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

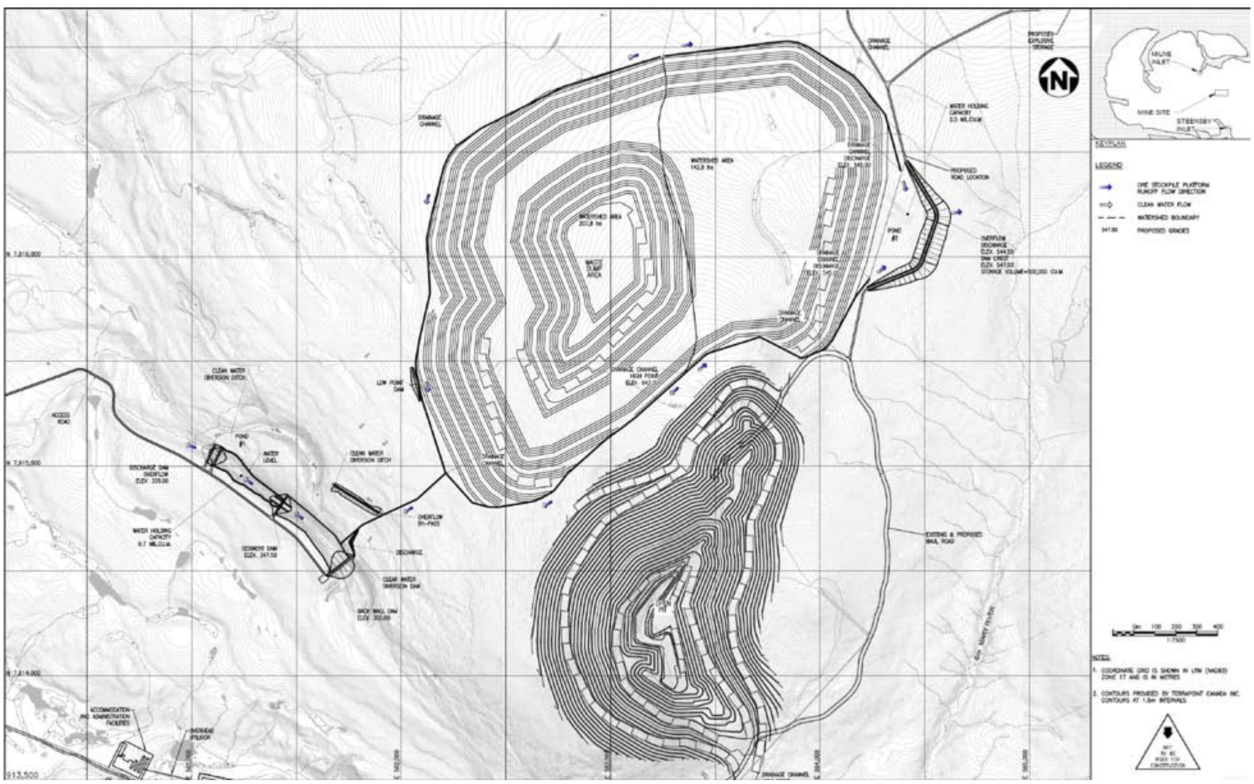

Figure 3-1: - General layout of Baffinland dams in Mine Site

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.

