Baffinland Iron Mines Corporation

LIFE-OF-MINE WASTE ROCK MANAGEMENT PLAN

BAF-PH1-830-P16-0031

Rev 0

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Index of Major Changes/Modifications

Item No.	Description of Change	Relevant Section
1	Update name and document number from H337697-0000-07-126-0012 - Waste Rock Management Plan to BAF-PH1-830-P16-0031 - Life-of-Mine Waste Rock Management Plan	Throughout Plan
2	Update Annex 3 Waste Rock Geological and Geochemical Characterization Program	Appendix 3
3	Update Baffinland's Commitments Section	Section 1.3
4	Update of Summary of Geochemical Sampling and Test Work based on mine rock ML/ARD report ("Mine Rock ML/ARD Characterization Report Deposit 1, Mary River Project, March 2014	Section 3.1.3
5	Update Performance indicators and Threshold sections to incorporate Type A Water Licence 2AM-MRY1325	Section 6
6	Addition of Appendix 6 - Phase 1 Waste Rock Management Plan (BAF-PH1-830-P16-0029)	Appendix 6

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ABBREVIATIONS

Abbreviation	Meaning
ABA	Acid-Base Accounting
AEEMP	Aquatic Environmental Effects Monitoring Program
Baffinland	Baffinland Iron Mines Corporation
Ca-NP/AP	Carbonate Neutralization Potential
EHS	Environmental, Health, and Safety
EIS	Environmental Impact Statement
INAC	Indian and Northern Affairs Canada
MMER	Metal Mining Effluent Regulations
NPR	Neutralization Potential Ratio
OB	Overburden Cores
PAG	Potentially Acid-Generating
psammite	Psammitic Gneiss
ROM	Run-of-Mine
SFE	Short-Term Metal Leaching Tests
SWM	Surface Water Management
TGD	Technical Guidance Document
the Project	Mary River Project
TSS	Total Suspended Solids
VEC	Valued Ecosystem Component

1 INTRODUCTION

1.1 PURPOSE

A waste rock disposal area designed for permanent storage of waste rock will be located north of the open pit. Based on the current mine plan, an estimated 640 Mt of waste rock will be generated from the mining of Deposit No. 1.

Open-pit mining will generate large quantities of waste rock that will be stored at dedicated locations and quantities of ore that will be stored temporarily in ore stockpiles while being crushed and transported to Milne and Steensby Ports. A modification of the mining plan has resulted in a smaller tonnage of waste rock being produced in the first years of operations. In order to effectively manage run-off during the slower build up of the waste rock dump a Phase 1 Waste Rock Management Plan (BAF-PH1-830-P16-0029), Appendix 6 is proposed and this is reflected in a smaller waste rock dump footprint and a diversion into Mary River to be constructed before the two main run-off collection ponds.

Waste rock and ore will require environmentally acceptable management and storage locations and practices. These materials have been characterized and grouped on the basis of geochemical static and kinetic test work. Environmental management plans are developed for each material group based on projected chemical reactivity and physical properties to ensure long-term environmentally acceptable storage. The Waste Rock Management Plan (WRMP) addresses the issues of siting, deposition of the waste rock, inspection, potential release of contaminants to the receiving environment, geotechnical stability, as well as closure considerations. As additional geochemical, geotechnical, and geological data are collected, and detailed engineering is completed, the management plan will be further optimized using an approach that protects the environment while operating in a cost-effective manner.

Baffinland's Waste Rock Management Plan satisfies the requirements of the Mine Site Reclamation Policy for Nunavut (AANDC, 2002).

1.2 REGULATORY REQUIREMENTS

Regulatory provisions related to mine site reclamation are enforced by the following acts and regulations:

- Territorial Lands Act and regulations
- Nunavut Land Claims Agreement
- Fisheries Act and regulations
- Canadian Environmental Protection Act; and
- Nunavut Waters and Nunavut Surface Rights Tribunal Act.

Runoff quality from the waste rock dumps must satisfy the requirements of the Metal Mining Effluent Regulations (MMER) SOR/2002-222 and meet the effluent quality requirements as outlined in Part F, Item 25 in Type A Water Licence 2AM-MRY1325.

1.3 BAFFINLAND'S COMMITMENTS

Baffinland provides adequate resources to implement and maintain the Environmental, Health, and Safety (EHS) Management System, including the necessary human, material, and financial resources. For Baffinland's Sustainable Development Policy, see below.

Baffinland
Iron Mines Corporation

At Baffinland Iron Mines Corporation, we are committed to conducting all aspects of our business in accordance with the principles of sustainable corporate responsibility and always with the needs of future generations in mind. Everything we do is underpinned by our responsibility to protect the environment, to operate safely and fiscally responsibly and to create authentic relationships. We expect each and every employee, contractor, and visitor to demonstrate a personal commitment to this policy through their actions. We will communicate the Sustainable Corporate Policy to the public, all employees and contractors and it will be reviewed and revised as necessary on an annual basis. These four pillars form the foundation of our corporate responsibility strategy:

1.0 HEALTH AND SAFETY

- We strive to achieve the safest workplace for our employees and contractors; free from occupational injury and illness from the very earliest of planning stages. Why? Because our people are our greatest asset. Nothing is as important as their health and safety.
- We report, manage and learn from injuries, illnesses and high potential incidents to foster a workplace culture focused on safety and the prevention of incidents.
- We foster and maintain a positive culture of shared responsibility based on participation, behaviour and awareness. We allow our workers and contractors the right to stop any work if and when they see something that is not safe.

2.0 ENVIRONMENT

- We employ a balance of the best scientific and traditional Inuit knowledge to safeguard the environment.
- We apply the principles of pollution prevention and continuous improvement to minimize ecosystem impacts, and facilitate biodiversity conservation.
- We continuously seek to use energy, raw materials and natural resources more efficiently and effectively. We strive to develop pioneering new processes and more sustainable practices.

- We understand the importance of closure planning. We ensure that an effective closure strategy is in place at all stages of project development and that progressive reclamation is undertaken as early as possible to reduce potential long-term environmental and community impacts.

3.0 INVESTING IN OUR COMMUNITIES AND PEOPLE

- We respect human rights and the dignity of others. We honour and respect the unique culture, values and traditions of the Inuit people.
- We contribute to the social, cultural and economic development of sustainable communities adjacent to our operations.
- We honour our commitments by being sensitive to local needs and priorities through engagement with local communities, governments, employees and the public. We work in active partnership to create a shared understanding of relevant social, economic and environmental issues, and take their views into consideration when making decisions.

4.0 TRANSPARENT GOVERNANCE

- We will take steps to understand, evaluate and manage risks on a continuing basis, including those that impact the environment, employees, contractors, local communities, customers and shareholders.
- We ensure that adequate resources are available and that systems are in place to implement risk-based management systems, including defined standards and objectives for continuous improvement.
- We measure and review performance with respect to our environmental, safety, health, socio-economic commitments and set annual targets and objectives.
- We conduct all activities in compliance with the highest applicable legal requirements and internal standards
- We strive to employ our shareholder's capital effectively and efficiently. We demonstrate honesty and integrity by applying the highest standards of ethical conduct.

Tom Paddon
President and Chief Executive Officer
September 2011

1.4 UPDATE OF THIS MANAGEMENT PLAN

The Waste Rock Management Plan (WRMP) will be updated based on the basis of findings obtained from the on-going waste rock geological and geochemical characterization program that is focused on current information gaps related to waste rock sampling, predictive geochemical sampling/testing programs, and better refining water quality modeling input parameters. Management reviews (see Section 8), incident investigations, regulatory changes, or other Project-related changes will also trigger updates of the WRMP.

1.5 RELATIONSHIP TO OTHER DOCUMENTS AND MANAGEMENT PLANS

The following documents should be viewed in concert with the Waste Rock Management Plan and are included as Appendices:

Appendix 1: *"Stormwater Management and Drainage System Design"* Dated November 2011. Prepared by Hatch (H337697-0000-10-122-0001);

Appendix 2: *"Development of Permafrost in Waste Rock Dumps-Preliminary Geotechnical Evaluation"* Dated November 2011. Prepared by Thurber

Appendix 3: *Mine Rock ML/ARD Characterization Report Deposit 1, Mary River Project". Dated March 2014.* Prepared by AMEC.

Appendix 4: *"Interim Waste Rock Stockpile Seepage Quality Model Report, Mary River Project". Dated January 2012.* Prepared by AMEC.

Appendix 5: *"Interim Open Pit Water Quality Model Technical Memorandum, Mary River Project". Dated January 2012.* Prepared by AMEC.

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

This WRMP should also be viewed in concert with the following additional plans:

- Waste Rock Dump Design Criteria (H337697-1130-20-122-0001) presented in Appendix 3B; Attachment 4; of the Final Environmental Impact Statement;
  - Construction Environmental Protection Plan (Hatch Document No. H349000-1000-07-126-0001).
  - Surface Water and Aquatic Ecosystems Management Plan (Baffinland Document No. BAF-PH1-830-P16-0036).
  - Interim Abandonment and Reclamation Plan. (Baffinland Document No. BAF-PH1-830-P16-0012).
- Volume 10, Appendix 10D-11 - Terrestrial Environmental Effects Framework (Addendum to the Final Environmental Impact Statement)
- Volume 10, Appendix 10D-12 - Environmental Monitoring Plan presented in Appendix 3B, Attachment 5; (Final Environmental Impact Statement).

2 TARGETED VECS

Targeted valued ecosystem components (VECs) for this management plan are surface water quality and terrestrial wildlife.

3 MITIGATION MEASURES

3.1 NATURE OF THE WASTE ROCK AND GEOCHEMICAL TESTING

The detailed description of the regional and local ore deposit geology is provided in Appendix 3. A description of the regional and local geology of Deposit No. 1, taken from Appendix 3, is provided below. For a description of the methods used in geochemical testing, please see Section 3.0 of Appendix 6B-1 of the Final Environmental Impact Statement.

3.1.1 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 north western 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
- amphibolites; 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.

3.1.2 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 a ~1300 m long northern portion and a ~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.

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.

3.1.3 Summary of Geochemical Sampling and Test Work

A mine rock ML/ARD report (*"Mine Rock ML/ARD Characterization Report Deposit 1, Mary River Project, March 2014."* Prepared by AMEC) is presented in Appendix 3 and provides the geochemical data for the waste rock characterization to the end of 2013. This report will be updated as additional field and laboratory data become available.

3.1.3.1 SAMPLING

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 2014). 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. An additional five boreholes including one in the hanging wall and four in the footwall (1290 m in total) were advanced in 2012 to specifically provide additional coverage of waste rock materials. Limited sampling of overburden material in the area has been completed.

The highly deformed nature of the deposit, the relatively high metamorphic grade and a lack of outcrop has largely restricted interpretation of waste material tonnages to a spatial (hanging wall and footwall) rather than a lithological basis. Thus, the waste material has been subdivided on the basis of zonal relationships around the iron ore for the hanging wall (HW) and footwall (FW). In 2011 spatial refinement of the waste rock model was completed that included subdivision of the HW and FW zones on the basis of broad geo-structural categories and observations of trends in observed sulphide mineralization. The subdivisions incorporate more schist dominated regions (hanging wall schist, HWS, and foot wall schist, 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 mineralized waste (MW) zone that has been identified as probable waste in the footwall. The boundaries of the subdivided waste rock distribution model were further refined in 2013 based on the additional 2012 drilling and characterization work.

For the detailed sampling programs conducted since 2010, samples were pre-selected using borehole logs within regular (~10 m) target intervals. All sampling was conducted or overseen by Baffinland geologists with experience at the deposit with the objective of selecting the most representative rock material within the target interval. Samples for ABA analysis comprised approximately one to two meter intervals of core.

For the 2011 and 2012 sampling programs the Baffinland geologists also systematically collected 10 to 15 cm of core that was visually representative of rock represented in adjacent ABA samples. ABA and mineralogy samples were described in the field according to standard rock coding for the site. It was recognized that the generally low NP and lack of carbonate as well as the low AP could add challenges to predicting the potential for acid generation for this project. Thus, a particular focus on the non-carbonate mineralogy was important.

For the 2012 waste rock drilling and sampling program sampling density for ABA analysis was increased slightly (~5-8 m) due to relatively low intersected rock volume afforded by this program from the relatively widely spaced boreholes. In addition, continuous sampling of each of the 2012 boreholes was completed at approximately 2m intervals with analysis for total sulphur and metals to assess down-hole continuity of mineralization in the waste units sampled.

In total for the entire waste rock volume 776 ABA and 376 mineralogy samples have been collected. An additional 259 samples have also been collected for the 2012 continuous sampling program described above.

3.1.3.2 Static Testing

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. Materials tested have primarily included waste rock (776 samples) with some testing of ore (21 samples) and overburden (7 near-surfaces outside of pit area).

Waste rock is characterized by generally low modified Sobek neutralization potentials (NP) and low sulphide contents with resulting low acid potentials (AP). Carbonate NP typically represents < 30% of the modified Sobek NP. Sulphide content in excess of 0.2% is generally predictive of an NPR (the ratio of NP/AP) less than 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 11% of waste rock is expected to be PAG.

The static ABA sampling program completed in 2011 included a component of mineralogical work (see below) to improve the overall understanding of ML/ARD of the waste rock and particularly the source of non-carbonate acid neutralizing potential in the waste rock. This, along with kinetic testing, has been identified as a critically important consideration to support and better understand the adequacy of non-carbonate neutralization capacity in waste rock to limit acidic drainage.

Overburden from the pit volume has not been specifically tested. However, selected samplings of overburden from potential borrow areas around the site and along the proposed Tote Road to the north have been completed (Knight Piésold 2008, AMEC 2010a). Testing of these largely glacially derived surficial materials indicated they were generally low in sulphide content and in many cases contained abundant carbonate presumably derived from the local Paleozoic carbonate rocks that outcrop in the region.

3.1.3.3 Mineralogy

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. Further information is available in Appendix 3, Section 4.3. Initial work was completed in 2012 and with follow up work initiated in 2013 and continuing.

3.1.3.3.1 Qualitative Mineralogy

Qualitative XRD work was completed on mineralogical samples collected in the 2011 field season. As expected, lithology plays a larger role in the mineralogy than the waste classification. Minerals that appeared in most samples were quartz and clinochlore. Micas (e.g. muscovite, phologopite and biotite) are also common among the samples. Other major rock forming minerals including feldspars, amphiboles (cummingtonite and hornblende) were also present throughout a variety of lithologies and waste classifications. A variety of garnets and hematite were also present in a number of samples. Magnetite and sometimes illite and talc were observed primarily in banded and high grade iron formation samples.

Pyrite was the only sulphide that was identified in the qualitative XRD. It was detected in banded and high grade iron formations, gniesses, metasediments, amphibolites and schists.

Carbonates that were detected include siderite, dolomite, ankerite and calcite. Siderite was observed only in the high grade iron formation samples and ankerite was observed only in the banded and high grade iron formation samples. Dolomite was observed in the banded and high grade iron formations, amphibolites and the metasediments. Calcite was present in the amphibolites, metasediments and the volcanic tuffs.

3.1.3.3.2 Detailed Mineralogy

A selection of 20 samples representing a range of waste types and lithologies was submitted for detailed mineralogical characterization with results provided in Appendix 3. An additional set of 28 samples representing a range of waste types, lithologies and ABA characteristics was submitted for detailed mineralogical analysis in 2013 and work is in progress.

Additional mineralogical work is underway so interpretation of the 2011 results is considered preliminary. Overall, the samples contain mineral assemblages typical of at least amphibolite metamorphic grade. Sixteen (16) of the twenty (20) samples contained sulphides and a variety were identified in the rocks studied. The sulphides pyrite (FeS_2), chalcopyrite ($CuFeS_2$), pyrrhotite ($Fe_{(1-x)}S$), and sphalerite (Fe,Zn)S were commonly identified as accessory minerals. Pentlandite, ($(Fe, Ni, Co)_9S_8$) was identified in three samples and marcasite (FeS_2) was identified in one (1) sample. Only one sample contained measurable amounts of pyrite (1.8 wt.%, by Rietveld analysis). No sulphides were identified in four (4) of the samples and all other samples contained sulphide in trace amounts.

In most cases the sulphides were disseminated and fresh without oxidized shells and often included within silicate minerals.

The major rock forming silicate minerals observed in this study include: quartz, feldspar (plagioclase and alkali feldspar), amphibole (cummingtonite and hornblende), biotite, muscovite, and chlorite. Plagioclase composition spanned the range from albite to anorthite composition with the latter when present likely to be more prone to more rapid weathering. The other major rock forming mineral was the oxide magnetite, which occurred in iron formation.

The rocks observed in this study can be subdivided into five groups based on the relative abundance of the major rock forming minerals: quartz-feldspar-rich, amphibolite (composed dominantly of amphibole and plagioclase), magnetite-rich, mica-rich (biotite and/or muscovite), and chlorite-rich. However, field lithological classifications (which may be based on additional textural information) generally do not coincide with the above subdivision. No carbonate minerals were identified in this study, however, the Leco carbon content of the corresponding ABA sample set (data not available at the time of sample selection) were all less than 0.21%. Carbonates may also be present as fracture fillings or coatings at spacings beyond that assessed in the detailed mineralogy.

3.1.3.4 Kinetic Testing

Ten (10) waste rock samples were run in humidity cells for 53 weeks in 2008 and 2009. A further 17 waste rock samples were initiated in humidity cell tests in May 2011 for between 109 and 120 weeks of reported data. Nine (9) of these samples were standard humidity cells and eight (8) were NP depleted humidity cells designed to assess drainage quality in the absence of carbonate NP. The pH of most cells was in the range of 5.5 to 7 throughout testing. Of the 17 cells in operation since 2011, three cells exhibited slowly declining pH throughout testing reaching a minimum measured weakly acidic pH of between 4.5 and 5 after approximately two (2) years of operation (under laboratory conditions). Selected humidity cell tests are planned to continue.

Kinetic testing results and cold climate conditions at site suggest the lag time to acid on-set in PAG rock would be on the order of five (5) years or longer.

Total sulphide content of samples is weakly correlated with sulphate release rates; however, through the current periods of testing metal release rates and trends vary among the cells. Though metal release rates are generally low in most cells, release rates are the highest in the lower pH humidity cells with notable release rates for cadmium, cobalt, copper, nickle, lead and zinc in two (2) cells which also contain near worst case solid concentrations for these metals in Deposit 1 mine rock.

Work is continuing on mineralogical characteristics and kinetic testing to improve the understanding of the long term behaviour of the low NP and low AP PAG waste rock materials.

3.2 Field Test Piles

Work is continuing to confirm the feasibility of developing field test pads at the site using selected waste rock material generated during early mine development. If feasible, field test piles will be setup and instrumented for both thermal monitoring and drainage quality. Operation and monitoring of such test piles would better inform the project about projected drainage quality and water quality modeling assumptions under site-specific cold climate conditions. Where field test piles are established, laboratory testing representative of the test pile material will also be completed to provide direct comparison and insight into the scaling factors from laboratory to field.

3.3 Construction of the Waste Rock Stockpile

3.3.1 Deposition Strategy

The low quantities of PAG material identified in hanging wall and footwall rocks, and the apparently slow sulphide reactivity, supports the planned management of PAG materials by encapsulation in a permafrost core of the constructed stockpile and the outer 50m of the dump being constructed of non-PAG material.

Because of the northern location, it is likely that the majority of waste rock area material will be permanently frozen, and that only the upper surficial material will be subject to seasonal freezing and thawing. The frozen material is expected to form an effective barrier for acid-forming reactions since liquid water is largely unavailable and this will limit the potential for sulphide oxidation.

Waste rock will be deposited in lifts, using deposition methods that would enhance permafrost aggradations into the Waste Rock Stockpile using the guidelines presented in Section 3.3.2. As far as possible, a bottom layer of non-PAG waste rock will be placed while the ground is frozen allowing the level of permafrost to rise in elevation by conduction. It expected that a permanently frozen impermeable core will form in the waste rock storage area within the first few years after placement. The technical memorandum on the development of permafrost in waste rock stockpiles is included in Appendix 2.

Studies of waste rock in permafrost demonstrate that these frozen layers form an effective barrier to water and oxygen, thereby preventing significant oxidation of sulphidic waste rock located below the surficial active zone. The surficial “active” layer, which will be subject to seasonal freeze-thaw, will be constructed of non acid generating rock as the waste rock stockpile develops.

Therefore, over the long term, runoff water quality which is influenced by contact water that flows through the active layer in the waste rock stockpile will not be affected.

3.3.2 Guidelines Used to Develop the Waste Rock Stockpile

The design of the waste rock storage area is based on the conservative assumption that up to 20% of the waste rock could be potentially acid-generating. The design guidelines which follow will develop over time as the results of any on-going studies and site specific experience developed:

- A 2- to 3-m thermal barrier of non-PAG waste rock will be placed during the winter months to protect the permafrost layer during the summer months and allow development of the permafrost through conduction
- PAG waste rock should be segregated from non-PAG rock and encapsulated within the pile
- At closure, the active layer of the waste dumps should consist of non-PAG rock
- Final toe 100 m from the final pit crest, to be reviewed after further geotechnical drilling and stability analysis
- 2:1 (H:V) overall slopes
- 1.5:1 (H:V) individual lift slopes
- 10-m lifts, triple-benching (30 m benches)
- 15-m berms between benches
- 150-m segments (5 benches)
- Upper segment (above 680 m elev.) toe moved back 120 m from crest of bottom segment (below 680 m elev.)
- No overburden or PAG rock in the upper segment
- No overburden or PAG rock in the in-pit dump
- Overburden or PAG rock contained within a cell of non PAG
- Overburden located in southeast corner (with short haul in case needed for reclamation); and
- PAG rock all in same watershed in the waste rock stockpile.
- Haul ramps for the waste stockpile are similar in design to those within the pit at 33 m wide with 10% grade. Final access ramps are from the east and west sides of the pit, tying into the pit design.
- Overburden is surrounded with non-PAG waste rock to steepen the slopes. A separate overburden structure would require shallower slopes of 2.5:1 (H:V) and would result in a larger footprint. Enclosing the overburden slopes within the non PAG rock was chosen as a preferred option.
- The perimeter of the waste rock stockpile will be a minimum of 31 m from any water body.

For the conceptual arrangement and relationship in the waste rock storage area between the potentially acid-generating (PAG) rock and overburden cores (OB), and non-PAG waste rock cover, see Figure 3-1 (AMEC 2010b).

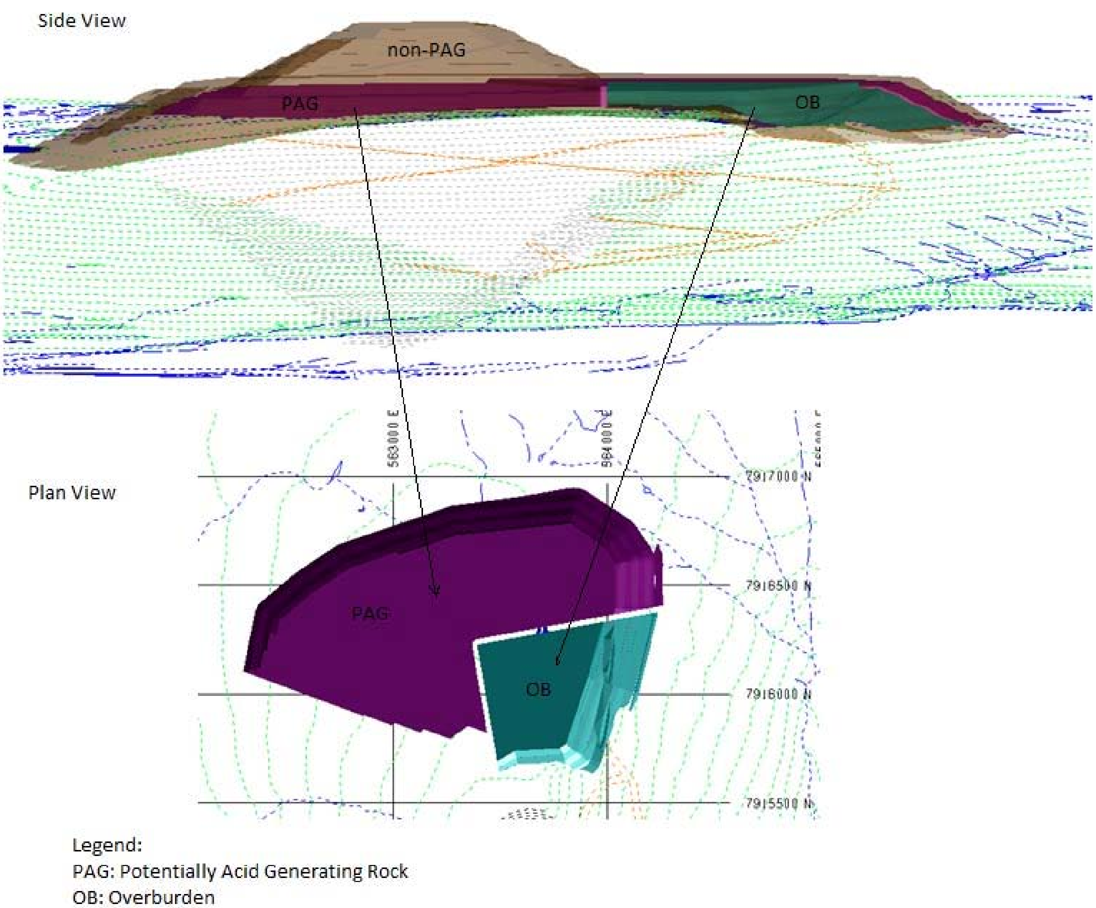


FIGURE 3-1: PLACEMENT OF WASTE ROCK

3.4 Quantities of Waste Rock Generated Over Mine Life

A modification of the mining plan has resulted in a smaller tonnage of waste rock being produced in the earlier years of operations. The new mining plan produces up to 3.5 Mt of direct shipping ore annually during the first five years of operations and a total of 17.4 Mt of waste rock during years 1-5, none of which is PAG, Following construction of the rail line and Steensby Port, production of ore and waste will increase quickly with a total of about 640 Mt of waste rock and 32 Mt of overburden produced over the thirty year mine life. Of this total up to 145 Mt may be PAG.

The volume of waste rock delivered to the waste rock storage area is recorded and may be reported as required.

3.5 PHASING OF WASTE ROCK DEPOSITION OVER TIME

For a conceptual schematic of the expected development of the waste rock stockpile footprint over the life of the mine, see Figure 3.2 (AMEC 2010b). The initial waste rock storage layout for the first five years of mining, Phase 1 of the waste rock stockpile, is illustrated in Appendix 6, Phase 1 Waste Rock Management Plan, (BAF-PH1-830-P16-0029). As additional geochemical, geotechnical, and geological data are collected, and the detailed engineering is completed, the waste rock plan will be optimized based on the application of best management practices and efficiencies.

During the life-of-mine, a geotechnical investigation will be carried out in areas where there are potential instabilities. These results will be incorporated into the ongoing detailed mine plan. Specifically a stability analysis of the waste rock stockpile and the open pit will be carried out to show that the combined structures are stable (refer to “Slope Stability Analysis for the Waste Rock Dump” presented in Volume 3, Appendix 3B, Attachment 4).

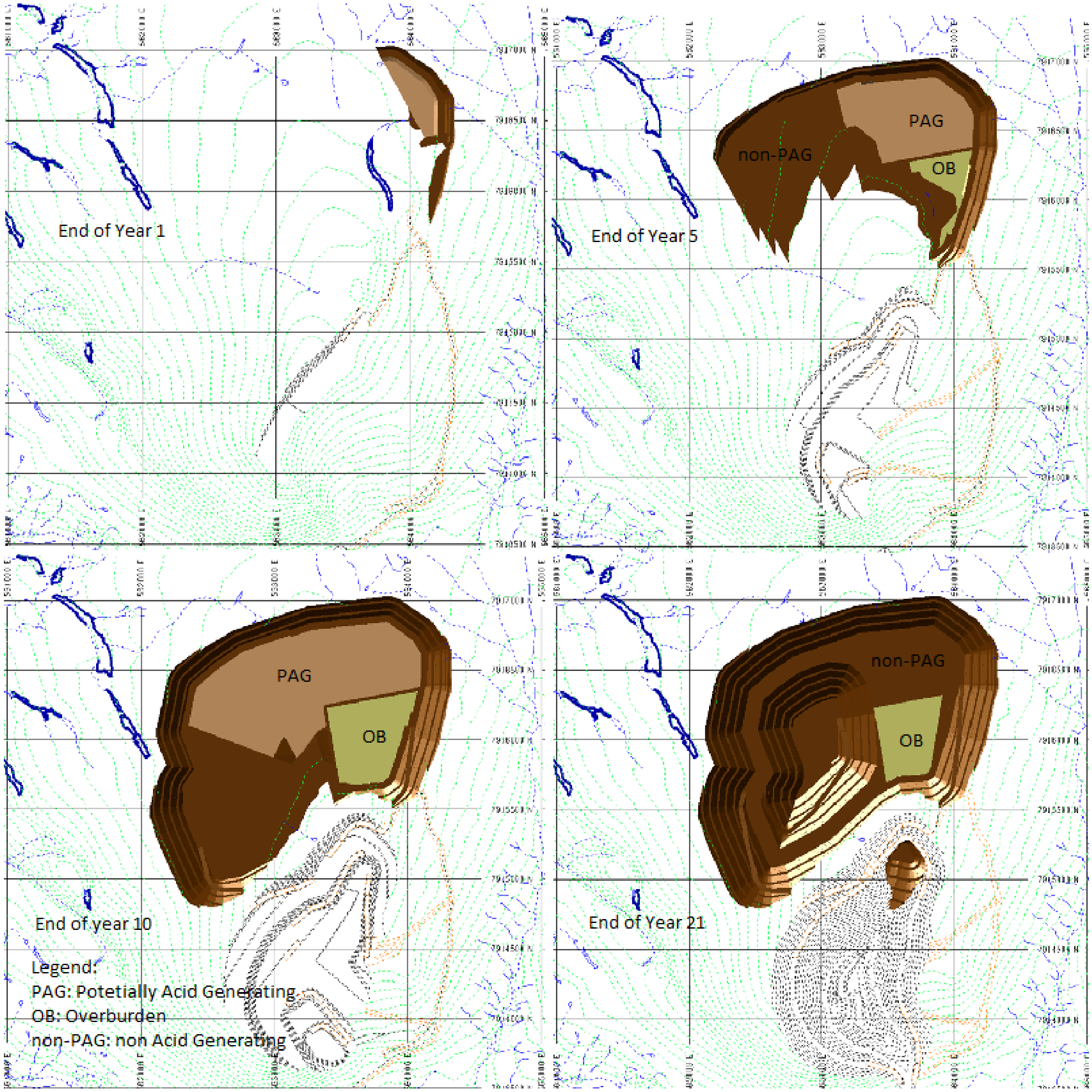


FIGURE 3-2: EVOLUTION OF THE WASTE ROCK STOCKPILE OVER THE LIFE-OF-MINE

3.6 ORE STORAGE

Ore mined in the pit will be dumped on a small run-of-mine (ROM) stockpile located near the mobile crusher located on the South side of the pit. The capacity of the ROM stockpile is expected to be in the order of 3,500 t.

Following crushing, the ore is loaded directly into ore transport trucks for transport to Milne Port. Since ore will be stored in these locations only temporarily and the drainage during operations is controlled, there is little concern about long-term potential effects of PAG material stored at these locations. Runoff Management and Monitoring

The stormwater management system with the associated dam safety assessment and dam design is included in "Stormwater Management and drainage system design" (H337697-0000-10-122-0001) in Appendix 1

3.6.1 Waste Rock Stockpile Area

The first phase of runoff management for years 1-5 for the waste rock stockpile area will consist of channels formed by berms around the stockpile perimeter produced by two roads one on each side of the waste dump. These will channel the run off downstream of the waste dump where a sedimentation pond is formed by construction of a berm about 3 m high. The pond will be lined and is sized to contain the 1:100 year storm event falling on the dump area. Clean, non contact water from upstream of the waste dump will be diverted around the dump by upstream diversion berms. The sedimentation pond will have an overflow weir capable of passing the 1:200 year storm event.

Further phased drainage management berms and ponds will be designed as mining progresses. All phases of the run off management system are designed such that the discharge from sedimentation ponds flows directly into existing water courses such that surface erosion is minimized and no additional impacts are created.

The final run off management system for the waste rock storage area is shown in Figure 3-3 and will consist of collection berms around the perimeter and two appropriately sized surface water management (SWM) ponds. The system is designed to operate on the following basis:

- Clean or "non-contact" water will be diverted away from the waste rock stockpile to minimize the volume of water that comes into contact with the waste rock (contact water). The non-contact waters will be discharged (drain) into their respective watersheds.
- During freshet, runoff will be contained in two SWM ponds indicated in Figure 3-3 where suspended solids will settle out. Both SWM ponds are sized to contain the two (2) year return event for sedimentation purposes.
- The larger "west" SWM pond, of 700,000 m^3 capacity and located west of the open pit and southwest of the waste rock stockpile, and will decant water to an existing drainage that leads to Camp Lake tributary 1 with final discharge intro Camp Lake.
- The smaller "east" SWM pond, of 400,000 m^3 capacity and will discharge to an existing drainage that reports to a tributary of the Mary River.

The volume of sediment to be collected in the SWM ponds will vary from year to year. Ponds will be inspected after freshet and the sediment removed when required. The sediment is non-toxic and will be hauled to the waste rock stockpile for disposal.

Collection berms will be designed during the detailed design phase when the final configuration of the stockpile has been determined.

The SWM pond collection system will be monitored for runoff quality and compared with MMER criteria. Berms rather than ditches will be used to provide drainage diversions in consideration of the challenges in the arctic, e.g., ice-rich soils and lenses. Berm construction is designed to maintain the frozen layer and prevent any subsurface flow or flows that would undermine the berms.

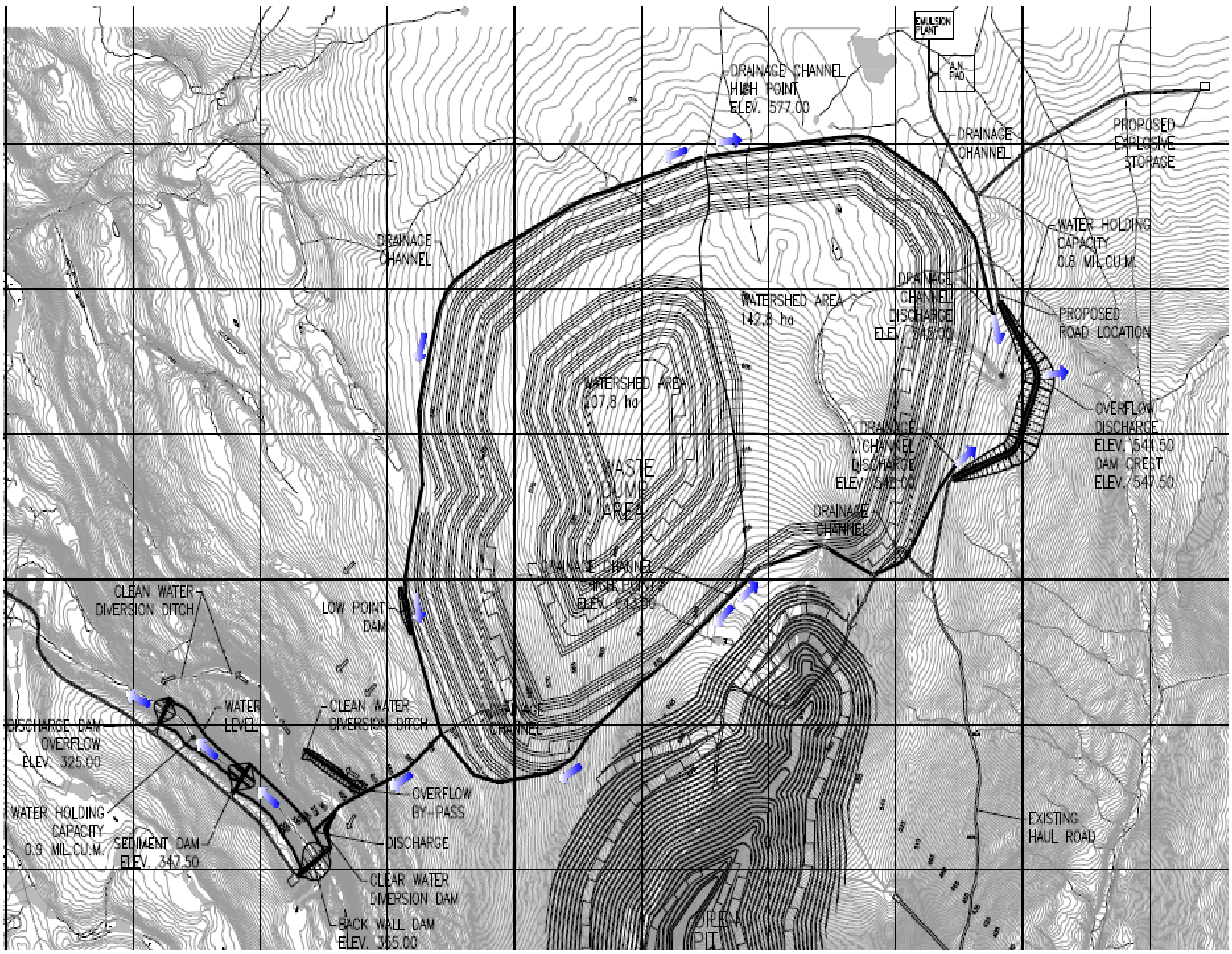


FIGURE 3-3: WATER MANAGEMENT STRUCTURES FOR THE WASTE ROCK STORAGE AREA

3.6.2 Mining Area Run-off

Runoff from the mining area/open pit will require sedimentation to meet TSS requirement before discharge. This will be sent to the Life-of-Mine East SWP for sedimentation before discharge.

3.6.3 Run-off Water Quality

Snow will accumulate in the waste rock stockpile during the winter and during the summer the melted snow along with any rainfall will seep through the active zone runoff the sides of the dump or drain from the foot of the perimeter of the dump. The estimate of waste rock stockpile run-off water quality is presented in Appendix 4, "Interim Waste Rock Stockpile Seepage Quality Model Report, Mary River Project". Dated January 2012. Prepared by AMEC. This shows that, following sedimentation, runoff from seepage of water through the waste rock meets all the MMER discharge requirements.

Run-off from the open pit area has also been modelled and the results presented in Appendix 5, "Interim Open Pit Water Quality Model Technical Memorandum, Mary River Project". January 2012. Prepared by AMEC. This shows that, following sedimentation, open pit area runoff meets the MMER discharge requirements.

This modelling does not take into account the potential for explosive residue material remaining on the waste rock after blasting to be dissolved by seepage water as ammonium or nitrate ions and carried downstream. This can lead to nitrate and/or ammonia levels in receiving water bodies exceeding acute toxicity limits.

With the use of modern emulsified explosives the potential to dissolve in water is very low and with the use of best management practices in explosives handling and blasting the risk is considered to be very low. As such no treatment of mine effluent for ammonia or nitrate is anticipated to be required.

Experience acquired at the Diavik mine indicates that the use of good SOP and best management practice for handling and loading of explosives in blastholes can reduces losses of explosives.

3.6.4 Run-off Water Treatment Alternative

Water quality modelling (Appendices 4 and 5) indicates that the waste rock pile and open pit area runoff water will not contain concentrations of metals in excess of discharge requirements based upon the Metal Mining Effluent Regulations. In addition, ammonia and nitrate in runoff are not expected to cause receiving water impacts or regulatory exceedances.

However, In the event that ongoing WQ modelling or field monitoring shows a trend toward exceedance of discharge requirements, then water treatment facilities will be constructed.

A review of the treatment schemes that were considered for both metal and ammonia/nitrate removal follows:

3.6.4.1 Potential Runoff Water Treatment Alternatives for Metal Removal

Resins

The ion exchange resins are insoluble matrices usually in the form of small diameter balls. This material is structured to present a multitude of pores on the surface to trap metal ions in the case of contaminated mine drainage. A variety of this material is available on the market, each resin should be chosen based on the elements to be captured. This technology has been set aside until more detailed waste characteristics are available to establish the operating costs for such a system. In addition, the operation of ion exchange equipment is quite complex and this is a key concern for this site.

Polymer Addition

Certain polymers are able to effectively precipitate the Nickel. However the chemical costs for these proprietary chemicals is not considered cost-effective. This will be reviewed when more detailed waste characteristics are available.

Sodium Hydrosulfite Treatment

Sodium hydrosulfite is added to cause metals to precipitate as sulphides which can then be sold for further processing to recover the metals. The precipitated metals and water are pumped into a clarifier where the treated water is discharged into the environment and solids are removed to be managed. This process has been set aside until more detailed waste characteristics are available to establish economic feasibility of such a system.

Ozonation

The ozonation process is mainly used for the treatment of drinking water. Ozone is generated from oxygen in the air. Subsequently, ozone is bubbled into the water to be treated. Ozone oxidizes the transition metals to their higher oxidation states in which they usually form less soluble oxides and are easy to remove by filtration. Metals that can be removed in this way include Fe, Cd, Cr, Co, Cu, Pb, Mn, Ni and Zn. This method produces very little sludge however the purchase of an ozone generator capable of treating a continuous flow of water is very expensive. In addition, costs in energy consumption could be high. As such this treatment method has been discounted.

Biofilters-Sulphide Precipitation

The principle of biofiltration is used for many applications in the treatment of water for many years. It consists of passing water to be treated through a granular bed where a biofilm will be developed by microorganisms. In the case of water contaminated with metals, the sulphate-reducing bacteria will result in the precipitation of metal sulphides and thus removing metals from the effluent. The bacteria moderated process requires constant operating conditions which are difficult to maintain in site conditions for a plant at Mary River and this technique is not considered appropriate.

Activated Carbon

Activated carbon has a microporous structure which gives the material a high adsorption capacity. As water passes through a carbon filled filter vessel metals are adsorbed and the water treated is discharged. After saturation, the carbon is “stripped” of the contaminants and regenerated. The costs and complexity associated with this option mean that it will not be considered further.

Lime Precipitation

By far, the most commonly used commercial process for treating metal contaminated mine drainage is lime precipitation where an aqueous solution of CaCO3 precipitates metals as solid hydroxides which are then removed as a sludge. Although several other processes are also possible for metal removal, in this situation the simplicity of the system operation is a key requirement and as such lime treatment is the preferred technique as this is the simplest most reliable operation.

Contaminated waste rock run-off water will be directed through the sedimentation pond where suspended solids will settle out. The run-off water will then be pumped into the lime treatment plant. The first step is one where the drainage is neutralized in a mix tank with controlled addition of lime to attain a desired pH set-point (see figure 3-4).

The slurry is then contacted to a flocculants and fed to a clarifier for solid/liquid separation. Some sludge is recycled from the bottom of the clarifier to the neutralization tank. The clarifier overflow may be released directly or a sand filtration system or polishing pond may be used to further reduce residual suspended solids. It should be noted that several heavy metals will be precipitated during this process (Al, Co, Cu, Fe, Pb, Zn…).

The effluent leaves the system to be discharged to the environment (after controlling for pH) and the sludge is collected and dewatered before disposal. Carbon dioxide will be used for pH control. It reduces high pH levels quickly. It is not stored as an acid solution so it is considered safer than sulphuric acid and it is non-corrosive to pipes and equipment and requires less equipment and monitoring costs.

Note that the effectiveness of a treatment with NaOH (caustic) is similar to that obtained with lime. However, this product is more difficult to handle and more expensive.

Figure 3-4 below shows an example of the lime treatment system.

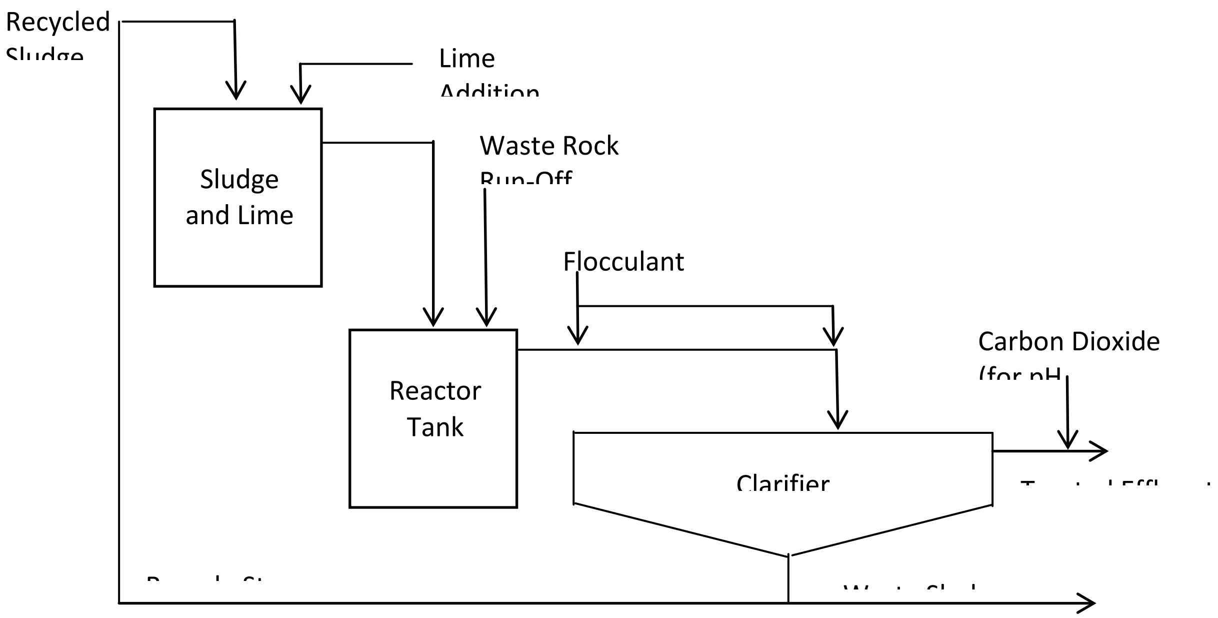


FIGURE 3-4: LIME TREATMENT SYSTEM

If required, the batch run-off treatment system will be located in the main infrastructure area to the South of the West SWP. The treatment system will discharge by pipeline directly to Mary River during the summer months. Run-off requiring treatment would be trucked to this facility from the other ore and waste rock run-off ponds at the mine site.

