Atlantic Gold

Appendix F.1

Fifteen Mile Stream Project:
Geochemical Source Term Predictions,
Lorax Environmental Services Ltd.

Atlantic Gold

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Geochemical Source Term Predictions

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1.   Introduction

The Fifteen Mile Stream (FMS) project is a proposed gold mine owned by Atlantic Mining Nova Scotia Corporation (AMNS) who is preparing an Environmental Impact Statement (EIS) that will be submitted to Nova Scotia Environment (NSE) and the Canadian Environmental Assessment Agency (CEAA) as part of the project's regulatory requirements. Lorax Environmental Services Ltd. (Lorax) was retained by AMNS to develop geochemical source terms as input for the site-wide water quality model that is being developed in support of the EIS.

The drainage chemistry from the various Fifteen Mile Stream facilities discussed herein is influenced by a variety of geochemical and physical factors. The overarching controls that will govern the water quality associated with any facility that contains exposed mine materials, include:

- Mineralogy and geochemistry of the exposed material;

- Reactive surface area;

- Water-to-rock ratio;

- Depositional environment (*e.g.*, saturated versus unsaturated conditions); and

- Temperature.

The prediction of both the elemental concentrations in contact water from the Waste Rock Storage Areas (WRSAs), overburden and ore stockpiles, pit walls, and the Tailings Management Facility (TMF) was conducted using a combination of kinetic test results as well as site monitoring and analogue data from the operational Touquoy Mine. Table 1-1 provides an overview of all facilities for which geochemical source terms were derived as well as the respective model approach. Where predictions relied on upscaling of kinetic test results, a number of calibration work stages were implemented.

Blasting of waste and ore rock will result in the coating of particle surfaces with N species (ammonia, nitrite, nitrate) from explosives by-products. In waste rock and ore storage facilities, this process is generally responsible for the release of these species into the receiving environment. A source term model in consideration of the explosives type, water/rock ratios was generated separately in order to predict drainage chemistry specific to nitrogen. The following sections discuss the background and rationale for the various considerations built into the geochemical source term model.

Table 1-1:
Overview of Source Term Locations and Modelling Approach Used
(Excluding N Source Terms)

Mine Component	Contaminant Source	Approach
Process water	Mill	Tailings supernatant
Tailings Beach	Mill; Tailings	Shake Flask Extraction tests
Porewater/seepage	Mill; Tailings	Saturated columns
Pit Walls	Waste rock & Ore	Upscaling of kinetic tests
NAG WRSA	Waste rock	Upscaling of kinetic tests
PAG WRSA	Waste rock	Upscaling of kinetic tests
TMF Embankment	Waste rock	Upscaling of kinetic tests
Low-Grade Ore SP	Ore	Upscaling of kinetic tests
Topsoil SP	Soil	Shake Flask Extraction tests
Till SP	Till/Overburden	Shake Flask Extraction tests

Notes: PAG = Potentially Acid Generating; NAG= Non-Acid Generating; WRSA = Waste Rock Storage Area, SP = Stockpile;
TMF = Tailings Management Facility.

2. Source Term Derivation Approach

2.1 Waste Rock and Ore Upscaling

A flow chart of the work stages comprising the scale-up of kinetic tests results, which was applied to model the contact water chemistry for the WRSAs, low-grade ore stockpile and pit walls, is given in Figure 2-1. Each of these work stages is described in detail below. Importantly, scaling factors used in this exercise were generally derived via inverse modelling of available Touquoy site monitoring data. Note that source terms relating to the TMF (process and porewater, beach runoff), TMF embankments, as well as the till and topsoil stockpiles do not rely on the upscaling approach presented in this chapter and are discussed in detail in Sections 2.2 through 2.4. Further, nitrogen source terms considering the use of explosives were developed using a different scaling approach and are discussed separately in Section 3.
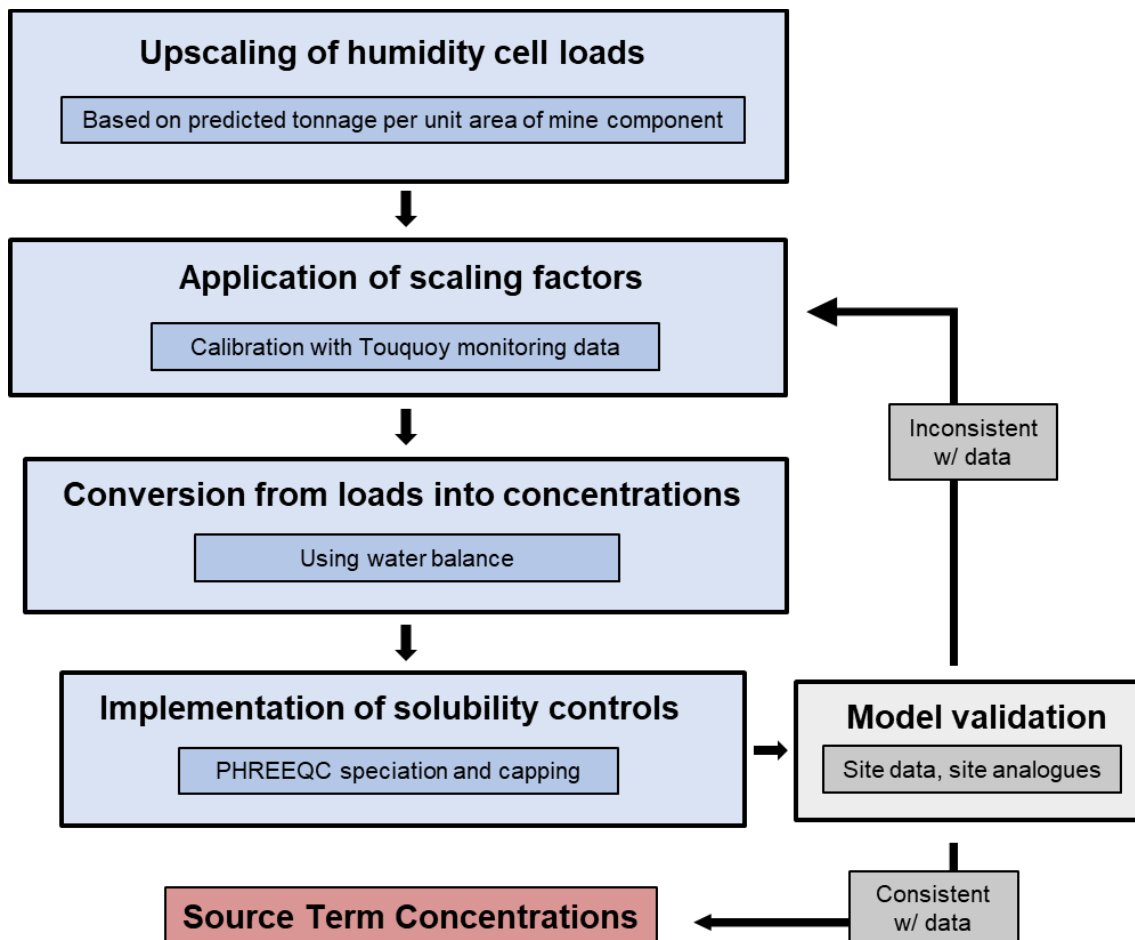
Figure 2-1:   Work stages involved in the scaling of geochemical source terms.

2.1.1   Derivation of Humidity Cell Loading Rates

Aqueous geochemical signatures produced by water in contact with mine wastes are predominately controlled by the mineralogical make-up of the materials as well as mining-related processes (*e.g.*, processing, blasting, *etc.*), with sulphide mineral oxidation and carbonate mineral dissolution generally dictating pH. Trace elemental leaching signatures are typically governed by the sulphide mineral reactivity, abundance and type, although other phases can be relevant (*e.g., * oxide minerals). Based on these considerations, humidity cell tests used for the calculation of loading rates were selected to capture representative lithological and mineralogical variables.

2.1.1.1   *Neutral Loading Rates*

Loading rates are herein defined as the mass of a solute released per kg of rock material over one week of humidity cell testing (mg/kg/wk). Two mine phases, End of Mining (EOM) and Post-Closure (PC), were modelled using loading rates from different humidity cell cycles. For each of these mine phases, a Base Case and an Upper Case scenario were implemented. An overview of the scenarios modelled and humidity cells used for the FMS source term predictions is presented in Table 2-1. Conceptually, it was assumed that potentially acid-generating (PAG) materials would remain neutral during operations up until the end of mining. Input loading rates were derived from four humidity cells representing the four major waste rock types and one humidity cell representing low-grade ore to be stored on site. The waste rock loading rates were grouped into the following categories to allow for the reconciliation with the units presented in the waste rock production schedule:

- *Argillite* (HC 1 = **AR** = Argillite w/ <5% Greywacke interbeds and HC 2 = **AG** = Argillite w/ 5- 49% Greywacke interbeds) and

- *Greywacke* (HC 3 = **GA** = Greywacke w/ 20-50% Argillite interbeds and HC 4 = **GW** = Greywacke w/ < 20% Argillite interbeds)**.**

To derive a neutral model input, humidity cell data were proportioned to be representative of the static test populations' sulphide sulphur content. Specifically, the sulphide sulphur content for each cell was put into context by calculating the percentile of the corresponding static test population within each modelled geologic mine unit. The weighting of the two humidity cells to derive the loading rate for each unit was then determined based on this statistical value. An overview of how the different tests were accounted for is given in Table 2-2.

2.1.1.2 *Acidic Loading Rates*

None of the FMS humidity cells had turned acidic during their laboratory runtime such that assumptions had to be made with respect to the long-term (PC) drainage chemistry of the FMS potentially-acid generating (PAG) rock under acidic conditions. Using a humidity cell from Cochrane Hill which produced neutral as well as acidic drainage, "acid factors" (AF) were calculated for each species that relates the neutral and acidic water chemistry as follows:

$$AF_i = L_{Ai}/L_{Ni}$$

where L_{Ai} is the loading rate of species i under acidic conditions in HC7 (cycles 33-37) and L_{Ni} is the loading rate of species i in neutral HCs (cycles 33-37). This value was then multiplied with the FMS neutral source term in question to derive loading rates that are representative of acidic conditions. Importantly, these loading rates were only applied proportional to the percentage of PAG materials in the PC scenario of the modelled location. It should be noted that this approach is considered preliminary and geochemical source term model outputs will be updated for the PC scenario once acidic drainage from at least one of the FMS humidity cells is observed. Neutral and acidic loading rates that were used as model input for both the EOM and PC mine phases are summarized in Table 2-3 through Table 2-5.

