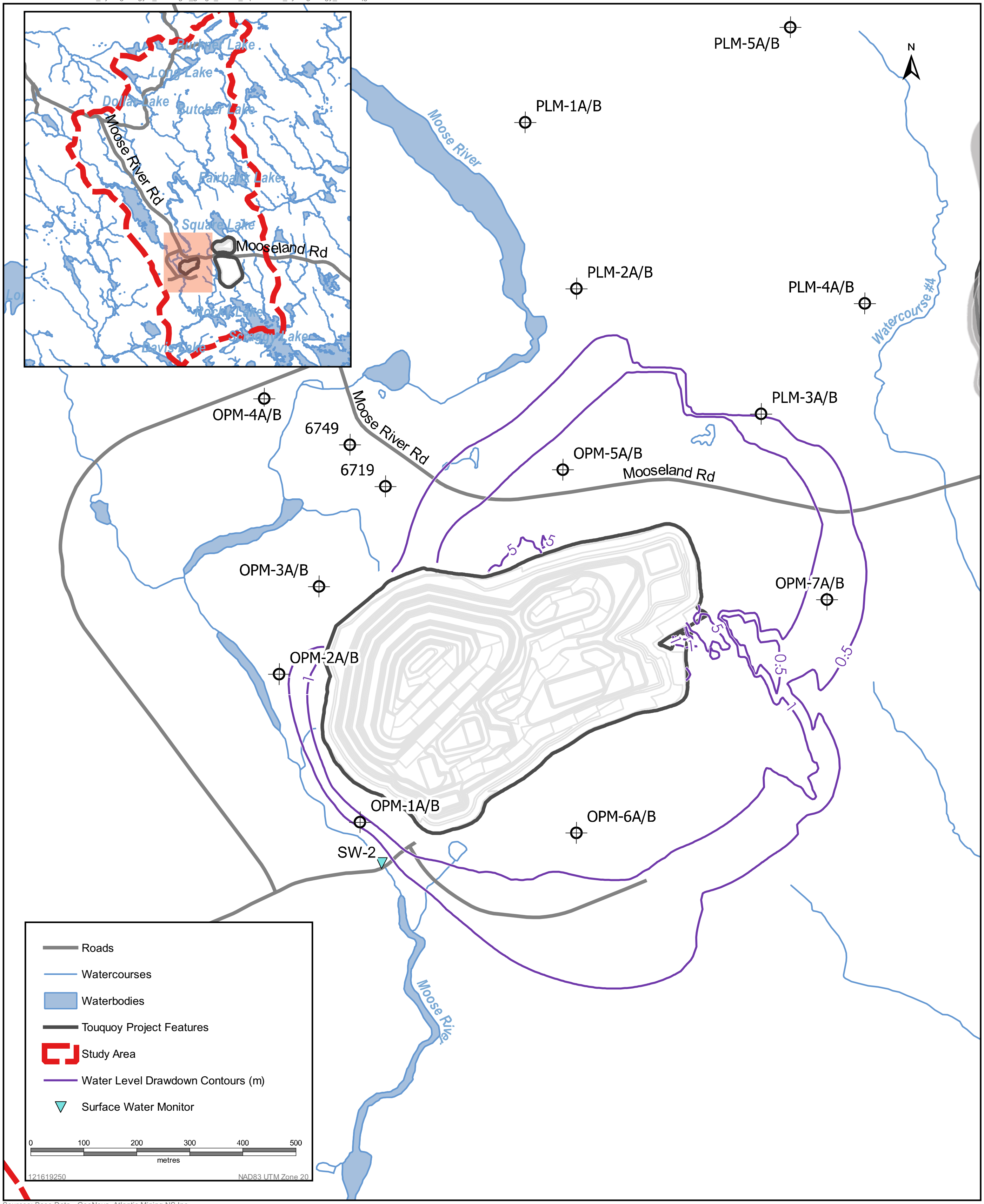


Figure 5.3 Simulated Groundwater Inflow Rates by Pit Lake Stage

5.4 POST-CLOSURE

5.4.1 Model Setup

The disposal of tailings in the Touquoy open pit has the potential to degrade the water quality in the open pit. This water can then migrate from the open pit through groundwater and degrade the water quality in the receiving environments. Therefore, the transport of groundwater from the Touquoy pit to potential receptors was simulated by use of a solute transport model (MT3D-USGS).



Sources: Base Data - GeoNova, Atlantic Mining NS Inc.

Drawdown at End of FMS Operations (Pit Lake Full)

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Figure 5.4

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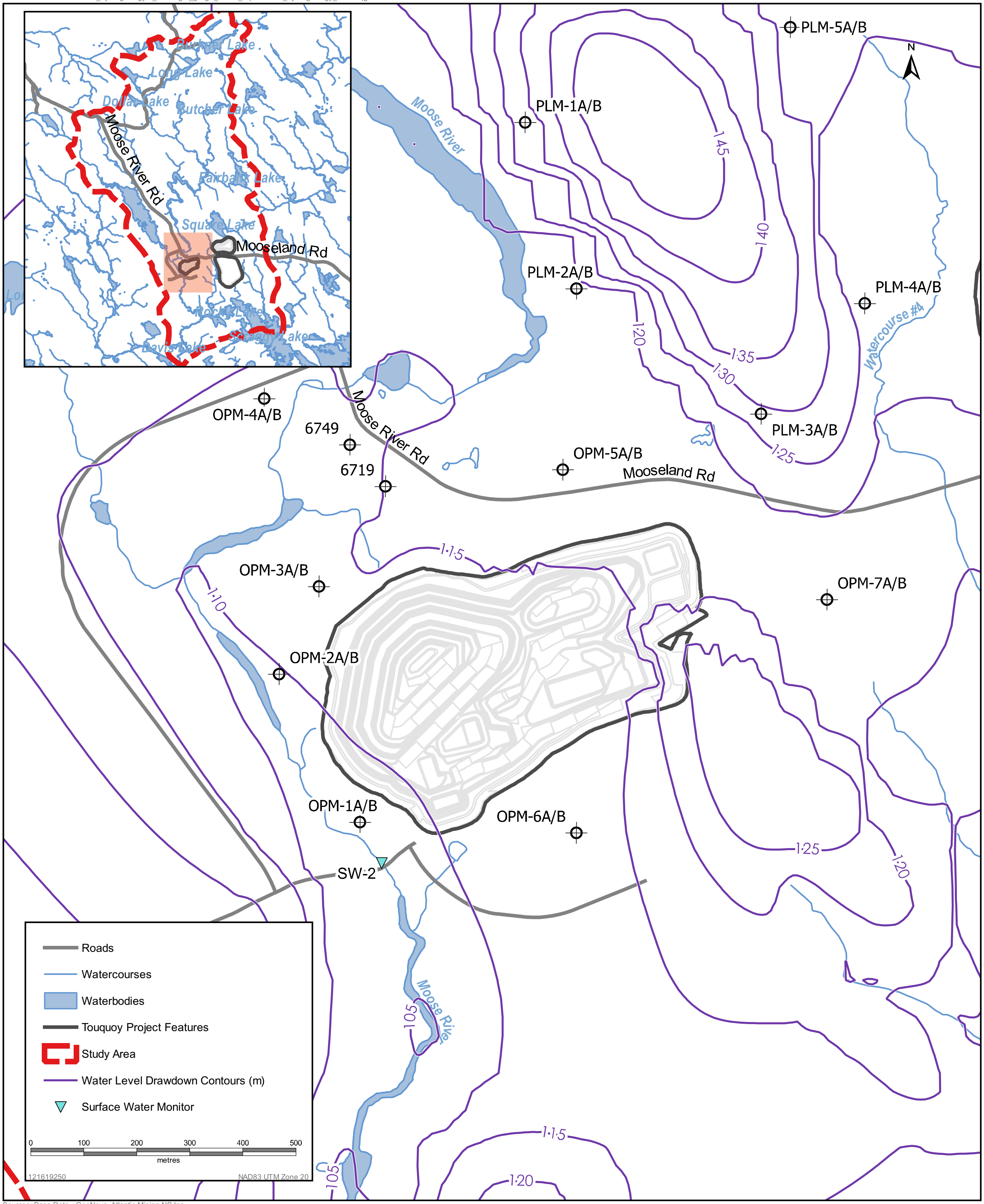


Sources: Base Data - GeoNova, Atlantic Mining NS Inc.

