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Memorandum

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To	Patricia Randell, Justin Stockwell	Page	1
CC	Tom Wingrove		
Subject	Additional Concepts for Long-Term Stabilization of Mt. Nansen Tailings Dam		
From	Kendall Thiessen		
Date	July 3, 2011	Project Number	60159089 (402.12)

Introduction

This memorandum is a revision and update to the Memorandum dated December 9, 2010, by the same author. This document is a supplement to the discussions in the AECOM November 2010 report: *Geotechnical Assessment and Costing of the Mt. Nansen Mine Closure Alternatives,* and it addresses some of the comments provided by the reviewers of that report. The following discussion applies to the proposed upgrades to the existing Mt. Nansen tailings dam included in:

- Option 1: Tailings Dam Upgrade with Water Cover
- Option 2: Tailings Dam Upgrade with Saturated Soil Cover.

This memorandum provides additional comments regarding the anticipated long-term effectiveness of anchoring the toe-berm with permafrost, and discusses alternative measures to permanently improve the stability of the Mt. Nansen tailings dam. This assessment is conceptual in nature due to the limited available information.

Background

Numerical stability analysis (AECOM 2010 and EBA 2002) found that the tailings dam does not currently meet the minimum factor of safety established by the Canadian Dam Association Guidelines (2007) for pseudo-static earthquake analysis (minimum FS of 1) and post-earthquake loading scenarios (minimum FS of 1.2-1.3). The inadequate stability in the post-earthquake loading scenario is largely due to a zone of thawed foundation material situated beneath the dam which would be liquefiable in the event of an earthquake. EBA (2002) reported the results from CPT probe holes at 17 locations, and used the results to determine the liquefaction potential of the dam and foundation soils. They concluded that liquefaction was likely to occur under the maximum design earthquake at the following locations (EBA 2002):

- within the foundation soils underneath the central and south portions of the dam crest
- within the foundation soils beneath the toe-berm
- several other localized areas, including small pockets within the dam fill itself.

The assessment completed by EBA is not extensive enough to determine whether the zones of liquefiable soils are continuous or if they are confined to specific soil strata. The liquefaction study only investigated soil conditions above the permafrost.

In the AECOM report (2010), Option 1 and Option 2 called for constructing a toe-berm and keying the toe-berm into permafrost to improve the calculated stability. The addition of a toe-berm alone does not help the stability for this scenario as the liquefied soils are assigned a residual "cohesive" shear strength, without a frictional component. EBA (2002) used a residual strength of 14.4 kPa for the thawed foundation soil based on a method proposed by Idriss (1998). Similar residual strength values for the liquefied sand are estimated using empirical relationships developed by Olson and Stark (2002) which correlate SPT blowcounts with a residual shear strength.

The stability of the dam under these analysis scenarios can be improved by either eliminating the liquefaction potential of the foundation soils by densifying the soil, or the stability can be improved by providing additional resistance by way of a shear key, rockfill caissons, structural reinforcing or cementation etc..

Permafrost Enhancement with Thermosyphons

The engineering purpose of the thermosyphons is to maintain and enhance permafrost beneath the proposed toe-berm. The toe-berm would interact structurally with the permanently frozen foundation material by way of a "shear key". The shear key could either be constructed of a compacted granular material installed to key into the frozen foundation material or alternatively, the same effect could be achieved by locally building the permafrost upwards into the granular toe-berm (Figure 1). The permafrost enhancement would be aided by thermosyphonse as described in AECOM 2010.

