TECHNICAL MEMORANDUM

DATE October 15, 2019 **Project No.** 19120487/6000

TO Karyn Lewis
Lupin Mines Incorporated

CC Ken Bocking, Dionne Filiatrault

FROM Bret Timmis and Kristin Salzsauler **EMAIL** Kristin_Salzsauler@golder.com

CLOSURE GEOCHEMICAL SOURCE TERM AND SEEPAGE WATER QUALITY MODEL FOR PERFORMANCE EVALUATION OF THE ESKER COVER FOR THE WASTE ROCK "DOME" AT LUPIN MINE

1.0 INTRODUCTION

The Lupin Mine (the Site) is a past producing mine located in western Nunavut, approximately 400 kilometres (km) northeast of Yellowknife, Northwest Territories and is owned by Lupin Mines Incorporated (LMI). Development of the Site to extract gold began in 1980 and operations occurred from 1983 until 2005. From 2005 to present, the Site has been in "care and maintenance" with mine operations suspended and progressive rehabilitation works conducted. LMI is requesting the renewal and amendment of the existing Type "A" Water Licence No: 2AM-LUP1520, to allow for Final Closure and Reclamation of the Lupin Mine Project (Lupin). The Nunavut Water Board (NWB or Board) Water Licence Application No. 2AM-LUP1520 Technical Meeting was held between June 6 and 7, 2019 in Kugluktuk. Appendix D of the June 18, 2018 Pre-Hearing Conference Decision Report outlines the agreed upon List of Commitments (Commitments). Golder completed a geochemical source term and seepage water quality model in response to Commitments No.1 and No.7 (below).

No.	Party responsible for commitment	Party who raised	Issue – TM Commitment
1.	LMI	CIRNAC	Completion of Human Health Ecological Risk Assessment (HHERA) (to include geochemical, thermal and seep modelling studies)
7.	LMI	CIRNAC	Geochemical source term and load model for seepage from the waste rock storage "Dome."

This technical memorandum presents geochemical source terms for materials at the site at closure, and the results of surface water quality modelling completed to evaluate the performance of the proposed waste rock dome. Environmental effects analysis of the water quality model results is discussed in the Human Health and Ecological Risk Assessment (HHERA) (Golder, 2019a). The geochemical source terms and results of the water quality model presented in this memorandum are intended to support the closure design and to outline potential risks rather than to provide absolute values.

2.0 FINAL CLOSURE AND RECLAMATION PLAN

Historical mining at Lupin Mine produced approximately 1 million cubic metres (m^3) of waste rock (Golder, 2018). The waste rock was used to construct various elements of mine infrastructure, including roads, the airstrip and a large pad underlying the mill site and camp facilities. The results of previous phases of geochemical testing (Golder, 2017) indicate that the majority of waste rock is either potentially acid-generating (PAG) or of uncertain acid generation potential, and is capable of leaching metals (arsenic, aluminum, cadmium, cobalt, copper, iron, nickel, and zinc) at concentrations greater than applicable water quality criteria.

The Final Closure and Reclamation Plan (FCRP) for the Site proposes to consolidate much of the waste rock in the mill and camp area into a central “dome” and to cap it with an infiltration reduction cover comprising a 1.0 metre (m) thick layer of esker sand and gravel (Golder, 2018). The objectives of the cover are 1) to limit the surface exposure of waste rock and 2) to reduce the amount of infiltration into waste rock in order to control the volume of acid rock drainage (ARD) impacted seepage out of the toe of the dome. The reduction in surface infiltration relies in part on the cover being frozen during winter and early spring to promote surface runoff rather than infiltration during the freshet period.

After closure, the waste rock dome is expected to be roughly circular and to cover an area of about 30 hectares (ha). It will contain or overlie about 820,000 m^3 of waste rock and it will have a surface slope of about 1.6%.

3.0 GEOCHEMICAL CHARACTERIZATION OF IN SITU WASTE ROCK

The geochemistry of waste rock currently at surface at the Site was evaluated in a previous investigation by Golder (2017), based on a dataset of 127 samples collected in 2004 (URS 2005), 2006 (Morrow 2006) and 2017. This investigation involved collection of thirty waste rock and overburden grab samples to confirm the acid rock drainage and metal leaching potential if in situ materials at the Site. Waste rock samples were submitted for geochemical testing, including acid base accounting (ABA), net acid generating testing (NAG), whole rock and trace metal analysis, and short-term leach testing. Additionally, nine seepage surface water samples were collected in 2017 to evaluate the composition of water after interaction with waste rock. Analytical results of seepage samples, NAG leachate, and short-term leach test leachate were compared to Canadian Council of Ministers of the Environment (CCME) Canadian Environmental Quality Guidelines (CEQG) Water Quality Guidelines for the Protection of Aquatic Life (Freshwater). Comparison to CEQG criteria was completed for the purpose of identifying parameters of potential environmental concern.

Geochemical test results for samples collected as part of the field investigation completed by Golder (2017) were added to the existing waste rock geochemistry database, which was described in Morrow (2006). Acid generation potential was evaluated according to the criteria in MEND (2009), using the ratio of neutralization potential (NP) to acid potential (AP). The combined geochemical dataset consists of 127 samples, of which 41 were classified as non-PAG (NP/AP > 2), 59 were classified as PAG (NP/AP < 1) and 27 had an uncertain acid generation potential (NP/AP between 1 and 2). Using this dataset, up to 68% of the waste rock at the Site could be potentially acid generating (PAG and uncertain samples).

Metal leaching potential was evaluated using the results of short-term leach tests (shake flask extraction [SFE], and comprehensive analysis of NAG leachates), and seepage water quality results. Analytical results of SFE leachates indicated that most samples produced leachate concentrations of aluminum, arsenic, cadmium, copper, iron, nickel, and zinc greater than CEQG criteria. Analytical results of NAG leachate indicated that most samples produced leachate concentrations of aluminum, arsenic, cadmium, chromium, copper, iron, nickel, phosphorus, and selenium greater than CEQG criteria. Seepage sample results indicated that most samples contained pH values outside the range of applicable CEQG criteria, and concentrations of aluminum, arsenic, cadmium, copper, nickel, and zinc greater than CEQG criteria.

In August 2019, 22 additional waste rock samples were collected from shallow test pits in waste rock to further refine understanding of waste rock geochemistry at Lupin, through elimination of gaps in spatial coverage and confirmation of historic analyses. Samples were submitted for geochemical testing, including ABA, NAG, whole rock, and trace metal analysis. A subset of samples will be submitted for short-term leach testing and humidity cell testing. Laboratory results of waste rock for samples collected in August 2019 are currently pending and will be reported under separate cover. Additionally, 14 seepage surface water samples were collected in 2019 to evaluate the composition of water after interaction with waste rock; these results have been incorporated in source terms where applicable as described in Section 4.2.1.

4.0 CONCEPTUAL MODEL

The proposed waste rock dome is planned to be constructed over historic mine infrastructure including the mill, camp, crown pillar, and tank farm. As illustrated in Figure 1, the dome is located at an area of watershed divides, with cover runoff and seepage reporting to multiple watersheds as follows:

- Upper Sewage Lake
- Lower Sewage Lake
- Boot Lake
- East Lake
- Contwoyto Lake

Water quality predictions were completed for the following prediction nodes in the receiving environment:

- East Lake Outlet
- Boot Lake Outlet
- Lower Sewage Lake Outlet

All watersheds report to Contwoyto Lake. Given the large size of Contwoyto Lake (>500 square kilometres [km^2]), it is assumed that mine related effects in the majority of the lake will be negligible and that observable effects (if any) would be limited to the immediate vicinity of stream confluences with Contwoyto Lake for those streams affected by waste rock seepage. It is anticipated that mixing of mine impacted water with Contwoyto Lake at these confluences will result in concentrations at or below background conditions or applicable water quality criteria due to the relatively low flow rates of mine impacted streams. Predictive modelling of water chemistry values for Contwoyto Lake in the vicinity of these confluences has not been completed to date.

The Crown Pillar Watershed, located within the waste rock dome, drains internally into the underground mine workings. Measurements by LMI staff in 2019 indicate that the depth to water within mine workings is greater than 100 m. The mine workings have been permitted to flood since closure (2006); however, the current water level remains greater than 50 m below the level of Contwoyto Lake. It is therefore apparent that the underground mine workings do not have a strong hydraulic connection with either the talik below Contwoyto Lake or the sub-permafrost groundwater flow system. Based on the current water level thirteen years after closure, it is uncertain if or when the mine workings may overflow resulting in surface discharge. If such surface discharge does occur in the future, drainage would occur from the Portal & Adit (Figure 1) (the lowest elevation mine opening), and report directly to Contwoyto Lake via overland flow. Because of its hydraulic isolation, water within the Crown Pillar Watershed is not included in the water quality model predictions.

LEGEND

- CONTOUR (10 m INTERVAL)
- FLOW DIRECTION
- WATERSHED BOUNDARY
- WATERCOURSE
- ROAD
- INFRASTUCTURE FOOTPRINT
- LANDFILL
- REHABILITATED DISTURBED AREA
- TAILINGS TO BE REMOVED TO TCA
- WASTE ROCK COVERED
- WASTE ROCK REMOVED
- WATERBODY

0 250 500

1:15,000 METRES

NOTE(S)

1. AFTER BLASTING, THE CROWN PILLAR WATERSHED WILL DRAIN INTERNALLY INTO THE UNDERGROUND MINE WORKING.
2. SPILLWAYS WILL BE EXCAVATED THROUGH THE SEWAGE LAKE DAMS AT CLOSURE LEAVING THEM FREE DRAINING.