Table 2-1:
Laboratory Tests and Scenarios Used to Derive Neutral Input Loading Rates

Facility	Laboratory test used	Phase	Scenario	Cycles Used
Waste Storage Facilities	FMS HC 1 through HC 4	Operational	Base Case	median of cycles 5-15
		(End of Mine)	Upper Case	90th percentile of cycles 5-15
		Long-Term	Base Case	median of cycles 33-37
		(Post-Closure)	Upper Case	90th percentile of cycles 33-37
Pit Walls	FMS HC 1 through HC 4	Operational	Base Case	median of cycles 5-15
		(End of Mine)	Upper Case	90th percentile of cycles 5-15
		Long-Term	Base Case	median of cycles 33-37
		(Post-Closure)	Upper Case	90th percentile of cycles 33-37
Low-Grade Ore Stockpile	FMS HC 5	Operational	Base Case	median of cycles 5-15
		(End of Mine)	Upper Case	90th percentile of cycles 5-15
		Long-Term	Base Case	median of cycles 33-37
		(Post-Closure)	Upper Case	90th percentile of cycles 33-37

Notes: HC = Humidity Cell; TMF = Tailings Management Facility

Table 2-2:
Weighting of Humidity Cells to Derive Neutral Input Loading Rates

Sample ID	Lithology Code	Sulphide S (%)	Percentile of population	Weighting
Argillite				
HC1	AG	0.345	54%	72%
HC2	AR	0.565	90%	28%
Greywacke				
HC3	GA	0.49	96%	26%
HC4	GW	0.22	53%	74%

Notes: HC = Humidity Cell

Table 2-3:
Neutral Short-Term Loading (EOM) Rates Used as Input for the FMS Source Term Model

Parameter	Unit	Argillite		Greywacke		Ore	
		Base Case	Upper Case	Base Case	Upper Case	Base Case	Upper Case
Sulphate	mg/kg/wk	12	14	8.5	11	7.1	13
Al	mg/kg/wk	0.039	0.076	0.054	0.074	0.066	0.072
Ag	mg/kg/wk	0.000012	0.000012	0.000011	0.000011	0.000011	0.000011
As	mg/kg/wk	0.0050	0.0055	0.017	0.038	0.0055	0.013
Ca	mg/kg/wk	5.7	6.6	5.8	6.3	5.2	6.7
Cd	mg/kg/wk	0.0000012	0.0000033	0.0000013	0.0000033	0.00000066	0.0000022
Co	mg/kg/wk	0.000021	0.000040	0.0000081	0.000026	0.0000068	0.000025
Cr	mg/kg/wk	0.0000070	0.000034	0.0000089	0.000043	0.0000067	0.000039
Cu	mg/kg/wk	0.00031	0.0010	0.00021	0.00064	0.00019	0.0028
Fe	mg/kg/wk	0.0016	0.0059	0.0016	0.0053	0.0016	0.0054
Hg	mg/kg/wk	0.0023	0.011	0.0022	0.0028	0.0022	0.0023
Mn	mg/kg/wk	0.0017	0.0048	0.013	0.015	0.0089	0.0099
Mo	mg/kg/wk	0.00014	0.00047	0.000084	0.00013	0.000066	0.00012
Ni	mg/kg/wk	0.000077	0.00017	0.000088	0.00021	0.000090	0.00015
Pb	mg/kg/wk	0.0000051	0.000012	0.0000047	0.000017	0.0000089	0.000023
Sb	mg/kg/wk	0.000064	0.00013	0.000057	0.00016	0.000044	0.000059
Se	mg/kg/wk	0.0000094	0.000029	0.0000088	0.000012	0.000029	0.000042
Tl	mg/kg/wk	0.0000012	0.0000036	0.0000011	0.0000020	0.0000011	0.0000014
U	mg/kg/wk	0.00018	0.00028	0.00042	0.00056	0.00012	0.00015
Zn	mg/kg/wk	0.00046	0.00047	0.00044	0.00045	0.00044	0.00045

Table 2-4:
Neutral Long-Term (PC) Loading Rates Used for NAG material as Input for the FMS Source Term Model

Parameter	Unit	Argillite		Greywacke		Ore	
		Base Case	Upper Case	Base Case	Upper Case	Base Case	Upper Case
Sulphate	mg/kg/wk	9.8	11	6.7	9.1	15	17
Al	mg/kg/wk	0.023	0.023	0.040	0.044	0.025	0.036
Ag	mg/kg/wk	0.000011	0.000012	0.000011	0.000012	0.000011	0.000012
As	mg/kg/wk	0.0037	0.0038	0.0092	0.0095	0.0052	0.0080
Ca	mg/kg/wk	5.3	5.7	5.6	6.5	7.7	8.4
Cd	mg/kg/wk	0.0000035	0.0000046	0.00000068	0.0000023	0.0000013	0.0000020
Co	mg/kg/wk	0.000028	0.000041	0.000011	0.000013	0.000034	0.000053
Cr	mg/kg/wk	0.000018	0.000019	0.000018	0.000019	0.000017	0.000019
Cu	mg/kg/wk	0.00072	0.0014	0.00034	0.00053	0.00029	0.00033
Fe	mg/kg/wk	0.0017	0.0099	0.0017	0.0042	0.0017	0.0027
Hg	mg/kg/wk	0.0023	0.0024	0.0022	0.0024	0.0022	0.0024
Mn	mg/kg/wk	0.0013	0.0022	0.010	0.012	0.0088	0.014
Mo	mg/kg/wk	0.00032	0.00072	0.000096	0.00010	0.000067	0.000079
Ni	mg/kg/wk	0.000042	0.000071	0.000024	0.000036	0.00030	0.00044
Pb	mg/kg/wk	0.0000056	0.000036	0.0000072	0.000013	0.0000022	0.0000024
Sb	mg/kg/wk	0.00021	0.00022	0.00020	0.00021	0.00019	0.00021
Se	mg/kg/wk	0.0000092	0.0000096	0.0000089	0.0000095	0.000017	0.000021
Tl	mg/kg/wk	0.0000035	0.0000040	0.0000020	0.0000026	0.0000026	0.0000028
U	mg/kg/wk	0.000066	0.00011	0.00022	0.00033	0.000064	0.00011
Zn	mg/kg/wk	0.00046	0.00048	0.00045	0.00048	0.00043	0.00047

Table 2-5:
Acid Factors and Acidic Long-Term (PC) Loading Rates Used for PAG material in the FMS Source Term Model

Parameter	Unit	Argillite		Greywacke		Ore		*Acid Factor (unitless)*
		Base Case	**Upper Case**	**Base Case**	**Upper Case**	**Base Case**	**Upper Case**	
Sulphate	mg/kg/wk	22	25	15	21	33	39	2.3
Al	mg/kg/wk	0.13	0.14	0.24	0.26	0.15	0.21	5.9
Ag	mg/kg/wk	0.000011	0.000011	0.000011	0.000011	0.000010	0.000011	0.95
As	mg/kg/wk	0.020	0.020	0.048	0.050	0.027	0.042	5.3
Ca	mg/kg/wk	1.1	1.2	1.1	1.3	1.6	1.7	0.20
Cd	mg/kg/wk	0.00095	0.0013	0.00019	0.00063	0.00035	0.00054	273
Co	mg/kg/wk	0.0066	0.0094	0.0025	0.0030	0.0080	0.012	232
Cr	mg/kg/wk	0.000017	0.000018	0.000017	0.000018	0.000016	0.000018	0.95
Cu	mg/kg/wk	0.010	0.020	0.0047	0.0075	0.0040	0.0046	14
Fe	mg/kg/wk	2.7	16	2.7	6.8	2.7	4.4	1618
Hg	mg/kg/wk	0.0022	0.0023	0.0021	0.0023	0.0020	0.0022	0.95
Mn	mg/kg/wk	0.012	0.019	0.091	0.11	0.077	0.12	8.8
Mo	mg/kg/wk	0.000024	0.000054	0.0000071	0.0000076	0.0000050	0.0000058	0.074
Ni	mg/kg/wk	0.013	0.021	0.0071	0.011	0.090	0.13	301
Pb	mg/kg/wk	0.0014	0.0090	0.0018	0.0032	0.00054	0.00060	253
Sb	mg/kg/wk	0.00019	0.00020	0.00019	0.00020	0.00018	0.00020	0.95
Se	mg/kg/wk	0.000068	0.000071	0.000066	0.000071	0.00013	0.00015	7.4
Tl	mg/kg/wk	0.000022	0.000025	0.000012	0.000016	0.000016	0.000018	6.2
U	mg/kg/wk	0.00053	0.00089	0.0018	0.0027	0.00052	0.00086	8.1
Zn	mg/kg/wk	0.37	0.38	0.36	0.38	0.34	0.38	799

2.1.2 Scaling of Geochemical Loads

One of the most critical steps in the development of geochemical source terms is the scaling of geochemical loads from small-scale laboratory experiments to mine-site dimensions. In theory, if the entire modelled facility was contacted by water under conditions similar to those seen in humidity cell experiments, the upscaled maximum leachable load ML (in mg) would be written as:

$$ML_i = r_i * m * t$$

where r_i is the geochemical loading rate for species i; m is the mass (in kg) of the material contained in a facility of interest; and t (in wk) is the time interval of interest.

Through empirical and theoretical studies (*e.g.,* Malmström *et al.*, 2000; Kempton, 2012; Andrina *et al.*, 2012; Sapsford *et al.*, 2009; Kirchner & Mattson, 2015; Bornhorst & Logsdon, 2016), it is now well-established that this approach will strongly overestimate the geochemical load that is expected to drain from mine facilities due to the marked differences between laboratory and field conditions. To account for these differences, "scaling factors" are applied in the development of geochemical source terms that are based on humidity cell data. These scaling factors are implemented into the source term prediction model simply by multiplication with the maximum leachable load calculated above according to

$$SL_i = ML_i * SF_a * SF_b * \ldots * SF_x$$

where SL_i is the scaled load for species i (in mg) and SF is the scaling factor for a given parameter to be scaled (a, b, x). In the absence of site monitoring data, such parameters typically include grain size, water/rock ratio, and, temperature. The following describes in detail the derivation of the individual scaling factors employed in the FMS source terms model.

2.1.2.1 Particle Size

Before representative material is placed into laboratory kinetic test cells, rock samples are crushed to a nominal grain size of <1/4" to allow for better comparability of reaction rates across different experiments containing different geological materials. The particle size distribution of the mine rock stockpiles, and other facilities influences the degree of water-rock interaction by controlling the exposed surface area; surface area increases exponentially as the particle size decreases. Therefore, the largest relative surface area per mass is associated with the finest particles which may comprise a relatively small quantity of the WRSA. Strömberg and Banwart (1999) observed a large difference in weathering rates between fine particles and larger waste rock at the Aitik mine in northern Sweden.

Particles with diameters smaller than 25 mm were shown to account for 80% of the sulphide and silicate weathering. The same study determined the <25 mm fraction to be only about 27% of the total waste rock mass. Similar conclusions have been drawn in other studies that have examined the effect of particle size on geochemical release rates (*e.g.*, Fines *et al.* 2003; Frostad *et al.*, 2005; and Neuner *et al.*, 2009).

In consideration of the above, it can be assumed that only a fraction of material contained in the modelled mine components is reactive. Observations made on site suggest that the argillite end-member is generally more fissile and friable than greywacke waste rock. As such, particle size scaling factors of 10% and 20% were assigned to greywacke and argillite, respectively.

2.1.2.2   Contact Water

Laboratory experiments are conducted using high water-rock ratios (0.5L:1kg) that allow for the flushing of virtually all material surfaces placed into the reactor cell. The hydrogeology of unsaturated waste rock facilities has been subject to much research and most studies suggest that only a portion of the rock mass contained in these facilities is contacted by infiltrating water (Marcoline *et al.*, 2006; Andrina *et al.*, 2009, Neuner *et al.*, 2009). The larger the mine storage facility for a given infiltration rate, the more rock material will be physically shielded from water contact as preferential flow paths develop and water is diverted along higher permeability layers. Furthermore, low water-rock ratios within a mine rock or tailings facility are more likely to result in the development of geochemical equilibrium conditions (Morin, 2013). Therefore, after a certain mass of rock material has been flushed, further physical contact may not necessarily lead to an increase in concentrations as kinetic or thermodynamic limitations are reached (*e.g.*, Kirchner & Mattson, 2015).