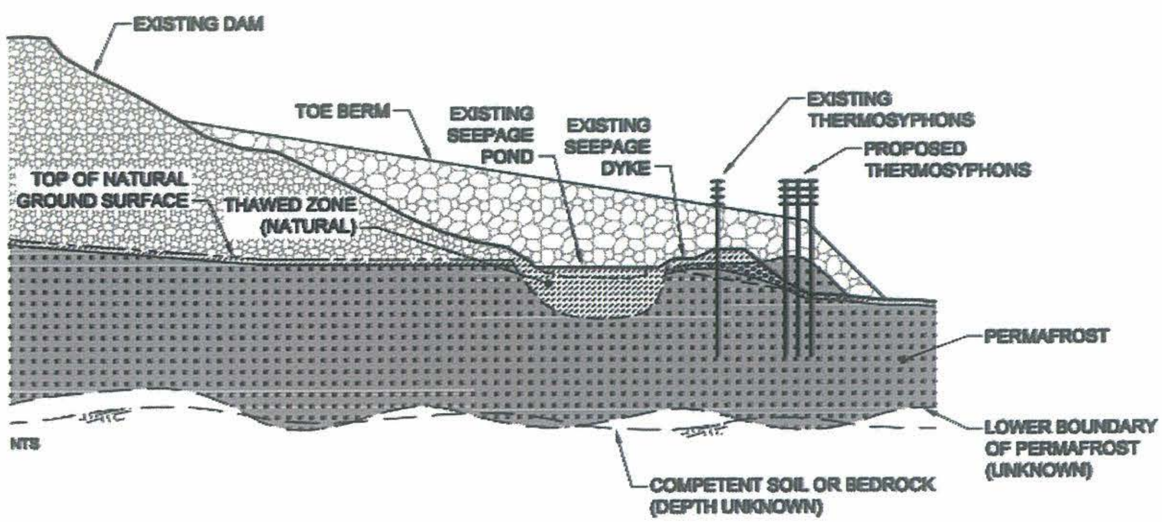

Figure 1. Proposed toe-berm with permafrost aggraded as a shear key.

The analysis performed by Naviq Consulting Ltd (2010) demonstrated that thermosyphons should be able to form and maintain permafrost under current or moderately warmer climate conditions. Thermosyphons have been effectively used at this site to aggrade permafrost into the existing seepage collection pond dike (AECOM 2010). The concepts for addressing the impacts of seepage are discussed.

The expected lifespan of a thermosyphon has not been established as many of the first thermosyphons, installed in the 1960's, are still in operation today. Some regular maintenance and periodic replacement of the thermosyphons should be anticipated. It would be reasonable to assume a 50 year lifespan for the thermosyphons before they would require replacement or extensive maintenance.

There is some uncertainty regarding the long term feasibility of thermosyphons as a way of maintaining frozen ground considering potential future climatic scenarios. The analysis by Naviq (2010) demonstrated that if current warming trends continue unabated, thermosyphons would no longer be able to maintain the frozen ground at some point in the future. The effectiveness of thermosyphons is negatively affected by warmer temperatures by both reducing the thermosyphon efficiency and increasing seasonal thawing. The analysis showed that with the estimated warming trends (0.08°C/year based on the past 50 years), the thermosyphons would only be able to maintain permafrost in a 1 m radius around the evaporator in 100 years (ie. mean annual temperature 8°C above the present). If future climate change was limited to moderate warming, say 3°C above the present mean annual temperature, thermosyphons may possibly be a permanent solution. The long term performance would be improved with the inclusion of an insulating layer (Naviq 2010).

If thermosyphons are used to enhance the permafrost, but climate warming trends continued, then it would be expected that at some time in the future there would be significant or total thawing of the permafrost in the area of the toe, despite the contributions of thermosyphons (Figure 2). At such a time, some additional ground improvement measures would be required to maintain the long term stability of the dam. Monitoring of ground temperatures after the installation of the thermosyphons would be required to determine if and when additional stabilization measures are implemented.