REFERENCE(S)

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DATUM: NAD83 PROJECTION: UTM ZONE 12

CLIENT
MANDALAY RESOURCES CORPORATION

PROJECT
LUPIN MINE CLOSURE

TITLE
MINE AND MILL SITE AREA – WATERSHEDS

LUPIN MINES INCORPORATED

YYYY-MM-DD	2019-10-15
DESIGNED	IM
PREPARED	AA
REVIEWED	IM
APPROVED	KAB

PROJECT NO.	CONTROL	REV.	FIGURE
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Within each watershed, water flowing to each prediction node is comprised of the following sources illustrated in Figure 2:

- Natural Runoff (including reclaimed land)
- Cover Runoff
- Waste Rock Seepage
- Runoff from facilities not reclaimed (i.e., airstrip, Boot Lake watershed only)

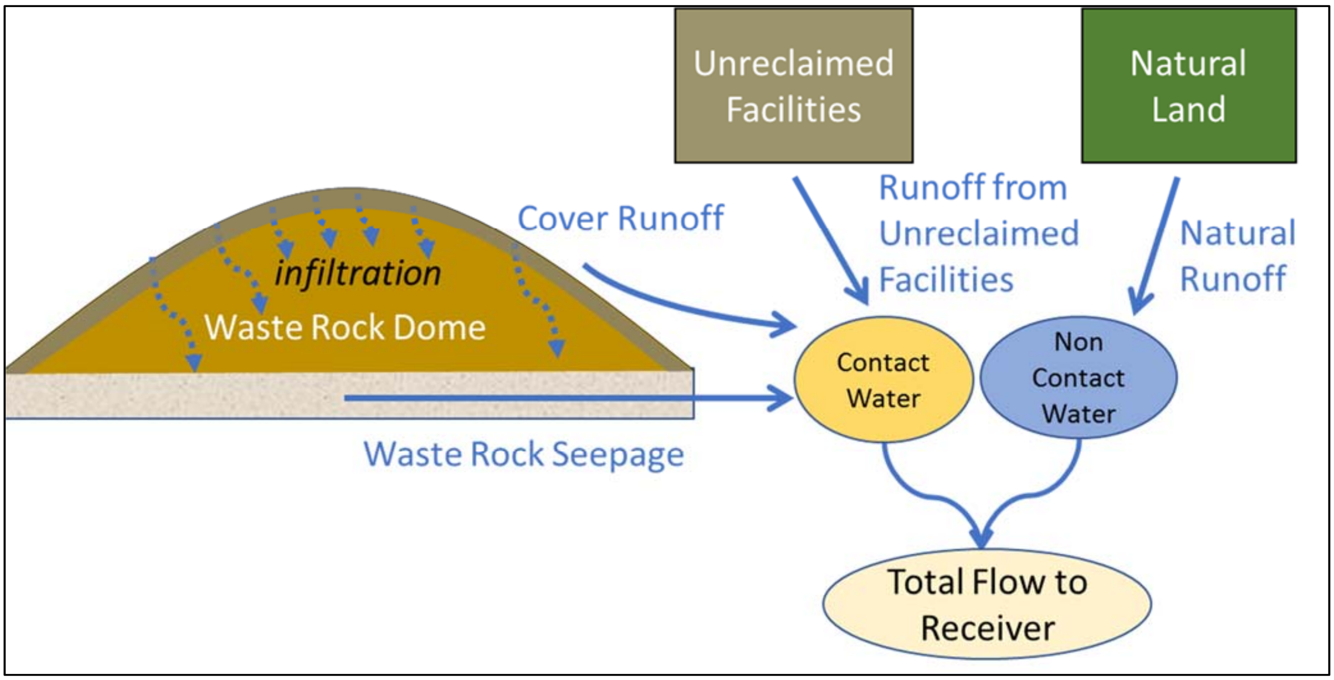


Figure 2: Conceptual Model of Site Flows

At present, waste rock is stored in relatively shallow stockpiles across the Site, and seepage characteristic of ARD is discharging from the toes of these stockpiles (Section 2.0). Relative to current conditions, the model relies upon conceptual assumptions based on the proposed waste rock dome design discussed in Section 1.0 which were applied to simulate the following post-reclamation conditions achieved by the proposed waste rock dome:

- a smaller waste rock footprint than the existing stockpile area;
- capping the waste rock dome with a granular esker material so that runoff does not come in direct contact with the waste rock; and
- using grading and seasonal freezing to limit infiltration; thereby reducing the fraction of the direct precipitation that comes in direct contact with the waste rock.

5.0 MODELLING METHODOLOGY

5.1 Modelling Approach

A water quality and geochemical model was created using a combination of Microsoft Excel and PHREEQC Interactive (PHREEQCi) version 3.3.5 (Parkhurst and Appelo, 1999). PHREEQC is an aqueous geochemical modelling code developed by the United States Geological Survey (USGS). The suite of parameters used in the water quality model was limited to those included in the minteq.v4.dat thermodynamic database. PHREEQC simulates thermodynamic equilibrium of input solutions with the aqueous species, mineral phases and atmospheric gases in the model. The model code simulates the precipitation of secondary mineral phases (which can immobilize dissolved constituents), allowing the attenuation of constituents to levels expected in natural surface water.

The geochemical model was conducted in the following steps:

(1) Aqueous solutions developed as model source terms were brought to thermodynamic equilibrium.

PHREEQC requires that all input solutions be electrically neutral to achieve numerical stability in solving the simultaneous equations that are used in the calculations. Non-electrically neutral input solutions were adjusted to neutrality through the addition of chloride (when anion deficient) or sodium (when cation deficient). Both are ions that are generally highly mobile and form highly soluble salts and, therefore, are unlikely to be associated with reactions involving the fate and transport of the key metals.

(2) The aqueous solutions were mixed in proportions equal to the mixing ratios determined for each catchment in PHREEQC using the following equation:

$$C = \sum^{n} CiFi$$

where:

C = predicted concentration in the catchment identifier (milligrams per litre [mg/L])

Ci = source term concentration ‘i’ (mg/L)

Fi = source term flow proportion “i” (unitless)

n = number of inflows (unitless)

Each flow proportion was multiplied by the corresponding input concentration value, and the sum of all these calculations was used to predict the final concentration at each mixing point. The water quality model ran on four one month-long timesteps for a typical year to evaluate differences in water quality resulting from seasonal variation in cover runoff and infiltration over the course of the open-water season.

(3) The resulting predicted chemical solution for each prediction node was equilibrated by allowing mineral precipitation to occur based on selected geochemically-credible mineral phases that are known to precipitate/dissolve in surface waters.

The potential for mineral precipitation was assessed using the saturation index (SI) calculated according to the following equation:

$$SI = \log \frac{IAP}{K_{sp}}$$

The saturation index is the ratio of the ion activity product (IAP) for a given mineral and the solubility product (K_{sp}). An SI greater than 0.5 indicates that the solution is supersaturated with respect to a particular mineral phase, and mineral precipitation may occur. An SI less than -0.5 denotes undersaturation and indicates that the mineral in question will have a general propensity to dissolve. Mineral phases with SI values between 0.5 and -0.5 are considered to be in equilibrium with the solution.

5.2 Geochemical Inputs

5.2.1 Overview of Geochemical Source Term Development

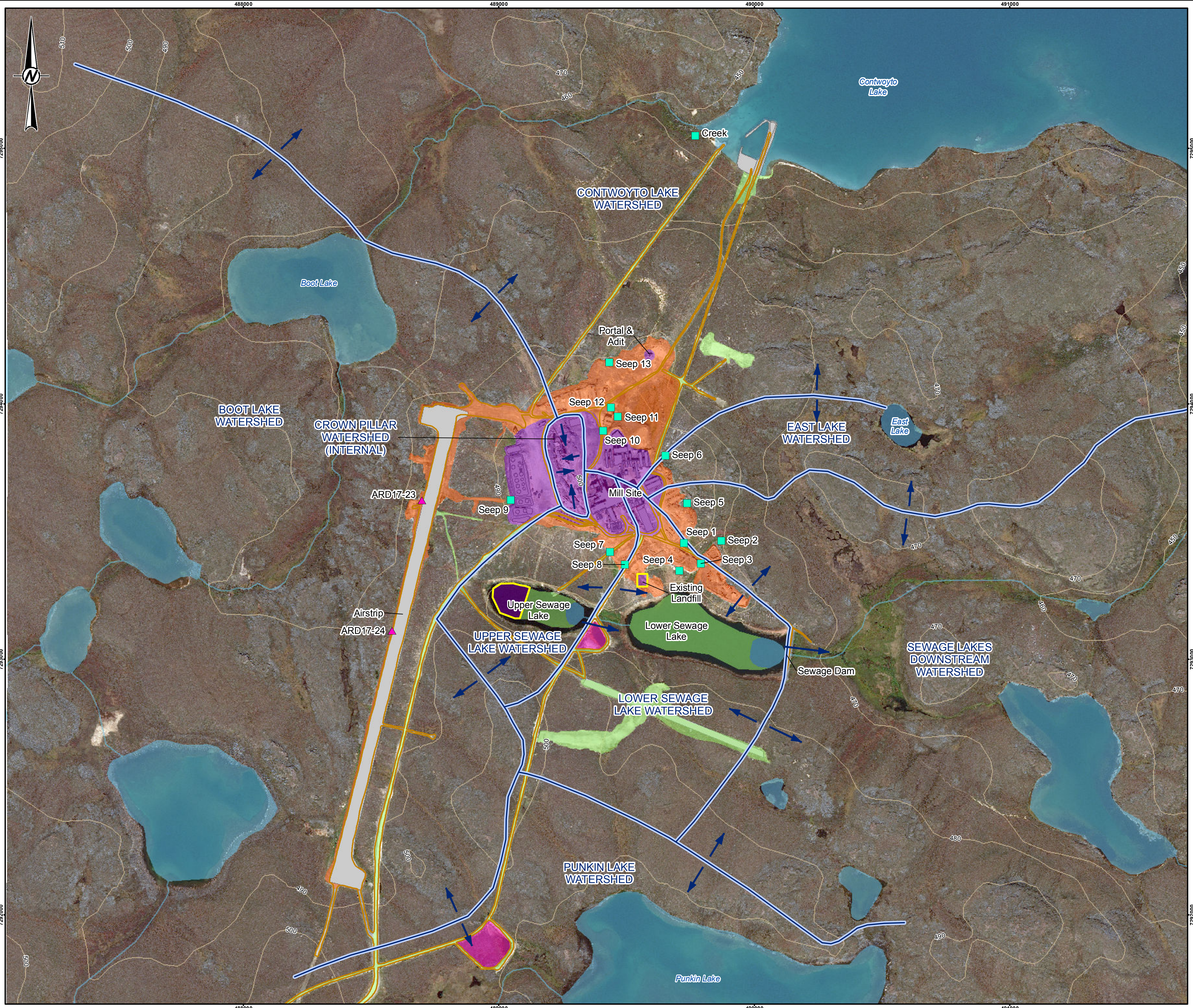
The geochemical source terms were developed using surface water quality, seepage water quality, and results of short-term leach testing. Additional static geochemical laboratory results are anticipated to be available in Q4 2019 and kinetic geochemical laboratory results are anticipated to be available in Q2 2020, at which time the geochemical source terms will be reviewed and updated.