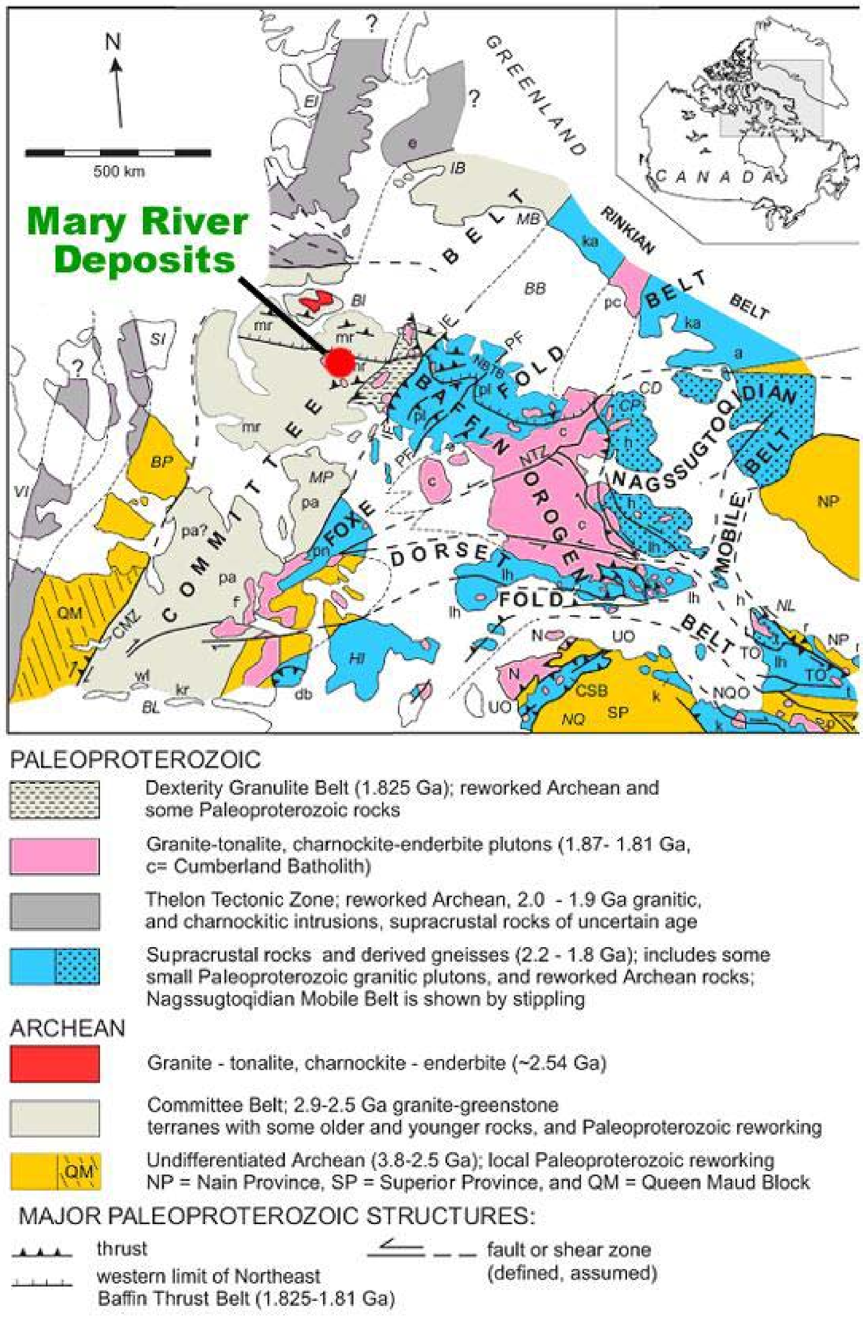

Figure 3-2: Regional Geology Map of Baffin Island (Jackson et. al, 2000)

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 -10ºC

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 -10ºC 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 ºC). 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).

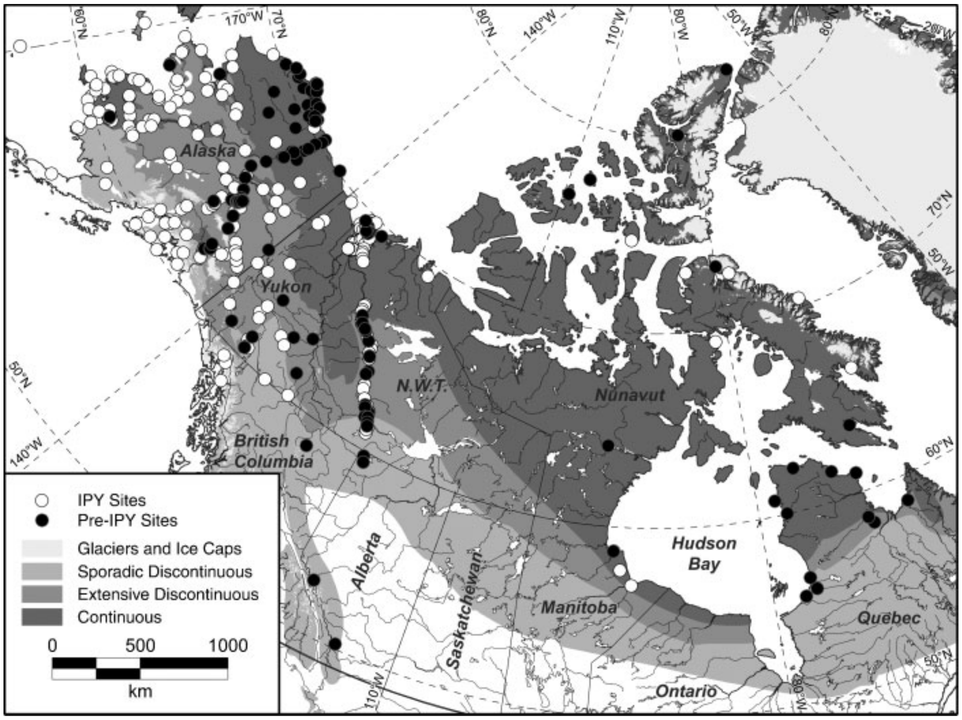

Figure 3-3: The permafrost distribution map of North America based on that of Brown et al. (1997)

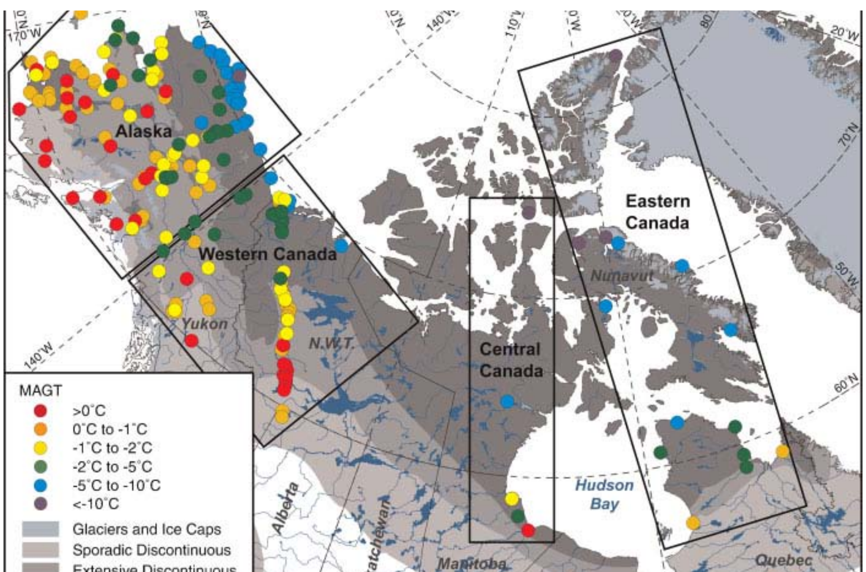

Figure 3-4: Mean annual ground temperature (MAGT) during the International Polar Year period where data were available