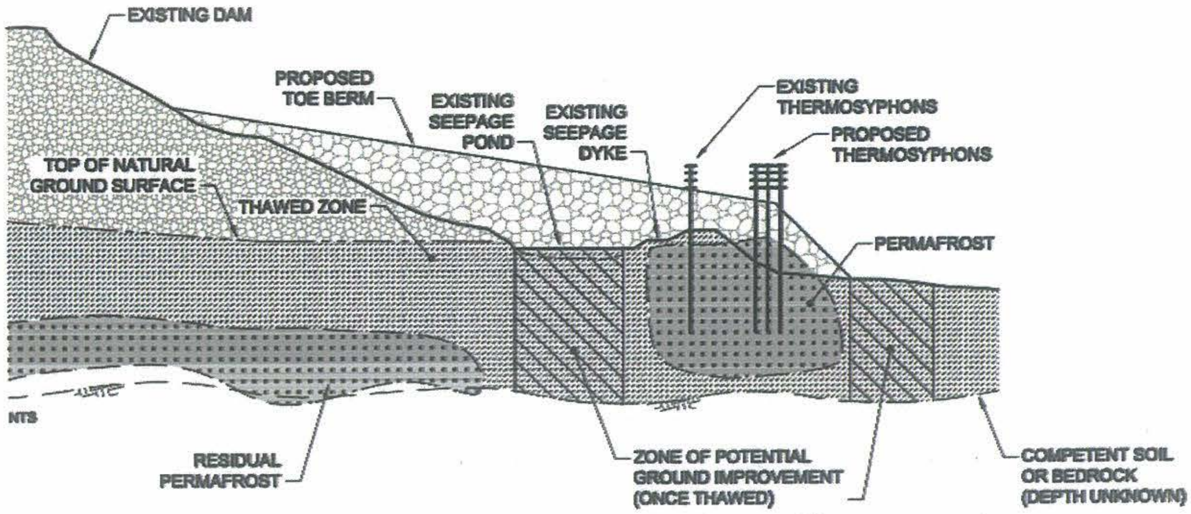

Figure 2. Potential future thaw with thermosyphons and ground improvement.

This memo will not comment on the expected nature, likelihood, magnitudes, or timing of future climate changes as there is considerable uncertainty and variability in predictions from climate experts.

Seepage Management

The concept for addressing seepage through the toe-berm is to channelize the flows, and insulate the zone of permafrost enhanced by thermosyphons. The details for seepage flow management have not been developed, as the options are at a conceptual stage. However, the following discussion will provide a more in-depth description of the concept to support the decision making process, and demonstrate confidence that seepage can be controlled in a manner that will not compromise the performance of the thermosyphons or excessively degrade the natural permafrost.

The groundwater seepage will naturally flow towards, and then follow the lowest point along the valley bottom, generally following the flow paths with the least resistance. The seepage through the dam would be managed by utilizing these concepts. A drainage channel of coarse rock would be established across the toe of the existing dam, which would be shaped to funnel seepage towards the bottom of the valley, near the center of the toe-berm. A typical section is shown in Figure 3. The coarse rock drainage channel would extend the full length of the toe-berm exiting at the toe. Insulation would be provided either at the top of the toe-berm or at some intermediate level, as shown in Figure 3, unless it was found the thickness of the toe-berm was adequate for insulation.

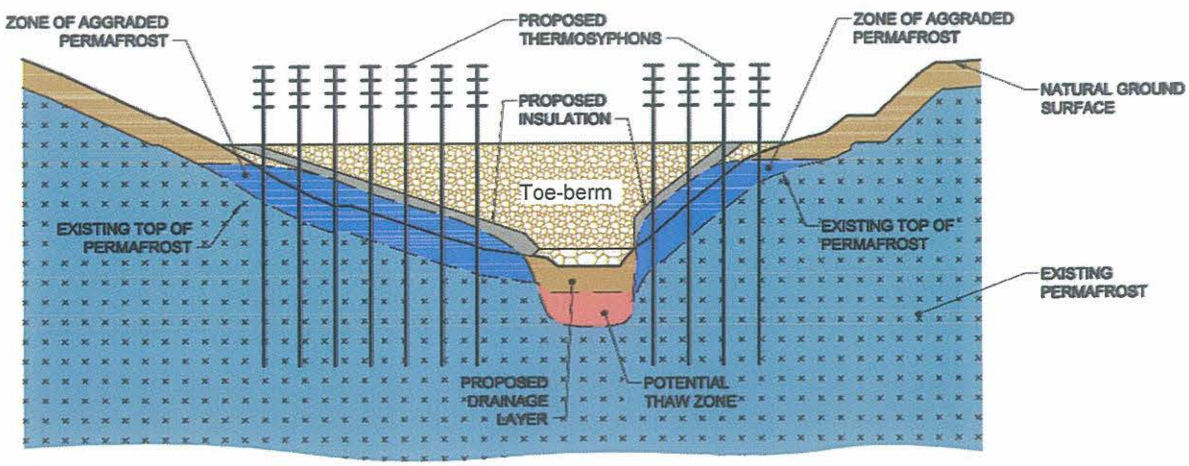

Figure 3. Section (South-North) through proposed toe-berm showning drainage layer, insulation and thermosyphon arrangement.