Appendix A presents analytical results used to develop the geochemical source terms. Appendix B presents the geochemical source terms. Geochemical source terms based on surface water quality and seepage water quality monitoring data were calculated using total metals concentrations. Source terms based on SFE results were developed using dissolved metal concentrations. In the case of waste rock seepage and airstrip runoff, source term development was guided by the spatial distribution of available samples (Figure 3). Source terms were compiled using the complete set of available data for a given group of inputs (Table 1) with two source terms calculated for each input in order to produce unique model scenarios to represent uncertainty in geochemical source terms. The two cases calculated for each source term include:

- 50^{th} Percentile of source data concentrations, to represent expected conditions; and,
- 75^{th} Percentile of source data concentrations, to represent upset conditions.

Table 1: Geochemical Source Term Inputs

Contributing Feature	Sewage Lakes	Boot Lake	East Lake
Natural Runoff	Fingers Lake	Fingers Lake	Fingers Lake
Cover Runoff	Esker SFE	Esker SFE	Esker SFE
Waste Rock Seepage	Seeps 1, 2, 3, 4, 7, 8	Seep 9	Seeps 5 & 6
Airstrip Runoff	N/A	ARD17-23 SFE & ARD17-24 SFE	N/A



LEGEND

- 2017 ACID ROCK DRAINAGE SAMPLE LOCATION
- SURFACE WATER SEEP SAMPLE LOCATIONS
- CONTOUR (10 m INTERVAL)
- FLOW DIRECTION
- WATERSHED BOUNDARY
- WATERCOURSE
- ROAD
- INFRASTUCTURE FOOTPRINT
- LANDFILL
- REHABILITATED DISTURBED AREA
- TAILINGS TO BE REMOVED TO TCA
- WASTE ROCK COVERED
- WASTE ROCK REMOVED
- WATERBODY

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DATUM: NAD83 PROJECTION: UTM ZONE 12

CLIENT
MANDALAY RESOURCES CORPORATION

PROJECT
LUPIN MINE CLOSURE

TITLE
MINE AND MILL SITE AREA – WATERSHEDS AND DATA INPUTS TO GEOCHEMICAL SOURCE TERMS

LUPIN MINES INCORPORATED

YYYY-MM-DD	2019-10-15
DESIGNED	IM
PREPARED	AA
REVIEWED	IM
APPROVED	KAB

PROJECT NO.	CONTROL	REV.	FIGURE
19120487	6000	0	3

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5.2.2 Natural Runoff

Limited surface water quality monitoring data is available in the immediate vicinity of the mine site. To develop a natural runoff source term representative of concentrations within a water body affected only by natural runoff and direct precipitation, surface water quality monitoring data from Fingers Lake (approximately 6 kilometres southeast of the mill site) was selected, using available data from the period 2005 through 2016. Fingers Lake is also used as a background water quality monitoring location in Environmental Effects Monitoring (EEM) studies for Lupin Mine.

5.2.3 Cover Runoff

The cover runoff source term was developed from analytical results of leachate produced by SFE testing of three samples of the proposed cover materials (esker sediments). According to the SFE method (MEND, 2009), samples are mixed with DI water at a 3:1 liquid to solid ratio in an extraction vessel. The vessel is shaken immediately, and an initial pH is recorded. The slurry is then shaken for 24 hours, after which a final pH is measured, and the supernatant is extracted for analysis. The results of shake flask extractions are commonly used to estimate the potential composition of water that comes into contact with test materials; however, the results of short-term leach tests do not directly measure the expected effluent chemistry of the test material under ambient conditions due to:

- Relatively small sample size and volume.
- Short duration of the test may not be sufficient to account for representative water-rock interaction times and mineral reaction rates (i.e., sulphide oxidation).
- Enhanced dissolution of some mineral phases due to lab-imposed conditions (i.e., pH, redox, and agitation).

5.2.4 Waste Rock Seepage

A unique waste rock seepage source term was developed for each watershed based on the location of seepage sampling. As illustrated in Figure 3, and noted in Table 1, the seepage sampling locations were sorted by watershed. Accordingly, the waste rock seepage source term for each watershed was developed from those samples collected within each watershed. A single exception exists in the case of the East Lake watershed, in which only a single sample result from Seep 6 was available; to improve source term reliability the single sample result from Seep 5 (located ~100 m south of watershed divide) was included in the East Lake source term calculation. This approach is considered reasonable given that the pH of the two samples is essentially the same (difference of 0.01 pH units) and therefore there are no significant differences in geochemical controls affecting reported concentrations.

5.2.5 Airstrip Runoff

The airstrip is entirely within the Boot Lake watershed and was constructed with historic waste rock. No laboratory analyses of seepage or runoff from the airstrip are available. Given the long exposure history of waste rock in the airstrip, and relatively shallow and distributed pattern of deposition of waste rock in the airstrip (as compared to a waste rock dump), it is anticipated that seepage and runoff from the airstrip is likely to contain reduced acidity and metal concentrations compared to seepage from waste rock in the vicinity of the mill site. Two samples of waste rock from the airstrip (Figure 3) were submitted for SFE testing in 2017 (Golder, 2017), and these results were used to develop the airstrip runoff source term. As noted in Section 3.2.2, SFE results are a useful estimate of the potential composition of water that comes into contact with test materials; however, they are not a direct measurement of runoff quality under ambient conditions, and therefore carry greater uncertainty than on-site monitoring data.

5.3 Hydrologic Inputs

Hydrologic inputs to the water quality model were developed based on the results of thermal and seepage modelling completed by Golder (2019b), and the relative surface areas of features contributing flow to a prediction node. The following sections describe the development of hydrologic model inputs.

5.3.1 Contact Water Loss from Waste Rock Dome

Hydrological model inputs were developed based on results from the thermal and seepage modelling under current (2019) climatic conditions, discussed in Golder (2019b). Future climate results (to the year 2100, assuming an increase in annual mean temperature of 4.95ºC) from the thermal and seepage modelling were also produced and evaluated for applicability to the water quality model (Golder 2019b). The range of flow proportions produced using current climate data is equal to the range of flow proportions under future climate conditions, and monthly proportions are only impacted by the month to which they apply. Under future climate conditions the flow proportions are advanced one month earlier (i.e., June values become applicable to May, September values become applicable to August) and current September values are applicable to both September and October.

Thermal and seepage modelling produced results for water loss from the waste rock dome via three pathways:

- Cover Runoff;
- Waste Rock Seepage; and,
- Evaporation.

Only the net volume of water leaving the waste rock dome influences water quality predictions, therefore evaporation was not carried forward. Thermal and seepage modelling results were provided for a two-year period; to address variability between the two modelled years, the more conservative year in which waste rock seepage volumes were greater relative to cover runoff was selected as an input to the water quality model. This approach is conservative based on geochemical source terms described in Section 3.2, in which metal concentrations in the waste rock seepage source term are greater than in the cover runoff source term. The resulting proportions of water loss from the waste rock dome via these two pathways by month in the open-water season is presented in Table 2.

Table 2: Waste Rock Dome Water Volume Loss Proportions by Month

Contact Water Type	June	July	August	September
Cover Runoff	100%	20.3%	0%	0%
Waste Rock Seepage	0%	79.7%	100%	100%

Note: Water is also lost from the waste rock dome via evaporation; however, seepage water quality source terms are reflective of sampling post-evaporative waters.

5.3.2 Flows Reporting to Receiving Watersheds

Watersheds which may receive flow from the waste rock dome were delineated (Figure 1) to determine the area of each feature that will have a unique chemical source term applied in the model. As described in Section 3.0, three watersheds were evaluated to develop water quality predictions, and four features were identified to contribute flow with unique chemical source terms to these receiving water bodies. The airstrip is entirely within the Boot Lake watershed and therefore for all other watersheds only three features contribute flow. The proportionate area of each feature within each watershed is defined in Table 3.