Water Table Contours at End of FMS Operations (Pit Lake Full)

Stantec

Beaver Dam Gold Project

Figure 5.5

The simulation considers the transport of a conservative solute from the water in the open pit with a source concentration of 1 mg/L through the groundwater to the receiving environment over time. Solute transport was conducted for a period of 500 years. The solute transport model was set up using the transport parameters shown on Table 5.2. Porosity for each geologic material is based on the mid-range of expected values from the literature. Dispersivity is assumed based on the spatial scale of solute transport. The solute is assumed to have the diffusion coefficient of chloride, a conservative tracer.

Table 5.2 Assigned and calibrated solute transport model parameter values

Parameter	Assigned Value
Porosity	
Overburden Units	0.3
Weathered Bedrock Units	0.1
Competent Bedrock	0.05
Tailings	0.3
Dispersivity (All Geologic Media)	
Longitudinal (m)	5
Transverse and Vertical (m)	1
Solute Species	
Diffusion Coefficient[1] (m^2/s)	1.4×10^{-9}

Notes:

1. Diffusion coefficient is the product of the free-water diffusion coefficient (2.8×10^{-9} m^2/s for chloride) and an assumed value of tortuosity (0.5).

The water quality associated with the tailings pore water was determined by Lorax Environmental Services (Lorax 2018), based on this assumption that the Beaver Dam tailings would have the same characteristics as Touquoy based on the similarity in the characteristics of the source rock, and that the tailings will be produced by the same mill at the Touquoy site. The source terms concentrations (mg/L) for various parameters of concern determined by Lorax are presented on Table 5.3. These source terms are multiplied by the relative concentrations generated by the model to estimate the mass loading and average concentrations of groundwater discharging to surface water receptors. The water quality in the Touquoy pit lake above the tailings were conservatively assumed to have the same quality as the pore water in the tailings.

5.4.1.1 Sensitivity of Solute Transport to Mapped Faults

Several mapped faults were identified on Figure 2.4. As discussed in Section 3.3.2, the hydrogeologic properties of the faults have not been characterized, although water bearing faults in the vicinity of the open pit were identified. As the groundwater flow model was able to calibrate without assigning differing properties in the faults compared to the native bedrock, it is reasonable to expect that the bulk properties of the hydraulic conductivity in the bedrock units from the model are appropriate, as discussed in Section 4.2.

In order to assess the potential impacts from the faults on the predicted water quality loadings to Moose River, the groundwater flow model was modified to include these fault features. The hydraulic conductivity of the fault alignments presented on Figure 2.4 was assigned to be an order of magnitude higher and an order of magnitude lower than the native bedrock, and the flow and transport simulations were re-run to predict the extent of the plume originating from the open pit.

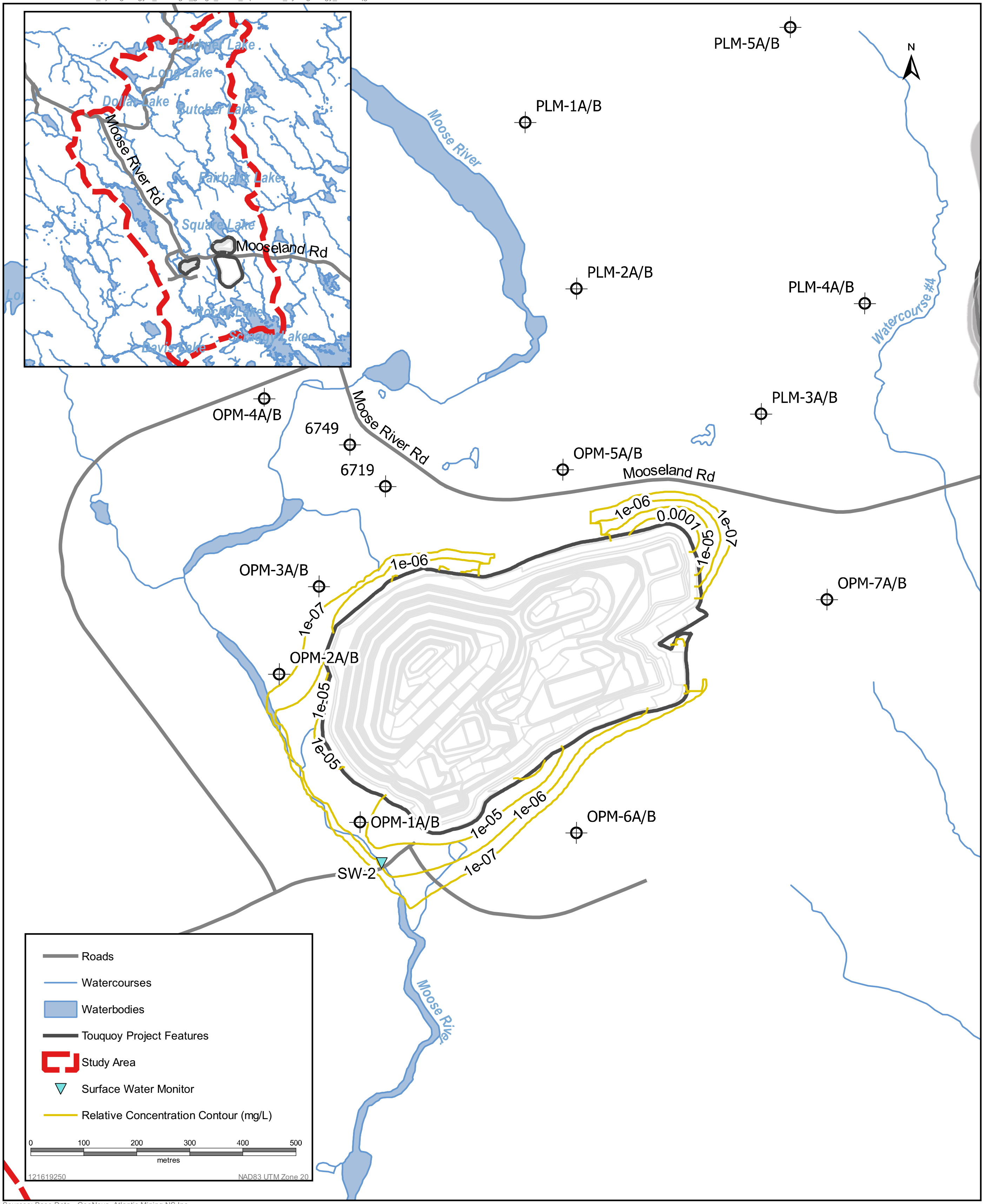
5.4.1.2 Sensitivity of Solute Transport to Bedrock Porosity

The porosity values for bedrock presented on Table 5.2 were adjusted to evaluate the sensitivity of the solute transport results to the porosity in the bedrock. The porosity of the weathered bedrock was assumed to vary from 0.1 to 0.01. The porosity of the competent bedrock was assumed to vary from 0.05 to 0.05 to 0.0001. The average concentrations in Moose River for the various porosity rates used are presented.

5.4.2 Results

The predicted relative concentrations in groundwater originating from the filled open pit are presented on Figures 5.6 to 5.8. The relative concentrations are multiplied by the source term concentrations for the parameters of primary concern in the open pit to predict the concentrations and mass loadings to the receiving environment over time. The distributions of the concentrations after 50 years are shown on Figure 5.6, after 100 years on Figure 5.7, and after 500 years on Figure 5.8. These relative concentrations were multiplied by the source term concentrations for the various parameters of concern provided by Lorax (2018) to estimate the mass loading to, and average concentration in, Moose River over time, as shown on Tables 5.3 and 5.4, respectively.

The average concentrations of arsenic discharged to Moose River over the 500-year simulation period are shown on Figure 5.9. As shown on the figure, the average concentrations of arsenic (and other parameters) in the discharge to the river stabilize after about 150 years.



Sources: Base Data - GeoNova, Atlantic Mining NS Inc.