The area of ground improvement shown in the AECOM 2010 drawings highlighted an area across the full width of the toe-berm. The details of exactly where the thermosyphons and insulation would be installed have not been established at this stage of the design. The zone of ground improvement does not need to extend across the full width of the toe-berm, as long as adequate resistance can be developed elsewhere beneath the berm. The thermosyphons could be installed along the north and south sides of the toe-berm leaving the soil surrounding the drainage channel near the center of the toe-berm to thaw and/or freeze naturally.

The stability analysis should be revisited during preliminary and detailed design to optimize the design. A 3-dimensional stability and stress-deformation analysis would be beneficial, but may not be necessary to develop a final design. The total resisting force required to achieve the required design factor of safety would be similar whether that resistance is developed across the full width of the toe-berm, or in zones on both sides of a drainage channel.

There are several observations of the site conditions that support an assessment that the seepage through the dam would not render stabilization by way of freeze back into the toe-berm ineffective:

- Dome Creek has been conveying water along the bottom of the valley for several millennia. Permafrost has been encountered in every test hole drilled along the bottom of the valley, even at points near or along the creek alignment (or alignment prior to construction of the tailings dam). Under current and proposed operating conditions the seepage rates through the dam and along the foundation material will be several orders of magnitude less than the flow rates in Dome Creek.

- Test holes drilled in the vicinity of the toe near the dam centerline, encountered permafrost near the interface of the dam fill and the natural ground surface, in the organic layer (testhole 12861-08 EBA 2009 or MW 09-21, AECOM 2010), demonstrating that there has been negligible degradation at these locations over time. The groundwater flows at these test hole locations would be only slightly lower than the current flow rates further downslope in the area of the proposed toe-berm, (not considering seepage reduction through the dam due to proposed upgrades). This is evidence that thawing in the foundation material has not been greatly affected by the flow rates seen through the dam. In summary, if there has been no significant thawing of permafrost upslope of the proposed toe-berm due to seepage flows, then it would be expected that the seepage flows through the toe-berm would not have a significant negative impact on the permafrost, considering the decrease in seepage rates expected after the dam upgrades.

- Thermosyphons have been effective at enhancing permafrost through the seepage collection pond dike. The pond water has acted as a heat source adjacent to the dike, but this source of heat has been overcome by the thermosyphons, as the permafrost has agraded into the dike (AECOM 2010). The water in the seepage collection pond would act as a similar boundary condition as flowing groundwater, as it has a large thermal mass, and would probably have enough convection to maintain a relatively constant boundary condition against the dike interface. In addition, the proposed thermosyphon array would have a much greater cooling capacity, per unit volume of soil, then the current installations.

Ground Improvement Alternatives Not Requiring Permafrost

There are several technologies that provide reinforcing, or reduce the liquefaction potential of the thawed soil to increase the calculated stability of the Mt. Nansen Tailings dam under post-earthquake conditions without depending on permafrost. The following list of potential ground improvement technologies was developed with input from several reputable contractors with extensive experience in ground improvement:

Densification:
- Dynamic compaction*
- Vibro-compaction*
- Vibro-replacement
- Blast- compaction

Cementation:
- Jet grouting
- Compaction grouting*
- Chemical grouting
- Deep mixing

Replacement:
- Excavation and replacement*
- Rockfill caissons*

*Methods that may be most appropriate to conditions at Mt. Nansen.
The densification methods generally increase the strength and reduce the liquefaction potential of unfrozen soil by increasing the density (ie. compacting) the soil. The cementation methods fill the voids with a cement grout that displaces water and bonds the soil particles together while compacting the surrounding soil. These densification and cementation methods cannot be applied to frozen material. The replacement methods involve the removal of a volume of the loose, frozen soil with unfrozen, compacted granular material. These ground improvement methods are only effective if

they can be implemented over the full depth of the liquefiable soil. The densification and cementation methods can only be applied if the permafrost is destroyed by natural or artificial processes. The replacement methods have the significant advantage of not requiring ground thawing, thus eliminating the expense and uncertainty associated with thawing the ground.