Table 3: Flow Proportions

Catchment	Contributing Flows	June	July	August	September
Sewage Lakes	Natural Runoff	93.3%	93.3%	93.3%	93.3%
	Cover Runoff	6.7%	1.4%	0.0%	0.0%
	Waste Rock Seepage	0.0%	5.3%	6.7%	6.7%
Boot Lake	Natural Runoff	98.9%	98.9%	98.9%	98.9%
	Cover Runoff	0.4%	0.1%	0.0%	0.0%
	Waste Rock Seepage	0.0%	0.3%	0.4%	0.4%
	Airstrip Runoff	0.7%	0.7%	0.7%	0.7%
East Lake	Natural Runoff	97.6%	97.6%	97.6%	97.6%
	Cover Runoff	2.4%	0.5%	0.0%	0.0%
	Waste Rock Seepage	0.0%	1.9%	2.4%	2.4%

The model is conservative in the assumption that all cover runoff, waste rock seepage, and airstrip runoff reaches the prediction node within each watershed. No channels have been observed to transport flow from existing waste rock piles to receiving water bodies. It is probable that a portion of waste rock seepage flows travelling overland from the toe of the proposed waste rock dome to the receiving water body could evaporate or infiltrate prior to reaching a receiving water body. Therefore, the model may overestimate the predicted concentrations in the modelled catchments.

5.4 Key Model Assumptions

The water quality model was developed with the following assumptions:

- Reported concentrations in analytical results used in source term development that were less than the detection limit were assumed to be equal to one-half the detection limit.
- Source terms were developed using total metal concentrations in order to produce results directly comparable to receiving environment water quality criteria. However, this approach may overestimate receiver water chemistry concentrations in lakes, where particulate settling is likely to be enhanced relative to samples used in source term development.
- Redox potential of modelled solutions is equal to 400 millivolts (mV), which is representative of oxidized surface water.
- Background water quality as measured from Fingers Lake is representative of background water quality in the systems modelled.
- All contact water (i.e., cover runoff, water rock seepage and airstrip runoff) reaches the predictions nodes in the receiving environment. No adjustments were made to account for water loss due to infiltration or evaporation during overland flow.
- Modelled water bodies have reached steady-state long term conditions.
- In water bodies with stored volume (e.g., Boot Lake), no time-lag is included to account for progressive changes in water quality resulting from monthly loading differences.

6.0 MODEL RESULTS

Geochemical source terms and hydrological inputs were used to develop receiving water quality predictions to evaluate the performance of the proposed waste rock dome in reducing chemical loading to the environment. Environmental effects analysis of the water quality predictions is discussed in the Human Health and Ecological Risk Assessment (HHERA) (Golder, 2019a). Complete water quality model results are presented in Appendix C. Table 4 presents the annual range of results (open-water season only) for key parameters for the 50th percentile source terms scenario. Model results include future water quality estimates based on the conceptual model and site geography described in Section 3.0 for the following prediction nodes:

- East Lake Outlet;
- Boot Lake Outlet; and,
- Lower Sewage Lake Outlet.

It is noted that the dam at the outlet of Lower Sewage Lake is planned to be breached in the future and Lower Sewage Lake will cease to exist. It is uncertain whether a small area of ponded water will continue to exist or only a stream channel; however, this difference has no impact on the model results given that the model does not rely on mixing with a stored reservoir volume.

The relatively smaller watersheds of Lower Sewage Lake and East Lake are anticipated to see generally higher metal concentrations as compared to Boot Lake, where the larger watershed results in a greater proportion of natural runoff relative to contact water.

Table 4: Annual Range of Model Results for Key Parameters, 50th Percentile Source Terms

Parameter	Units	East Lake Outlet	Boot Lake Outlet	Lower Sewage Lake Outlet
pH	-	5.0 – 6.6	5.6 – 6.5	6.5 – 6.9
Sulphate	mg/L	2.6 – 9.2	2.6 – 4.3	2.7 – 35
Aluminum	mg/L	0.001 – 0.040	0.001 – 0.003	0.001 – 0.002
Arsenic	mg/L	0.0010 – 0.0015	0.0013 – 0.0016	0.0010 – 0.0016
Cadmium	mg/L	0.00001 – 0.00004	0.00001 – 0.00002	0.00001 – 0.00002
Chromium	mg/L	0.000034 – 0.000083	0.000032 – 0.000061	0.000002 – 0.000040
Copper	mg/L	0.0003 – 0.0039	0.0003 – 0.0004	0.0003 – 0.0005
Iron	mg/L	0.0006 – 0.0236	0.0007 – 0.0052	0.0003 – 0.0007
Lead	mg/L	0.000019 – 0.000061	0.000017 – 0.000048	0.000002 – 0.000027
Manganese	mg/L	0.004 – 0.026	0.004 – 0.010	0.006 – 0.063
Nickel	mg/L	0.0008 – 0.0112	0.0006 – 0.0023	0.0013 – 0.0077
Zinc	mg/L	0.0004 – 0.0083	0.0006 – 0.0018	0.0004 – 0.0145

The water quality model results indicate that seasonal effects (i.e., freezing) on the waste rock dome are a controlling factor on water quality. The fraction of water attributable to runoff from natural ground or reclaimed surfaces is constant within the model. Therefore, monthly variation in water quality is attributable to whether precipitation and snowmelt on top of the waste rock dome runs off (only interacting with cover materials) or infiltrates (primarily interacting with waste rock) producing seepage from the toe of the dome. In June, all contact water occurs as runoff from the cover materials, producing the lowest predicted metal concentrations. Conversely, August and September results indicate the greatest monthly concentrations of metals, as all water seeps through the cover into the waste rock dome.

The predicted pH values at all model nodes are moderately acidic to neutral, ranging from 5.6 to 6.9. Lower Sewage Lake outlet is anticipated to contain the greatest concentrations for a small majority of constituents modelled, including sulphate (2.7 – 35 mg/L), arsenic (0.00097 – 0.00164 mg/L), manganese (0.006 – 0.063 mg/L), uranium (0.00003 – 0.00017 mg/L), and zinc (0.0004 - 0.0145 mg/L). East Lake is anticipated to contain the greatest concentrations for a minority of the constituents modelled, including aluminum (0.0012 – 0.0403 mg/L), cadmium (0.000009 – 0.000041 mg/L), cobalt (0.00017 – 0.00483 mg/L), copper (0.0003 – 0.0039 mg/L), iron (0.001 – 0.023 mg/L), and nickel (0.0008 – 0.0112 mg/L). Due to the large watershed of Boot Lake, and corresponding large proportion of natural runoff, only a few constituents are expected at the greatest concentrations in Boot Lake, including nitrate (0.002 – 0.006 mg/L N), tin (0.000086 – 0.000086 mg/L), and vanadium (0.00006 – 0.00006 mg/L); these constituents reflect greater concentrations in natural runoff water quality and airstrip runoff relative to waste rock seepage. Values above refer to model results for the 50^{th} Percentile inputs scenario.

The results presented herein represent model results after equilibration with geochemically-credible mineral phases. Solubility constraints imposed by the equilibration step resulted in the precipitation of several mineral phases, resulting in a reduction in concentrations of certain metals in the equilibrated model results relative to model results without equilibration. Mineral phases predicted to precipitate include basaluminite ($Al_4(OH)_{10}SO4$), boehmite (γ-AlO(OH)), ferrihydrite (Fe_2O_3•$0.5H_2O$), and jarosite ($KFe_3(OH)_6(SO_4)_2$). Metals which declined in concentration due to mineral precipitation and sorption include arsenic, aluminum, beryllium, chromium, copper, iron, phosphorus, and lead.

7.0 CONCLUSIONS

Waste rock at Lupin mine is proposed to be consolidated in a “dome” for long-term management to enhance chemical stability of the waste rock. The majority of the waste rock has the potential to generate acidity and metals, and analyses of seepage collected from the Site indicate that acidity and elevated concentrations metals (including aluminum, arsenic, cadmium, cobalt, copper, nickel, and zinc) are present in water which has infiltrated into the waste rock. Geochemical characterization of waste rock will continue using samples collected from the site in August 2019.

Water quality modelling of receiver water bodies was conducted to evaluate the potential performance of a granular esker cover with respect to limiting generation of ARD-impacted waters from the waste rock pile at the Lupin Mine. The modelling was conducted using PHREEQC and consisted of mixing contact water from cover runoff and waste rock seepage with natural runoff. The model results reflect the impact of the proposed waste rock dome in reducing the volume of seepage produced by consolidation of existing waste rock into a smaller footprint receiving a comparatively smaller fraction of precipitation than the existing footprint and construction of an infiltration reduction cover with low ARD potential materials. The model is conservative in the assumption that all cover runoff, waste rock seepage, and airstrip runoff reach the prediction node within each watershed. Given that no flow channels currently exist from waste rock to receiving water bodies, it is probable that at closure, some portion of waste rock dome seepage will evaporate or infiltrate along the flow path to the receiving water bodies. As such, the model may conservatively overestimate the predicted concentrations in the modelled catchments.

The predicted composition of water at each receiving node are expected to vary on a monthly basis during the open-water season depending on the proportion of precipitation and snowmelt that report as cover runoff versus infiltration. The relatively smaller watersheds of Lower Sewage Lake and East Lake are anticipated to see generally higher metal concentrations as compared to Boot Lake, where the larger watershed results in a greater proportion of natural runoff relative to contact water.

Water quality modelling was completed based on results from the thermal and seepage modelling for current (2019) climatic conditions (Golder, 2019b). Results based on predicted future climatic conditions to the year 2100 were also produced from the thermal and seepage model and were evaluated for applicability to the water quality model. The range of concentrations produced using current climate data is equal to the range of concentrations under future climate conditions, and predictions are only affected by the month to which they apply, the actual values are unchanged. Under future climate conditions, all monthly results are advanced one month earlier (i.e., June results become applicable to May, September results become applicable to August) and current September results are applicable to both September and October. Therefore, the duration of peak concentrations (controlled by months in which water loss from the waste rock dome is 100% seepage) would increase from two months (August and September) to four months (July through October).