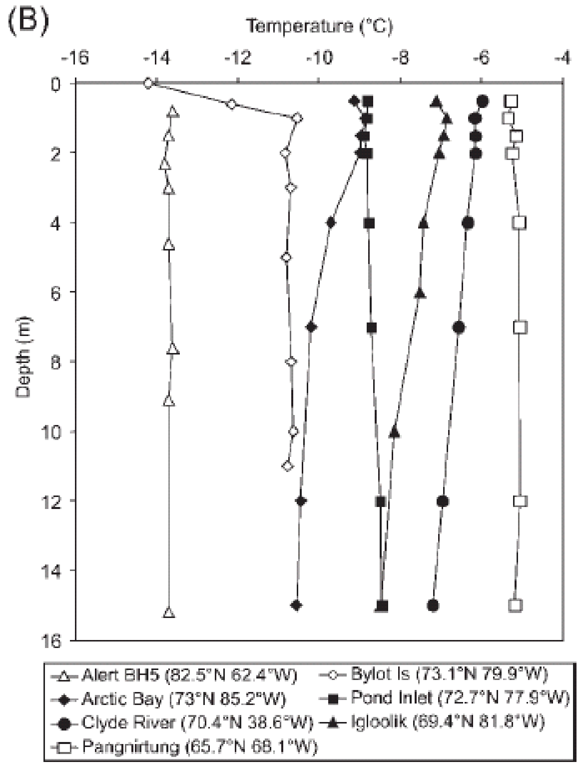

Figure 3-5: Mean annual ground temperature profiles during the International Polar Year for selected sites in the eastern and high Canadian Arctic (Smith et. al. 2010)

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.

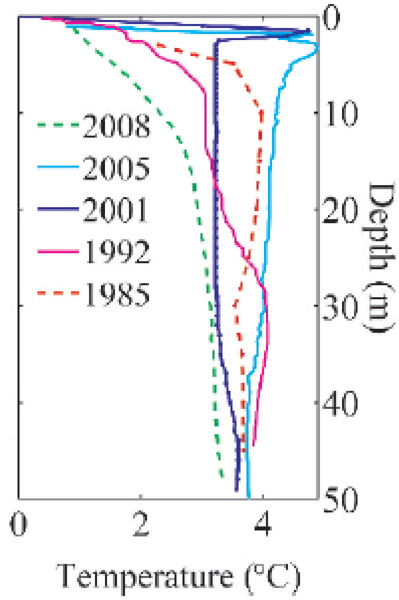

Figure 3-6: Temperature profile for Lake C3 in the high Canadian Arctic (Derek R. Mueller et. al. 2009)

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 ºC (see Figure 3-5).
- The reservoir-bottom mean water temperature is assumed to be 4 ºC (see Figure 3-6).
- The design basis for the local air temperatures as follows:
  - The air temperature for the warmest condition is 7ºC.
  - The air temperature for the coldest condition is -25 ºC.
- 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.

