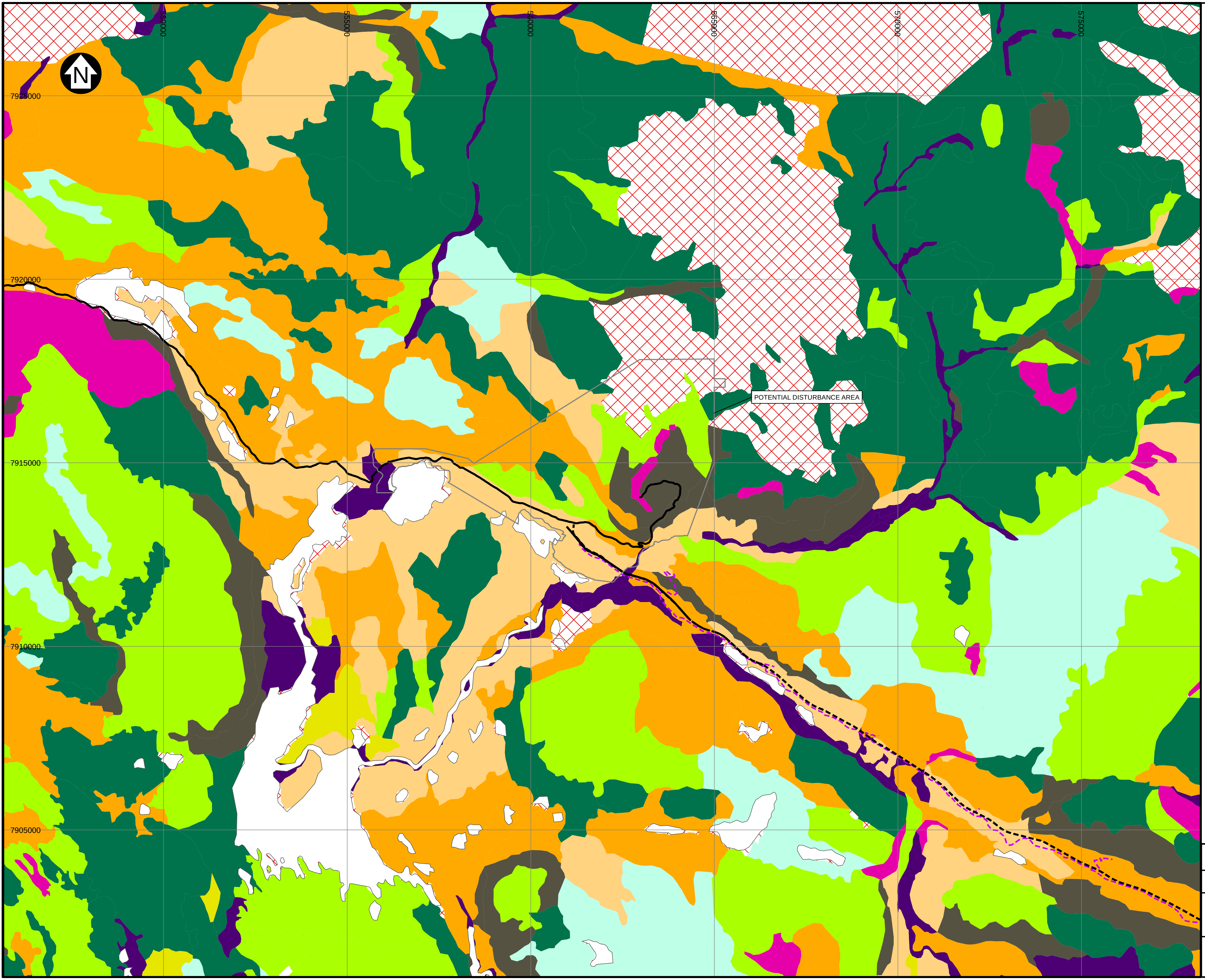


FIGURE ID: BL_Vol6_GIS_004 Surficial Geology in the Mine Site Area Figure 6-2-3.mxd

SURFICIAL DEPOSITS
QUATERNARY
HOLOCENE

Ca — **COLLUVIUM: block and rubble accumulations, 1-50 m thick.** Talus: active block and rubble accumulations as much as 50 m thick forming talus aprons and fans below cliffs resulting from rock falls and debris flows; commonly crossed by debris flow channels and léeves.

Ap — **FLUVIAL SEDIMENTS: alluvium; gravel and sand, 2-20 m thick.** Alluvial deposits: gravel and sand; 2-20 m thick; active braided floodplains, terraces, and fans; includes active proglacial outwash.

MARINE AND GLACIAL MARINE SEDIMENTS: gravel, sand, silt, and clay, 1-20 m thick, deposited in deltaic and beach environments during regression of the postglacial sea.

Mr — Beach sediments: gravel and sand, 1-5 m thick, forming ridges and swales.

Mt — Deltaic sediments: clay, silt, sand, and gravel, 5-20 m thick, forming coarsening upward sequences under dissected terraces.

Mv — Deepwater proglacial silt veneers: silt, clay silt, and fine sand with dropstones, 1-2 m thick.

GLACIAL LACUSTRINE SEDIMENTS: clay, silt, sand, and gravel deposited in glacier dammed lakes in deepwater, beach, and deltaic environments.

Lt — Deltaic sediments: clay, silts, sand, and gravel, 5-20 m thick, forming coarsening upward sequences under dissected terraces.

Lb — Deepwater proglacial silt: silt, clay silt, and fine sand with dropstones; veneers 1-2 m thick; blankets 2-5 m thick.

GLACIOFLUVIAL SEDIMENTS: gravel and sand, 1-10 m thick, deposited behind, at, and in front of the ice margin.

Gt — Proglacial outwash: gravel and sand, 1-10 m thick, forming braided floodplains, terraces, and fans.

Gh — Ice contact stratified drift: gravel and sand, 1-5 m thick forming eskers, and kames.

EARLY HOLOCENE AND WISCONSINAN

TILL: nonsorted stony muds, 0.5-60 m thick, deposited in subglacial and ice marginal environments; lithic composition generally reflects underlying bedrock.

Tm — End moraine: 5-60 m high, composed of or mantled by till, extensively kettled in places; large features mainly cored by debris-rich relict glacier ice.

Tv — Till veneer: 0.5-2 m thick and discontinuous; some surfaces armoured by stones due to washing by subglacial meltwater.

Tb — Till blanket: 2-10 m thick forming an undulating blanket with drumlines and ribbed (Rogen) moraines in places.

BEDROCK
PRE-QUATERNARY

R — Rock: rock of various compositions and ages (Jackson and Sangster, 1987) variously modified by glacial erosion during the Quaternary and with patchy till cover; hilly and hummocky surfaces, ice moulded in places, with lake basins in subglacially scoured regions; cliffs reslting from glacial over-steepening; in places veneered by thin till, commonly bouldery.

LEGEND:

- ▭ WATER
- ☐ POTENTIAL DISTURBANCE AREA
- ☒ SURFICIAL GEOLOGY NOT AVAILABLE
- ― MILNE INLET TOTE ROAD
- ‐ ‐ ‐ PROPOSED RAIL ALIGNMENT
- ‐ ‐ ‐ CONSTRUCTION ACCESS ROAD

NOTES:

1. BASE MAP: © HER MAJESTY THE QUEEN IN RIGHTS OF CANADA, DEPARTMENT OF NATURAL RESOURCES (2004). ALL RIGHTS RESERVED.
2. COORDINATE GRID IS SHOWN IN UTM NAD83 ZONE 17 AND IS IN METRES.
3. BODIES OF WATER ARE SHOWN IN WHITE.

SCALE 1,000 500 0 1,000 2,000 3,000 4,000 5,000 m

BAFFINLAND IRON MINES CORPORATION

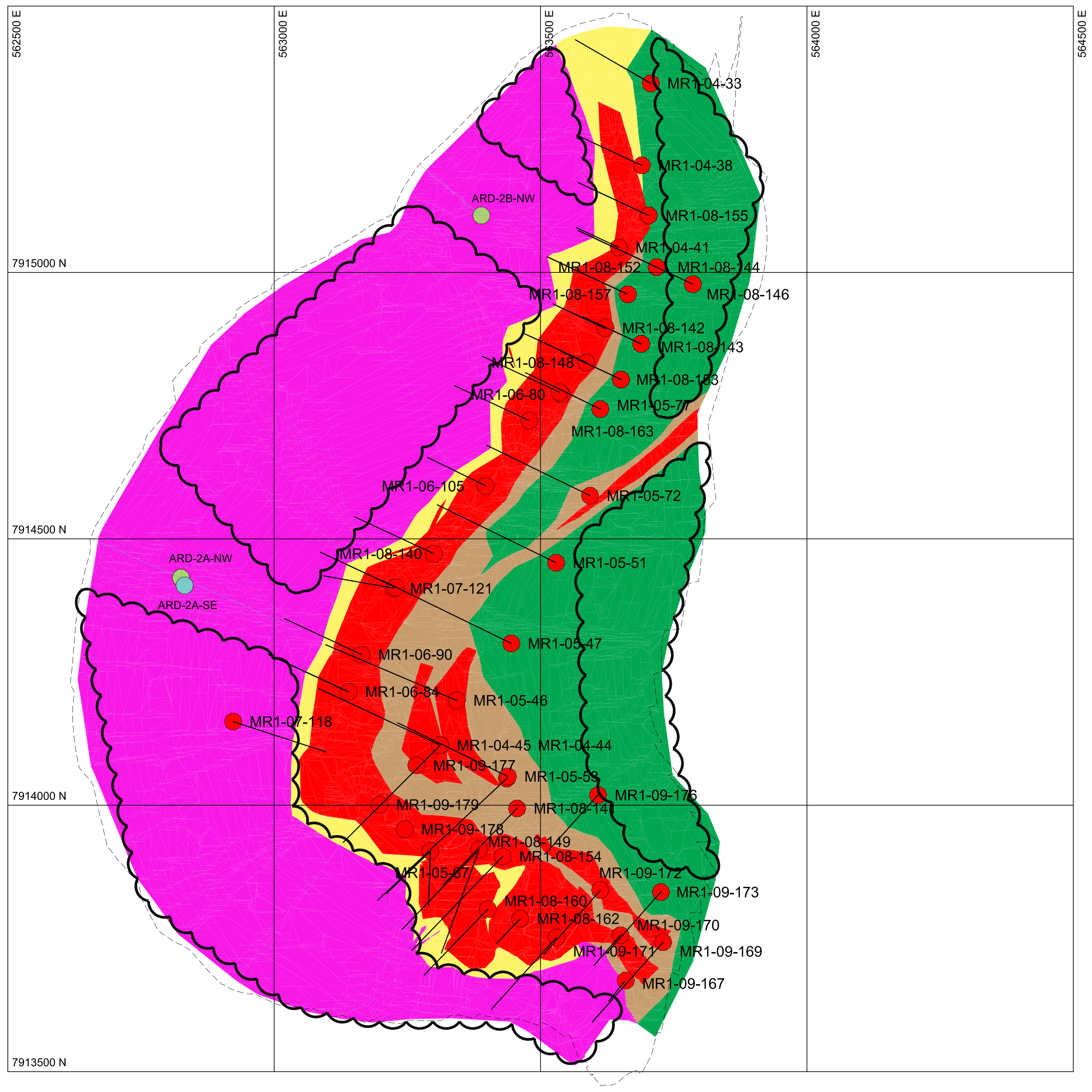
MARY RIVER PROJECT

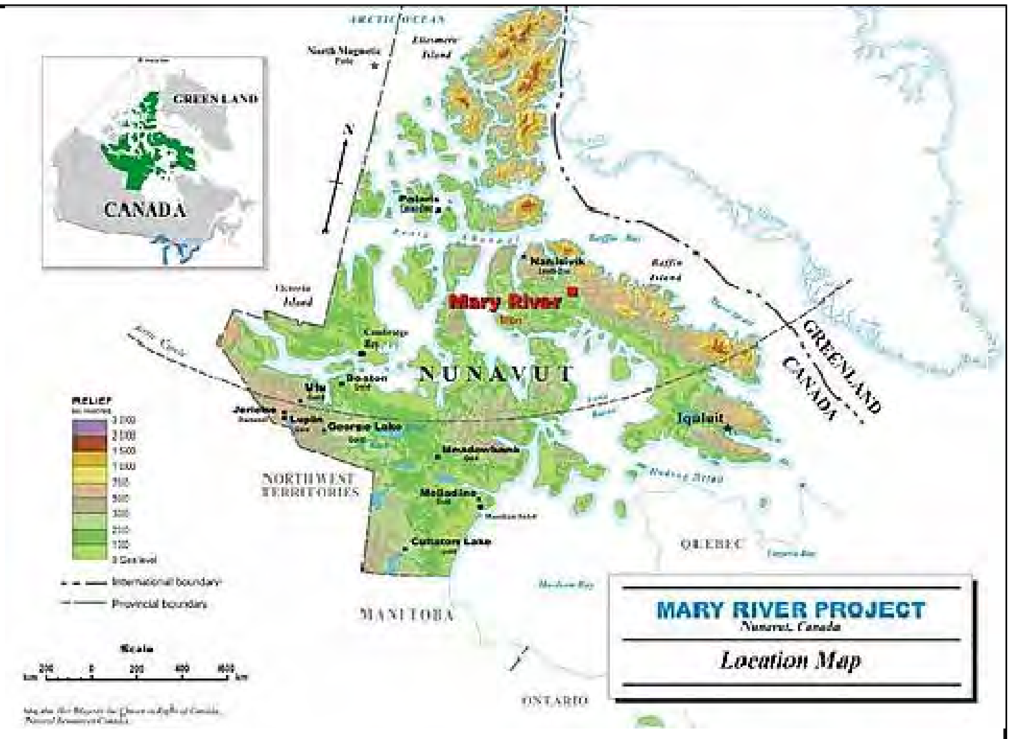
SURFICIAL GEOLOGY
IN THE MINE SITE AREA

REF. NO.
BL_Vol6_GIS_004

FIGURE 6-2.3

REV
0





MARY RIVER PROJECT
Nunavut, Canada

Location Map

LEGEND:

🟩	HANGING WALL WASTE (UNDIFFERENTIATED)
🟫	HANGING WALL SCHIST
🟥	HIGH GRADE IRON FORMATION
🟨	FOOT WALL SCHIST
🟪	FOOT WALL WASTE (UNDIFFERENTIATED)
- - -	LIFE OF MINE PIT BOUNDARY
◯	AREA OF PROPOSED WASTE ROCK FILL - IN DRILLING FOR 2012

0 100 200 500m

1:10 000 SCALE

DRAFT

CLIENT LOGO Baffinland Iron Mines Corporation	CLIENT: BAFFINLAND IRON MINES CORPORATION	DWN BY: G.G. CHK'D BY: J.M.	PROJECT MARY RIVER PROJECT
	AMEC Environment & Infrastructure 160 Traders Boulevard East Mississauga, Ontario, Canada L4Z 3K7	DATUM: NAD 83 PROJECTION: UTM Zone 17 m CM SCALE: 1:10,000	TITLE DEPOSIT No. 1 WASTE ROCK GEOLOGY, DRILL HOLES AND 2012 FILL-IN DRILLING TARGET AREAS

DATE:	JAN 2012
PROJECT NO:	TC1115923
REV. NO.:	A
FIGURE No.	A-1

P:\EM\Projects\2011\TC111523 Geochemical Support of final EIS\Drawings\-BA- WASTE ROCK GEOLOGY\TC1115923BA001.dwg - Layout1 - Jan. 16, 2012 2:52pm - greg.gwynne

Appendix 4:
Interim Waste Rock Stockpile Seepage Quality Model Report

INTERIM WASTE ROCK STOCKPILE SEEPAGE QUALITY MODEL
MARY RIVER PROJECT

Submitted to:
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January 2012

TC111523

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1.0 INTRODUCTION

AMEC was retained by Baffinland Iron Mines Corporation (Baffinland) to conduct seepage quality modeling for the waste rock stockpiles to support an environmental impact statement (EIS). The following report summarizes the expected waste rock stockpile seepage quality following closure of the proposed Mary River Iron Ore mine. The estimate is based on available laboratory data, the mine plan and assumptions regarding the physical qualities of the waste rock stockpile.