The final location and configuration of the outfall from the facility will be determined during final design. The sludge generated in the treatment facility will be tested before disposal for leachate toxicity characteristics. If suitable it will be disposed of in the landfill or in a designated location within the waste rock stockpile. If it fails the test and is designated as hazardous then it will be dried and shipped off-site for disposal.

3.6.4.2 Potential Runoff Water Treatment Alternatives for Ammonia/Nitrate Removal

The main risk of explosive residues in water is acute toxicity of effluent discharge. MMER discharges cannot be acutely toxic to the receiving environment.

Given the oxidising conditions of the system it is expected that nitrate will be more likely than ammonia to be present in run-off.

Nitrate and ammonia removal technologies can be divided into three categories. These categories are ion exchange, electrochemical ion exchange and biological de-nitrification.

Biological De-nitrification (for removal of both ammonia and nitrate)

Ammonia is typically removed from wastewater via biological nitrification according to the following two-step reaction; the first step is moderated by Nitrosomonas bacteria, the second by Nitrobacter bacteria. The nitrification process results in the end formation of the nitrate ion and the nitrates then converted to nitrogen gas in a process known as biological denitrification.

The bacteria moderated process requires constant operating conditions which are difficult to maintain in site conditions for a plant at Mary River and this technique is not considered appropriate.

Ion Exchange

Nitrate: Nitrates are soluble and cannot be treated via neutralization or precipitation, but they can be removed via ion exchange. A strong-base anion resin is typically used; however, it will attract sulfates even more readily than nitrates. This can be a capacity problem for nitrate removal if sulphate levels are high, so more selective nitrate resins should be used when this is the case. Both resins are regenerated with sodium or calcium salts. This process produces a brine waste that must be handled.

Ammonia: Ion exchange systems treat ammonia effectively. The choice of resin depends on the other cations and anions in the wastewater that may interfere. The process produces a brine waste that must be handled.

Electro-Chemical Ion Exchange

Electrochemical ion exchange is relatively untested but does not generate a waste stream.

In this two-stage system ion-exchange (IX) is the first stage in which the ammonia is removed from the wastewater. Once the IX media is loaded with ammonium, the media is regenerated by circulating a brine solution through the column. The ammonium ion is transferred into the regenerant solution and is subsequently oxidized to N_2 gas using an electrochemical reactor. Thus, the regenerant solution can be continuously reused.

In the case of nitrate removal the nitrate is removed by a selective ion exchange resin first. Once the IX media is loaded with nitrate, the media is regenerated by circulating a brine solution through the column. The nitrate ion is transferred into the regenerant solution and is subsequently reduced to N_2 gas using an electrochemical reactor. Thus, the regenerant solution can be continuously reused.

Breakpoint Chlorination of Ammonia

In the breakpoint chlorination process, chlorine is added to wastewater to chemically oxidize ammonium ions to various products (primarily nitrogen gas); under proper operating conditions, 95 to 99% of the ammonia-nitrogen in wastewater can be converted to nitrogen gas. The system is simple and cost-effective.

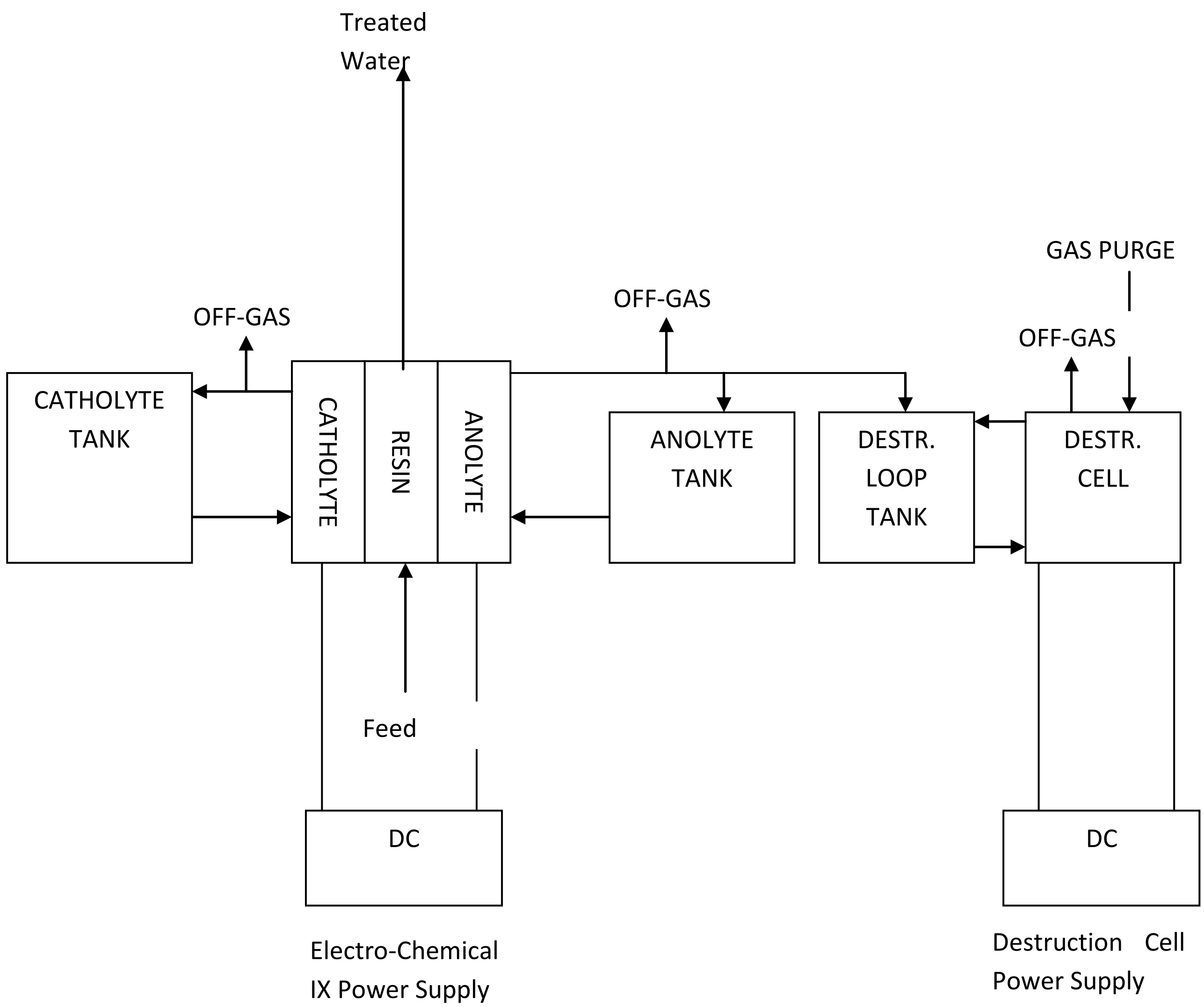
Preferred Potential Treatment method for Nitrate/Ammonia removal

Based upon the descriptions of the various process options above if a nitrate removal system is deemed necessary it would be electro-chemical ion exchange. Although this system has a relatively high capital cost the operating costs are low, there is no waste stream to handle and it does not have the difficulties with varying feed concentrations that biological treatment systems have.

Ammonia would be removed through breakpoint chlorination method.

A schematic of the proposed electro-chemical ion exchange process is given below:

Electro-Chemical Ion Exchange



4 CLOSURE

Full details of project closure are included in the existing Interim Mine Closure & Reclamation Plan (BAF-PH1-830-P16-0012), and the approved Preliminary Mine Closure and Reclamation Plan (H339697-0000-07-126 0014) to be found in FEIS Appendix 10G. At closure the principal objectives are the safety of the public and maintaining the physical and chemical stability of the permanent structure to ensure that there is no long-term environmental impact.

Mine planning will ensure that at closure the exterior of the dump consists of a layer of non-PAG material up to 50 m thick. To minimize active layer thickness a stockpile of overburden will be retained to spread a layer of less permeable material over the top of the dump.

4.1 CLIMATE CHANGE CONSIDERATIONS

Studies of waste rock in permafrost demonstrate that permafrost forms an effective long-term barrier to water and oxygen, thereby preventing significant oxidation of sulphidic waste rock located below the surficial active zone. The surficial "active" zone, which will be subject to seasonal freeze-thaw, will not reach the 50m thickness of non-PAG material in the long-term (within 200 years) under the influence of climate change (Intergovernmental Panel on Climate Change, 2007).

Therefore, over the long term, runoff water quality which is influenced by contact water that flows through the active layer in the waste rock stockpile will not be affected.

5 ROLES AND RESPONSIBILITIES

For roles and responsibilities for implementation of the Waste Rock Management Plan, see Table 5-1.

TABLE 5-1: ROLES AND RESPONSIBILITIES

Position	Responsibility
VP Sustainability	• Accountable for environmental performance of the mining operation. • Establishes goals and targets for environmental performance.
EHS Superintendent	• Responsible for implementing Baffinland Environmental Management Plans. • Provides direction on environmental issues to the Site Management Team. • Responsible for staffing Environmental Department. • Supervises/conducts site inspection and audits. • Initiates and manages environmental studies as required. • Manages external environmental consultants/specialists. • Responsible for environmental reporting as required by permits and authorizations. • Responsible for liaison with regulatory agencies on all environmentally related issues.
Environmental Consultants	• Provide specialist advice and input on environmental matters. • Conduct environmental studies and monitoring programs. • Conduct audits of operations, as requested. • Prepare environmental reports.
Contractors/Subcontractors	• Contractors/subcontractors are considered equivalent to Baffinland staff in all aspects of environmental management and control and their responsibilities in this respect mirror those of Baffinland personnel. Contractor personnel will be included in the onsite induction process. • Contractors/subcontractors are responsible for complying with the requirements of the EPP. • Responsibilities of the contractors/subcontractors supervisors include the following: ◆ Conducting regular site checks/inspections to ensure that regular maintenance is undertaken to minimize environmental impacts; and ◆ Providing personnel with appropriate environmental toolbox/tailgate meetings and training.

6 PERFORMANCE INDICATORS AND THRESHOLDS

Runoff quality from the waste rock and ore storage runoff management ponds is the most relevant environmental performance indicator. Discharge from these ponds shall not exceed the effluent quality limits of Part F, Item 25 in Type A Water Licence 2AM-MRY1325 and site-specific indicators shown in Table 6-1.

TABLE 6-1: DISCHARGE PERFORMANCE INDICATORS AND THRESHOLDS

Indicator	Units	Maximum Concentration of Any Grab Sample
pH		$6.0 < pH < 9.5$
Ammonia	mg/L	Monitored but not regulated
Nitrate	mg/L	Monitored but not regulated
Sulphate	mg/L	To be established
Arsenic	mg/L	0.5
Copper	mg/L	0.30
Lead	mg/L	0.20
Nickel	mg/L	0.50
Zinc	mg/L	0.5
TSS	mg/L	15
Oil and Grease		No visible sheen
Toxicity		Non-Acutely Toxic

In addition, Environmental Effects Monitoring or biological monitoring will be carried out as required by MMER.

Conductivity, pH and sulphate will be used as early-warning indicators to identify potential acid generation in the waste rock storage area. Ammonia and Nitrate will be monitored in run-off to ensure that no explosive material remaining on the blasted waste rock has been dissolved by water infiltrating the active layer.

Any contaminants of potential concern identified from on-going testing will be measured to provide temporal data on effluent quality that could potentially affect the receiving water quality.

The Aquatic Effects Monitoring Plan (AEMP) will be implemented to monitor environmental effects of effluent discharge from the SWM ponds at Mary River. Results of the AEMP can trigger additional adaptive management actions such as further treatment of pond effluent, if required.

7 MONITORING AND REPORTING REQUIREMENTS

7.1 EFFLUENT QUALITY MONITORING

Effluent quality monitoring consists of acute toxicity test work and effluent quality monitoring. All water quality monitoring locations are shown in the Environmental Monitoring Plan.

7.1.1 ACUTE TOXICITY TESTING

For the requirements of the acute toxicity test work, see MMER Schedule 5 and the Aquatic Effects Monitoring Plan.

7.1.2 WATER QUALITY MONITORING

Monthly water quality monitoring (starting after freshet until end of September) will include the following information and analyses:

- Sampling location
- Temperature of the water
- Specific conductance; TSS.
- pH, alkalinity, acidity
- Concentrations of ammonia, sulphate and nitrate
- Concentrations of arsenic, copper, lead, nickel, zinc

Annual water quality monitoring will include the monthly analyses, plus mercury, aluminum, cadmium, chromium, iron, and molybdenum.

7.1.3 GROUND TEMPERATURE MONITORING

Following consultation with experts from NRCan, the appropriate instrumentation will be installed in the waste rock stockpile to monitor ground temperatures and confirm the aggradations of permafrost within the waste rock stockpile and the thickness of the active layer.

Data from temperature sensors installed to monitor the ground temperatures will be collected on a regular basis and used to ensure that frozen conditions are maintained below the waste rock stockpile. In addition, the data will be used to calibrate the waste rock stockpile thermal model.

Baffinland will carry out thermal modeling of the waste rock stockpile when suitable data is available to demonstrate the robustness of the proposed waste rock stockpile deposition design and confirm that frozen conditions are maintained in the waste rock stockpile. This will take long-term climate change into account (200 years).

In the detailed design phase, a geotechnical investigation will be carried out in areas where there are potential instabilities. These results will be incorporated into the detailed design. Specifically a stability analysis of the waste rock stockpile and the open pit will be carried out to show that the combined structures are stable (refer to "Slope Stability Analysis for the Waste Rock Dump" presented in Volume 3, Appendix 3B, Attachment 4).

7.1.4 QA/QC

The QA/QC best practices that are outlined are designed to provide guidance to field staff and analytical laboratories to maintain a high level of confidence in the water quality data generated from the Project. The plan addresses best practice methods for water samples collected from lakes, streams, and rivers, treated wastewater effluent, drinking water, and site drainage.

7.2 Data Management

The EHS Superintendent is responsible for data management and reporting related to waste management. The data management system includes conducting routine inspections and monitoring, and providing these results to appropriate parties as required.

7.3 Reporting

An annual monitoring report will be submitted to the NIRB, NWB, QIA and other interested parties. The report will indicate:

- Dates on which each sample was collected for effluent characterization, sub-lethal toxicity testing, and water quality monitoring
- Location of the final discharge points from which samples were collected for effluent characterization
- Location of the final discharge point from which samples were collected for sublethal toxicity testing and the data on which selection of the final discharge point was based, in compliance with the MMER
- Latitude and longitude coordinates of sampling areas for water quality monitoring
- Results of effluent characterization, sublethal toxicity testing, and water quality monitoring;
- Methodologies used to conduct effluent characterization and water quality monitoring, and related method detection limits
- Charts showing trends in ground surface temperatures below and within the waste rock stockpile; and
- Description of quality assurance and quality control measures implemented and data related to implementation of those measures.

8 ADAPTIVE STRATEGIES

Baffinland is committed to continuous improvement in its work activities to reduce risks to the environment and improve operational effectiveness. The strategy employed at Baffinland is regular monitoring supported by operational change and adoption of other mitigation measures if warranted.

For the waste rock stockpile, information obtained over the life of the Project from the on-going characterisation of the waste rock will provide the basis for most modification or changes introduced in deposition strategy, runoff management and eventual closure.

As per the requirements of Baffinland's Environmental, Health, and Safety (HSE) Management Framework to be found in FEIS Volume 10 - Appendix 10A, Baffinland will conduct and document regular management reviews of its Waste Rock Management Plan. Such reviews will ensure monitoring results for the waste management plan are integrated with other aspects of the Project and that necessary adjustments are implemented as required. These reviews also provide a formal mechanism to assess the effectiveness of management in achieving company objectives and maintaining ongoing compliance with Project permits and authorizations.

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Appendix 1:
Stormwater Management and Drainage System Design

Stormwater Management and Drainage System Design

2011-11-09	B	Approved for Use – Environmental Permit	R. Zhou	D. Sanchez	J. Binns	
2011-10-06	A	Internal Review	R. Zhou	D. Sanchez		
DATE	REV.	STATUS	PREPARED BY	CHECKED BY	APPROVED BY	APPROVED BY
YYYY-MM-DD		HATCH				CLIENT

Table of Contents

Attachments

1. Introduction

The Mary River Project is a proposed iron ore mine and associated facilities located in northern Baffin Island, in the Qikiqtani Region of Nunavut. The Project involves the construction, operation, closure, and reclamation of a 18 million tonne-per-annum open pit mine that will operate for 21 years. The high-grade iron ore to be mined is suitable for international shipment after only crushing and screening with no chemical processing facilities. A railway system will transport ore from the mine area to an all-season deep-water port and ship loading facility at Steensby Port where to ore will be loaded into ore carriers for overseas shipment through Foxe Basin.

The project consists of the construction, operation, closure, and reclamation of an open pit mine and associated infrastructures for extraction, transportation and shipment of iron ore from two newly constructed ports at Milne inlet and Steensby inlet. After crushing and screening, iron ore will be transported from the Mine Site to the Ports for shipment.

The development requires managing stormwater runoff and flow by a well designed stormwater management system to reduce impacts of the development on the environment.

This design memo describes the stormwater water management and drainage system for the Mine Site, the Milne Port and the Steensby inlet.

2. Design Criteria and General Design Considerations

2.1 Objectives

The objectives of the design for the stormwater management and drainage are to provide: i) a safe and efficient stormwater drainage scheme that will minimize disruptions to the mine and operations (including construction) during wet weather periods, while minimizing the potential for negative impacts to the environment in the event of an uncontrolled release of stormwater runoff, ii) intercept and divert clean stormwater from undisturbed areas, and iii) provide peak flow reduction to mitigate flooding of the downstream areas.

2.2 Design Criteria

2.2.1 Surface Drainage

The general criteria for the stormwater management system is described below. Where applicable the criteria described correspond to that described in the Civil Design Criteria.

- All interior site grading and roads will be designed to provide continuous overland flow without erosion to a drainage ditch system.
- Provision must be made to ensure that there is a safe flow path for events up to the 1 in 10-year event, such that the runoff will not flood key mining areas, cause significant erosion, pick up excessive contaminants or cause other significant problems.

2.2.2 *External Surface Drainage*

Additional criteria for drainage of the external area are as follows:

- Run-off from undisturbed areas surrounding the mine site should be collected in clean-water perimeter ditches and diverted around and / or through the site perimeter.
- To the extent possible, these perimeter ditches will be designed to discharge at locations that best retain the characteristics of the existing (i.e., pre-development) natural drainage patterns.
- Clean water diversion ditches shall be designed to convey the 100-year flood event.

2.2.3 *Stormwater and Sediment Ponds*

Stormwater management ponds are designed to:

- Safely pass the Inflow design flood that meet CDA dam safety guidelines
- Reduce flooding in the downstream area
- Remove sediment concentration to meet the 15 mg/L discharge standard
- Be stable under design earthquake conditions
- Be stable under worst load conditions as required by CDA dam safety guidelines.

2.3 Dam Safety Assessment

The stormwater and sediment management ponds need embankment structures to create the required storages. These embankment structures meet the definition of dams (2 meters of height and retains more than 30,000 m^3 of water) and hence must follow the dam safety guidelines of the Canada Dam Association (2007). A dam classification is needed to determine many of the design parameters (such as the inflow design flood (IDF), and the design earthquake (DE)). The detailed dam safety assessment will be discussed in Appendix A.

3. Stormwater / Sediment Management and Drainage Systems

3.1 Mine Site

The general layout of the mine site development is presented in drawing no. H337696-4210-10-014-0001. The mine site stormwater management system includes dirty flow collecting ditches, clean water diversion ditches, and stormwater / sediment ponds. There are two main areas where stormwater management systems are required. One area is the treatment of stormwater and sediments surrounding the waste rock stockpile north of the main pit, and the other area is the treatment of stormwater and sediments surrounding the ore stockpile platform. The following sections discuss the two area's specific features.

3.1.1 *Waste Dump Stockpile Area*

Figure 3-1 shows the ditches and stormwater ponds for the treatment of the storm water runoff from the waste dump stockpile area. From Figure 3-1, the waste dump stockpile is surrounded by runoff collecting ditches. The ditches have four segments.

- Segment 1 (northeast portion) collects runoff from the waste dump stockpile and carries flow to the east then to the south down to Stormwater Pond 2.
- Segment 2 (Southeast portion) receives runoff from the waste dump stockpile and flows mainly to the east and discharges into Pond 2.
- Segment 3 (Northwest portion) collects stormwater and flows to the west then to the south and releases the water into Pond 1.
- Segment 4 (South West portion) collects flows from the waste dump area and flows mainly to the west then discharges flow into Pond 1.
- Between Pond 1 and the waste dump stockpile area, there is a large area where no development is planned and there will be no disturbance to the runoff generated from the area. The water is therefore clean. The flow from this area will, however, flow down in the south direction and will be discharged into Pond 1. This will lead to unnecessary treatment of clean water by Pond 1 reducing the sediment removal efficiency or increasing the pond storage requirement. In order to avoid to treat the clean water generated by the undisturbed watershed, a clean water diversion ditch is proposed to collect the clean water generated from the natural area and divert the flow to downstream of Pond 1. The location of the clean water diversion ditch is shown in Figure 3-1.

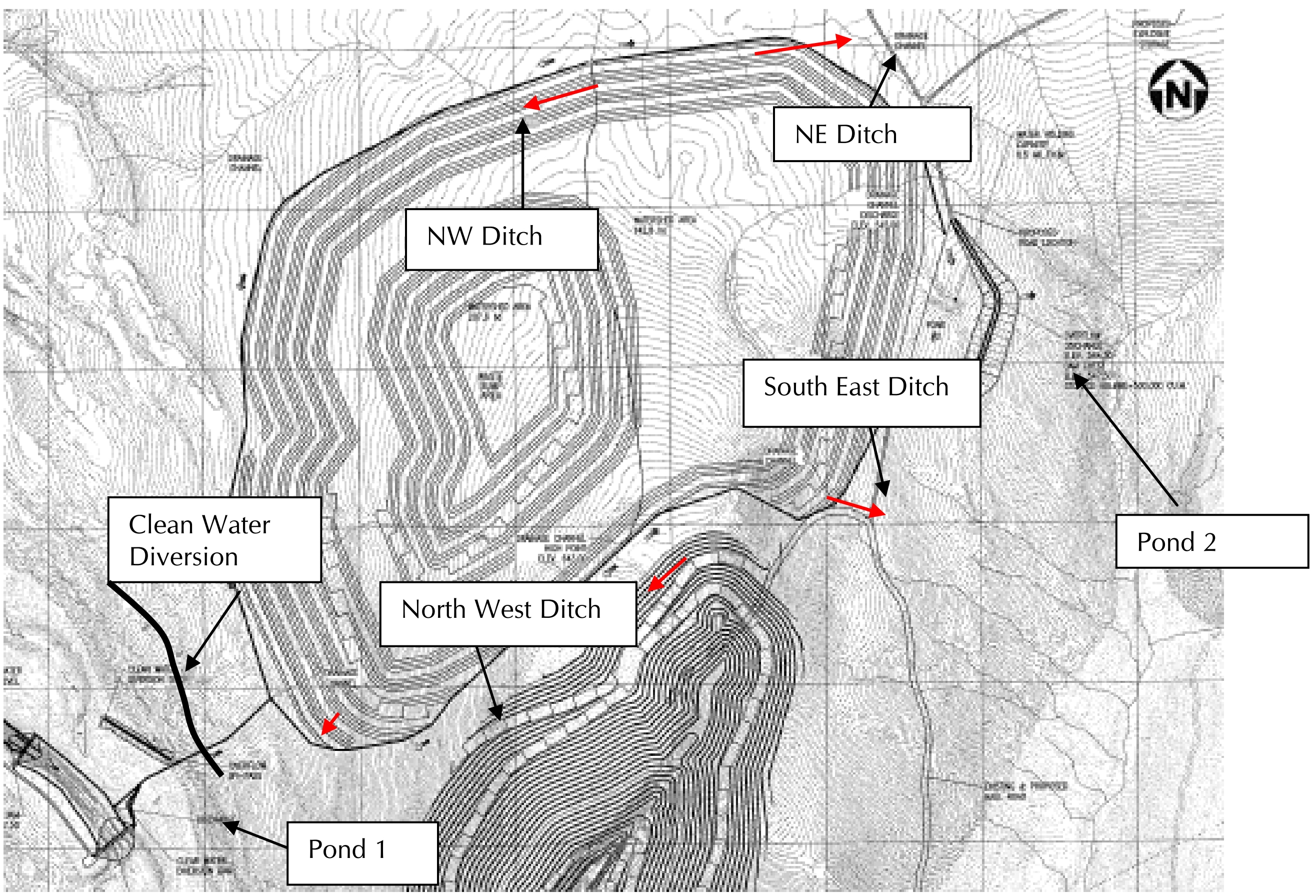

Figure 3-1: Stormwater Management System Layout - Waste Dump Stockpile Area

Two stormwater ponds are proposed to treat the stormwater for sediment removal.

- Pond 1 is located on the south west area downstream of the waste dump stockpile. This pond has two cells. Three dams will be required to form the pond cells. The pond releases flow into an existing downstream stream.
- Pond 2 is located to the East of the waste dump stockpile. The pond treats stormwater for sediment removal and then discharges to an existing downstream stream near the dam.

It shall be noted that the construction of the ditch and stormwater pond system for the waste rock stockpile area can be undertaken in phases corresponding to the waste rock dump development plan. Pond 1 and the runoff ditches to this pond shall be constructed before the waste rock dumping start. However, Pond 2 may not be needed until year 15 according to the current waste rock stockpile development plan. The basic criteria to determine if the construction shall be carried out is that the stormwater treatment system shall be in place once waste rock dumping begins in the affected drainage area.

The sizing of the required components (ditches and ponds will be discussed in the following sections.

3.1.2 Ore Stockpile Platform Area

3.1.2.1 Clean Water Diversion Ditch

The ore stockpile area is presented in H337697-4210-10-042-0003. The infrastructures in this area are still in the process of modifications. However, the general layout of the drainage system shall not change much from what is described in the following sections. Some changes are expected in the final design.

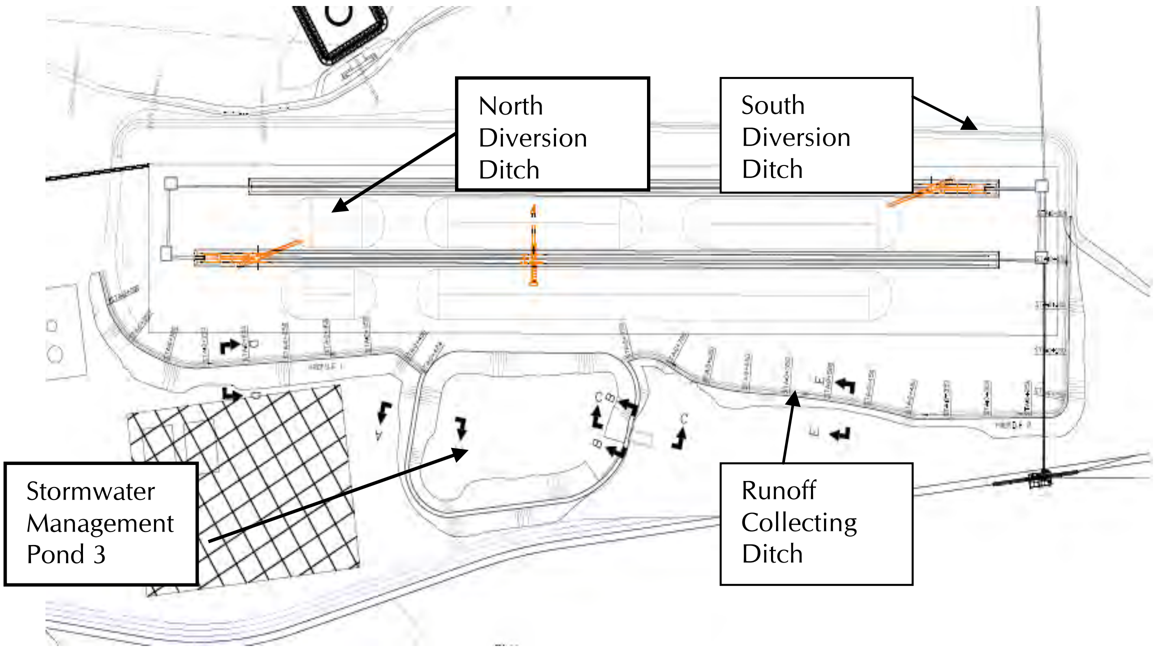

Figure 3-2: The Ore Stockpile Area (note: infrastructures in this area is still in the process of modifications and hence the ditch system may need minor modifications. But the general layout would remain unchanged)

In this region, the area north of the ore stockpile platform will be undisturbed and hence the runoff generated from that area will be clean water. The ground elevation of the north area is higher than the ore stockpile platform. The natural flow would flow into the ore stockpile working area and causes disturbance. The extra water will eventually enter the stormwater management pond for treatment leading to larger than needed SWM storage hence increase the cost. For the purpose of avoiding problems, a clean water diversion ditch was designed to divert the flow. This ditch has two segments as shown in Drawing Number H337697-4210-10-042-0003. The North West portion flows in a northwest direction and the North East portion flows in a southeast direction and both will be discharged into nearby existing streams.

3.1.2.2 *Drainage Ditch*

The runoff collection ditch is designed to collect runoff from the ore stockpile platform and carry flow into SWM Pond 3 for treatment.

3.1.2.3 *SWM Pond 3*

Pond 3 is designed to collect dirty water generated from the ore stockpile area for treatment. After treatment the flow will be discharged into an existing stream downstream.

3.2 Steensby Inlet

3.2.1 Ore Stockpile Platform on the Island

The Steensby Inlet (drawing H-337697-4510-10-014-0001) has two main areas where stormwater and sediment treatment are required. One area is the ore stockpile platform in the island. The infrastructures of the ore stockpile platform are still in the process of being laid out and changes will be made. The basic concept shown in Figure 3-4 is for the stormwater management system of the ore stockpile platform area.

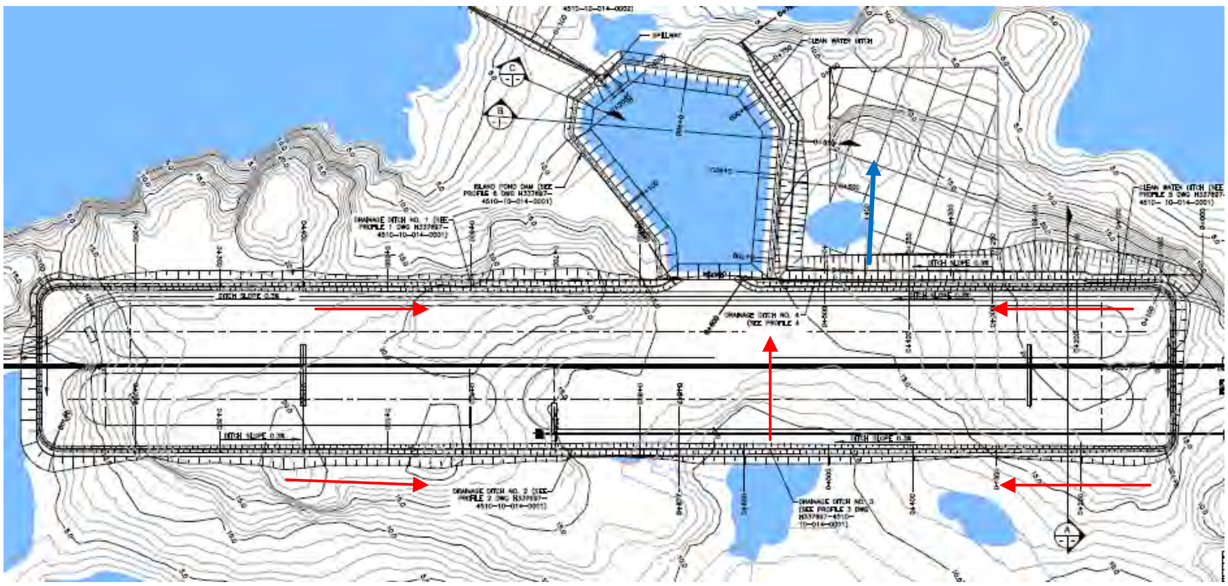

Figure 3-3: Ore Stockpile Platform Stormwater Management System

From Figure 3-3, the surrounding ditch collects the runoff generated by the ore stockpile platform area and puts it into the stormwater management pond northwest of the platform. After treatment, the flow is released to the ocean via the downstream channel. The flow arrows shown in Figure 3-3 indicate the flow collection plan.

There is a small area North West of the ore stockpile platform where flow generated will be clean water and therefore a clean water diversion ditch will be used to collect and divert the flow around the SWM pond.

The stormwater management pond is designed to treat the stormwater and sediment. The sizing of the ditches and the ponds will be discussed in the following sections.

3.2.2 *The Stormwater Management System for the Laydown and Storage Area*

This area has three components in the drainage and stormwater management system. The three components include:

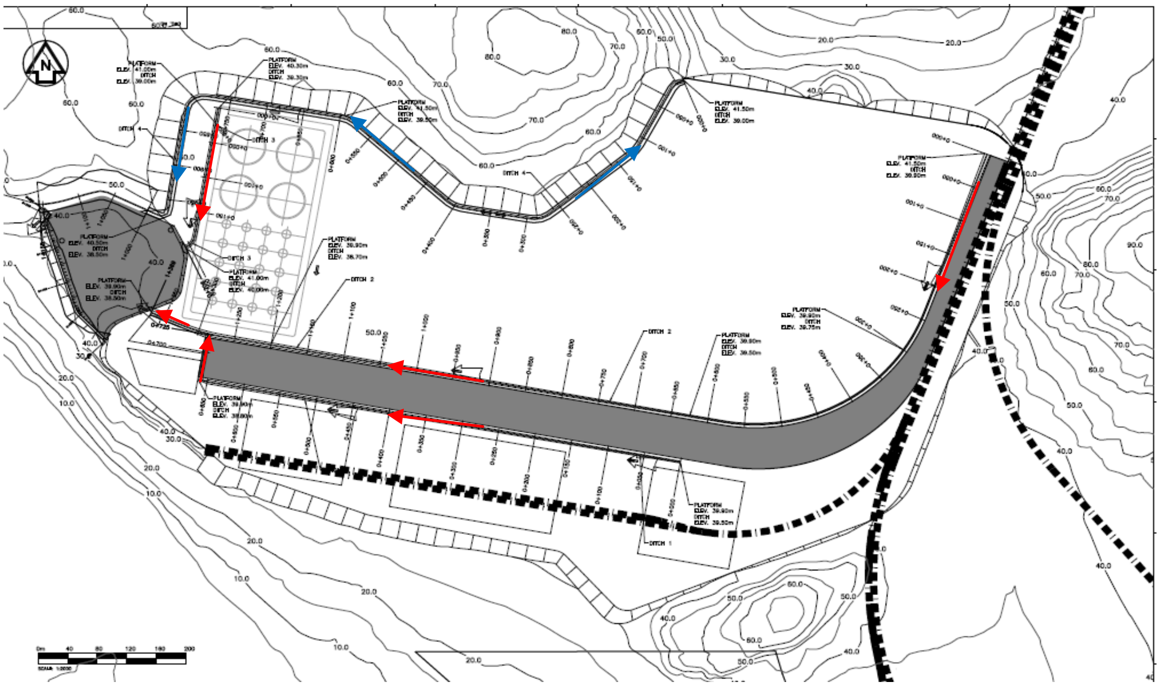

Figure 3-4: Stormwater Management and Drainage network

- Clean water diversion ditch (Figure 3-4)
  - The clean water diversion ditch has two segments. The East portion flows in a Northeast direction and discharges into a small lake north of the area. The second segment flow mainly in a West direction bypassing the stormwater management pond and directly discharges to the ocean.
- The drainage ditch collecting flow from the affected area to the pond for treatment (Figure 3-4)
- The stormwater management pond west of the area
  - After treatment, the water is released to the ocean.

3.3 Milne Inlet

The Milne inlet does not have permanent structures. The drainage work required is to collect the runoff and discharge it to the nearest streams or water courses. The area to be served is small and hence the sizes of the ditches are small. The area is shown in Figure 3-5.

In this area, there are small streams. Land near natural streams will be graded to drain to the natural stream and hence no ditches are required.

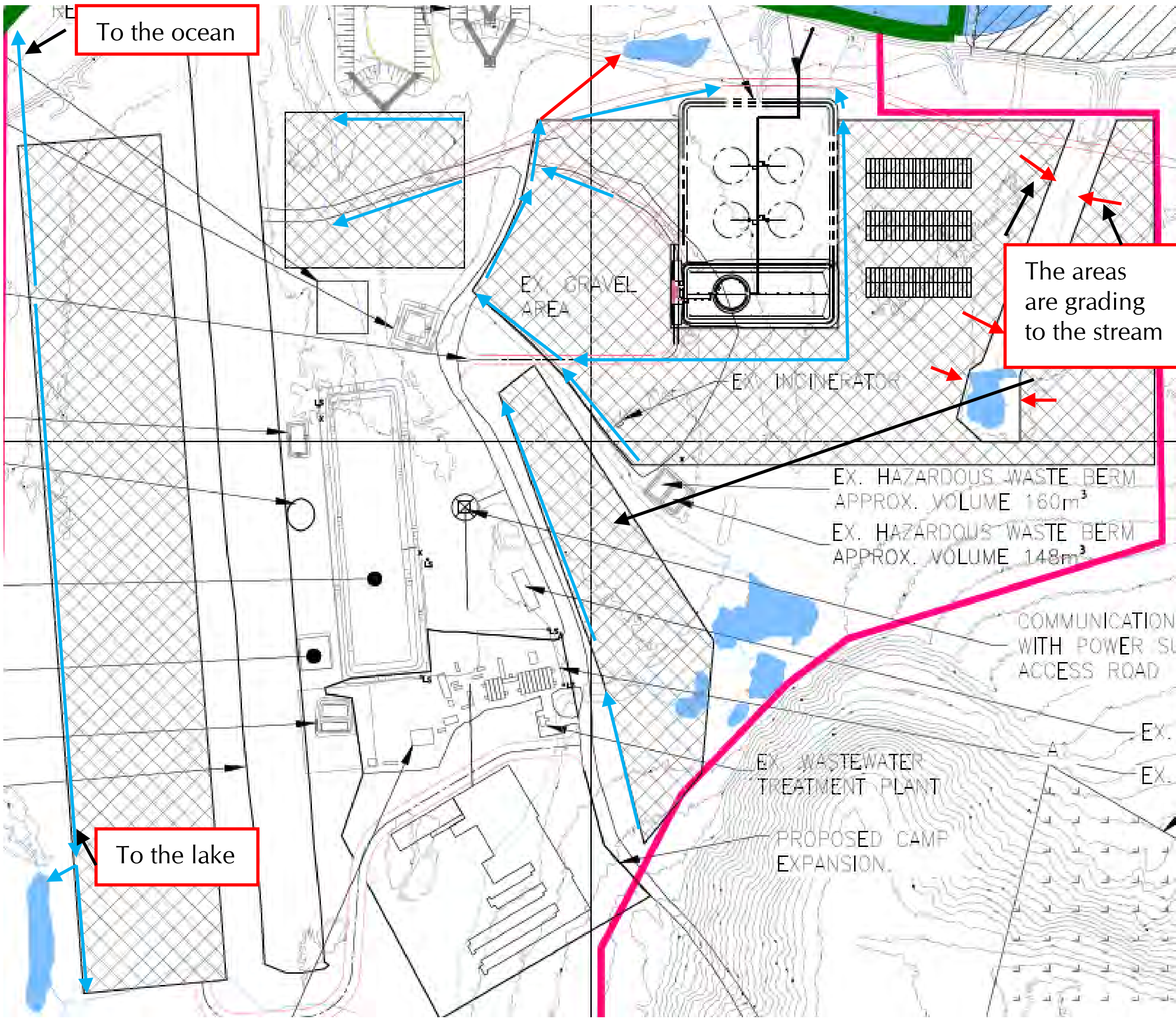

Figure 3-5: Milne Inlet Drainage Plan

4. Stormwater Pond Design

4.1 Stormwater Ponds

4.1.1 Mine site

In the Mine site, three stormwater / sediment ponds are proposed. These SWM ponds are designed to reduce peak flows, to store runoff generated in the area and to reduce sediment (TSS) concentration.

4.1.1.1 POND 1

Figure 4-1 shows the configuration of Pond 1. Pond 1 collects runoff from the waste rock dump for treatment. Pond 1 is formed by three dams. The Block dam has a crest elevation of 355 m.

This dam does not allow any flow over the embankment. Its only purpose is to block the flow. This dam has a SIGNIFICANT hazard classification and hence the inflow design flood is the 1:200 year flood (Appendix A).

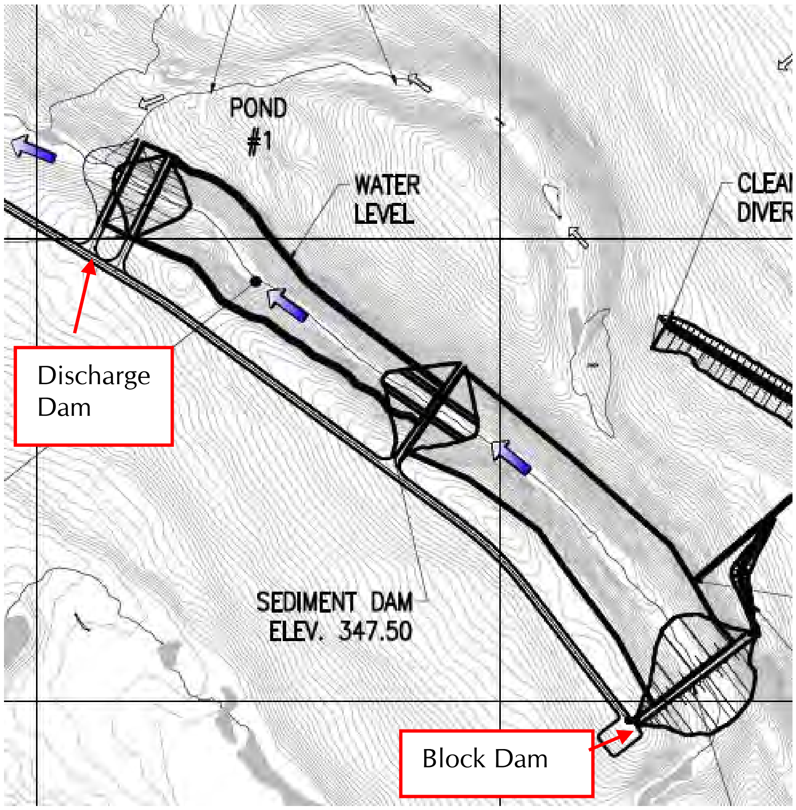

Figure 4-1: Mine site Pond 1 Configuration

The dam in the middle of Pond 1 is used for separating the pond into two cells. This dam has a crest elevation of 347.5 m. An overflow section in the middle of the dam will allow flows into cell 2. The overflow elevation is set at 344.5 m. The bottom width of the overflow weir is 10 m. The side slope of the weir is 2 (H):1 (V). The dam has a SIGNIFICANT hazard classification and the IDF is the 1:200 year flood (Attachment A).

The downstream dam has a crest elevation of 329 m. The dam has an overflow weir at elevation 326 m. The bottom width of the overflow weir is 10 m. the side slope of the overflow section is 2 (H):1 (V). This dam is classified as having a SIGNIFICANT hazard rating and the IDF is the 1:200 year flood (Appendix A). The total storage capacity of Pond 1 is approximately 0.7 million of cubic meters (MCM).

4.1.1.2 POND 2

Pond 2 collects runoff from the waste rock dump (east part) for sediment removal. The dam has a crest elevation of 547.5 m with an overflow weir at elevation 544.5 m. The dam height is approximately 27 m. The total volume of the pond is about 0.5 MCM. A spillway is designed to safely pass the IDF. The spillway bottom width is 10 m. The location of the spillway is on the northeast shoulder away from the dam body. The purpose is to avoid overtopping of the dam. Due to the fact that this dam is used as access road, the spillway side slope is designed to be 10 (H):1 (V) to allow road traffic. This dam has been classified as having a SIGNIFICANT hazard rating and the IDF is the 1:200 year flood.