Correcting for different water/rock ratios (i.e., contact water) in humidity cells versus full-scale mine facilities may be one of the largest uncertainties associated with a source term model if not calibrated. To increase the confidence in the scaling factor applied to correct for this parameter, humidity cell, geological, mine plan, and surface water monitoring data from the Touquoy minesite were utilized to develop an inverse model from which empirical scaling factors could be constrained. Specifically, scaled loading rates from argillite and greywacke humidity cell were upscaled to the tonnage (or surface area for pit walls) of the respective mine facility and, under consideration of the known water balance, compared to site monitoring data. Since the humidity cell data were already grain-size corrected, and monitoring data were preferentially collected during months in which a temperature correction would not apply, the resulting discrepancy between the predicted concentrations and the observed water monitoring values effectively represents the empirical contact water

factor. Besides the fact that the Touquoy site presents an excellent site analogue with respect to geology, this approach also has the advantage that it generates element-specific scaling factors. This is important as it has been shown that major and minor/trace metals cannot generally be predicted accurately using the same scaling factors (e.g. Kirchner & Mattson, 2015). Table 2-6 provides a more detailed description of the Touquoy parameters used in this calibration model. Several qualifiers need to be introduced in the context of the use of data from water monitoring stations:

- o Median concentrations from the respective water monitoring stations were used;

- o Concentrations measured at the waste rock ponds (SW-WRSP1 and -WRSP2) were artificially increased in the calibration model to account for 50% dilution along the flow path from the WRSA toe to the monitoring stations;

- o The flow assumed for the open pit (450,000 m3/yr) was derived from current pumping rates at site provided by AMNS. This value encompasses both pit wall runoff as well as groundwater flow. Groundwater geochemistry data from monitoring wells surrounding the open pit were used to estimate a geochemical loading contribution which was accounted for in order to derive a calibrated scaling factor for pit wall runoff only.

The calibrated scaling factors that resulted from this model were vetted and it was found that the direct application of the Touquoy WRSA calibration model values would likely lead to an overestimation of the predicted geochemical loads in the FMS WRSA and ore stockpile. The reason for this is that the water/rock ratio in these facilities in the EOM scenario is almost an order of magnitude lower than that estimated for the relatively small, operational Touquoy WRSA. As mentioned above, after a certain WRSA thickness is reached, equilibrium conditions are expected to be attained under neutral conditions for most species, especially for minor and trace elements. This means that increasing the tonnage (or thickness) of a waste facility with the same material type would not necessarily result in an increase in pore-water concentrations. Since humidity cell leachates would be upscaled to a larger mass however, lower scaling factors would need to be applied to arrive at the same concentrations. In accordance with this theory, the empirical contact water scaling factors derived from the Touquoy site data were adjusted to account for the different water/rock ratios and thicknesses of the Touquoy WRSA in comparison to the EOM configuration expected for the FMS facilities. The ultimately applied contact water scaling factor was calculated as follows:

$$\text{Contact Water } SF_i = \text{Calibrated } SF_i * WR_{FMS}/WR_{TQ}$$

where SF_i = Scaling factor for species i and WR_{FMS} and WR_{TQ} are the water/rock ratios for FMS and Touquoy facilities, respectively. Water/rock ratios are calculated as the estimated

annual net infiltration volume divided by the total tonnage of rock contained in the mine component. Final contact water scaling factors for FMS source term locations are listed in Table 2-7.

The considerable range in scaling factor values across the presented parameters is evidence of the difference in geochemical mobility, where species with a lower scaling factors are attenuated more strongly on larger scales relative to the loading rates seen in humidity cells.

2.1.2.3   Temperature

Kinetic experiments used for the source term model were conducted at SGS laboratories at a temperature of 22°C and it is well known that the rate of many geochemical reactions leading to the release of acidity and dissolved metals is temperature-dependent (*e.g.*, Nicholson *et al.*, 1988; SRK, 2006). For FMS ore, mine rock, and tailings, the oxidation of pyrite can be considered the main mechanism driving contaminant leaching. Dockrey and Mattson (2016) compared sulphate release rates produced by kinetic tests under room (22°C) and fridge (4°C) temperatures and found a 31% reduction in oxidation rate over this temperature change.

Due to the fact that the empirical scaling factors described in the previous section rely on Touquoy water quality monitoring data collected throughout the year; it is assumed that any temperature-related trends on drainage chemistry would be captured by these data. Therefore, no additional scaling factor was applied to correct for lower temperatures at site conditions.

Table 2-6:
Parameters from The Touquoy Site Used in the Calibration Exercise to Derive Scaling Factors for the FMS Source Term model

	Unit	Pit Walls	WRSA
HCs Used	Argillite	06-017, 06-012, 06-006, 06-049, 06-079	
	Greywacke	06-039, 06-06	
Facility Dimensions (Current)	Total	Footprint: 200,000 m2	Tonnage: 3.72 Mt
	Argillite	Footprint: 96,612 m2	Tonnage: 2.01 Mt
	Greywacke	Footprint: 103,388 m2	Tonnage: 1.71 Mt
Contact Water	-	450,000 m^3/yr	372,000 m^3/yr
Water Monitoring Station	-	SW-OP (Pit sump)	SW-WRSP1, SW-WRSP2 (Waste rock ponds)

Notes: HC = Humidity Cell; WRSA = Waste Rock Storage Area

Table 2-7:
Parameter-Specific Contact Water Scaling Factors Derived from the Touquoy Site
and Applied to the FMS Source Term Model

Parameter	Pit walls	PAG WRSA	NAG WRSA	LG Ore Stockpile
	kg/m2	*unitless*	*unitless*	*unitless*
Sulphate	19638	1.9	0.59	0.75
Al	56	0.014	0.0043	0.0055
Ag	1209	0.086	0.026	0.033
As	198	0.0095	0.0029	0.0037
Ca	4886	0.48	0.14	0.18
Cd	1341	0.32	0.096	0.12
Co	15291	1.2	0.35	0.45
Cr	21903	1.6	0.48	0.61
Cu	3441	0.24	0.074	0.094
Fe	1806	0.13	0.039	0.050
Hg	956	0.068	0.020	0.026
Mn	1936	0.27	0.083	0.11
Mo	15345	0.21	0.064	0.081
Ni	83712	3.6	1.1	1.4
Pb	16904	1.2	0.36	0.46
Sb	479	0.022	0.0066	0.0084
Se	18335	1.3	0.39	0.50
Tl	14636	1.0	0.31	0.40
U	11265	0.29	0.088	0.11
Zn	1802	0.13	0.039	0.050

Notes: PAG = Potentially Acid Generating; NAG = Non-Acid Generating; WRSA = Waste Rock Storage Area; LG = Low-Grade

2.1.3 Conversion of Loads into Concentrations

Average annual drainage and runoff concentrations for the two scenarios (EOM and PC) were calculated by dividing the final scaled geochemical loads (in mg) by the volume of water predicted to infiltrate into the facility of interest in a given year. These assumed infiltration values were provided by Knight Piésold (Jackson, pers. comm., 2018) and are summarized in Table 2-8 for the different facilities. Note that the pit wall hydrology is based on runoff rates.

During Post-Closure, a soil cover will be placed on the WRSA in order to limit infiltration and oxygen flow. A cover efficiency of around 60% was estimated, thereby reducing the

contact water volume to less than half of the EOM infiltration rates. No detail regarding cover placement or material was provided to Lorax and it was assumed that the reduction in flow will result in a proportional reduction in contact water. Therefore, the contact water scaling factor was set to 40% of the EOM contact water scaling factor for the PC WRSA scenario which effectively produces the same source term concentrations as would be expected for an uncovered PC configuration.

Table 2-8:
Overview of Contact Water for the FMS Mine Facilities Modelled by Upscaling of Kinetic Tests

Location	Scenario	Infiltration	Runoff	Footprint	Contact water
		% MAP	*% MAP*	*m²*	*L*
Pit Walls	EOM/PC	-	90%	1	1,296
PAG WRSA	EOM	85%	-	244,280	298,998,720
PAG WRSA	PC	34%	-	244,280	119,599,488
NAG WRSA	EOM	85%	-	305,820	374,323,680
NAG WRSA	PC	34%	-	305,820	149,729,472
Low-Grade Ore SP	EOM	85%	-	81,444	184,383,360
Low-Grade Ore SP	PC	34%	-	81,444	73,753,344

Notes: PAG = Potentially Acid Generating; NAG = Non-Acid Generating; WRSA = Waste Rock Storage Area; MAP = Mean Annual Precipitation = 1440 mm; EOM = End of Mining; PC = Post-Closure.

2.1.4   Model Validation and Capping

As a final step, the model output was compared to water quality results from other data sources, namely field-scale kinetic testing and site analogues (Touquoy). These data sources are highly valuable in re-assessing solubility limits and provide an opportunity to validate scaling factors used for the geochemical source term model.

During the scaling exercise it was noted that several species commonly fall below the detection limit in humidity cell leachates and/or the site analogue databases and are therefore not expected to be a concern due to their low solubility, at least under neutral conditions. In these cases (Ag, Cr, Cu, Hg, Tl, V), the respective detection limit and half the detection limit value were chosen as the solubility caps for the Upper Case and Base Case scenarios, respectively. No caps were applied to the PC scenario to maintain conservatism.

Due to the relatively well-constrained mineralogical fate of Fe, Al, and sulphate in mining environments, caps for these species were derived using the geochemical speciation code PHREEQC, which contains an extensive thermodynamic database (Parkhurst and Appelo, 1999). Table 2-9 provides an overview of the caps implemented and the concentration-limiting mineral phase for PHREEQC-modelled species.

Table 2-9:
Mineral Phases Considered in the Application of the PHREEQC Speciation Model

Parameter	Unit	EOM		PC		Data Source
		Base Case	Upper Case	Base Case	Upper Case	
SO_4	mg/L	Gypsum equilibrium		Gypsum equilibrium		PHREEQC-Gypsum
Ag	mg/L	0.00005	0.0001	-	-	Field and HC Data
Al	mg/L	Gibbsite equilibrium		Gibbsite equilibrium		PHREEQC-Gypsum
Cr	mg/L	0.0005	0.001	-	-	Field and HC Data
Cu	mg/L	0.001	0.002	-	-	Field and HC Data
Fe	mg/L	$Fe(OH)_3$ equilibrium		$Fe(OH)_3$ equilibrium		PHREEQC-$Fe(OH)_3$
Hg	mg/L	0.0000065	0.000013	-	-	Field and HC Data
Tl	mg/L	0.00005	0.0001	-	-	Field and HC Data
V	mg/L	0.001	0.002	-	-	Field and HC Data

Notes: EOM = End of Mining; PC = Post-Closure.

2.1.5 Example Calculation

To allow the reader a better understanding of the various steps taken to derive geochemical source term predictions, a step-by-step sample calculation is provided below:

Derivation of As-source term concentration for the FMS pit walls

(EOM; base case scenario)

As outlined in the previous sections, the following steps formed the basis for the prediction of pit wall drainage chemistry.