The proposed Mary River Project will consist of an open pit and adjacent waste rock stockpile, plus supporting buildings and infrastructure. Ore will be mined from the Deposit No. 1 pit and shipped directly offsite for further processing. A waste rock disposal area designed for permanent storage of waste rock will be located northwest of the open pit. Based on the mine plan for Deposit No. 1 (Hatch 2011a), an estimated 571 Mt of waste rock will be generated over a period of 21 years.

2.0 GEOLOGY

Baffinland Iron Mines Corporation (Baffinland) is planning to mine iron ore from Deposit No. 1 at their Mary River project (the Project), located on the northern half of Baffin Island, Nunavut Territory, Canada. The deposit is a high-grade example of Algoma-type iron formation, which is characterized by zones of massive, layered or brecciated hematite (sometimes in the specularite form) and magnetite, variably intermixed with banded oxide to silicate-facies iron formation.

A description of the following regional and local geology of Deposit No. 1, taken from Appendix 6B-1 of the FEIS, is provided below.

2.1 Regional Geology

The northern part of Baffin Island consists of the ca. 3.0-2.5 Ga Committee Fold belt which lies within the Rae domain of the western Churchill Province (Jackson and Berman, 2000). The Committee belt extends north-east for around 2000 km from south-west of Baker Lake, Nunavut Territory to northwestern Greenland. Four major assemblages of Precambrian rocks have been identified within the Committee Belt. The iron ore deposits occur as part of the supra-crustal rocks of the Neoarchean aged (2.76-2.71 Ga) Mary River Group in the region. The Central Borden Fault Zone passes within 1 km to the south-west of the site. This fault separates the highly deformed Precambrian rocks to the north-west from the early Paleozoic relatively flat lying sedimentary rocks to the southwest. The generalized stratigraphic sequence of the Mary River group from top to base according to Young et al. (2004) and Johns and Young (2006) is:

- interbedded ultramafic and intermediate volcanic rocks;
- quartzite;

- Algoma–type oxide and silicate–facies iron formation;
- amphibolite; and
- psammite and sedimentary migmatite.

The thickness of individual units varies considerably across the area. Ultramafic and gabbroic intrusions in the form of small sills and dykes (<10 m in thickness) may occur within the sedimentary rocks, iron formation and amphibolite units (Johns and Young, 2006). Locally these intrusions have been observed to contain thin sulphide veinlets and disseminated sulphides. At the deposit scale, the overall sequence can be complicated by inferred early isoclinal folds and ramp and flat thrust faults (Young *et al*., 2004) which create complex and variable stratigraphic relationships. The contact between the Mary River group and gneiss basement rock are generally not directly exposed, being obscured by younger granitic intrusions.

Iron formation within the Mary River Group occurs as an oxide- and silicate- facies unit. Oxide facies iron formations vary from lean magnetite-chert to iron-ore quality deposits of magnetite and hematite (Johns and Young, 2006). Genesis of high grade iron ores is the result of the Hudsonian age deformation and metamorphism of enriched Archean Banded Iron Formation. The silicate–facies iron formation is generally thin and found in association with the oxide–facies, although it also occurs on its own. It commonly contains coarse garnet, anthophyllite, cummingtonite, and actinolite porphyroblasts.

2.2 Deposit Geology

Deposit No.1 occurs at the nose of a syncline plunging steeply to the north-east (Aker Kvaerner, 2008). The iron formation occupies the nose and two limbs of this feature with an ~1300 m long northern portion and an ~700 m long southern portion. The footwall to the iron formation mainly consists of gneiss with minor schist, psammitic gneiss (psammite) and amphibolite. The hanging wall is primarily composed of schist and volcanic tuff with lesser amphibolite and metasediment.

The hanging wall primarily encompasses chlorite–actinolite schist and garnetiferous amphibolites. Meta-volcanic tuff is also a significant lithology identified in the hanging wall. The footwall mainly consists of quartz-feldspar-mica gneiss with lesser meta-sediment (greywacke) and quartz-mica schist. Microcline and albite are the predominant feldspars within the gneiss and biotite is generally more abundant than muscovite. Rocks are observed to represent at least amphibolite grade metamorphism.

The iron ore deposits at the Mary River project represent high-grade examples of Algoma-type iron formation and are composed of hematite, magnetite and mixed hematite-magnetite-specular hematite varieties of ore (Aker Kvaerner, 2008). The iron deposits consist of a number of lensoidal bodies that vary in their proportions of the main iron oxide minerals and impurity content of sulphur and silica in the ore. The massive hematite ore is the highest grade ore and also has the fewest impurities, which may indicate it was derived from relatively pure magnetite or that chert, quartzite and sulphides were leached and oxidized during alteration of the iron formation.

Intense deformation and lack of outcrop limit the ability to subdivide by lithology on the basis of future mined tonnages. Rather, the waste material has been subdivided on the basis of zonal relationships around the iron ore as described in Table 1.

Table 1: Summary of Waste Types and Tonnages

Waste Type	In-Pit Tonnage (t)	% of Waste	Lithologies (in approximate order of abundance)
Hanging wall (HW)	114,506,831	20.0	meta-volcanic (tuff); greywacke; amphibolite; chlorite, mica or amphibole schist; ultramafite; and gneiss
Hanging wall schist (HWS)	103,479,188	18.1	chlorite, mica, or amphibole schist; amphibolite; greywacke; and meta-volcanic (tuff)
Internal waste (IW)	2,982,893	0.5	schist; amphibolite; and meta-volcanic (tuff)
Deleterious ore (DO)	13,672,193	2.4	high grade iron formation (elevated Mn, S or P); and banded iron formation
Footwall schist (FWS)	45,917,213	8.0	chlorite, mica, or amphibole schist; gneiss; greywacke; amphibolite; and meta-volcanic (tuff)
Footwall (FW)	291,226,388	50.9	gneiss; metasediments (e.g. greywacke); chlorite, mica or amphibole schist; and amphibolites
Total	571,784,706	100.0	

3.0 WASTE ROCK ML/ARD CHARACTERIZATION

Assessment of the potential for ML/ARD from mine rock has been undertaken primarily by sampling of the Project’s archived exploration drill core. Sampling and analysis has been conducted in stages since 2006 (Knight Piésold 2008, Knight Piésold 2009, AMEC 2010) with an additional sampling program conducted in 2011 (AMEC 2012). The highly deformed nature of the deposit and the relatively high metamorphic grade has largely restricted interpretation of waste material tonnages to a spatial (hanging wall and footwall) rather than a lithological basis.

In addition to the archived drill core, three drillholes (318 m in total) were advanced in 2010 to specifically address a lack of representative waste material in the footwall of the deposit.

Work in 2011 included collection of an additional 377 samples of waste rock material on the basis of a revised waste type model that subdivided the hangingwall (HW) and footwall (FW) zones to incorporate more schist dominated regions (HWS and FWS) occurring generally in close proximity to the iron ore. It has been observed that sulphide content in these regions while variable is typically higher than that in the more distal hanging wall and footwall material. The revised waste model also incorporated an internal waste (IW) subdivision (waste fingering within the ore zone) and a deleterious ore (DO) zone that has been identified as probable waste in the footwall.

Static testing has included modified Sobek acid base accounting (ABA) with sulphur speciation and carbon analysis, net acid generation (NAG) testing, total element analyses, and short term leach analyses. A summary of static testing available to 2010 is provided in AMEC (2010), with updated ABA and total element analyses (aqua-regia ICP) data inclusive to 2011 summarized in Appendix A.

Waste rock is characterized by generally low modified Sobek neutralization potentials (NP) and low sulphide contents with resulting low acid potentials (AP) (Figure 1). Carbonate NP typically represents <30% of the modified Sobek NP. Sulphide content in excess of 0.5% is generally predictive of a Neutralization Potential Ratio (NPR=the ratio of NP/AP) less than 2 (Figure 2). Overall, assuming that a NPR ≤2 is representative of Potentially Acid Generating (PAG) material and based on the current understanding of waste distributions in the pit, an estimated 15% of waste rock is expected to be PAG.

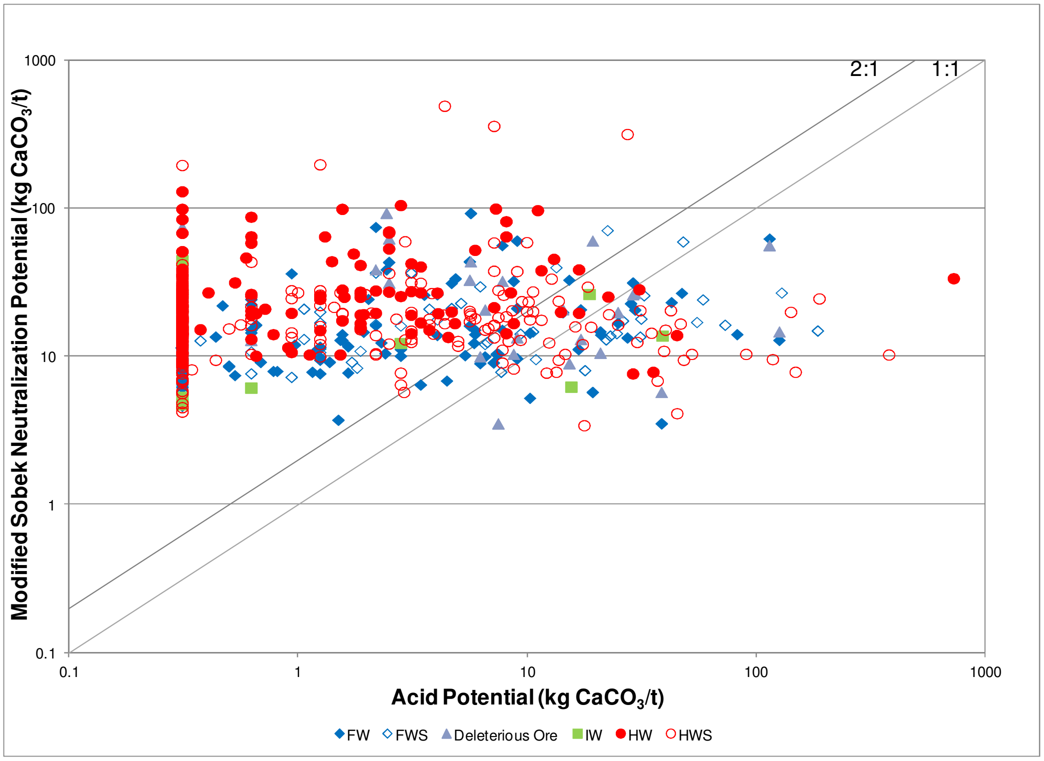

Figure 1: Neutralization Potential (NP) vs. Acid Potential (AP)

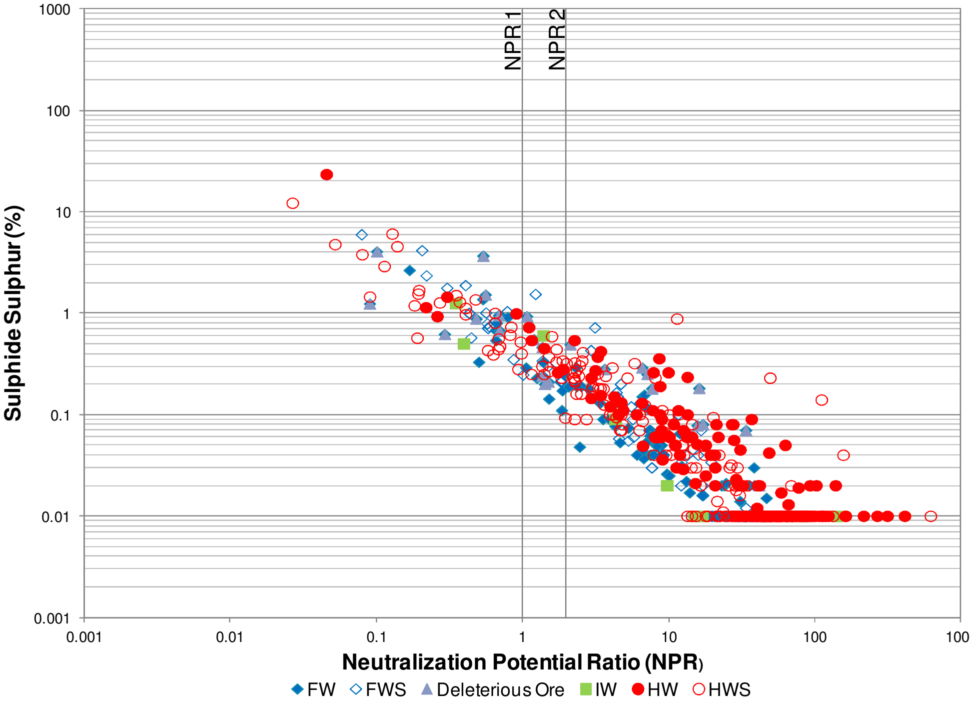

Figure 2: Neutralization Potential Ratio vs. Sulphide Sulphur

The static ABA sampling program completed in 2011 included a component of mineralogical work to improve the overall understanding of the waste rock ML/ARD characteristics and particularly the source of non-carbonate acid neutralizing potential in the waste rock. Selected samples have been characterized by qualitative and Rietveld XRD (R-XRD), optical microscopy and SEM to better understand the waste rock mineralogy in terms of ML/ARD. The work initiated in 2011 is on-going; however, initial results indicate the following:

Sulphides

- The most common sulphide mineral present is pyrite.
- Chalcopyrite is the next most abundant sulphide though usually at trace concentrations.
- Sphalerite (sometimes Cd bearing), pyrrhotite, pentlandite, cobalt-pentlandite and marcasite have also been identified as trace sulphide constituents.

Carbonates

- The most common carbonate minerals observed are dolomite-ankerite and siderite, with the latter more common in proximity to the ore. The siderite and the Fe component of the dolomite-ankerite carbonates are not expected to provide significant neutralization potential.