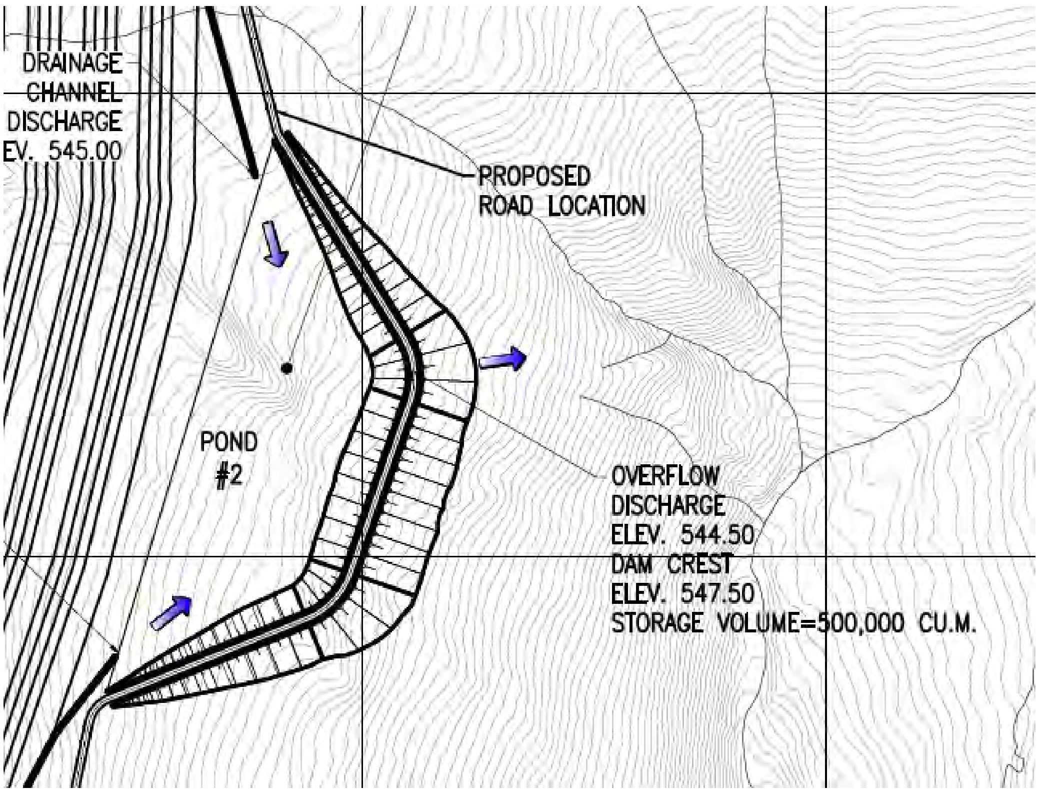

Figure 4-2: Mine site Pond 2 Configuration

4.1.1.3 POND 3

The location of pond 3 is shown in Figure 3-2. The dam to form pond 3 has a crest elevation of 204.5 m and an overflow weir at an invert elevation of 203.5 m. The overflow weir bottom width is 10 m with 2 (H):1 (V) side slopes. The storage is 0.15 MCM approximately. The surface area of the pond is about 3.6 ha. The dam has a SIGNIFICANT hazard classification and hence the IDF is the 1:200 year flood.

4.1.2 Steensby Inlet

The Steensby Inlet has two SWM ponds. Pond 1 is located on the island to treat the stormwater generated by the ore stockpile platform (Figure 3-3). The dam has a crest elevation of 13 m. An overflow weir has a bottom width of 10 m at invert elevation of 10.5 m. The dam has a SIGNIFICANT hazard rating and the IDF is the 1:200 year flood (Appendix A).

The SWM Pond 2 on the land is shown in Figure 3-4. The crest elevation of the dam is 40 m. The overflow weir invert elevation is 38 m. The width of the weir is 10 m. The side slope of the weir is 2 (H):1 (V). The dam has a storage of about 80,000 m^3. The hazard potential of this dam is SIGNIFICANT and hence the IDF is the 1:200 year flood event.

4.2 Peak Flow Estimation

The design of the drainage ditches requires the estimation of the peak flows for the design event. Flow estimation will be based on the following equations developed by Knight Piésold Consulting for drainage areas greater than or equal to 0.5 km^2:

$Q_2 = 1.1\ A^{0.79}$

$Q_5 = 1.7\ A^{0.77}$

$Q_{10} = 2.0\ A^{0.76}$

$Q_{25} = 2.6\ A^{0.75}$

$Q_{100} = 3.5\ A^{0.73}$

Where Q = peak flow instantaneous flow in m^3/s

A = drainage area in km^2 ($0.5\ km^2 \leq A \leq 1000\ km^2$)

When the drainage area is smaller than 0.5 km^2, the above equations cannot be used. In this case, the rational formulae will be applied for the estimation of peak design flows. The form of the equation is:

$Q = 0.28\ CIA$

Where, Q = peak instantaneous flow in m^3/s

A = drainage area in km^2

C = runoff coefficient = 0.9 (the runoff coefficient is high to reflect the high degree of saturation or freezing ground conditions during runoff flood event)

I = rainfall intensity corresponding to the time of concentration.

The time of concentration is calculated as: = where T_c = time of concentration (hour), L = the main channel length (km) and S = the channel slope (m/m).

The rainfall intensity-duration-frequency (IDF) curves of design storms have been analyzed by Knight Piésold Consulting and the IDF curves are summarized in Table 4-1.

Table 4-1: Design Storm Intensity-Duration-Frequency (IDF) Curves (mm/hr)

Duration	2 yrs	5 yrs	10 yrs	15 yrs	20 yrs	25 yrs	50 yrs	100 yrs	200 yrs
5 min	9.5	12.0	14.0	15.1	15.9	16.5	18.3	20.1	22.0
10 min	7.2	9.0	10.5	11.3	11.9	12.4	13.7	15.1	16.5
15 min	6.0	7.5	8.7	9.4	9.9	10.3	11.4	12.6	13.7
30 min	5.0	6.3	7.3	7.9	8.3	8.6	9.5	10.5	11.4
1 hr	4.0	5.2	6.1	6.6	7.0	7.3	8.1	9.0	9.9
2 hr	3.0	3.9	4.6	5.0	5.2	5.5	6.1	6.8	7.4
6 hr	2.0	2.7	3.3	3.6	3.9	4.0	4.6	5.1	5.7
12 hr	1.3	1.8	2.2	2.4	2.6	2.7	3.1	3.4	3.8
24 hr	1.0	1.4	1.7	1.9	2.0	2.1	2.4	2.7	3.0

The determination of the peak flows for each of the ditches will be discussed in Section 5.

4.3 Flood Routing in Stormwater Management Ponds

To design the spillways for stormwater ponds, the equations described in Section 4.1 will not be sufficient since the storage routing effects cannot be evaluated by the simple peak flow estimation equations. The storages in the ponds play an important role in the determination of water levels and peak outflows from the spillway. In this case, a flood routing model was used to fully assess the impact of the storages and the required spillway dimensions to safely pass the design floods for each pond.

The US EPA SWMM model was used for the flood routing assessment. The EPA Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of sub-catchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage / treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each sub-catchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps.

A SWMM model was established for each SWM pond in the Mine site and Steensby Inlet areas. The SWMM model was used to:

- Determine the spillway dimensions required to pass the inflow design flood (IDF)
- Evaluate the water quality performance of the ponds with respect to TSS removal (Section 4.4).

To simulate the flood routing processes in the SWM ponds during IDF, the return period of the inflow design flood shall be determined. This IDF is associated with the dam classification based on CDA dam safety guidelines. This dam classification for each dam will be discussed in Section 6 (Dam Design Section). The following section describes the design storms used in the SWMM model.

4.3.1 *Design Storm*

Design storm has three components:

- Design frequency (return period)
- Storm volume (mm) and duration (hours)
- Temporal distribution

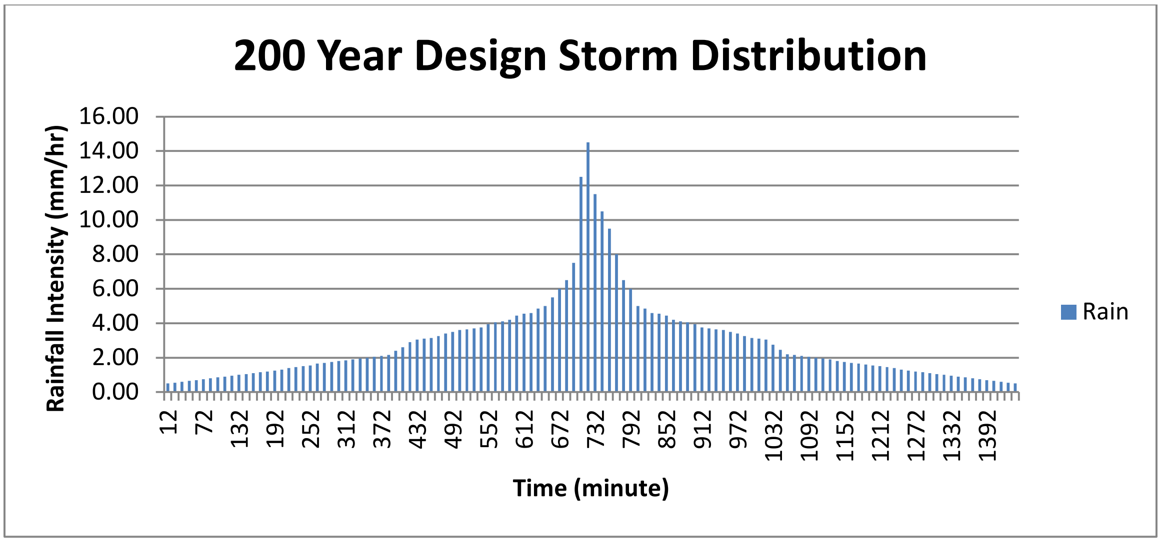

Figure 4-3: 200 Year Design Storm Distribution

The dam safety assessment results shown that the required IDF for all of the SWM pond embankment structure is the 1:200 year flood event. For the site, Knight Piésold Consulting determined that the 1:200 year design storm has 71 mm in 24 hour period.

The temporal distribution of the storm was developed based on the 'balanced storm' method. The 'balanced storm method' was described by D. H. Hoggan, 1996. The 24 hours 'balanced storm' temporal distribution of the 200 year storm is presented in Table 4-3. The total storm volume of this event is 71 mm. Figure 4-3 shows the intensity (mm/hr) for each rainfall block. The time interval is 12 minutes.

4.3.2 *Model Parameters*

The input to the model includes:

1. drainage areas of the sub-watershed
2. Surface roughness coefficient
3. Infiltration parameters
4. Sediment erosion parameters
5. Precipitation input
6. SWM pond configurations

The model will produce peak flows and flood hydrographs for each sub-watershed and will be able to calculate the combined flows at a confluence of sub-watersheds.

Table 4-3 summarizes the sub-watershed areas and the other basic parameters used in the model for Mine site.

Table 4-2: Mine Site SWMM model parameters

	Watershed Area (ha)	Percent Imperious %	Maximum Infiltration rate (mm/hr)
Pond 1	207.8	99	3
Pond 2	142.8	99	3
Pond 3	26.2	99	3

Note: 99% of imperious area is used for frozen ground conditions during spring runoff period which results in almost all precipitation becoming runoff.

Table 4-3: Steensby Inlet SWMM Model Parameters

	Watershed Area (ha)	Percent Imperious %	Maximum Infiltration rate (mm/hr)
Pond 1	23.3	99	3
Pond 2	61	99	3

4.3.3 *Spillway Rating Curves*

Spillway rating curves are calculated using standard weir equation:

Where Q = discharge (m^3/s)

C = weir coefficient = 1.70 (assuming broad crest weir)

B = Spillway bottom width (m)

H = head of water (m)

4.3.4 *Results*

The SWMM model is used to simulate flood routing processes in the stormwater ponds for the inflow design flood. The peak water levels in each of the ponds are obtained and summarized in Table 4-4 for the mine site and in Table 4-5 for the Steensby Inlet site.

Table 4-4: Peak flows and water levels in the ponds (Mine site)

	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak water level (m)	Crest Elevation (m)	Freeboard (m)
Pond 1	6.09	4.65	326.35	329	2.65
Pond 2	4.31	2.66	544.7	547.5	2.80
Pond 3	0.84	0.73	203.55	204.5	0.95

Table 4-5: Peak Flows and Water Levels in the ponds (Steensby Inlet)

	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak water level (m)	Crest Elevation (m)	Freeboard (m)
Pond 1	0.89	0.76	10.64	13	2.36
Pond 2	1.63	1.41	38.21	40	1.79

From Table 4-4 and Table 4-5, it is known that the spillway capacities are sufficient to safely pass the IDF. Also the freeboards meet the CDA dam safety requirement. The stormwater ponds reduced the peak flows 66% - 85% depending on the storage characteristics of the ponds.

Figure 4-4presents one example of the flood reduction function for Mine site Pond 2 IDF case. From the figure, it is evident that a significant peak flow reduction is achieved (2.66/4.31 =61.7%).

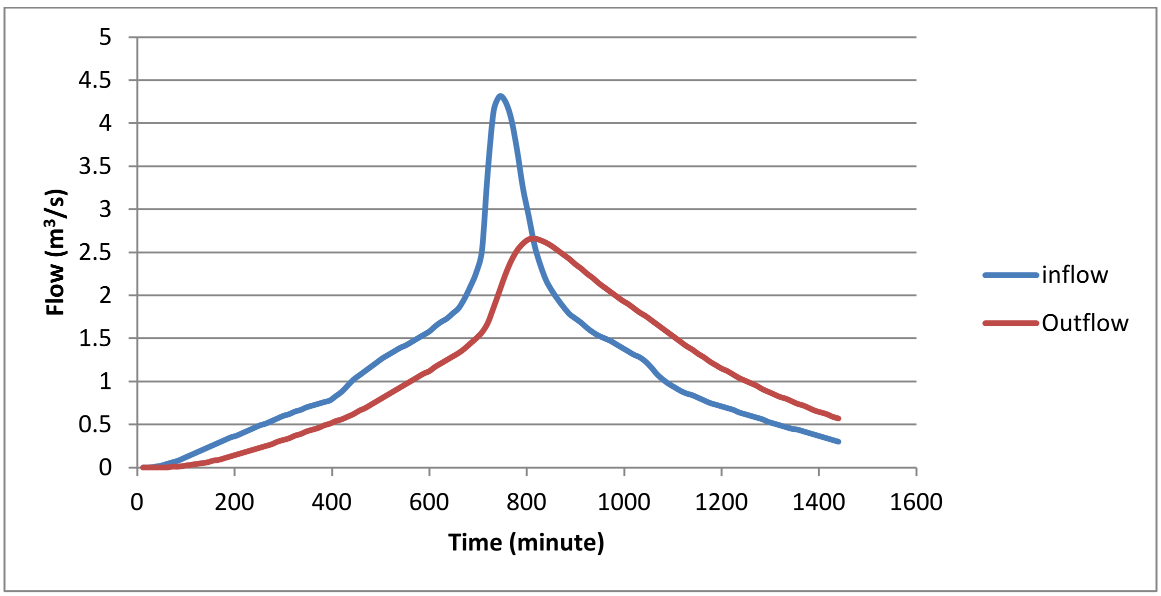

Figure 4-4 Inflow and outflow hydrographs, Mine Site Pond 2

In stormwater management, preventing peak flows from being higher than pre-development conditions is normally required. For this development, the flooding occurs normally on frozen ground and hence the pre- and post- development flood magnitudes does not change significantly and therefore the stormwater pond will improve the flood conditions of the site (compare to the pre-developed conditions). This is one benefit of the ponds.

4.4 Determination of Water Quality Capture Volume

4.4.1 WQCV Calculations

The water quality capture volume(WQCV) is an important design feature for stormwater quality control. The main pollutant to be controlled in the stormwater ponds is the sediment or total suspended solids (TSS) from the watershed. The target TSS concentration is 15 mg/L for all of the final discharge points. Many factors affect the TSS concentration including: A) amount of rainfall and runoff in the watershed, B) the sediment characteristics and the erosion potential, C) the pond storage and surface area, D) the outlet feature which determine the detention time, E) the TSS grain size distribution, and F) the size of the watershed and land use conditions, etc.

For the purpose of the stormwater pond design, the amount of rainfall and the detention time are the two key parameters that affect the performance of a stormwater pond. Current practice is to detent a 24 hours storm in the pond for 40 hours (Grizzard, 1986, Roesner, 1989) which will provide good TSS removal efficiency while the pond storage is still in manageable size. Longer detention time will lead to higher removal efficiency but requires a too large pond storage. Therefore, the detention time targeted for the water quality capture volume design is 40 hours.

The WQCV is the amount of storm to be treated in the detention storage. This amount varies from place to place. Typical values is to capture 25 mm storm (Ontario Ministry of Environment, 2003). For the Baffin land area, the 24 hours 25 mm storm is equivalent to a 1:2 year design storm approximately (Knight Piésold Consulting, 2010). This storm volume is used to estimate the WQCV storage requirement.

Table 4-6 summarize the WQCV for the ponds in the Mine Site and Table 4-7 presents the values for the ponds in the Steensby Inlet area.

Table 4-6: Pond WQCV Requirement (Mine Site)

	Drainage area (ha)	Design Storm (mm)	WQCV (M3)	Pond Surface (ha)	Depth between Core* and Spillway Invert m
Pond 1	207.8	25	51950	6.71	0.77
Pond 2	142.8	25	35700	10.9	0.33
Pond 3	26.2	25	6558	3.6	0.2

Table 4-7: Pond WQCV Requirement (Steensby Inlet)

	Drainage area (ha)	Design Storm (mm)	WQCV ($M^{3)}$	Pond Surface (ha)	Depth between Core* and Spillway Invert m
Pond 1	23.3	25	5835	2.6	0.22
Pond 2	61.0	25	15250	2.85	0.54

Note: core elevation mean the top elevation of the seepage cut off materials inside the dam bodies

To make the required WQCV storage available, there is a need to maintain the water level lower than the spillway invert elevation so that the storm runoff will be stored in the pond and then slowly releases to a downstream water course. The slow release mechanism will be provided using a porous rock fill weir at the entrance of the spillway. The basic concept is illustrated in Figure 4-5.

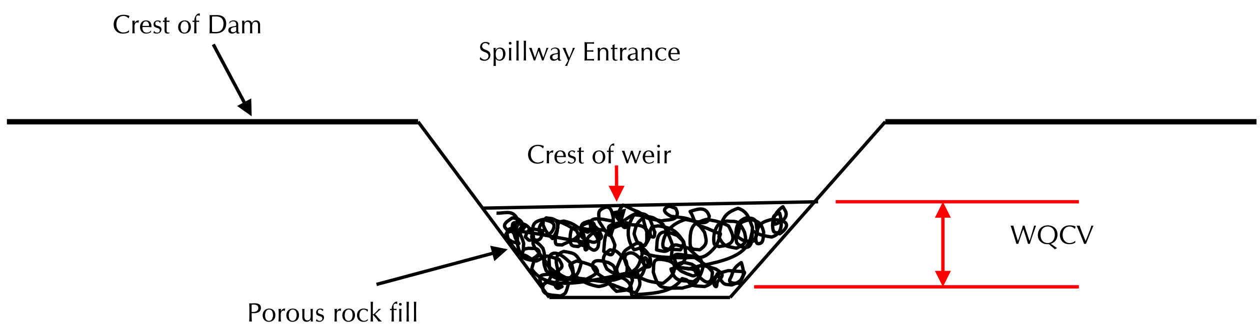

Figure 4-5: WQCV Concept Illustration

This slow flow release configuration is designed to work with dams where spillway can be constructed on natural ground. These dams include: Mine Site Pond 2 and 3 dams, the stormwater Pond 2 in Steensby Port of the laydown and storage area.

For dams for which the spillway cannot be located on natural ground (due to constrain of space), part of the embankment will have to be used as the spillway. In this case, the modified dam cross section option 2 (Figure 2.11 of Appendix B) will be used at the spillway location. This dam section allows a small amount of seepage flow into the porous rock fill area which acts as the slow flow release mechanism. This design will maintain the safety of the dam while providing the required slow flow release rate at the same time.

When rainfall occur, as long as the rainfall is smaller than or equal to 25 mm, all of the runoff will be stored in the WQCV zone (between normal water level and the invert of the pond spillway). The porous zone of the rock fill section will allow the runoff captured to slowly drain down to the normal water level. If the storm is 25 mm, then the time required for the water level to return to normal water level is 40 hours.

When the storm is higher than 25 mm, the WQCV will not be large enough to hold all of the runoff volume and spills will occur. The flow will directly run through the pond over the spillway and be discharged to the downstream river. In this case, the water quality standard may not be met (because there is no sufficient detention time to remove the TSS).

Based on the above discussions, it is evident that the provision of a porous zone above the spillway invert to allow the pond to drain slowly is a key design feature for water quality since without this discharge capacity the normal water level will be at the invert of the spillway and all runoff will be discharged directly to the downstream river. The TSS concentration may be too high.

For each pond, the depth between the porous weir and the invert elevation of the spillway is 1 m. (which is higher than the required values shown in Table 4-6 and Table 4-7, to provide higher TSS removal efficiencies).

4.4.2 SWMM Evaluation of the Pond Storage

A SWMM model was used to evaluate the performance of the WQCV in each pond. The input storm was the 1:2 year 24 hour design storm (25 mm of total rainfall volume). The most difficult parameter for this evaluation is the input TSS concentration since this value changes with many factors, such as the rainfall intensity and duration, the land surface conditions, the operation of the mining activities, etc. US EPA (1983) reported that typical stormwater TSS concentration is in the range of 180 mg/L - 548 mg/L depending on the land use. Therefore, a 300 mg/L and 550 mg/L was used in the model to simulate the performance of the SWM ponds. The value of 300 mg/L represents average concentration conditions and 550 mg/L represents the high concentration conditions. It is also noted that mining operation may result in much higher TSS load than Urban area. For this reason, the input TSS concentration five times higher than 550 mg/L (2750 mg/L) was also evaluated.

The equation for the evaluation of the TSS removal is based on the following treatment function of TSS in the SWM pond (SWMM Application Manual, 2009):

–

Where C = concentration of TSS (mg/L)

C* =TSS concentration that cannot be settled by gravity (mg/L) due to small grain size

K = model parameter related to detention time and pond representative depth

d = water depth in the pond

In this equation, it is known that the TSS concentration cannot settle in the pond by gravity is an important site specific parameter, depending on the sediment size distribution. This information, however, can only be available after the mining operation starts. Therefore, it is assumed that this value is less than 15 mg/L since if it is higher than 15 mg/L, no matter how big the sediment pond would be, the targeting TSS concentration will not be met.

Table 4-8 and Table 4-9 summarize the simulation results for the Mine Site and Steensby Inlet respectively.

Table 4-8: SWM Pond Outflow TSS Concentration (Mine site)

	Input TSS= 300 mg/L		Input TSS = 550 mg/L		Input TSS= 2750 mg/L	
	Peak mg/L	**Mean mg/L**	**Peak mg/L**	**Mean Mg/L**	**Peak Mg/L**	**Mean Mg/L**
Pond 1	11.5	8.7	11.7	8.5	13.6	8.6
Pond 2	14.6	10.3	19.0	10.7	54	14.4
Pond 3	12.5	10.1	14.6	10.4	33.4	12.5

Table 4-9: SWM Pond Outflow TSS Concentration (Steensby Inlet)

	Input TSS = 300 mg/L		Input TSS = 550 mg/L		Input TSS = 2750 mg/L	
	Peak Mg/L	**Mean Mg/L**	**Peak Mg/L**	**Mean Mg/L**	**Peak Mg/L**	**Mean Mg/L**
Pond 1	13.3	10.4	16.2	10.8	41.2	14.4
Pond 2	16.7	10.8	22.5	11.5	73.5	17.4

From Table 4-8 and Table 4-9, it is know that when the 25 mm storm runoff is stored for 40 hours, the mean TSS concentrations of the outflows from the ponds will be less than 15 mg/L. The peak concentration could be higher but these high concentrations will last only for a hour or so. The basic requirement of concentration less than 15 mg/L is met. It is very difficult to reduce the peak concentration since this will need an extremely large pond and longer detention time.

It shall be noted that the 25 mm storm has a return period of 2 years. This means that, on average, all storms less than the 2-year event will be controlled to have TSS concentration less than 15 mg/L.

Figure 4-6 shows the TSS concentration variation during the 2-year storm event in Mine Site

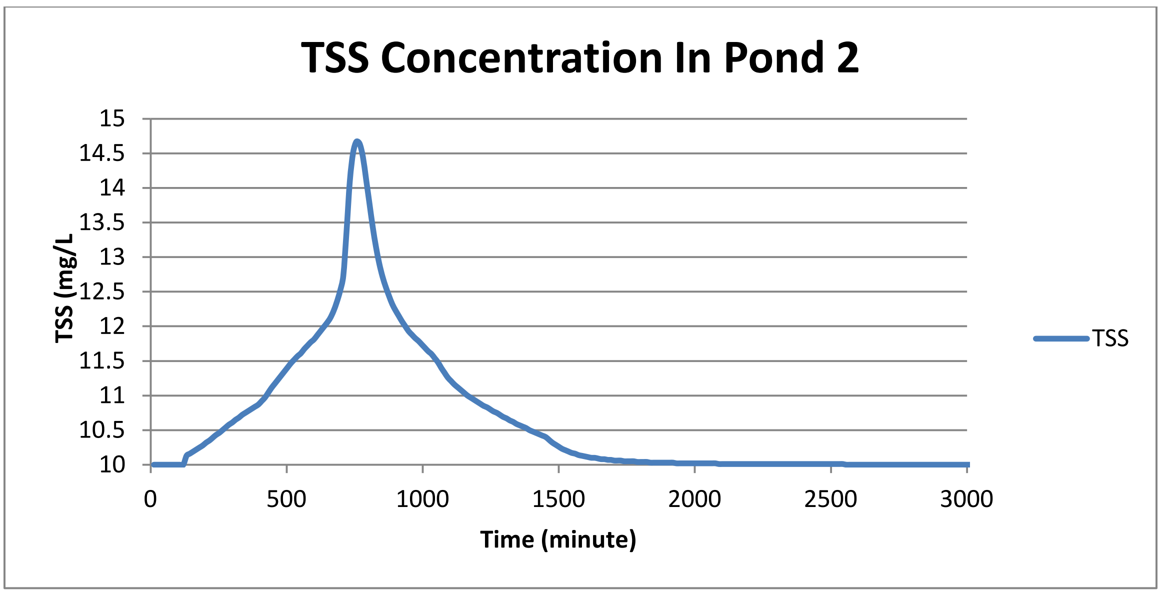

Figure 4-6: Pond TSS Removal Performance Example (Input TSS = 300 mg/L)

Pond 2 as an example of the TSS removal performance. This figure presents the out flow TSS concentration.

When the input TSS concentration is as high as 2,750 mg/L, the mean outflow TSS concentrations in most SWM ponds will still meet the requirement. The Pond 2 in Steensby Inlet will not have a higher mean TSS exceeding the 15 mg/L target.

It is concluded that the provided WQCV will meet the TSS concentration target for each of the ponds if the input concentrations are less than 2,750 mg/L and the TSS that cannot settle by gravity is below 15 mg/L. However, it is known that there are many factors affecting the TSS concentration of the site, uncertainties still exist. It is hence recommended that a monitoring system be established to measure the TSS concentration in runoff at various locations and if it is found that the TSS concentration exceeds the limit, additional treatment may be needed.

From Table 4-8, it is also interesting to note that the two cells arrangement in Mine site Pond 1 will improve the TSS removal performance due to additional detention time by the two-cell configuration.

5. Sizing of the Drainage Ditches

5.1 Mine Site Ditches

5.1.1 Waste Rock Stockpile

The drainage area for the waste rock stockpile was divided into four sub-areas. The four sub-areas were called NE, NW, SE, and SW and correspond with the channel alignments. The NW and SW channels combine to form an Outlet channel that leads to a sediment pond. The runoff was calculated using the equations given in Reference 1 as each sub-area was greater than 0.5 km^2. The 10 year design storm was used to size these channels. The runoff from each sub-area was calculated at the downstream end. Intermediate discharges along the proposed channel were calculated by prorating the discharge over the channel length.

The minimum channel bottom width listed in the Design Criteria is 1 m. This width was sufficient for all the channels except the Outlet channel at the waste rock stockpile. A 3 m channel bottom was used for its entire length.

The channel slopes ranged from 0.3 percent to 69 percent. The Outlet channel at the waste rock stockpile had the steepest slopes with a minimum slope of 14 percent and a maximum slope of 69 percent.

Reinforced concrete pipe (n = 0.013) was used for the closed drainage system in the Platform site. A minimum cover of 0.6 m was used over the top of the pipe. The minimum slope considered in the design was a slope that could achieve a pipe flow velocity of 1 m/s.

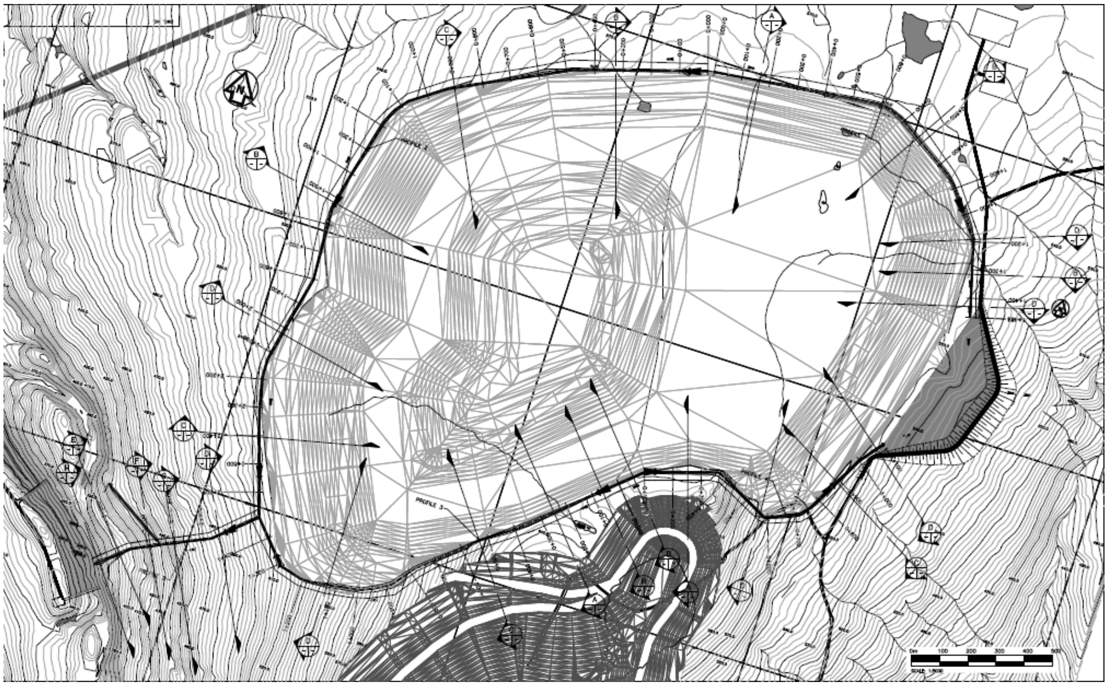

Figure 5-1: The Waste Rock Dump Ditches

Table 5-1: Ditch Size and Riprap Requirements (Waste Rock Stockpile Area)

Channel	Beginning Station (m)	End Station (m)	Channel Type	Discharge (cms)	Bottom Width (m)	d_{50} (mm)	d_{100} (mm)	Riprap thickness(mm)
Profile 1	0	120	A	0.1	1			
Profile 1	120	320	A	0.1	1			
Profile 1	320	370	B	0.4	1	80	100	100
Profile 1	370	655	B	0.5	1	80	100	100
Profile 1	655	890	B	0.8	1	80	100	100
Profile 1	890	1140	B	1.1	1	80	100	100
Profile 1	1140	1245	D	1.4	1	300	380	375
Profile 1	1245	1390	B	1.5	1	80	100	100
Profile 1	1390	1470	D	1.7	1	300	380	375
Profile 2	0	645	B	0.3	1	80	100	100
Profile 2	645	1160	C	0.6	1	160	200	200
Profile 2	1160	1885	B	1.1	1	80	100	100
Profile 2	1885	2160	D	1.8	1	300	380	375
Profile 2	2160	2470	C	2.0	1	160	200	200
Profile 2	2470	2680	C	2.3	1	160	200	200
Profile 2	2680	2795	D	3.2	3	300	380	375
Profile 2	2795	2960	D	3.2	3	300	380	375
Profile 2	2960	3035	G	3.2	3	650	820	813
Profile 2	3035	3110	F	3.2	3	540	680	675
Profile 2	3110	3130	F	3.2	3	540	680	675
Profile 2	3130	3255	E	3.2	3	480	600	600
Profile 2	3255	3290	H	3.2	3	SD	SmartDitch	
Profile 3	0	145	B	0.1	1	80	100	100
Profile 3	145	350	A	0.1	1			
Profile 3	350	565	C	0.3	1	160	200	200
Profile 3	565	705	C	0.5	1	160	200	200
Profile 3	705	910	D	0.6	1	300	380	375
Profile 3	910	1110	D	0.8	1	300	380	375
Profile 3	1110	1210	D	0.9	1	300	380	375
Profile 3	1210	1405	D	1.0	1	300	380	375
Profile 4	0	120	B	0.1	1	80	100	100
Profile 4	120	390	A	0.1	1			
Profile 4	390	500	D	0.4	1	300	380	375
Profile 4	500	560	D	0.5	1	300	380	375
Profile 4	560	615	D	0.6	1	300	380	375

Channel	Beginning Station (m)	End Station (m)	Channel Type	Discharge (cms)	Bottom Width (m)	d_{50} (mm)	d_{100} (mm)	Riprap thickness(mm)
Profile 4	615	740	D	0.7	1	300	380	375
Profile 4	740	1040	C	0.8	1	160	200	200
Profile 4	1040	1120	D	1.1	1	300	380	375
Clean Water	0	270	D	1.0	1	300	380	375

Figure 5-1 shows the ditches surrounding the waste rock dump area. The slope of the ditch in some area is steep and hence riprap protection is needed. Table 5-1 summarizes the ditch size and riprap requirement along the profiles. In Table 5-1, eight types of ditches are listed. Type A, B, C, D, E, F, G and H ditches have bottom width varying from 1 m. to 3 m. The different types of ditches are presented in Drawing H337696-4210-10-012-0001, Appendix C.

5.1.2 *Ore Stockpile Platform*

The offsite drainage area is about 0.2 km^2. The runoff is essentially undisturbed and is considered clean water. The design storm is the 100-year event. The runoff will be channelled into a North and a South channel. (See Figure 3-3) The outlet for these channels will be the existing drainage system.

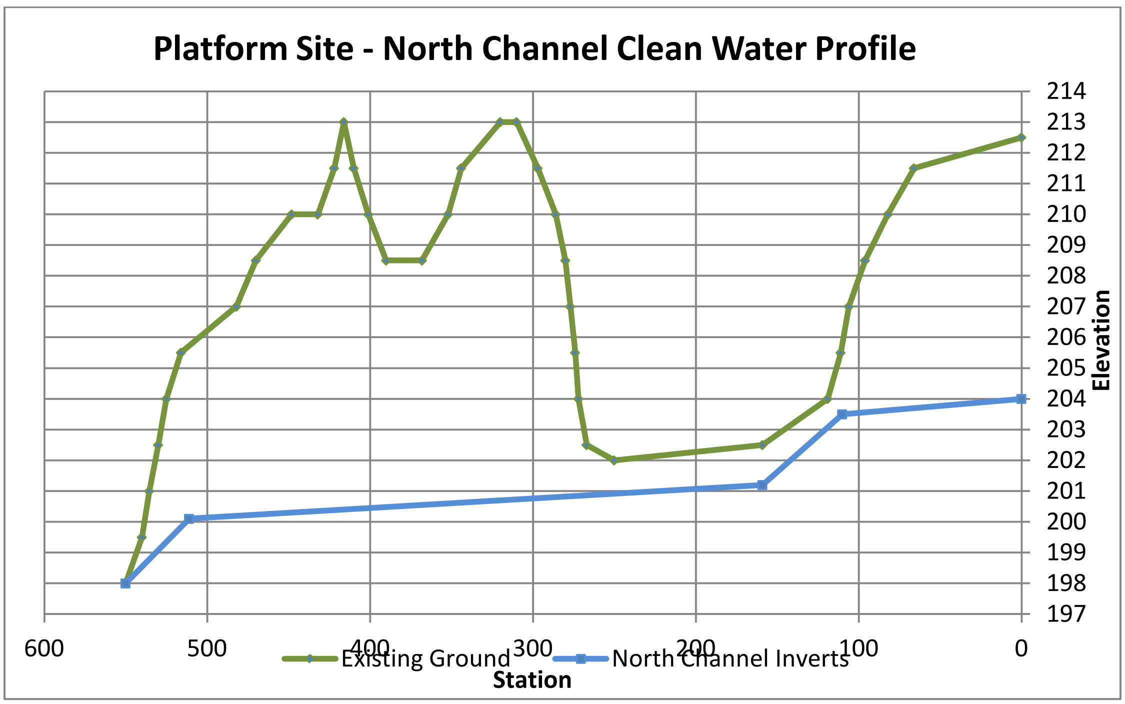

Figure 5-2: North Diversion Ditch (Ore Stockpile Platform

The channel profiles are shown in Figure 5-2 and

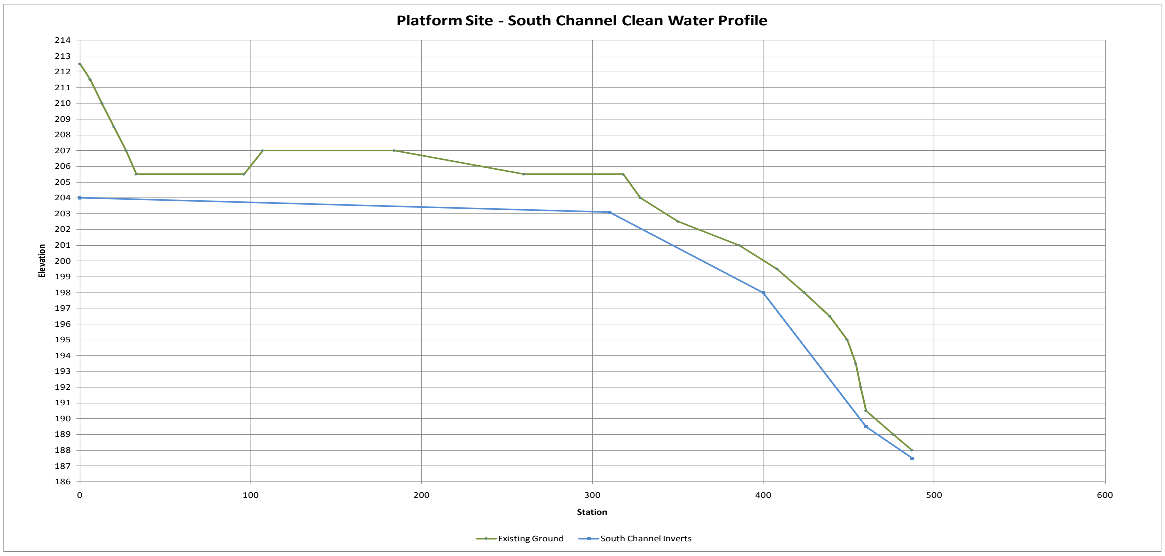

Figure 5-3. The channels range in slope from 0.3 percent to 14.2 percent. The discharges and D_{50} riprap for each section of the channel are shown in Table 5-2. The riprap for these channels was designed using References 6 and 7.

The interior of the Platform site will receive runoff from the stockpiles and will contain sediment. The design storm for the Platform site is the 10-year event. The drainage area for the Platform site is 0.23 km^2. The drainage of the area is served by grading the surface slope to flow to the surrounding ditches.

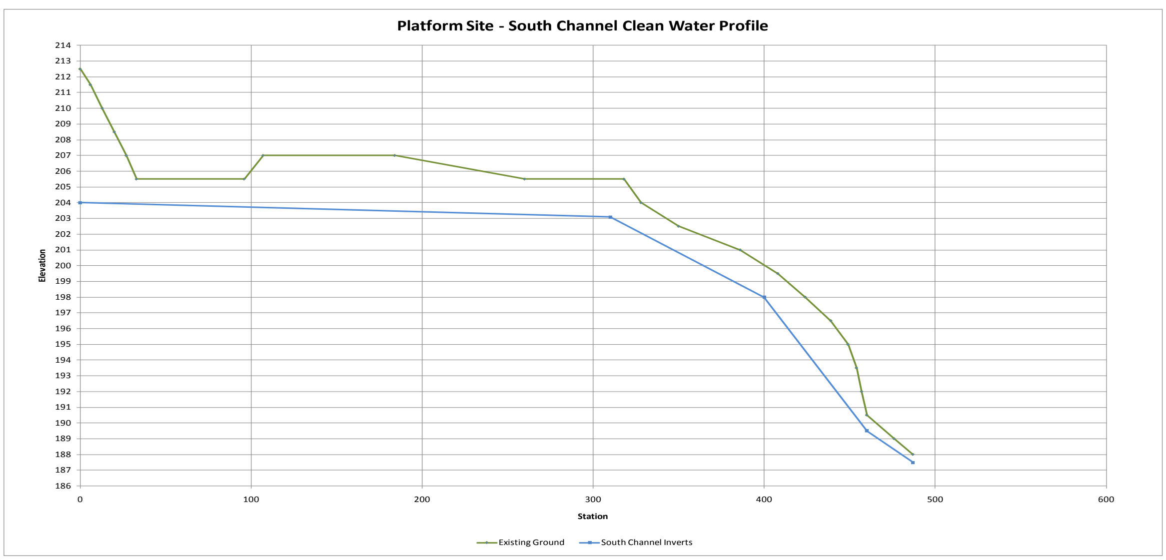

Figure 5-3: South Diversion Ditch (Ore Stockpile Platform)

Table 5-2: Ditch Size and Riprap Requirements (Clean Water Diversion Ditch)

Platform Clean Water Channels								
Channel	**Beginning Station (m)**	**End Station (m)**	**Channel Type**	**Discharge (cms)**	**Bottom Width (m)**	**d_{50} (mm)**	**d_{100} (mm)**	**Riprap thickness (mm)**
North	0	110	A	0.1	1			
North	110	159	B	0.1	1	80	100	100
North	159	511	A	0.45	1			
North	511	550	C	0.45	1	160	200	200
South	0	310	A	0.14	1			
South	310	400	C	0.14	1	160	200	200
South	400	460	D	0.14	1	300	380	375
South	460	487	C	0.14	1	160	200	200

5.2 Steensby Inlet

5.2.1 Ditch Surrounding Ore Stockpile Platform (Island)

This ditch collects flow from the ore stockpile platform and sends the runoff to the SWM pond for treatment. The total area is small and hence the minimum ditch with 1 m bottom width and 2:1 side slope will have sufficient flow capacity to carry the design flow of 0.32 m^3/s. The channel slope is 0.003 to 0.005

5.2.2 Ditch to the SWM Pond 2 (Fuel Farm and storage)

This ditch collects flow from the permanent laydown and storage area, and sends the runoff to the SWM pond for treatment. The total area is 61 ha. The ditch with 1 m bottom width and 2:1 side slope will have sufficient flow capacity to carry the design flow 1.56 m^3/s. The channel slope is 0.003 to 0.005. The ditches are shown in drawing number H337697-4510-10-014-0004 in Appendix C.

5.2.3 Clean Water Diversion Ditch

A clean water diversion ditch is required to allow the runoff from undisturbed area to bypass the system and to reduce the treatment requirement. Figure 3-3 shows the clean water ditches. From Figure 3-3 it is known that the ditch flows in two directions. The west part flows west and bypasses the SWM pond. The East ditch flows east and discharges to a existing water course north of the area. This ditch has a 1 m bottom width and 2 (H):1 (V) side slope with 0.005 channel slopes. The ditch has sufficient flow capacity to carry flows from the watershed. The ditch profiles and cross sections are presented in Drawing in Appendix C.

5.3 Milne Inlet

There are no permanent structures in Milne Inlet. The operations in this area will be short term activities. During operation, there is a need for drainage to avoid disturbance to works. For this reason, the drainage is aimed at draining stormwater into nearby streams without treatment (i.e. no stormwater ponds are required).

Figure 3-5 shows the overall drainage network for Milne Inlet site. In this area, if there is a stream nearby (about 150 m - 200 m), no ditches are planned. The land shall be graded to naturally drain to the existing stream. Where the distance to existing stream is longer than 150 m - 200 m, ditches are designed to collect the runoff and the ditches are then connected to the nearest existing stream.

The areas are small and the ditch having 1 m bottom width with 2 (H):1 (H) side slopes will be able to drain the stormwater generated from the areas. The ditches are shown in Drawing number H337697-7000-10-014-0001 in Appendix C.

6. Dams

The SWM ponds in the Mine Site and Steensby Inlet need embankment structures to create the storage required for stormwater treatment. This section describes the dam design aspect. First a dam safety assessment is performed to obtain the ICC rating of each dam structure and then important issues for the dam design are discussed.