1) Conversion of median weekly load to grain-size corrected annual load for each unit exposed in the pit walls:

*Median load * grain size factor * (weeks/year) = Grain-size corrected As-load*

Argillite: 0.0050 mg/kg/wk * 20% * 52 wk/yr = 0.052 mg/kg/yr

Greywacke: 0.017 mg/kg/wk * 10% * 52 wk/yr = 0.088 mg/kg/yr

Ore: 0.0055 mg/kg/wk * 15% * 52 wk/yr = 0.043 mg/kg/yr

2) Conversion of grain-size corrected annual load to proportioned load considering pit wall proportions at EOM:

$\sum$*(Grain-size corrected As-load * pit wall proportion) = Proportioned load*

0.052 mg/kg/yr * 16% + 0.088 mg/kg/yr * 58% + 0.043 mg/kg/yr * 25% = 0.070 mg/kg/yr

3) Apply empirical contact water scaling factors to account for hydrogeological pathways:

Proportioned load * contact scaling factor = Annual load from 1m² of pit wall exposure

0.070 mg/kg/yr * 198 kg/m² = 13.9 mg/yr

4) Convert into scaled annual loads into base case As concentrations:

Annual pit wall load (per 1m²) / annual pit wall runoff per 1m²

13.9 mg/yr / 1,296 L/yr = 0.011 mg/L

5) Apply secondary mineral controls and concentration caps

Arsenic was not capped and was not considered during geochemical speciation in PHREEQC. Therefore, this model step did not affect the final As source term concentrations.

2.2 Specific Waste Rock and Ore Model Assumptions

2.2.1 Prediction of pH

The pH of mine drainage is governed by a sensitive and complex acid-base balance which, in turn, is controlled by rock storage regime, solute speciation, water-rock ratios and the availability and type of acid-generating and acid-buffering solid phases. The upscaling approach described for waste rock and ore in this chapter focusses primarily on the relationship of metal release in a laboratory-scale versus mine-scale environment. Due to the uncertainties related to the prediction of pH through geochemical modelling and upscaling of humidity cell tests, pH values were predicted based on the knowledge gained from the FMS static and kinetic test programs in combination regional water quality data. It can be said with some certainty that the during the EOM scenario all mine facilities will yield circum-neutral conditions due to the neutralization potential afforded by the waste rock and ore. During Post-Closure, around 12.5% of waste rock and 70% of ore materials (if not processed) are estimated to be PAG and therefore become depleted in neutralization potential leading to the development of ARD. Waste rock PAG proportion estimates were based on the integration of NPR values into the geological block model to gain a spatial representation of environmental parameters. This exercise was not done for ore materials such that the prediction of PAG proportions within the ore shell relied on the relative amounts of PAG ore samples in the static test database.

There is currently no direct evidence from the FMS or Touquoy site of the pH range that will be produced from waste rock after carbonate mineral depletion. A survey of standing water in 50 slate quarries in the Meguma Formation throughout Nova Scotia found an average pH of 3.78 (Manchester, 1986). Furthermore, Kereks *et al.,* (1984) found mean pH

of 3.6 and 4.0 in two lakes north of Halifax. These results are consistent with ARD being buffered by hydrous ferric oxide (HFO) at approximately pH 3.5 (Blowes *et al.*, 2003). Given the relatively low overall sulphide contents in FMS rock, it can reasonably be expected that the pH in the PAG materials will be buffered at a similar range as in these other Meguma Formation sites with pH between 3.6 and 4.0. Hence, pH values for the PAG WRSA were set to 4 and 3.5 in the Base and Upper Case scenarios, respectively. By design, the NAG WRSA will continue produce circum-neutral pH in the long-term.

For the low-grade ore stockpile, the confluence of acidic drainage from PAG rock with alkaline contact water from NAG materials in post-closure was modelled, using PHREEQC, to yield a mixed pH of 4 to 5 (*i.e.,* buffered by Al-hydroxide) which is considered an adequate estimate for long-term drainage from this facility. A pH of 4.5 could therefore reasonably be expected as the best estimate for the Base Case scenario, while a pH of 4 is predicted for the more conservative Upper Case scenario.

2.2.2   WRSAs

Two geochemically distinct WRSAs will be built in order to facilitate the management of drainage from these facilities. One WRSA will be made up entirely of PAG waste rock while the second one will only contain NAG materials.

The PAG WRSA is composed of 3.14 Mt of waste material of which 26% represent argillite-rich rock (lithological codes AR and AG) while the remaining 74% are greywacke (lithological codes GW and GA). These proportions are equivalent in the EOM and PC scenarios. To calculate the tonnage of PAG waste rock to be produced during the life of mine, a geologic block model was generated using the Leapfrog^{TM} software. This modelling exercise considers both the geometry of the geological units and the spatial distribution of the samples to produce an interpolated grade shell at the NPR = 2 to discriminate between PAG and NAG zones. While sufficient neutralization potential is contained in these rocks to initially buffer the waste rock seepage at circum-neutral pH, it is likely that, owing to the depletion of NP in the PAG material, the pH will decrease to acidic conditions in the long-term. This reduced pH will have a direct effect on mineral solubility, metal leachability, and hence drainage chemistry, when comparing the End of Mine and the Post-Closure scenarios.

Material designated as NAG will be used for the construction of site infrastructure (*e.g.,* TMF embankments, roads, *etc.*) with excess material being destined for the NAG WRSA for permanent storage. Under consideration of the NAG waste rock being used for site infrastructure, the NAG WRSA will have a capacity of around 13 Mt, 60% of which is greywacke with the remaining 40% being classified as argillite.

2.2.3 Low-Grade Ore Stockpile

By definition, the low-grade ore stockpile is a temporary site feature that is expected to be processed at the End of Mining. Nevertheless, to account for the possibility that fluctuating gold prices will affect the mine plan rendering the low-grade or stockpile unprofitable, both EOM and PC scenarios were modelled. The ore tonnage assumed for the source term model was set at 5 Mt which represents the maximum amount of low-grade ore stored on site during operations. For the Post-Closure scenario, a PAG rock proportion of 70% was employed consistent with the static test database (Lorax, 2019).

2.2.4 Pit Walls

The FMS open pit will require dewatering during operations since the natural groundwater table is above the mining elevations. Runoff (via direct precipitation and snow melt) that comes into contact with the freshly exposed pit walls will also contribute to the water and loading balance within the open pit during operations. Generally, blasting practices will lead to the development of a blast-influenced (fracture) zone within the pit walls, a portion of which can be expected to fail and collapse onto underlying pit benches over time. Rinsing of pit wall surfaces and mine rock material that accumulates on the pit benches will release weathering products, in particular those related to sulphide oxidation.

As for the model assumptions used in the development of WRSA source terms, humidity cell units were grouped to represent argillite (AR and AG) and greywacke (GW and GA), as only these two units were resolved in the estimation of pit wall surface areas. The rock and environmental units exposed in the FMS pit are listed in Table 2-10. This table shows the estimated relative proportions of wall rock exposures in the FMS pit at EOM and in PC when the mine pit is fully flooded to the spillway elevation. The geologic block model yielded that, at this time, virtually no PAG rock will be exposed above the final pit lake elevation. This demonstrates the risk for development of ARD is, to some extent, tied to depth within open pit and proximity to the mineralized zone. A small portion of the FMS pit wall rock is not defined in the geologic block model. This 'undefined' unit is assumed to be 50% argillite and 50% greywacke for the purpose of source term calculation.

Table 2-10:
Pit Wall Rock Exposed in the FMS Pit for the EOM and PC Scenarios

	EOM	PC
Argillite	16%	19%
Greywacke	58%	70%
Ore	25%	11%

Notes: No potentially acid generating (PAG) material is expected to be exposed in the pit
walls after pit lake formation; EOM = End of Mining; PC = Post-Closure; wall rock
present above spillway elevation

2.3 Specific Tailings Model Assumptions

Ore processing at the FMS site will employ a conventional floatation circuit producing a gold concentrate which will then be hauled to the Touquoy mill for the final gold extraction steps via cyanidation. The tailings produced during initial ore processing steps, comprising a conventional rougher and cleaner flotation, will be stored in a TMF on the FMS property. This TMF will comprise a surface impoundment in which tailings are partially submerged by a water cover with tailings beaches developing along the dammed perimeter.

The geochemical behaviour of saturated (water-covered) tailings is known to differ distinctly from that of unsaturated (beached) tailings with the availability of oxygen, and thereby redox conditions, being the main driver with respect to material leaching characteristics. In the submerged portion of the TMF, potential contaminant sources include (i) those contained in the tailings process water (supernatant) as well as (ii) those associated with post-depositional processes, including the reductive dissolution of metal-bearing tailings phases in submerged tailings materials.

Tailings materials exposed in the beach portions of the TMF will be subject to oxidative weathering where sulphide oxidation and neutralization processes are expected to control contact water chemistry. In contrast to the waste rock, the fine grain size of tailings is expected to limit oxygen ingress into the tailings beach. Therefore, the thickness of the tailings package affected by aerobic weathering processes and releasing pore water and runoff into the tailings pond is expected to be less than 2 m after years of exposure (Holmström *et al.*, 2001).

Two samples of tailings solids generated during metallurgical testing in 2018 were characterized through acid-base-accounting (ABA), metals analysis and shake flask extraction (SFE) tests in order to understand the short-term leaching behaviour of these materials. These two tailings samples represent the waste products of a split circuit (Test 6) and a conventional flotation circuit (Test 10) that were evaluated during the 2018 metallurgical test program (Lorax, 2019) where the conventional circuit has since been identified as the preferred ore processing method for FMS. The corresponding tailings sample has an NPR of 2.0 and was therefore classified as NAG. As such, one key assumption that will be carried forward in the prediction of TMF-related source terms is that contact waters in this facility (unsaturated and saturated) will remain pH-neutral in the long-term.

2.3.1 Tailings Supernatant (End of Mining)

Tailings supernatant represents the process water that is discharged to the TMF as part of the tailings slurry. While tailings are being discharged during operations phase, it can be

assumed that the supernatant chemistry will dominate the aqueous chemistry in the tailings pond and pore water. Supernatant from the Test 10 (conventional circuit) tailings slurry was decanted and underwent extensive geochemical analysis. This supernatant water was used directly as a proxy for the process water that will be discharged into the FMS TMF during operations. Since only one representative tailings supernatant sample was available at the time of source term development, only one scenario (Base Case) was provided for this model iteration.

2.3.2   Tailings Beach

Tailings slurries will be discharged from spigot along the perimeter of the TMF with process water (supernatant) and beach runoff collecting in the topographic lows of the facility. This will lead to the exposure of tailings beaches which, depending on the slurry disposal rates, may be exposed to the atmosphere in some areas for extended periods of time before being covered by fresh tailings layers. The oxidative weathering of these tailings beaches will contribute a geochemical load to the tailings pond in Post-Closure.

SFE tests were conducted on both FMS tailings samples obtained during metallurgical testwork conducted in 2018. For the purpose of the source terms presented herein, these samples are used as the basis for the prediction of beach runoff chemistry. This was done simply by using the average and maximum SFE leachate concentrations to represent the Base and Upper Case scenarios, respectively. Since the SFE method agitates tailings samples for 24 hours, it is assumed that the resulting concentrations are a conservative proxy for the tailings beach runoff.