Silicates

- Quartz, plagioclase, k-feldspar, amphiboles (e.g. cummingtonite and hornblende), biotite, muscovite, and chlorite (Fe-rich and Mg-rich) are the major silicate rock forming minerals present.
- Plagioclase ranged from albite (Na rich) to anorthite (Ca rich) in composition.
- Silicate minerals occurring more typically in minor to trace amounts include garnet, epidote, staurolite, cordierite, and andalusite.

Oxides

- Oxide minerals identified include magnetite, hematite, goethite, ilmenite and chromite with granular magnetite in waste iron formation.

The mineralogical work underway is being directed to better understand the potential non-carbonate NP sources among the different waste rock types.

4.0 MODEL DESCRIPTION

Based on the mine plan, the total tonnage of waste rock is estimated to be 571 Mt (Hatch, 2011a). For waste rock management Baffinland will adopt operational management practices that will enhance permafrost development in the waste rock stockpile and minimize the active zone thickness. Waste rock management will also include the segregation at source of Potentially Acid Generating (PAG) rock from Non-Potentially Acid Generating (non-PAG) rock. Selective placement of PAG and non-PAG wastes will be utilized to encapsulate the PAG material within non-PAG rock prior to the on-set of acidic conditions.

The waste rock seepage quality model described in this report has been developed based on Baffinland's proposed waste management plan, with the following assumptions:

- Construction of the waste rock pile is complete and the mine site is in Closure;
- A thermal steady-state condition has been achieved in the waste pile, with established permafrost conditions occurring in all but the outer active layer of the pile;
- Hydrology of the pile is in a steady-state condition;
  - Seepage only occurs from the active layer;
  - Annual seepage flows equal annual infiltration rates, no infiltration is lost to the permafrost zone;
- Sulphide oxidation occurs within the active layer, but not within the permafrost zone;
- The rate of sulphide oxidation in the active layer is temperature dependent;
- PAG and non-PAG rock will be effectively segregated during mining such that;
  - PAG rock will be placed within the core of the stockpile;
  - Only non-PAG waste rock will be present within the active layer; and
- Waste management practices will be utilized in the waste rock stockpile construction to:
  - Promote permafrost development within the piles, and
  - Minimize the active layer thickness of the waste stockpiles.

In addition, the waste rock management plan includes construction of the waste rock stockpiles such that seepage will be contained and collected within two separate catchments (East and West) adjacent to the pit.

The mass balance seepage quality model utilizes mass loadings from waste rock using source terms derived from laboratory testing of humidity cells. Sulphate and metal loadings were calculated from the concentrations and volumes of leachates measured from the humidity cells. For scaling purposes, loadings of sulphate and metals were normalized to an estimated surface area (mg/m^2/wk) of the waste rock in the humidity cells based on surface areas calculated from grain size analysis. Estimated waste rock tonnages from the mine plan were used to determine the mass of the stockpile. The surface area normalized loading rates from the humidity cells and an estimated waste rock surface area in the stockpile were used to calculate the loadings of the parameters of interest from the stockpile.

Water infiltrating through the stockpile was assumed to flush accumulated loadings from the waste rock surface area within the active layer during the discharge months. The model is based on a monthly schedule to best reflect seasonal changes in the climatic and water flow conditions at the site. The calculated mass loadings were coupled with estimated water flows assumed from available hydrologic information in order to estimate concentrations of sulphate and metals in seepage from the stockpiles.

The mass balance model was used to calculate the load of sulphate and metals that will be released from the waste rock stockpile. However, the concentrations of these parameters in the stockpile effluent will depend on the solubility constraints for those parameters. The concentrations of certain parameters may reach conditions that cause them to exceed saturation with respect to some mineral phase. To address this, the geochemical program, PHREEQC was used to assess the solubility constraints on selected results of the mass balance model by using the calculated effluent quality from the mass balance model (including pH) as inputs. A description of the approach and results of this equilibration step are described in Section 6.

The water quality model included estimation of relevant parameters listed in the MMER effluent regulations (arsenic, copper, lead, nickel, and zinc). In addition, sulphate, trace metals, and major cation concentrations in the waste rock stockpile seepage were also estimated.

5.0 MODEL ASSUMPTIONS AND DATA SOURCES

In addition to the model assumptions discussed in Section 4, this section provides additional details and describes the data sources used in the model. Detailed data is provided in supporting references and Appendix A.

5.1 Physical Framework for the Model

5.1.1 Material Balance

The following bullets summarize the material balance:

- The material balance used for the model was based on the mine plan (Hatch, 2011a).
- Acid Base Accounting (ABA) results from previous geochemical testing (Knight Piésold (2008) and AMEC (2010)) and the recent geochemical testing program conducted by Baffinland (AMEC 2012) were used to define the proportions of non-PAG and PAG rock (Appendix A).
- Overall, assuming that an NPR ≤ 2 is representative of PAG material and based on the current understanding of waste distributions in the pit, an estimated 15% of the waste rock is expected to be PAG. The proportions of non-PAG and PAG rock in the pit are shown in Table 2.

Table 2: Waste Rock Classification in Mary River Deposit No.1

Waste Type	Number of samples	NPR* < 2		Modeled In-Pit Tonnage	Estimated PAG Tonnage
	N	n	%	t	t
HW	142	10	7.0	114,506,831	8,063,861
HWS	207	48	23.2	103,479,188	23,995,174
IW	11	3	27.3	2,982,893	813,516
DO	27	15	55.6	13,672,193	7,595,663
FWS	99	23	23.2	45,917,213	10,667,635
FW	127	14	11.0	291,226,388	32,103,696
Total	613	113	18.4	571,784,706	83,239,546

* NPR = mod. Sobek NP/AP

% PAG normalized to tonnage = 15

- As discussed, the model assumes that permafrost has aggraded into the stockpiles and has reached a steady-state condition. Therefore, seepage only occurs from the active layer of the pile containing only non-PAG rock and there are no water losses to permafrost.
- The thickness of the active layer is assumed to be 10 meters based on long term monitoring of the Ekati Mine waste stockpiles (EBA, 2011) which indicated the active layer thickness ranges from 1 to 10 m.
- The mass of waste rock in the active layer was estimated assuming a uniform thickness across the surface of the designed waste stockpile (Hatch 2011b).

5.1.2 Hydrology

Water inputs to the waste rock stockpile were based on monthly precipitation values (Appendix A) provided by Knight Piésold (2011) and the following assumptions.

- The only water flow into the stockpiles is from direct precipitation on the stockpile footprint areas, either as rainfall or the melting of accumulated snowpack;
- Approximately 45% of precipitation in September and all precipitation in October through May occurs as snow and are stored on the stockpile. It was assumed that 70% of the stored snow was melted in June and the rest of the stored snow was melted in July (Knight Piésold 2011);
- An infiltration coefficient of 0.7 was assumed for the waste rock pile. The infiltration coefficient was defined as the proportion of the precipitation including the melted snow that percolated into the pile;

- Seepage discharging from the waste rock only occurs during the summer months (June to September inclusive); and
- The monthly infiltrating water will completely flush the accumulated oxidation products from the active layer within the waste rock piles.

5.2 Geochemical Source Terms

- Expected loading rates from the waste rock were derived from humidity cell data. The humidity cell testing program was conducted for 53 weeks on 10 rock samples from the Mary River project in early 2008. In May 2011, humidity cell testing was initiated on an additional 9 rock samples; data for these samples are available at this time for 21 weeks;
  - The samples tested in the humidity cells were mainly waste rock samples with NPR<2, and the sulphide contents of those rock samples were higher than median sulphide content in the waste rock samples that underwent the static testing. Therefore, the resulting source terms may be higher than what will be expected from the waste rock stockpile;
  - Surface areas of humidity cell samples were estimated at 7 to 12 m^2/kg based on grain-size analysis;
  - Leachates from several waste rock samples had somewhat lower pH (5.5 to 6.5), but none of the PAG rock samples produced strongly acidic drainage over the course of the humidity cell testing;
  - Loading rates used for the non-PAG leaching presently being modeled were based on median release rates calculated from selected humidity cells (excluding weak acid cells) (Appendix A);
- Sulphide oxidation rates were assumed to be 50% of laboratory rates during the months with mean monthly temperature above zero (June to August) and 15% during the remainder of the year (months with average below freezing temperatures) due to reduced temperatures (MEND, 1996);
- Detection limit values were handled using the following protocol (EPA, 1991):
  - For elements that reported >50% of their humidity cell leachate concentrations below their respective method detection limit (MDL) (antimony, arsenic, cadmium, chromium, copper, iron, lead, mercury, selenium, silver, thallium and zinc) the <MDL values were set to equal half the applicable detection limit.
  - For the remaining elements, <MDL values were set to equal the applicable MDL value;
- The effective reactive surface area of waste rock in the pile was assumed to be 50 m^2/tonne;

  - Estimates of the surface area for the Project waste rock are not available. Therefore, the estimate (50 m^2/tonne) was based on a review of published and unpublished data including a recent study by AMEC on the grain size / surface area of waste rock at a large open pit copper porphyry project. Data from these sources indicated waste rock surface areas ranging from 13 to 52 m^2/tonne;
- The pH of the waste rock stockpile seepage was estimated based on the median of the pH of the humidity cells selected for determining loading rates;
- An ARD onset time of 5 years was assumed for the PAG mine rock in the stockpiles based on the estimated average carbonate neutralization potential (Carbonate NP) depletion time derived from humidity cell testing of PAG materials;
  - Carbonate NP depletion was calculated based on average release rate of calcium and magnesium during steady-state conditions, assuming carbonate was the only source for NP, The Carbonate NP values from the ABA results were used to estimate the initial NP of the materials; and
  - Water quality at the site will be regulated using MMER values.

6.0 MODELED WASTE ROCK STOCKPILE SEEPAGE QUALITY

The estimated drainage concentrations for the model base case are provided in Table 3. As discussed previously, these mass balance derived values may exceed geochemical solubility limits and therefore, the results were checked through geochemical equilibration in PHREEQC using the Minteq v4 database. The resulting equilibrated values are also provided in Table 3.

The equilibration step assumed the estimated pH of 6.9 and that waters were oxidizing and in equilibrium with atmospheric O_2. In the absence of site specific secondary mineral precipitate information, a set of solid phases were identified that may reasonably be expected to precipitate for the given conditions. For Ca and SO_4 gypsum ($CaSO_4 \cdot 2H_2O$) was assumed to be the most probable geochemical control and for Al, amorphous $Al(OH)_3$ was assumed, although both of these phases are under saturated in the modeled waters. As expected for the circum-neutral oxidizing conditions, the equilibrated Fe and Mn concentrations are also low with solubility effectively limited by ferrihydrite (poorly crystalline Fe oxyhydroxide) and manganite (MnO(OH)) respectively. It should be noted that manganite was selected as a suitable low temperature phase; however, it is possible that higher solubility Mn phases (or a mixed Fe-Mn oxyhydroxide) could be kinetically favoured that would result in somewhat higher equilibrated Mn concentrations. Thermodynamic data is not readily available for such phases.

The PHREEQC modeling identified other possible low temperature phases above saturation that could limit solubility of Al and SO_4 in this system (e.g. basaluminite $Al_4(SO4)(OH)_{10} \cdot 5(H_2O)$ and alunite $KAl_3(SO_4)_2(OH)_6)$; however, whether these or other possible solid phase solubility controls are likely to be present would require further investigation.

Seepage concentrations were predicted on a monthly basis (June to September) with the maximum concentrations occurring during June. Estimated seepage concentrations (unequilibrated and equilibrated) by month are presented in Appendix B.

The highest concentrations are predicted by the model to occur during the month of June. This is due to the flushing of reaction products which accumulated over the previous winter season.

Table 3: Estimated Water Quality of Waste Rock Stockpile Seepage

Parameters	MMER values	Maximum (June)			
		West Catchment		East Catchment	
		Unequilibrated	Equilibrated	Unequilibrated	Equilibrated
pH	**6 – 9.5**	6.9	6.9	6.9	6.9
Sulphate (mg/L)		33	33	26	26
Arsenic (mg/L)	0.5	0.0025	0.0025	0.0020	0.0020
Copper (mg/L)	0.3	0.0031	0.0031	0.0025	0.0025
Lead (mg/L)	0.2	0.00020	0.00020	0.00016	0.00016
Nickel (mg/L)	0.5	0.0019	0.0019	0.0015	0.0015
Zinc (mg/L)	0.5	0.013	0.013	0.010	0.010
Aluminum (mg/L)		0.12	0.12	0.095	0.095
Antimony (mg/L)		0.0031	0.0031	0.0025	0.0025
Boron (mg/L)		0.025	0.025	0.020	0.020
Cadmium (mg/L)		0.000020	0.000020	0.000016	0.000016
Chromium (mg/L)		0.0029	0.0029	0.0023	0.0023
Cobalt (mg/L)		0.00079	0.00079	0.00063	0.00063
Iron (mg/L)		0.024	<0.002	0.019	<0.002
Manganese (mg/L)		0.0095	0.00004	0.0076	0.00004
Mercury (mg/L)		0.00057	0.00057	0.00045	0.00045
Molybdenum (mg/L)		0.010	0.010	0.0078	0.0078
Selenium (mg/L)		0.0077	0.0077	0.0051	0.0051
Silver (mg/L)		0.000064	0.000064	0.000051	0.000051
Thallium (mg/L)		0.00029	0.00029	0.00023	0.00023
Vanadium (mg/L)		0.0010	0.0010	0.00083	0.00083
Barium (mg/L)		0.064	0.064	0.051	0.051
Sodium (mg/L)		0.41	0.41	0.32	0.33
Potassium (mg/L)		12.4	12.4	9.9	9.9
Calcium (mg/L)		15.3	15.3	12.2	12.2
Magnesium (mg/L)		8.6	8.6	6.9	6.9

7.0 SENSITIVITY ANALYSIS

Sensitivity analysis was performed on the model to assess the impact of variation of the critical physical parameters on the model estimates. The scenarios for the sensitivity analysis are summarized in Table 4.

Table 4: Sensitivity Analysis on the Model Parameters

Model Parameters	Scenario	Reactive Surface Area (m^2/tonne)	Winter Reaction Factor	Summer Reaction Factor	Infiltration Coefficient	Flushing Ratio	Active Zone Thickness (m)
	Base case	50	0.15	0.5	0.7	1	10
Active layer thickness	Case A1	50	0.15	0.5	0.7	1	20
	Case A2	50	0.15	0.5	0.7	1	40
	Case A3	50	0.15	0.5	0.7	1	80 m from side, 15 m from top
Reactive Surface Area	Case B1	30	0.15	0.5	0.7	1	10
	Case B2	100	0.15	0.5	0.7	1	10
	Case B3	250	0.15	0.5	0.7	1	10
	Case B4	500	0.15	0.5	0.7	1	10
Active layer thickness and surface area	Case B5	500	0.15	0.5	0.7	1	80 m from side, 15 m from top
Infiltration Coefficient	Case C1	50	0.15	0.5	0.4	1	10
	Case C2	50	0.15	0.5	1	1	10
Flushing Ratio	Case D1	50	0.15	0.5	0.7	0.8	10
	Case D2	50	0.15	0.5	0.7	0.6	10
Reaction Rate	Case E1	50	0.5	0.5	0.7	1	10
	Case E2	50	1.0	1.0	0.7	1	10

Results of the sensitivity analysis are presented in Appendix B with a summary as follows:

- The reactive surface area and the infiltration coefficient are the key drivers on model results.
- Lowering the infiltration coefficient (i.e., increasing water losses prior to infiltration) increases concentrations proportional to the volumetric decrease in inflow.
- An increase in the active layer thickness or reactive surface area within the active layer results in an increase in discharge concentrations proportional to the increased surface area.
- In the extreme scenario, Case B5, where both the active zone thickness layer and the reactive surface area were increased to high values, the estimated seepage

concentrations approach MMER limits for copper (detection limit based loading value), and exceed MMER limits for zinc (detection limit based loading value).