Application of geochemical controls including mineral precipitation and sorption resulted in depression of certain metal concentrations, most notably aluminum, relative to model results without geochemical controls. Model results for the 50^{th} Percentile inputs scenario indicate anticipated pH values at all model nodes are moderately acidic to neutral, ranging from 5.6 to 6.9. Environmental effects analysis of the water quality predictions is discussed in the Human Health and Ecological Risk Assessment (HHERA) (Golder, 2019a).

8.0 LIMITATIONS

Care was taken to incorporate known processes into the water quality model, as understood during model development. However, in natural systems and complex man-made systems, observed conditions will almost certainly vary with respect to estimated conditions. Water quality modelling requires the use of many assumptions due to the uncertainty related to determining the physical and geochemical characteristics of a complex system. Given the inherent uncertainties and assumptions of the model approach, the results of the model should be used as a tool to aide in the design of closure options and to outline potential risks rather than to provide absolute values.

This model was constructed based on the conceptualization of sources and release mechanisms, combined with data interpretation, to describe water quality conditions at the Site. Where uncertainty exists in model input values, conservative inputs and assumptions have been applied. Climatic controls, which may influence infiltration, evaporation, geochemical processes, and flow within the catchments, were not modelled, except for those which were captured in thermal and seepage modelling of the waste rock dome (Golder, 2019b). Therefore, the model could potentially overestimate the predicted concentrations in the modelled catchments.

The solubility controls imposed by equilibrium reactions consider the saturation state of the selected mineral phases and only indicate which reactions are possible thermodynamically, not necessarily which reactions are likely to occur in the environment. Kinetic barriers may inhibit mineral precipitation reactions from taking place.

The model results are based on the input data collected during site characterization studies and environmental effects monitoring (EEM) studies conducted by Golder and other consultants. Known processes (e.g., metal leaching from waste rock and cover materials) were incorporated based on data as provided. Changes in the Site conditions, input data, or assumptions regarding the Site conditions will necessarily result in changes to water quality model predictions.

9.0 CLOSURE

We trust that this technical memorandum meets your present requirements. If you have any questions, please do not hesitate to contact the undersigned.

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List of Appendices:

- Appendix A - Analytical Results Used in Geochemical Source Term Development
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https://golderassociates.sharepoint.com/sites/107254/project files/5 technical work/6000 geochem & wq modelling/6040 reporting/19120487_lupin_surface_wq_model_15oct2019.docx

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APPENDIX A

Analytical Results Used in Geochemical Source Term Development

Parameter	Units	Natural Runoff										
		Fingers Lake	**Fingers Creek**	**FC2**	**FL5**	**FL1**	**FL3**	**FL5**	**FC2**	**FL-1**	**FL-3**	**FL-5**
		5-Sep-05	**5-Sep-05**	**8-Sep-08**	**8-Sep-08**	**8-Sep-08**	**21-Aug-10**	**21-Aug-10**	**27-Aug-10**	**30-Aug-16**	**30-Aug-16**	**30-Aug-16**
pH	-	6.5	6.3	6.6	6.6	6.6	6.78	6.75	6.92	6.4	6.5	6.3
Alkalinity	mg/L $CaCO_3$	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	3.8	5.8	3.2
Nitrate	mg/L N	0.1	< 0.1	< 0.006	0.007	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006
Chloride	mg/L	< 1	< 1	< 1	2	< 1	< 0.5	< 0.5	< 0.5	-	-	-
Sulphate	mg/L	2.7	2.6	2.54	2.67	2.36	2.49	2.49	2.49	-	-	-
Silver	mg/L	0.00000326	0.00000138	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.00005	< 0.00005	< 0.00005
Aluminum	mg/L	0.0164	0.0103	0.0192	0.0158	0.0162	0.0133	0.0374	0.0171	0.00517	0.00604	0.00511
Arsenic	mg/L	0.00207	0.00121	0.00121	0.00143	0.00133	0.00171	0.00167	0.00175	0.00123	0.00127	0.00128
Boron	mg/L	0.00145	< 0.00005	< 0.001	< 0.001	< 0.001	0.0025	0.0028	0.0022	0.0114	0.0108	0.009
Barium	mg/L	0.00175	0.00147	0.00186	0.00185	0.00172	0.00153	0.00168	0.0019	0.0123	0.00989	0.00866
Berylium	mg/L	< 0.000003	< 0.000003	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.000054	0.000027	0.000021
Calcium	mg/L	1.1	1.6	1.5	1.1	0.8	-	-	-	-	-	-
Cadmium	mg/L	0.00000886	< 0.000002	< 0.000017	< 0.000017	< 0.000017	< 0.00005	< 0.00005	< 0.00005	< 0.000005	< 0.000005	< 0.000005
Cobalt	mg/L	0.0000493	0.0000691	0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.00016	0.00328	0.00322	0.0031
Chromium	mg/L	0.0000999	< 0.00003	< 0.00006	< 0.00006	< 0.00006	0.000069	0.00013	0.000079	0.00481	0.0019	0.00113
Copper	mg/L	0.000562	0.00039	< 0.0006	< 0.0006	< 0.0006	< 0.0006	< 0.0006	< 0.0006	0.0004	0.0004	0.0004
Iron	mg/L	0.0302	0.0181	0.034	0.028	0.028	0.0384	0.0449	0.0942	0.0183	0.0249	0.0181
Mercury	mg/L	< 0.00000001	< 0.00000001	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	-	-	-
Potassium	mg/L	< 0.5	0.6	0.4	0.5	0.4	-	-	-	-	-	-
Magnesium	mg/L	0.6	0.7	0.7	0.6	0.5	-	-	-	-	-	-
Manganese	mg/L	0.00287	0.00382	0.0038	0.0025	0.0025	0.00436	0.00352	0.0116	< 0.00005	< 0.00005	< 0.00005
Molybdenum	mg/L	0.0000165	0.00000837	< 0.00006	< 0.00006	< 0.00006	< 0.00006	< 0.00006	< 0.00006	< 0.00005	< 0.00005	< 0.00005
Sodium	mg/L	0.601	0.402	0.441	0.427	0.434	0.474	0.443	0.474	0.00042	0.00037	0.00049
Nickel	mg/L	0.000394	0.000339	0.00065	0.00059	0.00044	0.000504	0.000526	0.00065	0.000412	0.000441	0.000423
Phosphorus	mg/L	0.02	< 0.02	0.005	0.008	0.008	< 0.001	0.0185	0.0016	-	-	-
Lead	mg/L	0.000279	0.000013	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00001	< 0.00001	< 0.00001
Antimony	mg/L	0.0000106	0.00000603	< 0.00003	< 0.00003	< 0.00003	< 0.00003	< 0.00003	< 0.00003	< 0.00002	< 0.00002	< 0.00002
Selenium	mg/L	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	-	-	-
Silicon	mg/L	0.0923	0.0124	-	-	-	-	-	-	< 0.005	< 0.005	< 0.005
Tin	mg/L	< 0.00003	< 0.00003	-	-	-	< 0.0001	< 0.0001	< 0.0001	-	-	-
Strontium	mg/L	0.00489	0.0053	0.0051	0.0048	0.0046	0.00472	0.00476	0.00563	0.000029	0.000023	0.000018
Thallium	mg/L	0.0000011	0.00000123	-	-	-	< 0.00003	< 0.00003	< 0.00003	-	-	-
Uranium	mg/L	0.00000481	0.00000472	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	-	-	-
Vanadium	mg/L	0.0000533	< 0.000005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	0.000106	< 0.00005	-	-	-
Zinc	mg/L	0.00216	0.00167	< 0.0008	< 0.0008	< 0.0008	< 0.0008	< 0.0008	< 0.0008	< 0.0008	< 0.0008	0.00273

Notes:

[1] Data source: Water quality analyses of field collected surface water from Fingers Lake.

Parameter	Units	Cover Runoff		
		ARD19-23	ARD19-24	ARD19-25
pH	-	4.51	6.09	6.07
Alkalinity	mg/L $CaCO_3$	<0.5	3.5	2
Nitrate	mg/L N	0.063	0.022	0.005
Chloride	mg/L	0.75	0.41	0.07
Sulphate	mg/L	15.1	5.9	<0.5
Silver	mg/L	<0.00008	<0.00008	<0.00008
Aluminum	mg/L	0.023	0.007	0.016
Arsenic	mg/L	<0.0002	0.0003	0.0011
Boron	mg/L	<0.01	<0.01	<0.01
Barium	mg/L	0.058	0.005	0.0002
Berylium	mg/L	0.0001	<0.0001	<0.0001
Calcium	mg/L	1.89	1.14	0.16
Cadmium	mg/L	0.00012	<0.00001	<0.00001
Cobalt	mg/L	0.0177	0.0044	0.0001
Chromium	mg/L	<0.0005	<0.0005	<0.0005
Copper	mg/L	0.0204	0.0018	0.0033
Iron	mg/L	<0.02	<0.02	<0.02
Mercury	mg/L	<0.0005	<0.0005	<0.0005
Potassium	mg/L	3.68	1.97	0.29
Magnesium	mg/L	1.07	0.7	0.087
Manganese	mg/L	0.0881	0.0475	0.0009
Molybdenum	mg/L	<0.0001	<0.0001	0.0003
Sodium	mg/L	0.8	0.71	0.07
Nickel	mg/L	0.0563	0.0133	<0.0005
Phosphorus	mg/L	0.05	<0.05	<0.05
Lead	mg/L	<0.0005	<0.0005	<0.0005
Antimony	mg/L	<0.0001	0.0002	0.0002
Selenium	mg/L	<0.0005	<0.0005	<0.0005
Silicon	mg/L	0.44	0.74	0.26
Tin	mg/L	<0.0005	<0.0005	<0.0005
Strontium	mg/L	0.0118	0.0051	0.0008
Thallium	mg/L	0.00008	0.00008	<0.00005
Uranium	mg/L	0.00013	<0.00005	0.0001
Vanadium	mg/L	<0.001	<0.001	<0.001
Zinc	mg/L	<0.001	<0.001	<0.001

Notes:

[1] Data source: short-term leach test results.