2.3.3   Tailings Porewater

Following cessation of the tailing discharge, post-depositional processes will become increasingly important over time in the saturated tailings. Depending on the mineralogy of the tailings materials and the aqueous regime, these post-depositional processes may attenuate or release contaminants within the TMF pore water. The potential for chemical instability of tailings in the saturated portions of the TMF in the long-term is in response to contrasting redox conditions in the mill (basic pH, oxidizing redox potentials) and TMF environments (circum-neutral pH, low redox potential). In this regard, both redox- and pH-dependent mechanisms may promote the dissolution of tailings phases.

A saturated tailings column containing Test 10 FMS tailings solids was initiated in March 2019. The purpose of this column experiment is to mimic long-term, suboxic conditions that can be expected in the FMS tailings pore water and seepage (Lorax, 2019). At the time of preparation of the geochemical source terms, only eight weeks of data leachate were available from this experiment and leaching conditions that would be expected in

post-closure had not yet been reached. However, saturated column data from a much longer kinetic test runtime (>1 year) is available for Touquoy tailings showing relatively stable leachate, suboxic leachate chemistry. These data were used to calculate conversion factors correlating short- and long-term leachate data internally for the Touquoy kinetic test cells. These factors were then applied to the FMS saturated column in order to predict the long-term leaching behaviour on the basis of the available short-term data. The conversion factors (CF) were calculated using Touquoy kinetic test data as follows:

$$CF = C_{li} / C_{si}$$

where C_{li} is the concentration of species i in the last three available sampling cycles (week 50-58) and C_{si} is the concentration of species i in week 8 of the saturated column experiment. Median and 90th percentile concentrations were used to calculate C_{li} for the Base and Upper Case scenarios, respectively. An overview of the different CF values used for the development of the FMS tailings pore water source terms is given in Table

Table 2-11:
Conversion Factors derived from Touquoy Saturated Column Data to Model Long-Term FMS Tailings Porewater Chemistry

		Conversion Factor	
		Base Case	**Upper Case**
Sulphate	mg/L	1.1	1.1
Al*	mg/L	0.42	0.79
Ag	mg/L	1.0	1.0
As	mg/L	2.1	4.3
Ca	mg/L	1.4	1.5
Cd	mg/L	0.71	1.5
Co	mg/L	0.59	0.79
Cr	mg/L	1.0	1.0
Cu	mg/L	1.6	2.9
Fe*	mg/L	0.14	0.26
Hg	mg/L	1.0	1.0
Mn	mg/L	2.9	5.1
Mo	mg/L	0.63	0.88
Ni	mg/L	2.5	4.2
Pb	mg/L	0.65	0.96
Sb	mg/L	0.37	0.56
Se	mg/L	0.91	1.7
Tl	mg/L	2.0	3.1
U	mg/L	0.90	0.96
Zn	mg/L	0.21	0.28

2.3.4   TMF Embankments

The TMF embankment at the FMS site will be built with waste rock material that is suitable for construction purposes which is expected to primarily represent greywacke rock sourced from the open pit. The Touquoy surface water monitoring network includes water quality stations at the toe of the TMF embankments and it can reasonably be assumed that, at least initially, embankment runoff contributes the main water source to these stations before the TMF seepage breakthrough has occurred. Since the Touquoy TMF is also built primarily with locally sourced greywacke material, these embankment monitoring stations provide an excellent site analogue that can be used in the prediction of FMS TMF embankment chemistry.

Since the TMF embankment will be built with NAG waste rock only, ARD will not be an issue. With this in mind, the prediction of the drainage chemistry from the FMS TMF was based on the median (Base Case) and 90th percentile (Upper Case) concentrations measured in four Touquoy TMF embankment monitoring stations (SCP1 through SCP4) before April 2018. This date marks the breakthrough of conservative geochemical tracers from TMF porewater (Na, Cl, SO_4) and may no longer be representative of the greywacke geochemical signature. Due to the nature of the analogue dataset, no long-term TMF source terms were developed specifically and it is conservatively assumed that the derived EOM source terms would also apply in the PC scenario.

2.4   Specific Overburden Assumptions

2.4.1   Till and Topsoil Stockpiles

Overburden will be stripped from the surface before mine development and stockpiled in a till and a topsoil stockpile. This material will later be used for reclamation purposes. Due to its deposition/formation environment and heavily weathered nature, overburden material is generally low in or devoid of sulphide minerals. As a result, the disturbance and relocation of these types of materials is not expected to have the same long-term effects on water quality as ore and waste rock drainage. Nevertheless, exposure of overburden in stockpiles with increased surface area will still cause contact water to adopt a geochemical signature, requiring the consideration of the till and topsoil stockpiles in the FMS water quality models.

Till material from within the FMS mine footprint was recovered during a drilling program led by Golder Associates (Golder, 2018). A total of five till samples were recovered during this program and the drill logs and geochemical test results were provided to Lorax. In addition, eight samples were collected from two existing Touquoy till piles during a Lorax site visit in October 2018. All samples were characterized via acid-base accounting (ABA),

metal content after aqua-regia digestion, and shake flask extractions (SFE) to gain insight into the short-term leachability of this material type. SFE data from of FMS and Touquoy till samples were used directly for the generation of geochemical source terms for the till stockpile.

During the 2018 Lorax site visit, five topsoil samples were retrieved from the Beaver Dam mine footprint via shallow test pitting. Although this material is from a different location, it is assumed that the soil characteristics between Beaver Dam and FMS are sufficiently similar to warrant the use of these topsoil samples as a proxy for the FMS source terms.

The till and topsoil materials were generally found to be devoid of or low in sulphide minerals (<0.02% to 0.12 %), and hence SFE tests are considered an adequate, conservative method to predict the quality of water coming in contact with these stockpiles. While the topsoil samples are generally also depleted in carbonate (<0.05%), several till samples show detectable inorganic carbon in the range of 0.05 % to 2.79% with a median of 0.065%. As such, it can be expected that the pH of drainage from the till stockpile will be higher than that in contact with topsoil.

Geochemical source terms for the two material types were derived as the median and 90th percentile SFE leachate values from the corresponding database for the Base and Upper Case scenarios, respectively.

3. Nitrogen Source Term Approach

Nitrogen (N) based blasting reagents have been identified by Pommen (1983) as a source of N compounds in pit walls and WRSA at surface mining operations. The nitrogen compounds ammonium (NH_4^+) and nitrate (NO_3^-) are the primary constituents of ammonium nitrate (AN) based explosives, while nitrite (NO_2^-) is typically formed during and after blasting. Under ideal blasting conditions the explosion reaction consumes all ammonium and nitrate in the explosives to form nitrogen gas. However, in practice ideal blasting conditions are not achieved and small proportions of the explosives remain as residue on blasted surfaces.

For surface mining operations the export of N to the receiving environment has been observed to be predominantly in the form of nitrate, and to a lesser extent, nitrite and ammonia (Ferguson and Leask, 1988). The N containing residues on pit walls and exposed blasted rock surfaces are rapidly flushed by contact water (Revey, 1996; Forsyth *et al.*, 1996; Cameron *et al.,* 2007; Mueller *et al.,* 2015). However, in unsaturated waste rock piles preferential and capillary flow paths develop that can lead to variable and delayed flushing of the pile (Fala *et al.,* 2003; Smith and Beckie, 2003; Stockwell *et al.,* 2006; Marcoline *et al.*, 2006; Fretz *et al.,* 2011). A delay in blast-related N release from waste rock piles has been observed at various surface mines and has been documented at Diavik (Baily *et al.*, 2013). The N available for leaching is limited to the wetted areas of the pile and the type of flow paths that develop, therefore N release from a large rock pile can persist for years after rock placement.

Sections 3.1 and 3.2 summarize the approach used in the development of nitrogen species source terms for the EOM scenario. The derivation of nitrogen depletion rates to be used in the Post-Closure scenario is described in Section 3.3.

3.1 WRSA Nitrogen Loading Model Approach (EOM)

While Touquoy site monitoring data was available for drainage, at the time of source term development, this database only captured around 6 months of WRSA drainage chemistry. As described above, significant delay can be expected in the transport of the nitrogen signature from the source to downstream receivers. Furthermore, the release of stored nitrogen loads from waste rock piles is generally mass-dependent which does not make the still relatively small Touquoy WRSA a reliable proxy for the purpose of nitrogen concentration predictions. Therefore, a nitrogen loading model using the FMS WRSA dimensions and hydrogeological was generated and calibrated with site analogue data. The N loading model is based on an empirically derived approach for surface coal mines

(Ferguson and Leask, 1988) that estimates N loads based on the mining schedule and planned explosives use, and accounts for delayed release of N loads observed in waste rock piles. The derived N loads and WRSA infiltration rate at EOM were used to estimate Base Case and Upper Case concentrations for ammonia, nitrate and nitrite.

Note: The nitrogen source terms presented herein were originally derived for one larger WRSA (15.4 Mt) in which both PAG and NAG waste rock are co-deposited. Since the revision of the mine plan, nitrogen predictions were not re-modelled and the source terms presented in the following are applied to both the PAG and the NAG WRSA. Since nitrogen loads are strongly tied to the total mass of waste rock stored in a facility, this approach is considered conservative, especially for the smaller PAG WRSA.

The N loading model considers the planned explosives use rate and the waste rock placement schedule to calculate N loads stored in the last year of operations. The concentrations of ammonia, nitrite and nitrate at EOM are derived from the WRSA infiltration rate at EOM and an assumed N species distribution from literature values. Key model assumptions are summarized below:

- Mining, explosive use, waste rock production and placement will proceed as per the mine plan;

- The explosives product is TITAN® XL 1000, a bulk AN-based emulsion product manufactured by Dyno Nobel. The exact nitrogen content in TITAN® XL 1000, is proprietary therefore it is assumed to contain 25% N, similar to the N content typically found in AN-based emulsion explosives;

- The explosives usage per tonne of blasted rock, also known as the powder factor (PF), is 0.2 kg/t;

- Best explosive use and blasting practices will be implemented to maximize explosive consumption during blasting (*i.e.,* to minimize explosives residue on waste rock surfaces);

- Empirical observations of N loading to waste rock piles by Ferguson and Leask (1988) are a reasonable proxy for N loading from the WRSA.

- The EOM infiltration value for the WRSA provided by Knight Piésold (Jackson, pers. comm., 2018) is 1,296 mm;

- The N release and decay observations at the Diavik Diamond Mines (Baily *et al.*, 2013) and British Columbia surface coal mine waste rock studies (Lorax *et al.*, 2017) are a reasonable proxy for N release from the WRSA;

- Nitrogen is exported to the aqueous downstream receiving environment in N species proportions that are similar to average distributions observed by Ferguson and Leask (1988), with nitrate, ammonia and nitrite respectively representing 87%, 11% and 2% of the N load released; and,

- For the purpose of N source term derivation, the background levels for ammonia, nitrite and nitrite are assumed to be zero.