- Variation of the winter reaction rates only affected seepage concentrations in June when oxidation products accumulated over the winter months were flushed from the stockpile.
- Reducing the flushing ratio from 1 to 0.6 shifts the maximum discharge concentration from June to September due to the accumulation of oxidation products over that time.

These results confirm that minimizing the reactive surface area within the dump will aid in the reduction of metal loads from the stockpiles. Increased active layer thicknesses and mine rock surface areas will result in increased concentrations of parameters in the stockpile seepage. As described in the model assumptions, surface area data from the Project waste rock are not available. Differences in the actual surface area of the waste rock could lead to notable differences in the expected seepage quality. This has been explored in the sensitivity analysis (Appendix B, Table B3).

Geochemical release rates were not addressed in the sensitivity analysis due to a lack of data. In general, the use of laboratory derived loadings in the model may overestimate actual sulphide oxidation and metal release rates in the field due to the more aggressive nature of laboratory humidity cell tests which are designed to accelerate the weathering process in sample materials. Further, the source terms are largely based on non-acidic PAG humidity cells with higher sulphide contents than may be expected for much of the non-PAG waste rock produced. This suggests that model loading rates might be overly aggressive. However, median humidity cell rates used in the model were at laboratory detection limits for many metals. This, combined with the near neutral pH inferred, suggests that limitations on availability of humidity cell data may be exerting only a limited bias into the loading source terms. However, additional kinetic testing of a wider range of non-PAG materials would provide more robust source terms for the model under current assumptions. Lower detection limits should be applied where possible on the parameters of concern.

8.0 UNCERTAINTIES

Uncertainties with this water quality model include the following:

- The water quality model is based on the mine plan, waste rock stockpile configuration, water balance and geochemical data. Changes to these inputs could significantly alter the results of the model;
- The current model is based on a number of assumptions as discussed in this report (permafrost extent, stockpile hydrology, acid drainage source terms, etc.) and should be updated where more appropriate data becomes available;
- The current model has considered the surface area based on a review of published and unpublished data from other mine projects which could be different from the actual surface area of the Project waste rock; and

- Current model estimates are based upon simplified estimates of the seepage pH. These pH values can have a significant impact on the estimated loadings and concentrations of metals predicted in the model.

9.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be made regarding the estimates of seepage quality from the proposed Mary River project waste rock stockpiles:

- Based on the assumptions and data used in the model, the results suggest that arsenic, copper, lead, nickel, and zinc concentrations in the waste rock stockpile seepage will be below MMER values;
- Estimates of the pH are difficult to make due to the sensitivity of pH to numerous factors not considered in this mass balance prediction. However, as a preliminary estimate, seepage from the stockpiles is expected to maintain a circum-neutral pH;
- The following recommendations are made to improve future modeling estimates:
  - Thermal modeling to estimate the permafrost zone and active layer thickness should be undertaken. This modeling should be done to both assess the formation of the permafrost in the stockpile, and the behavior of the stockpile under longer term (including changing) climatic conditions.
  - Additional geochemical sampling and testing to refine estimates of the volumes of non-PAG and PAG rock in the pit volumes;
  - Continuation of the kinetic testing program to refine ARD onset time and mass-release rates, including extended monitoring of those humidity cells which begin to produce acidic conditions; and
  - Investigate possible studies that could lead to a more direct assessment of the surface area of the waste rock.

10.0 REFERENCES

Aker Kvaerner, 2008. Definitive Feasibility Study Report Mary River Iron Ore Project Northern Baffin Island, Nunavut.

AMEC, 2012. Interim Mine Rock ML/ARD Report, Mary River Project. January, 2012.

AMEC, 2010. Interim Report on ML/ARD Characterization Mary River Project, Deposit No.1, December, 2010.

EBA. 2011. 2010 Summary of Ground Temperature Conditions in Waste Rock Storage Areas EKATI diamond Mine, NT.

EPA.1991. Guideline for Handling Chemical Concentration Data Near the Detection Limit in Risk Assessment. http://www.epa.gov/reg3hwmd/risk/human/info/guide3.htm

Hatch. 2011a. Correspondence from Ian Thompson, November 16, 2011.

Hatch. 2011b. Correspondence from Ian Thompson, December 12, 2011.

Knight Piésold. 2011. Correspondence from Kyle Terry, November 17, 2011.

Knight Piésold. 2008. Environmental Characterization of Deposit No.1 Waste Rock, Ore & Construction Material. 18 December, 2008.

Knight Piésold. 2009. Environmental Assessment of Waste Materials Originating from the Bulk Sample Program from Deposit No.1, Baffinland Mary River Project (NB09-00189, March 2009).

MEND, 1996. MEND Project 1.61.2 Acid Mine Drainage in Permafrost Regions: Issues, Control Strategies and Research Requirements.

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APPENDIX A

Table A1. Summary of Acid Base Accounting Results of Rock Samples

	Paste pH	Total Sulphur	Sulphate Sulphur	Sulphide Sulphur*	Total Carbon	AP	NP	Ca-NP	NPR	Ca-NPR
		(wt.%)				(kg $CaCO_3$/tonne)				
All Waste Rock										
No. of sample	613	613	613	613	613	613	613	613	613	613
Minimum	3.8	<0.005	<0.01	<0.01	0.005	0.31	<0.01	0.42	0.0001	0.002
Maximum	10	22	5.5	23	6.7	731	487	558	621	605
Mean	8.8	0.38	0.09	0.30	0.21	9.23	22	17	30	11
Standard Deviation	0.86	1.36	0.27	1.24	0.69	39	32	58	44	38
Median	8.7	0.08	0.03	0.03	0.02	0.94	15	1.67	19	3
10th Percentile	7.9	0.01	0.01	0.01	0.01	0.31	7.80	0.75	0.70	0.11
90th Percentile	9.8	0.73	0.18	0.59	0.40	18	36	34	67	15
Hanging Wall (HW)										
No. of sample	142	142	142	142	142	142	142	142	142	142
Minimum	7.3	<0.005	<0.01	<0.01	0.008	0.31	7.60	0.67	0.046	0.003
Maximum	10	22.2	0.6	23.4	3.8	731	129	320	413	285
Mean	8.9	0.31	0.06	0.26	0.20	8.26	29	17	45	20
Standard Deviation	0.57	1.87	0.08	1.97	0.41	61	23	34	57	43
Median	8.9	0.05	0.03	0.02	0.03	0.63	20	2.67	33	5.38
10th Percentile	8.2	0.01	0.01	0.01	0.01	0.31	11	1.17	3.28	0.40
90th Percentile	9.7	0.44	0.14	0.26	0.65	8	63	54	89	51
Hanging Wall Schist (HWS)										
No. of sample	207	207	207	207	207	207	207	207	207	207
Minimum	6.1	<0.005	<0.01	<0.01	0.005	0.31	<0.01	0.42	0.006	0.005
Maximum	10	17.8	5.5	12.2	6.7	381	487	558	621	605
Mean	8.3	0.49	0.12	0.38	0.17	12	25	15	28	8.70
Standard Deviation	0.57	1.51	0.41	1.15	0.74	36	49	62	52	45
Median	8.3	0.12	0.05	0.06	0.02	1.97	16	1.67	11	1.33
10th Percentile	7.7	0.01	0.01	0.01	0.01	0.31	7.8	0.75	0.54	0.08
90th Percentile	9.0	0.94	0.21	0.73	0.11	23	33	8.8	68	11
Footwall (FW)										
No. of sample	127	127	127	127	127	127	127	127	127	127
Minimum	4.8	<0.005	<0.01	<0.01	0.005	0.31	3.70	0.42	0.1691	0.005
Maximum	10	3.3	0.6	2.7	2.5	82.8	36	208	96	38
Mean	9.4	0.15	0.05	0.10	0.04	3.09	13	3.5	24	4.05
Standard Deviation	0.8	0.38	0.10	0.29	0.22	9.12	5.9	18	19	6.0
Median	9.6	0.03	0.02	0.01	0.02	0.31	11	1.33	25	2.56
10th Percentile	8.8	0.01	0.01	0.01	0.01	0.31	7.5	0.42	1.90	0.19
90th Percentile	10	0.27	0.11	0.19	0.04	5.94	22	3.2	47	7.6

Table A1. Summary of Acid Base Accounting Results of Rock Samples

	Paste pH	Total Sulphur	Sulphate Sulphur	Sulphide Sulphur*	Total Carbon	AP	NP	Ca-NP	NPR	Ca-NPR
		(wt.%)				(kg $CaCO_3$/tonne)				
Footwall (FWS)										
No. of sample	*99*	*99*	*99*	*99*	*99*	*99*	*99*	*99*	*99*	*99*
Minimum	*3.9*	*<0.005*	*<0.01*	*<0.01*	*0.005*	*0.31*	*<0.01*	*0.42*	*0.0001*	*0.002*
Maximum	*10.2*	*6.1*	*1.5*	*6.0*	*3.3*	*186.3*	*71*	*278*	*114*	*387*
Mean	*8.7*	*0.42*	*0.09*	*0.33*	*0.16*	*10.29*	*16*	*13*	*24*	*7.67*
Standard Deviation	*1.1*	*0.99*	*0.20*	*0.85*	*0.52*	*26.59*	*10*	*43*	*23*	*40*
Median	*9.1*	*0.06*	*0.03*	*0.02*	*0.02*	*0.50*	*13*	*1.25*	*19*	*2.40*
10th Percentile	*7.7*	*0.01*	*0.01*	*0.01*	*0.01*	*0.31*	*7.7*	*0.50*	*0.57*	*0.09*
90th Percentile	*9.8*	*1.09*	*0.17*	*0.87*	*0.15*	*27.25*	*26*	*12.8*	*54*	*6*
Deleterious Ore (FW 1300 & 1400)										
No. of sample	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*	*27*
Minimum	*3.8*	*<0.005*	*<0.01*	*<0.01*	*0.010*	*0.31*	*<0.01*	*0.83*	*0.004*	*0.015*
Maximum	*9.7*	*4.4*	*1.1*	*4.1*	*5.3*	*127*	*92*	*439*	*42*	*180*
Mean	*8.2*	*0.89*	*0.21*	*0.67*	*1.51*	*21*	*29*	*126*	*9*	*22*
Standard Deviation	*1.2*	*1.09*	*0.27*	*1.00*	*1.71*	*31*	*23*	*143*	*13*	*42*
Median	*8.4*	*0.58*	*0.11*	*0.28*	*0.98*	*9*	*21*	*81*	*1*	*5.03*
10th Percentile	*7.0*	*0.12*	*0.02*	*0.05*	*0.01*	*1.56*	*7.6*	*1.05*	*0.22*	*0.13*
90th Percentile	*9.2*	*1.85*	*0.52*	*1.35*	*3.98*	*42*	*61*	*332*	*34*	*54*
Internal Wastes (IW)										
No. of sample	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*11*
Minimum	*7.9*	*0.008*	*<0.01*	*<0.01*	*0.007*	*0.31*	*4.70*	*0.58*	*0.35*	*0.037*
Maximum	*9.5*	*1.3*	*0.3*	*1.3*	*0.1*	*39.1*	*44*	*8.8*	*141*	*8.0*
Mean	*8.5*	*0.28*	*0.06*	*0.23*	*0.02*	*7.16*	*16*	*2.1*	*35*	*2.9*
Standard Deviation	*0.56*	*0.44*	*0.09*	*0.40*	*0.03*	*13*	*12*	*2.3*	*45*	*2.6*
Median	*8.5*	*0.03*	*0.02*	*0.01*	*0.02*	*0.31*	*14*	*1.4*	*15*	*2.67*
10th Percentile	*8.0*	*0.01*	*0.01*	*0.01*	*0.01*	*0.31*	*5.3*	*0.67*	*0.40*	*0.08*
90th Percentile	*9.3*	*0.88*	*0.16*	*0.60*	*0.03*	*19*	*26*	*2.5*	*83*	*5.3*

Notes:

AP = Acid potential in tonnes $CaCO_3$ equivalent per 1000 tonnes of material. AP is determined from calculated sulphide sulphur content: S(T) - S(SO_4).

NP = Neutralization potential in tonnes $CaCO_3$ equivalent per 1000 tonnes of material.

Ca-NP = Carbonate NP is calculated from TC originating from carbonates and is expressed in kg $CaCO_3$/tonne.

NPR = Net Potential Ratio = NP/AP; Carb-NPR = Carb-NP/AP

*Where NP or AP values are equal to or less than zero, NPR is calculated assuming detection limit (NP = 0.2 kg $CaCO_3$/tonne, AP = 0.03 kg $CaCO_3$/tonne).