Parameter	Units	Waste Rock Seepage														
		Sewage Lakes Watershed											East Lake Watershed		Boot Lake Watershed	
		SEEP 1	SEEP 1	SEEP 2	SEEP 2	SEEP 3	SEEP 3	SEEP 4	SEEP 7	SEEP 7	SEEP 7B	SEEP 8	SEEP 5	SEEP 6	SEEP 9	SEEP 9
		17-Aug-17	20-Aug-19	17-Aug-17	20-Aug-19	17-Aug-17	20-Aug-19	20-Aug-19	17-Aug-17	21-Aug-19	21-Aug-19	21-Aug-19	20-Aug-19	20-Aug-19	18-Aug-17	21-Aug-19
pH	-	7.23	7.6	4.62	4.89	7.32	7.96	7.5	6.6	8.27	8.26	8.2	3.93	3.94	3.88	3.79
Alkalinity	mg/L $CaCO_3$	56	30.4	<0.5	<1	110	64	22.6	68	123	121	99	<1	<1	<0.5	<1
Nitrate	mg/L N	2.1	0.807	<0.01	0.391	<0.01	0.795	0.294	<0.01	<0.025	<0.025	<0.025	0.198	0.462	1.7	0.589
Chloride	mg/L	70	8.2	28	27.3	93	36.4	15.2	18	17.1	17.2	25.9	2.88	7.4	46	17
Sulphate	mg/L	640	486	520	232	730	840	527	310	293	293	283	278	283	500	406
Silver	mg/L	<0.0001	<0.00001	<0.0001	<0.00001	<0.0001	<0.00001	<0.00001	<0.0001	0.000015	0.000011	<0.00001	0.000011	<0.00001	<0.0001	<0.00001
Aluminum	mg/L	2.6	1.27	0.64	2.3	0.019	0.187	0.747	0.12	0.28	0.135	0.0628	4.46	9.59	1.9	3.78
Arsenic	mg/L	0.36	0.00935	0.025	0.0151	0.071	0.0649	0.00112	0.047	0.0561	0.0468	0.0253	0.0104	0.00761	0.0058	0.0108
Boron	mg/L	0.31	0.297	0.37	0.693	0.34	0.254	0.102	0.086	0.111	0.109	0.103	0.042	0.036	0.033	0.035
Barium	mg/L	0.047	0.0209	0.034	0.0438	0.055	0.0219	0.0104	0.023	0.0346	0.032	0.0126	0.016	0.0316	0.017	0.0203
Berylium	mg/L	<0.001	0.0008	<0.001	0.00022	<0.001	<0.0001	0.00011	<0.001	<0.0001	<0.0001	<0.0001	0.00138	0.00251	<0.001	0.00159
Calcium	mg/L	210	157	150	162	260	270	151	99	125	125	113	67.4	62	150	109
Cadmium	mg/L	0.00074	0.00135	0.002	0.00295	0.00022	0.000618	0.000172	0.00014	0.000159	0.000147	0.0000451	0.000989	0.00169	0.0016	0.00167
Cobalt	mg/L	0.088	0.201	0.022	0.00998	0.059	0.0363	0.0177	0.11	0.0208	0.0197	0.00105	0.148	0.247	0.24	0.211
Chromium	mg/L	0.012	0.00018	<0.001	0.00113	<0.001	0.00066	0.00021	0.0017	0.00169	0.00079	0.00039	0.00049	0.00072	<0.001	0.00053
Copper	mg/L	0.024	0.00783	0.023	0.131	0.0028	0.00757	0.013	0.0098	0.00366	0.00323	0.00438	0.123	0.173	0.022	0.0393
Iron	mg/L	7.7	1.23	11	1.56	3.7	1.87	0.064	16	1.74	1.3	0.11	0.868	1.15	1.2	1.09
Mercury	mg/L	-	<0.000005	-	<0.000005	-	<0.000005	<0.000005	-	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005	-	<0.000005
Potassium	mg/L	17	14.5	6.7	10.1	19	20.1	11.8	9.4	11.8	12.2	10.9	5.35	5	11	7.94
Magnesium	mg/L	28	17.3	23	13.1	34	42.5	29.5	35	17.9	17.7	14.6	14.7	14.6	27	19.3
Manganese	mg/L	1.2	1.08	0.44	0.39	1.4	0.654	0.184	2.7	0.942	0.905	0.00129	0.734	1.23	2.3	1.48
Molybdenum	mg/L	0.0013	0.000869	0.0003	0.00252	0.0022	0.00122	0.000207	0.00053	0.00141	0.00141	0.000754	0.000108	0.000072	<0.0002	<0.00005
Sodium	mg/L	57	14.1	29	19.1	63	32	19.2	24	15.4	15.6	24.4	6.41	6.09	38	14.5
Nickel	mg/L	0.28	0.51	0.063	0.0243	0.11	0.236	0.114	0.25	0.0555	0.0535	0.0514	0.314	0.582	0.44	0.483
Phosphorus	mg/L	<0.1	<0.05	<0.1	0.126	<0.1	<0.05	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05
Lead	mg/L	0.015	0.000485	0.0014	0.00714	0.00032	0.000902	<0.00005	0.001	0.000827	0.00047	0.000141	0.00194	0.00115	0.0071	0.00607
Antimony	mg/L	0.00092	0.00013	0.003	0.022	<0.0006	0.00232	<0.0001	<0.0006	0.00043	0.00042	0.00013	<0.0001	<0.0001	<0.0006	<0.0001
Selenium	mg/L	0.00063	0.00049	0.00021	0.000057	<0.0002	0.000497	0.000351	0.00074	0.000157	0.000173	0.000154	0.000318	0.000249	0.00068	0.00035
Silicon	mg/L	8.1	7.23	2.3	6.19	7.1	6.6	6.09	9.1	8.16	7.86	4.84	10.4	13.2	7.6	10.9
Tin	mg/L	<0.001	<0.0001	<0.001	<0.0001	<0.001	<0.0001	<0.0001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.001	<0.0001
Strontium	mg/L	0.94	0.712	0.65	0.437	1.1	1.31	0.513	0.34	0.422	0.417	0.339	0.239	0.226	0.49	0.38
Thallium	mg/L	<0.0002	0.000016	<0.0002	0.000023	<0.0002	0.000022	0.000016	<0.0002	0.000024	0.000022	<0.00001	0.000036	0.000059	<0.0002	0.00008
Uranium	mg/L	0.01	0.011	<0.0001	0.00109	0.0022	0.00196	0.000562	0.00067	0.00295	0.00296	0.0161	0.0026	0.000745	0.0049	0.00983
Vanadium	mg/L	0.0065	<0.0005	<0.001	<0.0005	0.0012	<0.0005	<0.0005	0.0025	0.00085	<0.0005	<0.0005	<0.0005	<0.0005	<0.001	<0.0005
Zinc	mg/L	0.22	0.34	0.64	0.286	0.1	0.269	0.134	0.035	0.215	0.204	0.0137	0.159	0.5	0.29	0.344

Notes:

[1] Data source: Water quality analyses of field collected seepage water.

Parameter	Units	Airstrip Runoff	
		ARD17-23	ARD17-24
pH	-	5.07	5.79
Alkalinity	mg/L $CaCO_3$	1	3
Nitrate	mg/L N	-	-
Chloride	mg/L	-	-
Sulphate	mg/L	22.4	10.2
Silver	mg/L	<0.00002	<0.00002
Aluminum	mg/L	0.05	0.0098
Arsenic	mg/L	0.0426	0.0789
Boron	mg/L	<0.05	<0.05
Barium	mg/L	0.0125	0.0046
Berylium	mg/L	<0.0001	<0.0001
Calcium	mg/L	5.8	3.3
Cadmium	mg/L	0.00012	0.000055
Cobalt	mg/L	0.0122	0.0053
Chromium	mg/L	<0.001	<0.001
Copper	mg/L	0.00251	0.00095
Iron	mg/L	0.524	0.0262
Mercury	mg/L	<0.00005	<0.00005
Potassium	mg/L	2.13	2.37
Magnesium	mg/L	1.08	0.438
Manganese	mg/L	0.105	0.0839
Molybdenum	mg/L	<0.001	<0.001
Sodium	mg/L	0.477	0.456
Nickel	mg/L	0.0319	0.009
Phosphorus	mg/L	<0.01	<0.01
Lead	mg/L	0.00036	<0.0002
Antimony	mg/L	<0.0005	<0.0005
Selenium	mg/L	<0.0001	<0.0001
Silicon	mg/L	0.81	0.61
Tin	mg/L	<0.005	<0.005
Strontium	mg/L	0.036	0.0193
Thallium	mg/L	0.000029	0.000016
Uranium	mg/L	0.00023	0.00011
Vanadium	mg/L	<0.005	<0.005
Zinc	mg/L	0.0572	0.0139

Notes:

[1] Data source: short-term leach test results.