6.1 Dam Safety Assessment

Due to the fact that the embankment structures for stormwater management meets the CDA definition of dams, according to the 2007 CDA guidelines, a dam safety assessment (DSA) was performed to evaluate the incremental consequence category (ICC) classification. This assessment is necessary since many of the design parameters must be consistent with the CDA dam safety requirements. If a dam is designed and constructed but it does not meet the dam safety requirements, it will have to do costly modifications to meet these requirements at a later stage. The design criteria are different for each ICC rating. The details of the dam safety assessment can be found in Appendix A. Here only the main conclusions are listed.

An ICC rating is based on an assessment of incremental impacts of dam failure on loss of life (LOL), social and economical losses and environmental impacts. If a dam causes hazard to the downstream area, this hazard is evaluated and rated based on the CDA guidelines.

Table 6-1: summary of Dam ICC ratings (Mine Site)

		Dam Height (m)	LOL	Social and Economic Loss	Environmental Damages	Overall
Pond 1	**Block Dam**	25	Low	Low	Significant	Significant
	Sediment Dam	25	Low	Low	Significant	Significant
	Discharge Dam	25	Low	Low	Significant	Significant
Pond 2 Dam		27	Low	Low	Significant	Significant
Pond 3 Dam		12	Low	Low	Significant	Significant

Table 6-2: S summary Dam ICC ratings (Steensby Inlet)

	Dam Height (m)	LOL	Social and Economic Loss	Environmental Damages	Overall
Pond 1 Dam	8	Low	Low	Significant	Significant
Pond 2 Dam	6	Low	Low	Significant	Significant

Based on CDA guidelines, the inflow design flood (IDF) and design earthquake (DE) for each structure are tabulated in Table 6-3 and Table 6-4.

Table 6-3: IDF and Design Earthquake Requirements (Mine Site)

		ICC	IDF	DE
Pond 1	**Block Dam**	Significant	1:200	1:1000
	Sediment Dam	Significant	1:200	1:1000
	Discharge Dam	Significant	1:200	1:1000
Pond 2 Dam		Significant	1:200	1:1000
Pond 3 Dam		Significant	1:200	1:1000

Table 6-4: IDF and Design Earthquake Requirements (Steensby Inlet)

	ICC	IDF	DE
Pond 1 Dam	Significant	1:200	1:1000
Pond 2 Dam	Significant	1:200	1:1000

6.2 Dam Section Design

6.2.1 Stability

Dam design is based on CDA guidelines for IDF, DE and stability. Table 6-5 summarizes the safety factors used for the Mary River Project dam design. Four load cases were checked. Table 6-5 summarizes the required Factor of Safety (FS) for the dam design based on CAD guideline corresponding to:

- steady state seepage corresponding to the normal water level (NWL)
- steady-state seepage at NWL in conjunction with earthquake loading
  - *Note:* The peak ground acceleration (PGA) for the site is 0.122 *g* based on data from the Canadian Geologic Society (CGS) corresponding to a 1:1000-yr return period. The detailed PGA for the site is shown in the Appendix B of the dam design report in Appendix B of this report.
- upstream slope stability subject to rapid drawdown
- slope stability of the upstream and downstream dam slopes at the end-of-construction before impounding water.

Table 6-5: Summary of the required Factor of Safety for Baffin land dam design based on CAD guideline

Load Combinations	Required Minimum FS	Type of Analysis
Steady Seepage corresponding to the NWL	1.5	Static analysis
Steady Seepage at NWL plus Earthquake Loads	1.0	Pseudo-static analysis
Upstream slope stability under rapid drawdown	1.2	Static analysis
Dam slope stability Just end of construction	1.3	Static analysis

6.2.2 *Thermal Conditions for Design*

The design basis thermal conditions are:

- The MAGT profiles at Baffinland Mary River is assumed to -10ºC (see Figure 6 of Appendix B)
- The reservoir-bottom mean water temperature is assumed to be 4ºC (see Figure 7 of Appendix B)
- The annual air temperatures was assumed to vary sinusoidally as follows:
  - max average air temperature is 7ºC in July
  - min. average air temperature is -25ºC in February.
- The natural active layer thickness is assumed to be 2 m (Wahl and Gharapetian, 2009)
- It is assumed that the foundation of the reservoir will thaw to the depth of 8 m in 50 years in the conceptual design stage.

6.2.3 *Additional Specific Requirement*

In addition to maintaining storm water retention requirements, the SWM ponds are required to have sufficient retention time to facilitate sedimentation of sediment within the reservoir (section 4.4.1). A small amount of seepage is required to help maintain the water level in control. The required seepage is assumed to be in the order of 10 L/s for the entire dam. This can be maintained by designing the dam to allow for controlled seepage to meet the flow requirements.

The anticipated type of service of the embankment is to retain water continuously.

6.3 Dam Section

Figure 6-1 presents a typical dam section for Mine site SWM Pond 2 dam. The dam has the following features:

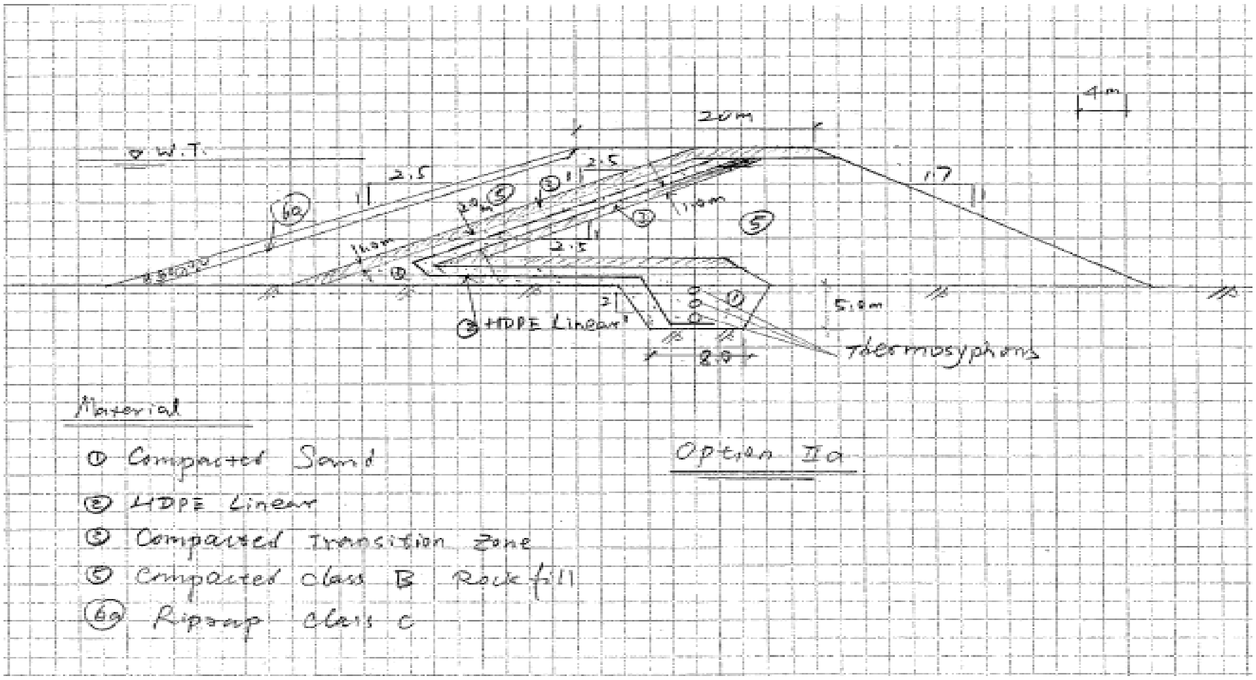

Figure 6-1: Typical Dam Cross Section

The dam consists of a rock fill dam with an HDPE liner as the primary seepage barrier. The main materials in this dam option consist of:

- Zone 1 – Bedding Material (Sand 0-13 mm or crusher fines)
- Zone 2 - Transient Zone
- Zone 3 – Compacted Rock fill
- Zone 5 - Riprap-Class C.

This dam section has been considered to permit a small amount of seepage through the upper part of the dam to control the reservoir during normal operating conditions. An additional liner is proposed to allow controlled seepage of water through the embankment without permitting it to enter the frozen key trench.

The estimated dam geometry consists of a 20 m wide crest (road traffic requirement) for this dam, 2.5H:1V U/S slope gradient, 1.7H:1V D/S slope gradient, a frozen key trench extending 5 m below ground surface and thermal siphons to maintain the thermal regime of the key trench. The crest of this dam is used for the access road and hence the crest width is design to be 20 m. For other dams, the crest width is set to be 5 m.

All of the dams use the same configuration with different crest elevation, spillway invert elevation and impermeable core elevation. These are summarized in Table 6-6 and Table 6-7.

Table 6-6: Dam Design Features (Mine site)

		Crest			Slope (H:V)		Spillway			Height m
		Elevation m	Width m	Length m	Up-stream	Down-stream	Width m	Side slope	Invert m	
Pond 1	Block Dam	355.0	5	150	2.5:1	1.7:1	-	-	-	25
	Sediment Dam	347.5	5	150	2.5:1	1.7:1	10	2:1	344.5	25
	Discharge Dam	329.0	5	150	2.5:1	1.7:1	10	2:1	326.0	25
Pond 2 Dam		547.5	20	800	2.5:1	1.7:1	10	2:1	544.5	27
Pond 3 Dam		204.5	5	400	2.5:1	1.7:1	10	2:1	203.5	12

Table 6-7: Dam Design Features (Steensby Inlet)

	Crest			Slope (H:V)		Spillway			Height m
	Elevation m	Width m	Length m	Up-stream	Down-stream	Width m	Side slope	Invert m	
Pond 1 Dam	13.0	5	600	2.5:1	1.7:1	10	2:1	10.5	8
Pond 2 Dam	40.0	5	500	2.5:1	1.7:1	10	2:1	38.0	6

7. Material Take Off Estimates

Material take off estimations were undertaken for the ditches and dams. These MTO estimations reflects the current design conditions. Some of the design may be modified and hence new MTO estimations will have to be undertaken when changes are made.

7.1 Ditches

A: Mine Site Waste Rock Dump ditches:

- Excavation volume: 234,000 m^3
  - Riprap volume and filter: 21,274 m^3
  - Fill material volume: not expected
  - Geo textile: 62,597 m^2

B: Mine site Ore Stockpile Clean Diversion Water Ditch:

- Excavation volume: 2,400 m^3
  - Riprap volume: not expected
  - Fill material volume: not expected

C: Mine site Ore Stockpile Drainage Ditch

- Excavation Volume (clean water Diversion): 147,600 m^3
  - Riprap volume: not expected
  - Fill material Volume: 183,545 m^3

D: Steensby Island Drainage Ditch

- Excavation Volume: 38,300 m^3
  - Fill material Volume: 729,760 m^3

E: Steensby Clean Water Diversion Ditch

- Excavation Volume: 103,700 m^3
  - Fill material Volume: Not expected

F: Steensby Drainage Ditch on the fuel farm and storage area

  - Excavation volume: 236,100 m^3
  - Fill material Volume: not expected

G: Milne Inlet Drainage Ditch

  - Excavation volume: 9,000 m^3
  - Fill volume: not expected

7.2 Dams

- Mine site Pond 1 Block Dam: 25,000 m^3
- Mine site Pond 1 Sediment Dam: 110,000 m^3
- Mine site Pond 1 Discharge Dam: 90,000 m^3
- Mine site Pond 2 Dam: 551,500 m^3
- Mine site Pond 3 Dam:
  - fill material: 152,837 m^3
  - excavation at spillway: 855 m^3
- Steensby Inlet Pond 1 Dam: 285,000 m^3
- Steensby Inlet Pond 2 Dam: 11,300 m^3
- Excavation at spillway 17,000 m^3

8. Remaining Works

The current design deals with the overall stormwater management and drainage system for the Mine site, Steensby Inlet and Milne Inlet. The major structures have been designed. There are still details to be completed in the next phase of the design. The detailed design will include:

- Hydraulic design of spillway structures, energy dissipater (if required) and erosion control measures. At this stage, the spillway dimensions were determined to make sure that the dams can pass the inflow design flood.
- Dam sections were designed to be stable under different load conditions. The section is not intended to allow overtopping of the dam body since the dam is an embankment structure and overtopping of the dam body shall be avoided. However, it is known that Pond 1 in Mine site and Pond 2 in Steensby may have to allow overtopping of the dam body due to various constrains. For these dams, special design will be required to allow overtopping.
- Culverts at several locations where ditches cross roads and / or other structures. At these locations, culverts are needed.
- It has to be realized that the design is a dynamic process. Some of the design features may need to be adjusted to meet the requirements of other disciplines. A few iterations between different requirements may be needed to make the entire system work. Therefore, some additional works will be required to make adjustments in the next phase of the design.

9. References

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Attachment A

Dam Safety Assessment Memo

Project Memo

August 23, 2011

TO: John Binns FROM: Ross Zhou

Baffinland Iron Mines Corporation
Mary River Project

Dam Safety Assessment

1. Introduction

The Mary River Project is a proposed iron ore mine and associated facilities ocated in northern Baffin Island, in the Qikiqtani Region of Nunavut. The Project involves the construction, operation, closure, and reclamation of a 18 million tonne-per-annum open pit mine that will operate for 21 years. The high-grade iron ore to be mined is suitable for international shipment after only crushing and screening with no chemical processing facilities. A railway system will transport an additional 18 Mt/a of ore from the mine area to an all-season deep-water port and ship loading facility at Steensby Port where to ore will be loaded into ore carriers for overseas shipment through Foxe Basin.

In the drainage system for stormwater management at the Milne Port, the Steensby Port and the mine site, dykes will be constructed for establishing stormwater management ponds. Based on the definition of Canadian Dam Association's Dam Safety Guidelines (CDA, 2007), a water retaining structure with storage over 30,000 m^3 and height exceeding 2.5 meters is defined as a dam and hence must meet the dam safety requirements. The dam safety requirements consistent of many aspects including risk management system, meeting the design standards and having proper operation, maintenance and surveillance procedures (OMS). And if the dam is classified as HIGH incremental hazard potential (IHP), a proper emergency preparedness and response plan (EPRP) is required.

Due to the fact that the embankment structures for stormwater management meets the CDA definition of dams, according to the 2007 CDA guidelines, a dam safety assessment (DSA) was performed to evaluate the incremental consequence category (ICC) classification. This assessment is necessary since many of the design parameters must be consistent with the CDA dam safety requirements. If a dam is designed and constructed but it does not meet the dam safety requirements, it will have to do costly modification to meet these requirements at later stage. The design criteria are different for each ICC rating. Therefore, a ICC classification must be assessed before any actual work starts.

This dam safety assessment (DSA) is not a full scaled DSA and hence it only addresses the main issues to allow the selection of proper inflow design flood and design earthquake. Many other aspects required by the CDA guidelines will have to be addressed later (for example, if a dam is classified as HIGH ICC structure, EPRP document must be prepared. If required, the EPRP will be done in later stage).

2. CDA Dam Classification and IDF Requirements

Dam classification forms the basis of dam design criteria. Every dam must first be classified based on consequences or risk of dam failure. The CDA dam classification system is presented in Table 2- 1. In the table, a classification of consequences is based on three aspects: incremental loss for loss of life (LOL), Environmental and cultural values (EC), and infrastructure and economics (IE). Based on the degree of damages, each dam will be assigned a incremental consequence category (ICC). The inflow design flood (IDF) will be determined according to the ICC classification.

Table 2- 1: Dam Classification

Dam class	Population at risk [note 1]	Incremental losses		
		Loss of life [note 2]	Environmental and cultural values	Infrastructure and economics
Low	None	0	Minimal short-term loss No long-term loss	Low economic losses; area contains limited infrastructure or services
Significant	Temporary only	Unspecified	No significant loss or deterioration of fish or wildlife habitat Loss of marginal habitat only Restoration or compensation in kind highly possible	Losses to recreational facilities, seasonal workplaces, and infrequently used transportation routes
High	Permanent	10 or fewer	Significant loss or deterioration of *important* fish or wildlife habitat Restoration or compensation in kind highly possible	High economic losses affecting infrastructure, public transportation, and commercial facilities
Very high	Permanent	100 or fewer	Significant loss or deterioration of *critical* fish or wildlife habitat Restoration or compensation in kind possible but impractical	Very high economic losses affecting important infrastructure or services (e.g., highway, industrial facility, storage facilities for dangerous substances)
Extreme	Permanent	More than 100	Major loss of *critical* fish or wildlife habitat Restoration or compensation in kind impossible	Extreme losses affecting critical infrastructure or services (e.g., hospital, major industrial complex, major storage facilities for dangerous substances)

Note 1. Definitions for population at risk:

None—There is no identifiable population at risk, so there is no possibility of loss of life other than through unforeseeable misadventure.

Temporary—People are only temporarily in the dam-breach inundation zone (e.g., seasonal cottage use, passing through on transportation routes, participating in recreational activities).

Permanent—The population at risk is ordinarily located in the dam-breach inundation zone (e.g., as permanent residents); three consequence classes (high, very high, extreme) are proposed to allow for more detailed estimates of potential loss of life (to assist in decision-making if the appropriate analysis is carried out).

Note 2. Implications for loss of life:

Unspecified—The appropriate level of safety required at a dam where people are temporarily at risk depends on the number of people, the exposure time, the nature of their activity, and other conditions. A higher class could be appropriate, depending on the requirements. However, the design flood requirement, for example, might not be higher if the temporary population is not likely to be present during the flood season.

Table 2- 2: Inflow Design Flood Requirement (CDA, 2007)

Consequence Class	IDF
Low	1/100-year
Significant	Between 1/100 and 1/1000-year (Note 1)
High	1/3 between 1/1000-year and PMF (Note 2)
Very High	2/3 between 1/1000-year and PMF Note 2)
Extreme	PMF

Note 1. Selected on basis of incremental flood analysis, exposure and consequence of failure.
Note 2. Extrapolation of flood statistics beyond 1/1000-year flood (10^{-3} AEP) is generally discouraged. The PMF has no asssociated AEP. The flood defined as "1/3 between 1/1000-year and PMF" or "2/3 between 1/1000 year and PMF" has no defined AEP.

Table 2- 2 presents the IDF requirement corresponding to each of the ICC classification.

According to the CDA 2007 Dam Safety Guidelines, each dam has to be evaluated separately. This memo describes the results of the assessment for each structure in the mine site, the Milne port and Steensby Port. At this stage, there is no dam safety guidelines in Nunavut and hence the assessment will use the CDA guidelines as the basis of the evaluation.

3. ICC Classification

3.1 Minesite Stormwater Pond 1 Discharge Dam

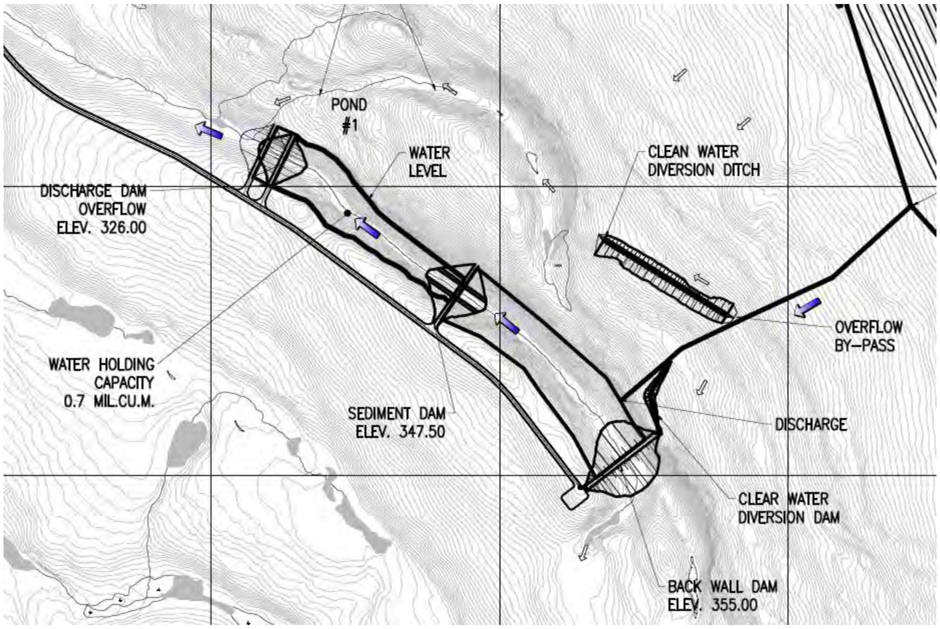

Figure 3-1: Dam Locations of Pond 1

This dam is the downstream most structure to retain stormwater in Pond 1. The dam shown on Figure 3-1 has an overflow weir at elevation 326 m. Te length of the dam at the crest is about 150 m. The height of the dam is about 25 m. The dam retains 0.7 million m^3 of water at the normal water level. If the dam fails, the released water will be discharged to the downstream area and eventually be stored in Camp Lake.

There is an access road which may have some erosion damages. In the downstream area, there is no permanent residents and hence no loss of life (LOL) will be resulted. The sediment in the pond will be released to the downstream area and may reach Camp Lake. The sediment will settle in Camp Lake leading to some environmental damages to the lake water quality. The water in Camp lake is used for water supply and hence this high concentration of sediment may have some impacts to the water quality. According to this description, the dam will have zero (0) LOL. There will be no third party economic losses. Therefore, this dam is classified as LOW incremental consequence category (ICC) for LOL and Economics. With respect to the environmental losses, the ICC is classified as SIGNIFICANT due to the impacts to water quality in the downstream area.

The overall ICC category is then SIGNIFICANT.

Based on the CDA guidelines, the inflow design flood shall be between 1:100 year and the 1:1,000 year flood. Due to the relatively low impacts to the downstream area from LOL and economic aspects, and is significant for environmental impact, a 1:200 year design flood is appropriate.

For earthquake, the design level will be the 1:1,000 event based on the CDA guidelines.

3.2 Minesite Stormwater Pond 1 Sediment Dam

This dam is located upstream of the discharge dam (Figure 3-1) and downstream of the back wall dam. This dam is acting as sediment barrier for the stormwater pond. The dam is approximately 25 m high and crest length is about 150 m. The crest elevation is at 347.5 m. If the dam fails, the water will be retained in the downstream pond between the discharge dam and the sediment dam. Then if the discharge dam fail because of the failure of the sediment dam, the ICC is SIGNIFICANT. Therefore, the sediment dam will have the same ICC classification as the discharge dam. The design flood shall therefore be the 1:200 year event. The design earthquake will be the 1:1,000 year event.

3.3 Minesite Stormwater Pond 1 Back Wall Dam

The back wall dam is located on the upstream end of the stormwater Pond 1 to form the upstream cell of the pond. The dam is 25 m high and about 150 m long at the crest. If the dam fails, there will be no LOL and no third party economical damages. The environmental impact would be significant because the released water contains high concentration of sediment from the waste rock stockpile. The overall ICC category assigned to this dam is SIGNIFICANT.

The inflow design flood for this dam shall be the 1:200 year flood and the design earthquake is the 1:1,000 year event.

3.4 Minesite Stormwater Pond 2 Dam

Figure 3-2 shows the location of the Pond 2 dam. This dam is approximately 15 m high and 800 m long at the crest. The volume of water stored is in the order of 500,000 m^3. The dam crest is an access road. The dam discharges to the Mary River.

If the dam fails, the outflow will enter Mary River and be discharged to the downstream water course. There will be no LOL since there are no residents in the downstream area. The economical damage will be the road operation which is a short term and internal damages. There is no third party damages. Therefore the ICC for LOL and economical damages are LOW.

For environmental damages, there will be high concentration of sediment released to the Mary River and this will lead to water quality problem. But the impact shall be short term water quality problem. The ICC classification for this dam is therefore SIGNIFICANT.

Based on this classification, the inflow design flood shall be the 1:200 year flood and the design earthquake will be the 1:1,000 event.

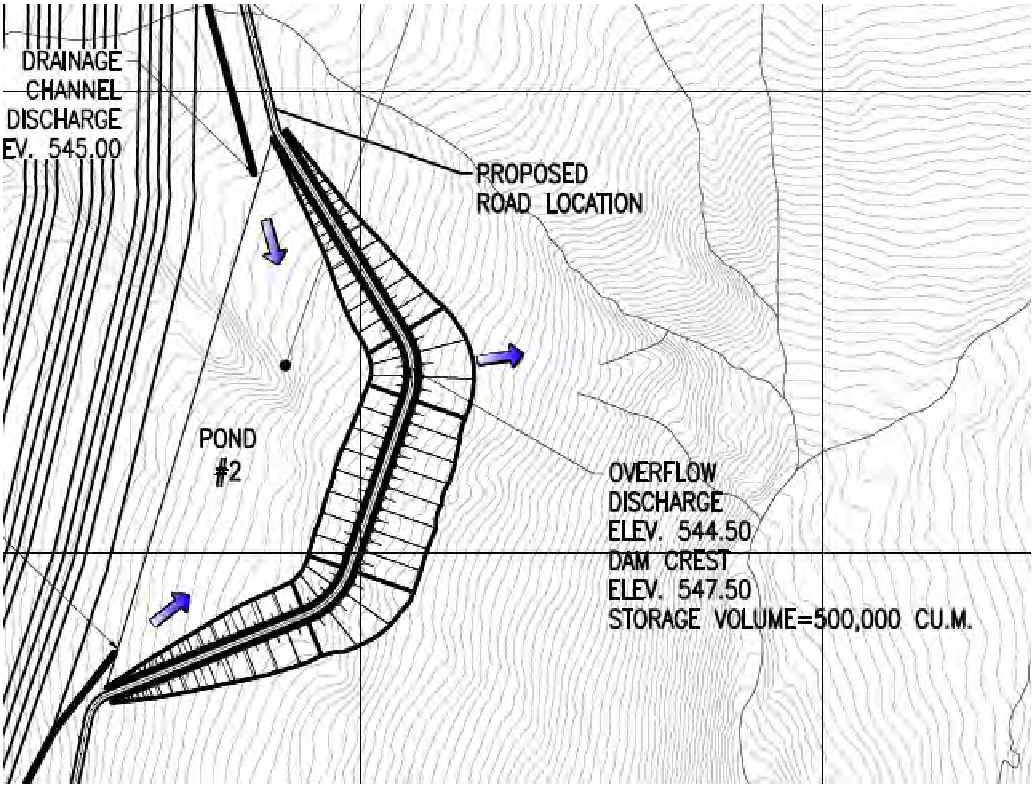

Figure 3-2: Minesite Pond 2 Dam

3.5 Minesite Stormwater Pond 3 Dam

This dam is located downstream of ROM Stockpile to form the stormwater management pond. The dam is shown on Figure 3-3.

The dam crest elevation is 264.3 m. The dam is 9.3 m high and about 150 m long. The storage is 35,000 m^3.

The failure of this dam will lead to no LOL and third party economical damages and hence the ICC for LOL and Economic damages are LOW. The failure of the dam will lead to high concentration of sediment be released to Mary River which will have short term water quality impacts to the river. The ICC assigned to the dam for Environmental aspect is SIGNIFICANT. And the overall ICC classification is SIGNIFICANT.

The inflow design flood shall therefore be the 1:200 year flood and the design earthquake is the 1:1,000 year event.

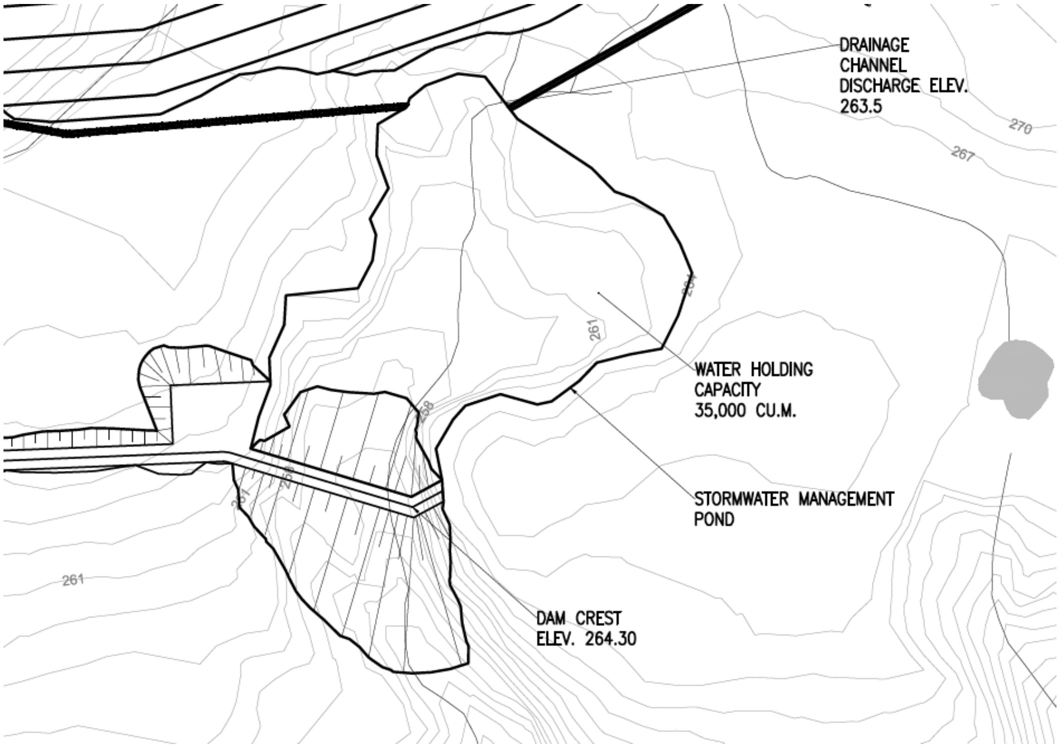

Figure 3-3: Stormwater Management Pond 3 Dam

3.6 Minesite Stormwater Pond Dam

This dam is located just upstream of the waste water clarification pond. The dam is about 12 m high and more than 400 m long. The storage capacity of the pond is 150,000 m^3. If the dam fails, there will be no LOL and third party economical damages. Therefore, the ICC for LOL and economical losses are LOW. The released water will lead to water quality problem in Sheardown Lake. The ICC classification for environmental impact is SIGNIFICANT. The overall ICC for this dam is then SIGNIFICANT.

The inflow design flood shall be the 1:200 year flood and the design earthquake level is the 1:1,000 year event.

The dam is shown on Figure 3-4.

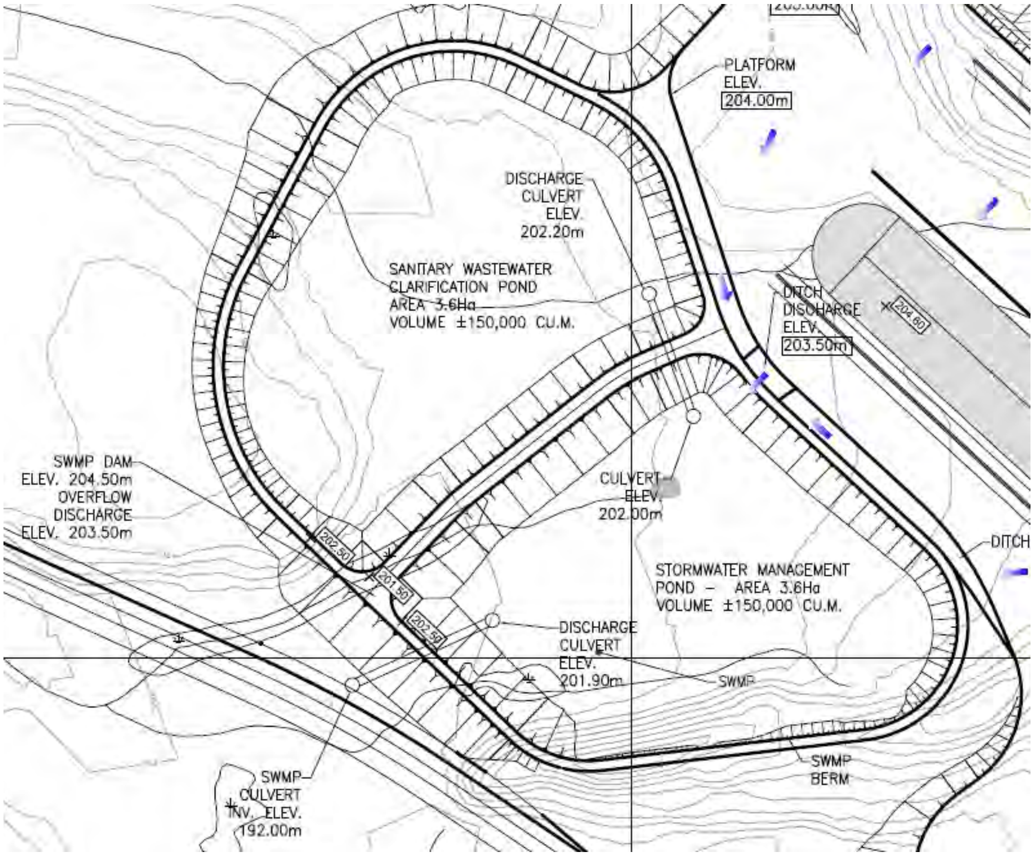

Figure 3-4: Stormwater Management Pond 4 Dam

3.7 Milne Port Stormwater Pond 10 Dam

This dam is shown on Figure 3-5. This dam is located on the west side of the proposed ore stockpiles in the port operating area. The pond collecting runoff from the stockpile and then the runoff will be pumped to Pond 9. The storage capacity of the pond is 40,000 m^3, the dam height is about 6 m. and the crest length is about 250 m.

If the dam fails, the storage will be discharged to Phillips Creek. The downstream 1,200 m runway will be flooded. There will be no LOL and no third party economic losses. The ICC for LOL and economical losses are LOW. The released sediment will lead to environmental damages to the downstream Phillips Creek. The environmental loss is classified as SIGNIFICANT. The overall ICC is SIGNIFICANT.

The IDF for this dam shall be the 1:200 year flood and the design earthquake is the 1:1,000 year event.

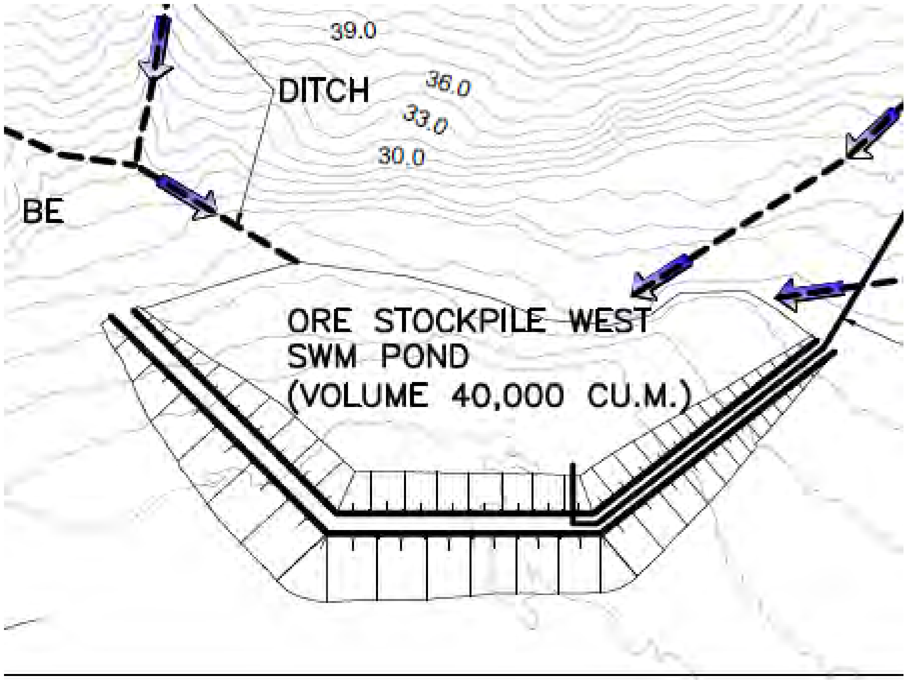

Figure 3-5: Pond 1 Dam (Milne Port)

3.8 Milne Port Stormwater Pond 9 Dam

This dam is the ore stockpile east pond within the platform. The dam crest is 52 m and the depth of the dam is about 6 m. The total storage of pond has is 200,000 m^3. There will be no LOL and third party economical damages if the dam fails since the pond is located just upstream of the ocean and hence the failure of the dam will lead flows be discharged into the ocean. Therefore, the ICC for LOL and economical damages are LOW. The released water contains high concentration of sediment which will lead to some environmental damages to the downstream water body. The ICC for environmental damages is SIGNIFICANT.

To properly design the dam, a 1:200 year flood shall be used for inflow design flood and the design earthquake is the 1:1,000 year event.

Figure 3-6 shows the general layout of the proposed stormwater management pond.

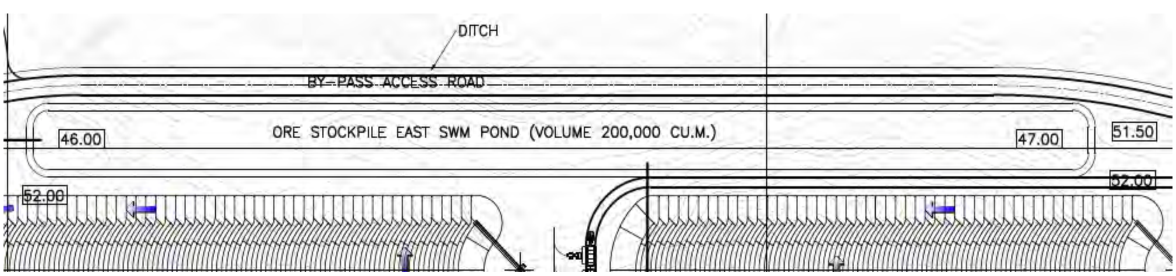

Figure 3-6: SWM Pond no. 9, Milne Port

3.9 Steensby Port, Ore Stockpiles Stormwater Management Pond Dam

This dam is shown on Figure 3-7. The dam is about 8 m high and 600 m long. The pond has a storage capacity of 125,000 m^3. There will be no LOL and third party economical damages if the dam fails since the pond is located just upstream of the ocean and hence the failure of the dam will lead flows be discharged into the ocean. Therefore, the ICC for LOL and economical damages are LOW. The released water contains high concentration of sediment which will lead to some environmental damages to the downstream water body. The ICC for environmental damages is SIGNIFICANT.

To properly design the dam, a 1:200 year flood shall be used for inflow design flood and the design earthquake is the 1:1,000 year event.

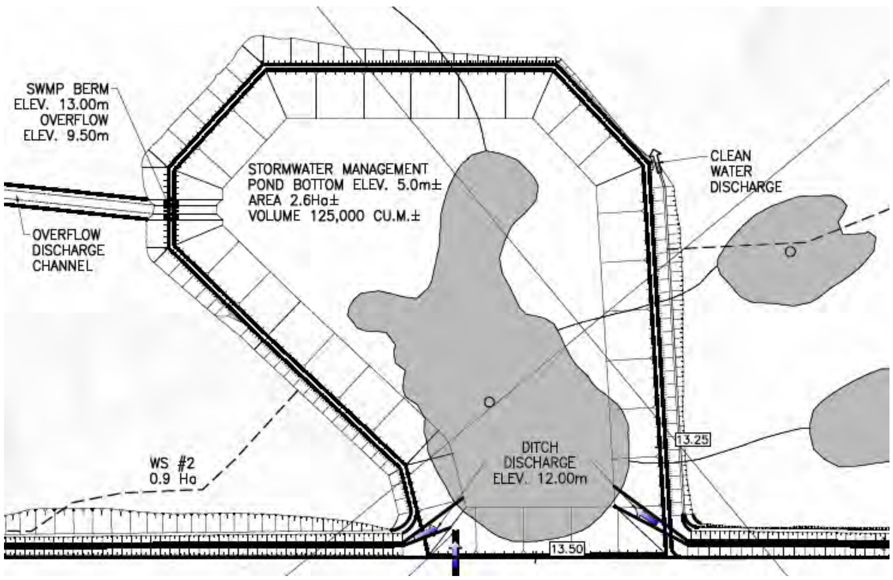

Figure 3-7: Steensby Port Ore Stockpile Stormwater Management Pond

3.10 Steensby Port, Platform Stormwater Management Pond Dam

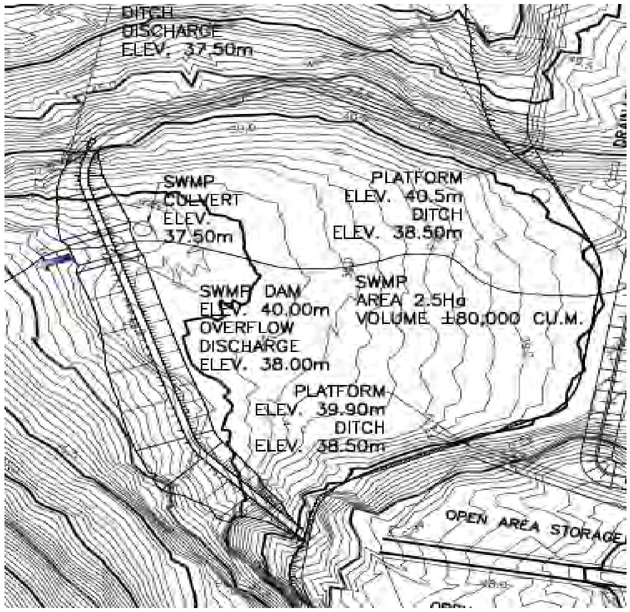

Figure 3-8: Platform Stormwater Management Pond Dam

This dam is located at the west side of the platform for collecting stormwater from the platform area. The dam height is about 4 m and the length of the crest is about 500 m. The total storage is about 80,000 m^3.

If the dam fails, there will be no LOL and third party economical damages. The ICC for LOL and economical losses are LOW. for environmental damages, there will be short term water quality problem to the ocean. The ICC for environment perspective is therefore SIGNIFICANT. The overall ICC is SIGNIFICANT.

Therefore, the inflow design flood for this dam shall be the 1:200 year flood and the design earthquake is the 1:1.000 year event.

4. Freeboard Requirement

For preventing overtopping of the crest during significant wind event, a minimum of 0.9 m freeboard is required during the passage of the inflow design flood (USBR, 1987).

5. Conclusions

It is concluded based on this assessment that:

1. The stormwater management dams have a SIGNIFICANT ICC classification based mainly on environmental damages to the water quality. The LOL and economical damages are LOW. Due to this ICC rating, the inflow design floods and design earthquake are determined
2. The inflow design flood corresponding to the SIGNIFICANT ICC rating shall be the 1:200 year flood. The IDF will be used for designing the spillways for each of the dams.
3. The design earthquake level will be the 1:1,000 year event. The design earthquake will be used for determining the embankment stability during dynamic conditions.

6. References

- Baffinland Iron Mines Corporation, 2010, Mary River Project, Environmental Impact Statement
- CDA, 2007, Dam Safety Guidelines, Canadian Dam Association
- USBR, 1987, Design of Small Dams, A Water Resource Technical Publication, US Bureau of Reclamation

RZ:rz

Attachment B

Dam Design Report

Project Report

Baffinland Mary River Project
Mary River Project

Conceptual Design for Dam

2011-11-09	A	Approved for Use - Environmental Permit	G. Liang	S. Hinchberger	J. Binns	
DATE	REV	STATUS	PREPARED BY	CHECKED BY	APPROVED BY	APPROVED BY
YYYY-MM-DD			HATCH			CLIENT

Safety • Quality • Sustainability • Innovation

Table of Contents

Safety • Quality • Sustainability • Innovation

1. Introduction

The Mary River Project is located on the northern half of Baffin Island at Latitude 71° and Longitude 79° approximately 1000-km northwest of Iqaluit, the capital of the Nunavut Territory The mineral properties of BIM consist of three mining leases covering a total area of 1593.4 ha. The Project involves the construction, operation, closure, and reclamation of a 21 million tonne-per-annum open pit mine that will operate for 21 years. In addition to developing the mine site, two ports (Steensby and Milne) will be developed to transport ore from Baffin Island to processing facilities elsewhere. Figure 1-1 shows the location of the Mary River Project.

As part of the storm water management system, Baffinland has identified the need for a series of storm water management (SWM) ponds at the Milne Port, the Steensby Port and the Mine Site, respectively. The SWM ponds will require construction of embankment dykes or dams on permafrost. The current report focuses on embankment dam options at the Mine Site only. Two conceptual dam designs are presented along with a recommendation of the preferred option. It is also felt that the options can also be considered for the Milne and Steensby Ports. The following sections summarize: i) Scope of the work; ii) General background; iii) Conceptual design of the embankment; iv) discussion and v) conclusion and recommendation.