Table A2. Summary of Aqua-regia Extracted Metal Content of Rock Samples

	Hg	Au	Ag	Al	As	Ba	Be	Bi	Ca	Cd	Co	Cr	Cu	Fe	K	Li	Mg	Mn	Mo	Na	Ni	P	Pb	Sb	Se	Sn	Sr	Ti	Tl	U	V	Y	Zn
	µg/g	µg/g	µg/g	%	µg/g	µg/g	µg/g	µg/g	%	µg/g	µg/g	µg/g	µg/g	%	%	µg/g	%	µg/g	µg/g	%	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	%	µg/g	µg/g	µg/g	µg/g	µg/g
All Waste Rock																																	
No. of sample	564	376	376	617	617	617	617	617	617	617	617	617	617	617	617	617	617	617	616	564	617	376	617	617	617	617	617	617	617	617	617	376	617
Minimum	0.10	0.020	0.01	0.001	0.50	0.01	0.020	0.01	0.003	0.02	0.25	0.500	0.10	0.003	0.0001	2.00	0.002	2.300	0.10	0.001	0.10	2.00	0.26	0.10	0.70	0.50	0.22	0.00001	0.02	0.002	1.00	0.47	0.70
Maximum	0.20	1.4	11	13	260	3000	19	34	11	30	140	2400	480	70	7	370	15	35000	450	2.20	2410	6900	2174	25	20	12	410	1	20	100	460	26	3280
Mean	0.10	0.03	0.16	4.3	5.64	204	0.98	1.41	0.7	0.4	25	232	51.6	13	0.96	20	3.48	1512	6	0.05	113	561	13	1.87	1.77	1.64	14	0.14	1.13	8.60	78	4.59	61
Standard Deviation	0.004	0.07	0.59	2.7	20	366	1.26	5.81	1.5	1.4	21	310	57	15	1.14	23	3	3196	26	0.11	182	743	91	4.59	3.58	1.82	28	0.14	3.47	23.03	75	3.52	143
Median	0.10	0.02	0.08	3.9	0.70	81.0	0.64	0.09	0.2	0.1	19	110	30	7	0.48	15	2.60	570	2	0.02	64	320	4.20	0.80	0.70	0.90	6.50	0.10	0.20	1.30	58	3.70	42
10th Percentile	0.10	0.02	0.01	0.69	0.50	1.60	0.09	0.09	0.04	0.02	6	28.6	3.76	2.30	0.01	3	0.76	230	0.40	0.01	7.4	22	1.20	0.80	0.70	0.50	2.00	0.01	0.02	0.04	8.60	1.40	13
90th Percentile	0.10	0.02	0.33	8.0	7.50	498	2.40	1.70	2.2	0.5	51	590	120	38	2.60	39	7.60	3080	10	0.12	264	1350	19	1.94	2.54	4.88	24	0.34	2	8	170	9	100
Hanging Wall (HW)																																	
No. of sample	124	89	89	142	142	142	142	142	142	142	142	142	142	142	142	142	142	142	142	124	142	89	142	142	142	142	142	142	142	142	142	89	142
Minimum	0.10	0.02	0.01	0.06	0.50	0.22	0.02	0.01	0.03	0.02	1.10	10	1.20	0.87	0.004	2.00	0.30	130	0.10	0.01	6.80	23	0.39	0.10	0.70	0.50	1.50	0.002	0.02	0.002	1.00	0.67	3.80
Maximum	0.20	0.03	0.49	11	159	420	5.1	34	10	4.9	110	2400	240	65	4.7	75	14.0	35000	44.0	2.2	2410	2000	68	25	20	6.0	410	0.7	20	100	380	10	490
Mean	0.10	0.02	0.10	4.59	5.74	102	0.70	0.88	1.64	0.28	31	280	83	7.24	0.64	20	3.89	1681	2.20	0.11	148	357	4.51	2.31	1.91	1.56	27	0.16	0.96	10	115	3.6	56
Standard Deviation	0.01	0.002	0.09	2.71	21	107	1.03	4.06	1.93	0.67	19	335	52	7.71	0.67	14	3.35	3145	4.67	0.22	267	329	6.88	5.61	3.26	1.84	50	0.14	2.76	25	89	1.6	52
Median	0.10	0.02	0.07	3.95	0.70	72	0.20	0.09	1.00	0.08	26	170	92	5.40	0.45	17	2.60	940	0.80	0.05	94	280	2.65	0.80	0.70	0.50	11	0.13	0.10	0.12	97	3.7	43
10th Percentile	0.10	0.02	0.03	1.60	0.50	5.05	0.05	0.09	0.10	0.02	13	68	8.77	1.71	0.05	4.10	0.76	282	0.30	0.01	36	176	0.93	0.80	0.70	0.50	3.32	0.03	0.02	0.02	27	1.8	16
90th Percentile	0.10	0.02	0.20	8.40	6.66	284	2.28	2.00	4.10	0.79	55	620	140	14	1.40	37	9.40	3390	4.29	0.22	207	480	8.91	2.00	6.00	6.00	68	0.29	5.00	70	279	5.2	103
Hanging Wall Schist (HWS)																																	
No. of sample	194	136	136	208	208	208	208	208	208	208	208	208	208	208	208	208	208	208	208	194	208	136	208	208	208	208	208	208	208	208	208	136	208
Minimum	0.10	0.02	0.01	0.001	0.50	0.01	0.02	0.04	0.00	0.02	0.25	0.50	0.10	0.003	0.0001	2.00	0.002	2.30	0.10	0.00	0.10	2.0	0.26	0.10	0.70	0.50	0.22	0.00001	0.02	0.003	1.0	0.47	0.70
Maximum	0.10	0.16	1.3	13	170	1300	5.10	34	11	4.00	140	1500	480	66	4.00	370	11	14000	100	0.27	1040	6900	230	25	20	12	100	0.59	20	100	460	17	460
Mean	0.10	0.02	0.14	4.88	7.87	100	1.14	1.18	0.62	0.24	32	292	51	17	0.47	23	4.46	1276	4.31	0.02	163	429	6.07	1.78	1.61	1.52	10.62	0.08	0.82	6.64	88	3.1	55
Standard Deviation	0	0.015	0.19	2.64	20	197	1.12	5.23	1.75	0.65	24	293	57	14	0.73	32	2.59	1667	11	0.03	160	765	17	4.27	3.23	1.71	15	0.10	3.18	21	80	2.4	55
Median	0.10	0.02	0.08	5.00	1.70	14	0.81	0.12	0.12	0.06	27	210	31	13	0.09	16	4.05	680	1.50	0.01	120	190	2.90	0.80	0.70	0.90	5.80	0.04	0.05	0.91	70	2.7	44
10th Percentile	0.10	0.02	0.01	0.60	0.50	1.07	0.13	0.09	0.02	0.02	6.84	21	3.32	5.04	0.01	2.00	1.10	240	0.40	0.01	15	9.0	1.17	0.80	0.70	0.50	1.50	0.01	0.02	0.04	8	0.91	12
90th Percentile	0.10	0.02	0.30	8.03	16	300	2.73	0.74	0.56	0.28	61	720	120	41	1.60	43	8.16	2930	9.21	0.04	373	1050	10	1.90	2.00	3.72	22	0.19	0.53	3.53	173	5.4	100
Footwall (FW)																																	
No. of sample	112	55	55	127	127	127	127	127	127	127	127	127	127	127	127	127	127	127	126	112	127	55	127	127	127	127	127	127	127	127	127	55	127
Minimum	0.10	0.02	0.01	0.35	0.50	2.60	0.03	0.06	0.01	0.02	1.20	8.00	0.70	0.72	0.01	2.00	0.36	110	0.10	0.00	2.30	71	0.91	0.80	0.70	0.50	1.60	0.01	0.02	0.11	1.00	2.2	6.40
Maximum	0.10	1.40	11.00	9.30	13	3000	5.10	34	1.60	30	79	2200	330	62	6.00	92	15	18000	53	0.18	870	2400	2174	25	20	11	170	0.63	20	100	210	26	3280
Mean	0.10	0.05	0.36	3.53	1.39	362	0.84	2.56	0.32	0.85	14	182	41	4.80	1.97	24	2.36	629	4.20	0.06	52	694	35	1.90	2.34	2.21	12	0.24	2.08	14	54	9.2	106
Standard Deviation	0	0.19	1.5	2.27	2.12	528	0.92	8.22	0.29	2.88	13	363	57	5.67	1.22	16	2.32	1569	8.35	0.04	133	559	194	4.54	4.89	2.21	21	0.14	4.78	28	48	5.3	298
Median	0.10	0.02	0.10	2.80	0.50	180	0.56	0.12	0.22	0.18	9.30	80	20	4.00	1.90	22	1.50	460	2.00	0.05	9.40	590	10	0.80	0.70	1.30	6.60	0.24	0.64	3.00	38	8.9	61
10th Percentile	0.10	0.02	0.02	1.22	0.50	64	0.17	0.09	0.09	0.02	4.60	35	4.02	1.70	0.44	6.60	0.75	260	0.40	0.02	4.96	158	3.40	0.80	0.70	0.50	3.10	0.05	0.20	1.30	11	3.4	22
90th Percentile	0.10	0.02	0.42	7.30	6.00	700	2.14	3.00	0.63	3.06	26	334	104	7.70	3.64	43	5.24	828	8.55	0.11	104	1320	39	2.00	6.00	6.00	21	0.43	5.00	70	140	16	164
Footwall (FWS)																																	
No. of sample	96	63	63	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	96	101	63	101	101	101	101	101	101	101	101	101	63	101
Minimum	0.10	0.02	0.01	0.14	0.50	0.58	0.14	0.09	0.03	0.02	2.10	12	0.60	1.70	0.00	2.00	0.22	70	0.30	0.00	3.50	23	0.76	0.10	0.70	0.50	1.60	0.004	0.02	0.03	1.00	1.1	5.70
Maximum	0.10	0.22	1.30	12	17	2200	5.20	34.00	1.60	4.00	84	1500	380	69	6.50	140	9.30	23000	360	0.23	450	5400	410	25	20	10	42	0.48	20	100	290	14	140
Mean	0.10	0.03	0.13	4.17	1.72	391	1.08	1.58	0.28	0.23	16	136	30	14	1.40	16	2.72	1323	11	0.04	57	1059	15	1.60	1.47	1.56	7.93	0.15	1.13	6.69	55	5.7	34
Standard Deviation	0	0.03	0.22	2.64	2.90	469	0.86	6.36	0.30	0.67	14	196	53	16	1.34	17	1.95	3276	39	0.03	92	994	42	3.99	3.35	1.52	6.83	0.12	3.41	19	51	2.5	26
Median	0.10	0.02	0.06	3.60	0.50	230	0.83	0.10	0.18	0.11	12	75	13	7.70	1.10	11	2.20	380	2.40	0.03	17	820	6.20	0.80	0.70	1.00	5.90	0.12	0.38	2.00	38	5.4	26
10th Percentile	0.10	0.02	0.01	0.86	0.50	3.10	0.38	0.09	0.07	0.02	5.10	29	2.50	2.90	0.01	2.00	0.85	150	0.80	0.01	7.10	150	2.30	0.80	0.70	0.50	2.60	0.02	0.02	0.49	8.00	3.0	9.40
90th Percentile	0.10	0.02	0.41	7.50	4.50	1000	2.00	0.93	0.67	0.20	31	310	65	46	3.30	32	5.20	2300	16	0.08	150	2460	26	0.80	1.30	3.00	16	0.31	1.60	6.50	130	8.8	68
Deleterious Ore (FW 1300 & 1400)																																	
No. of sample	27	25	25	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	25	27	27	27	27	27	27	27	27	27	25	27
Minimum	0.10	0.02	0.02	0.07	0.50	0.08	0.12	0.09	0.00	0.02	2.20	12	2.40	0.69	0.004	2.00	0.05	200	1.00	0.00	8.70	2.0	1.00	0.80	0.70	0.50	0.55	0.002	0.02	0.05	4.00	0.57	6.20
Maximum	0.10	0.14	1.10	6.90	260	1900	6.40	1.50	1.20	0.38	54	920	250	70	3.90	47	7.60	32000	450	0.07	550	2800	32	0.90	3.50	2.50	11.00	0.44	1.60	5.20	120	7.6	61
Mean	0.10	0.03	0.23	1.65	25	169	0.87	0.29	0.26	0.09	19	86	40	44	0.48	6.22	1.77	7607	28	0.01	56	424	8.01	0.80	1.01	0.92	3.50	0.06	0.20	1.07	25	3.8	22
Standard Deviation	0	0.03	0.25	2.34	58	436	1.27	0.34	0.25	0.09	15	181	49	23	1.11	9.28	1.93	8342	86	0.02	102	676	8.45	0.02	0.68	0.57	2.70	0.11	0.39	1.44	25	1.5	14
Median	0.10	0.02	0.16	0.41	2.40	2.20	0.45	0.12	0.19	0.05	17	42	31	51	0.01	2.00	1.10	4200	3.80	0.01	34	93	6.00	0.80	0.70	0.60	2.50	0.02	0.03	0.42	22	3.4	16
10th Percentile	0.10	0.02	0.04	0.12	0.50	0.58	0.18	0.09	0.05	0.02	4.46	14	7.74	9.44	0.01	2.00	0.18	306	1.20	0	10	8.6	1.20	0.80	0.70	0.50	0.99	0.004	0.02	0.13	5.60	2.4	9.96
90th Percentile	0.10	0.07	0.43	6.32	60	478	1.60	0.84	0.48	0.20	43	83	68	68	1.88	13	3.70	19200	55	0.04	83	1172	21	0.80	1.94	1.92	7.22	0.20	0.70	3.26	55	6.2	43
Internal Waste																																	
No. of sample	11	8	8	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	11	12	8	12	12	12	12	12	12	12	12	12	8	12
Minimum	0.10	0.02	0.01	0.12	0.50	0.01	0.04	0.09	0.01	0.02	3.30	32	1.10	3.40	0.01	2.00	0.13	360	0.30	0.01	6.30	2.0	0.87	0.80	0.70	0.50	0.27	0.002	0.02	0.08	1.00	0.57	7.60
Maximum	0.10	0.03	0.21	7.3	6.00	160	19	3.00	0.52	0.50	43	1260	73	63	0.35	47	8.20	1500	4.00	0.02	430	2400	22	25	6.00	6.00	12	0.10	5.00	75	130	6.5	90
Mean	0.10	0.02	0.06	3.3	1.06	17	2.48	0.36	0.17	0.11	19	322	16	28	0.04	10	3.37	853	1.96	0.01	102	677	4.76	2.92	1.21	1.09	4.11	0.03	0.44	7.06	55	2.5	36
Standard Deviation	0	0	0.07	3.1	1.58	45	5.28	0.83	0.19	0.15	14	346	20	21	0.10	14	3.01	351	1.45	0.00	119	930	6.47	6.96	1.52	1.57	3.77	0.03	1.44	21	48	2.0	27
Median	0.10	0.02	0.02	3.3	0.50	2.35	0.84	0.09	0.12	0.03	19	250	10	24	0.01	5.00	4.05	800	1.60	0.01	93	258	2.10	0.80	0.70	0.50	4.05	0.03	0.02	1.20	51	2.0	43
10th Percentile	0.10	0.02	0.01	0.14	0.50	0.76	0.06	0.09	0.01	0.02	3.53	38	1.42	5.69	0.01	2.00	0.16	497	0.33	0.01	6.70	2.7	1.40	0.80	0.70	0.50	0.46	0.002	0.02	0.20	2.10	0.78	7.91
90th Percentile	0.10	0.02	0.13	7.10	1.42	12	2.85	0.31	0.51	0.20	37	569	29	54	0.02	26	7.21	1290	3.97	0.01	159	1980	13	1.88	1.17	1.28	9.34	0.05	0.06	1.78	119	4.7	62

Table A3.
Monthly Precipitation Used for the Model
(Knight Piesold, 2011)

Parameter	Precipitation	Precipitation Derived from Discharge*
	mm	mm
January	7	
February	3.9	
March	9.1	
April	12.4	
May	15.4	
June	20.6	96.3
July	28.4	60.9
August	44.6	44.6
September	30.1	15.0
October	20.9	
November	15.0	
December	9.50	

* Assumes approximately 45% the precipitation in September and all of the precipitation in October through May falls as snow and was melted during June (70%) and July (30%).