[2] Chloride and Nitrate results were not available for airstrip leach test results; waste rock seepage data from all locations used as conservative alternate.

APPENDIX B

Geochemical Source Terms

Appendix B: Geochemical Source Terms
50th Percentile Source Terms
Waste Rock Water Quality Model
Lupin Mine Closure Project

Parameter	Units	50th Percentile					
		Natural Runoff	Cover Runoff	Waste Rock Seepage - East Lake	Waste Rock Seepage - Boot Lake	Waste Rock Seepage - Sewage Lake	Airstrip Runoff
pH	-	6.60	6.07	3.94	3.84	7.55	5.43
Alkalinity	mg/L $CaCO_3$	2.50	2.00	0.50	0.38	64.00	2.00
Nitrate	mg/L N	0.0030	0.0220	0.3300	1.1445	0.0125	0.4957
Chloride	mg/L	0.50	0.41	5.14	31.50	25.90	20.85
Sulphate	mg/L	2.52	5.90	280.50	453.00	486.00	16.30
Silver	mg/L	0.000050	0.000040	0.000008	0.000028	0.000011	0.000020
Aluminum	mg/L	0.0158	0.0160	7.0250	2.8400	0.2800	0.0299
Arsenic	mg/L	0.00133	0.00030	0.00901	0.00830	0.04680	0.06075
Boron	mg/L	0.00220	0.00500	0.03900	0.03400	0.25400	0.05000
Barium	mg/L	0.00185	0.00500	0.02380	0.01865	0.03200	0.00855
Berylium	mg/L	0.00010	0.00005	0.00195	0.00105	0.00022	0.00010
Calcium	mg/L	1.10	1.14	64.70	129.50	151.00	4.55
Cadmium	mg/L	0.000009	0.000005	0.001340	0.001635	0.000220	0.000088
Cobalt	mg/L	0.000069	0.004400	0.197500	0.225500	0.022000	0.008750
Chromium	mg/L	0.000079	0.000250	0.000605	0.000515	0.000660	0.001000
Copper	mg/L	0.00030	0.00330	0.14800	0.03065	0.00783	0.00173
Iron	mg/L	0.0280	0.0100	1.0090	1.1450	1.7400	0.2751
Mercury	mg/L	0.000010	0.000250	0.000003	0.000003	0.000003	0.000050
Potassium	mg/L	0.400	1.970	5.175	9.470	11.800	2.250
Magnesium	mg/L	0.600	0.700	14.650	23.150	23.000	0.759
Manganese	mg/L	0.0029	0.0475	0.9820	1.8900	0.9050	0.0945
Molybdenum	mg/L	0.00003	0.00005	0.00009	0.00006	0.00122	0.00100
Sodium	mg/L	0.43	0.71	6.25	26.25	24.00	0.47
Nickel	mg/L	0.0004	0.0133	0.4480	0.4615	0.1100	0.0205
Phosphorus	mg/L	0.0080	0.0250	0.0250	0.0375	0.0250	0.0100
Lead	mg/L	0.000025	0.000250	0.001545	0.006585	0.000827	0.000280
Antimony	mg/L	0.000015	0.000200	0.000050	0.000175	0.000420	0.000500
Selenium	mg/L	0.000050	0.000250	0.000284	0.000515	0.000210	0.000100
Silicon	mg/L	0.0025	0.4400	11.8000	9.2500	7.1000	0.7100
Tin	mg/L	0.00005	0.00025	0.00005	0.00028	0.00005	0.00500
Strontium	mg/L	0.00476	0.00510	0.23250	0.43500	0.51300	0.02765
Thallium	mg/L	0.000015	0.000080	0.000048	0.000090	0.000023	0.000023
Uranium	mg/L	0.00003	0.00010	0.00167	0.00737	0.00220	0.00017
Vanadium	mg/L	0.000025	0.000500	0.000250	0.000375	0.000250	0.005000
Zinc	mg/L	0.0004	0.0005	0.3295	0.3170	0.2150	0.0356

75th Percentile Source Terms
Waste Rock Water Quality Model
Lupin Mine Closure Project

Parameter	Units	75th Percentile					
		Natural Runoff	Cover Runoff	Waste Rock Seepage - East Lake	Waste Rock Seepage - Boot Lake	Waste Rock Seepage - Sewage Lake	Airstrip Runoff
pH	-	6.45	5.29	3.93	3.81	7.25	5.25
Alkalinity	mg/L $CaCO_3$	2.50	1.13	0.50	0.31	26.50	1.50
Nitrate	mg/L N	0.0050	0.0425	0.3960	1.4223	0.5930	0.8038
Chloride	mg/L	0.50	0.58	6.27	38.75	32.20	25.74
Sulphate	mg/L	2.62	10.50	281.75	476.50	583.50	19.35
Silver	mg/L	0.000050	0.000040	0.000010	0.000039	0.000050	0.000020
Aluminum	mg/L	0.0168	0.0195	8.3075	3.3100	1.0085	0.0400
Arsenic	mg/L	0.00169	0.00070	0.00970	0.00955	0.06050	0.06983
Boron	mg/L	0.00590	0.00500	0.04050	0.03450	0.32500	0.05000
Barium	mg/L	0.00528	0.03150	0.02770	0.01948	0.03920	0.01053
Berylium	mg/L	0.00010	0.00008	0.00223	0.00132	0.00050	0.00010
Calcium	mg/L	1.50	1.52	66.05	139.75	186.00	5.18
Cadmium	mg/L	0.000017	0.000063	0.001515	0.001653	0.001045	0.000104
Cobalt	mg/L	0.001630	0.011050	0.222250	0.232750	0.073500	0.010475
Chromium	mg/L	0.000630	0.000250	0.000663	0.000523	0.001410	0.001000
Copper	mg/L	0.00040	0.01185	0.16050	0.03498	0.01800	0.00212
Iron	mg/L	0.0362	0.0100	1.0795	1.1725	5.7000	0.3996
Mercury	mg/L	0.000010	0.000250	0.000003	0.000003	0.000003	0.000050
Potassium	mg/L	0.500	2.825	5.263	10.235	15.750	2.310
Magnesium	mg/L	0.700	0.885	14.675	25.075	31.750	0.920
Manganese	mg/L	0.0038	0.0678	1.1060	2.0950	1.1400	0.0997
Molybdenum	mg/L	0.00003	0.00018	0.00010	0.00008	0.00141	0.00100
Sodium	mg/L	0.46	0.76	6.33	32.13	30.50	0.47
Nickel	mg/L	0.0006	0.0348	0.5150	0.4723	0.2430	0.0262
Phosphorus	mg/L	0.0121	0.0375	0.0250	0.0438	0.0500	0.0100
Lead	mg/L	0.000025	0.000250	0.001743	0.006843	0.001200	0.000320
Antimony	mg/L	0.000015	0.000200	0.000050	0.000238	0.001620	0.000500
Selenium	mg/L	0.000050	0.000250	0.000301	0.000598	0.000494	0.000100
Silicon	mg/L	0.0124	0.5900	12.5000	10.0750	7.9800	0.7600
Tin	mg/L	0.00005	0.00025	0.00005	0.00039	0.00050	0.00500
Strontium	mg/L	0.00500	0.00845	0.23575	0.46250	0.82600	0.03183
Thallium	mg/L	0.000015	0.000080	0.000053	0.000095	0.000100	0.000026
Uranium	mg/L	0.00003	0.00012	0.00214	0.00860	0.00648	0.00020
Vanadium	mg/L	0.000032	0.000500	0.000250	0.000438	0.001025	0.005000
Zinc	mg/L	0.0010	0.0005	0.4148	0.3305	0.2775	0.0464