Vibro-compaction and dynamic compaction are thought to be technically feasible methods of densifying the in situ soil once it has thawed. Additional material would be added at the surface (and possibly at depth for vibro-compaction) to maintain the ground elevation as the soil is compacted. Dynamic compaction would only be effective in the upper 10 m. Vibro-compaction could be implemented to a depth of 30 m if the soil conditions permit.

Compaction grouting would be technically feasible for improving thawed soils but its costs are significantly more than vibro-compaction per cubic metre. Because compaction grouting can be targeted at specific stratum, it may become a more appealing option if the zones of liquefiable soil are not extensive and can be delineated. Compaction grouting may also be a suitable improvement method if improvements are required below a layer that could not be easily penetrated by vibro-compaction equipment. Chemical or jet grouting can also be used to increase density and provide reinforcing and may be better solutions under certain ground conditions.

To implement one of the densification or cementation techniques of ground improvement in the near future, the permafrost at the base of the dam would need to be thawed by an engineered process (Figure 4). Once this zone is thawed, one of the densification or cementation methods could be implemented improve the characteristics of the soil as discussed in the following sections. Future freeze-thaw cycles should not have a significant impact on the engineering properties of the improved soil. Ground thawing is discussed later in this document.

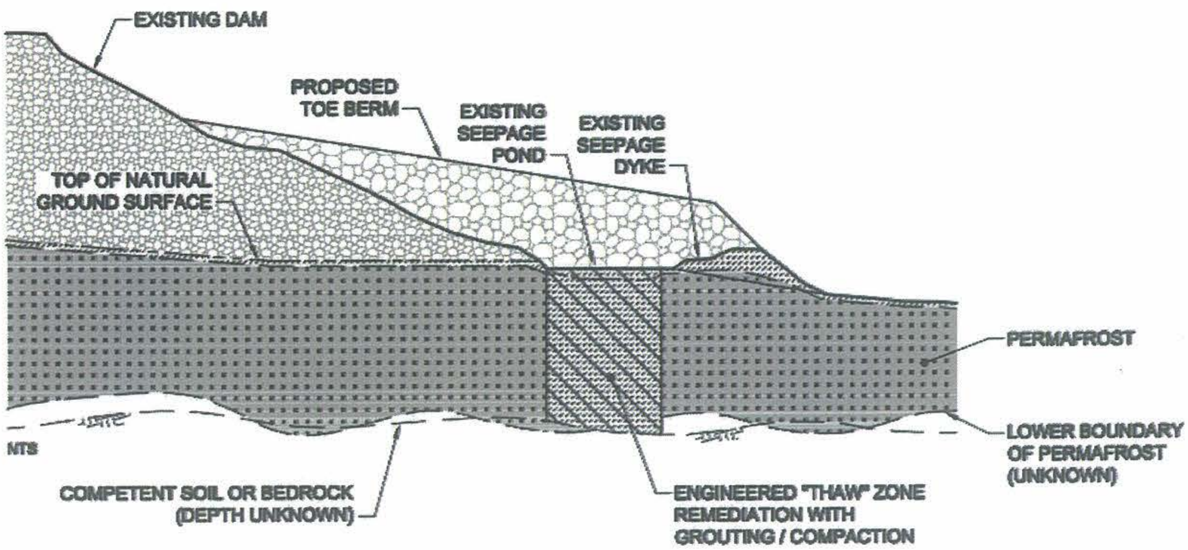

Figure 4 Engineered thawing for the purpose of ground improvement,

Alternatively, if the depth that required improvement was relatively shallow, it would be most economical to excavate the frozen, and potentially liquefiable soil, and replace it with compacted fill (possibly sourced from the waste rock). The frozen soil could be excavated using drill-and-blast methods if it is safe and practical. The stability of the dam during construction is imperative, and the impact of any temporary construction activities must be considered.