Table A4.
Release Rates Used for the Model

Parameter	Release Rates
	mg/m^2/week
Sulphate	0.28
Arsenic	2.80E-05
Copper	4.94E-05
Lead	2.40E-06
Nickel	1.37E-05
Zinc	1.68E-04
Aluminum	1.24E-03
Cadmium	4.11E-07
Cobalt	6.67E-06
Chromium	4.94E-05
Iron	3.07E-04
Molybdenum	8.81E-05
Selenium	1.06E-04
Silver	1.06E-06
Antimony	2.62E-05
Barium	8.05E-05
Manganese	5.42E-04
Boron	2.16E-04
Vanadium	1.45E-05
Thallium	8.41E-06
Mercury	9.63E-06
Tin	1.11E-05
Stronsium	3.90E-04
Sodim	3.45E-03
Potassium	1.05E-01
Calcium	1.30E-01
Magnesium	7.28E-02

Note: rates based on median release rates of selected humidity cells

APPENDIX B

Table B-1. Monthly Predicted Water Quality of Waste Rock Stockpile Seepage

Parameters	MMER values	June				July				August				September			
		West Catchment		East Catchment		West Catchment		East Catchment		West Catchment		East Catchment		West Catchment		East Catchment	
		Unequilibrated	Equilibrated	Unequilibrated	Equilibrated	Unequilibrated	Equilibrated	Unequilibrated	Equilibrated	Unequilibrated	Equilibrated	Unequilibrated	Equilibrated	Unequilibrated	Equilibrated	Unequilibrated	Equilibrated
Sulphate (mg/L)		33	33	26	26	15	15	12	12	21	21	17	17	19	19	15	15
Arsenic (mg/L)	0.5	0.0025	0.0025	0.0020	0.0020	0.0012	0.0012	0.0009	0.0009	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001
Copper (mg/L)	0.3	0.0031	0.0031	0.0025	0.0025	0.0015	0.0015	0.0012	0.0012	0.0020	0.0020	0.0016	0.0016	0.0018	0.0018	0.0014	0.0014
Lead (mg/L)	0.2	0.00020	0.00020	0.00016	0.00016	0.00009	0.00009	0.00007	0.00007	0.00013	0.00013	0.00010	0.00010	0.00011	0.00011	0.00009	0.00009
Nickel (mg/L)	0.5	0.0019	0.0019	0.0015	0.0015	0.0009	0.0009	0.0007	0.0007	0.0012	0.0012	0.0010	0.0010	0.0011	0.0011	0.0008	0.0008
Zinc (mg/L)	0.5	0.013	0.013	0.010	0.010	0.006	0.006	0.005	0.005	0.008	0.008	0.007	0.007	0.007	0.007	0.006	0.006
Aluminum (mg/L)		0.12	0.12	0.095	0.095	0.055	0.055	0.044	0.044	0.075	0.075	0.060	0.060	0.067	0.07	0.054	0.054
Antimony (mg/L)		0.0031	0.0031	0.0025	0.0025	0.0014	0.0014	0.0011	0.0011	0.0020	0.0020	0.0016	0.0016	0.0017	0.0017	0.0014	0.0014
Boron (mg/L)		0.025	0.025	0.020	0.020	0.012	0.012	0.009	0.009	0.016	0.016	0.013	0.013	0.014	0.014	0.012	0.012
Cadmium (mg/L)		0.000020	0.000020	0.000016	0.000016	0.000009	0.000009	0.000007	0.000007	0.000012	0.000012	0.000010	0.000010	0.000011	0.000011	0.000009	0.000009
Chromium (mg/L)		0.0029	0.0029	0.0023	0.0023	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.002	0.002	0.001	0.001
Cobalt (mg/L)		0.00079	0.00079	0.00063	0.00063	0.0004	0.0004	0.0003	0.0003	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
Iron (mg/L)		0.024	<0.002	0.019	<0.002	0.011	<0.002	0.009	<0.002	0.015	<0.002	0.012	<0.002	0.014	<0.002	0.011	<0.002
Manganese (mg/L)		0.0095	0.00004	0.0076	0.00004	0.004	0.00003	0.004	0.00003	0.006	0.00004	0.005	0.00003	0.005	0.00003	0.004	0.00003
Mercury (mg/L)		0.00057	0.00057	0.00045	0.00045	0.00026	0.00026	0.00021	0.00021	0.00036	0.00036	0.00029	0.00029	0.00032	0.00032	0.00026	0.00026
Molybdenum (mg/L)		0.010	0.010	0.0078	0.0078	0.0046	0.0046	0.0036	0.0036	0.0062	0.0062	0.0050	0.0050	0.0056	0.0056	0.0044	0.0044
Selenium (mg/L)		0.0077	0.0077	0.0051	0.0051	0.0030	0.0030	0.0024	0.0024	0.0041	0.0041	0.0033	0.0033	0.0036	0.0036	0.0029	0.0029
Silver (mg/L)		0.000064	0.000064	0.000051	0.000051	0.000030	0.000030	0.000024	0.000024	0.000041	0.000041	0.000033	0.000033	0.000036	0.000036	0.000029	0.000029
Thallium (mg/L)		0.00029	0.00029	0.00023	0.00023	0.00014	0.00014	0.00011	0.00011	0.00019	0.00019	0.00015	0.00015	0.00017	0.00017	0.00013	0.00013
Vanadium (mg/L)		0.0010	0.0010	0.00083	0.00083	0.00048	0.00048	0.00038	0.00038	0.00066	0.00066	0.00052	0.00052	0.00059	0.00059	0.00047	0.00047
Barium (mg/L)		0.064	0.064	0.051	0.051	0.0297	0.0297	0.0237	0.0237	0.0406	0.0406	0.0324	0.0324	0.0362	0.0362	0.0289	0.0289
Sodium (mg/L)		0.41	0.41	0.32	0.33	0.19	0.19	0.15	0.15	0.26	0.26	0.21	0.21	0.23	0.23	0.18	0.18
Potassium (mg/L)		12.4	12.4	9.9	9.9	5.8	5.8	4.6	4.6	7.9	7.9	6.3	6.3	7.0	7.0	5.6	5.6
Calcium (mg/L)		15.3	15.3	12.2	12.2	7.1	7.1	5.7	5.7	9.7	9.7	7.8	7.8	8.7	8.7	6.9	6.9
Magnesium (mg/L)		8.6	8.6	6.9	6.9	4.0	4.0	3.2	3.2	5.4	5.4	4.4	4.4	4.9	4.9	3.9	3.9

Table B-2. Predicted Water Quality of Waste Rock Stockpile Seepage
Sensitivity Analysis on Active Layer Thickness

Parameters	Case	Base Case		Case A1		Case A2		Case A3	
	Active layer	10 m		20 m		40 m		80 m from the side and 15 m from the top	
	Infiltration Coefficient	0.7		0.7		0.7		0.7	
	Flushing ratio	1		1		1		1	
	Winter reaction ratio	0.15		0.15		0.15		0.15	
	Summer reaction ratio	0.5		0.5		0.5		0.5	
	Reactive surface area	50 m^2/tonne		50 m^2/tonne		50 m^2/tonne		50 m^2/tonne	
		West Catchment	**East Catchment**	**West Catchment**	**East Catchment**	**West Catchment**	**East Catchment**	**West Catchment**	**East Catchment**
	MMER values	**Unequilibrated**		**Unequilibrated**		**Unequilibrated**		**Unequilibrated**	
Sulphate (mg/L)		33	26	66	52	131	105	173	98
Arsenic (mg/L)	0.5	0.0025	0.0020	0.0050	0.0040	0.0100	0.0080	0.0132	0.0074
Copper (mg/L)	0.3	0.0031	0.0025	0.0062	0.0050	0.012	0.0100	0.0165	0.0093
Lead (mg/L)	0.2	0.00020	0.00016	0.00040	0.00032	0.00079	0.00063	0.00105	0.00047
Nickel (mg/L)	0.5	0.0019	0.0015	0.0037	0.0030	0.0075	0.0060	0.0099	0.0056
Zinc (mg/L)	0.5	0.013	0.010	0.026	0.021	0.051	0.041	0.068	0.038
Aluminum (mg/L)		0.12	0.095	0.24	0.19	0.47	0.38	0.63	0.35
Antimony (mg/L)		0.0031	0.0025	0.0062	0.0049	0.0123	0.0099	0.0163	0.0092
Boron (mg/L)		0.025	0.020	0.051	0.041	0.102	0.082	0.135	0.076
Cadmium (mg/L)		0.000020	0.000016	0.000039	0.000031	0.000078	0.000062	0.000103	0.000058
Chromium (mg/L)		0.0029	0.0023	0.0058	0.0047	0.0116	0.0093	0.0154	0.0087
Cobalt (mg/L)		0.00079	0.00063	0.0016	0.0013	0.0031	0.0025	0.0042	0.0023
Iron (mg/L)		0.024	0.019	0.048	0.039	0.096	0.077	0.127	0.072
Manganese (mg/L)		0.0095	0.0076	0.019	0.015	0.038	0.030	0.050	0.028
Mercury (mg/L)		0.00057	0.00045	0.0011	0.0009	0.0023	0.0018	0.0030	0.0017
Molybdenum (mg/L)		0.010	0.0078	0.020	0.016	0.039	0.031	0.052	0.029
Selenium (mg/L)		0.0077	0.0051	0.015	0.010	0.031	0.021	0.041	0.019
Silver (mg/L)		0.000064	0.000051	0.00013	0.00010	0.00026	0.00021	0.00034	0.00019
Thallium (mg/L)		0.00029	0.00023	0.00058	0.00047	0.0012	0.0009	0.0015	0.0009
Vanadium (mg/L)		0.0010	0.00083	0.0021	0.0017	0.0041	0.0033	0.0055	0.0031
Barium (mg/L)		0.064	0.051	0.13	0.10	0.26	0.20	0.34	0.19
Sodium (mg/L)		0.41	0.32	0.81	0.65	1.63	1.30	2.15	1.21
Potassium (mg/L)		12.4	9.9	24.8	19.8	49.6	39.6	65.5	37.0
Calcium (mg/L)		15.3	12.2	30.6	24.5	61.2	48.9	80.9	45.7
Magnesium (mg/L)		8.6	6.9	17.2	13.7	34.3	27.4	45.4	25.6

Table B-3. Predicted Water Quality of Waste Rock Stockpile Seepage
Sensitivity Analysis on Reactive Surface Area

Parameters	**Case**	**Base Case**		**Case B1**		**Case B2**		**Case B3**		**Case B4**		**Case B5**	
	Active layer	10 m		10 m		10 m		10 m		10 m		80 m from the side and 15 m from the top	
	Infiltration Coefficient	0.7		0.7		0.7		0.7		0.7		0.7	
	Flushing ratio	1		1		1		1		1		1	
	Winter reaction ratio	0.15		0.15		0.15		0.15		0.15		0.15	
	Summer reaction ratio	0.5		0.5		0.5		0.5		0.5		0.5	
	Reactive surface area	50 m^2/tonne		30 m^2/tonne		100 m^2/tonne		250 m^2/tonne		500 m^2/tonne		500 m^2/tonne	
		West Catchment	**East Catchment**	**West Catchment**	**East Catchment**	**West Catchment**	**East Catchment**	**West Catchment**	**East Catchment**	**West Catchment**	**East Catchment**	**West Catchment**	**East Catchment**
	MMER values	**Unequilibrated**		**Unequilibrated**		**Unequilibrated**		**Unequilibrated**		**Unequilibrated**		**Unequilibrated**	
Sulphate (mg/L)		33	26	20	16	66	52	164	131	328	262	1,733	980
Arsenic (mg/L)	0.5	0.0025	0.0020	0.0015	0.0012	0.0050	0.0040	0.012	0.010	0.025	0.020	0.132	0.074
Copper (mg/L)	0.3	0.0031	0.0025	0.0019	0.0015	0.0062	0.0050	0.016	0.012	0.031	0.025	0.165	0.093
Lead (mg/L)	0.2	0.00020	0.00016	0.00012	0.00010	0.00040	0.00032	0.00099	0.00079	0.0020	0.0016	0.0105	0.0047
Nickel (mg/L)	0.5	0.0019	0.0015	0.0011	0.0009	0.0037	0.0030	0.0094	0.0075	0.019	0.015	0.099	0.056
Zinc (mg/L)	0.5	0.013	0.010	0.008	0.006	0.026	0.021	0.064	0.051	0.13	0.10	0.68	0.38
Aluminum (mg/L)		0.12	0.095	0.071	0.057	0.237	0.189	0.59	0.47	1.18	0.95	6.26	3.54
Antimony (mg/L)		0.0031	0.0025	0.0018	0.0015	0.0062	0.0049	0.015	0.012	0.031	0.025	0.163	0.092
Boron (mg/L)		0.025	0.020	0.015	0.012	0.051	0.041	0.13	0.10	0.25	0.20	1.35	0.76
Cadmium (mg/L)		0.000020	0.000016	0.000012	0.000009	0.000039	0.000031	0.000098	0.000078	0.00020	0.00016	0.00103	0.00058
Chromium (mg/L)		0.0029	0.0023	0.0017	0.0014	0.0058	0.0047	0.015	0.012	0.029	0.023	0.154	0.087
Cobalt (mg/L)		0.00079	0.00063	0.00047	0.00038	0.0016	0.0013	0.0039	0.0031	0.0079	0.0063	0.042	0.023
Iron (mg/L)		0.024	0.019	0.014	0.012	0.048	0.039	0.12	0.096	0.24	0.19	1.27	0.72
Manganese (mg/L)		0.0095	0.0076	0.0057	0.0046	0.019	0.015	0.047	0.038	0.095	0.076	0.50	0.28
Mercury (mg/L)		0.00057	0.00045	0.00034	0.00027	0.0011	0.0009	0.0028	0.0023	0.0057	0.0045	0.030	0.017
Molybdenum (mg/L)		0.010	0.0078	0.0059	0.0047	0.020	0.016	0.049	0.039	0.098	0.078	0.52	0.29
Selenium (mg/L)		0.0077	0.0051	0.0046	0.0031	0.015	0.010	0.039	0.026	0.077	0.051	0.41	0.19
Silver (mg/L)		0.000064	0.000051	0.000039	0.000031	0.00013	0.00010	0.00032	0.00026	0.00064	0.00051	0.0034	0.0019
Thallium (mg/L)		0.00029	0.00023	0.00018	0.00014	0.00058	0.00047	0.0015	0.0012	0.0029	0.0023	0.0154	0.0087
Vanadium (mg/L)		0.0010	0.00083	0.00062	0.00050	0.0021	0.0017	0.0052	0.0041	0.0103	0.0083	0.055	0.031
Barium (mg/L)		0.064	0.051	0.038	0.031	0.13	0.10	0.32	0.26	0.64	0.51	3.38	1.91
Sodium (mg/L)		0.41	0.32	0.24	0.19	0.81	0.65	2.03	1.62	4.06	3.25	21.5	12.1
Potassium (mg/L)		12.4	9.9	7.44	5.94	24.8	19.8	62.0	49.5	124	99.0	655	370
Calcium (mg/L)		15.3	12.2	9.19	7.34	30.6	24.5	76.6	61.2	153	122	809	457
Magnesium (mg/L)		8.6	6.9	5.15	4.11	17.2	13.7	42.9	34.3	85.8	68.6	454	256

Table B-4. Predicted Water Quality of Waste Rock Stockpile Seepage
Sensitivity Analysis on Infiltration Coefficient