APPENDIX C

Model Results

Parameter	Units	Model Scenario: 50th Percentile Source Term Inputs											
		East Lake Outlet				Boot Lake Outlet				Lower Sewage Lake Outlet			
		June	July	August	September	June	July	August	September	June	July	August	September
pH	-	6.6	5.1	5.0	5.0	6.5	5.7	5.6	5.6	6.5	6.9	6.9	6.9
Alkalinity	mg/L $CaCO_3$	2.4	1.7	1.6	1.6	2.4	2.3	2.3	2.3	2.3	5.5	6.3	6.3
Nitrate	mg/L N	0.00002	0.00305	0.00395	0.00395	0.00234	0.00519	0.00591	0.00591	0.00048	0.00000	0.00000	0.00000
Chloride	mg/L	1.2	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.2	2.5	2.8	2.8
Sulphate	mg/L	2.6	7.9	9.2	9.2	2.6	3.9	4.3	4.3	2.7	28.3	34.9	34.9
Silver	mg/L	0.000050	0.000049	0.000049	0.000049	0.000050	0.000050	0.000050	0.000050	0.000049	0.000048	0.000047	0.000047
Aluminum	mg/L	0.00118	0.02382	0.04033	0.04033	0.00116	0.00235	0.00294	0.00294	0.00115	0.00196	0.00219	0.00219
Arsenic	mg/L	0.00097	0.00140	0.00145	0.00145	0.00131	0.00154	0.00157	0.00157	0.00097	0.00157	0.00164	0.00164
Boron	mg/L	0.00227	0.00292	0.00309	0.00309	0.00255	0.00263	0.00265	0.00265	0.00239	0.01567	0.01904	0.01904
Barium	mg/L	0.00193	0.00229	0.00238	0.00238	0.00191	0.00195	0.00196	0.00196	0.00206	0.00350	0.00387	0.00387
Berylium	mg/L	0.000023	0.000118	0.000130	0.000130	0.000022	0.000063	0.000068	0.000068	0.000025	0.000003	0.000002	0.000002
Calcium	mg/L	1.1	2.3	2.6	2.6	1.1	1.5	1.6	1.6	1.1	9.1	11.1	11.1
Cadmium	mg/L	0.0000089	0.0000346	0.0000411	0.0000411	0.0000095	0.0000143	0.0000155	0.0000155	0.0000087	0.0000201	0.000023	0.000023
Cobalt	mg/L	0.000173	0.003886	0.004831	0.004831	0.000146	0.000788	0.000951	0.000951	0.000359	0.001297	0.001535	0.001535
Chromium	mg/L	0.000034	0.000079	0.000083	0.000083	0.000032	0.000059	0.000061	0.000061	0.00004	0.000003	0.000002	0.000002
Copper	mg/L	0.00034	0.00315	0.00386	0.00386	0.0003	0.0004	0.00042	0.00042	0.00047	0.00031	0.00027	0.00027
Iron	mg/L	0.0006	0.0187	0.0236	0.0236	0.0007	0.0043	0.0052	0.0052	0.0007	0.0003	0.0003	0.0003
Mercury	mg/L	0.0000158	0.000011	0.0000098	0.0000098	0.0000111	0.0000104	0.0000102	0.0000102	0.000026	0.0000129	0.0000095	0.0000095
Potassium	mg/L	0.438	0.499	0.515	0.515	0.419	0.441	0.446	0.446	0.505	1.029	1.163	1.163
Magnesium	mg/L	0.602	0.871	0.939	0.939	0.602	0.667	0.683	0.683	0.607	1.796	2.098	2.098
Manganese	mg/L	0.004	0.022	0.026	0.026	0.004	0.009	0.010	0.010	0.006	0.052	0.063	0.063
Molybdenum	mg/L	0.00003	0.000031	0.000031	0.000031	0.000037	0.000037	0.000037	0.000037	0.000031	0.000094	0.00011	0.00011
Sodium	mg/L	0.44	0.67	0.73	0.73	0.54	0.62	0.64	0.64	0.45	3.20	3.90	3.90
Nickel	mg/L	0.0008	0.0091	0.0112	0.0112	0.0006	0.0019	0.0023	0.0023	0.0013	0.0064	0.0077	0.0077
Phosphorus	mg/L	0.0077	0.0072	0.0073	0.0073	0.0073	0.0070	0.0070	0.0070	0.0084	0.0072	0.0071	0.0071
Lead	mg/L	0.000019	0.000055	0.000061	0.000061	0.000017	0.000043	0.000048	0.000048	0.000027	0.000003	0.000002	0.000002
Antimony	mg/L	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00003	0.00004	0.00004	0.00004
Selenium	mg/L	0.00005	0.00006	0.00006	0.00006	0.00005	0.00005	0.00005	0.00005	0.00006	0.00006	0.00006	0.00006
Silicon	mg/L	0.006	0.108	0.134	0.134	0.004	0.016	0.019	0.019	0.015	0.181	0.223	0.223
Tin	mg/L	0.000055	0.000051	0.00005	0.00005	0.000086	0.000086	0.000086	0.000086	0.000063	0.000053	0.00005	0.00005
Strontium	mg/L	0.00477	0.00914	0.01025	0.01025	0.00492	0.00617	0.00649	0.00649	0.00478	0.03187	0.03876	0.03876
Thallium	mg/L	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
Uranium	mg/L	0.00003	0.00006	0.00006	0.00006	0.00003	0.00005	0.00005	0.00005	0.00003	0.00014	0.00017	0.00017
Vanadium	mg/L	0.00004	0.00003	0.00003	0.00003	0.00006	0.00006	0.00006	0.00006	0.00006	0.00004	0.00004	0.00004
Zinc	mg/L	0.0004	0.0067	0.0083	0.0083	0.0006	0.0016	0.0018	0.0018	0.0004	0.0117	0.0145	0.0145

75th Percentile Source Term Inputs
Waste Rock Water Quality Model
Lupin Mine Closure Project

Parameter	Units	Model Scenario: 75th Percentile Source Term Inputs											
		East Lake Outlet				Boot Lake Outlet				Lower Sewage Lake Outlet			
		June	July	August	September	June	July	August	September	June	July	August	September
pH	-	6.4	5.1	5.0	5.0	6.4	5.7	5.6	5.6	6.2	6.4	6.5	6.5
Alkalinity	mg/L $CaCO_3$	2.3	1.6	1.4	1.4	2.3	2.3	2.3	2.3	2.3	2.9	3.1	3.1
Nitrate	mg/L N	0.00071	0.00489	0.00597	0.00597	0.00512	0.00871	0.00962	0.00962	0.00247	0.00461	0.00515	0.00515
Chloride	mg/L	2.2	2.3	2.4	2.4	2.4	2.5	2.6	2.6	2.1	4.5	5.1	5.1
Sulphate	mg/L	2.8	8.0	9.3	9.3	2.8	4.1	4.5	4.5	3.1	33.7	41.5	41.5
Silver	mg/L	0.000050	0.000049	0.000049	0.000049	0.000050	0.000050	0.000050	0.000050	0.000049	0.000050	0.000050	0.000050
Aluminum	mg/L	0.00104	0.02839	0.04850	0.04850	0.00105	0.00279	0.00351	0.00351	0.00105	0.00109	0.00112	0.00112
Arsenic	mg/L	0.00137	0.00176	0.00182	0.00182	0.00175	0.00199	0.00202	0.00202	0.00139	0.00097	0.00081	0.00081
Boron	mg/L	0.00588	0.00656	0.00673	0.00673	0.00621	0.00629	0.00632	0.00632	0.00584	0.02290	0.02725	0.02725
Barium	mg/L	0.00591	0.00584	0.00582	0.00582	0.00541	0.00538	0.00537	0.00537	0.00703	0.00744	0.00755	0.00755
Berylium	mg/L	0.000029	0.000125	0.000137	0.000137	0.000026	0.000068	0.000073	0.000073	0.000035	0.000002	0.000002	0.000002
Calcium	mg/L	1.5	2.7	3.1	3.1	1.5	1.9	2.0	2.0	1.5	11.3	13.8	13.8
Cadmium	mg/L	0.0000181	0.000046	0.0000531	0.0000531	0.0000178	0.0000224	0.0000236	0.0000236	0.0000201	0.0000723	0.0000855	0.0000855
Cobalt	mg/L	0.001857	0.005917	0.006951	0.006951	0.001727	0.00237	0.002534	0.002534	0.00226	0.005589	0.006435	0.006435
Chromium	mg/L	0.00048	0.000569	0.000581	0.000581	0.000476	0.000516	0.000522	0.000522	0.000474	0.00001	0.000006	0.000006
Copper	mg/L	0.00065	0.00353	0.00426	0.00426	0.00043	0.00052	0.00054	0.00054	0.00114	0.00082	0.0007	0.0007
Iron	mg/L	0.001	0.0203	0.0255	0.0255	0.001	0.005	0.006	0.006	0.0013	0.0009	0.0008	0.0008
Mercury	mg/L	0.0000158	0.000011	0.0000098	0.0000098	0.0000111	0.0000104	0.0000102	0.0000102	0.000026	0.0000126	0.0000093	0.0000093
Potassium	mg/L	0.556	0.603	0.615	0.615	0.521	0.543	0.548	0.548	0.656	1.345	1.520	1.520
Magnesium	mg/L	0.704	0.970	1.037	1.037	0.702	0.772	0.790	0.790	0.712	2.358	2.777	2.777
Manganese	mg/L	0.005	0.025	0.030	0.030	0.005	0.011	0.012	0.012	0.008	0.065	0.080	0.080
Molybdenum	mg/L	0.000033	0.000032	0.000031	0.000031	0.000037	0.000037	0.000037	0.000037	0.00004	0.000105	0.000122	0.000122
Sodium	mg/L	0.47	0.62	0.66	0.66	0.59	0.68	0.70	0.70	0.48	2.06	2.47	2.47
Nickel	mg/L	0.0014	0.0106	0.0130	0.0130	0.0009	0.0021	0.0025	0.0025	0.0029	0.0139	0.0167	0.0167
Phosphorus	mg/L	0.0115	0.0108	0.0108	0.0108	0.0110	0.0106	0.0105	0.0105	0.0126	0.0062	0.0054	0.0054
Lead	mg/L	0.000028	0.000058	0.000066	0.000066	0.000025	0.000046	0.000051	0.000051	0.000037	0.000005	0.000003	0.000003
Antimony	mg/L	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00003	0.0001	0.00012	0.00012
Selenium	mg/L	0.00005	0.00006	0.00006	0.00006	0.00005	0.00005	0.00005	0.00005	0.00006	0.00007	0.00007	0.00007
Silicon	mg/L	0.012	0.119	0.147	0.147	0.009	0.022	0.025	0.025	0.024	0.208	0.255	0.255
Tin	mg/L	0.000055	0.000051	0.00005	0.00005	0.000086	0.000086	0.000086	0.000086	0.000063	0.000077	0.00008	0.00008
Strontium	mg/L	0.00508	0.00945	0.01056	0.01056	0.00520	0.00652	0.00685	0.00685	0.00523	0.04882	0.05992	0.05992
Thallium	mg/L	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
Uranium	mg/L	0.00003	0.00007	0.00008	0.00008	0.00003	0.00005	0.00006	0.00006	0.00003	0.00037	0.00046	0.00046
Vanadium	mg/L	0.00004	0.00004	0.00004	0.00004	0.00007	0.00007	0.00007	0.00007	0.00006	0.00008	0.00008	0.00008
Zinc	mg/L	0.001	0.009	0.011	0.011	0.0014	0.0023	0.0026	0.0026	0.001	0.0157	0.0193	0.0193