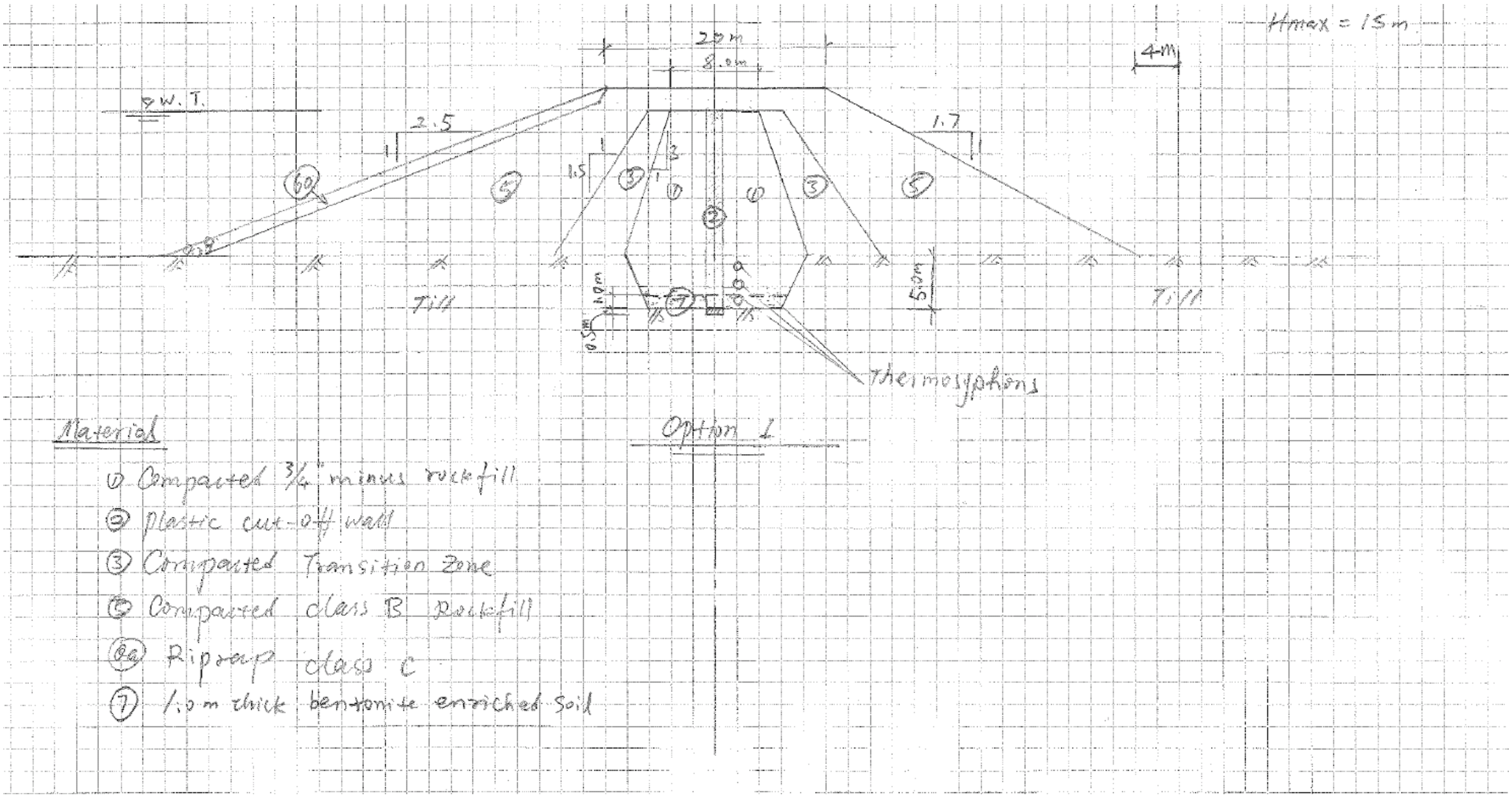

Figure 5-1: Dam Option

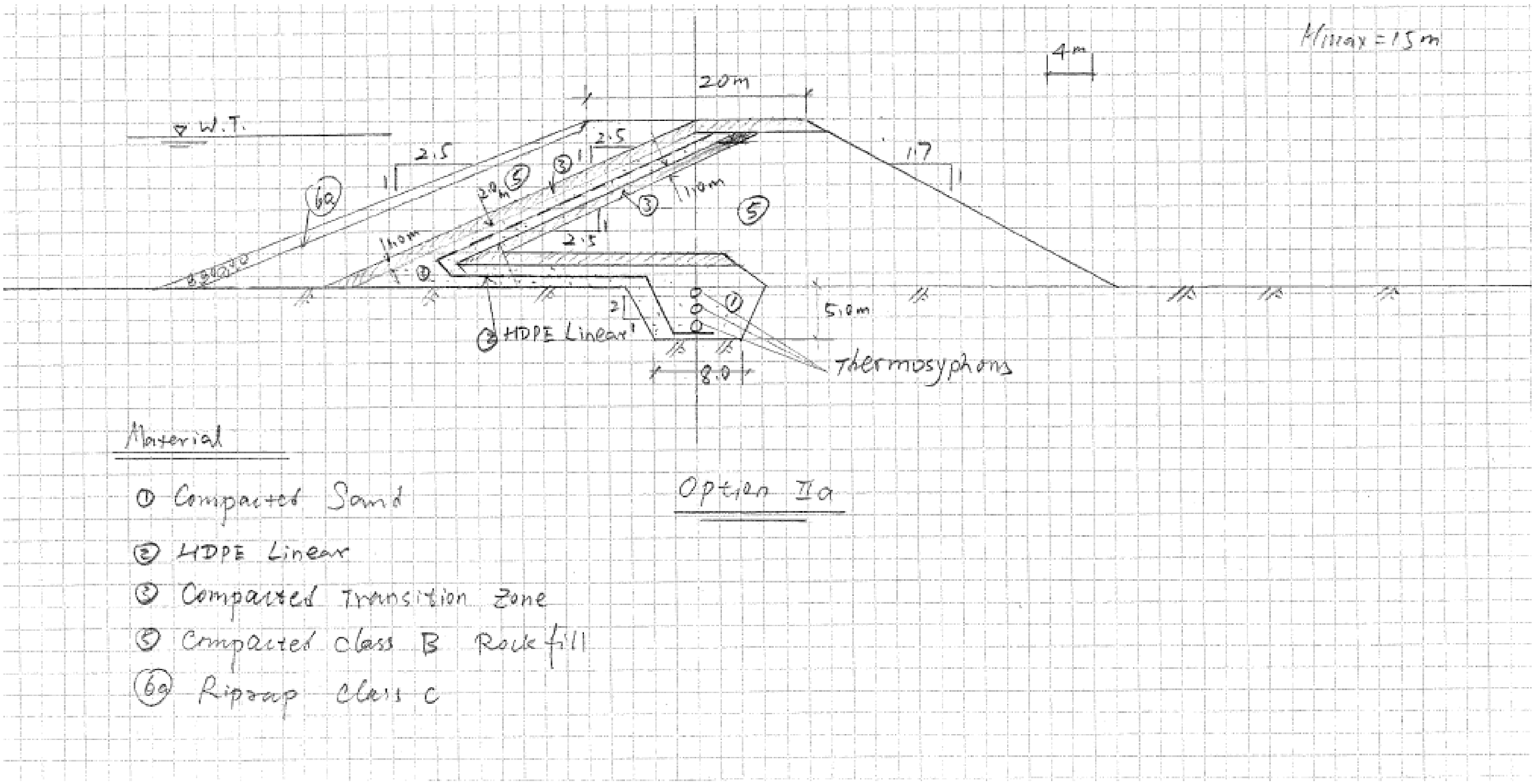

Figure 5-2: Dam Option 2

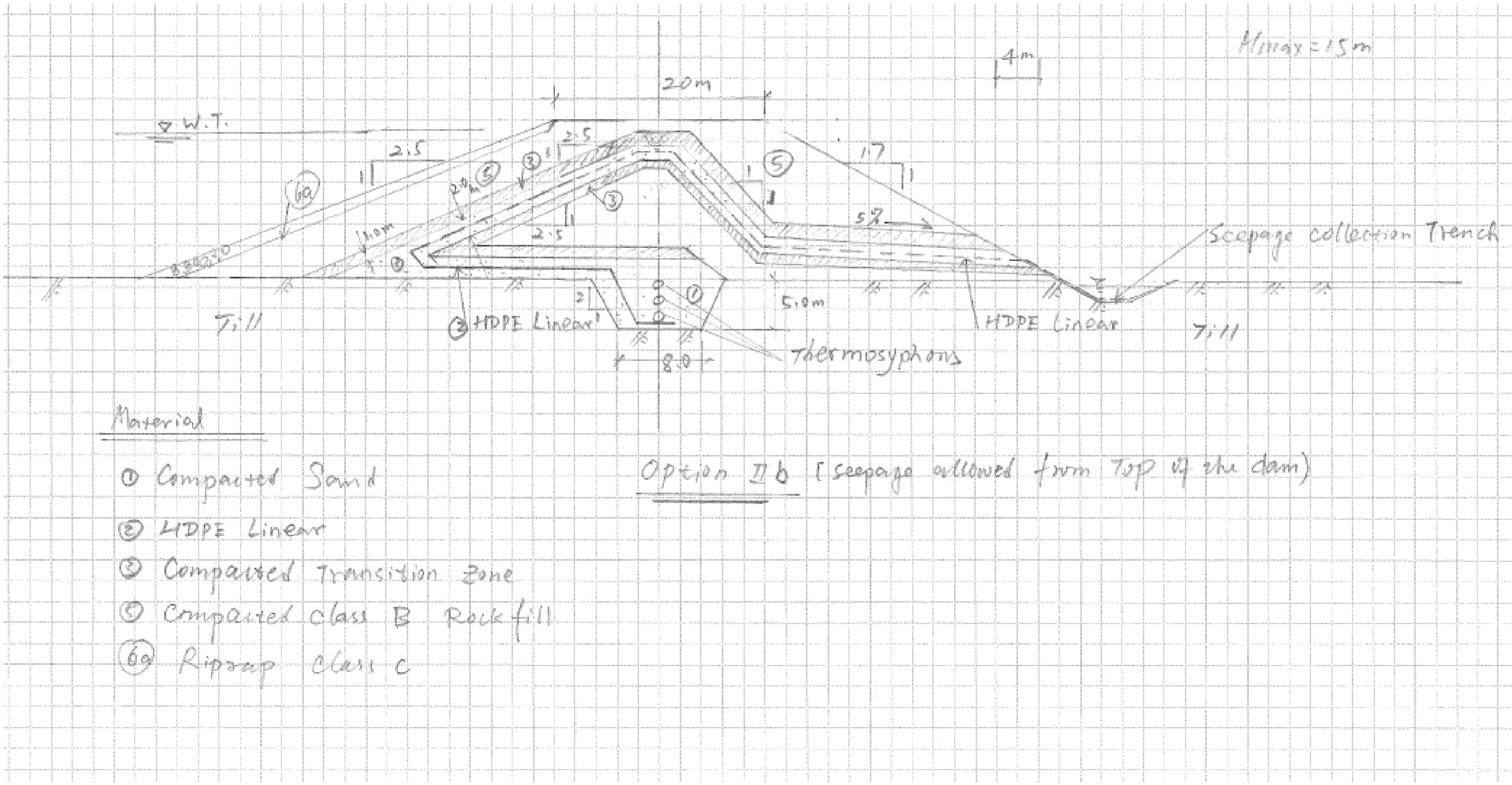

Figure 5-3: Mortified Dam Option 2

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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Appendix A