Relative Concentration Contours in Groundwater 50 Years Following Pit Lake at Stage 108 m

Stantec

Beaver Dam Gold Project

Figure 5.6

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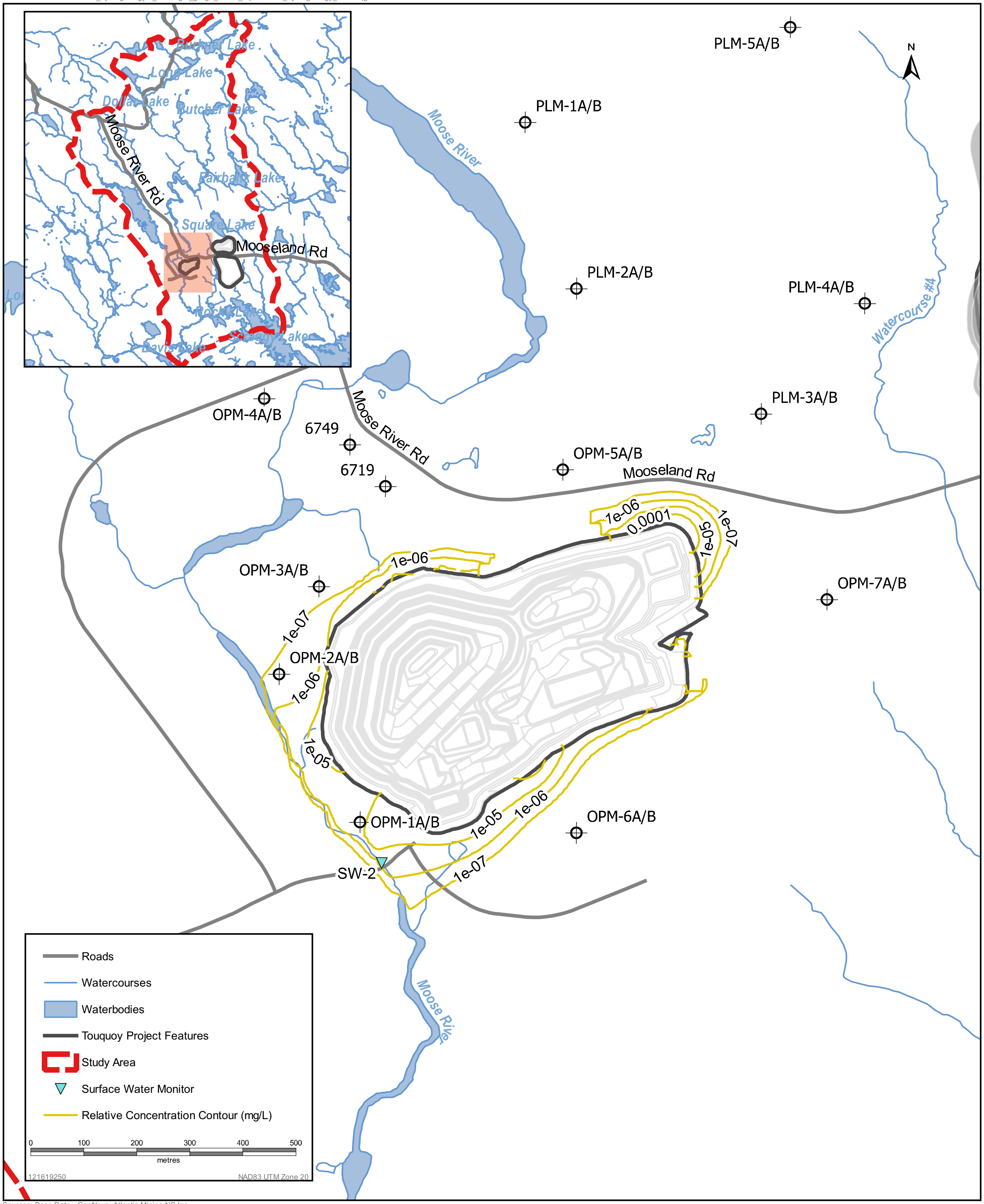

Sources: Base Data - GeoNova, Atlantic Mining NS Inc.

Relative Concentration Contours in Groundwater 100 Years Following Pit Lake at Stage 108 m

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Figure 5.7

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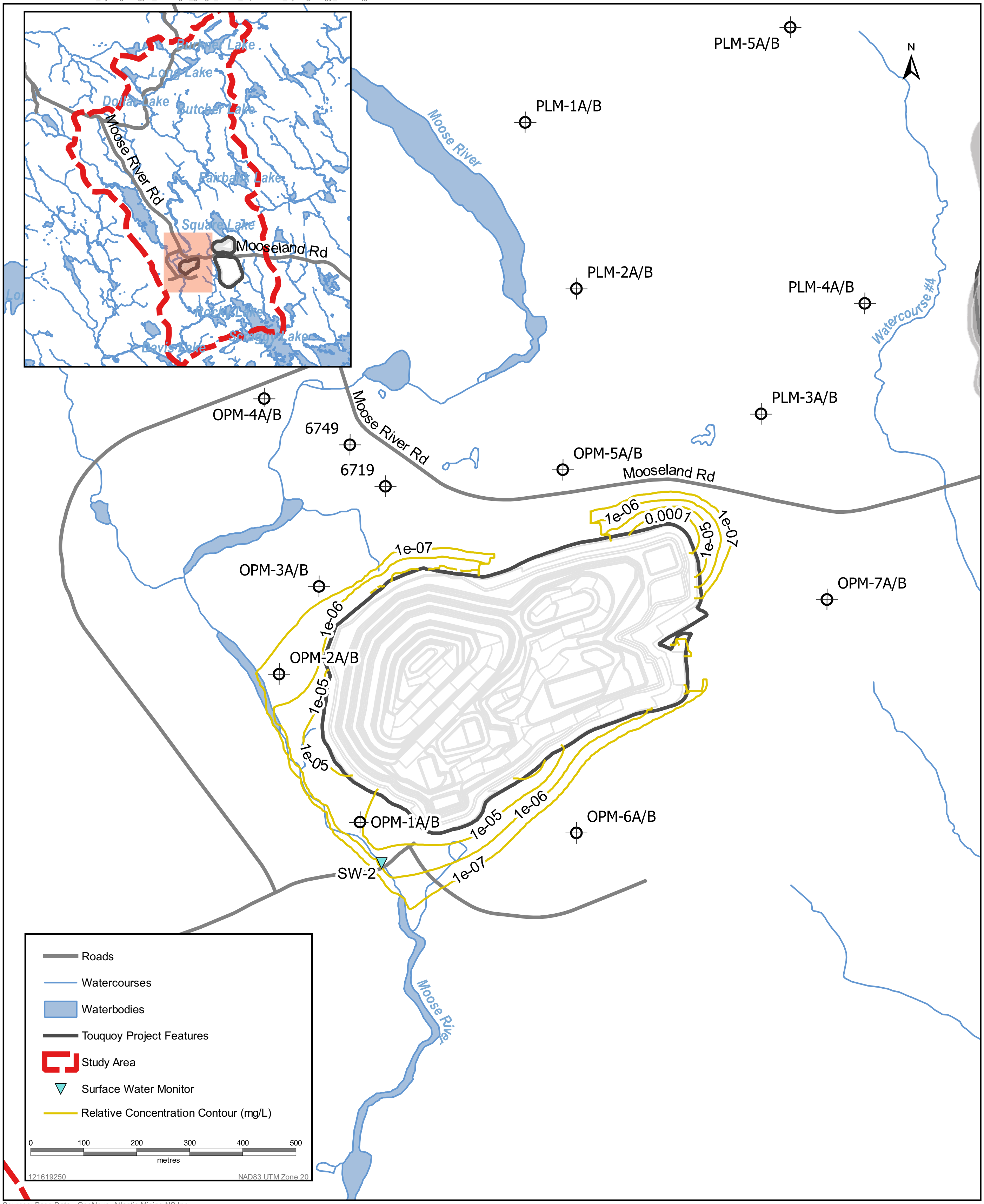

Sources: Base Data - GeoNova, Atlantic Mining NS Inc.