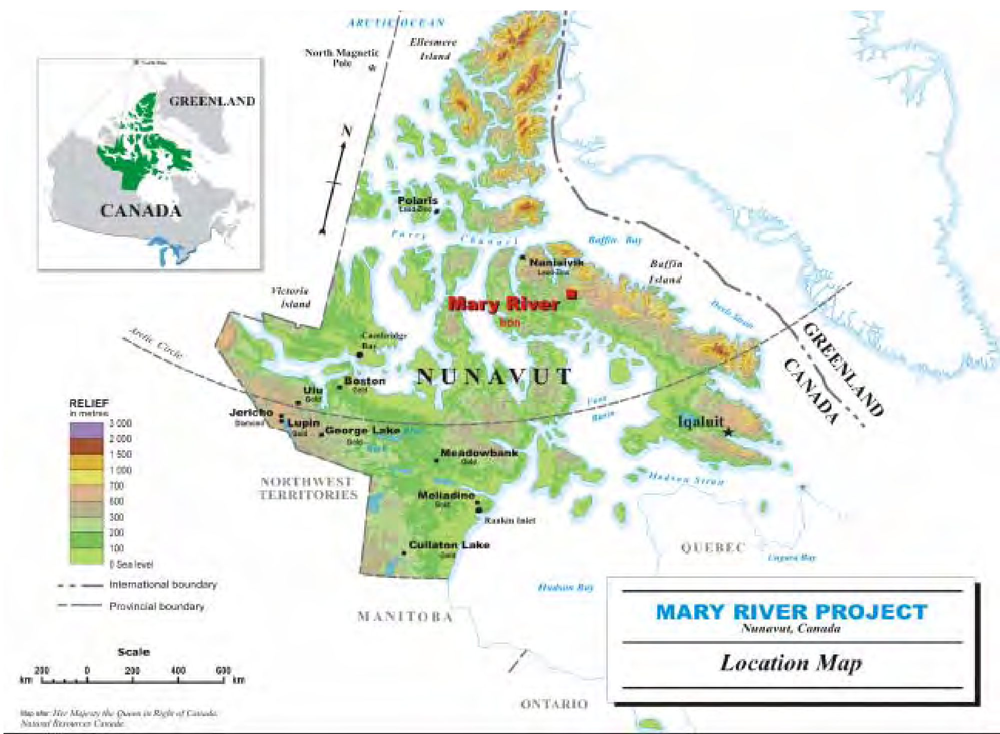

Figure 1-1: Location of Baffinland Mary River Project

1.1 Scope of work

Earth and rock fill embankment dams with various heights are required to provide containment for SWM ponds at the Mary River sites (Mine Site). Hatch was retained to develop a conceptual design for the proposed dams. The scope of work at this stage included:

- A literature review of the design and construction of embankment dykes and dams on permafrost.
- A review of the site specific geothermal data for embankment/dam design.
- Assessment of the main factors to be considered for design.
- Establishment of a preliminary design basis for the embankment/dams.
- Develop feasible embankment / dam options.
- Identify the preferred option for the next design stage.

In this report, the conceptual design of the dams at Mine site SWM Pond 2, 3 and the Milne Port SWP 10 are considered. The maximum dam height is 15 m; However, the recommended dam option could be used at the Mary River sites.

2. Literature Review-Embankment Dams Built on Permafrost

The design, construction and operation of embankment dams and dykes in the Arctic and Subarctic present unique problems related to freezing temperatures and the behaviour of frozen soil and rock materials exposed to the influence of unfrozen water. Challenges of major concern typically experienced in these conditions include:

- Thawing of structures foundered on permafrost.
- Earth movement due to freeze-thaw cycles.
- Placing of frozen soils and fill.
- Scheduling of construction in remote areas having a harsh climate.

A literature review was conducted to investigate the performance of previously constructed embankment dams and dykes on permafrost. Table 2-1 summarizes the typical problems experienced (Francis, 1987), which can be categorized as either (a) Thawing erosion due to seepage (see cases No. 1-5) and failure to maintain the thermal regime of the embankment and its foundation (see cases No. 6-15). Table 2-2 provides a summary of successful cases of embankment dam construction on permafrost. The typical dam sections in Appendix A correspond to the cases shown in Table 2-1and Table 2-2.

The design of water-retaining embankments on permafrost can be divided into two general types: i) frozen and ii) thawed. Frozen embankments are design so that the embankment and its foundation are frozen through the entire service life of the structure. In contrast, thawed embankments are designed to thaw during the service life and design provisions are made to accommodate and tolerate the effect of thawing. The following summarizes the main considerations for designing embankments in cold regions and for selecting the type of embankment for a particular site.

- the anticipated type of service of the embankment (i.e. retain water continuously or only intermittently)
- the width, depth, temperature and chemical composition of the body of water to be retained by the embankment
- regional and local climate conditions
- the temperature of the existing permafrost
- the extent and depth of permafrost in the area
- the availability and type of earth materials available for construction
- the accessibility of the construction site for logistics involving man-made construction materials (i.e. geomembranes and geosynthetics)
- the effects of construction and operation of the embankment and reservoir on the environment
- frost action on dry slopes and crest of the embankment
- the consequences to life, property, and environment in the event of embankment failure
- the orientation of the downstream slope (dry slope) of the embankment with respect to solar radiation
- the economics of constructing a selected design in the code region.

Table 2-1: Summary of Embankments built on Permafrost– Embankments with Problems (Francis, 1987)

No.	River Name	Location	Embank. Type	Height (m)	Length (m)	Built Year	Problem Description	Reference
1	Unknown	Northern Former USSR	Compacted earth	21.4	230	1967	Municipal water supply dam was completed in 1970. A breach occurred through embankment at supply intake pipes due to thermal erosion and seepage.	Anisimov & Sorokin (1975)
2	Hess Creek	Livengood, AK	Hydraulic & compacted earth fill	24	488	1946	The dam was for mine water supply. In 1962, embankment breached at interface with spillway due to thermal erosion and seepage	Rice & Simoni (1963)
3	Myla River	Zarechnyy Region, Former USSR	Compacted frozen sand	-	-	1954	Constructed of un-compacted frozen sand during winter. Seepage through earth dam and joints in wooden spillway caused thawing and failure of dam in 1954	Lyskaniv (1964)
4	Vilyuy River (Dam I)	Former USSR	Sand and silt Dyke w/ crib cut off	12	300	1960	During initial operation in 1960, large seepage occurred and spillway was completed destroyed in the first flood. After reconstruction in 1969, leakage was observed from reservoir through caverns in the foundation and at contact points with the spillway. Causes of problems: i) spillway too small for flood; 2) ice-retaining structures not located far enough U/S from the dam; 3) fissures in the foundation not sealed; 4) poorly compacted cutoff	Biyanov (1966)
5	Vilyuy River (Dam II)	Former USSR	Embank. with clay-ice core	3	-	1960	Clay-ice core constructed in winter with frozen clay and water. Seepage along spillway-embankment contact resulted in degradation of frozen core and loss of water-retaining function.	Biyanov (1966)
6	Dolgaia River	Noril'sk, Former USSR	Refrigerated earth	10	130	1942	A "Clay-concrete core" with two rows of freezing pipes parallel to dam axis. Thermal region of the core was not maintained causing thawing of the embankment	Tsvetkova(1960), Borisov & Shamshura (1959)
7	Srednity El'gen River	Kolyma River Basin, Former USSR	Earth	-	-	-	Large deformation and cracks occurred along the dam due to seepage and thawing. Seepage developed where timber piling was used as a cutoff.	Tsvetkova (1960)

No.	River Name	Location	Embank. Type	Height (m)	Length (m)	Built Year	Problem Description	Reference
8	Myaun-dzha River	Kolyma River Basin, USSR	Earth fill w/core	8	860	1952	The abutment of the dam was not protected by freeze pipes and thawing occurred at this location in the summer. The ensured seepage caused failure of the dam	Tsvetkova (1960)
9	Amozer River	Near Mogocha on the Amer Railroad, USSR	Grib-core Rock-earth fill	4	-	1910-1916	Failed due to seepage and thawing through body of the embankment	Tsvetkova (1960)
10	Kvadrat-nyy River	Noril'sk, USSR	Compacted earth-fill	6	-	-	Dam used for cooling water supply for electric power station. Failed within one year after construction by thawing of foundations and abutment soils	Biyanov & Shamshura (1959)
11	Stake 89 (Picket Creek)	Noril'sk, USSR	Compacted earth-fill	5.5	-	-	Failed two years after construction when seepage through the unfrozen soil thawed the frozen soil.	Tsvetkova (1960)
12	Mykyrt River	City of Petrovsk-Zabaykalskiv, USSR	Earth	9.5	-	1792	In attempting to repair the wooden spillway of the 137-yr-old dam, proper measures were not taken to preserve the frozen embankment and it failed. The dam had to be completely rebuilt in 1945.	Tsvetkova (1960)
13	Pravaya Magda-gacha River	Northern Previous USSR	Compact earth with concrete diaphragm	7.3	-	-	Failed after two years of operation. Large deformation of dam resulted in cracks in the diaphragm all along the embankment dam and at the junction of the weir. Final failure occurred during heavy thunder storm when leakage appeared at the crest. Failure occurred over a 65m length.	Tsvetkova (1960), Saverenskii (1950)
14	Bol'shoy Never River	Skovorodino, USSR	Earth silt and gravel with clay core	9.6	530	1932	The clay-ice core became semi-liquid and the stability of the dam was threatened. In 1934 ballast was applied to the slopes and wooden piling was driven, soil behind the piling was replaced by more impervious materials and a wood gallery was constructed to catch the seepage. Deep thawing of the foundation soil and bedrock in 1936 did not cause serious problems.	Tsvetkova (1960)
15	Vilyuy River (Dam V)	USSR	Random earth fill w/ timber	16.8	332	-	Constructed on ice-saturated clayey silt and disintegrated rock overlying fissured clay-limestone. In the spring of 1965 and 1966 boils appeared downstream of the dam. Seepage was caused by thawing of ice in rock joints during construction.	Biyanov(1966)

Table 2-2: Summary of literature review of successful embankments built on Permafrost

No.	Name	Permafrost/ Location	Foundation Material	Type	Function	Height (m)	Reservoir depth (m)	Impervious barrier	Reference
1	Ekati Diamond Mine (2002)	North West Territories (Continuous Permafrost)	N/A	Rock fill with central frozen key trench, geomembrane core and GCL on U/S slope.	Surface water management	15	13.3	-Frozen key trench of min. embedment 2.0m, and Thermosyphons; -Polypropylene (UPP) geomembrane (used in core)-GCL on U/S side of dam-Non woven LP geotextile used as an upstream cushion)	Gräpel et. al (2005)
2	Diavik Diamond Mine (2001)	North West Territories (Continuous Permafrost)	Varies: Frozen Silty Sand Till (ice rich upper zone), over Bedrock	Rock fill with central frozen key trench and HDPE liner	Dredged sediment control	9 - 14	10	-HDPE liner-Frozen cut-off trench to ice-poor soil or bedrock (min 1m)	Holubec et. al (2003)
3	Snap Lake Dam 1 (2000)	North West Territories (Continuous Permafrost)	Intact bedrock	Rock fill with HDPE liner and frozen cut-off trench	Residual processed kimberlite storage	7	5.5 (total storage)	-Frozen cut-off trench to intact bedrock-Textured HDPE liner	J. Cassie (2003)
4	Kettle Dykes (1971)	Manitoba (Discontinuous Permafrost)	Varies: Frozen Silts and cemented Sands, bedrock, sandy clay	-Semi pervious (sand fill) homogenous fill with U/S and D/S filters-thaw-consolidation design	Hydroelectric	8	~4	-Wide structure and low gradients allowed for controlled seepage.	N. J. Smith (1983)
5	Kelsey Dykes (1971)	Manitoba (Discontinuous Permafrost)	Bedrock	-Earth fill (clay core with gravel shell)-thaw-consolidation design	Hydroelectric	6	N/A	-Wide structure and low gradients allowed for controlled seepage	N. J. Smith (1983)

Note: the available typical cross sections of the dam design are summarized in Appendix A

3. Site Specific Background

3.1 Summary of Mary River Dams

Nine SWM Ponds and embankment dams are proposed for the Mary River Project. Table 3-1 summarizes the characteristics of the dams; Figure 3-1 shows the general layout of the dam locations. As required, only the conceptual design of the dams at Mine site SWM Pond No. 2 and No. 3 and the Milne Port SWM Pond No. 10 are considered. The maximum dam height is 15m. In general, however, the recommended dam option could be considered for SWM ponds at the other Mary River Project sites. Geotechnical data is currently unavailable for dam design. However, based on boreholes drilled in adjacent areas (MWD 003 and 004) and site visits between 25-29 July, 2011, the foundation conditions likely consists of a 0-13.5m of glacial till deposits underlain by bedrock. The bedrock is assumed to be fractured. The ground water table was not reported in the borehole logs of MWD003 and 004.

Table 3-1 : Summary of the proposed dams for Baffinland Mary River Project (Hatch Memo, 2011)

No	Name1	Function	Max. Height (m)	Dam Crest el. (m)	Length (m)	Reservoir Capacity (m3)	ICC classification
1	Minesite SWM Pond No. 1 Discharge Dam	This dam is the downstream most structure to retain stormwater in pond #1	25	327	160	7E6	Significant
2	Minesite Stormwater Pond No. 1 Sediment Dam	This dam is acting as sediment barrier for the stormwater pond	25	347.5	150	-	Significant
3	Minesite Stormwater Pond No. 1 Back Wall Dam	to form the upstream cell of the pond	25	355	150	-	Significant
4	Minesite Stormwater Pond No. 2 Dam	Storm water management	27	547.5	800	5E6	Significant
5	Minesite Stormwater Pond No. 3 Dam	Storm water management	12	204	400	1.5E+5	Significant

No	Name1	Function	Max. Height (m)	Dam Crest el. (m)	Length (m)	Reservoir Capacity (m3)	ICC classification
6	Steensby Port, Ore Stockpiles Stormwater Manageme nt Pond Dam	Storm water management	8	13	600	1.3E+5	Significant
7	Steensby Port, SWM pond Dam	Storm water management	12	40	500	80,000	Significant

Note: only highlighted dams are considered in this stage and the maximum dam height is 27 m

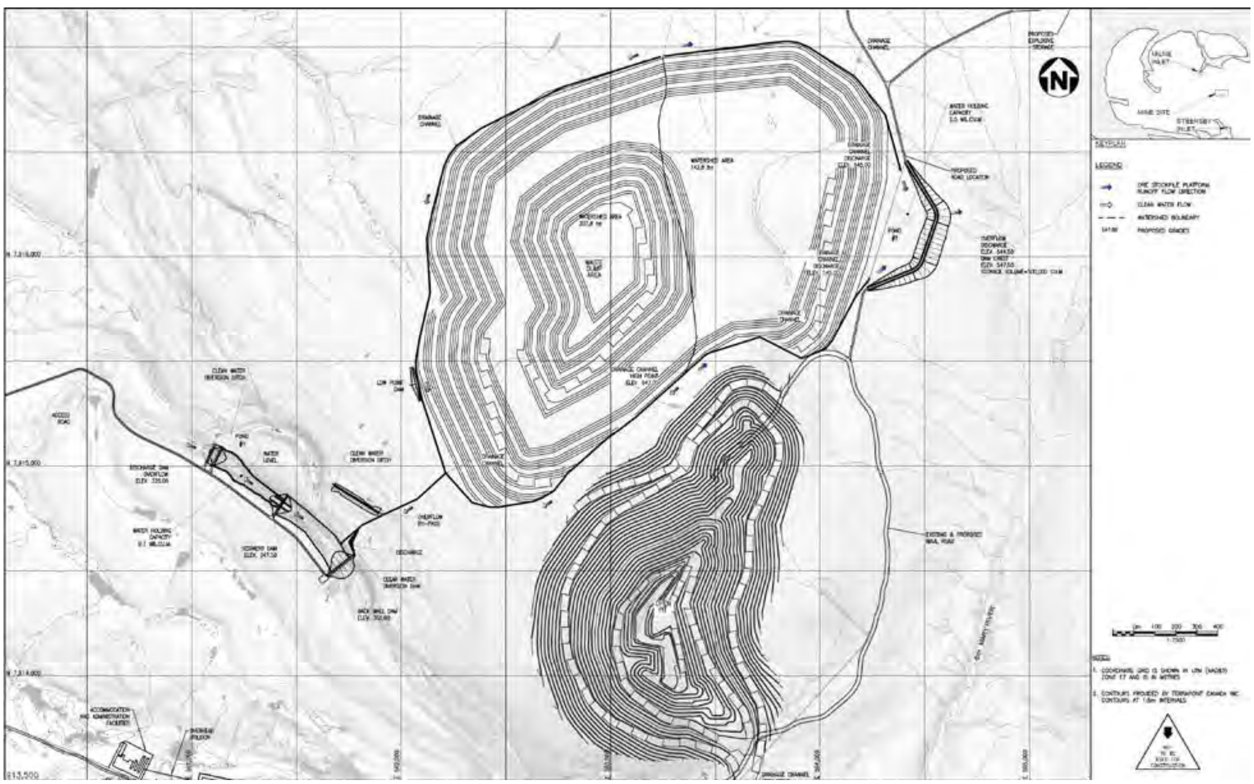

Figure 3-1: - General layout of Baffinland dams in Mine Site

3.2 Climate

The North Baffin region is located within the Northern Arctic Ecozone, as delineated in the National Ecological Framework for Canada (Agriculture and Agri-Food Canada, 2000). Typical Arctic environments exists at the Baffinland Mary River Project sites. The area experiences average annual temperature of -15 C. North Baffin Island has a semiarid climate with relatively little precipitation. The region experiences 24-h darkness with less than 2 hours of twilight from approximately November 12 to January 29. Frost-free conditions are short and are from late June to late August. There is continuous daylight from approximately May 5 to August 7. The months of July and August bring maritime influences and are usually the wettest (snow may still occur). During September to November, temperature and the number of daylight hours start to decrease, and by mid-October the mean daily temperature is well below 0°C. The highest amount of snowfall typically occurs during this period. A condition called “Arctic white out” often occurs during this time, where diffuse white clouds blend into the white snow covered landscape, reducing visibility and increasing the likeliness of disorientation. This condition can also occur in April and May.

3.3 Regional Geology

The local bedrock is of the Mary River Group, which is part of the Committee Belt. This belt comprises an assemblage of granite-greenstone terrains, rift basin sediments and volcanic rocks which lie within the northern Churchill Province and extend from south-west of Baker Lake for over 2000 km to north-western Greenland (Jackson and Berman, 2000). The Committee Belt is joined to the south by the Baffin Orogen. Figure 3-2 shows the Regional Geology Map of Baffin Island (Jackson et. al, 2000). The Committee Belt has been divided into major assemblages, which include the following:

- Archean-age banded granite migmatites and three or more phases of gneissic granitic intrusions, traversed by deformed amphibolite dikes. Ages 3.7 to 2.85 Ga, are unconformably overlain by the Mary River Group. The units are strongly metamorphosed.
- Late-Archean Mary River Group; a diverse assemblage of metasedimentary and metavolcanic rocks, preserved in narrow, folded greenstone belts. Ages 2.76 to 2.72 Ga. Belts generally show a lower sequence of varied metavolcanics, overlain by metasedmentary-metavolcanic sequences including iron formation, succeeded by an upper group of metavolcanic and metapelitic clastic sedimentary units with high-level metamorphism.
- Paleoprotorozoic Piling Group; metasedimentary/metavolcanic sequence including quartzites, marble, sulphidic iron formation, black schists, mafic metavolcanics. Ages 1.9 to 1.8 Ga with medium-level metamorphism.
- Mesoproterozoic Bylot Supergroup, in the Borden Rift Basin; siliciclastic and carbonate sedimentary rocks, some mafic volcanic units. Age 1.27 Ga with low-level metamorphic facies.
- Early Paleozoic Cambro-Ordovician (Turner Cliffs-Ship Point Formation); unmetamorphosed clastic and carbonate sedimentary rocks, locally preserved in northwesterly-trending grabens. Age 400 to 500 million years.

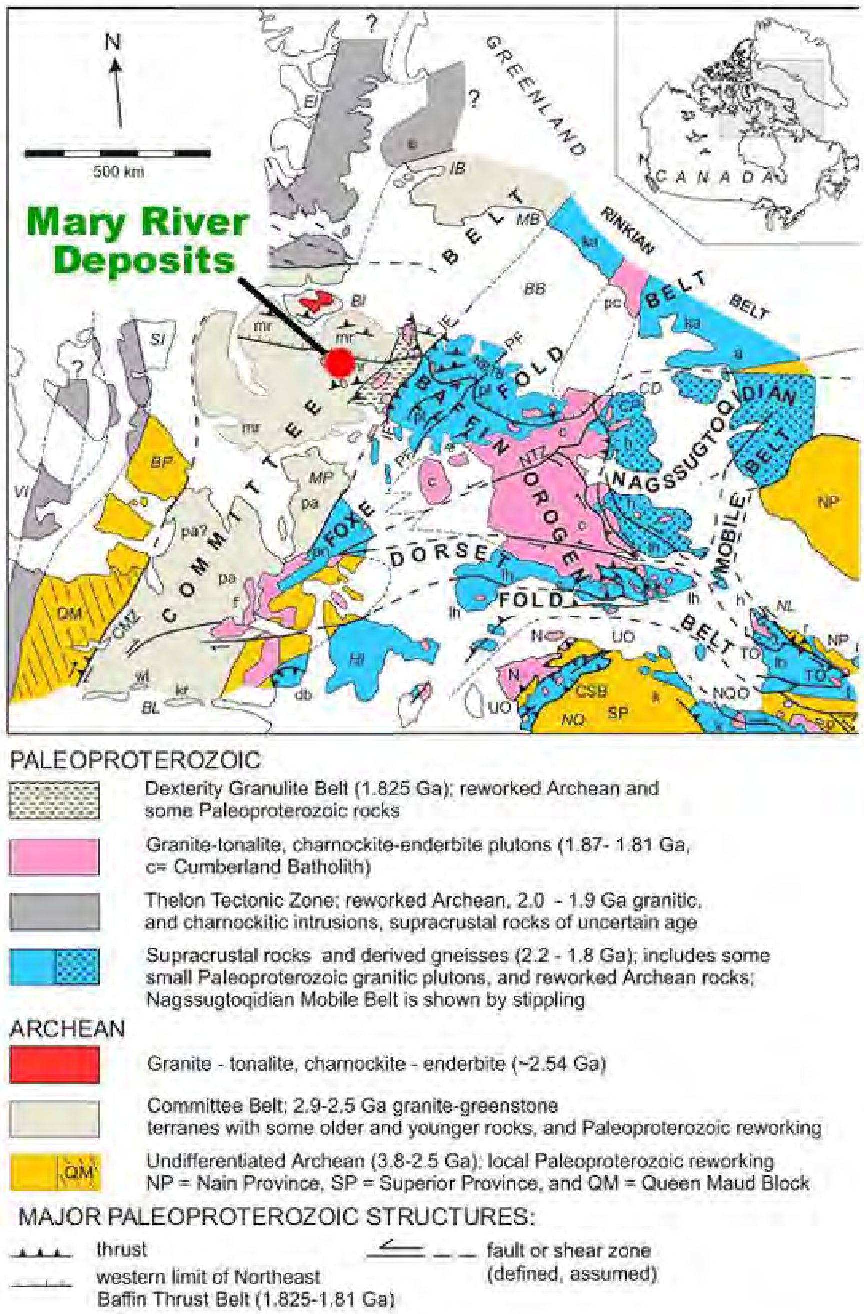

Figure 3-2: Regional Geology Map of Baffin Island (Jackson et. al, 2000)

3.4 Geothermal Conditions

The thermal state of permafrost in the Baffinland Mary River area is based on the literature review related to the thermal state of permafrost in North America. The Mary River Project is located on the northern half of Baffin Island at Latitude 71° and Longitude 79°. Permafrost monitoring is currently conducted at 350 sites throughout the permafrost regions of North America (Smith et. al 2010). Figure 3-3 shows the permafrost distribution map of North America based on Brown et al. (1997). Figure 3-4 summarized Mean annual ground temperature (MAGT) during the International Polar Year period where data were available ((Smith et. al 2010). The source summary data are given in IPA (2010).

It can be seen that the thermal states of permafrost of Baffinland Mary River area are:

- Continuous permafrost area;
- The MAGT is -5 ° to -10°C

Long-term monitoring sites operating in the eastern Arctic are located on Ellesmere Island (Smith et. al 2010). Several new boreholes were drilled and instrumented in the Baffin Region of Nunavut during 2008 to provide baseline permafrost data for community climate change adaptation plans (Figure 3-3). Figure 3-5 shows MAGT profiles based on the monitoring. It can be seen that the MAGT ranges between -5 and -10°C at the five communities in the Baffin region. It is considered acceptable to assume the MAGT profiles at the Mary River Project are similar to those for the Baffin region (i.e. -5 ~ -10 °C). The active layer thickness (i.e. the zone of freeze-thaw) is up to 2 m thick. The total permafrost depth is about 500 m (Wahl and Gharaptian 2009).

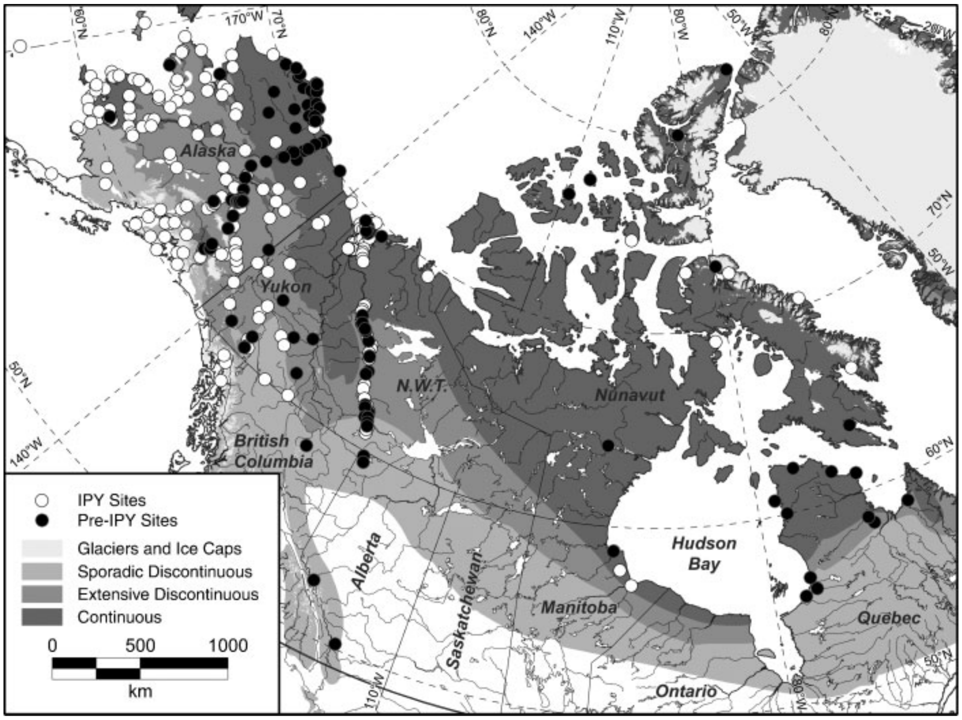

Figure 3-3: The permafrost distribution map of North America based on that of Brown et al. (1997)

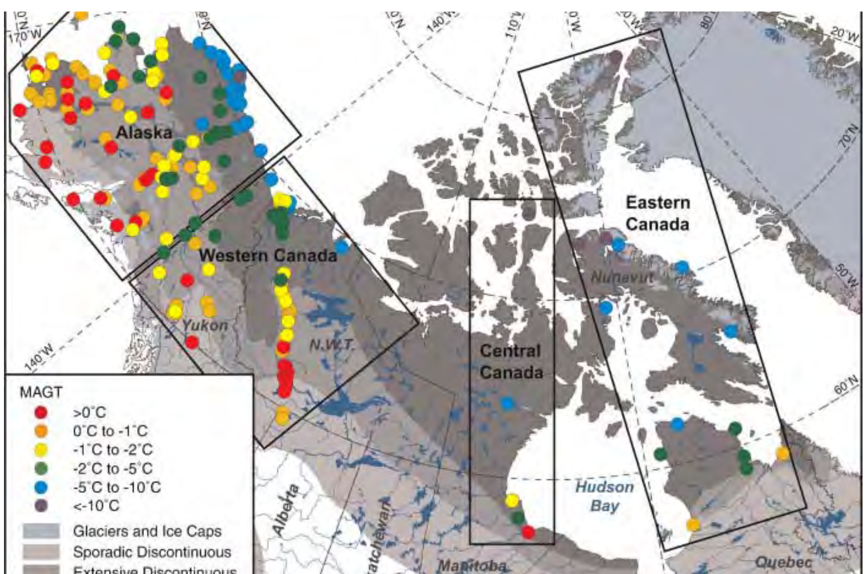

Figure 3-4: Mean annual ground temperature (MAGT) during the International Polar Year period where data were available

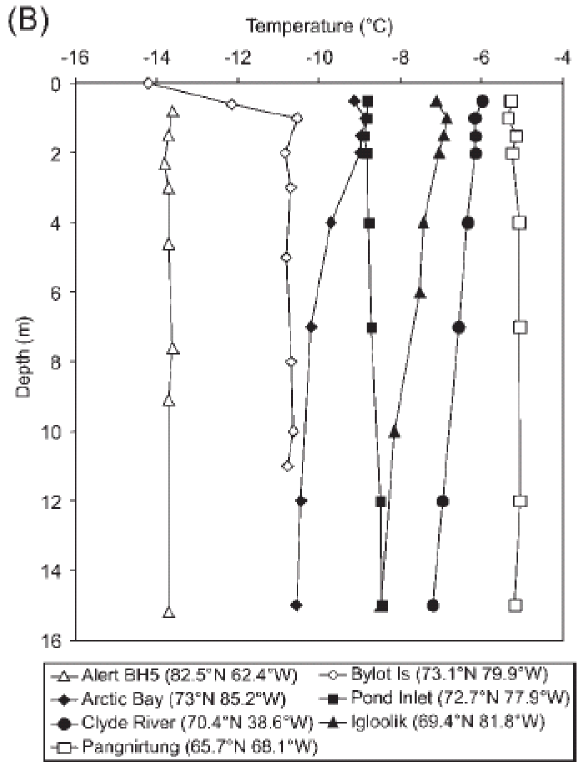

Figure 3-5: Mean annual ground temperature profiles during the International Polar Year for selected sites in the eastern and high Canadian Arctic (Smith et. al. 2010)

Literature data on the thermal regime of reservoirs in Arctic climates could not be found. However, Figure 3-6 shows the temperature profile with depth for a fresh water lake in the high Canadian Arctic. The temperature readings were taken during the spring and summer months, from April to August between 1985 to 2008. It can be noted that the water temperature increases with depth and the lake bottom temperature does not exceed 4 degrees. For a smaller water body such as a reservoir, the temperature variation with depth can be expected to be far less. For the purpose of thermal analysis and design, assuming a mean reservoir-bottom temperature of 4 °C should be adequate.

Table 3-2 presents the monthly average air temperature for Pond Inlet, NU from Environment Canada from 1976 to 2005. It can be seen that the highest average air temperature is 6.2 °C in July and the lowest is -32 °C in February. The average annual temperature is about -15 °C.

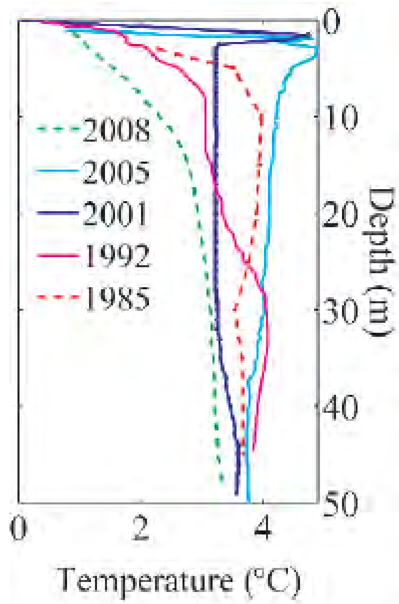

Figure 3-6: Temperature profile for Lake C3 in the high Canadian Arctic (Derek R. Mueller et. al. 2009)

Table 3-2: Monthly Average Air Temperatures for Pond Inlet, NU

Month	Average Temp (C)
January	-32.2
February	-34.0
March	-30.0
April	-21.4
May	-9.1
June	2.0
July	6.2
August	4.4
September	-1.3
October	-10.5
November	-21.9
December	-28.0

3.5 2011 Site Visit

A site visit to the Mary River area was conducted from July 18 to 22, 2011. The objectives were to:

- inspect the proposed dam site to assess the topography, geology, construction materials and thermal conditions
- assess requirements of geotechnical site investigations at the dam sites.

Some shallow test pits were excavated using a shovel to investigate the near surface soils and depth to frozen ground. In general, the surface at the dam site comprises glacial till and frozen ground was encountered 0.5 m below the ground surface. Figure 3-7 and Figure 3-8 show the pictures taken at the dam site for the proposed Mine site SWM Pond No. 2.

Figure 3-7: Photographs taken during the 2011 site visit - Dam site of for the proposed Mine site pond No. 2

Figure 3-8: Photographs taken during the 2011 site visit - Test pit in the dam site of for the proposed Mine site pond No. 2

4. Dam Design Criteria

4.1 CDA Guidelines for Dam Slope Stability

The dam design criteria is based on 2007 CDA Dam Safety Guidelines. Table 4-1 summarizes the safety factors recommended for the Mary River Project dam design. Four load cases are proposed. Table 5 summarizes the required Factor of Safety (FS) for the dam design based on CAD guideline corresponding to:

- Steady state seepage corresponding to the normal water level (NWL)
- Steady-state seepage at NWL in conjunction with earthquake loading. Note: The peak ground acceleration (PGA) for the site is 0.122 *g* based on data from the Canadian Geologic Society (CGS) corresponding to a 1:1000-yr return period. The detailed PGA for the site is shown in the Appendix B
- Upstream slope stability subject to rapid drawdown
- Slope stability of the dam slopes at the end-of-construction before impounding water.

Table 4-1: Summary of the required Factor of Safety for Baffinland dam design based on CAD guideline

Load Combinations	Required Minimum FS	Type of Analysis
Steady Seepage corresponding to the NWL	1.5	Static analysis
Steady Seepage at NWL plus Earthquake Loads	1.0	Pseudo-static analysis
Upstream slope stability under rapid drawdown	1.2	Static analysis
Dam slope stability Just end of construction	1.3	Static analysis

4.2 Thermal Conditions for Design

The design basis thermal conditions are:

- The MAGT profiles Baffinland Mary river is assumed to -10 °C (see Figure 3-5).
- The reservoir-bottom mean water temperature is assumed to be 4 °C (see Figure 3-6).
- The design basis for the local air temperatures as follows:
    - The air temperature for the warmest condition is 7°C.
    - The air temperature for the coldest condition is -25 °C.
- The natural active layer thickness is assumed to be 2 m (Wahl and Gharapetian, 2009).
- It is assumed that the foundation of the reservoir will thaw to the depth of 8 m in 50 years in the conceptual design stage.

4.3 Additional Specific Requirement

In addition to maintaining storm water retention requirements, the SWM ponds are required to have sufficient retention time to facilitate sedimentation of sediment within the reservoir. A small amount seepage is required to help maintain the water level in control. The required seepage is assumed to be in the order of 10 L/s for the entire dam. This can be maintained by designing the dam to allow for controlled seepage to meet the flow requirements.

The anticipated type of service of the embankment is to retain water continuously.

5. Conceptual Dam Options

Mine site SWM Pond No. 2 dam has a height of 15m and it is the highest among three dams. Consequently, conceptual designs have been prepared for Mine site SWM Pond No. 2 dam. The two design options evaluated are:

- Option 1 – Rock fill dam with central plastic cut-off wall;
- Option 2 – Rock fill dam with High Density polyethylene (HDPE) Liner and central cut-off trench.

The design options are discussed in the following sections.

5.1 Option 1- Rockfill Dam with Central Plastic Concrete Cut-off Wall

Figure 5-1 shows the typical cross section for Option 1. The option consists of a rock fill dam with an inner core of compacted ¾ inch minus rock fill, a central plastic cut-off wall and a compacted transition zone. The following zones are envisioned:

- Zone 1 – Compacted ¾ inch minus rock fill
- Zone 2 - Plastic cut-off wall
- Zone 3 - Compacted Transition zone
- Zone 5 - Compacted Class B rockfill
- Zone 6a - Riprap-class C
- Zone 7- Bentonite enriched soil.

The estimated dam geometry consists of a 20 m wide dam crest (transportation requirement), 2.5H:1V U/S slope gradient, 1.7H:1V D/S slope gradient, 0.9 m wide central plastic concrete cut-off wall extending 5.5 m below the ground surface, and thermosyphons installed in the lower key trench to maintain the frozen permafrost foundation.

5.2 Option 2 - Rockfill Dam with High Density Polyethylene (HDPE) Liner and Frozen Key Trench

Figure 5-2 shows the typical cross section for Option 2. The option consists of a rock fill dam with an HDPE liner as the primary seepage barrier. The main materials in this dam option consist of:

- Zone 1 – Bedding Material (Sand 0-13mm or crusher fines)
- Zone 2 - Transient Zone
- Zone 3 – Compacted Rockfill
- Zone 5 - Riprap-Class C.

Figure 5-3 shows a modified typical dam cross section corresponding to Option 2. This dam section has been considered to permit a small amount of seepage through the upper part of the dam to control the reservoir during normal operating condition. An additional liner is proposed to allow controlled seepage of water through the embankment without permitting it to enter the frozen key trench.

The estimated dam geometry consists of a 20 m wide crest (transportation requirement), 2.5H:1V U/S slope gradient, 1.7H:1V D/S slope gradient, a frozen key trench extending 5m below ground surface and thermal siphons to maintain the thermal regime of the key trench.

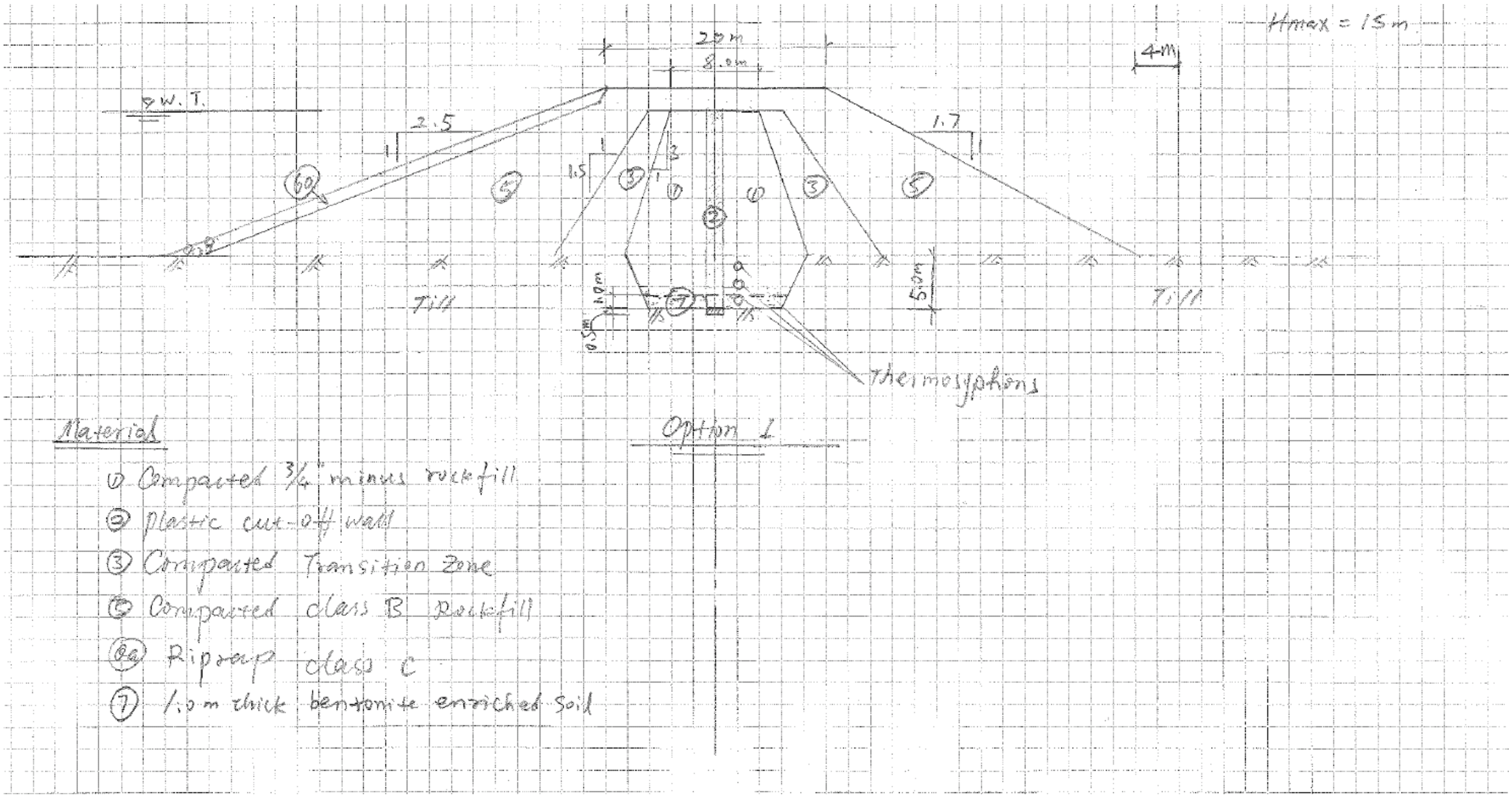

Figure 5-1: Dam Option

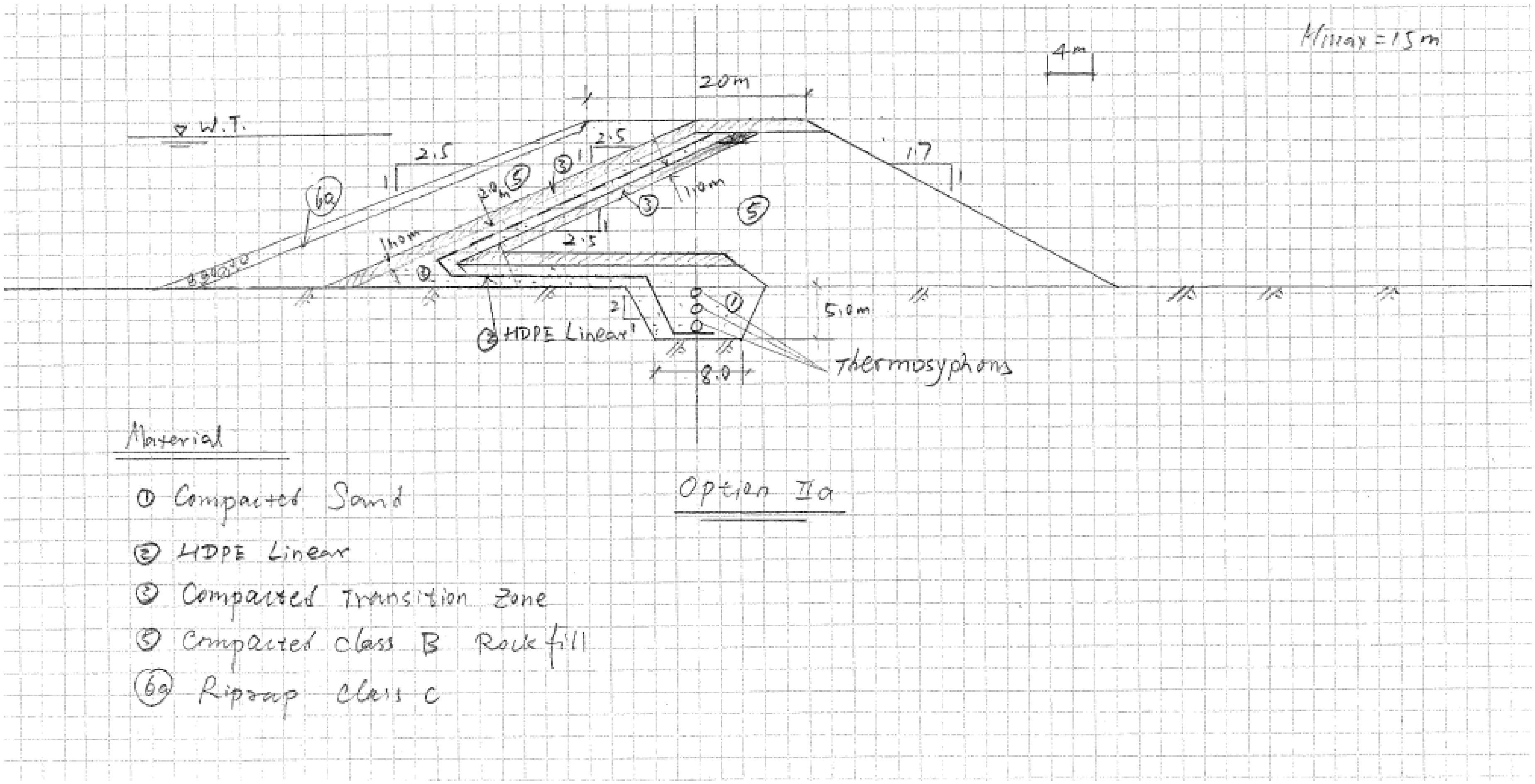

Figure 5-2: Dam Option 2

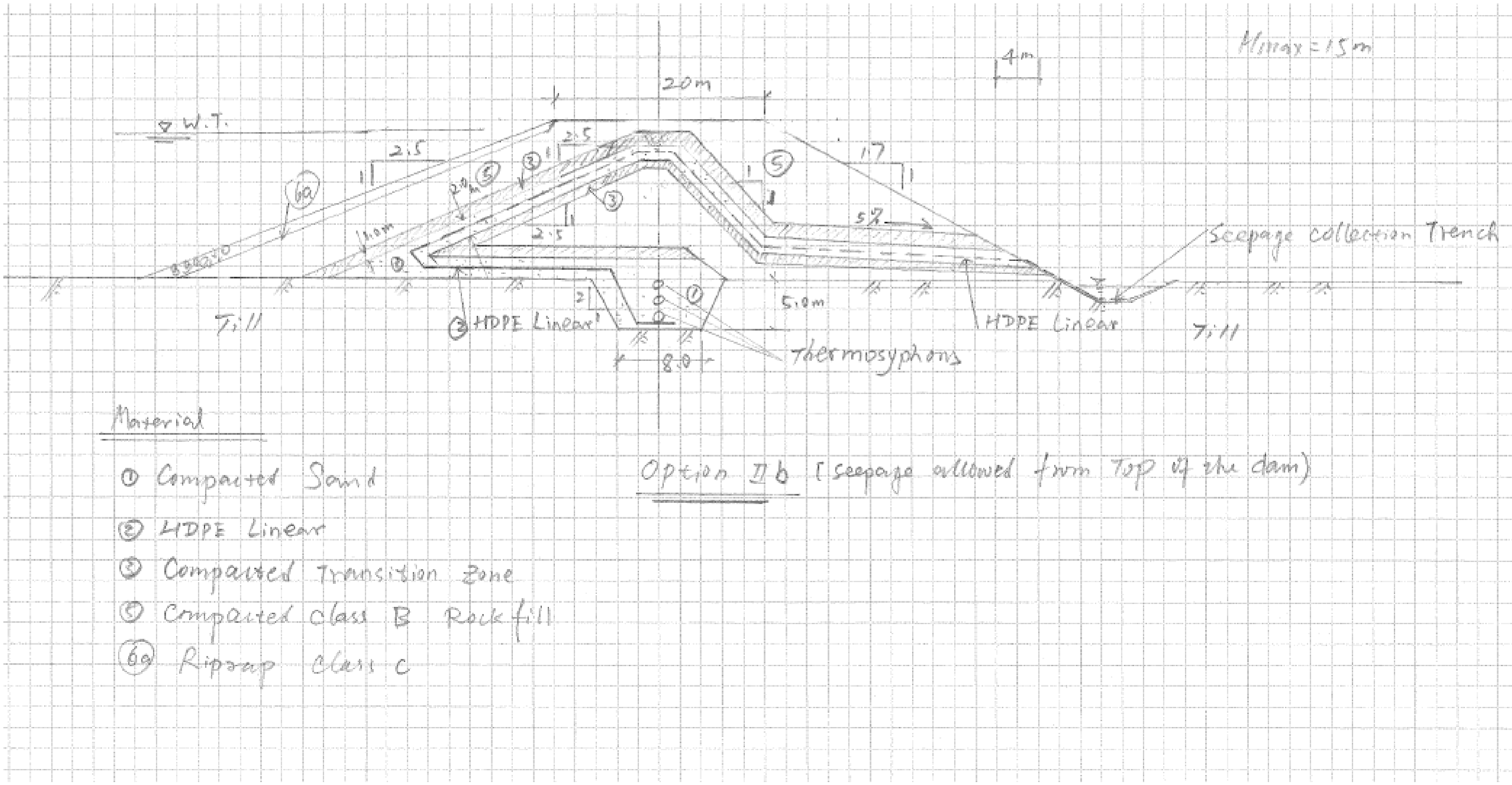

Figure 5-3: Mortified Dam Option 2

6. Discussion

6.1 Feasible Seepage Defence

Previous boreholes at the Mary River Project site indicate that the area is generally underlain by 0-13.5 m of Till followed by bedrock. The till is generally granular in nature, implying that impervious fill materials (e.g. sitly calys) are not readily available on site. In addition, the till is typically frozen and excavation of the material will be difficult and borrow development unecomonmic. Due to lack of the natural unfrozen imperious materials, the only feasible means of controlling seepage in the embankment area:

- Plastic cut-off wall (e.g. Diavik Dam A154) or
- Geosynthetic liner (e.g. Diavik dredged sediment control dam: HDPE liner, Ekati surface water management dam: polypropylene liner).