3.1.1 N Loading to the WRSA

The procedures described by Ferguson and Leask (1988) were used to estimate the N loads added to the WRSA in the year of deposition. Ferguson and Leask (1988) studied coal mines discharges in southeastern British Columbia and described an empirical method for estimating the N loads added to WRSA based on the amount and type of explosive used annually. For surface mines that use more than 20% emulsion the following N loading equation was derived:

$$N_{Load\,(k)} = 0.94\% \times E_{An(k)} + 5.1\% \times E_{Em(k)}$$

Where, $N_{Load\,(k)}$ is the annual nitrogen load (kg N) in year k of mine operation; $E_{An(k)}$ is the annual ANFO explosive use (kg N) in year k of mine operation; and, $E_{Em(k)}$ is the annual emulsion explosive use (kg N) in year k mine operation.

Ferguson and Leask (1988) observed that emulsion explosives were generally used in challenging blasting conditions where ammonium nitrate fuel oil (ANFO) explosives were unlikely to be efficiently consumed (*e.g.,* typically where water was in contact with non-detonated explosives). Although emulsion explosives are designed to detonate in the presence of water, challenging conditions are inferred to reduce the emulsion explosives consumption efficiency and therefore contribute higher N loads to rock surfaces as indicated in the emulsion term of the loading equation. It is reasonable to expect that emulsion explosives used in good blasting conditions will be efficiently consumed and contribute N loads similar to the rate indicated in the ANFO term (0.94%) in the loading equation. However, for the N loading model the ANFO term in the loading equation is set to zero and 100% of the emulsion explosives are conservatively assumed to contribute N at the higher rate (5.1%) indicated in the emulsion term of the N loading equation.

The planned explosive use and waste rock placement tonnages, and N loading calculation results are summarized in Table 3-1.

Table 3-1:
Estimated Annual Nitrogen (N) Loading to the Waste Rock Storage Area (WRSA)

Mine Year	Y1 [A]	Y2	Y3	Y4	Y5	Y6
Quantity of waste rock placed (kt)	3,829	5,191	4,221	1,900	295	0
Explosives usage (kg)	765,724	1,038,205	844,185	380,008	58,942	0
Explosives N content (kg-N)	191,431	259,551	211,046	95,002	14,735	0
N load added to WRSA (kg-N)	9,763	13,237	10,763	4,845	752	0

[A] Rock placed in the WRSA in year PP (40 kt) is included in this total.

3.1.2 Annual N Release from the WRSA

The release rate of N loads from the WRSA was derived from observations at Diavik reported by Baily *et al* (2013) that were scaled to FMS using the WRSA infiltration rate at Closure. The observations of test rock piles at Diavik indicate the release of significant nitrogen levels in waste rock test piles commenced with the third freshet (*i.e.,* the third year) after rock deposition. Further an average 8.2% of the total nitrogen load was released in the first three years after waste rock placement.

Increases in precipitation are expected to lead to increased infiltration and N release to WRSA infiltration water. The mean annual precipitation (MAP) observed at Diavik is 280 mm (Fretz *et al.,* 2011). The MAP at FMS is 1,440 mm, significantly higher than precipitation levels observed at Diavik mine. To estimate N release from the WRSA the Diavik N release rate was scaled-up based on precipitation and infiltration values. As described previously, preferential and capillary flow paths are likely to develop in the WRSA leading to variable release of N from the WRSA. To be consistent with the approach used for geochemical source terms, an infiltration rate of 90% of the MAP (1,296 mm) was used to proportionately scale-up the Diavik N load release using the equation below with the results shown in Table 3-2. An annual 35.8% N release was derived for the WRSA according to the following equation:

$$r_{FMS} = \frac{I_{FMS}}{P_D} \times r_D$$

where, r_{FMS} is the N release estimated for FMS; r_D is the N release observed at Diavik; I_{FMS} is infiltration (mm/yr) at FMS; and, P_D is the mean annul precipitation (mm/yr) at Diavik.

Table 3-2:
Derivation of the Annual N Load Release from the WRSA

Term	Value
Diavik MAP (mm) (P_D)	280
WRSA Infiltration (90% MAP) (mm) (P_{EG})	1296
Diavik N release (2007-2010) (r_D)	8.2%
WRSA N release (r_{EG})	36%

3.1.3 N Loads Released from the WRSA at End of Mine

The N loads released from the WRSA at EOM were derived by estimating the stored N load and applying the release factor to that load. For the Base Case scenario, the stored N load is adjusted for N release from the WRSA that is expected to occur annually during mining, whereas the Upper Case scenario assumes the entire N load added to the WRSA annually is stored in the WRSA and that all N is released in the last year of operations.

3.1.3.1 Base Case

For each annual waste rock quantity placed in the WRSA the N load released annually was calculated using the N release rate and the stored N load. Accelerated wetting of the WRSA is expected relative to observations at Diavik due to the overall warmer conditions and elevated precipitation at FMS. Therefore, the N release was modelled to commence the second year after waste rock placement, rather than the three year lag time observed at Diavik. The N release during the year of rock placement and the following year is assumed to be zero in both years. The N loads released from the WRSA was calculated using the following formula:

$$N_{Release} = r_{FMS} \times N_{Stored}$$

where, $N_{Release}$ is the N released (kg-N) from the annual waste rock quantity; r_{FMS} is the annual N release (%) estimated for FMS; and, N_{Stored} is the N stored (kg-N) in the annual waste rock quantity.

The amount of N stored in each annual waste rock quantity is the difference between the N load stored in year of placement, and the amount N released subsequent to placement. Nitrogen release the year of rock placement and the first year after rock placement is assumed to be zero in both years; from second year onwards, the N stored is reduced by the annual N release as represented by the following equation:

$$N_{Stored\,(i)} = N_{Load\,(i=0)} - \sum_{a=2}^{i,i\geq2} N_{Released\,(a)}$$

where, $N_{Stored\ (i)}$ is N stored in waste rock year i after placement; $N_{Load\ (i=0)}$ is the N load (kg N) the year of placement; and, $N_{Released\ (a)}$ is the N released (kg-N) year a after placement.

The amount of N stored in the WRSA at the end of each year was calculated by summing the nitrogen stored in each annual waste rock quantity placed:

$$N_{Stored,WRSF\ (k)} = \sum_{i=0}^{n} N_{Stored\ (i,k)}$$

where, $N_{Stored,WRSF\ (k)}$ is N stored (kg N) in the WRSA at the end of year k; and, $N_{Stored\ (i,k)}$ is N stored (kg N) in annual rock quantity i in at the end of year k, where n equals the number of annual waste quantities placed to the end of year k.

The annual N release from the WRSA was calculated by summing the nitrogen release from each annual waste rock quantity placed:

$$N_{Released,WRSF\ (k)} = \sum_{i=0}^{n} N_{Release\ (i,k)}$$

where, $N_{Released,WRSF\ (k)}$ is total nitrogen released (kg N) from the waste rock pile in year k; and, $N_{Released\ (i,k)}$ is the N released (kg N) from annual waste rock quantity i in year k, where n equals the number of annual waste quantities placed to the end of year k.

The results of the Base Case N storage and release calculations are presented in Table 3-3 and Figure 3-1. The N load released in Y6 (7,089 kg-N) was used to model the Base Case N load from the WRSA at EOM.

Table 3-3:
Derivation of the Base Case N Loads Release at End of Mine (Y6)

N Load, Storage and Release (WRSA)	Nitrogen (kg-N)					
Year of Mine Operation	Y1	Y2	Y3	Y4	Y5	Y6
N Load Added in the Year of Waste Deposition	9,763	13,237	10,763	4,845	752	0
WRSA N Stored, Cumulative	9,763	23,000	30,264	28,119	20,528	13,439
WRSA N Release, Annual	0	0	3,500	6,990	8,343	7,089
Y1 Waste Annual N Release			3,500	2,245	1,440	924
Y2 Waste Annual N Release				4,745	3,044	1,953
Y3 Waste Annual N Release					3,858	2,475
Y4 Waste Annual N Release						1,737
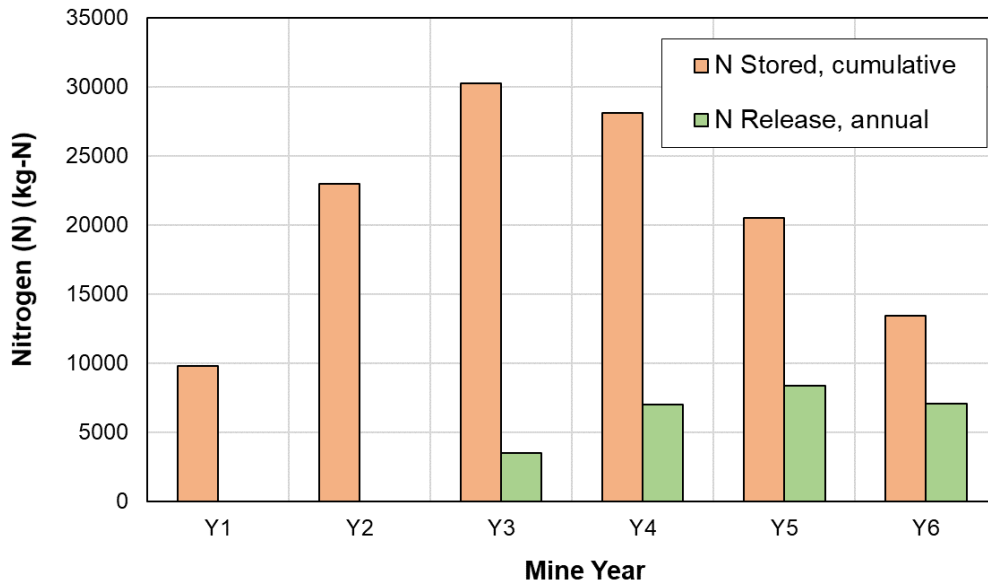
Figure 3-1: **Predicted Annual N Loads Stored and Released from the WRSA to End of Mine (Y6)**

3.1.3.2   *Upper Case*

In contrast to the Base Case scenario, the Upper Case scenario conservatively assumes N loads accumulate in the WRSA and are not released until End of Mine. The methodologies described in the previous sections were used to calculate the N stored and released from the WRSA at EOM. The Ferguson and Leask (1988) equation for mines using more than 20% emulsion was used calculate the N stored in WRSA and the N release rate was applied to this total to derive the Upper Case N release of 14,109 kg-N from the WRSA at EOM. The calculations are summarized in Table 3-4 below.

Table 3-4:
WRSA Upper Case N Load Derivation

WRSA Tonnage at Closure (t):	15,435,453
Explosives Used (kg)	3,087,091
N in Explosives Used (kg-N)	771,773
N Stored in WRSA (F&L, > 20% emulsion)	39,360
N Release Rate (%)	35.80%
N Released at End of Mine (kg-N)	14,109

3.1.4   **Conversion of N Loads into Concentration**

Average annual WRSA drainage N species concentrations were calculated by dividing the N loads released at EOM by the volume of water predicted to infiltrate into the WRSA at

EOM, and proportionately distributing the N load as specific nitrogen species. The assumed EOM infiltration value for the WRSA was provided by Knight Piésold (Jackson, pers. comm., 2018) and is summarized in Table 2-8. The N loads were distributed among the nitrogen species (ammonia, nitrite and nitrate) according to observations by Ferguson and Leask (1988) with most of the load exported as nitrate (87%) and the balance as ammonia (11%) and nitrite (2%). These calculations were conducted according to the following equation:

$$C_{N\ Species} = \frac{N_{Released} \times p_{N\ Species} \times 1000}{F}$$

where, $C_{N\ Species}$ is the N species source term (mg/L); $N_{Released}$ is the total N release (kg-N) from the WRSA at EOM; $p_{N\ Species}$ is proportion of N as ammonia, nitrite or nitrate; and, F is WRSA infiltration volume (m^3) at EOM.