Typical Cross Section Used for Previous Embankment on Permafrost Foundation

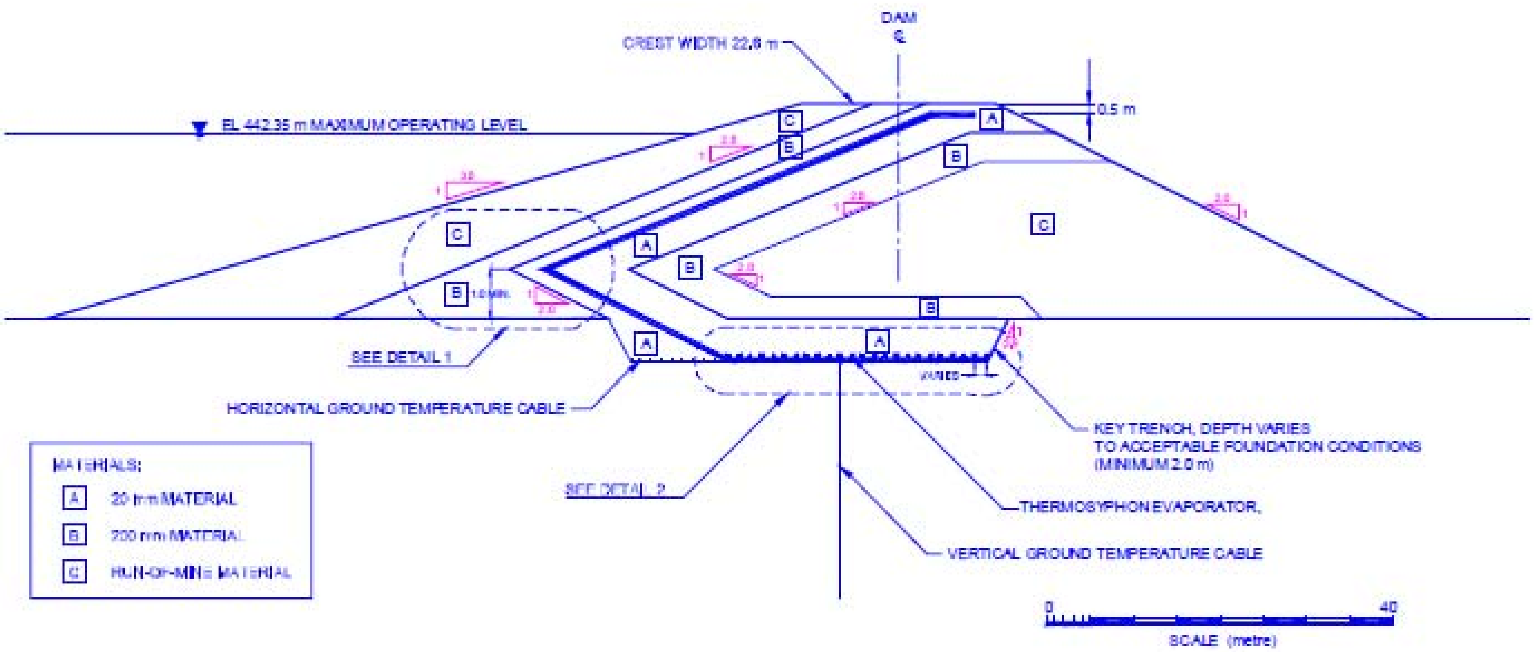

Figure A1- 1: Typical Section for EKATI Diamond Mine Dam (Gräpel et. al 2005)

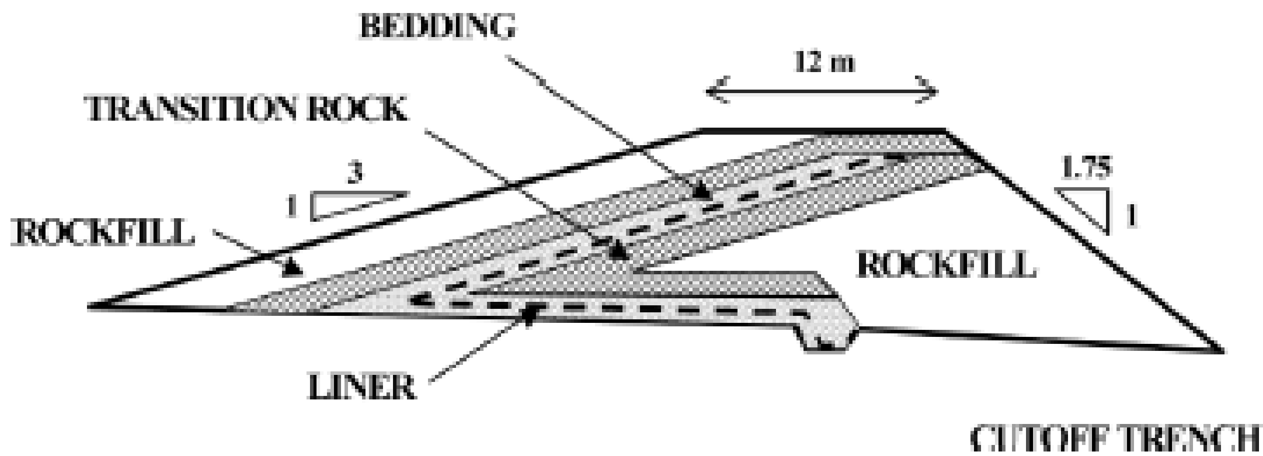

Figure 3. Schematic dam design section.