Parameters	Case	Base Case		Case C1		Case C2	
	Active layer	10 m		10 m		10 m	
	Infiltration Coefficient	0.7		0.4		1	
	Flushing ratio	1		1		1	
	Winter reaction ratio	0.15		0.15		0.15	
	Summer reaction ratio	0.5		0.5		0.5	
	Reactive surface area	50 m^2/tonne		50 m^2/tonne		50 m^2/tonne	
		West Catchment	East Catchment	West Catchment	East Catchment	West Catchment	East Catchment
	MMER values	Unequilibrated		Unequilibrated		Unequilibrated	
Sulphate (mg/L)		33	26	57	46	23	18
Arsenic (mg/L)	0.5	0.0025	0.0020	0.0044	0.0035	0.0017	0.0014
Copper (mg/L)	0.3	0.0031	0.0025	0.0055	0.0044	0.0022	0.0017
Lead (mg/L)	0.2	0.00020	0.00016	0.00035	0.00028	0.00014	0.00011
Nickel (mg/L)	0.5	0.0019	0.0015	0.0033	0.0026	0.0013	0.0010
Zinc (mg/L)	0.5	0.013	0.010	0.022	0.018	0.009	0.007
Aluminum (mg/L)		0.12	0.095	0.207	0.166	0.083	0.066
Antimony (mg/L)		0.0031	0.0025	0.0054	0.0043	0.0022	0.0017
Boron (mg/L)		0.025	0.020	0.045	0.036	0.018	0.014
Cadmium (mg/L)		0.000020	0.000016	0.000034	0.000027	0.000014	0.000011
Chromium (mg/L)		0.0029	0.0023	0.0051	0.0041	0.0006	0.0004
Cobalt (mg/L)		0.00079	0.00063	0.00138	0.00110	0.00204	0.00163
Iron (mg/L)		0.024	0.019	0.042	0.034	0.017	0.013
Manganese (mg/L)		0.0095	0.0076	0.0166	0.0133	0.0066	0.0053
Mercury (mg/L)		0.00057	0.00045	0.00099	0.00079	0.00040	0.00032
Molybdenum (mg/L)		0.010	0.0078	0.017	0.014	0.007	0.005
Selenium (mg/L)		0.0077	0.0051	0.0136	0.0090	0.0054	0.0036
Silver (mg/L)		0.000064	0.000051	0.000112	0.000090	0.000045	0.000036
Thallium (mg/L)		0.00029	0.00023	0.00051	0.00041	0.00072	0.00058
Vanadium (mg/L)		0.0010	0.00083	0.0018	0.0014	0.0002	0.0002
Barium (mg/L)		0.064	0.051	0.112	0.089	0.045	0.036
Sodium (mg/L)		0.41	0.32	0.71	0.57	0.28	0.23
Potassium (mg/L)		12.4	9.9	21.7	17.3	8.68	6.93
Calcium (mg/L)		15.3	12.2	26.8	21.4	10.7	8.57
Magnesium (mg/L)		8.6	6.9	15.0	12.0	6.0	4.8

Table B-5. Predicted Water Quality of Waste Rock Stockpile Seepage
Sensitivity Analysis on Flushing Ratio

Parameters	Case	Base Case				Case D1				Case D2			
	Active layer	10 m				10 m				10 m			
	Infiltration Coefficient	0.7				0.7				0.7			
	Flushing ratio	1				0.8				0.6			
	Winter reaction ratio	0.15				0.15				0.15			
	Summer reaction ratio	0.5				0.5				0.5			
	Reactive surface area	50 m^2/tonne				50 m^2/tonne				50 m^2/tonne			
		June		September		June		September		June		September	
		West Catchment	**East Catchment**	**West Catchment**	**East Catchment**	**West Catchment**	**East Catchment**	**West Catchment**	**East Catchment**	**West Catchment**	**East Catchment**	**West Catchment**	**East Catchment**
	MMER values	**Unequilibrated**		**Unequilibrated**		**Unequilibrated**		**Unequilibrated**		**Unequilibrated**		**Unequilibrated**	
Sulphate (mg/L)		33	26	19	15	27	22	28	22	22	18	41	33
Arsenic (mg/L)	0.5	0.0025	0.0020	0.0014	0.0011	0.0021	0.0016	0.0021	0.0017	0.0017	0.0014	0.0031	0.0025
Copper (mg/L)	0.3	0.0031	0.0025	0.0018	0.0014	0.0026	0.0021	0.0027	0.0021	0.0021	0.0017	0.0039	0.0031
Lead (mg/L)	0.2	0.00020	0.00016	0.00011	0.00009	0.00016	0.00013	0.00017	0.00014	0.00013	0.00011	0.00025	0.00020
Nickel (mg/L)	0.5	0.0019	0.0015	0.0011	0.0008	0.0015	0.0012	0.0016	0.0013	0.0013	0.0010	0.0023	0.0019
Zinc (mg/L)	0.5	0.013	0.010	0.007	0.006	0.011	0.008	0.011	0.009	0.009	0.007	0.016	0.013
Aluminum (mg/L)		0.12	0.095	0.067	0.054	0.098	0.078	0.102	0.081	0.080	0.064	0.15	0.12
Antimony (mg/L)		0.0031	0.0025	0.0017	0.0014	0.0025	0.0020	0.0026	0.0021	0.0021	0.0017	0.0039	0.0031
Boron (mg/L)		0.025	0.020	0.014	0.012	0.021	0.017	0.022	0.017	0.017	0.014	0.032	0.026
Cadmium (mg/L)		0.000020	0.000016	0.000011	0.000009	0.000016	0.000013	0.000017	0.000013	0.000013	0.000011	0.000024	0.000020
Chromium (mg/L)		0.0029	0.0023	0.0016	0.0013	0.0006	0.0005	0.0007	0.0005	0.0005	0.0004	0.0010	0.0008
Cobalt (mg/L)		0.00079	0.00063	0.00045	0.00036	0.00241	0.00192	0.00250	0.00200	0.00197	0.00158	0.0036	0.0029
Iron (mg/L)		0.024	0.019	0.014	0.011	0.020	0.016	0.021	0.017	0.016	0.013	0.030	0.024
Manganese (mg/L)		0.0095	0.0076	0.0054	0.0043	0.0078	0.0063	0.0081	0.0065	0.0064	0.0051	0.0119	0.0095
Mercury (mg/L)		0.00057	0.00045	0.00032	0.00026	0.00047	0.00038	0.00049	0.00039	0.00038	0.00031	0.00071	0.00057
Molybdenum (mg/L)		0.010	0.0078	0.0056	0.0044	0.0081	0.0065	0.0084	0.0067	0.0066	0.0053	0.0123	0.0098
Selenium (mg/L)		0.0077	0.0051	0.0036	0.0029	0.0064	0.0042	0.0056	0.0044	0.0052	0.0035	0.0084	0.0064
Silver (mg/L)		0.000064	0.000051	0.000036	0.000029	0.000053	0.000042	0.000055	0.000044	0.000044	0.000035	0.000080	0.000064
Thallium (mg/L)		0.00029	0.00023	0.00017	0.00013	0.00085	0.00068	0.00089	0.00071	0.00070	0.00056	0.0013	0.0010
Vanadium (mg/L)		0.0010	0.00083	0.00059	0.00047	0.00024	0.00019	0.00025	0.00020	0.00020	0.00016	0.00037	0.00029
Barium (mg/L)		0.064	0.051	0.036	0.029	0.053	0.042	0.055	0.044	0.043	0.035	0.080	0.064
Sodium (mg/L)		0.41	0.32	0.23	0.18	0.34	0.27	0.35	0.28	0.28	0.22	0.51	0.41
Potassium (mg/L)		12.4	9.9	7.0	5.6	10.2	8.2	10.6	8.5	8.4	6.7	15.5	12.4
Calcium (mg/L)		15.3	12.2	8.7	6.9	12.7	10.1	13.1	10.5	10.4	8.3	19.2	15.3
Magnesium (mg/L)		8.6	6.9	4.9	3.9	7.1	5.7	7.4	5.9	5.8	4.6	10.8	8.6

Note: Concentrations represent the seepage quality 2 years after mine closure

Table B-6. Predicted Water Quality of Waste Rock Stockpile Seepage
Sensitivity Analysis on Reaction Rate Factor

Parameters	Case	Base Case		Case E1		Case E2	
	Active layer	10 m		10 m		10 m	
	Infiltration Coefficient	0.7		0.7		0.7	
	Flushing ratio	1		1		1	
	Winter reaction ratio	0.15		0.5		1	
	Summer reaction ratio	0.5		0.5		1	
	Reactive surface area	50 m^2/tonne		50 m^2/tonne		50 m^2/tonne	
		West Catchment	East Catchment	West Catchment	East Catchment	West Catchment	East Catchment
	MMER values	Unequilibrated		Unequilibrated		Unequilibrated	
Sulphate (mg/L)		33	26	87	69	174	139
Arsenic (mg/L)	0.5	0.0025	0.0020	0.0066	0.0053	0.0175	0.0140
Copper (mg/L)	0.3	0.0031	0.0025	0.0083	0.0066	0.0308	0.0246
Lead (mg/L)	0.2	0.00020	0.00016	0.00052	0.00042	0.0015	0.0012
Nickel (mg/L)	0.5	0.0019	0.0015	0.0050	0.0040	0.0085	0.0068
Zinc (mg/L)	0.5	0.013	0.010	0.034	0.027	0.105	0.084
Aluminum (mg/L)		0.12	0.095	0.31	0.25	0.78	0.62
Antimony (mg/L)		0.0031	0.0025	0.0082	0.0065	0.016	0.013
Boron (mg/L)		0.025	0.020	0.067	0.054	0.13	0.11
Cadmium (mg/L)		0.000020	0.000016	0.000052	0.000041	0.00026	0.00020
Chromium (mg/L)		0.0029	0.0023	0.0077	0.0062	0.015	0.012
Cobalt (mg/L)		0.00079	0.00063	0.0021	0.0017	0.0042	0.0033
Iron (mg/L)		0.024	0.019	0.064	0.051	0.19	0.15
Manganese (mg/L)		0.0095	0.0076	0.025	0.020	0.050	0.040
Mercury (mg/L)		0.00057	0.00045	0.0015	0.0012	0.0060	0.0048
Molybdenum (mg/L)		0.010	0.0078	0.026	0.021	0.055	0.044
Selenium (mg/L)		0.0077	0.0051	0.017	0.014	0.066	0.053
Silver (mg/L)		0.000064	0.000051	0.00017	0.00014	0.00066	0.00053
Thallium (mg/L)		0.00029	0.00023	0.00077	0.00062	0.0052	0.0042
Vanadium (mg/L)		0.0010	0.00083	0.0027	0.0022	0.0091	0.0072
Barium (mg/L)		0.064	0.051	0.17	0.14	0.34	0.27
Sodium (mg/L)		0.41	0.32	1.08	0.86	2.2	1.7
Potassium (mg/L)		12.4	9.9	32.8	26.2	65.6	52.4
Calcium (mg/L)		15.3	12.2	40.5	32.4	81.1	64.8
Magnesium (mg/L)		8.6	6.9	22.7	18.2	45.4	36.3

Appendix 5:
Interim Open Pit Water Quality Model Technical Memorandum

Annex 5
Interim Open Pit Water Quality Model Technical Memorandum

TECHNICAL MEMORANDUM

To	**Jim Millard, Baffinland**	Project #	**TC111523**
From	**Judy Andrina, AMEC** **Steve Walker AMEC**	cc	**Steve Sibbick, AMEC** **Richard Cook, Knight Piésold**
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Date	**16 January 2012**		

Subject **Interim Open Pit Water Quality Model, Mary River Project**

1.0 INTRODUCTION

AMEC was retained by Baffinland Iron Mines Corporation (Baffinland) to conduct seepage quality modeling for the proposed Deposit No.1 open pit to support an environmental impact statement (EIS). Ore will be mined from the Deposit No. 1 pit and shipped directly offsite for further processing. Based on the mine plan for Deposit No. 1, the open pit will be mined for a period of 21 years (Hatch 2011). The following memorandum report contains estimates of the preliminary open pit water quality during the 21 years of mine life for the proposed Mary River Project. The estimate is based on available laboratory data, and general assumptions regarding the physical qualities of the future open pit.

2.0 MODEL DESCRIPTION

Based on the mine plan (Hatch 2011), the Deposit No.1 will be mined for 21 years. During the mine operation the drainage within the pit/mined perimeter (hereafter referred to as “pit walls”) will be managed by collecting at either perimeter drains (early in mine life) or to pit sump(s). The preliminary water quality model described in this memo has been developed to estimate the expected quality of water draining from the open pit during the mine operation.

The model developed is a mass balance model utilizing mass loadings from the pit wall surface areas. During the operational phase of the mine, some of the pit walls will be exposed long enough that acidic conditions may occur on potentially acid generating (PAG) surfaces. However, kinetic testing (humidity cell) results for the project have yet to produce any acidic conditions. Therefore, source terms derived from laboratory testing of humidity cells were used to derive source terms for the non-potentially acid generating (non-PAG) surfaces and non-acidic PAG surfaces. For acidic conditions on PAG rock surfaces, metals analysis of leachate from Net Acid Generation (NAG) analyses were scaled and used to develop source terms. The use of NAG leachate analyses for the estimation of acidic sources terms is likely to result in prediction of worse water quality from acidic drainage than may actually occur.

For scaling purposes, loadings of sulphate and metals were normalized to an estimated surface area (mg/m^2/wk) of the waste rock in the humidity cells based on surface areas calculated from grain size analysis. The surface area normalized loading rates from the humidity cells and an estimated surface area for the pit wall were used to calculate the loadings of the parameters of interest from the pit during non-acidic conditions.

Direct precipitation was assumed to completely flush accumulated loadings from pit wall surface areas. The model is based on the site annual water balance derived from available hydrologic information. Calculated mass annual loadings from the pit walls were coupled with these estimated flows to estimate the annual mean concentrations of sulphate and metals in seepage from the pit.

However, the concentrations of these parameters in the pit seepage will depend on the solubility constraints. The concentrations of certain parameters may reach conditions that cause them to exceed saturation with respect to some mineral phase. To address this, preliminary equilibration using the geochemical program, PHREEQC was used to assess the solubility constraints on selected results of the mass balance model by using the calculated effluent quality (including pH) as inputs. A description of the approach and results of this equilibration step are described in Section 4.

The model included estimation of relevant parameters listed in the MMER effluent regulations (arsenic, copper, lead, nickel, and zinc). In addition, sulphate, trace metals, and major cation concentrations in the pit drainage were also estimated. Preliminary pit model results were estimated based on water quality at years 6, 10, 15 and 21.

3.0 MODEL ASSUMPTIONS AND DATA SOURCES

This section provides additional details and describes the data sources used in the model. Detailed data is provided in supporting references and Appendix A.