Relative Concentration Contours in Groundwater 500 Years Following Pit Lake at Stage 108 m

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Figure 5.8

Table 5.3 Predicted Mass Loading to Moose River from Groundwater

Parameter	Source Term Concentration (mg/L)	Mass Loading (g/d)			
Elapsed Time (years)		10	50	100	500
Sulphate	897	1.3×10^{-1}	3.3×10^{-1}	3.7×10^{-1}	4.0×10^{-1}
Aluminum	0.0469	6.6×10^{-6}	1.7×10^{-5}	1.9×10^{-5}	2.1×10^{-5}
Silver	0.00001	1.4×10^{-9}	3.7×10^{-9}	4.1×10^{-9}	4.4×10^{-9}
Arsenic	3.07	4.3×10^{-4}	1.1×10^{-3}	1.3×10^{-3}	1.4×10^{-3}
Calcium	86.9	1.2×10^{-2}	3.2×10^{-2}	3.6×10^{-2}	3.8×10^{-2}
Cadmium	0.00002	2.8×10^{-9}	7.3×10^{-9}	8.3×10^{-9}	8.9×10^{-9}
Cobalt	0.0262	3.7×10^{-6}	9.6×10^{-6}	1.1×10^{-5}	1.2×10^{-5}
Chromium	0.0002	2.8×10^{-8}	7.3×10^{-8}	8.3×10^{-8}	8.9×10^{-8}
Copper	0.00937	1.3×10^{-6}	3.4×10^{-6}	3.9×10^{-6}	4.1×10^{-6}
Iron	0.0326	4.6×10^{-6}	1.2×10^{-5}	1.3×10^{-5}	1.4×10^{-5}
Mercury	0.000005	7.0×10^{-10}	1.8×10^{-9}	2.1×10^{-9}	2.2×10^{-9}
Magnesium	14.8	2.1×10^{-3}	5.4×10^{-3}	6.1×10^{-3}	6.6×10^{-3}
Manganese	0.37	5.2×10^{-5}	1.4×10^{-4}	1.5×10^{-4}	1.6×10^{-4}
Molybdenum	0.0603	8.4×10^{-6}	2.2×10^{-5}	2.5×10^{-5}	2.7×10^{-5}
Nickel	0.00685	9.6×10^{-7}	2.5×10^{-6}	2.8×10^{-6}	3.0×10^{-6}
Lead	0.0000248	3.5×10^{-9}	9.1×10^{-9}	1.0×10^{-8}	1.1×10^{-8}
Tin	0.00604	8.4×10^{-7}	2.2×10^{-6}	2.5×10^{-6}	2.7×10^{-6}
Selenium	0.000193	2.7×10^{-8}	7.0×10^{-8}	8.0×10^{-8}	8.5×10^{-8}
Tellurium	0.0000154	2.2×10^{-9}	5.6×10^{-9}	6.4×10^{-9}	6.8×10^{-9}
Uranium	0.00203	2.8×10^{-7}	7.4×10^{-7}	8.4×10^{-7}	9.0×10^{-7}
Zinc	0.0096	1.3×10^{-6}	3.5×10^{-6}	4.0×10^{-6}	4.3×10^{-6}
WAD CN	0.005	7.0×10^{-7}	1.8×10^{-6}	2.1×10^{-6}	2.2×10^{-6}
Total CN	0.087	1.2×10^{-5}	3.2×10^{-5}	3.6×10^{-5}	3.9×10^{-5}
Nitrate (as N)	0.053	7.4×10^{-6}	1.9×10^{-5}	2.2×10^{-5}	2.3×10^{-5}
Nitrite (as N)	0.11	1.5×10^{-5}	4.0×10^{-5}	4.5×10^{-5}	4.9×10^{-5}
Ammonia	34	4.8×10^{-3}	1.2×10^{-2}	1.4×10^{-2}	1.5×10^{-2}

Table 5.4 Predicted Average Groundwater Concentration Discharging to Moose River

Parameter	Source Term Concentration (mg/L)	Average Concentration (mg/L)			
Elapsed Time (years)		5	60	150	500
Sulphate	897	4.9×10^{-4}	1.3×10^{-3}	1.4×10^{-3}	1.5×10^{-3}
Aluminum	0.0469	2.5×10^{-8}	6.6×10^{-8}	7.5×10^{-8}	8.0×10^{-8}
Silver	0.00001	5.4×10^{-12}	1.4×10^{-11}	1.6×10^{-11}	1.7×10^{-11}
Arsenic	3.07	1.7×10^{-6}	4.3×10^{-6}	4.9×10^{-6}	5.3×10^{-6}
Calcium	86.9	4.7×10^{-5}	1.2×10^{-4}	1.4×10^{-4}	1.5×10^{-4}
Cadmium	0.00002	1.1×10^{-11}	2.8×10^{-11}	3.2×10^{-11}	3.4×10^{-11}
Cobalt	0.0262	1.4×10^{-8}	3.7×10^{-8}	4.2×10^{-8}	4.5×10^{-8}
Chromium	0.0002	1.1×10^{-10}	2.8×10^{-10}	3.2×10^{-10}	3.4×10^{-10}
Copper	0.00937	5.1×10^{-9}	1.3×10^{-8}	1.5×10^{-8}	1.6×10^{-8}
Iron	0.0326	1.8×10^{-8}	4.6×10^{-8}	5.2×10^{-8}	5.6×10^{-8}
Mercury	0.000005	2.7×10^{-12}	7.1×10^{-12}	8.0×10^{-12}	8.6×10^{-12}
Magnesium	14.8	8.0×10^{-6}	2.1×10^{-5}	2.4×10^{-5}	2.5×10^{-5}
Manganese	0.37	2.0×10^{-7}	5.2×10^{-7}	5.9×10^{-7}	6.4×10^{-7}
Molybdenum	0.0603	3.3×10^{-8}	8.5×10^{-8}	9.6×10^{-8}	1.0×10^{-7}
Nickel	0.00685	3.7×10^{-9}	9.7×10^{-9}	1.1×10^{-8}	1.2×10^{-8}
Lead	0.0000248	1.3×10^{-11}	3.5×10^{-11}	4.0×10^{-11}	4.3×10^{-11}
Tin	0.00604	3.3×10^{-9}	8.5×10^{-9}	9.7×10^{-9}	1.0×10^{-8}
Selenium	0.000193	1.0×10^{-10}	2.7×10^{-10}	3.1×10^{-10}	3.3×10^{-10}
Tellurium	0.0000154	8.4×10^{-12}	2.2×10^{-11}	2.5×10^{-11}	2.6×10^{-11}
Uranium	0.00203	1.1×10^{-9}	2.9×10^{-9}	3.2×10^{-9}	3.5×10^{-9}
Zinc	0.0096	5.2×10^{-9}	1.4×10^{-8}	1.5×10^{-8}	1.6×10^{-8}
Weak Acid Dissociable Cyanide	0.005	2.7×10^{-9}	7.1×10^{-9}	8.0×10^{-9}	8.6×10^{-9}
Total Cyanide	0.087	4.7×10^{-8}	1.2×10^{-7}	1.4×10^{-7}	1.5×10^{-7}
Nitrate (as N)	0.053	2.9×10^{-8}	7.5×10^{-8}	8.5×10^{-8}	9.1×10^{-8}
Nitrite (as N)	0.11	6.0×10^{-8}	1.6×10^{-7}	1.8×10^{-7}	1.9×10^{-7}
Ammonia (as N)	34	1.8×10^{-5}	4.8×10^{-5}	5.4×10^{-5}	5.8×10^{-5}

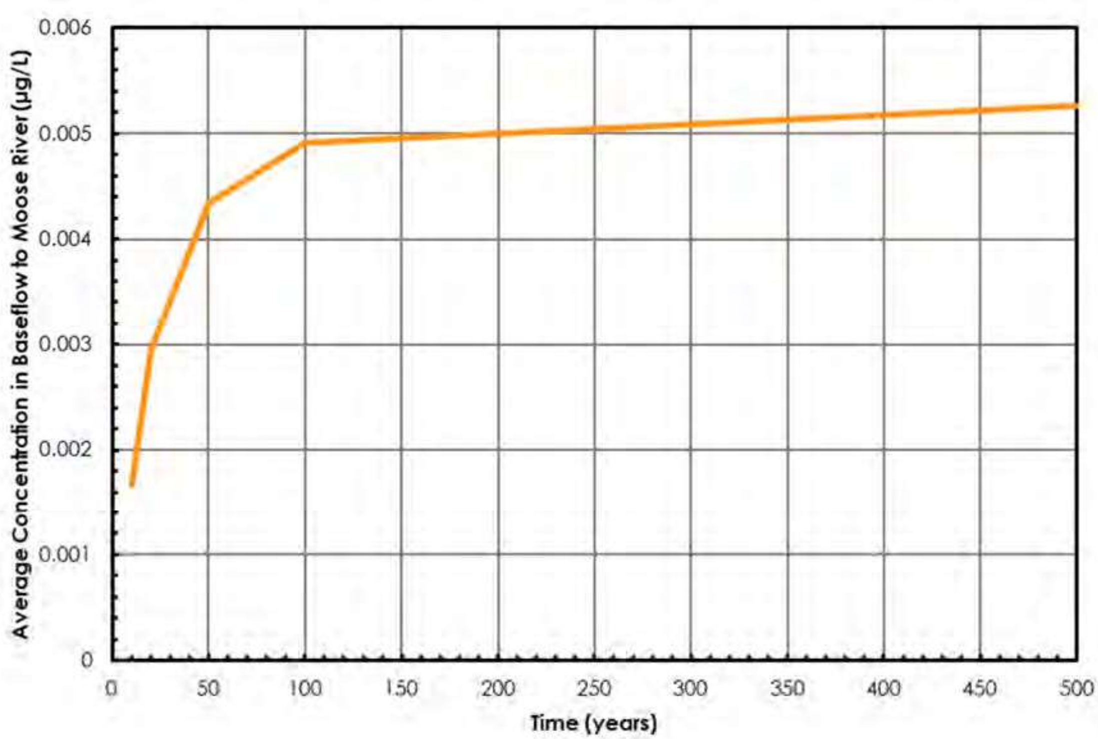

Figure 5.9 Simulated Average Concentrations of Arsenic Discharged to Moose River in Groundwater Seepage

The mass loading and average concentration of the parameters of concern listed in Tables 5.3 and 5.4 are combined with surface water concentrations and discharges from the open pit to predict the water quality in Moose River, as detailed in Stantec (2021).