In the foundation, a frozen key trench (e.g. Diavik dredged sediment control dam, Ekati surface water management dam: Frozen key trench with thermosyphons) is most likely required. For conceptual design purposes, a 5 m depth has been assumed but the actual depth will likely be in the order of 2 m to 3 m supported by adequate thermal modeling and with thermal siphons to ensure maintenance of the frozen conditions.

6.2 Dam Slopes and Crest Width

Although steeper upstream slopes are typically feasible for rock fill embankments, the U/S of Options 1 and 2 have been flatted to accommodate possible settlement of the upstream section due to thawing of the foundation soils when the reservoir is filled. It is assumed that the foundation of the reservoir will thaw to the depth of 10 m in 50 years in the conceptual design stage.

In general, the 2.5H:1V and 1.7H:1V are designed for the upstream and downstream slope of the dam, respectively. Finite element analysis should be done to develop settlement criteria for the upstream slope and to ensure acceptable strains on impervious elements in the dam (i.e. cut-off wall or geomembrane). Geosynthetic reinforcement could be considered to control internal strains in the embankment.

The width of the dam crest could be varied based on the requirement of the transportation on the dam crest. For the dams with transportation requirement, the crest width is 20 m; For the dams without transportation requirement, the minimum width of crest is 5 m which just meet the access requirement for construction.

6.3 Requirements for Thermal Analysis

The reservoir stores unfrozen water and associated heat energy, which will invariably result in the thawing of foundation soil and rock. The jointed rock will be more susceptible to thawing due to the low porosity and water stored in the rock mass compared to soil.

Although the Mary River Project area is located in the continuous permafrost region of Canada and the natural MAGT is in the range of -5 o to -10°C (assumed -10°C for design in this stage), the heating effect of the reservoir water which will cause growth of the thawed zone and may cause complete thawing of the dam foundation. To avoid this, design must be undertaken using thermal analysis as a basis for design to ensure the thermal regime (i.e. frozen ground) is maintained.

6.4 Geotechnical Investigation

The July 2011 site visit indicated that the ground surface around the Mine Site SWM Pond No. 2 is covered by glacial till material. Although the depth of the till is unclear, the frozen ground was found just 0.5 m below the ground surface when excavations were made by hand using a shovel. Due to the high drilling cost in this area, one borehole drilling to the bedrock for each dam site is considered to be adequate. Reasonable assumptions can be made regarding the soil foundations in the central portions of the dam sites and the probable bedrock foundations at the higher ground comprising the abutments. Suitable details can be designed for each condition.

6.5 Construction Material

There are abundant natural till / sand and granular material deposit in the Mary River Project area. However, many of these deposits are frozen and development of borrow areas to produce significant quantise of granular and till material for dam construction is unlikely.

Rock fill will be abundant and for dam construction it can be crushed and processed to provide the required materials.

Due to lack of the natural thawed imperious materials, a Plastic cut-off wall or Geosynthetic liner with frozen key trenches (thermosyphons) appear to the most appropriate for dam construction. Comparing Plastic cut-off wall and Geosynthetic liner, construction of a plastic concrete cut-off wall will require special equipment and technique for cold region construction, which is likely to be expensive compared to using geosynthetics. In addition, there is more precedent for the use of Geosynthetic liners; Consequently Option 2 is preferred.

6.6 Seepage Requirements

The project hydrologist has requested that a design be developed, which will permit some seepage for water levels above the internal core of the dam. This has been done and is presented in Figure 11. There is no precedent for permitting seepage over the top of cores for dams or dyke in cold regions. The possible effect could be loss of thermal regime in the frozen key trench and loss of seepage control. To mitigate this effect, the geomembrane core has been extended downstream to direct seepage water away from the key trench.

Although this should be adequate, it would be preferable if a small 2m high broad crested rock fill weir could be constructed in the spillway entrance to provide similar function. The weir could be designed to permit the 10l/s seepage and with zoning to filter the leakage thereby retaining any sediment.

7. Recommendations

Considering design, construction and cost for the Baffinland SWM Pond dams, the following dam section is recommended:

- Rock fill dam with HDPE Liner and central cut-off trench (Option 2) is recommended for design;
- The dam could be designed as shown in Figure 5-3 to permit seepage over top of the core as required by hydrologists. However, considering risk to satisfactory performance and cost, it is recommended that the spillway be built with a rock fill broad crested weir at the entrance, which will serve similar function.

For final design, the preliminary design basis described herein should be improved and finalized for the next phase, and geotechnical site investigations done at each dam site to characterize the foundation conditions. In addition, the dams should be designed using thermal analysis to ensure integrity of the thermal regime. Access roads should be designed for each dam.

8. References

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14. G.H Wahl and R. Gharapetian, 2009. Mary River Deposit No. 1 Resource and Mine Planning Report. Mary River Iron Ore Project, Northern Baffin Island, Nunavut. GH Wahl and Associates Geological Consulting. October 2009.

15. Ross Zhou, Hatch project memo, Dam Safety Assessment , Baffinland Mary River Project , May 18, 2011

Appendix A

Typical Cross Section Used for Previous Embankment on Permafrost Foundation

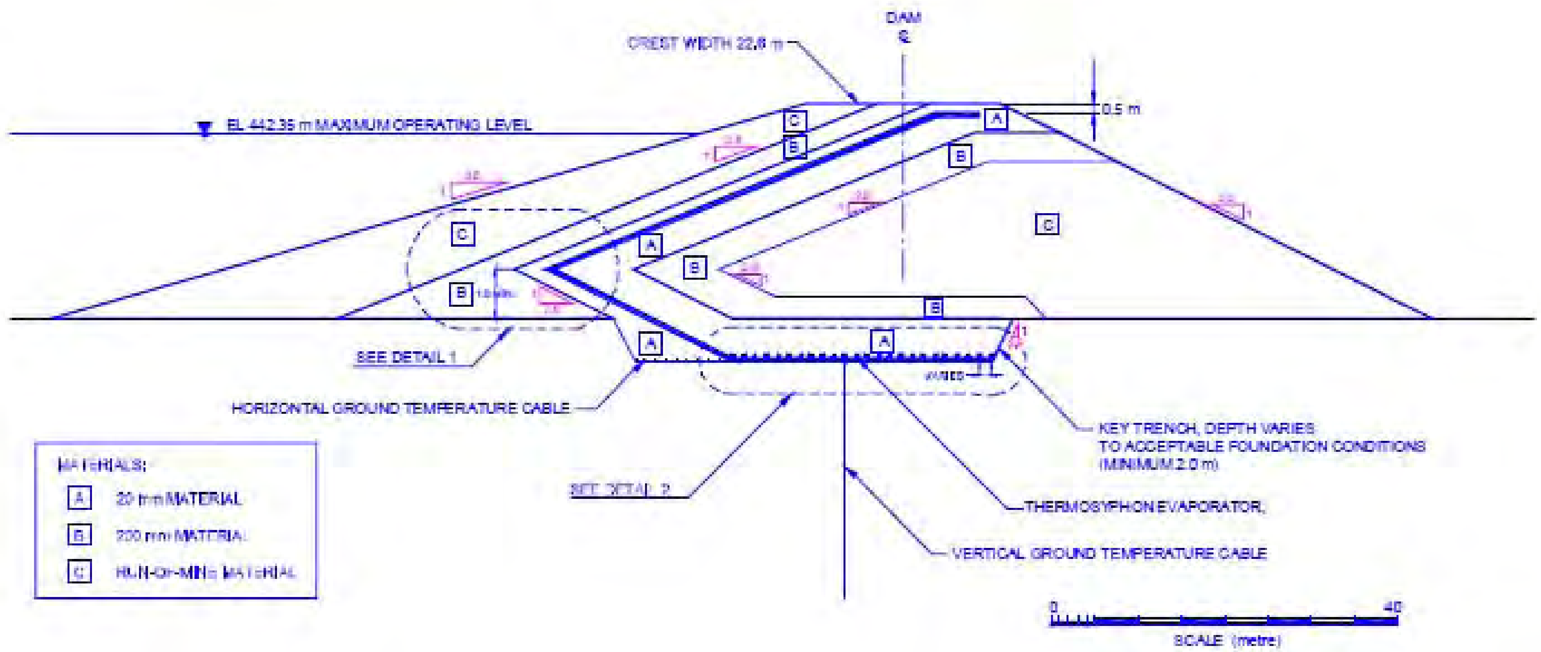

Figure A1- 1: Typical Section for EKATI Diamond Mine Dam (Gräpel et. al 2005)

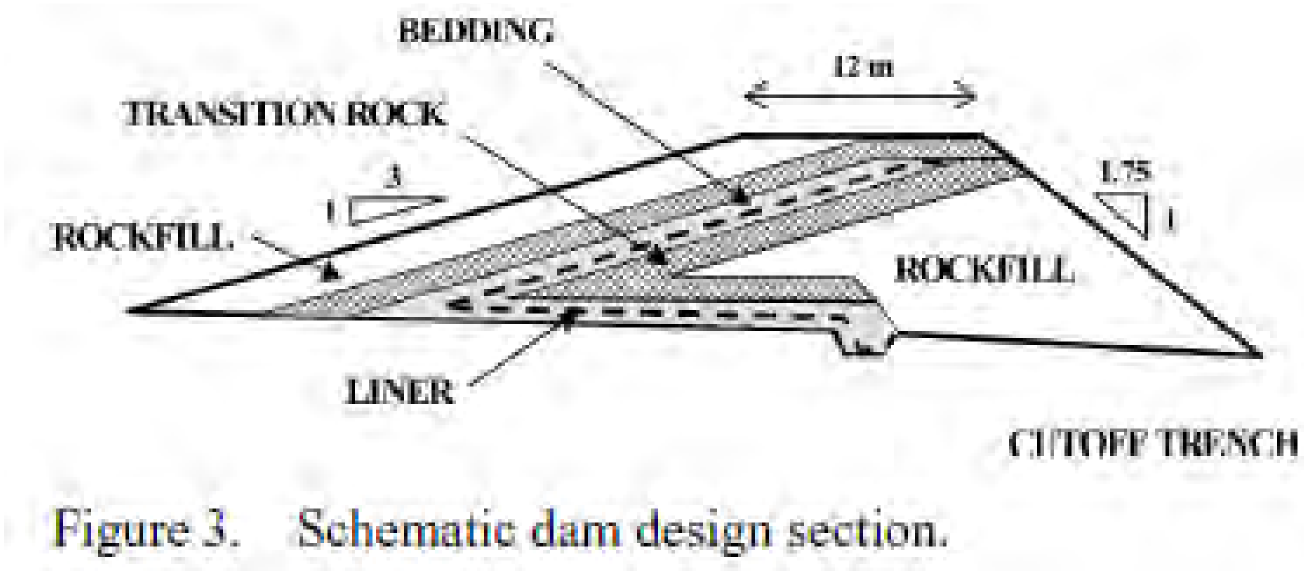

Figure A1- 2: Diavik Diamond Mine (West Dam) (Holubec et. al 2003)

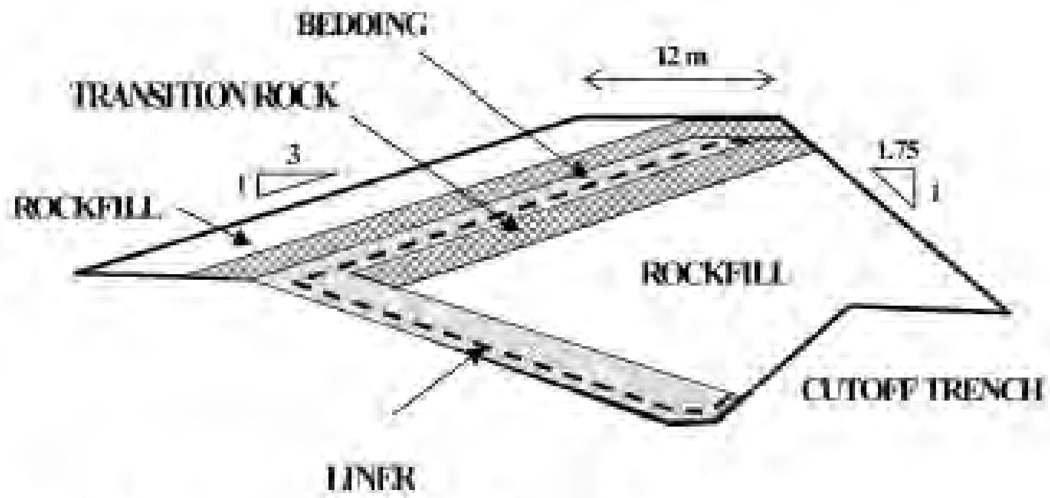

Figure 4. Dam section at the talik.

Figure A1- 3: Diavik Diamond Mine (West Dam) (Holubec et. al 2003)

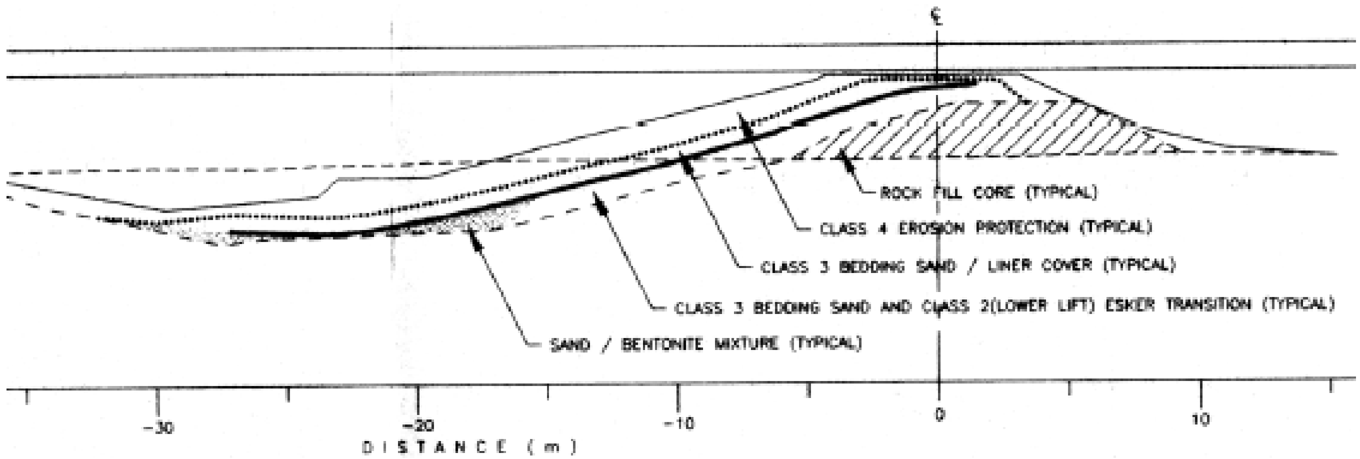

Figure A1- 4: Snap Lake Dam 1 (J. Cassie 2003)

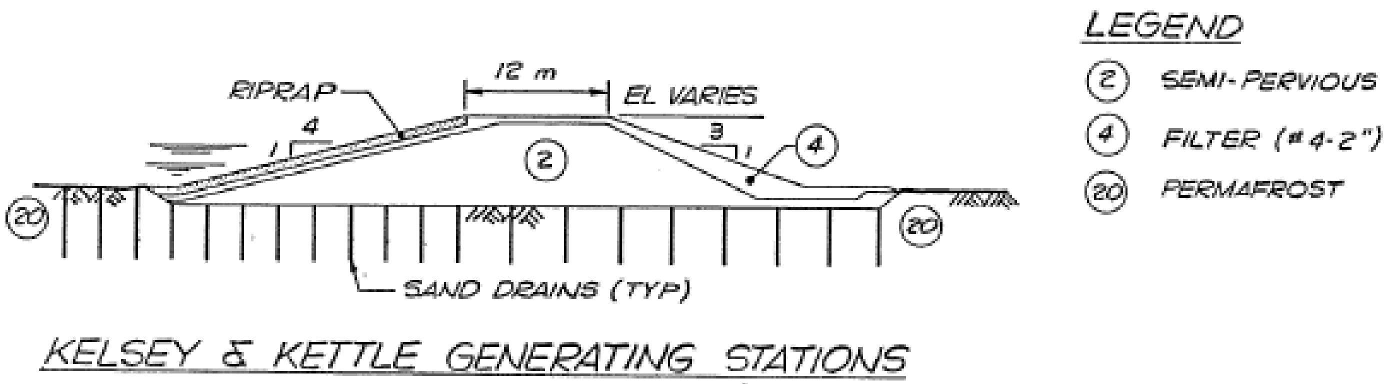

Figure A1- 5: Kelsey Dyke (N. J. Smith 1983)

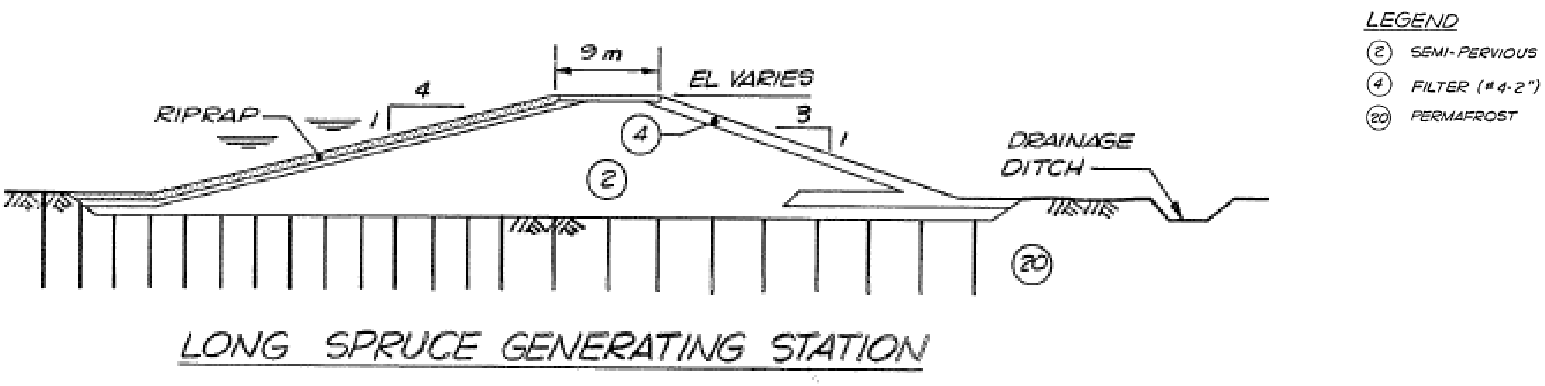

Figure A1- 6: Long Spruce Dykes (N. J. Smith, 1983)

Appendix B

Seismic Data

HATCH Calculations

By S. Shaif | Date July 18/11 | Project No. H337697

Checked ______ | Date ______ | Calculation No. __

Subject Mary River, Baffin Island, NU | Page 1 of 1

Estimate of PGA for 1/10,000 year return period - Firm Ground and Hard Rock

Estimate of PGA for 1/10,000 year return periods

Based on Firm Ground

Return Period (years)	100	475	1000	2475	10000
2005 NBCC, Firm Ground	0.025	0.075	0.131	0.239	0.570*
2005 NBCC, Hard Rock	0.018	0.054	0.094	0.172	0.410*

* Estimated Value

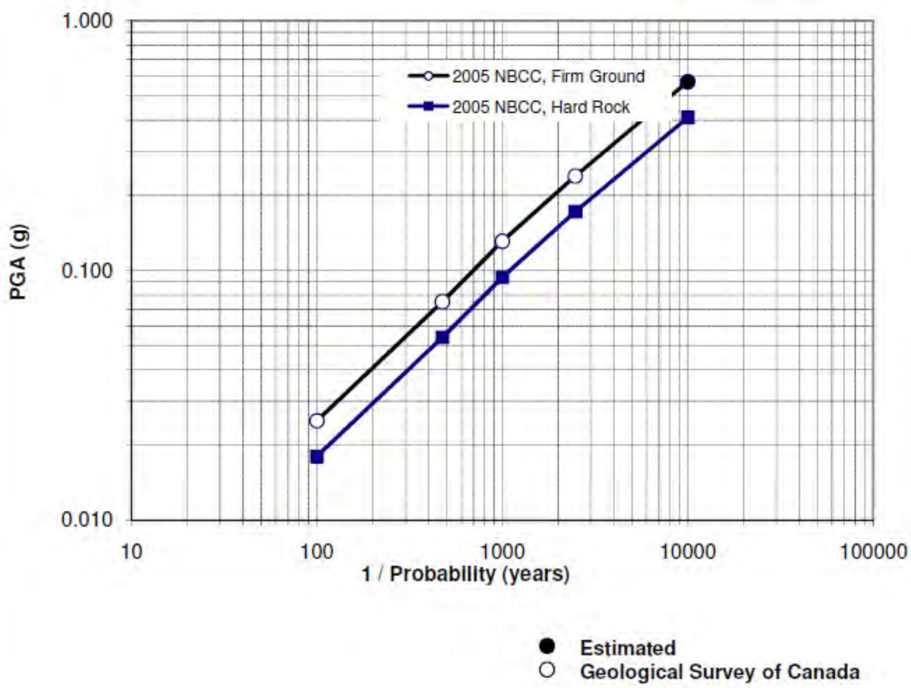

Figure B1- 1

Safety • Quality • Sustainability • Innovation

2010 National Building Code Seismic Hazard Calculation

INFORMATION: Eastern Canada English (613) 995-5548 français (613) 995-0600 Facsimile (613) 992-8836
Western Canada English (250) 363-6500 Facsimile (250) 363-6565

Requested by: Shathli Shaif, Hatch — July 18, 2011

Site Coordinates: 71.9215 North 79.3612 West

User File Reference: Mary River, Baffin LAnd

National Building Code ground motions:
2% probability of exceedance in 50 years (0.000404 per annum)

Sa(0.2)	Sa(0.5)	Sa(1.0)	Sa(2.0)	PGA (g)
0.425	0.205	0.117	0.040	0.239

Notes. Spectral and peak hazard values are determined for firm ground (NBCC 2010 soil class C - average shear wave velocity 360-750 m/s). Median (50th percentile) values are given in units of g. 5% damped spectral acceleration (Sa(T), where T is the period in seconds) and peak ground acceleration (PGA) values are tabulated. Only 2 significant figures are to be used. ***These values have been interpolated from a 10 km spaced grid of points. Depending on the gradient of the nearby points, values at this location calculated directly from the hazard program may vary. More than 95 percent of interpolated values are within 2 percent of the calculated values.***

Ground motions for other probabilities:

Probability of exceedance per annum	0.010	0.0021	0.001
Probability of exceedance in 50 years	40%	10%	5%
Sa(0.2)	0.067	0.165	0.249
Sa(0.5)	0.043	0.102	0.142
Sa(1.0)	0.027	0.063	0.085
Sa(2.0)	0.008	0.020	0.028
PGA	0.025	0.075	0.131

References

National Building Code of Canada 2010 NRCC no. 53301; sections 4.1.8, 9.20.1.2, 9.23.10.2, 9.31.6.2, and 6.2.1.3
Appendix C: Climatic Information for Building Design in Canada - table in Appendix C starting on page C-11 of Division B, volume 2

User's Guide - NBC 2010, Structural Commentaries NRCC no. XXXXX (in preparation)
Commentary J: Design for Seismic Effects

Geological Survey of Canada Open File xxxx
Fourth generation seismic hazard maps of Canada: Maps and grid values to be used with the 2010 National Building Code of Canada (in preparation)

See the websites *www.EarthquakesCanada.ca* and *www.nationalcodes.ca* for more information

Aussi disponible en français

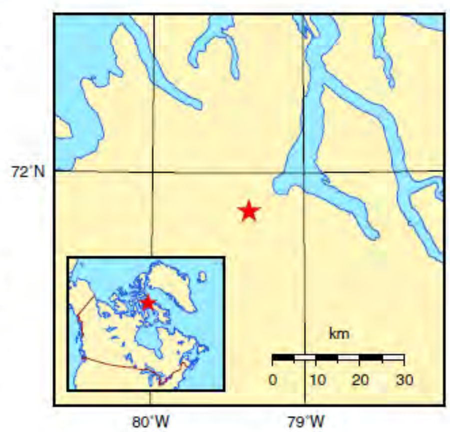

Figure B1- 2

Appendix 2:
Development of Permafrost in Waste Rock Dumps – Preliminary Geotechnical Evaluation

THURBER ENGINEERING LTD.

TECHNICAL MEMORANDUM

To:	John Binns	**Date:**	23 Nov 2011
cc	Harry Charalambu ,Ramli Halim	**Rev:**	1
From:	Bruce Smith, Steve Sather, Sabia Remtulla	**File:**	19-1605-126

MARY RIVER PROJECT
DEVELOPMENT OF PERMAFROST IN WASTE ROCK DUMPS
PRELIMINARY GEOTECHNICAL EVALUATION

1. PURPOSE

This memorandum presents the results of a preliminary literature review to assess the factors that are expected to control the development of permafrost within the proposed waste rock dump at the Mary River Mine, specifically with respect to the development of permafrost within the waste rock dump as it reaches its final configuration with a volume of about 600 Mt.

A plan map showing the layout of the Mary River Iron Mine, including the open pit mine and waste rock dump, is attached as Figure A.1 in Appendix A. As shown on the map, the waste rock will be placed on the north side of the open pit mine.

This technical memorandum presents a summary of the information that has been gathered to date with respect to the development of permafrost in waste rock dumps in Northern Canada and describes a number of options that can be considered to ensure permafrost will develop in the dump at the Mary River Mine.

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2. HEAT TRANSFER PROCESSES

For the purpose of this discussion, permafrost may be defined as any soil or rock which remains below freezing (0^{o}C) during the thaw season each year. There are three heat transfer processes, as discussed in more detail in the following sections, which will have a major influence on the development of permafrost within the proposed waste dump at the Mary River Mine:

1. Convective air flows;
2. Heat conduction; and
3. Exothermic chemical reactions.

Solar radiation is an important source of heat, of course, but it will only influence the surface temperature of the waste rock dump and will not be discussed further.

Mass transport of heat, due to the flow of water in drainage courses though embankments, is also an important heat transfer mechanism in permafrost regions, however it is not considered further in this memorandum since it is understood that measures will be taken to prevent the flow of large volumes of water through the waste rock dump.

3. CONVECTIVE AIR FLOWS

Theoretical methods of modelling convective air flows in waste rock dumps have been developed and, together with temperature measurements in a test waste rock pile at the Diavik Mine, have demonstrated that air convection can have a major influence on ground temperatures and the development of permafrost within waste rock dumps (Arenson et al, 2007; and Pham et al, 2008).

These investigations have shown that air convection dominates the thermal regime in dry, porous rock dumps that have a high permeability to air. In contrast, the influence of convective air flow is negligible in well graded waste rock which has a low air permeability, particularly if the void spaces are partially or completely filled with water or ice.

If the waste rock dump is porous, such that it has a high permeability to air flows, then during the winter months, cold dense air flows into the waste dump, displacing warm air so that the interior temperatures in the dump can fall to minus 20^{o}C or lower. If the rock dump is very permeable to air, then the temperatures within the dump can fluctuate in response to daily changes in the ambient air temperature.

During the thaw season, when ambient air temperatures are warmer, the cold air within the waste dump may remain within the rock dump because the cold air is denser than the ambient air. The degree to which the cold air is contained within the dump depends on the physical configuration of the waste dump, the variability and distribution of porous zones within the dump and wind speeds and directions.

For example, if the waste dump is raised above the surrounding ground surface and the air permeability is high, the denser, cold air will flow out of the dump and be replaced by warmer ambient air during the thaw season.

Similarly, if a strong wind blows for several days from one direction, then the air pressure on the windward side of the dump will be higher than on the lee side and the cold air can be blown out of the dump and be replaced with warm air. This situation is exacerbated, of course, if the waste dump is higher than the surrounding area and particularly if the height of the dump is high relative to its width.

Finally, the orientation and continuity of porous layers within the waste dump can have a major influence on interior temperatures throughout the year.

Figure A.2 in Appendix C illustrates the ground thermal regime that could develop in a porous waste dump at the Mary River Mine, late in the thaw season. The depth of thaw due to convective air flow during the thaw season is difficult to predict since it will depend on the distribution and continuity of porous layers within the dump. However, under unfavourable conditions, the depth of annual thaw could range up to tens of meters or more. Therefore, during the early stages of mine operations, when the waste dump is relatively small, the entire mass of waste rock could thaw during each thaw season.

4. HEAT CONDUCTION

In most natural soil deposits in Northern Canada, where the void spaces are filled with water or ice, the soil is effectively impervious to air flows, convection has a negligible effect on the temperature regime and heat conduction dominates heat transfer processes.

Heat conduction in permafrost is a process that has been studied extensively over several decades and is well understood. Numerical models have been developed and calibrated against field measurements, such that it is possible to make reasonably accurate predictions of ground temperatures and the development of permafrost, provided an adequate set of input data is available.

Ground temperatures have been measured as a function of depth in the vicinity of the Mary River Mine for several years. A typical distribution of ground temperature with depth, which illustrates the ground temperatures during late March (when ground temperatures are lowest) and in late August (when ground temperatures are a maximum), is presented on the upper portion of Figure A.3. As shown, ground temperatures near the ground surface vary significantly throughout the year, being very cold in the winter and rising well above freezing during the thaw season.

As illustrated, annual ground temperatures attenuate with depth and become more or less constant at about minus 10^{o}C below a depth of about 10 metres in the vicinity of the Mary River Mine. This temperature, which is referred to as the average annual ground temperature, is a function of the average annual air temperature at each particular location and generally increases at lower elevations and latitudes. For example, the average annual ground temperature in the vicinity of the Ekati Diamond Mine has been found to be about minus 6^{o}C (Arenson et al, 2007).

Ground temperatures reach a maximum in the late fall when the maximum depth of thawing occurs. In the example shown in the upper portion of Figure A.3, the maximum depth of thaw occurs at a depth of about 1.5 metres, which is the point at which the temperature curve crosses the freezing point (0^{o}C). The zone above 1.5 metres is not considered to be permafrost (since it thaws every year) and is referred to as the active layer, while the zone below the active layer is permafrost, since it never thaws.

Heat conduction in moist soils is dominated by the latent heat of fusion of ice to water (and vice versa) and therefore by the water content of the soil. The curve shown on the lower portion of Figure A.3 illustrates the significant influence that water content has on the depth of thaw in a well graded gravel.

As illustrated on the figure, at high water contents, the maximum annual depth of thaw at a location near the Mary River Mine will be about 2 metres, depending on the average water content in the near surface soil. In contrast, the depth of maximum thaw can range up to about 5 metres, due to heat conduction alone, if the near surface soil is well drained and contains no moisture. Convective air flows, which begin to dominate in dry, porous material, could increase the depth of thaw even further, depending on the air permeability in the dry gravel; however this effect has not been included in the curve shown on the lower portion of Figure A.3.

If, over a very long period of time, the soil in the upper layers of the dump were to dry out completely, (for example if there were many years with no precipitation), then the depth of annual thawing could increase, depending on the extent to which convective air flows begin to affect the heat transfer process. Under very dry climate conditions however, ARD caused by surface water infiltrating into the dump would not be of concern.

5. EXOTHERMIC CHEMICAL REACTIONS

It is understood that exothermic chemical reactions, such as the oxidation of pyrite and other minerals, may have a significant influence on the temperatures within a waste rock dump, depending on the concentration of the reactive chemicals, the ground temperatures within the dump (warmer ground temperatures can accelerate the chemical reaction and the rate at which heat is generated) and other factors which have not been investigated as part of this review (Morin, 2003).

The heat from such reactions would be transferred by conduction to the surrounding ground and could degrade the permafrost. It is recommended that the potential for exothermic reactions occurring in the waste rock dump be investigated by a qualified geochemist, since such reactions could have a significant influence on the development of permafrost within the dump.

If necessary, a number of methods for dealing with this potential source of heat can be considered, including segregation of the highly reactive material and submerging it in water; segregating the highly reactive material within the waste rock dump and cooling it with ventilation ducts; or distributing the reactive material throughout the waste dump so that the critical mass of reactive material required to generate high temperatures cannot occur.

6. DISCUSSION

General

If convective air flow and exothermic reactions in the waste rock dump can be limited, such that only conduction dominates the process of heat transfer and the water content within the upper 3 or 4 metres can be increased to about 5 percent, then, as illustrated on Figure A.4, it can be expected that the annual depth of thaw would be less than 2 metres and the internal temperature within the dump at depth would stabilize after a few years to converge to the average annual ground temperature in this area (minus 10^{o}C).

That is, it should be possible to develop permafrost within a major portion of the waste rock dump at the Mary River Mine, particularly in view of the relatively low average annual ground temperatures that have been recorded in this area.

Minimizing Convective Air Flows

If the waste rock is dry and porous, convective air flows will dominate the heat transfer process and may prevent the development of permafrost within a significant portion of the waste dump. Heat flows due to air convection appear to be difficult to predict and control and therefore it is believed that the most effective approach will be to implement methods to limit or prevent convective air flow. Limiting air flow is also an advantage because it will reduce the availability of oxygen to potential acid generating (PAG) rocks within the dump.

A number of methods for minimizing convective air flows in the waste rock dump can be considered as follows:

1) Waste rock is normally placed by end dumping the rock, which causes a porous layer of cobbles and boulders to form near the base of each bench that can be highly permeable to air. Methods of end dumping the waste rock in cells that will break up the continuity of these porous layers have been used successfully to reduce air flow into rock dumps at other mines and should be considered during detailed design of the waste rock dump at the Mary River Mine (Chamber of Mines of South Africa, 1996).

2) A second option which can be considered is to locate the waste rock dump in a closed depression, (or surround the dump with containment dikes) so that surface water flows into, and remains within, the dump. The water will fill the void spaces in the waste rock and freeze, reducing the permeability to air and minimizing the depth of thaw that occurs each thaw season.

   In non-permafrost regions, this approach would be unacceptable because surface water which flowed into the waste rock dump would infiltrate into the ground below the dump and contaminate the ground water. In this case, however, the site is underlain by permafrost to depths of several hundred metres, so that water from the dump cannot infiltrate into the ground below the dump.

3) It may be possible to develop cost effective methods of blasting the waste rock in the mine such that most of the material is well graded, so that it will limit convective air flows within the dump. This approach might be feasible at the Mary River Mine; however it will depend on the mechanical properties of the waste rock formations, the blasting pattern and other factors. The feasibility of controlling the gradation of the waste rock cannot be determined until the mine begins operations.

4) Another approach would be to reduce the air permeability of the waste rock dump by placing one or more layers of well graded material (such as the local sandy till) to a depth of 2 or 3 metres over the surface of the waste rock dump during mining operations. The effectiveness of this approach could be enhanced significantly by watering the sandy till as it is being placed, to reduce the annual depth of thaw within the dump.

   It is understood that implementation of this method is being considered on a trial basis at the Diavik Mine; however it has not been possible to confirm this. If the use of a sandy till cover is considered for the Mary River Mine, it would be important to undertake trials during the early stages of mine operations to confirm its effectiveness and refine the placement procedures.

5) Finally, consideration can be given to covering the final surface of the waste dump with an impermeable capping layer of natural material or a synthetic membrane liner, which would prevent convective air flow into the dump and in addition, if the layer were properly designed and installed, would prevent snow melt and rainfall from infiltrating into the dump.

   The use of a membrane liner may be a cost effective solution, however if the waste rock in the dump remains dry, then the annual depth of thaw due to heat conduction could still range up to about 5 meters. Field observations have demonstrated that membrane liners such as high density polyethylene (HDPE) can be expected to last for at least 50 years without deteriorating, provided they are covered to protect them from sunlight and ground settlements are limited. While there is no conclusive evidence available at this time, it is possible that such liners will deteriorate over periods as long as several hundred years.

Whatever option is chosen to promote the development of permafrost within the dump and minimize the depth of annual thaw, it will be essential to install thermistor strings and other instrumentation in strategic locations throughout the dump to measure actual ground temperatures and verify that permafrost is developing within the dump as expected.

Climate Change

While there is considerable debate about the causes of climate warming, most scientists agree that average air temperatures in the northern hemisphere have been increasing since the end of the Little Ice Age about 200 years ago. The predicted rate of temperature increase over the next few centuries is also the subject of much debate however, recent estimates (Natural Resources

Canada, 2011) indicate that mean annual air temperatures on northern Baffin Island will increase between 1995 and 2060 by 4 to 5 degrees Celsius, which corresponds to a rate of increase of between 6.2 and 7.7 degrees per century.

Average annual ground temperatures in Northern Canada are generally proportional to the average annual air temperature at each location and will therefore increase at about the same rate that the average annual air temperature increases. As mentioned, the average annual ground temperature at the Mary River Mine Site is about minus 10^{o}C and therefore if the average annual air temperature were to increase at the predicted rates, then the mean annual ground temperature will be close to 0^{o}C, 130 to 170 years from the present. It may take an additional 50 or 100 years before permafrost at the Mary River Mine site degrades completely, due to latent heat effects.

As described on the Natural Resources Canada website, future climate predictions must be treated with caution, since they are subject to change based on the acquisition of additional climate data and refinements to the predictive models.

7. IMPLICATIONS OF PERMAFROST FOR PREVENTING ARD FORMATION

It is understood that geochemical tests on rock samples from the open pit mine indicate that only a small portion of the waste rock is likely to generate acid rock drainage (ARD), however further testing is required to confirm this.

It is understood that consideration is being given to minimizing ARD from the waste rock dump by segregating the potential acid generating (PAG) waste rock within the dump and encapsulating it in non-PAG material to minimise the infiltration of air and water. In addition, the formation of permafrost within the dump would inhibit ARD. The technique of minimizing ARD by freezing waste rock has been attempted at a number of other hard rock mines in Northern Canada and Alaska and a number of organizations have and are continuing research into methods for long term containment of ARD in permafrost regions. Thurber Engineering has completed a preliminary review of relevant published literature concerning this issue; however it has not been possible to interview mine operators in Northern Canada and Alaska

An overview of the difficulties of predicting and containing ARD from the waste rock dumps at the Ekati Diamond Mine, which is located about 400 km north of Yellowknife, Northwest Territories, has been published by Morin (Morin, 2003). During initial mine planning, it had been expected that permafrost would quickly aggrade into the waste rock dumps at the Ekati Mine and therefore it was expected that seepage and ARD from the dump would be negligible.

However, within a year after the start of mine operations in 1998, ARD was observed at several monitoring stations, which led to further investigations and the development of mitigation measures; which are reported to have been successful. (Hayley, 2011). It is understood that ground temperature measurements in the waste rock dumps have established that the annual depth of thaw in the dumps ranges to a maximum of about 5 metres.

The waste rock dumps at the lead-zinc mine at Nanisivik in northern Baffin Island were decommissioned at least 5 years ago, when they were covered with about 2 metres of well graded material to prevent convective air flows and minimized the infiltration of surface water. It is understood (Cassie, 2011) that the waste rock dumps have remained frozen and annual site inspections have found no water seepage (and therefore no ARD) emanating from the dumps.

The experience at these northern mines has prompted further research into the factors affecting the development of permafrost in waste rock dumps, including the development of convective thermal models and the construction and monitoring of a small waste rock pile at the Diavik Diamond Mine, which is located about 30 km south of the Ekati Mine (Arenson et al., 2007).

8. RECOMMENDATIONS

The results of this preliminary review have identified at least one (Nanisivik) cost effective method to ensure that permafrost will develop in the waste rock dump and be effective at preventing ARD from the dump. It is recommended however, that as currently proposed, seepage water from the Mary River waste rock dump be controlled and contained in holding ponds, where it can be monitored and treated as necessary during mine operations.

Thermal analyses of the waste rock dump to predict the long-term distribution of permafrost within the dump will be required. The heat transfer processes can be simulated with available computer models, however, none of the models can confirm that permafrost will develop within the dump, without more reliable input data regarding the method of placing the waste rock and the resulting properties of the waste rock in the dump. In addition, it will be important to calibrate the thermal analyses against existing case histories including, in particular, the Nanisivik mine. Therefore it is recommended that detailed thermal analyses be postponed until detailed information from the monitoring program of the waste rock dump at Nanisivik can be obtained and more information becomes available with respect to the properties of the proposed waste rock dump at Mary River.

During the first few years of mine operations, once the properties of the waste rock are better defined, including the grain size distribution and the chemistry and distribution of the PAG rocks, methods of containing and treating the PAG rock in the waste rock dump can be further developed, tested and refined, with the objective of establishing those procedures that will ensure that ARD can be minimized in the long term.

Monitoring of ground temperatures and the development of permafrost within the waste rock dump and measuring the properties and volume of seepage water from the dump should continue during mine operations and after decommissioning of the dump. This work should include periodic updating of the thermal analyses, which should be calibrated to actual measured ground temperatures and incorporate any changes to the climate change predictions produced by Natural Resources Canada.

It is recommended that a qualified geochemist review the potential for exothermic chemical reactions occurring in the Mary River waste rock dump, so that the most effective methods for mitigating this potential source of heat can be established.

The scope of this review has been limited by time constraints and it is recommended that a more comprehensive study and review of the literature and other sources of information be undertaken since there may be additional published information concerning the control of ARD using permafrost in northern regions.

It is recommended that environmental scientists at some of the other mines in permafrost regions be contacted, including the Ekati and Diavik Mines in the Northwest Territories, the decommissioned Nanisivik Mine at Arctic Bay on Baffin Island and the Red Dog Mine in Alaska. These mine operators will have practical experience in the control of ARD from waste dumps in permafrost that should be of benefit to the design of the waste rock dump at Mary River.