Rockfill caissons may be a suitable method of providing sufficient shear strength to maintain the stability of the dam if the sands are liquefied due to an earthquake. The caissons could be installed in the frozen sand, and would maintain their integrity if the surrounding loose sands thawed at some future time. The caissons would be advanced to a competent soil or bedrock strata. They would be backfilled with crushed rockfill (inert waste rock may be suitable), and compacted with a vibrolance. Rockfill is considered to be more suitable than concrete caissons because of its flexibility and the local availability of material. Rockfill caissons would also provide a vertical drainage path for excess porewater pressures.

There is inadequate subsurface information to develop these concepts further at this time, but we have confidence that there is an engineering solution to maintaining the stability of the Mt. Nansen Tailings Dam with or without permafrost. The key pieces of information needed to further assess the ground improvement alternatives are:

- Thickness, extent and characteristics of the permafrost zone.
- Depth to bedrock or other competent, non-liquefiable bearing layer.
- Characteristics and properties of materials in the permafrost zone. Frozen samples could collected and then transported in a frozen state to a materials testing facility, where they would be thawed and tested under confinement to determine thawed properties. The

applicability of some of the improvement measures are limited by grain sizes, and the occurrence of dense layers.
- Depth of thawing beneath seepage collection pond. The "warm" pond water may have accelerated thawing beneath the pond.

The depth of the overburden has not been confirmed in the vicinity of the proposed toe-berm, but reports have identified the depth of bedrock ranging from 1m, on the valley slopes, to over 20 m in the valley bottom (Higgs and Associates 1994). A test hole drilled by Klohn Leonoff Ltd approximately 400m North-East of the proposed toe-berm, in the Dome Creek Valley refused at 28 m, but bedrock was not confirmed (Klohn Leonoff 1988). Two test holes drilled by AECOM in 2009 in the north terrace area were advanced up to 19 m through overburden before refusal in permafrost. The test holes drilled through the dam (by AECOM 2009) were advanced through a maximum of 14 m of overburden before refusal. Downstream of the seepage collection dam, in the vicinity of the proposed toe-berm, an air-rotary drill refused at 5 m (though the type of bit used is not noted) (AECOM 2010). Based on this information it could be expected that the depth to bedrock or a competent bearing layer may be as little as 5 m, but may be greater than 30 m.

The interpretation of the CPT results by EBA (2002) do indicate a general trend of reduced liquefaction potential with depth, suggesting that it may not be necessary to extend ground improvement measures all the way to bedrock, though this cannot be confirmed with the current information.

To implement densification or cementation methods of ground improvements in the near future, the permafrost would need to be thawed. Thawing of frozen ground has been implemented on numerous projects, but typically the thawing is limited to relatively shallow depths where surface heating through artificial or passive solar means is effective. Steam injection wells have been used successfully to thaw an area 3000 m^2 to a depth of 12.2 m over a 3 ½ month period (Andersland and Ladanyi 2004). By extension, it would be reasonable to expect that a similar technique may be suitable to thaw to the depths required for this project. A circulation system may also be suitable, similar to a vertical loop used for geothermal applications. A number of contractors experienced in the far north, and experts in the field of permafrost engineering were consulted, but none had experience with costing or implementing this type of thawing program.

Developing a detailed methodology and estimating the costs of thawing the soil would require a level of design which is beyond the scope of this memo. Some considerations that need to be addressed included:

- Dimensions of area to be thawed (ie. volume)
- Thermal properties including temperature, unfrozen water content function, and heat capacity
- Source of heat, cost of fuel, and efficiency of heat source and distribution system
- Potential sources of heat loss (flowing groundwater for example)
- Heat distribution including installation of steam injection wells, or circulation heat loops
- Collection of excess pore water
- Seasonal, environmental and location limitations

Estimated Costs

Estimated costs for select methods of ground improvement are plotted against the required depth of improvement in Figure 5. It is important to note that the costs for dynamic compaction and vibro-compaction do not include an allowance for thawing of the in situ soil. The excavation and replacement option would not require ground thawing.