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

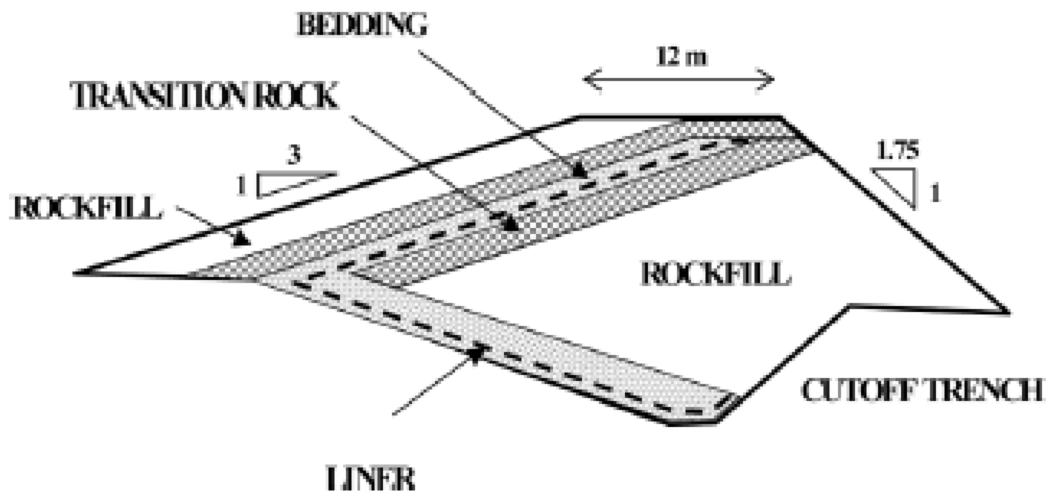

Figure 4. Dam section at the talik.

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

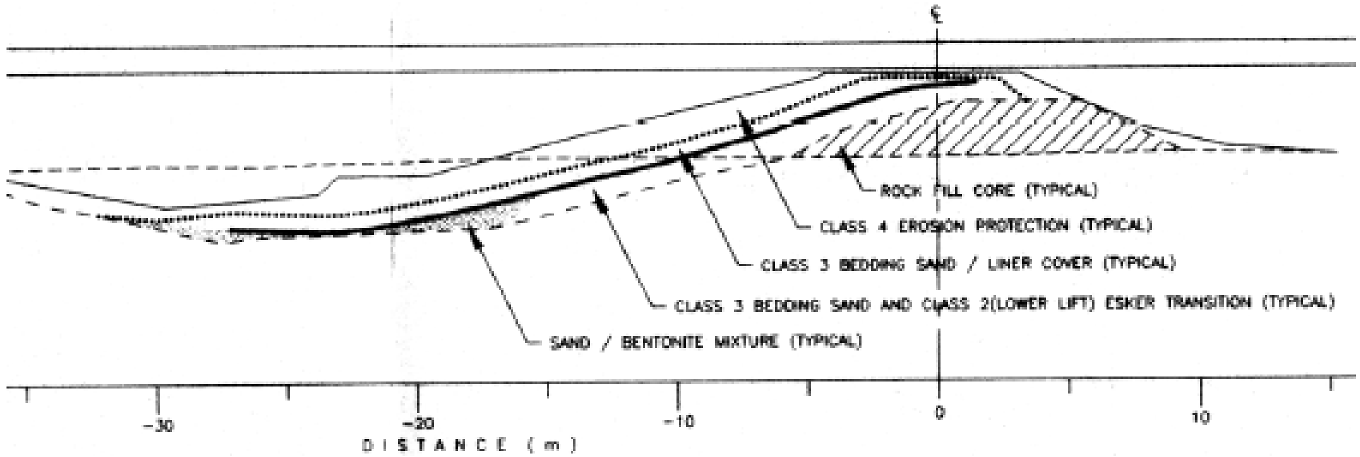

Figure A1- 4: Snap Lake Dam 1 (J. Cassie 2003)

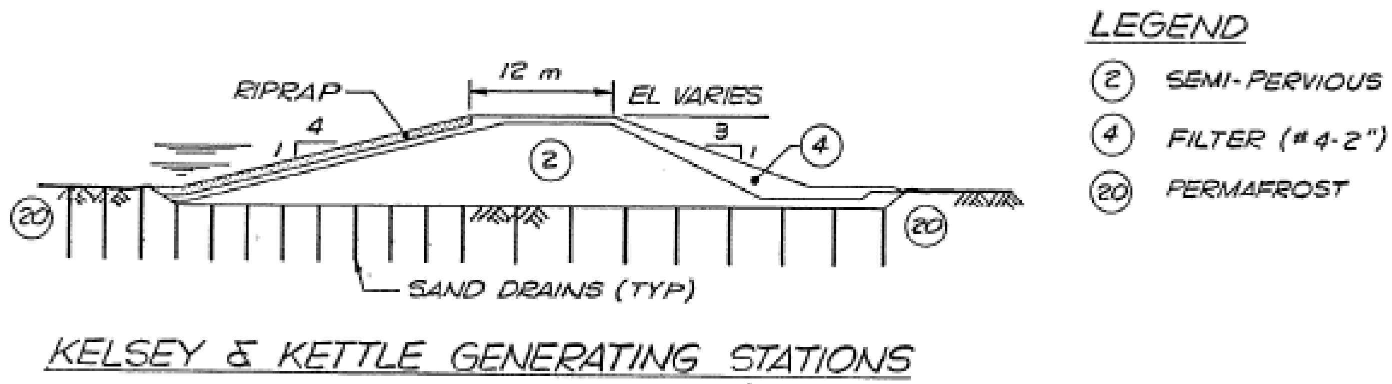

Figure A1- 5: Kelsey Dyke (N. J. Smith 1983)