3.1 Physical Framework for the Model

3.1.1 Surface Area

- The exposed pit surface area used for the model was based on the mine plan and the block model (Hatch, 2011 & Hatch, 2012) for the mine years 6, 10, 15 and 21. The surface area was assigned for each rock type (e.g., hangingwall (HW), footwall (FW) hangingwall schist (HWS), footwall (FW), footwall schist (FWS), internal waste (IW), delerious ore (DO), ore and overburden). The proportion of non-PAG and PAG rock exposed on the pit surface area was assigned based on the current understanding of the percentage PAG for each material type as described in AMEC (2012a) and summarized in Table 1. Source terms were assigned to each of the surface areas on the basis of the proportion of non-PAG and PAG for that material type;

Table 1: Waste Rock Classification in Mary River Deposit No.1

Waste Type	Number of samples	NPR* < 2		Modeled In-Pit Tonnage	Estimated PAG Tonnage
	N	n	%	t	t
HW	142	10	7.0	114,506,831	8,063,861
HWS	207	48	23.2	103,479,188	23,995,174
IW	11	3	27.3	2,982,893	813,516
DO	27	15	55.6	13,672,193	7,595,663
FWS	99	23	23.2	45,917,213	10,667,635
FW	127	14	11.0	291,226,388	32,103,696
Total	613	113	18.4	571,784,706	83,239,546

* NPR = mod. Sobek NP/AP

% PAG normalized to tonnage = 15

- The surface area that will be exposed longer than ARD on set time (currently estimated to be 5 years) was estimated by Hatch (2012). These exposed surface area estimates included HW, FW, HWS and FWS waste types; and

- The proportion of PAG for ore rock was initially assumed to be 20%; however, based on continuous mining of ore during operations no acidic drainage was incorporated from ore.

3.1.2 Hydrology

Water inputs to the pit were based on monthly precipitation values provided by Knight Piésold (2011) as shown in Appendix A and the following assumptions:

- The only water flow into the pit is from direct precipitation within the pit/mined footprint area, either as rainfall or the melting of accumulated snowpack; no additional natural drainage or catchments flow to the pit (Knight Piésold (2011);
- Approximately 45% of precipitation in September and all precipitation in October through May occurs as snow and are stored within the pit limit. It was assumed that 70% of the stored snow melted in June and the rest of the stored snow melted in July (Knight Piésold 2011);
- Runoff within the pit/mined footprint perimeter collects at either perimeter drains (early time) or to pit sump(s) for management during operations; and
- The infiltrating water will completely flush the accumulated oxidation products from the pit surfaces.

3.2 Geochemical Source Terms

- Expected loading rates from the pit surface area that contained non-PAG and PAG materials during non-acidic conditions were derived from humidity cell data (AMEC 2012b). The humidity cell testing program was conducted for 53 weeks on 10 representative rock samples collected from the Project area in early 2008. In May 2011, humidity cell testing was initiated on an additional 9 rock samples; data for these samples are available at this time for 21 weeks and summarized as follows:
    - The samples tested in the humidity cells were mainly waste rock samples with NPR<2, and the sulphide contents of those rock samples were higher than median sulphide content in the waste rock samples that underwent the static testing. Therefore, the resulting source terms could be higher than what would be expected from the non-PAG mine rock drainage;
    - Surface areas of humidity cell samples were estimated at 7 to 12 m^2/kg based on grain-size analysis;
    - Leachates from several waste rock samples had somewhat lower pH (5.5 to 6.5), but none of the PAG rock samples produced strongly acidic drainage over the course of the humidity cell testing;
- Loading rates used for the leaching of non-PAG and PAG rock during non-acidic conditions were based on median release rates calculated from selected humidity cells (excluding weak acid cells) (Appendix A);
- Loading rates from the pit rock surface area for PAG material under acidic conditions were derived from available weak acid humidity cell and NAG leachate results.
- The sulphate and metal loadings of ore materials were assumed to be the same as loadings from the waste rock materials;
- Overburden material was assumed to have no load contribution;
- Yearly average loadings were calculated based on the sum of summer month and freezing month loadings. Sulphide oxidation rates were assumed to be 50% of laboratory rates during the months with mean monthly temperature above zero (June to August) and 15% during the remainder of the year (months with freezing temperatures) due to reduced temperatures (MEND, 1996);
- Detection limit values were handled using the following protocol (EPA, 1991):
    - For elements that reported >50% of their humidity cell leachate concentrations below their respective method detection limit (MDL) (antimony, arsenic, cadmium, chromium, copper, iron, lead, mercury, selenium, silver, thallium and zinc) the <MDL values were set to equal half the applicable detection limit; and,
    - For the remaining elements, <MDL values were set to equal the applicable MDL value.

- The effective reactive surface area of the pit walls was assumed to be 50 times the calculated pit wall surface (calculated from pit dimensions) to allow for surface roughness and fracture influences (Morin and Hutt, 2004);
- Based on limited data, a simple estimate of pH for the pit water drainage was made based on mixing of the seepage generated from the non-PAG and PAG materials at the pit wall, in proportion to the surface area of those materials present (hydrogen ion concentration basis);
    - A median pH of the humidity cells (pH of 6.9) during non-acidic condition was selected to represent the non-PAG rock and non-acidic conditions for PAG rock.
    - A median pH of 2.7 from NAG testing of 49 rock samples with NPR<2 was used to represent the leachate pH from PAG rock under acidic conditions.
- An ARD onset time of 5 years was assumed for the PAG mine rock based on the estimated average carbonate neutralization potential (Carbonate NP) depletion time derived from humidity cell testing of PAG materials; and,
    - Carbonate NP depletion was calculated based on average release rate of calcium and magnesium during steady-state conditions, assuming carbonate was the only source for NP. The Carbonate NP values from the ABA results were used to estimate the initial NP of the materials.
- Water quality at the site will be regulated using MMER values.

4.0 MODELED PIT SEEPAGE QUALITY

The modeled seepage quality from the pit for years 6, 10, 15 and 21 are presented in Table 2. For the first ten years of operation, the predicted water quality meets MMER average values for pH and the metals indicated. Based on pit progress estimates provided by Hatch (2012) PAG rock exposed at year 6 that has the potential to remain undisturbed for the 5 year lag time required to begin generating acidic drainage. Therefore in the model, potential acidic drainage from portions of the pit walls are expected to occur after year 11 and impacts on the pit water quality are expected. For years 15 and 21 modeled metal concentrations are predicted to be less than MMER limits, but pH may be lower than the MMER limit of 6.

The equilibration step assumed the estimated pH and that waters were oxidizing and in equilibrium with atmospheric O_2. In the absence of site specific secondary mineral precipitate information, a set of solid phases were identified that may reasonably be expected to precipitate for the given conditions. For Ca and SO_4 gypsum ($CaSO_4 \bullet 2H_2O$) was assumed to be the most probable geochemical control, although it is under saturated in the modeled waters. For Al, $Al(OH)_3$ (amorphous) is saturated in all but the most acidic waters and precipitation of this phase would result in a small attenuation in Al concentration for these results. As expected for the circum-neutral oxidizing conditions, the equilibrated Fe and Mn concentrations are also low with solubility effectively limited by ferrihydrite (poorly crystalline Fe oxyhydroxide) and manganite (MnO(OH)) respectively. With increasingly acid conditions at later time, less attenuation of Fe and Mn is observed. It should be noted that manganite was selected as a suitable low temperature phase; however, it is possible that higher solubility Mn phases (or a mixed Fe-Mn oxyhydroxide) could be kinetically favoured that would result in somewhat higher equilibrated Mn concentrations. Thermodynamic data is not readily available for such phases.

5.0 UNCERTAINTIES

Uncertainties with this water quality model include the following:

- The water quality model is based on the currently available mine plan which includes estimates of the pit configuration and progress over time, as well as the site water balance and available geochemical data. Changes to these inputs could significantly alter the results of the model;
- The current model estimates are based upon limited geochemical data for acidic leachates. Results of the NP depleted cells that are currently in operation will be used to refine the source terms used for acidic drainage in the model; and,
- Estimates of the pit wall surface area are based on a review of published and unpublished data from the other mine projects which could be different from the actual surface of the pit walls. Significant changes in surface area could lead to significant changes in the estimated water quality.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be made regarding the estimates of pit seepage quality from the proposed Mary River project:

- Based on the assumptions and data used in the model, the results suggest that arsenic, copper, lead, nickel, and zinc concentrations in the pit seepage will be below MMER values during mine life.
- Estimates of pH are difficult to make due to the sensitivity of pH to numerous factors not considered in this mass balance prediction. As a preliminary estimate, seepage from the pit is expected to maintain a circum-neutral pH until year 10. Sometime after year 11 the on-set of some acidic drainage is predicted to lead to impacts on the pit water that may lead to pH values below the MMER minimum of pH 6.
- The following recommendations are made to improve future modeling estimates:
    - Continuation of the kinetic testing program to refine ARD onset time and mass-release rates during non-acidic as well as acidic conditions for waste rock, including extended monitoring of those humidity cells which begin to produce acidic conditions;
    - Additional geochemical sampling and testing to refine the volumes of non-PAG and PAG waste and ore at the projected pit limits; and

- Kinetic testing of a limited number of PAG and non-PAG ore materials representative of ore to be exposed at pit limits in order to improve prediction of future drainage quality from these exposures in the pit.

7.0 REFERENCES

AMEC, 2012a. Interim Mine Rock ML/ARD Report, Mary River Project, January, 2012.

AMEC, 2012b. Waste Rock Stockpile Seepage Quality Model Mary River Project, January, 2012.

EPA.1991. Guideline for handing chemical concentrations data near the detection limit in risk assessment. http://www.epa.gov/reg3hwmd/risk/human/info/guide3.htm

Hatch. 2012. Correspondence from Ian Thompson, January 5, 2012.

Hatch. 2011. Correspondence from Ian Thompson, November 16, 2011.

Knight Piésold. 2011. Correspondence from Kyle Terry, November 17, 2011.

Knight Piésold. 2008. Environmental Characterization of Deposit No.1 Waste Rock, Ore & Construction Material. 18 December, 2008.

MEND, 1996. MEND Project 1.61.2 Acid Mine Drainage in Permafrost Regions: Issues, Control Strategies and Research Requirements.

Morin, K. and Hutt, N., 2004. The Minewall Approach for estimating the geochemical effects of mine walls on pit lakes. Pit Lakes 2004. United States Environmental Protection Agency. 16 – 18 November 2004.

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TABLE

Table 2. Preliminary Predicted Water Quality of Pit Seepage

Parameters	MMER values	Year 6		Year 10		Year 15		Year 21	
		Unequilibrated	Equilibrated	Unequilibrated	Equilibrated	Unequilibrated	Equilibrated	Unequilibrated	Equilibrated
pH	6 - 9.5	6.9	6.5	6.9	6.5	5.2	5.1	4.3	4.2
Sulphate (mg/L)		77	77	80	80	88	88	158	158
Arsenic (mg/L)	0.5	0.006	0.006	0.006	0.006	0.006	0.006	0.007	0.007
Copper (mg/L)	0.3	0.007	0.007	0.008	0.008	0.016	0.016	0.074	0.074
Lead (mg/L)	0.2	0.0005	0.0005	0.0005	0.0005	0.0007	0.0007	0.0022	0.0022
Nickel (mg/L)	0.5	0.004	0.004	0.005	0.005	0.018	0.018	0.11	0.11
Zinc (mg/L)	0.5	0.030	0.030	0.031	0.031	0.035	0.035	0.062	0.062
Aluminum (mg/L)		0.28	0.24	0.29	0.24	0.77	0.77	4.2	4.2
Antimony (mg/L)		0.007	0.007	0.007	0.007	0.007	0.007	0.008	0.008
Boron (mg/L)		0.060	0.060	0.062	0.062	0.067	0.067	0.11	0.11
Cadmium (mg/L)		0.00005	0.00005	0.00005	0.00005	0.00006	0.00006	0.00016	0.00016
Chromium (mg/L)		0.007	0.007	0.007	0.007	0.008	0.008	0.019	0.019
Cobalt (mg/L)		0.002	0.002	0.002	0.002	0.008	0.008	0.053	0.053
Iron (mg/L)		0.057	<0.002	0.059	<0.002	0.12	0.031	0.59	0.22
Manganese (mg/L)		0.15	0.0001	0.16	0.0001	0.20	0.10	0.57	0.57
Mercury (mg/L)		0.0013	0.0013	0.0014	0.0014	0.0014	0.0014	0.0016	0.0016
Molybdenum (mg/L)		0.023	0.023	0.024	0.024	0.024	0.024	0.027	0.027
Selenium (mg/L)		0.015	0.015	0.016	0.016	0.016	0.016	0.022	0.022
Silver (mg/L)		0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0008	0.0008
Thallium (mg/L)		0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0009	0.0009
Vanadium (mg/L)		0.0024	0.0024	0.0025	0.0025	0.0025	0.0025	0.0029	0.0029
Barium (mg/L)		0.022	0.022	0.023	0.023	0.024	0.024	0.034	0.034
Sodium (mg/L)		1.0	1.0	1.0	1.0	1.1	1.1	1.8	1.8
Potassium (mg/L)		29.2	29.2	30.1	30.1	30.2	30.2	34.9	34.9
Calcium (mg/L)		36.0	36.0	37.2	37.2	37.4	37.4	43.4	43.4
Magnesium (mg/L)		20.2	20.2	20.8	20.8	22.9	22.9	39.9	40.0

Note: Equilibrated concentrations assume equilibrium with amorphous $Al(OH)_3$, ferrihydrite and manganite where estimated concentrations exceed saturation indices for those phases.

APPENDIX A

Table A1.
Precipitation Data Used for the Model
(Knight Piésold, 2011)

Parameter	Precipitation	Precipitation Derives for Discharge
	mm	mm
January	7	
February	3.9	
March	9.1	
April	12.4	
May	15.4	
June	20.6	96.3
July	28.4	60.9
August	44.6	44.6
September	30.1	15.0
October	20.9	
November	15.0	
December	9.50	

Note: Approximately 45% the precipitation in September and all of the precipitation in October through May fell as snow and was melted during June (70%) and July (30%).

Table A2.
Release Rates Used for the Model

Parameter	Average Yearly Release Rates for Non Acidic Condition*	Average Yearly Release Rates for Non Acidic Condition**
	mg/m^2/year	**mg/m^2/year**
Sulphate	5.97	164
Arsenic	0.0005	0.001
Copper	0.001	0.15
Lead	0.00004	0.004
Nickel	0.0003	0.26
Zinc	0.002	0.065
Aluminum	0.022	9.2
Cadmium	0.000004	0.0003
Cobalt	0.0001	0.12
Chromium	0.001	0.026
Iron	0.004	1.23
Molybdenum	0.002	0.0004
Selenium	0.001	0.011
Silver	0.00001	0.001
Antimony	0.001	0.000
Barium	0.002	0.019
Manganese	0.012	0.93
Boron	0.005	0.090
Vanadium	0.0002	0.0002
Thallium	0.0001	0.0004
Mercury	0.0001	0.0002
Tin	0.0002	0.00004
Strontium	0.008	0.033
Sodium	0.074	1.7
Potassium	2.3	3.6
Calcium	2.8	5.1
Magnesium	1.6	39

Notes:*Rates based on median release rates of selected humidity cells
**Scaled from NAG testing results

Appendix 6:
Phase 1 Waste Rock Management Plan
(BAF-PH1-830-P16-0029)