It is recommended that Baffinland Iron Mines Corporation consider becoming involved in some of the studies that other agencies are undertaking into various methods for controlling ARD from waste rock dumps in Northern Canada. Full access to the various research programs will provide Baffinland with the most recent information concerning this issue and will, in turn, allow Baffinland to influence the direction of some of the research and provide researchers with practical experience from the mining operations at Mary River.

9. CLOSURE

We trust that the foregoing evaluation and recommendations meet your current requirements. Please contact us at any time if you have questions or require additional information.

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Review Principal

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N.W.T.

Sabia Remtulla,
Environmental Scientist

Attachements:

- References
- Statement of General Conditions
- Appendix A - Figures

PERMIT TO PRACTICE
THURBER ENGINEERING LTD.
Signature
Date 23 Nov 2011
PERMIT NUMBER: P0176
The Association of Professional Engineers, Geologists and Geophysicists of the NWT / NU

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STATEMENT OF LIMITATIONS AND CONDITIONS

1. STANDARD OF CARE

This study and Report have been prepared in accordance with generally accepted engineering or environmental consulting practices in this area. No other warranty, expressed or implied, is made.

2. COMPLETE REPORT

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment are a part of the Report which is of a summary nature and is not intended to stand alone without reference to the instructions given to us by the Client, communications between us and the Client, and to any other reports, writings, proposals or documents prepared by us for the Client relative to the specific site described herein, all of which constitute the Report.

IN ORDER TO PROPERLY UNDERSTAND THE SUGGESTIONS, RECOMMENDATIONS AND OPINIONS EXPRESSED HEREIN, REFERENCE MUST BE MADE TO THE WHOLE OF THE REPORT. WE CANNOT BE RESPONSIBLE FOR USE BY ANY PARTY OF PORTIONS OF THE REPORT WITHOUT REFERENCE TO THE WHOLE REPORT.

3. BASIS OF REPORT

The Report has been prepared for the specific site, development, design objectives and purposes that were described to us by the Client. The applicability and reliability of any of the findings, recommendations, suggestions, or opinions expressed in the document, subject to the limitations provided herein, are only valid to the extent that this Report expressly addresses proposed development, design objectives and purposes, and then only to the extent there has been no material alteration to or variation from any of the said descriptions provided to us unless we are specifically requested by the Client to review and revise the Report in light of such alteration or variation or to consider such representations, information and instructions.

4. USE OF THE REPORT

The information and opinions expressed in the Report, or any document forming part of the Report, are for the sole benefit of the Client. NO OTHER PARTY MAY USE OR RELY UPON THE REPORT OR ANY PORTION THEREOF WITHOUT OUR WRITTEN CONSENT AND SUCH USE SHALL BE ON SUCH TERMS AND CONDITIONS AS WE MAY EXPRESSLY APPROVE. The contents of the Report remain our copyright property. The Client may not give, lend or, sell the Report, or otherwise make the Report, or any portion thereof, available to any person without our prior written permission. Any use which a third party makes of the Report, are the sole responsibility of such third parties. Unless expressly permitted by us, no person other than the Client is entitled to rely on this Report. We accept no responsibility whatsoever for damages suffered by any third party resulting from use of the Report without our express written permission.

5. INTERPRETATION OF THE REPORT

a) Nature and Exactness of Soil and Contaminant Description: Classification and identification of soils, rocks, geological units, contaminant materials and quantities have been based on investigations performed in accordance with the standards set out in Paragraph 1. Classification and identification of these factors are judgmental in nature. Comprehensive sampling and testing programs implemented with the appropriate equipment by experienced personnel, may fail to locate some conditions. All investigations utilizing the standards of Paragraph 1 will involve an inherent risk that some conditions will not be detected and all documents or records summarizing such investigations will be based on assumptions of what exists between the actual points sampled. Actual conditions may vary significantly between the points investigated and the Client and all other persons making use of such documents or records with our express written consent should be aware of this risk and this report is delivered on the express condition that such risk is accepted by the Client and such other persons. Some conditions are subject to change over time and those making use of the Report should be aware of this possibility and understand that the Report only presents the conditions at the sampled points at the time of sampling. Where special concerns exist, or the Client has special considerations or requirements, the Client should disclose them so that additional or special investigations may be undertaken which would not otherwise be within the scope of investigations made for the purposes of the Report.

b) Reliance on Provided Information: The evaluation and conclusions contained in the Report have been prepared on the basis of conditions in evidence at the time of site inspections and on the basis of information provided to us. We have relied in good faith upon representations, information and instructions provided by the Client and others concerning the site. Accordingly, we cannot accept responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of misstatements, omissions, misrepresentations, or fraudulent acts of the Client or other persons providing information relied on by us. We are entitled to rely on such representations, information and instructions and are not required to carry out investigations to determine the truth or accuracy of such representations, information and instructions.

(see over . . . .)

c) Design Services: The Report may form part of the design and construction documents for information purposes even though it may have been issued prior to the final design being completed. We should be retained to review the final design, project plans and documents prior to construction to confirm that they are consistent with the intent of the Report. Any differences that may exist between the report recommendations and the final design detailed in the contract documents should be reported to us immediately so that we can address potential conflicts.

d) Construction Services: During construction we must be retained to provide field reviews. Field reviews consist of performing sufficient and timely observations of encountered conditions to confirm and document that the site conditions do not materially differ from those interpreted conditions considered in the preparation of the report. Adequate field reviews are necessary for Thurber to provide letters of assurance, in accordance with the requirements of many regulatory authorities.

6. RISK LIMITATION

Geotechnical engineering and environmental consulting projects often have the potential to encounter pollutants or hazardous substances and the potential to cause an accidental release of those substances. In consideration of the provision of the services by us, which are for the Client's benefit, the Client agrees to hold harmless and to indemnify and defend us and our directors, officers, servants, agents, employees, workmen and contractors (hereinafter referred to as the "Company") from and against any and all claims, losses, damages, demands, disputes, liability and legal investigative costs of defence, whether for personal injury including death, or any other loss whatsoever, regardless of any action or omission on the part of the Company, that result from an accidental release of pollutants or hazardous substances occurring as a result of carrying out this Project. This indemnification shall extend to all Claims brought or threatened against the Company under any federal or provincial statute as a result of conducting work on this Project. In addition to the above indemnification, the Client further agrees not to bring any claims against the Company in connection with any of the aforementioned causes.

7. SERVICES OF SUBCONSULTANTS AND CONTRACTORS

The conduct of engineering and environmental studies frequently requires hiring the services of individuals and companies with special expertise and/or services which we do not provide. We may arrange the hiring of these services as a convenience to our Clients. As these services are for the Client's benefit, the Client agrees to hold the Company harmless and to indemnify and defend us from and against all claims arising through such hirings to the extent that the Client would incur had he hired those services directly. This includes responsibility for payment for services rendered and pursuit of damages for errors, omissions or negligence by those parties in carrying out their work. In particular, these conditions apply to the use of drilling, excavation and laboratory testing services.

8. CONTROL OF WORK AND JOBSITE SAFETY

We are responsible only for the activities of our employees on the jobsite. The presence of our personnel on the site shall not be construed in any way to relieve the Client or any contractors on site from their responsibilities for site safety. The Client acknowledges that he, his representatives, contractors or others retain control of the site and that we never occupy a position of control of the site. The Client undertakes to inform us of all hazardous conditions, or other relevant conditions of which the Client is aware. The Client also recognizes that our activities may uncover previously unknown hazardous conditions or materials and that such a discovery may result in the necessity to undertake emergency procedures to protect our employees as well as the public at large and the environment in general. These procedures may well involve additional costs outside of any budgets previously agreed to. The Client agrees to pay us for any expenses incurred as the result of such discoveries and to compensate us through payment of additional fees and expenses for time spent by us to deal with the consequences of such discoveries. The Client also acknowledges that in some cases the discovery of hazardous conditions and materials will require that certain regulatory bodies be informed and the Client agrees that notification to such bodies by us will not be a cause of action or dispute.

9. INDEPENDENT JUDGEMENTS OF CLIENT

The information, interpretations and conclusions in the Report are based on our interpretation of conditions revealed through limited investigation conducted within a defined scope of services. We cannot accept responsibility for independent conclusions, interpretations, interpolations and/or decisions of the Client, or others who may come into possession of the Report, or any part thereof, which may be based on information contained in the Report. This restriction of liability includes but is not limited to decisions made to develop, purchase or sell land.

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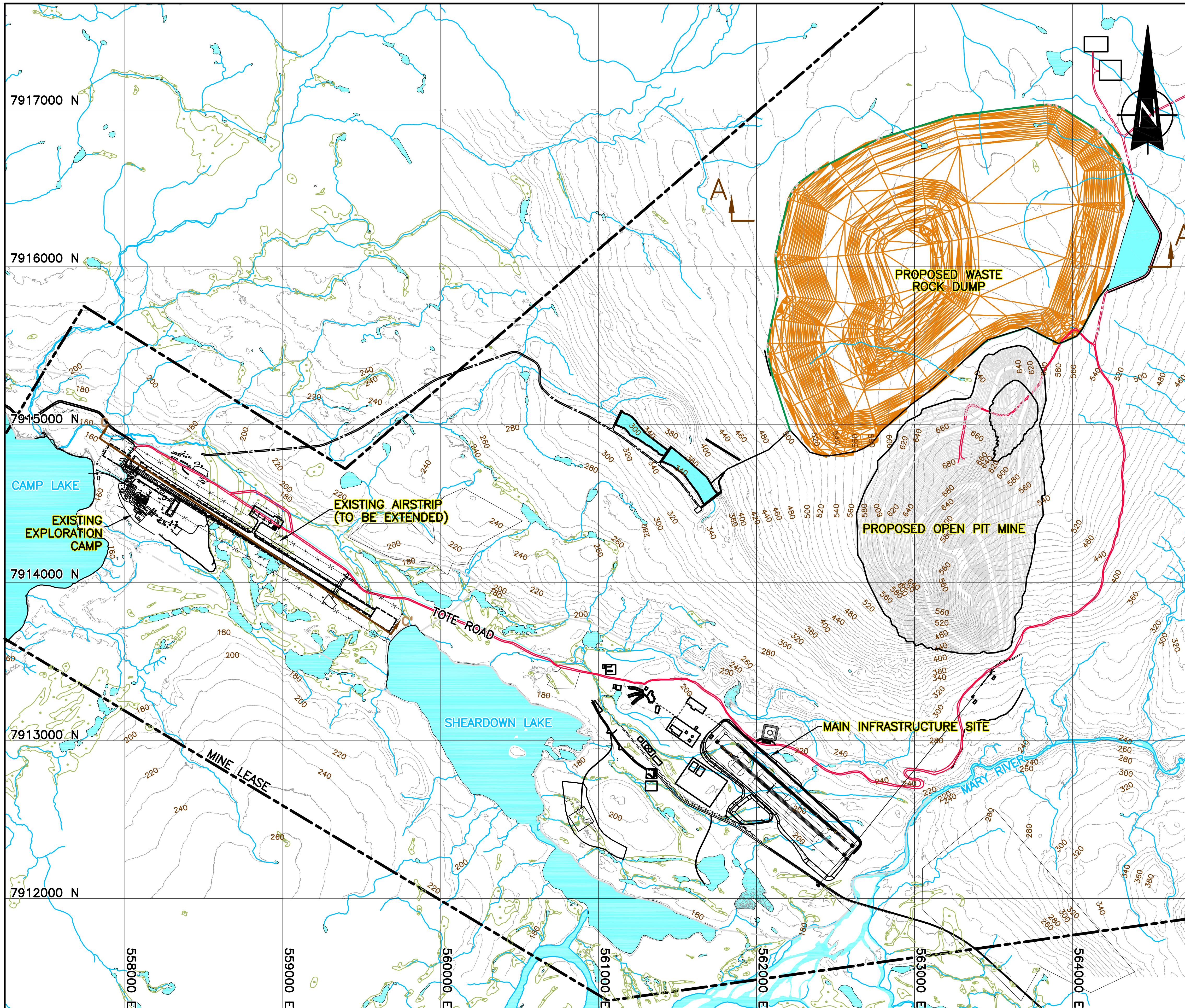
APPENDIX A

Figures



NOTES:

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ICB	LBS	LBS
SCALE 1:25 000	DATE SEPTEMBER 29, 2011	FILE No. 19-1605-126-C1A

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MARY RIVER PROJECT

OVERVIEW MAP OF THE MARY RIVER MINE SITE

FIGURE A.1

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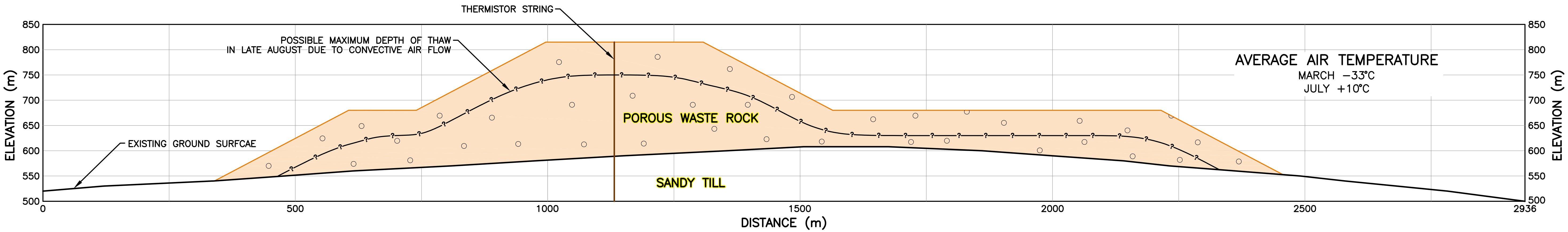

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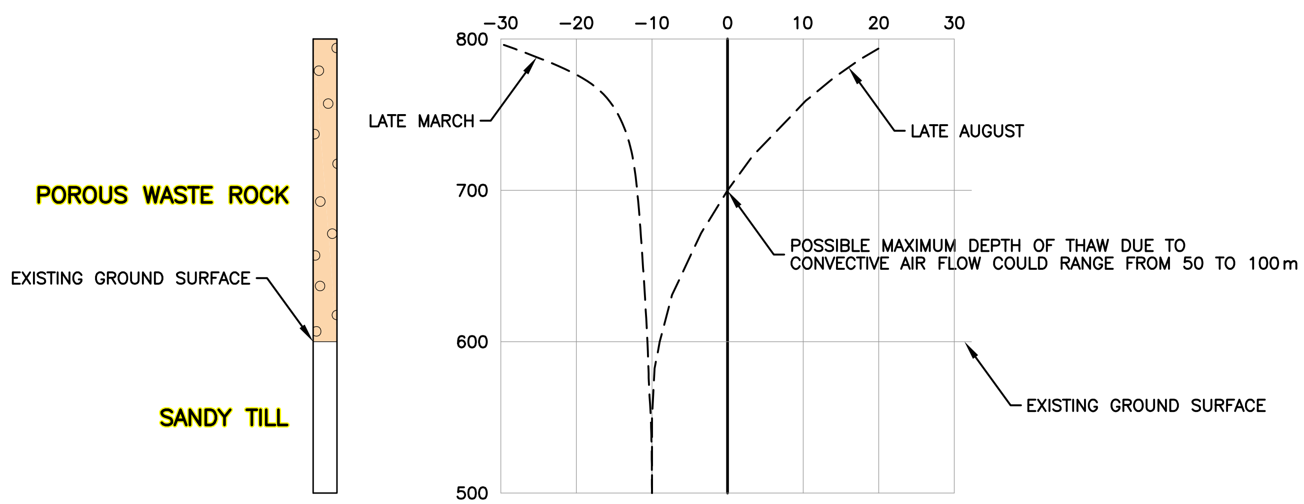

CONCEPTUAL TEMPERATURE DISTRIBUTION
IN WASTE ROCK DUMP IF CONVECTIVE AIR FLOW DOMINATES

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MARY RIVER PROJECT

CONCEPTUAL GROUND TEMPERATURES IN A POROUS WASTE ROCK DUMP DUE TO CONVECTIVE AIR FLOW

FIGURE A.2

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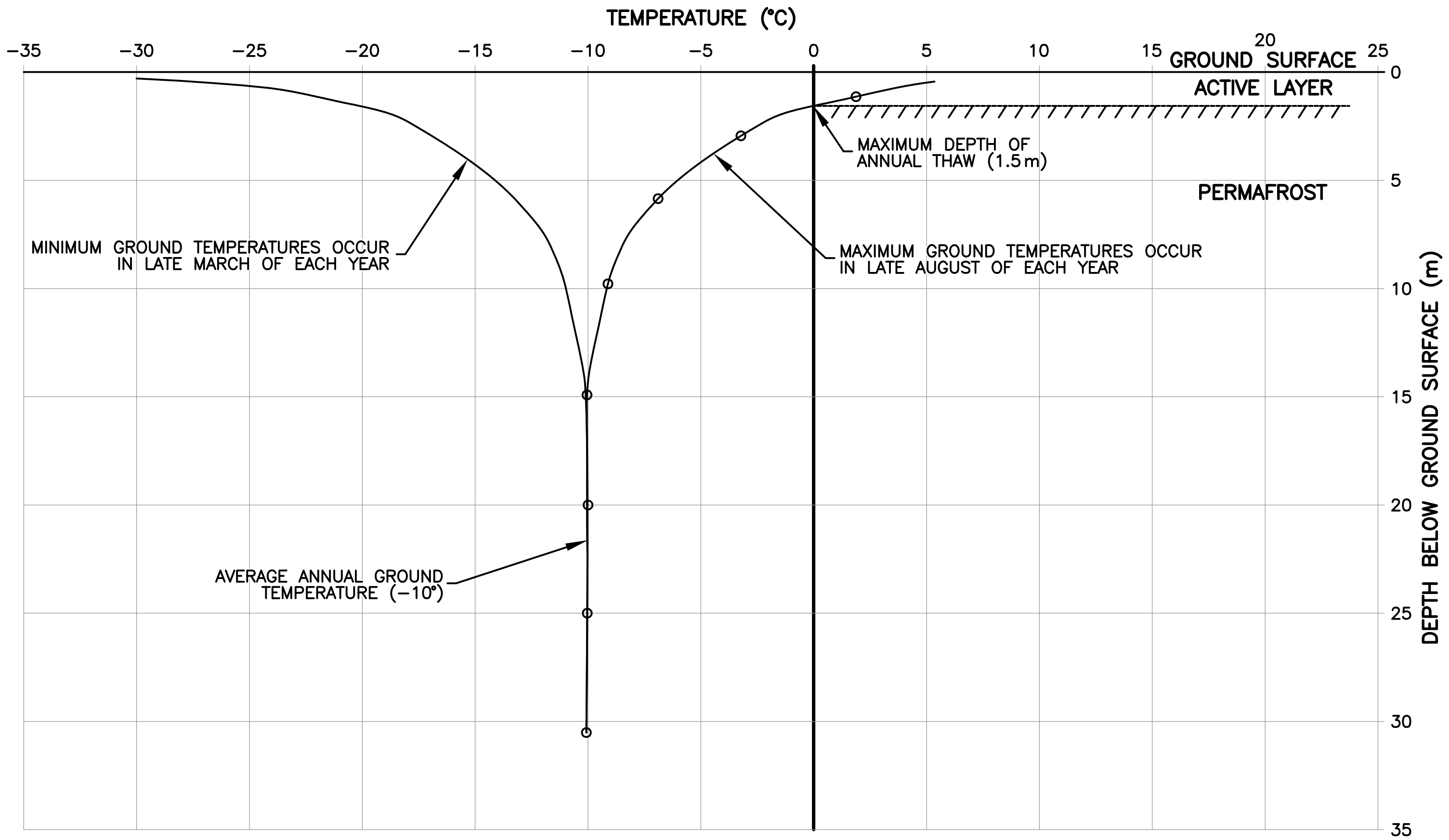
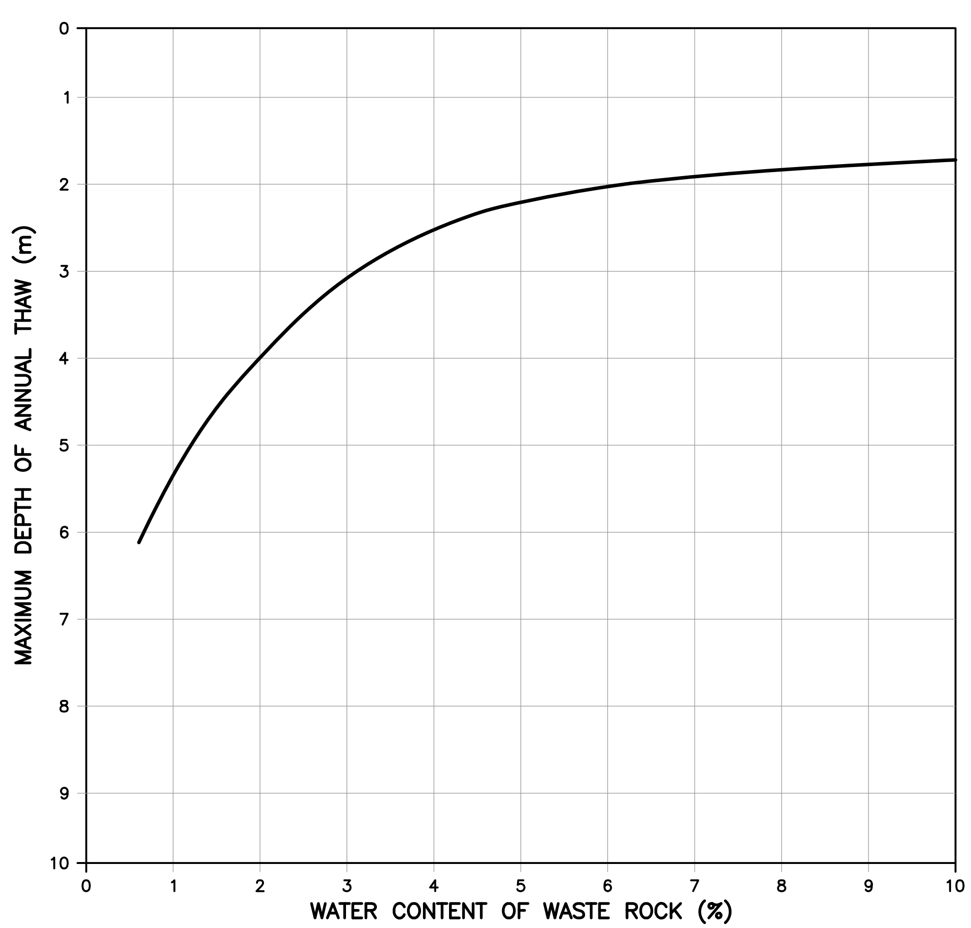


ANNUAL GROUND TEMPERATURES IN THE VICINITY OF THE MARY RIVER MINE SITE



APPROXIMATE DEPTH OF MAXIMUM ANNUAL THAW AS A FUNCTION OF SOIL WATER CONTENT

REV	DESCRIPTION	DRAWN BY	APPROVED BY	DATE (MM/DD/YY)
0	FINAL REPORT	ICB	LBS	11/7/11

DRAWN BY ICB	DESIGNED BY LBS	APPROVED BY LBS
SCALE AS SHOWN	DATE NOVEMBER 7, 2011	FILE No. 19−1605−126−D0A

HATCH™

MARY RIVER PROJECT

DEPTH OF THAW DUE TO HEAT CONDUCTION IN PERMAFROST

FIGURE A.3

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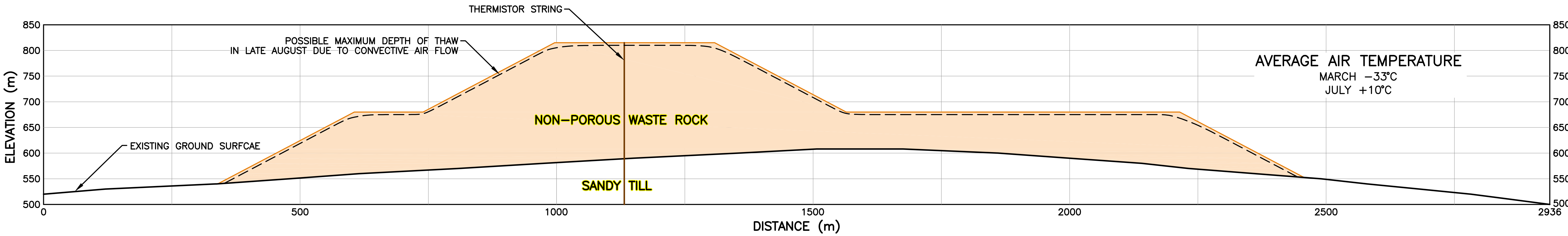
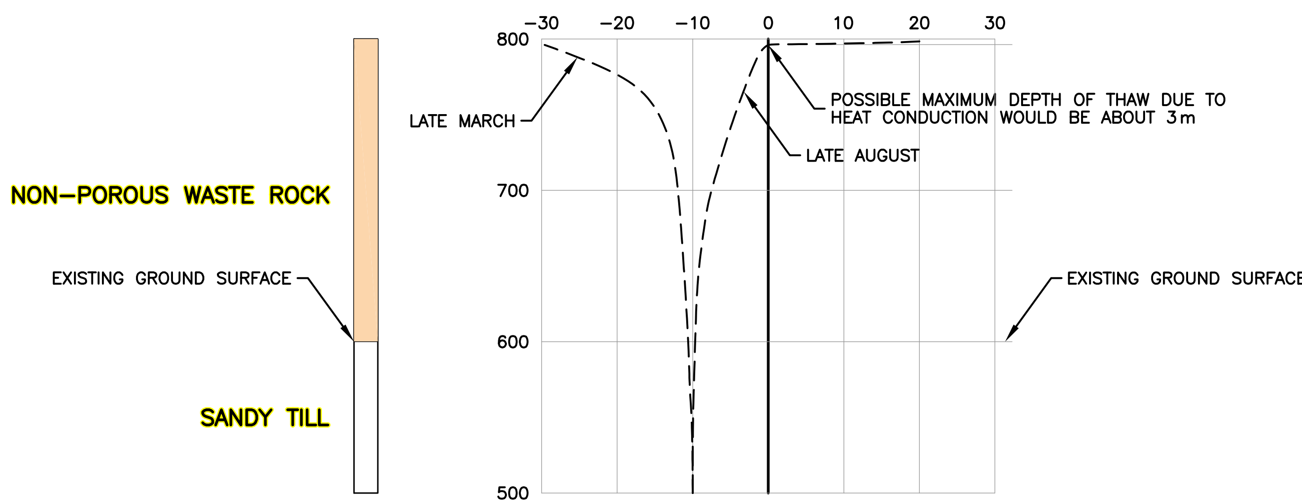


CROSS SECTION A–A'



CONCEPTUAL TEMPERATURE DISTRIBUTION
IN WASTE ROCK DUMP IF HEAT CONDUCTION DOMINATES

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CONCEPTUAL GROUND TEMPERATURES IN A NON-POROUS WASTE ROCK DUMP DUE TO HEAT CONDUCTION

FIGURE A.4

REV	DESCRIPTION	DRAWN BY	APPROVED BY	DATE (MM/DD/YY)
0	FINAL REPORT	ICB	LBS	11/7/11

DRAWN BY ICB	DESIGNED BY LBS	APPROVED BY LBS	
SCALE 1:8000	DATE SEPTEMBER 30, 2011	FILE No. 19−1605−126−C2A	

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Appendix 3:
Waste Rock Geological and Geochemical Characterization Program

WASTE ROCK GEOLOGICAL AND GEOCHEMICAL CHARACTERIZATION PROGRAM (2012-2014)

MARY RIVER PROJECT - DEPOSIT NO. 1

January 2012

Baffinland
Iron Mines Corporation

ACKNOWLEDGEMENTS

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BAFFINLAND IRON MINES CORPORATION

WASTE ROCK GEOLOGICAL AND GEOCHEMICAL CHARACTERIZATION PROGRAM (2012-2014)

MARY RIVER PROJECT - DEPOSIT NO. 1

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SECTION 1.0 - INTRODUCTION

1.1 BACKGROUND

A waste rock disposal area designed for permanent storage of waste rock will be located northwest of the Deposit No. 1 open pit (refer to attached Figure 3-2.3 (Appendix A), taken from the FEIS). Based on the current mine plan for Deposit No. 1, an estimated 570 Mt of waste rock will be generated over a period of 21 years. The shell of the open pit will eventually fill with meteoric water to an approximate volume of 45 million m^3 (Knight Piésold. 2008a).

As detailed in the associated Waste Rock Management Plan, open pit mining will generate large quantities of waste rock that will be stored at a dedicated location adjacent to the open pit. These waste rock materials have been characterized and grouped on the basis of geological characteristics and the results of geochemical static and kinetic test work. Environmental management plans are developed for each material group based on projected ltihology and mineralogy and chemical reactivity and physical properties to ensure long-term environmentally acceptable storage.

The results of the geochemical characterization of waste rock to date have been used to develop predictive water quality models. These models integrate the geochemical static and kinetic test results for the currently available sampling program with the overall geological, physical, and hydrological setting of the site, the proposed mine plan, and the operational waste rock management practices outlined in the Waste Rock Management Plan. These management practices are intended to minimize risk to the receiving environment from potential acidic, metal rich runoff and seepage. Similarly, a water quality model has been developed to generate predictions of pit water quality both during mine operations and post closure. The water quality models that have been developed are adaptable and will be updated over the next several years as new geochemical and physical data and interpretation become available, the mine plan is finalized, and environmental management practices are further refined.

Baffinland has recognized that there is a need to for an ongoing geological and geochemical characterization gap-filling program that will assist in confirming water quality model assumptions and predictions. During and subsequent to the NIRB pre-hearing technical meetings held in Iqaluit during late October, 2011 Baffinland acknowledged this requirement and committed to the following:

> "A sampling and testing program for the characterization of the waste rock for the period of 2012-2014 will be developed and will involve devising a representative sampling program for the waste rock based on the configuration of the ore body and the mining plan; analysis of the lithology, morphology and mineralogy of the waste rock; additional testing (both static and humidity cell). An independent expert will review and provide

guidance for this program. The characterisation program will be ongoing for the Life of the Project and will guide the development adaptive management strategies for waste rock management (should this be required over the life of the Project). This program will be presented in the FEIS.[1]"

1.2 PROGRAM COMPONENTS AND APPROACH

A waste rock geological and geochemical characterization program (the "Program") for the period 2012 to 2014 has been developed to address gaps in the existing database and to evaluate and adjust as warranted current assumptions used in predictive models. The Program is focussed on information gaps in the following component areas:

- Waste rock geology on the deposit scale utilizing surface mapping and drilling techniques;
- Predictive geochemical sampling and testing programs using mineralogical, static testing, and kinetic testing methodologies; and
- Sensitive input parameters (i.e., climate, hydrology, permafrost, and geochemical source terms) used to make water quality predictions for waste rock and open pit.

In the following sections of this document, the current data base is reviewed in relation to the above component areas, information gaps are identified, and programs to address gaps are proposed.

In addition, a preliminary operational and verification monitoring program is proposed for the post-2014 period when the commencement of pre-strip and mining of the open pit is scheduled to commence. This program will be subject to further adjustment based on the results of the 2012-2014 work.

[1] Commitment No. 233 as outlined in November 4, 2011, letter from Baffinland to NIRB, Re: Revised List of Commitments from Technical meeting.

SECTION 2.0 - MINE PLAN AND BASELINE SITE CONDITIONS

The mine plan, waste rock management plan, and baseline site conditions for the Project are described in detail within the FEIS. The reader is referred to the following sections of the FEIS for further information:

- Mine Plan – FEIS Volume 3, Project Description:
    - Section 3.4, Mine Site – Operation Phase
    - Table 3-3.1 Preliminary Schedule of Waste Rock Production
    - Figure 3-2.3 Mine Site Layout (Appendix A to this report)
- Waste Rock Management Plan – FEIS Volume 3, Appendix 3B, Attachment 5
    - Annex 2. Technical Memorandum from Thurber Engineering Ltd. to Hatch, dated November 23, 2011, Re: Development of Permafrost in Waste Rock Dumps – Preliminary Geotechnical Evaluation
    - Annex 4. Interim Waste Rock Stockpile Seepage Quality Model Report, Mary River Project. Dated January 2012. Prepared by AMEC
    - Annex 5. Interim Open Pit Water Quality Model Technical Memorandum, Mary River Project. Dated January 2012. Prepared by AMEC.
- Climate – FEIS Volume 5, Atmospheric Environment:
    - Section 1.0 – Climate
    - Tables 5-1.1 to 5-1.7, incl. – Climate normal, forecasts, and return periods for extreme temperature events
- Terrestrial Environment – FEIS Volume 6:
    - Section 2.1 – Landforms, Soils and Permafrost Baseline Summary, includes geochemical, geotechnical, geomechanical, and hydrological conditions
    - Appendix 6B-1 – Geochemical Evaluation of Ore and Waste Rock
    - Figure 6-2.3 – Surficial Geology in the Mine Site Area
- Freshwater Environment – FEIS Volume 7:
    - Section 1.0 – Regional Freshwater Setting
    - Section 2.1 – Freshwater Quantity Baseline Summary
    - Section 3.1 and 3.2 – Water and Sediment Quality Baseline Summary

A description of the regional and local geology for Deposit No. 1 is provided in Section 3.1.

SECTION 3.0 - GEOLOGY

3.1 OVERVIEW OF REGIONAL AND LOCAL GEOLOGY

The detailed description of the regional and local ore deposit geology is provided in Volume 6 of the FEIS, particularly Section 2.1 and Appendix 6B-1. Figure 6-2.3 (Appendix A to this report), is taken from the FEIS and shows the surficial geology of the mine site area. Figure A-1 (Appendix A to this report) shows the bedrock geology of Deposit No. 1 and exploration / environmental drill holes that have intersected and sampled the deposit and adjacent wall rock within the proposed pit perimeter. A description of the regional and local geology of Deposit No. 1, taken from Appendix 6B-1 of the FEIS, is provided below.

3.1.1 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.

3.1.2 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.

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.

3.2 EXISTING GEOLOGICAL DATABASE

The existing geological database for Deposit No. 1 was obtained primarily from drilling with surfacing mapping and geophysics providing only a minor source of data.

3.2.1 SURFACE MAPPING AND GEOPHYSICS

The exposed portions of Deposit No. 1 have been mapped systematically using standard geological mapping techniques since 2006. Some detailed mapping of individual outcrops has been performed on the southwest facing slope of the deposit to gain an understanding of the complexity of the structure that has affected the ore zone and wall rocks. Within the area of the proposed open pit, there is very little bedrock exposure of waste rock across the footwall and hanging wall. The exposure is estimated to be less than 10%. Based on discussions with senior Baffinland geological staff, there is no more information to be gained from ground work across this area. The overburden thickness maps for the deposit in the vicinity of the waste rock hanging wall and footwall areas are still in development.

Table 3-1 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	

The entire area of Deposit No. 1 was covered by airborne magnetic survey flown in 2008. Limited ground magnetic work was performed in 2010 and 2011 covering selected areas along the east and northernmost parts of the deposit. Ground gravity surveys were performed along the eastern edge and northeast portion of the deposit in 2011. The geophysics completed to date has been utilized primarily for ore zone delineation. It is the opinion of Baffinland geological staff that geophysical techniques would not be helpful in differentiating different waste rock lithologies on the scale required.

3.2.2 DRILLING

The existing geological database and interpretation of the Deposit No. 1 ore zone and waste rock is derived mainly from rotary core drilling, core logging, and core sampling. Since 2004, a total of 26,852 metres of drilling in 136 holes has been completed on Deposit No. 1. There has been drilling on Deposit No. 1 annually from 2004 to 2010. The locations of the drill holes that have been used as part of the geochemical characterization program and database are presented in Figure A-1.

The drilling season on Deposit No. 1 is of short duration (mid-June to end of August); therefore, most of the drilling completed in the early years was focused on ore delineation rather than waste rock delineation. It is of note, however, that most of the drill holes that intersected the ore zone were also continued for approximately 20 m into the wall rock (waste rock) providing some opportunity to characterize waste rock materials near the ore zone.

Since 2010, there has been a concerted effort to characterize the wall rock and three drill holes were advanced in 2010 through the footwall lithologies, specifically to provide representative information on the waste rock to be produced during mining. There was no drilling completed in 2011 since that program was focussed exclusively on geotechnical assessments. However, much of the wall rock core was relogged and resampled in an attempt to increase the existing waste rock geological and geochemical database.

3.3 IDENTIFIED DATA GAPS AND PROPOSED DRILLING PROGRAM

Based on a review of the deposit geology and drill hole locations shown on Figure A-1, there are large volumes of wall rock within the proposed pit perimeter that have not been systematically characterized by drilling. These areas occur mainly in the footwall of the deposit, but also within the hanging wall area. Figure A-1 shows these areas delineated by red cloud-like polygons. These delineated areas will be the focus for a 2000 to 3000 m drilling program using rotary core drill rigs to be completed during the summer of 2012. The drilling will be focussed on a series of eight to ten vertical cross-sections across the hanging wall and the footwall of the deposit at a section spacing yet to be finalized, but likely to be around 400 or 500 m. The recovered drill core will be logged and sampled in accordance to methods based on MEND (2009) and Price (1997). The drill core loggers and samplers will be trained and work under the direction and training of the project geochemists to ensure that core logging and sampling methodologies are consistently applied and will address the identified data gaps.

In an attempt to share available resources, the drilling locations for the 2012 geochemical characterization drilling program will be optimized so as to fill gaps related to the geotechnical and geomechanical aspects of the pit design. The recovered drill core will be used to assess both geochemical and geotechnical/geomechanical aspects of the pit design.

SECTION 4.0 - PREDICTIVE GEOCHEMICAL SAMPLING AND TESTING PROGRAMS EXISTING DATABASE

4.1 SAMPLING

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 2010a and AMEC 2012a). 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. Limited sampling of overburden material in the area has been completed.

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.

4.2 STATIC TESTING

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. Materials tested have primarily included waste rock (613 samples) with some testing of ore (21 samples) and overburden (seven near-surface outside of pit area).

Waste rock is characterized by generally low modified Sobek neutralization potentials (NP) and low sulphide contents with resulting low acid potentials (AP) (Figure 4-1). Carbonate NP typically represents < 30% of the modified Sobek NP. Sulphide content in excess of 0.5% is generally predictive of an NPR (the ratio of NP/AP) less than 2 (Figure 4-2). A summary of static ABA waste rock results by waste type are provided in Table 4-1. Overall, assuming that a NPR ≤ 2 is representative of 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.

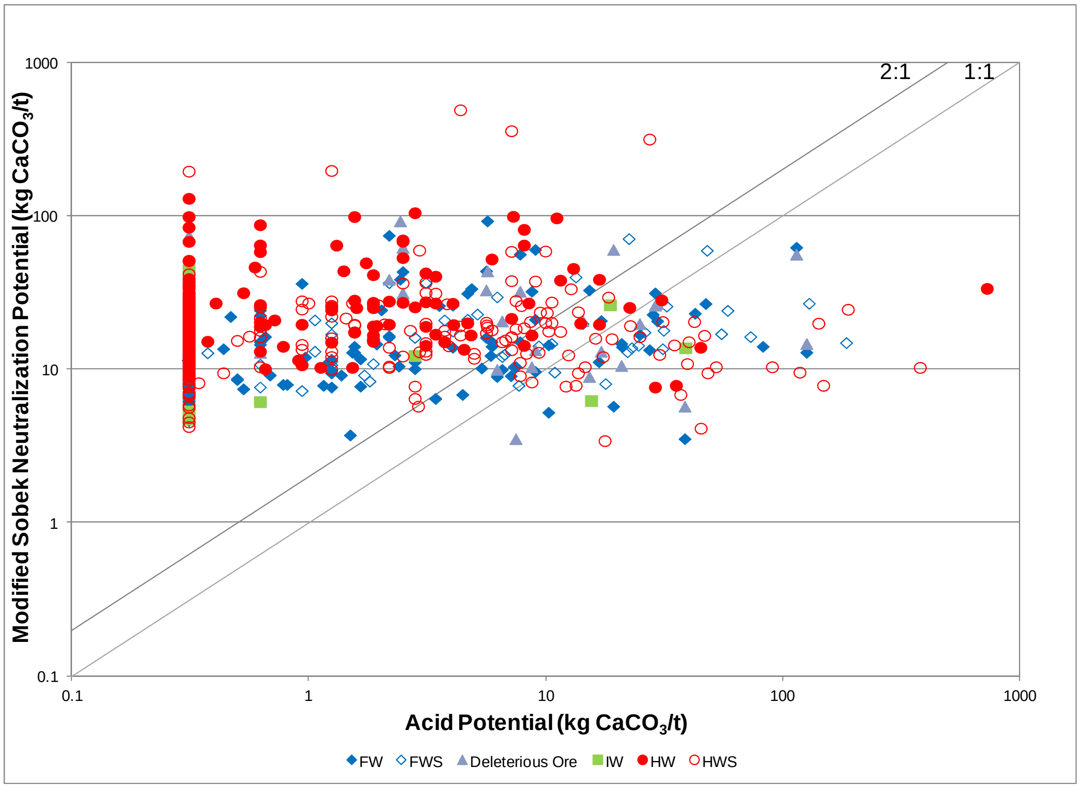

Figure 4-1 Neutralization Potential (NP) vs. Acid Potential (AP)

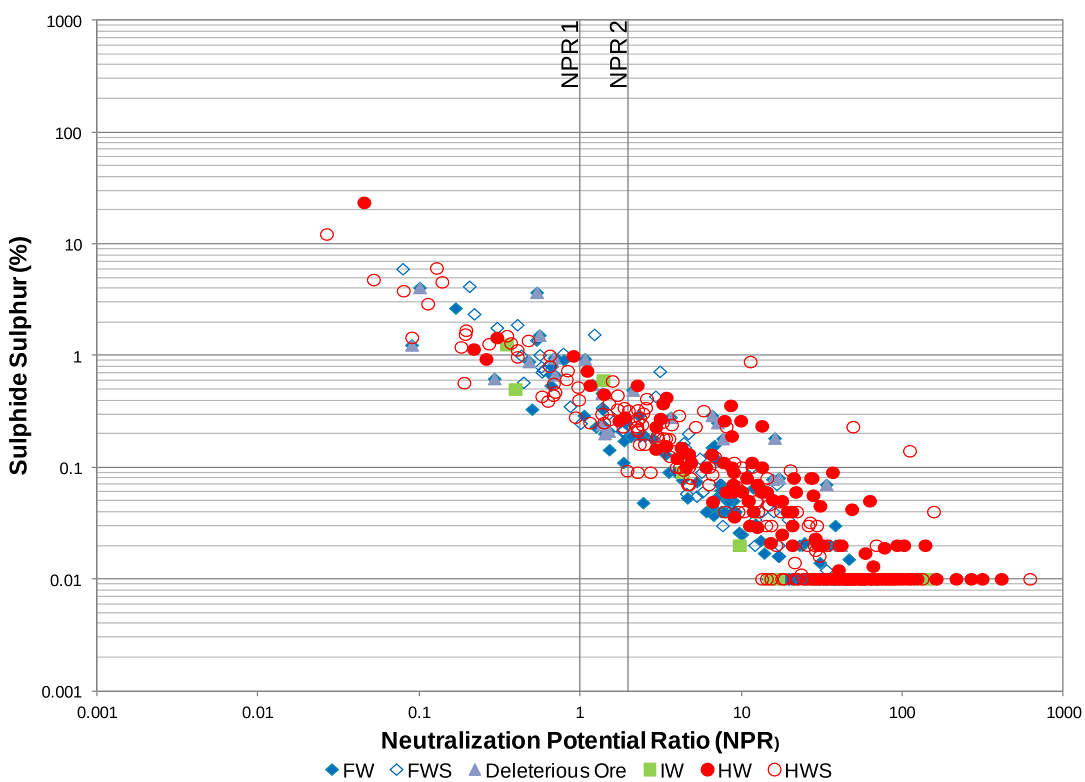

Figure 4-2 Neutralization Potential Ratio vs. Sulphide Sulphur

Table 4-1 **Summary of Waste Rock Static ABA Test Results**

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	7,595,662
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 static ABA sampling program completed in 2011 included a component of mineralogical work (see below) to improve the overall understanding of ML/ARD of the waste rock and particularly the source of non-carbonate acid neutralizing potential in the waste rock. This, along with kinetic testing, has been identified as a critically important consideration to support and better understand the adequacy of non-carbonate neutralization capacity in waste rock to limit acidic drainage.

Overburden from the pit volume has not been specifically tested. However, selected sampling of overburden from potential borrow areas around the site and along the proposed tote road to the north have been completed (Knight Piésold 2008, AMEC 2010b). Testing of these largely glacially derived surficial materials indicated they were generally low in sulphide content and in many cases contained abundant carbonate presumably derived from the local Palaeozoic carbonate rocks that outcrop in the region.