5.4.2.1 Sensitivity of Solute Transport to Mapped Faults

The sensitivity of the solute transport model to the potential hydraulic conductivity of the mapped faults was assessed by conducting scenarios that considered the faults to be ten times more permeable and ten time less permeable than the calibrated values. The predicted relative concentrations in groundwater originating from the filled open pit are presented on Figure 5.10. As shown on Figure 5.10, lowering the permeability of the faults increases the mass loading slightly compared to the values presented in Figure 5.9. This results in more flow (and mass) flowing through the rock matrix than was previously predicted through the faults. However, increasing the hydraulic conductivity of the faults by an order of magnitude significantly increases the predicted concentrations in Moose River. The predicted relative concentrations for the higher permeability faults are presented on Figure 5.11 and Figure 5.12 for 50 and 500 years following the filling of the open pit, respectively. As shown on Figure 5.10, the addition of higher permeability faults indicates that solute transport may proceed more quickly to Moose River than simulated in the case without higher permeability faults (i.e., Figure 5.6).

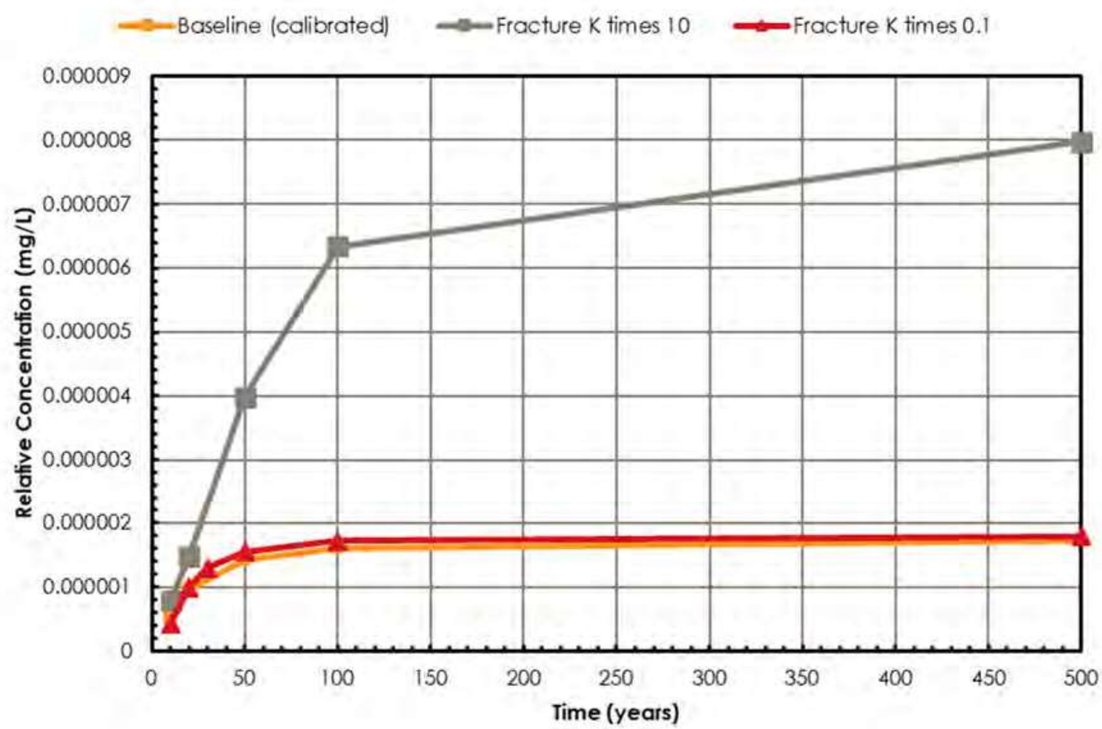

Figure 5.10 Sensitivity of Fracture Hydraulic Conductivity on Relative Concentrations in Moose River

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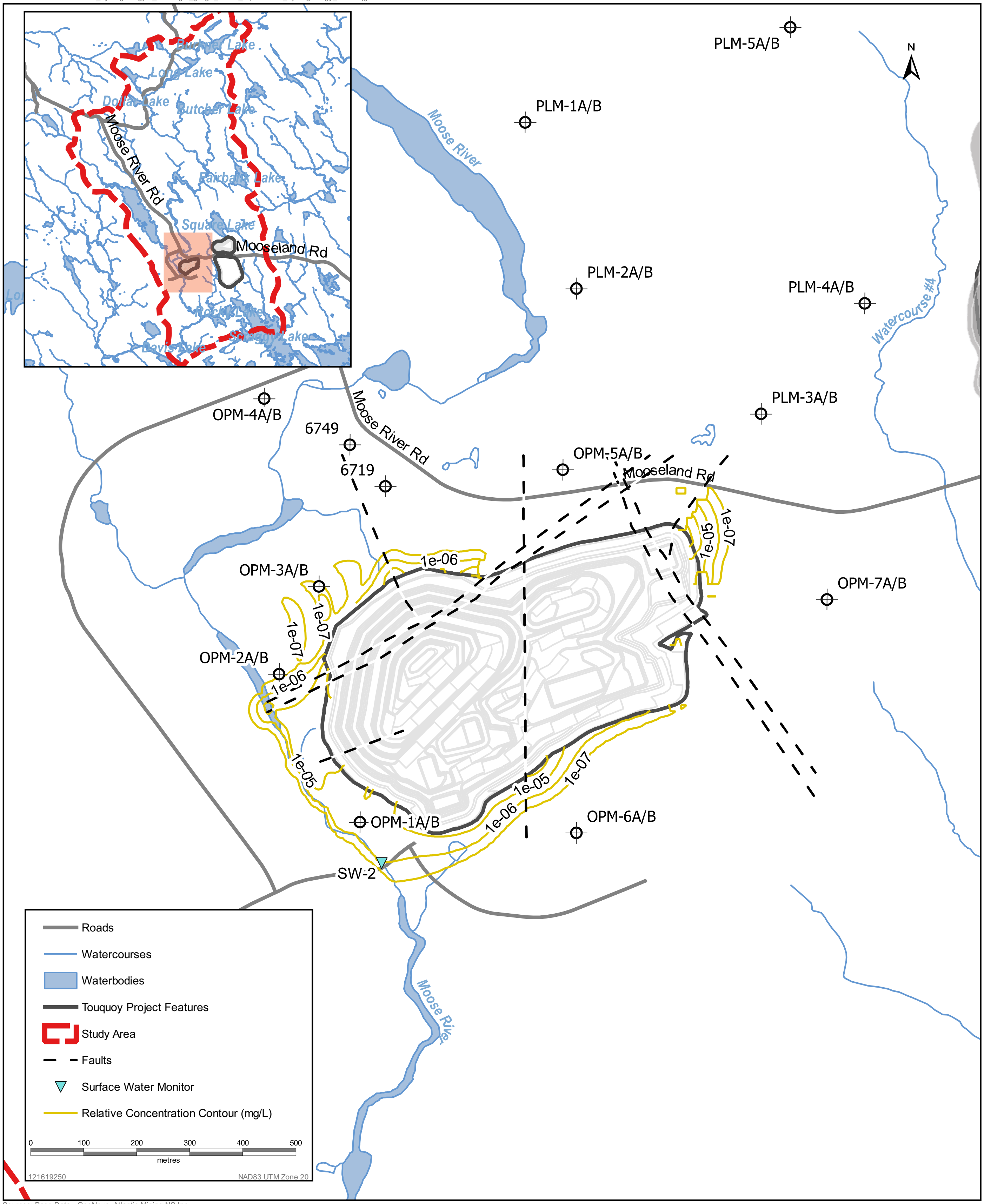

Sources: Base Data - GeoNova, Atlantic Mining NS Inc.