3.2 Tailings Embankment & Pit Wall Source Term Model Approach (EOM)

Operational monitoring data from the Touquoy site are available for the open pit and TMF embankments and were used directly in the EOM prediction of nitrogen concentrations for the same mine components at FMS. The direct use of Touquoy operational monitoring data was selected based on the following rationale:

- o The reactive rock mass that is available to leach residual nitrogen from blasting activities is much smaller in the TMF embankment and pit walls versus the WRSA. Therefore, the delay in the transport of stored nitrogen loads is expected to be much shorter from these facilities;

- o Lithologies and physical rock properties making up these mine components are considered sufficiently similar between Touquoy and FMS. While nitrogen loading rates are not necessarily dependent on the geochemistry of the rock, the physical properties defining a material's behaviour during blasting will likely affect the retention of nitrogen on particle surfaces.

The Touquoy water quality monitoring stations utilized for the prediction of nitrogen source terms are as follows:

- • Pit walls: SWOP

- • TMF embankments: SWSCP1 through SWSCP4, SW16, SW17

Median and 90th percentile values were used to derive a Base Case and an Upper Case EOM source term for these facilities, respectively. The monitoring time frame used for these predictions are from August 2017 - October 2018 and November 2017 - October 2018, for the pit walls and the TMF embankments, respectively.

3.3   Post-Closure N Source Term Derivation

It is known that, unlike species associated with the oxidation of sulphide minerals, N species concentrations will decrease once the addition of blasted material to a facility has ceased (*e.g*., Pommen, 1983). The N depletion rates depend on a variety of factors including the amount of reactive rock surfaces as well as flushing rates that are difficult to model. Long-term monitoring of waste rock drainage at the Roman-Trend Mine has shown that N depletion is not linear but rather is expressed as a decay curve (Figure 3-2) with the highest absolute N reduction observed in the early years after closure (Lorax, 2017). It was found that, in the Post-Closure period, nitrogen concentrations were reduced annually by >10% of the previous year's concentration after correction for seasonal variability. However, the tonnage of the waste rock facility at the Trend-Roman Mine as well as its flushing rates differ markedly from those expected for the FMS WRSA. Therefore, a conservative annual N depletion rate of 10% was scaled to FMS conditions as follows:

$$DR_{FMS} = DR_{TR} \times \frac{h_{TR}}{h_{FMS}} \times \frac{MAP_{FMS}}{MAP_{TR}}$$

where DR_{FMS} and DR_{TR} are the annual nitrogen depletion rates for FMS and the Trend-Roman Mine, respectively; h_{FMS} and h_{TR} are the thicknesses of the respective waste rock facilities; and MAP_{FMS} and MAP_{TR} are the mean annual precipitation at FMS and the Trend-Roman Mine, respectively. The input values used for this scaling exercise are given in Table 3-5. Note that the FMS WRSA height chosen for this scaling model conservatively represents the maximum value as provide by AMNS (pers. comm., 2019). The resulting scaled N depletion rate was DR_{FMS} was calculated to be 25% (Table 3-6) using these parameters. Note that it is herein assumed that nitrite and ammonia are depleted at the same rates as nitrate.

For the TMF embankment and the pit walls, the depletion of nitrogen species is expected to occur significantly faster than in the WRSA due to the smaller size and higher water/rock ratios in these mine components. The N depletion rate of TMF embankment was scaled in the same manner as the WRSA where a thickness of around 17 m was assumed (Table 3-5). Since the water/rock ratio in the pit walls that are influenced by blasting are expected to be relatively high, the use data from two field bins constructed with freshly blasted Touquoy material (argillite and greywacke) was considered appropriate to estimate nitrogen depletion rate in the open pit. These field bins were initiated in fall of 2017 and consist of around 150-200 kg of material forming a 0.8 – 1 m thick reactive rock column. Leachate data showed that within one year of field bin operation, the nitrate concentration was reduced by > 90% in both field bins. In that year, both nitrite and ammonia were reduced to below detection limit. To account for uncertainties related to an experimental runtime of only one year and to maintain conservatism, the annual nitrogen depletion rate for the FMS pit walls was set to 80% (Table 3-6).
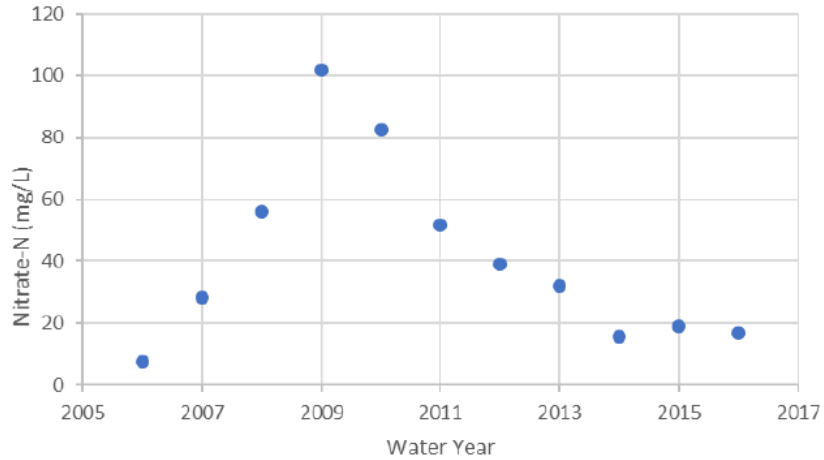
Figure 3-2:   Nitrate Concentration Trends Observed in a Waste Rock Monitoring Station at the Roman-Trend Mine (from Lorax, 2017)

Table 3-5:
Input Parameters Used to Scale the Roman-Trend Mine N Depletion Rate to FMS Conditions for the WRSA

Trend-Roman	
Height of WRSA	70 m
Mean Annual Precipitation	1,000 mm
Annual N Depletion Rate	10%
FMS	
Height of WRSA	70 m
Height of TMF Embankment	17 m
Mean Annual Precipitation	1,440 mm

Notes: The FMS WRSA height is the maximum value as per AMNS (2019).

Table 3-6:
Annual Nitrogen Depletion Rates Derived for Post-Closure for the Various FMS Mine Components

WRSA	
Nitrate	
Nitrite	25%
Ammonia	
Pit Runoff	
Nitrate	
Nitrite	80%
Ammonia	
TMF Embankments	
Nitrate	
Nitrite	60%
Ammonia	

4.   *Source Term Results*

4.1   *Waste Rock and Ore*

4.1.1   Waste Rock Storage Areas

Geochemical source terms for the PAG and NAG WRSAs at FMS are given in Table 4-1 and Table 4-2, respectively.

Table 4-1:
Geochemical Source Term Concentrations for the PAG WRSA

		EOM		PC	
		Base Case	Upper Case	Base Case	Upper Case
pH	-	7.5	7.5	4.0	3.5
Sulphate	mg/L	978	1189	2439	3013
Al	mg/L	0.0058	0.0059	0.19	0.21
Ag	mg/L	0.000050	0.000070	0.000060	0.000070
As	mg/L	0.0078	0.016	0.024	0.025
B	mg/L	0.21	0.30	0.17	0.25
Ca	mg/L	49	46	36	35
Cd	mg/L	0.000030	0.000070	0.011	0.020
Co	mg/L	0.0011	0.0025	0.33	0.45
Cr	mg/L	0.00050	0.0010	0.0018	0.0020
Cu	mg/L	0.0010	0.0020	0.12	0.21
Fe	mg/L	0.0041	0.0042	14	63
Hg	mg/L	0.000010	0.000010	0.000010	0.000010
K	mg/L	13	16	7.8	7.9
Mg	mg/L	10	12	16	17
Mn	mg/L	0.16	0.21	1.1	1.3
Mo	mg/L	0.0015	0.0039	0.00020	0.00039
Na	mg/L	35	48	17	34
Ni	mg/L	0.020	0.048	2.3	3.8
Pb	mg/L	0.00040	0.0012	0.14	0.46
Sb	mg/L	0.000090	0.00022	0.00029	0.00030
Se	mg/L	0.00081	0.0017	0.0059	0.0063
Tl	mg/L	0.000050	0.00010	0.0012	0.0014
U	mg/L	0.0065	0.0089	0.025	0.039
Zn	mg/L	0.0040	0.0041	3.2	3.4

Notes: EOM = End of Mining; PC = Post-Closure.

Table 4-2:
Geochemical Source Term Concentrations for the NAG WRSA

		EOM		PC	
		Base Case	Upper Case	Base Case	Upper Case
pH	-	7.5	7.5	7.5	7.5
Sulphate	mg/L	1146	1370	902	1095
Al	mg/L	0.0059	0.0059	0.0058	0.0058
Ag	mg/L	0.000050	0.000080	0.000070	0.000080
As	mg/L	0.0073	0.014	0.0044	0.0045
B	mg/L	0.26	0.37	0.18	0.25
Ca	mg/L	46	44	50	47
Cd	mg/L	0.000030	0.000080	0.000060	0.000090
Co	mg/L	0.0014	0.0030	0.0018	0.0026
Cr	mg/L	0.00050	0.0010	0.0022	0.0023
Cu	mg/L	0.0010	0.0020	0.010	0.020
Fe	mg/L	0.0041	0.0042	0.0041	0.0041
Hg	mg/L	0.000010	0.000010	0.000010	0.000010
K	mg/L	15	19	9.3	9.5
Mg	mg/L	12	14	6.6	7.1
Mn	mg/L	0.14	0.20	0.11	0.13
Mo	mg/L	0.0018	0.0053	0.0036	0.0074
Na	mg/L	36	50	26	27
Ni	mg/L	0.022	0.052	0.0093	0.015
Pb	mg/L	0.00045	0.0013	0.00058	0.0024
Sb	mg/L	0.00010	0.00024	0.00034	0.00036
Se	mg/L	0.00090	0.0022	0.00090	0.00095
Tl	mg/L	0.000050	0.00010	0.00022	0.00027
U	mg/L	0.0064	0.0089	0.0029	0.0045
Zn	mg/L	0.0045	0.0046	0.0045	0.0047

Notes: EOM = End of Mining; PC = Post-Closure.

4.1.2 Low-Grade Ore Stockpile

Geochemical source terms for the low-grade ore stockpile are given in Table 4-3.

Table 4-3:
Geochemical Source Term Concentrations for the Low-Grade Ore Stockpile

		EOM		PC	
		Base Case	Upper Case	Base Case	Upper Case
pH	-	7.5	7.5	4.5	4.0
Sulphate	mg/L	764	1562	3652	4254
Al	mg/L	0.0058	0.0059	0.15	0.22
Ag	mg/L	0.000080	0.000080	0.00013	0.00014
As	mg/L	0.0042	0.0098	0.019	0.029
B	mg/L	0.31	0.49	0.42	0.42
Ca	mg/L	55	42	33	32
Cd	mg/L	0.000020	0.000060	0.0064	0.0099
Co	mg/L	0.00064	0.0024	0.53	0.82
Cr	mg/L	0.00050	0.0010	0.0037	0.0040
Cu	mg/L	0.0010	0.0020	0.062	0.071
Fe	mg/L	0.0041	0.0042	4.4	15
Hg	mg/L	0.000010	0.000010	0.000020	0.000020
K	mg/L	13	19	16	17
Mg	mg/L	12	13	25	27
Mn	mg/L	0.20	0.22	1.4	2.2
Mo	mg/L	0.0011	0.0021	0.0012	0.0014
Na	mg/L	36	54	27	29
Ni	mg/L	0.026	0.043	19	27
Pb	mg/L	0.00087	0.0022	0.037	0.041
Sb	mg/L	0.000080	0.00010	0.00057	0.00062
Se	mg/L	0.0030	0.0044	0.011	0.014
Tl	mg/L	0.000050	0.00010	0.0012	0.0013
U	mg/L	0.0029	0.0037	0.010	0.017
Zn	mg/L	0.0046	0.0048	2.5	2.8

Notes: EOM = End of Mining; PC = Post-Closure.