4.3 MINERALOGY

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 late 2011 is continuing and will be reported in 2012; 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 in 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

4.4 KINETIC TESTING

Ten waste rock samples were run in humidity cells for 53 weeks in 2008 and 2009. A further 17 waste rock samples were initiated in humidity cell tests in May 2011. Nine of these samples were standard humidity cells and eight were NP depleted humidity cells designed to assess drainage quality in the absence of carbonate NP. Available humidity cell results have produced pH in the circum-neutral to weakly acidic (pH 5) range, but no strongly acidic drainage (pH<5) has occurred. All 2011 humidity cell tests are continuing.

Humidity cell metal leaching results are generally consistent with the sulphide mineralogy identified, with measureable loadings of copper, nickel, zinc and cobalt present in some humidity cells. Based on limited kinetic data, total sulphide content of samples is weakly correlated with sulphate release rates; however, through the current periods of testing metal release rates and trends vary among the cells. Overall, metal release rates for the weak acid (pH 5 to 6.5) humidity cells are higher than those of neutral pH cells. The metals copper, nickel, zinc and cobalt discussed above were also consistently identified at elevated levels in NAG leachate analyses of the net-acidic samples tested.

Two field lysimeters are in operation at the Mary River site. The two lysimeters were constructed by placing lump and fine ore left over from the 2008 bulk sampling program on an impermeable membrane to allow collection of run-off water. Though minor gypsum has been locally identified with some ore, the presence of sulphate and some elevated dissolved metals (e.g. nickel) has been inferred to be related to sulphide oxidation in these materials. Long-term storage of ore during operations is not expected; however, continued monitoring of these ore lysimeters may provide field scale and climate driven data pertinent to low NP sulphide oxidizing material.

Shallow hydrogeological investigations of the active zone in overburden adjacent to existing ore stockpiles were intiated during 2011 with the installation of four shallow monitoring wells. These wells will be monitored and sampled during the 2012 field season.

4.5 IDENTIFIED GEOCHEMICAL DATA GAPS AND ADDITIONAL WORK

The following data gaps and planned work to address them is outlined below.

Sampling

- The large extent of presently unsampled footwall material and smaller gaps in hanging wall material within the pit volume and adjacent to the ultimate pit on the HW side is to be drilled and sampled in 2012 (see Section 3).
- Overburden material within the pit volume is presently unsampled. Sampling of this material will be included to the extent possible in the additional planned drilling program or coordinated with other site work.

Static Testing

- In addition to the geological characterization of the above currently unsampled waste rock materials, static testing of these footwall, and hanging wall materials will be conducted as part of the planned drilling and sampling program in 2012. Sampling and analytical methods will be consistent with previous Project work.
- Static testing of representative overburden material samples within the pit volume is also planned.

Mineralogy

- Mineralogical characterization of drill core to better understand the effective neutralization potential of waste rock for the range of lithologies and waste types will continue in 2012.
- Detailed mineralogical characterization by R-XRD, optical microscopy and SEM is also planned for selected humidity cell samples that will include an attempt to identify and assess accumulated alteration products to support the understanding of metal attenuation during oxidative weathering of waste rock.

PAG Segregation

- The following work will continue or be initiated to identify the importance and ability to segregate PAG materials.
  - The overall percentage and distribution of PAG will be updated on the basis of the expanded footwall and hanging wall sampling program planned for 2012.
  - Continuous sampling over several targeted long sections of core will be completed in 2012 to better assess continuity of PAG materials at the bench scale.

- o Mineralogical and kinetic testing work will continue to be integrated with static testing results to improve the understanding of potential simplified surrogate relationships that can be used to assist in PAG segregation during operations should this be required.

Kinetic Testing

- A continued expansion of the laboratory kinetic testing program consistant with previous Project work is planned to include:
  - o Humidity cell testing of deteterious footwall ore not presently represented in kinetic testing data base;
  - o Humidity cell testing (as required) of presently unsampled lithostratigraphic units to be drilled in 2012;
  - o Column or humidity cell testing of a range of non-PAG materials of various sulphide contents to better understand metal leaching from this material, and
  - o Comparative kinetic testing of cold and room temperature leaching of selected PAG materials.
- On-going sampling of drainage from the existing lysimeters, other ore and waste stockpiles and rock-face seepage in the vicinity of the pit will continue for at least 2012 through 2014.
- Where possible, upgrades to existing lysimeters and adjacent active zone monitoring will be made to better quantify and constrain metal loadings released from these facilities.
- If suitable material is identified, field test piles will be setup and instrumented for both thermal monitoring and drainage quality.
- Where field test piles are established, laboratory testing representative of the test pile material will also be completed to provide direct comparison and insight into the scaling factors from lab to field.

SECTION 5.0 - WATER QUALITY PREDICTIONS – WASTE ROCK AND PIT

5.1 BASIS OF WASTE ROCK SEEPAGE AND PIT DRAINAGE WATER QUALITY MODELS

Mass loading models with limited geochemical attenuation modeling have been developed to predict water quality from the waste rock stockpiles and future pit water drainage. Detailed descriptions of the models are described in AMEC (2012b) and AMEC (2012c). Water inputs to the waste rock stockpile and pit models were based on monthly precipitation values provided by Knight Piésold (2011). Drainage only occurs during the summer months (June to September). Expected release rates for the mine rock were derived from available humidity cell data. There is presently no humidity cell data available for acidic drainage conditions. Therefore, where acidic drainage was required to be modeled preliminary source terms were established using NAG leachate metal data proportioned to a sulphate release rate set at five times the non-acidic sulphate rate. Key assumptions used in application of the source terms include:

- Sulphide oxidation rates were assumed to be 100% of laboratory rates during the summer months (June to September) and 50% during the remainder of the year (winter months) due to reduced temperatures (MEND 1996);
- The effective reactive surface area of waste rock in the pile was assumed to be 50 m^2/ton;
- 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); and
- An ARD onset time of 5 years was assumed for the PAG mine rock in the stockpiles and pit walls based on the estimated average carbonate neutralization potential (carbonate NP) depletion time derived from humidity cell testing of PAG materials.

5.2 EXISTING STATUS OF WASTE ROCK WATER QUALITY MODEL

The material balance used for the waste rock model was based on the current mine plan and a number of assumptions regarding the mine operation and mine waste management that are consistent with BIM plans and commitments.

Key assumptions in the current waste rock seepage model include the following:

- Construction of the waste rock stockpile 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 an outer 10 m active layer of the pile;
- Hydrology of the stockpile is in a steady-state condition;
- Seepage only occurs from the active layer of the stockpile and there are no groundwater inflows to the pit;
- 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; and
  - Only non-PAG waste rock will be present within the active layer.
- 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.

5.2.1 MODELING RESULTS

The estimated seepage concentrations (in process) for the waste rock model base case are provided in Table 5-1. Full details including discussion and sensitivity analysis of these results are provided in AMEC (2012b). These mass balance derived values may exceed geochemical solubility limits and therefore, the results were checked through geochemical equilibration in PHREEQC. The resulting equilibrated values are also provided in Table 5-1.

Table 5-1 Estimated Water Quality of Waste Rock Stockpile Seepage

Parameters	MMER values	Maximum			
		West Catchment		East Catchment	
		Unequilibrated	Equilibrated*	Unequilibrated	Equilibrated*
pH		6.9	6.9	6.9	6.9
Sulphate (mg/L)		124	124	99	99
Arsenic (mg/L)	0.5	0.012	0.012	0.010	0.010
Copper (mg/L)	0.3	0.022	0.022	0.018	0.018
Lead (mg/L)	0.2	0.001	0.001	0.001	0.001
Nickel (mg/L)	0.5	0.006	0.006	0.005	0.005
Zinc (mg/L)	0.5	0.075	0.075	0.060	0.060
Aluminum (mg/L)		0.554	0.321	0.443	0.295
Antimony (mg/L)		0.012	0.012	0.009	0.009
Boron (mg/L)		0.096	0.096	0.077	0.077
Cadmium (mg/L)		0.0002	0.0002	0.0001	0.0001
Chromium (mg/L)		0.022	0.022	0.018	0.018
Cobalt (mg/L)		0.0030	0.0030	0.0024	0.0024
Iron (mg/L)		0.137	<0.002	0.109	<0.002
Manganese (mg/L)		0.0358	0.00002	0.0286	0.00003
Mercury (mg/L)		0.004	0.004	0.003	0.003
Molybdenum (mg/L)		0.039	0.039	0.031	0.031
Selenium (mg/L)		0.047	0.047	0.038	0.038
Silver (mg/L)		0.0005	0.0005	0.0004	0.0004
Thallium (mg/L)		0.004	0.004	0.003	0.003
Vanadium (mg/L)		0.006	0.006	0.005	0.005
Barium (mg/L)		0.241	0.241	0.193	0.193
Sodium (mg/L)		1.535	1.535	1.227	1.227

Table 5-1 Estimated Water Quality of Waste Rock Stockpile Seepage (Cont')

Parameters	MMER values	Maximum			
		West Catchment		East Catchment	
		Unequilibrated	Equilibrated*	Unequilibrated	Equilibrated*
Potassium (mg/L)		46.8	46.8	37.4	37.4
Calcium (mg/L)		57.8	57.8	46.2	46.2
Magnesium (mg/L)		32.4	32.4	25.9	25.9

* Results oversaturated with respect to $Al(OH)_3$, ferrihydrite (poorly crystalline Fe oxide) and manganite (MnO(OH)) were equilibrated in PHREEQC (AMEC 2012b).

5.3 EXISTING STATUS OF PIT DRAINAGE WATER QUALITY MODEL

The material balance used for the pit drainage water quality model was based on the current mine plan, modeled waste distribution within the pit and a number of assumptions regarding the mine operation and pit management that are consistent with BIM plans and commitments. In order to model pit water quality during operations, additional information on mine progress over time has been provided by Hatch (2012).

Key assumptions in the current pit drainage model include the following:

- Water flow into the pit is by direct precipitation (rain and snow) within the pit/mined perimeter and no additional natural drainage or catchments drain to the pit;
- Draining water within the pit/mined perimeter collects at either perimeter drains (early time) or to pit sump(s) for management during operations;
- No groundwater inflow occurs to the pit and no evaporation loss from the pit surface;
- After closure, the pit will be filled to overflow at elevation 320 masl within five years; and,
- Overall pit water quality at a given point in time is derived by:
    - complete mixing of drainage proportioned on the basis of exposed (unflooded) incremental surface areas and the pit lake surface area (post flooding);
    - incremental surfaces are assigned on the basis of exposed (unflooded) surfaces from the block model within the pit (e.g. HW, FW, HWS, FWS, IW, DO, Ore and overburden);
    - source terms are assigned to each of the incremental surfaces on the basis of the percentage PAG for that material type;
    - metal release rates based on acidic conditions are allowed for PAG expected to have been exposed for more than 5 years; and,
    - total flushing of accumulated metals on surfaces is assumed during drainage period (June to September).

The pit drainage water quality model is presently under development and results are currently unavailable.

5.4 IDENTIFIED GAPS IN INPUT PARAMETERS AND SENSITIVITIES IN INPUT PARAMETERS AND PLANNED WORK

The mass balance waste rock and pit models were prepared using a number of assumptions in lieu of supporting data. Several items have been identified where additional work could either verify such assumptions or improve values estimated or assumed for the purposes of the modeling. These items are described below.

Hydrology

Modeling of the waste rock stockpile and pit identified that the models were sensitive to the volume of water flushing through the system. Therefore, any update to the understanding of pit and waste rock stockpile hydrology should be incorporated into the model.

Source Terms

The source terms for the waste rock and pit models for non-acidic conditions are presently based on available humidity cell data. Source terms for acidic drainage for pit water models are based on scaling of NAG leachate data with acidic drainage. This approach is considered highly conservative and could lead to significant overestimations regarding concentrations in acidic drainage. In general, source terms are sensitive parameters in predicting mass inputs into the system. Therefore, these source terms will be reevaluated with additional humidity cell data as they become available. Acidic leachate data in particular should it become available (e.g. with continued operation of the NP depleted humidity cells) may substantially increase the reliability of modeling acidic drainage at the site. Estimation of drainage inputs from non-PAG rock is presently based on largely PAG humidity cells operating under non-acidic drainage conditions. The planned addition of a range of humidity cells or column tests for non-PAG materials with a range in sulphide concentrations (Section 4) including samples without detectable sulphide could substantially improve reliability in the estimation of non-PAG drainage quality for the waste rock stockpile and pit.

Proportion of PAG Rock

The percentage PAG in the waste rock stock pile and at pit limits is an important and sensitive factor in predicting future water quality due to potential acidic drainage. Additional sampling and ML/ARD characterization work to be completed in 2012 will provide an update on the percentage and distribution of PAG material in the pit and resulting waste rock stockpile. This can then be incorporated in the existing models.

ARD On-set Time

The ARD on-set time for PAG rock is also a critical factor in predicting the timing of potential future acidic drainage. The current selection of 5 years on the basis of the average NP depletion time is believed to be a conservative (short) assumption. On-going humidity cell testing and a better understanding of the waste rock mineralogy and contributions to NP will be utilized to update the ARD on-set time for modeling efforts.

Surface Areas and Permafrost

The reactive surface area in both models as defined by scaling assumptions and, for the waste rock model, the active zone thickness, is a critical assumption in the model with high sensitivity. Direct estimation of the effective surface area is challenging. Some experience based guidance may be possible from expected rock behaviour during blasting. However, this parameter should continue to be managed through the use of sensitivity analysis. If a field test pile is to be constructed, comparison of representative lab data and field data may provide an indirect confirmation or assessment of this and other scaling factors. Thermal modeling of the waste rock stockpile is planned to estimate the expected active zone thickness of the waste rock stockpile, including global warming conditions. Modeling will also include an assessment of thermal effects from sulphide oxidation to evaluate the assumption that these effects are inconsequential for the relatively low-sulfide rock at Mary River and do not limit freeze-back into the waste rock stockpile.

A related issue to permafrost aggradation, active zone development and water flows through the system is the fate of water infiltrating into the permafrost zone of the stockpile. Currently, modeling assumes a steady state where flows into the pile equal flows out. However, water loses to permafrost formation are likely especially following placement of fresh rock. In the event a field test pile is constructed, instrumentation and monitoring will be utilized to provide data on the magnitude, duration and importance of such losses in the model. This work also will allow direct measurement of solute concentrations, which then can be used to calibrate the mass-balance modeling approach.

Mineralogy

Results determined by the model are equilibrated with respect to selected solid phases. In order to conduct the equilibration step, assumptions must be made with respect to sorption and precipitation reactions that may occur. With increased quality of site data, additional modeling considerations may be possible to improve predicted model results. Presently precipitation of assumed solid phases has been carried out using equilibrium thermodynamic assumptions in PHREEQC for a limited range of solutes; no sorption is currently modeled. Additional mineralogical work on post operational humidity cells is planned that could improve the understanding of metal leaching in the context of metal sorption and solid phase precipitation behaviour.

Section 6.0 - PROPOSED VERIFICATION AND OPERATIONAL MONITORING OF WASTE ROCK STORAGE AREA AND OPEN PIT (POST-2014)

A preliminary verification and operational monitoring program is proposed for the post-2014 period when the commencement of pre-strip and mining of the open pit is scheduled to commence. This program will be subject to further adjustment based on the results of the 2012-2014 work. The results of the verification and operational monitoring program will help to confirm long-term predictions related to, for example, active zone thickness/permafrost aggradation and waste rock/pit water quality. The monitoring program results will be carefully tracked over time, particularly during early years of operation, to ensure that condtions correspond with the predictions made. Trends showing potential divergence between predicted and actual conditions will be identified early on so that appropriate corrective actions can be evaluated and implemented as necessary to minimize potential environmental risk.

6.1 PHYSICAL MONITORING

It is expected that the Waste Rock Storage Area and open pit will be geotechnically stable based on the conservative design basis and parameters that will be adopted. It is the responsibility of the pit supervisors to visit all working areas every shift to check for working area hazards. Therefore, dumps and pit walls are inspected every shift and any hazardous conditions are reported.

6.2 TEMPERATURE MONITORING

Once the waste rock dump has sufficiently developed, ground temperature cables (GTCs) will be installed at locations within the dump footprint to monitor cooling within the dump and to measure seasonal variation in active zone thickness. The focus of the temperature monitoring will be on confirming active zone thicknesses and geometries across waste rock materials distributed throughout the waste rock dump. GTCs are typically installed in nests, with individual GTCs installed at different depths and measured several times annually to capture seasonal variation in active zone thickness. This approach has been effectively used at the Ekati Mine over the last decade.

6.3 ENVIRONMENTAL MONITORING

6.3.1 INSTRUMENTED TEST PILES

A program of carefully designed field test pads and laboratory columns should be considered as soon as waste rock becomes available, prior to or at the commencement of mining activiites. This program can assist in simulating and predicting drainage chemistry from the proposed waste rock stockpile and provide a relationship between kinetic test work and actual scaled up field conditions. In the absence of available waste rock to conduct a field test pad program, it is recommended that during the summer of 2012, field reconnaissance work be conducted to identify any suitable exposures of hanging wall and foot wall waste rock that could be mined on a small scale for the purpose of test pad construction and operation during 2013.

6.3.2 WASTE ROCK GEOCHEMISTRY

The technique for the identification and segregation of PAG and non-PAG waste rock will be refined based on the results of the 2012-2014 characterization program. It is likely that the identication will be based on a combination of analytical techniques that rely on both field visual observations, and on-site sulphur analyses of blasthole cuttings and of samples of blasted rock. For the purpose of validation of field results, an adequate percentage of samples will be sent to an external independent laboratory for standard ABA parameters.

The main objectives of geochemical monitoring will be to confirm the general geochemical characteristics of the waste rock prior to deposition in the waste rock pile. Initially, individual blast patterns or blasted rock piles will be differentiated on the basis of PAG vs. non-PAG, or some range therein. Once the individual blasts are identified, then the waste rock from those blasts can be managed appropriately in accordance with the waste rock management plan for the operation. Operational experience at other mining operations such as Diavik, Ekati, and Voiseys Bay provides evidence that this type of operational sampling and monitoring can provide adequate characterization of waste rock. As confidence builds during the iniitial confirmatory phase of operational geochemical sampling, it is anticipated that the frequency and intensitiy of sampling can be adjusted accordingly.

6.3.3 SEEPAGE AND PIT WATER MONITORING

Based on topographic and natural drainage considerations, preliminary locations for seepage monitoring will be established around the toe of the dump. Prior to construction of the waste rock dump, multi-year baseline samples will be collected at these locations interprteted to be near the toe of the dump and to represent natural drainage pathways. Actual locations will be selected based on field reconnaissance during construction. Samples will be collected at a minimum twice annually (mid-summer and late summer). A comprehensive seepage monitoring protocol and training program will be established to ensure consistant and high quality results are obtained from the program.

Similarly a pit sump monitoring program will also be implemented to monitor flows pumped from the open pit sump and to analyze for effluent quality parameters.

6.3.4 AQUATIC EFFECTS MONITORING

An extensive aquatic effects monitoring program (AEMP) has been developed that is designed to detect any changes to the aquatic environment downstream of the Deposit No. 1 waste rock storage area and open pit sump discharge outfall.

SECTION 7.0 - SUMMARY OF PROPOSED GEOCHEMICAL CHARACTERIZATION PROGRAM

7.1 IMPLEMENTATION SCHEDULE

The implementation schedule for the waste rock geological and geochemical characterization program (the Program) as described in Sections 3.0, 4.0, and 5.0 is presented in Table 7-1. The proposed verification and operational monitoring program described in Section 6.0 for the post 2014 period will be modified based on the results obtained from the 2012-2014 Program.

7.2 DATA MANAGEMENT AND REPORTING

Report updates for the Program will be provided in March of each year as part of annual reporting requirements. The reports will present the latest results for the previous calendar year including collected waste rock geology and geochemistry data, data interpretation, updates of the waste rock and pit water quality modeling, and the results of related work studies that are described in Sections 3.0, 4.0, and 5.0, herein.

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Table 7-1. Geochemical Characterization Program - Implementation Schedule 2012 to 2014

		Refer to Report Section	Description	Q1-2012	Q2-2012	Q3-2112	Q4-2012	Q1-2013	Q2-2013	Q3-2113	Q4-2013	Q1-2014	Q2-2114	Q3-2014	Q4-2014
1.0	**DRILLING PROGRAM**														
1.01	**Execute Drilling Program**	3.2.2, 3.3	2,000 - 3,000 m drill program utilizting rotary core rig focussed on footwall and hanging wall of the deposit.			■									
1.02	**Core Logging**	3.3	Log and sample core in accordance to established methods.			■									
1.03	**Field Scale Geological Interpretation**	3.3	Utilizing new information obtained from from drill logs, revise geological maps and cross-sections of the footwall and hanging wall of the deposit.			■	■								
2.0	**PREDICTIVE GEOCHEMICAL SAMPLING AND TESTING PROGRAMS**														
2.01	**Sampling**	4.1, 4.5	Systematic sampling of 2012 drill core of footwall and hanging wall based on established methods.			■									
2.02	**Static Testing**	4.2, 4.5	Static testing of select 2012 drill cores using established analytical methodologies.			■	■								
2.03	**Mineralogy**	4.3, 4.5	Detailed mineralogical characterization by R-XRD, optical microscopy, and SEM.				■								
2.04	**PAG Segregation**	4.5	Ongoing synthesis of available data to assess importance and ability to segregate PAG materials												
2.05	**Kinetic Testing - ongoing work**	4.4	Continuation of kinetic test initiated in May 2011.	■	■	■	■	■	■	■	■	■	■	■	■
2.06	**Kinetic Testing - from 2012 drill core**	4.4, 4.5	Continued expansion of laboratory kinetic test work program,				■	■	■	■	■	■	■	■	■
			Upgrade and ongoing sampling of lystimeters, monitoring wells, and seepage.			■				■				■	
			Assess feasibility of field waste rock test piles.			■									
			If feasible, construct and sample test piles.							■				■	
3.0	**WATER QUALITY PREDICTIONS - WASTE ROCK AND PIT**														
3.01	**Hydrology**	5.4	Collect additional hydrological data.			■				■				■	
3.02	**Source Terms**	5.4	Better quantify source terms for pit and waste rock models	■	■	■	■	■	■	■	■	■	■	■	■
3.03	**Proportion of PAG**	5.4	Better quantify proportion of PAG in waste rock pile and pit walls.					■	■	■	■	■	■	■	■
3.04	**ARD On-Set Time**	5.4	Improve understanding of ARD on-set times.			■	■	■	■	■	■	■	■	■	■
3.05	**Surface Areas and Permafrost**	5.4	Improve understanding of surface area scaling values, active zone thickness, and water infiltration into waste rock pile. Conduct thermal modeling of waste rock pile.			■	■	■	■	■	■	■	■	■	■
3.06	**Mineralogy**	5.4	Incorporate processes of metal sorption and solid phase precipitation behaviour.					■	■	■	■	■	■	■	■
4.0	**Reporting Updates**														
4.01	**Interim Waste Rock Geochemiscal Charcterization Report**	7.2	Annual report updates that present latest results of geochemical characterization program including waste rock geochemistry, waste rock and pit water quality modeling modeling, and related studies. Reports to be provided March 31 of each year.	■				■				■			
4.02	**Waste Rock Water Quality Modeling Report**	7.2													
4.03	**Open Pit Water Quality Modeling Report**	7.2													

SECTION 8.0 - REFERENCES

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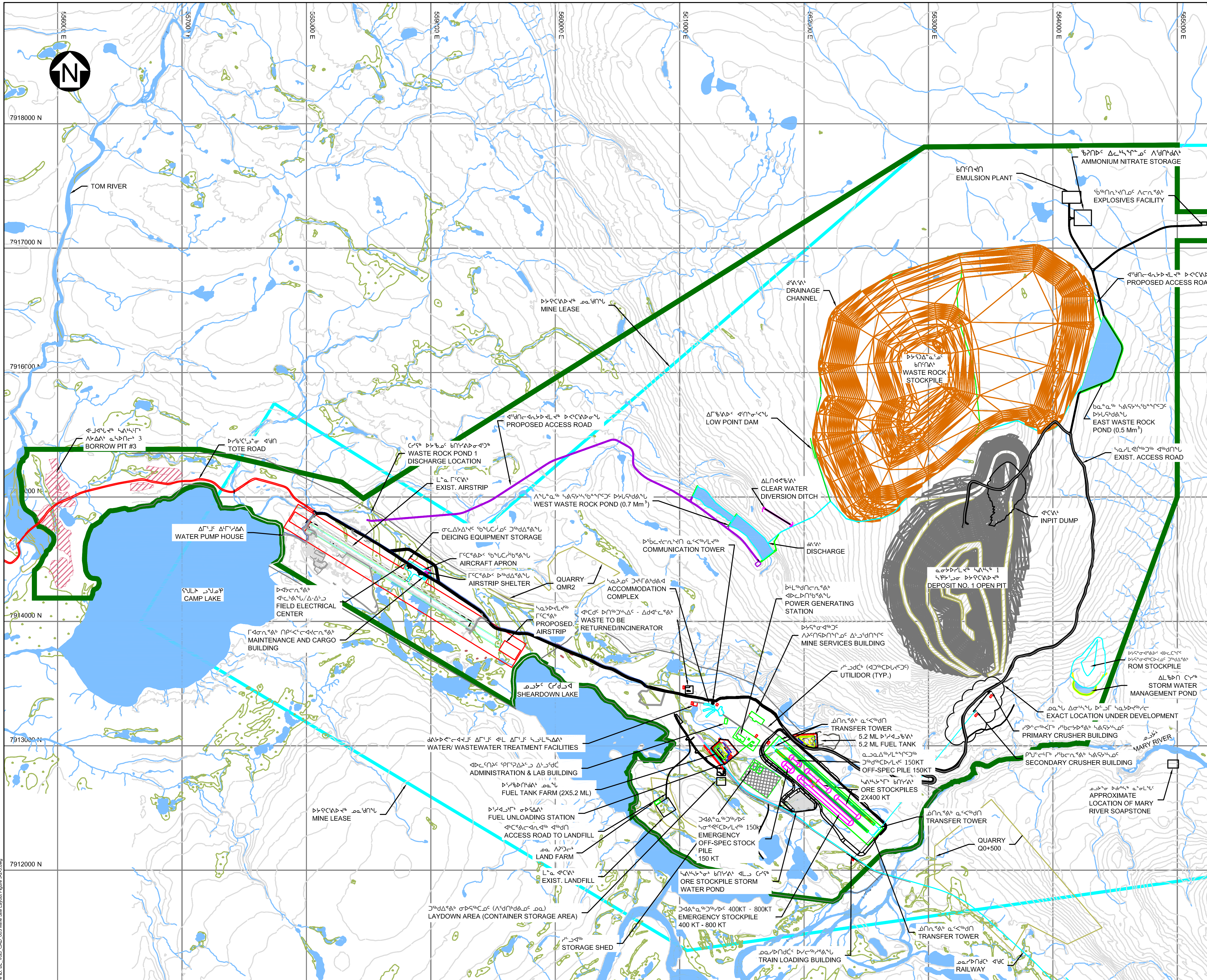
APPENDIX A

SUPPORT FIGURES



LEGEND:

- WATER
- EXISTING BORROW AREA
- LAYDOWN AREA
- RIVER/STREAM/DRAINAGE
- POTENTIAL DEVELOPMENT AREA
- COMMUNICATION TOWER

NOTES:

1. TOPOGRAPHY PROVIDED BY EAGLE MAPPING.
2. COORDINATE GRID IS SHOWN IN UTM (NAD83) ZONE 17 AND IS IN METRES.
3. CONTOURS ARE IN METRES. CONTOUR INTERVAL IS 10 METRES.
4. MATERIAL HANDLING AND PROCESSING LAYOUT WAS REVISED BASED ON AKER KVAERNER DRAWING DWG-2000-M-0003, REV C.
5. MINE SITE AS-CONSTRUCTED INFORMATION PROVIDED BY GENIVAR IN 2009.

SCALE 300 150 0 300 600 900 1200 1500 m

BAFFINLAND IRON MINES CORPORATION

MARY RIVER PROJECT

MINE SITE LAYOUT

Baffinland Iron Mines Corporation

REF NO BL_Vol3_CAD_003

FIGURE 3-2.3 REV 0

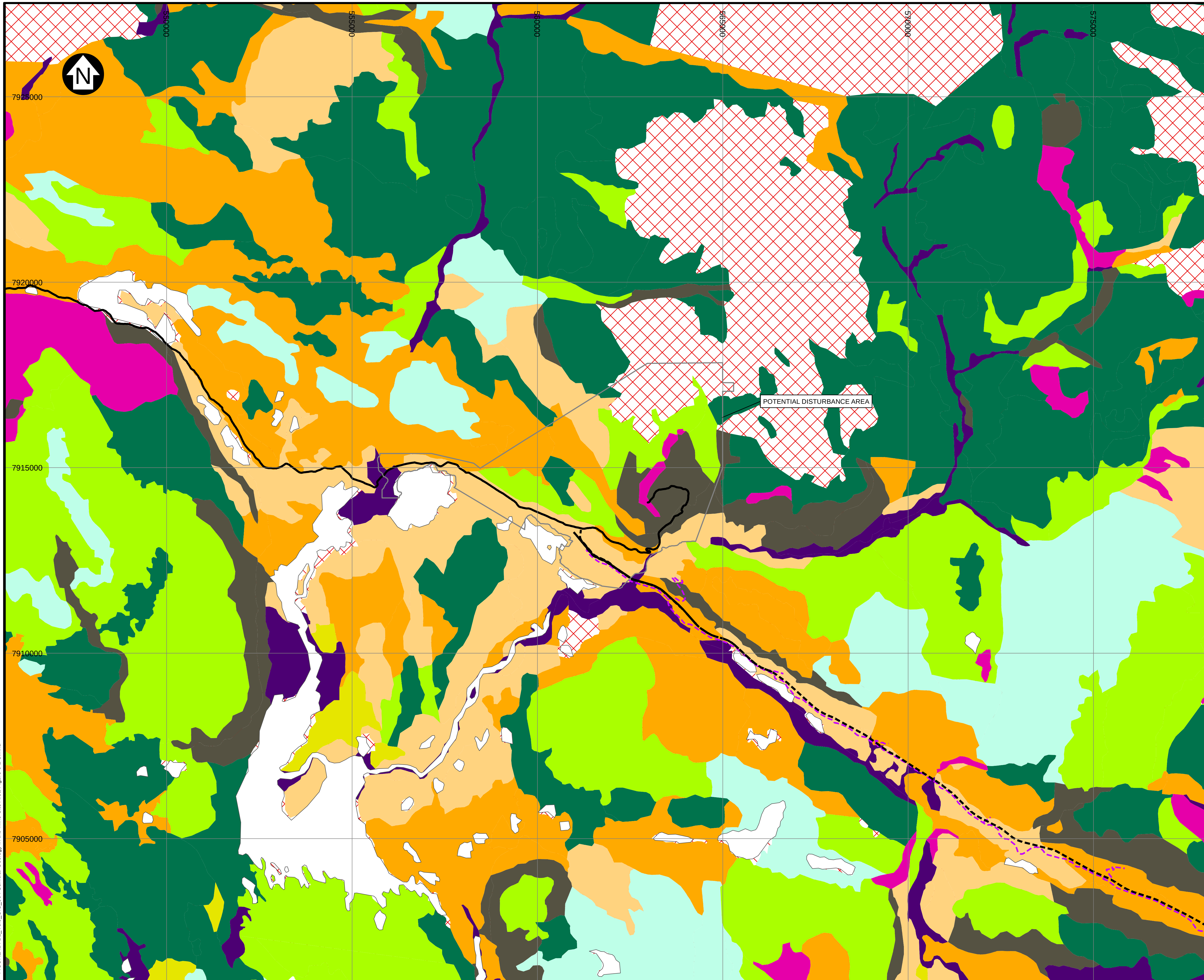


FIGURE ID: BL_Vol6_GIS_004 Surficial Geology in the Mine Site Area Figure 6-2-3.mxd

SURFICIAL DEPOSITS

QUATERNARY

HOLOCENE

Symbol	Description
	COLLUVIUM: block and rubble accumulations, 1-50 m thick.
Ca	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.
	FLUVIAL SEDIMENTS: alluvium; gravel and sand, 2-20 m thick.
Ap	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

Symbol	Description
	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

Symbol	Description
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

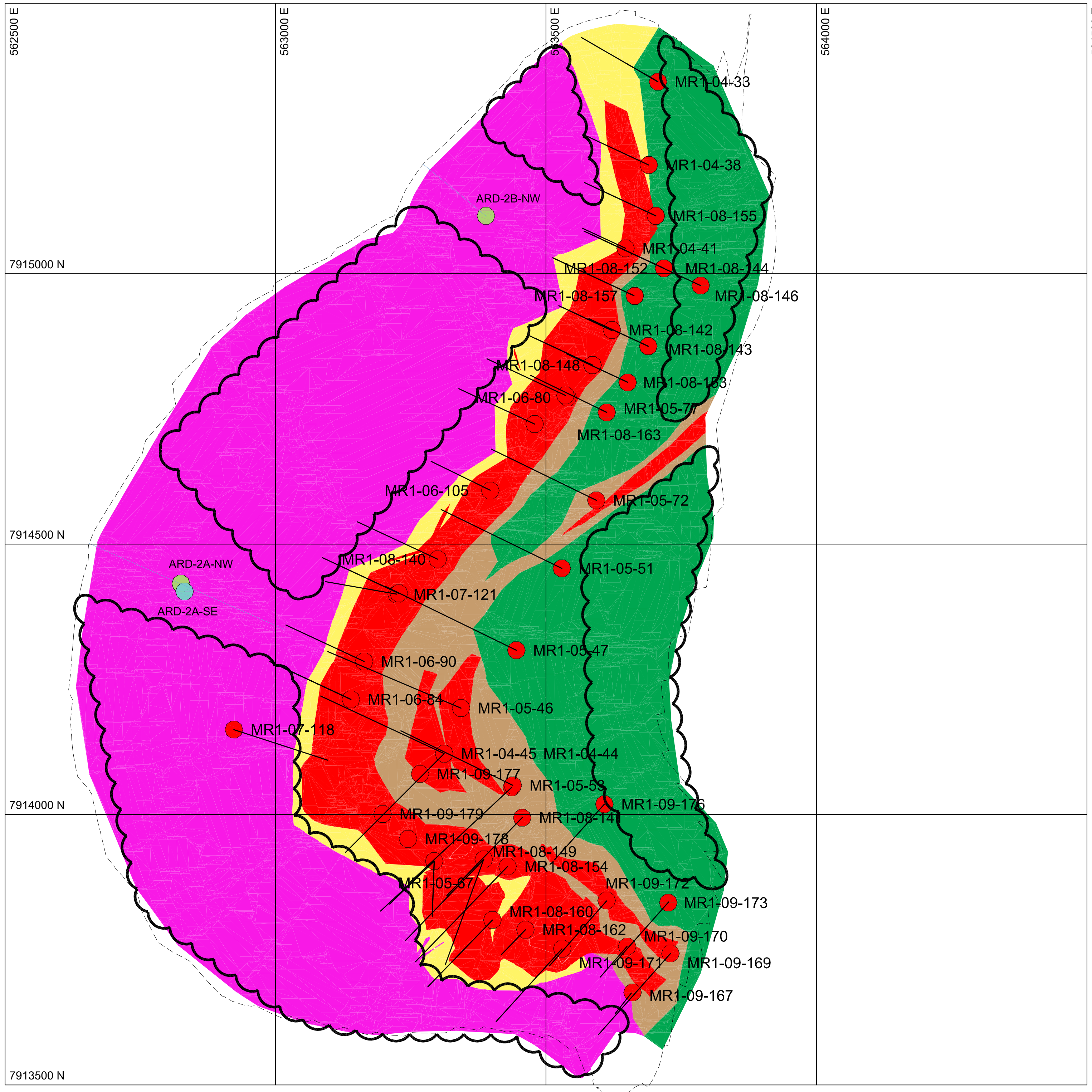
SURFICIAL GEOLOGY IN THE MINE SITE AREA

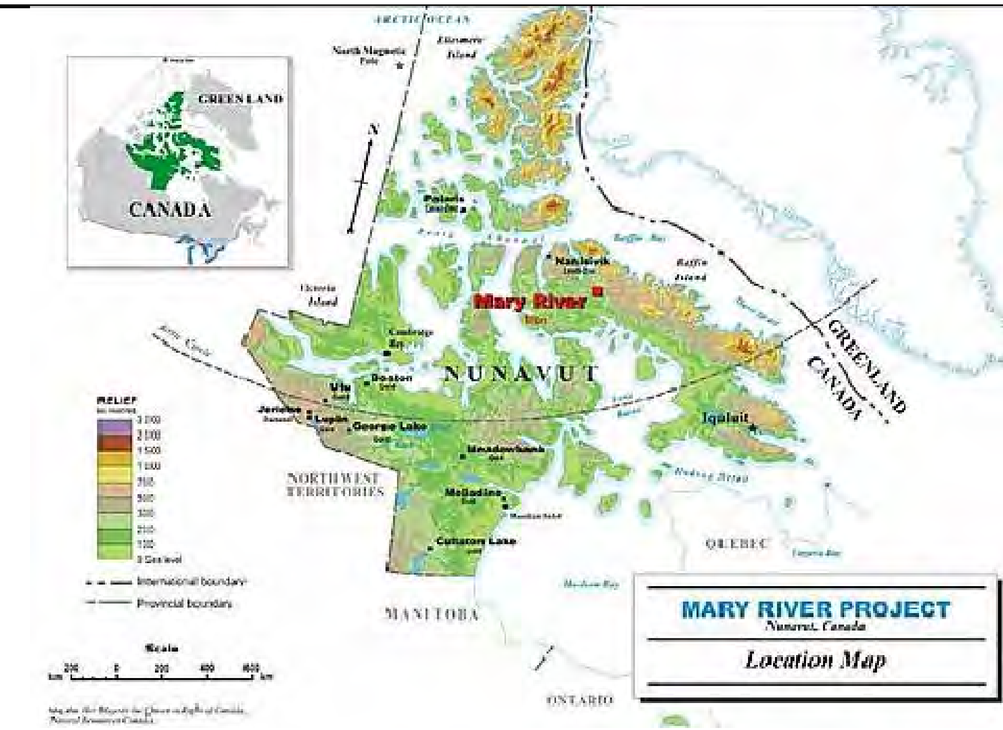
Baffinland

REF. NO. BL_Vol6_GIS_004

FIGURE 6-2.3

REV 0





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.	PROJECT: MARY RIVER PROJECT
	AMEC Environment & Infrastructure 160 Traders Boulevard East Mississauga, Ontario, Canada L4Z 3K7	CHK'D BY: J.M.	DATE: JAN 2012
	amec	DATUM: NAD 83	PROJECT NO: TC1115923
		PROJECTION: UTM Zone 17 m CM	TITLE: DEPOSIT No. 1 WASTE ROCK GEOLOGY, DRILL HOLES AND 2012 FILL-IN DRILLING TARGET AREAS
		SCALE: 1:10,000	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

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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.

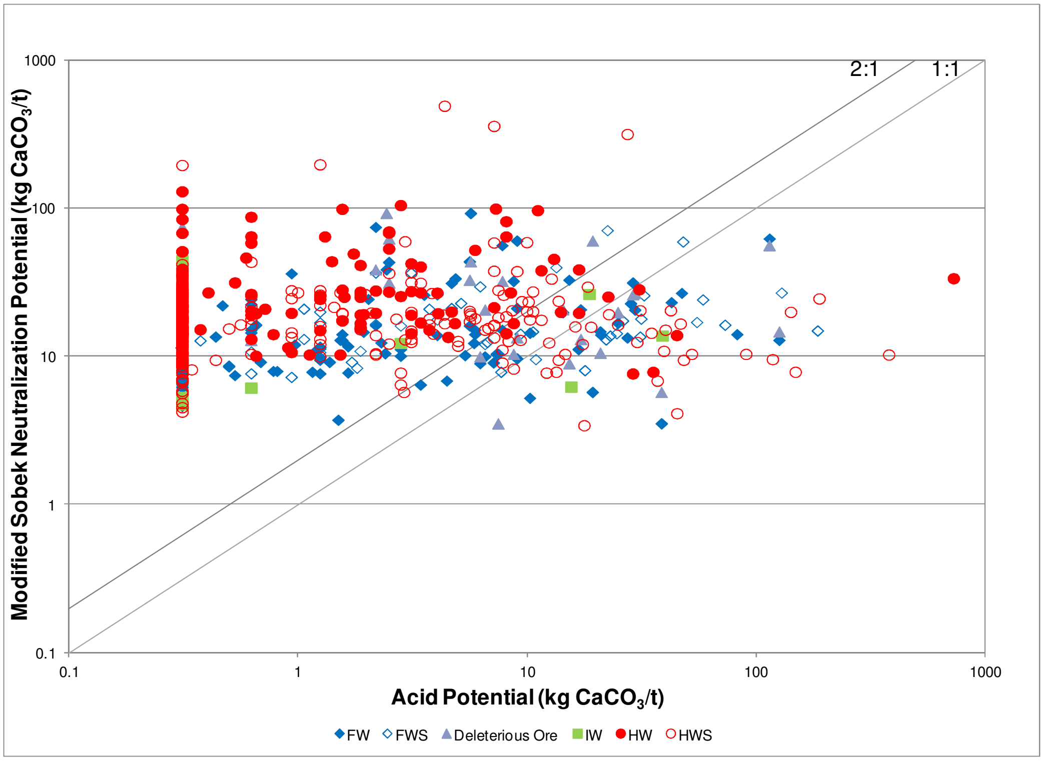

Figure 1: Neutralization Potential (NP) vs. Acid Potential (AP)

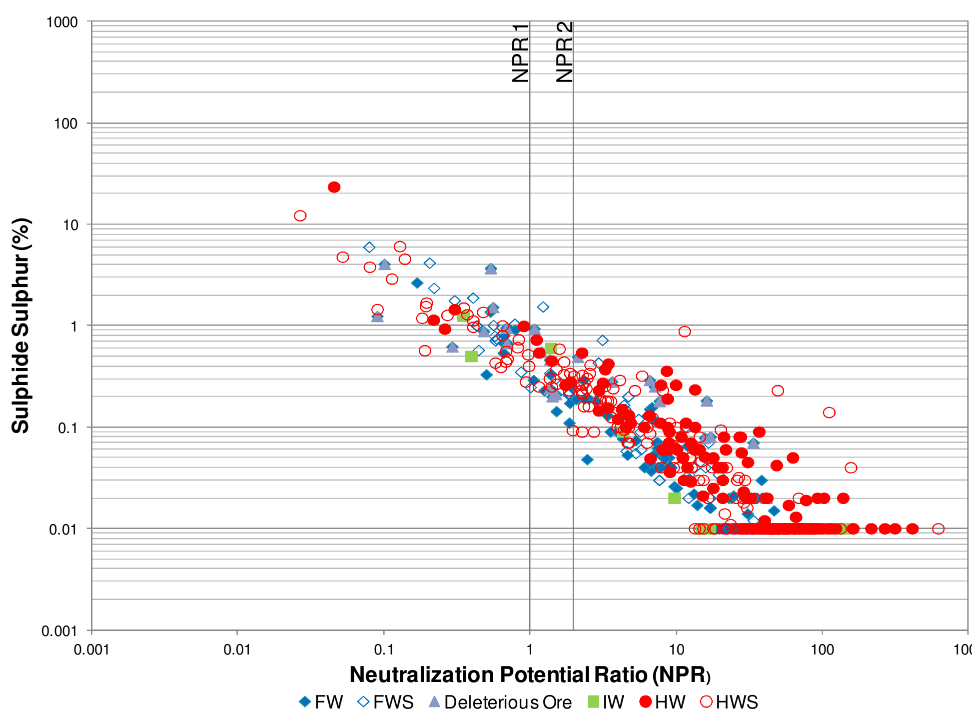

Figure 2: Neutralization Potential Ratio vs. Sulphide Sulphur

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.

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We trust the above report, along with enclosures satisfies your current requirements. If additional information is required, please do not hesitate to contact the undersigned.

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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*
10^{th} Percentile	*7.9*	*0.01*	*0.01*	*0.01*	*0.01*	*0.31*	*7.80*	*0.75*	*0.70*	*0.11*
90^{th} 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*
10^{th} Percentile	*8.2*	*0.01*	*0.01*	*0.01*	*0.01*	*0.31*	*11*	*1.17*	*3.28*	*0.40*
90^{th} 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*
10^{th} Percentile	*7.7*	*0.01*	*0.01*	*0.01*	*0.01*	*0.31*	*7.8*	*0.75*	*0.54*	*0.08*
90^{th} 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*
10^{th} Percentile	*8.8*	*0.01*	*0.01*	*0.01*	*0.01*	*0.31*	*7.5*	*0.42*	*1.90*	*0.19*
90^{th} Percentile	*10*	*0.27*	*0.11*	*0.19*	*0.04*	*5.94*	*22*	*3.2*	*47*	*7.6*

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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
10^{th} Percentile	7.7	0.01	0.01	0.01	0.01	0.31	7.7	0.50	0.57	0.09
90^{th} 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
10^{th} Percentile	7.0	0.12	0.02	0.05	0.01	1.56	7.6	1.05	0.22	0.13
90^{th} 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
10^{th} Percentile	8.0	0.01	0.01	0.01	0.01	0.31	5.3	0.67	0.40	0.08
90^{th} 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%).

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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

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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

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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

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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**
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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

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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 ($CaSO_4 \cdot 2H_2O$) 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

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TABLE

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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)