Relative Concentration Contours in Groundwater with High Permeability Faults 50 Years Following Pit Lake at Stage 108 m

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Figure 5.11

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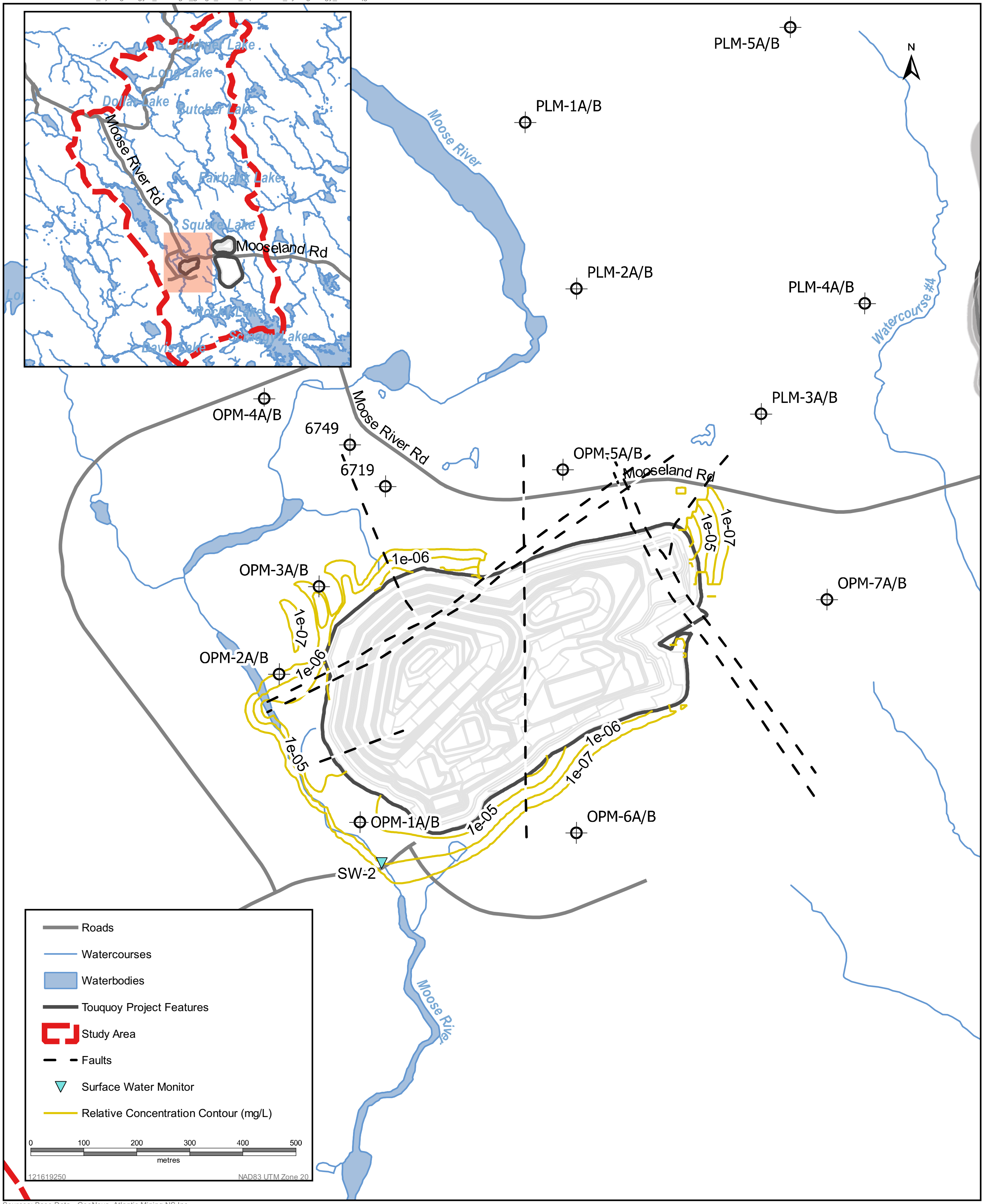

Sources: Base Data - GeoNova, Atlantic Mining NS Inc.

Relative Concentration Contours in Groundwater with High Permeability Faults 500 Years Following Pit Lake at Stage 108 m

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Beaver Dam Gold Project

Figure 5.12

Based on the sensitivity of the mapped faults to the predicted water quality in Moose River, there is the potential for additional mass to migrate toward Moose River. However, because the predicted concentrations shown on Figures 5.11 and 5.12 remain low (i.e., below detection limits), this transport is not expected to significantly alter the water quality in Moose River. The development of management, mitigation and contingency plans should consider the potential for higher permeability faulting, such as the grouting of high permeability faults, should observed concentrations exceed predictions during the post-closure period.

5.4.2.2 Sensitivity of Solute Transport to Bedrock Porosity

The sensitivity of the solute transport model to the potential porosity of the bedrock was assessed by conducting scenarios as shown on Figure 5.13. The porosity assigned to the shallow bedrock was varied between the baseline value of 10% to 1%, which is a reasonable lower bound to the weathered bedrock observed at the site. The porosity assigned to the deeper, more competent bedrock, was varied from the baseline value of 5% to 0.01%. The transport model was re-run to estimate the mass loading and predicted relative concentrations in groundwater discharge to Moose River.

As shown on Figure 5.13, the timing of the solute transport from the pit to Moose River is sensitivity to the bedrock porosity. However, the magnitude of the final concentrations in Moose River are not significantly different between the scenarios, with slightly lower relative concentrations predicted in the lower porosity scenarios.

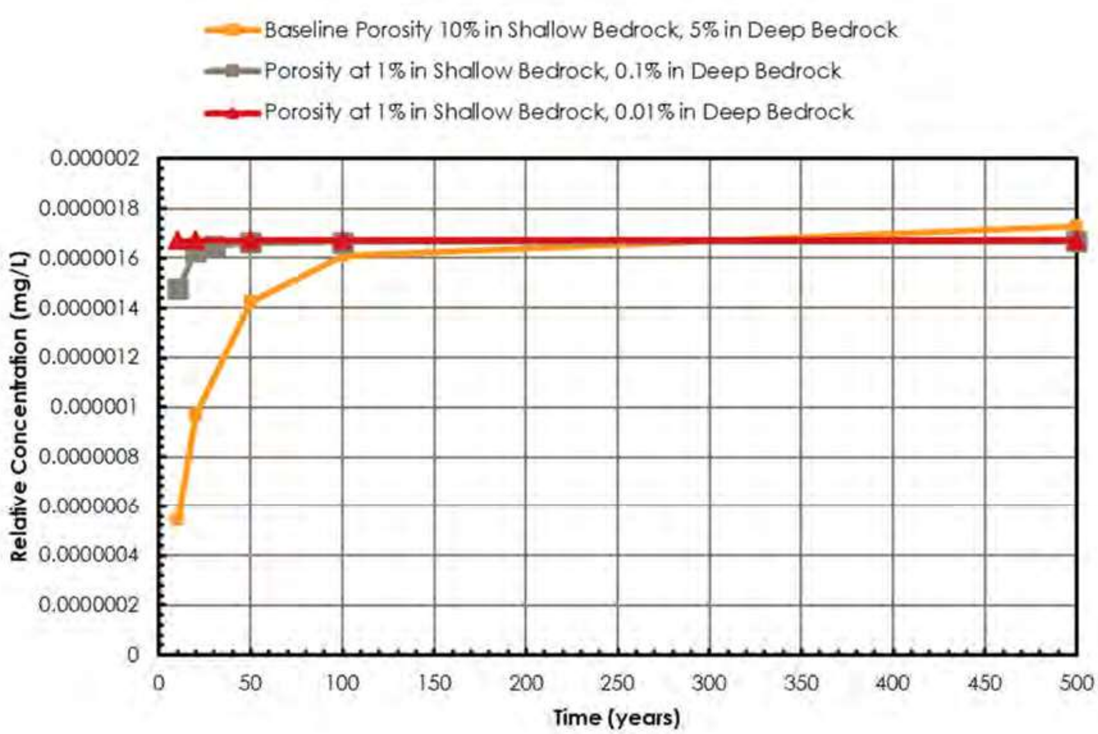

Figure 5.13 Sensitivity of Bedrock Porosity on Relative Concentrations in Moose River

5.5 PREDICTION CONFIDENCE

The approach used in model simulations completed for this Project was to incorporate conservative assumptions for predicting effects that may result from the Project. This report presents the assumptions made in developing these conservative predictions and discusses the high-level confidence of these predictions.