4.1.3 Pit Walls

Pit wall source terms used for input into the site-wide water quality model are presented in Table 4-4.

Table 4-4:
Geochemical Source Term Concentrations for FMS Pit Wall Runoff

		EOM		PC	
		Base Case	Upper Case	Base Case	Upper Case
pH	-	7.5	7.5	7.5	7.5
Sulphate	mg/L	704	964	658	801
Al	mg/L	0.0058	0.0058	0.0058	0.0058
Ag	mg/L	0.000070	0.000070	0.000070	0.000070
As	mg/L	0.011	0.023	0.0069	0.0075
B	mg/L	0.069	0.10	0.042	0.058
Ca	mg/L	57	50	59	53
Cd	mg/L	0.000010	0.000020	0.000010	0.000020
Co	mg/L	0.00087	0.0023	0.0015	0.0020
Cr	mg/L	0.00050	0.0010	0.0020	0.0021
Cu	mg/L	0.0010	0.0020	0.0077	0.013
Fe	mg/L	0.0041	0.0041	0.0040	0.0041
Hg	mg/L	0.000010	0.000010	0.000010	0.000010
K	mg/L	18	23	11	11
Mg	mg/L	9.9	12	5.7	6.0
Mn	mg/L	0.092	0.11	0.071	0.090
Mo	mg/L	0.0073	0.017	0.012	0.022
Na	mg/L	33	46	24	25
Ni	mg/L	0.037	0.080	0.028	0.042
Pb	mg/L	0.00053	0.0015	0.00051	0.0016
Sb	mg/L	0.00014	0.00030	0.00048	0.00051
Se	mg/L	0.0014	0.0024	0.00092	0.0010
Tl	mg/L	0.000050	0.00010	0.00018	0.00022
U	mg/L	0.016	0.021	0.0086	0.013
Zn	mg/L	0.0042	0.0043	0.0040	0.0043

Notes: EOM = End of Mining; PC = Post-Closure.

4.1.4 Nitrogen Source Terms

Nitrogen concentrations predicted for drainage from the WRSAs, pit walls, and the TMF embankment at EOM are presented in

Table 4-5. The PC scenario involves an annual nitrogen depletion rate rather than absolute concentrations. The approach chosen to derive this rate is described in Section 3.

Table 4-5:
Nitrogen Species Source Term Concentrations for FMS Mine Components at End of Mining

	unit	End of Mining	
		Base Case	**Upper Case**
WRSA			
Nitrate	mg N/L	13	26
Nitrite	mg N/L	0.3	0.59
Ammonia	mg N/L	1.6	3.2
Pit Runoff			
Nitrate	mg N/L	5.5	18
Nitrite	mg N/L	0.17	0.54
Ammonia	mg N/L	1.0	6.9
TMF Embankments			
Nitrate	mg N/L	7.1	9.0
Nitrite	mg N/L	0.17	0.30
Ammonia	mg N/L	0.31	0.49

4.2   Tailings

4.2.1   Tailings Supernatant (End of Mining)

The Base Case FMS tailings process water (supernatant) predictions are given in Table in Table 4-6.

Table 4-6:
Geochemical Source Term Concentrations Associated with the FMS Tailings Supernatant

		Tailings Supernatant
		Base Case
pH	-	8.0
Sulphate	mg/L	135
Al	mg/L	0.026
Ag	mg/L	0.0000050
As	mg/L	0.012
B	mg/L	0.021
Ca	mg/L	25
Cd	mg/L	0.0000050
Co	mg/L	0.0000090
Cr	mg/L	0.00010
Cu	mg/L	0.00010
Fe	mg/L	0.0010
Hg	mg/L	0.0000050
K	mg/L	32
Mg	mg/L	3.5
Mn	mg/L	0.018
Mo	mg/L	0.016
Na	mg/L	63
Ni	mg/L	0.00076
Pb	mg/L	0.0000050
Sb	mg/L	0.00031
Se	mg/L	0.00028
Tl	mg/L	0.0000060
U	mg/L	0.00016
Zn	mg/L	0.010

Notes: Al and Fe underwent PHREEQC speciation.

4.2.2 TMF Beach Runoff

The source term concentrations predicted for TMF beach runoff are presented in Table 4-7.

Table 4-7:
Predicted Concentrations for Tailings Beach Runoff

		Tailings Beach Runoff	
		Base Case	Upper Case
pH	-	7.9	8.0
Sulphate	mg/L	79	83
Al	mg/L	0.023	0.026
Ag	mg/L	0.000025	0.000025
As	mg/L	0.0096	0.013
B	mg/L	0.014	0.015
Ca	mg/L	22	22
Cd	mg/L	0.0000050	0.0000050
Co	mg/L	0.000028	0.000032
Cr	mg/L	0.00014	0.00015
Cu	mg/L	0.0011	0.0014
Fe	mg/L	0.0052	0.0044
Hg	mg/L	0.000013	0.000020
K	mg/L	11	14
Mg	mg/L	1.9	1.9
Mn	mg/L	0.011	0.012
Mo	mg/L	0.0096	0.014
Na	mg/L	43	54
Ni	mg/L	0.00045	0.00050
Pb	mg/L	0.000025	0.000030
Sb	mg/L	0.00045	0.00045
Se	mg/L	0.00023	0.00033
Tl	mg/L	0.0000040	0.0000050
U	mg/L	0.00024	0.00025
Zn	mg/L	0.0010	0.0010

Notes: Al and Fe underwent PHREEQC speciation

4.2.3   Tailings Pore Water (Long-Term)

The final source term concentrations predicted for the long-term FMS TMF pore water are presented in Table 4-8.

Table 4-8:
Long-Term (Post-Closure) Pore Water Concentrations Predicted for the FMS TMF

		Tailings Pore Water	
		Base Case	Upper Case
pH	-	8.1	8.1
Sulphate	mg/L	225	244
Al	mg/L	0.0055	0.010
Ag	mg/L	0.0000050	0.0000050
As	mg/L	0.053	0.11
B	mg/L	0.052	0.053
Ca	mg/L	42	44
Cd	mg/L	0.000011	0.000022
Co	mg/L	0.0000050	0.0000070
Cr	mg/L	0.00010	0.00010
Cu	mg/L	0.00016	0.00029
Fe	mg/L	0.00063	0.0011
Hg	mg/L	0.0000050	0.0000050
K	mg/L	40	45
Mg	mg/L	6.6	7.3
Mn	mg/L	0.22	0.39
Mo	mg/L	0.040	0.055
Na	mg/L	89	92
Ni	mg/L	0.00073	0.0012
Pb	mg/L	0.0000030	0.0000050
Sb	mg/L	0.000090	0.00014
Se	mg/L	0.00017	0.00031
Tl	mg/L	0.0000040	0.0000060
U	mg/L	0.00023	0.00025
Zn	mg/L	0.00021	0.00028

Notes: Al and Fe underwent PHREEQC speciation

4.3 Overburden

Source terms for the FMS till and topsoil stockpiles are presented in Table 4-9. Note that the same source terms are applied to the EOM and PC scenarios.

Table 4-9:
Geochemical Source Term Concentrations for the Till and Topsoil Stockpiles

		Topsoil Stockpile		Till Stockpile	
		Base Case	**Upper Case**	**Base Case**	**Upper Case**
pH	mg/L	5.5	5.0	6.7	5.5
Sulphate	mg/L	1.7	2.2	36	68
Al	mg/L	0.078	0.55	0.0078	0.10
Ag	mg/L	0.000030	0.000030	0.000030	0.000030
As	mg/L	0.0025	0.0070	0.0021	0.015
B	mg/L	0.0050	0.0050	0.0055	0.017
Ca	mg/L	0.95	1.1	15	42
Cd	mg/L	0.000030	0.000060	0.000030	0.00029
Co	mg/L	0.00069	0.00096	0.00039	0.011
Cr	mg/L	0.00076	0.0011	0.00025	0.00086
Cu	mg/L	0.00095	0.0027	0.0017	0.0041
Fe	mg/L	0.23	0.42	0.023	0.18
Hg	mg/L	0.000030	0.000030	0.000030	0.000030
K	mg/L	0.67	1.4	0.81	1.3
Mg	mg/L	0.41	0.53	2.3	6.5
Mn	mg/L	0.087	0.11	0.19	0.72
Mo	mg/L	0.000050	0.000050	0.00059	0.0065
Na	mg/L	1.4	2.1	4.4	6.2
Ni	mg/L	0.0014	0.0017	0.0011	0.020
Pb	mg/L	0.00013	0.00094	0.00011	0.00052
Sb	mg/L	0.000050	0.000050	0.00023	0.00054
Se	mg/L	0.00077	0.00096	0.00051	0.00091
Tl	mg/L	0.000050	0.000050	0.000050	0.000090
U	mg/L	0.000080	0.00010	0.000060	0.00075
Zn	mg/L	0.0050	0.0099	0.0050	0.014

Notes: EOM = End of Mining; PC = Post-Closure.

5. *Recommended Future Work*

Geochemical source term predictions heavily rely on theoretical constraints, representative geochemical testwork, and the availability of site analogue data. To close data gaps that would increase the confidence in the geochemical source term predictions for future model iterations, the following recommendations are made:

- Continued operation of FMS PAG humidity cells to assess the long-term effect of metal leaching behaviour in site-specific materials as well as to understand material-specific metal mobility under acidic conditions.

- Additional sampling and static testing of waste rock material to increase the confidence in the sulphur and NP contents as well as PAG proportions within this population, since these parameters have a direct impact on the source term model results.

- Collection of site-specific topsoil samples to understand and asses this material's geochemical variability and in support of topsoil stockpile source terms.

- Continued tracking and reporting of Touquoy WRSA tonnage, footprint, and lithological proportions along with continued waste rock drainage monitoring to allow for better calibration of model and scaling factors which can be applied to the FMS WRSA in future model iterations. This is especially relevant for nitrogen-specific source terms, since nitrogen commonly shows lag times in its release from larger waste rock facilities.

- Concentrate from the FMS processing plant will be shipped to the Touquoy site where the final ore extraction step will be conducted using cyanidation. It is expected that the relatively small quantity of tailings generated during this process will be co-deposited with Beaver Dam tailings in the Touquoy open pit. To understand the geochemical impact of this tailings disposal plan, it is recommended that this material be tested via ABA and potentially other characterization methods.

6.   Closure

This Lorax report was prepared and reviewed by the undersigned.

Yours sincerely,
Lorax Environmental Services Ltd.

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