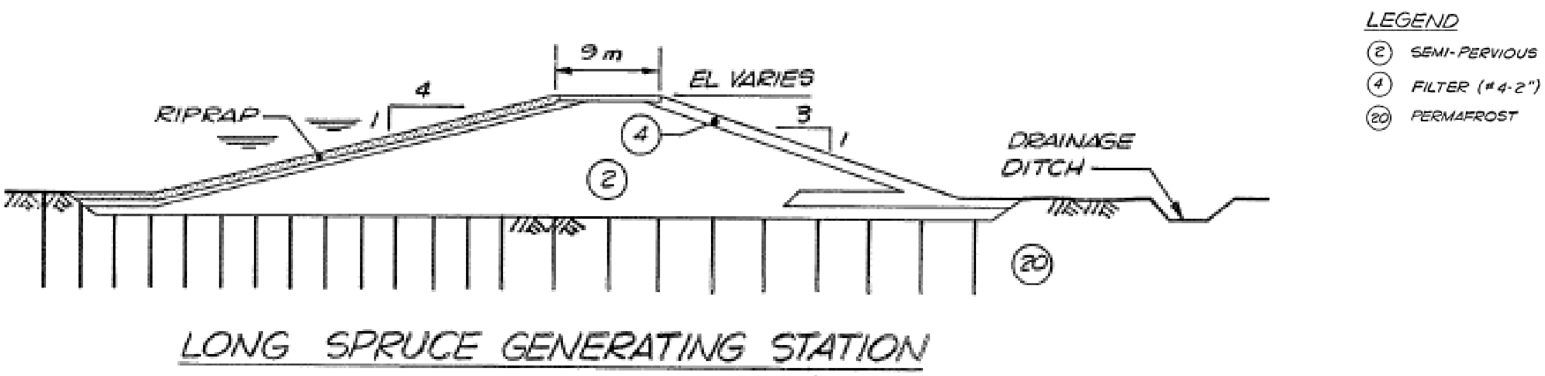

Figure A1- 6: Long Spruce Dykes (N. J. Smith, 1983)

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

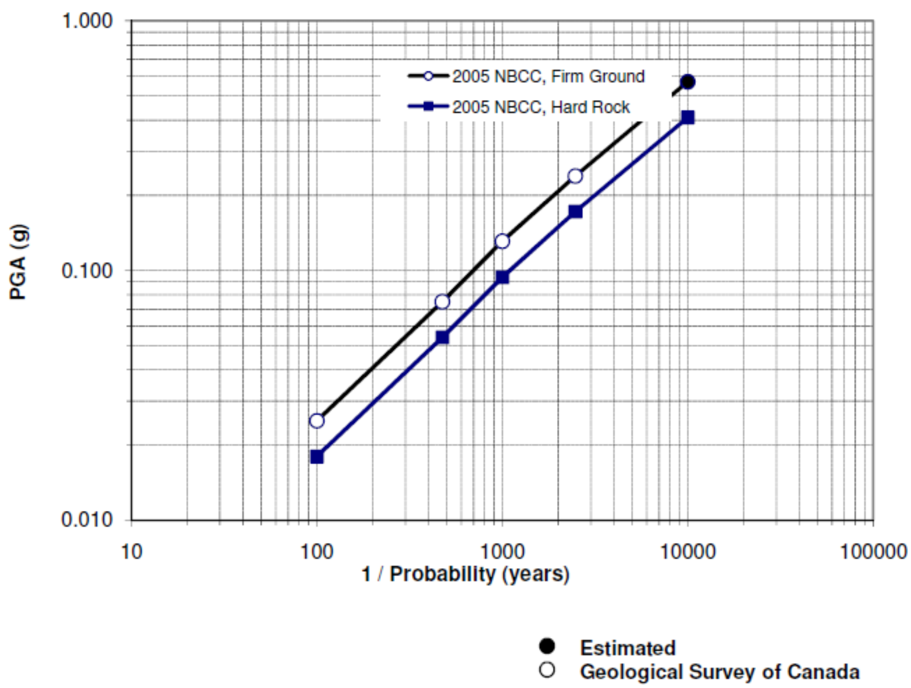

Figure B1- 1

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

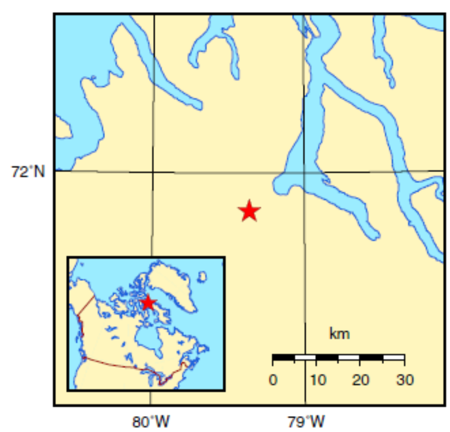

Figure B1- 2

Annex 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.

2. HEAT TRANSFER PROCESSES

For the purpose of this discussion, permafrost may be defined as any soil or rock which remains below freezing (0^oC) 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^oC 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°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°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°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.

Thurber Engineering Ltd.
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Review Principal

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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

References:

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THURBER

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 . . . .)

INTERPRETATION OF THE REPORT *(continued . . . .)*

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.