The modelling was conducted using an EPM approach., This is appropriate based on the regional scale of the modelling, and considering that flow was predicted to occur primarily through the shallow weathered bedrock, which is highly fractured, and therefore behaves like a porous medium.

The groundwater flow modelling was conducted using a model calibrated to water levels, and baseflow targets to establish baseline conditions. Predictions made using the model are based on several conservative assumptions to reduce the influence of uncertainty in the predictions. Therefore, the confidence in the predictions made using the model is considered high.

6.0 CONCLUSIONS

A three-dimensional steady-state groundwater flow model and solute transport model was constructed using MODFLOW to simulate groundwater conditions prior to the development of the Touquoy Pit, baseline conditions (i.e., when Touquoy Pit has been fully dewatered), changes to groundwater inflows during operations (i.e., when the Beaver Dam tailings are filling the open pit), and to evaluate potential changes to water quality in the receiving environment due to the subaqueous disposal of tailings in the Touquoy pit post-closure (i.e., when the pit is full). The model was prepared using a conceptual model and hydrostratigraphic framework developed from regional and site-specific data, and assumed homogeneous properties within the units. A good calibration of model parameters was obtained, as evaluated by comparing simulated and observed groundwater levels and estimated baseflow. The parameter values for hydraulic conductivity are similar to those obtained from other analyses of field observations.

At baseline, the open pit will be fully dewatered, and is simulated to intercept groundwater seepage at a rate of 768 m^3/d. The extent of the corresponding drawdown cone, as delineated by the 0.5 m drawdown contour, extends approximately 600 m south of the open pit and about 50 m west of the site toward Moose River. The inflow to the open pit decreases as it is filled with tailings and water during Beaver Dam operations, until the open pit stage reaches the maximum level of 108 m CGVD2013. At this stage, the groundwater seepage decreases to 373 m^3/d, and the corresponding drawdown cone is about the same as the baseline condition. Groundwater baseflow to Moose River is reduced by less than 1% in all cases.

Upon the filling of the open pit to its ultimate lake stage at 108 m CGVD2013, groundwater flow is dominated by flow from the pit to Moose River through the glacial till and weathered fractured bedrock. Solute transport in this case is dominated by advection (movement with the flow of groundwater). Solute transport modelling using the calibrated model simulates a slow migration of solutes to Moose River, with concentrations approaching a steady state after about 100 years of travel. Mass loadings for various parameters of concern are simulated by the model for inclusion in a surface water mixing model of Moose River (Stantec 2021). These mass loadings represent the additional contribution from the open pit, and is additive to baseline groundwater quality.

The presence of preferential pathways, such as fractures and faults not characterized in previous field assessment, were assessed with sensitivity analyses in the model to predict the potential migration of solutes from pit into the receiving environment. The results of the sensitivity analyses indicated that should the faults have higher hydraulic conductivity, solute transport to Moose River would occur more quickly. Therefore, the potential for higher permeability faults should be considered in the development of management, mitigation and contingency plans.

The groundwater flow and solute transport modelling was conducted with the best available information on the hydrogeologic conditions at the Touquoy site. However, it is recommended that the following data gaps be addressed to improve the reliability of the predictions made with the model:

- Update the Beaver Dam tailings geochemical characterization assessment to refine the current tailings source term estimates.
- Perform geochemical testing of water quality in the Touquoy Pit lake to predict the concentrations of potential compounds of concern in the open pit lake. These data could then be simulated to predict actual concentrations to the receiving environment.

7.0 REFERENCES

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APPENDIX A

Concordance Table

Stantec

Response to Regulator Comments Regarding Groundwater Modelling Update to Address November 5, 2020 Information Request from IAAC for the Beaver Dam and Fifteen Mile Stream Projects.

Item	Comment	Response
Nova Scotia Environment (Email from Bridget Tutty 9/12/2020)		
NSE-1	Provide representation in the document of the new model discretization. Include a figure showing the overall site modelling grid and domain.	See Section 4.1
NSE-2	Provide information and a cross-section figure from the Moose River to the open pit which shows the hydrogeological conceptual model (including details of actual stratigraphy) for groundwater interactions as well as the model layers and parameters that are representative of this.	See Section 4.1
NSE-3	Update the revised model groundwater calibration analysis based on changes to the model grid, include stream baseflow target for both average annual and yearly minimum flow conditions.	See Section 4.4.3
NSE-4	Update the uncertainty/sensitivity analysis to include the variable effects of streambed conductivity on observed streamflows and groundwater influx to the open pit.	See Section 4.4.6
NSE-5	General question – will long-term ambient hydrogeochemical quality (e.g. observations of elevated pH in the pit water and some monitoring wells) have any effect on the stability and solubility of any parameters found in the proposed tailings? Some parameters such as Arsenic may be more soluble at higher pH levels. If so, are such mixing interaction effects included in the long term transport modelling predictions?	This is beyond the scope of the groundwater flow modelling, and will be addressed under separate cover.
Fisheries and Oceans Canada – Email from Chris Burbidge (11/12/2020)		
DFO-1	DFO needs to understand the plausible worst-case scenario regarding changes in flow in Moose River from the projects and the associated effects to fish and fish habitat to verify compliance with the Fisheries Act. It is not immediately clear how the use of averages in the model will give an indication of the worst-case scenario.	Groundwater fluctuations to baseflow are longer-term processes and vary less frequently than precipitation and runoff processes that are observed in surface water. The groundwater modelling approach can be used to estimate the “worst-case” by reducing the “lowest flows” in the streams by the average summer baseflow reductions calculated using the model.
DFO-2	Actual low flows in Moose River during summer are often much lower than the monthly average. For example, the average flows in the river in August have been estimated to be 0.39 m3/s at SW-2. In August 2019, the lowest flow measured was 0.055 m3/s at SW-2. Flow data from Moose River in summer 2020 have not been provided, but data from a nearby hydrometric station [Middle River of Pictou at	As described in response to DFO-1, groundwater fluctuations in baseflow are longer-term processes that vary less frequently than precipitation and runoff processes. The baseflow reductions for the summer months calculated using this approach are expected to be representative throughout the summer, even if specific

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Item	Comment	Response
	Rocklin (01DP004)] shows that the lowest flow in August 2020 was likely less than 1% of the Mean Annual Discharge.	flows in the stream may be reduced due to lack of precipitation.
DFO-3	It is not clear what is meant by the statement "The average summer conditions will be based on the lowest flows available for the Moose River." on page 1.	This was intended to mean the summer with the lowest flows observed in Moose River (i.e., 2019).
DFO-4	The "lowest observed flow conditions from 2019, and 2020" (page 2) may not represent the potential lowest summer flow conditions (i.e., historical minimum flow).	Our stated goal was to reproduce the lowest observed flows, as we do not have sufficient information to confirm the water levels for potential historical minimum flows in Moose River.
DFO-5	Previous comments: The September 2020 tech memo shows that the measured drawdown at well pairs OPM-1A/B and OPM-2A/B located in between the current open pit and Moose River are 28% to 793% greater than predicted by the groundwater model. The tech memo states that this difference is likely due to local variations in hydraulic connectivity near the wells not represented in the model. The location of these wells mean that they are particularly relevant to the assessment of potential effects to Moose River. Please provide a description of the factors related to hydraulic connectivity at this location that could explain this variation and consider this information in the revised groundwater model.	See Section 4.4.3
DFO-6	The April 2019 groundwater model describes how watercourses are considered in the model using the River package. For Moose River, the model assumed a uniform river width of 8 m and depth of 1 m. A comparison of the estimated mean monthly flows and the stage-discharge curves provided in the tech memo for the water stations in Moose River in the vicinity of the open pit suggest that water depths of 1 m in Moose River in vicinity of the open pit would be relatively rare and would be expected to occur only during temporary high flow events and that an average depth of approximately 0.6 m is more representative of mean annual flows, if only one depth value is to be used in the model. Furthermore, the average channel width estimated in the September 2019 tech memo from the habitat surveys in the vicinity of the open pit was approximately 12 m. Please update the model's river package with the best available information about Moose River.	See Section 4.3.3
DFO-7	The April 2019 groundwater model uses an estimated mean annual discharge (MAD) in Moose River at SW-2 of 1.23 m3/s. The analysis in the 2020 tech memo estimated MAD to be 1.15 m3/s using flow measurements from surface water stations in Moose River in the vicinity of the open pit and a regression analysis of	See Section 4.3.3

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Item	Comment	Response
	long-term data from eight (or possibly ten) WSC stations. Please update the model with the best estimate of MAD for Moose River.	
NRCan – D. Paradis (email from Kathryn MacCarthy 14/12/2020)		
NRCan-1	Given my review of I4, I summarize my main concerns using the scope of work proposed here. I also provide additional concerns reviewing I4. Main points in the Memo (see comments below in the text): 1. Baseflow calibration. 2. Streambed conductance. 3. Numerical dispersion. 4. Effective porosity. 5. Faults impact. Additional points from I4 that need clarifications:	See responses below.
NRCan-2	1. Fig. 4.1: This figure shows the model layer with corresponding stratigraphy. The thickness of each layer and their spatial relations with the pit and the Moose River is however not well illustrated. **Information Request:** A few cross-sections should be presented to better illustrate the conceptual and numerical models. In particular, deep of the pit with respect to the bottom of the numerical model, and the stratigraphy between Moose River and the pit.	See Section 4.1
NRCan-3	2.Table 5.1: Dispersivity is expected to be much higher in the weathered bedrock than competent bedrock. Why is the proponent using the same dispersivity values for weathered and competent bedrock? **Information Request:** Please explain the rationale for using the same dispersivity value for weathered bedrock and the competent bedrock.	As presented by Gelhar (1992), dispersivity is a scale dependent parameter that can be estimated based as 10% of the representative length of the expected plume. The longitudinal dispersivity of 5 m was selected based on the representative distance between the open pit and Moose River (i.e., 50 m).
NRCan-4	3a. Fig 5.4: This figure showing drawdowns may falsely suggest that the pit is gaining water from the Moose River. A map of the hydraulic heads with main groundwater flow direction would be more illustrative of the situation. **Information Request:** Provide a map of the hydraulic heads for comment # 3a above.	See Figure 5.5.
NRCan-5	3b. Fig. 5.5: Also, given the very small relative concentrations predicted away from the pit, and the relatively coarse cells (spatially and vertically) of the model grid with	The grid Peclet number was in the original modelling varied between 5 and 10, and varies between 1 and 10

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Item	Comment	Response
	respect to the distance between Moose River and the pit, has the Peclet number been verified to avoid numerical artifacts (e.g., numerical dispersion and numerical oscillations) to ensure realistic transport simulations? **Information Request:** a clarification is required for comment #3b wrt. Peclet number.	for the current modelling (depending on whether the grid cell is 5 m or 50 m long). Although it is usually suggested to select the grid spacing so that the Peclet number does not exceed 2, in many cases acceptable solutions with mild oscillation are achieved with grid Peclet numbers as high as 10 (Huyakorn and Pinder 1983). The predicted concentration results were reviewed to confirm that oscillatory behaviour did not adversely affect the results (i.e., by checking for negative concentrations in the modelling results).
NRCan-6	3c. Fig. 5.10: This figure seems to show numerical oscillations. To be verified. **Information Request:** confirm whether Figure 5.10 shows numerical oscillations.	The interpreted numerical oscillations are due to flow through the high conductivity faults. The maximum length of timesteps was adjusted in the modelling to avoid numerical oscillations in the updated modelling results. The sensitivity runs presented in Section 5.
NRCan-7	Section 6.0 Conclusions: "Upon the filling of the open pit to its ultimate lake stage at 108 m asl, groundwater flow is anticipated to flow from the pit to Moose River through the glacial till and weathered fractured bedrock.". This is an interesting analysis, but this should be illustrated and discussed in the main body of the report. Should present cross-sections with heads simulated in each layer of the model. **Information Request:** Illustrate and discuss the groundwater flow from the pit to the Moose River, present cross sections with heads simulated in each layer of the model.	The conclusions have been updated based on the updated modelling text.
NRCan-8	Table 5.3: Should tell if those concentrations exceed the authorized concentrations in receiving environments. **Information Request:** confirm whether the concentrations exceed the authorized concentrations in the receiving environments (Table 5.3).	The concentrations in the previous modelling were below the MDMER limits in the receiving environment. The updated modelling results will be compared to MDMER limits in the receiving environment in the updated modelling report.
NRCan-9	Section 1.0: Drawdowns at Moose River are restricted by the modelling approach. In this approach river stage is fixed by the model using constant head boundary condition. This is a limitation of fully-saturated models where rivers cannot be let free. **Baseflow calibration:** However, what matters is the amount of water exchanged between the river and the aquifer. To know the impact of pumping on the river, a	See Section 4.4

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Item	Comment	Response
	mass balance around the river should be done. An important piece of information to get meaningful mass balance is the calibration of the model with baseflow estimated from field measurements. If the model can reproduce field baseflow, we can be more confident in the impact assessment.	
NRCan-10	Section 2.0 Task 1 – re: "streambed sediments": **Streambed conductance**: To be conservative, the streambed conductance should be kept the same as the underlying sediments/bedrock. Using very low conductance value may isolate the river from the main aquifer, and then underestimate the amount of water withdrawn from pumping. Calibration with field-based baseflow estimates will thus be very important to assess the hydraulic connection between Moose River and the aquifer. **Baseflow calibration:** Also, an additional sensitivity analysis showing the sensitivity of baseflow to parameters should be conducted. Parameters of interest are hydraulic conductivity, recharge and streambed conductance. **Effective porosity:** Finally, it would be also useful to see a sensitivity analysis for contaminant concentrations reaching Moose River. In addition to the previous parameters used for baseflow sensitivity analysis, effective porosity should also be tested.	See Section 4.4.6
NRCan-11	Section 2.0 Task 1 – re: "summer low-flow condition.": **Numerical dispersion:** Likely with no recharge?	As indicated in Section 4.3.2, both recharge and evapotranspiration (ET) have be included as separate processes in the modelling update. Therefore recharge will be reduced in the summer, but ET will be increased. The net result is an effective recharge of 22 mm/yr, as calculated using the recharge and ET rates presented in Table 4.6.
NRCan-12	Section 2.0 Task 1 – re: "…flow conditions from 2019 and 2020. These years represent the most complete datasets available…": **Baseflow calibration:** How those 2019 and 2020 year compare to historical conditions. Are they wet, dry or average years ? For annual and low-flow period.	Below average precipitation were observed in the summers of 2019 and 2020.
NRCan-13	Section 2.0 Task 1 – re: "Refining the grid cell size in the existing modell…": **Numerical dispersion:** Refining the grid at the vertical layer should between the Moose River and the pit also be considered. Horizontal and vertical resolutions are particularly important for transport simulations where numerical dispersion (too large Peclet number) seems to be an issue in I4.	The vertical discretization in the vicinity of the open pit was reviewed, and was not updated as part of this update. The relatively fine vertical discretization in the vicinity of the open pit and Moose River does not warrant additional refinement in the shallow model layers.

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Item	Comment	Response
NRCan-14	Section 2.0 Task 2 – re: “transport simulations”: **Numerical dispersion:** Appropriate cell size in the region between Moose River and the pit should be used to avoid numerical artifact in the transport simulations. See previous comment. **Effective porosity:** Porosity is also important for transport simulations. Large porosities will accumulate mass in the aquifer and delay migration times. The opposite for low porosity values. What is the supporting information for porosity? Porosity should be also included in the sensitivity simulations. **Effective porosity:** Moreover, porosity values reported in I4 seems to reflect total porosity. For transport simulation, effective porosity should instead be used. Effective porosity is generally much lower than total porosity. Especially in bedrock formations where much of the pores are not interconnected and an important proportion of water is not contributing to flow (stagnant water). To be conservative, without field/lab support, effective porosity values on the lower-end range of reported values in the literature should be used.	A sensitivity analysis for the effects of porosity on transport runs is provided in Section 5.4.2.2.
NRCan-15	Section 2.0 Task 2 – re: “Additional model runs…”: **Faults impact:** Given that no field work can support the role of the faults, a conservative scenario with high permeability faults should be used.	This was the approach used in the previous modelling, and has been updated in Section 5.4.2.1 of the current report.