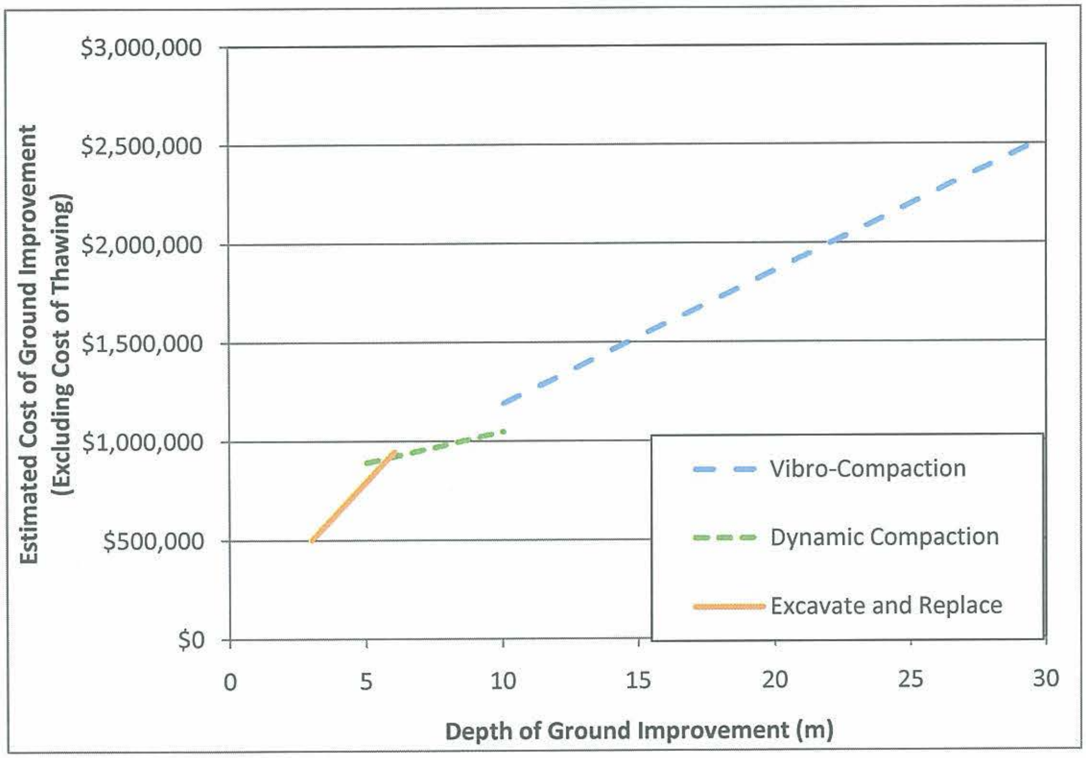

Figure 5. Estimated costs of various ground improvement methods vs. required improvement depth. These costs do not include thawing of the in situ soil.

The cementation methods also require ground thawing, and are approximately an order of magnitude more expensive than vibro-compaction per cubic metre of improved ground. If grouting can be targeted at specific zones, it may be a cost effective solution.

The cost of installing rockfill caissons to a depth of 12 m through frozen sand has been estimated at $12,500,000. It should be noted that this estimate assumes consistent frozen ground conditions. Challenging subsurface conditions could increase this cost. Although this cost is significantly more than the costs of the other ground improvement measures, it does not require any ground thawing (cost which has not been included in the costs plotted in Figure 5). The $12,500,000 for installing rockfill caissons should be carried as a provisional cost for ground improvement as this measure can be implemented without ground thawing.

Table 01 summarizes these methods, and indicates our confidence in the feasibility of these methods. It should be noted that as the depth of required improvement increases, that the level of confidence decreases. With greater improvement depth comes greater uncertainty in ground conditions, fewer applicable methods and more technical challenges. Excavation and replacement, or rockfill columns could be implemented at the present time, under a wide range of ground conditions, without requiring ground thawing. This is reflected in our higher level of confidence shown in Table 01.

Table 01. Summary of potential ground improvements

Depth Range	Technique	Thawing Required	Level of Confidence
5-10	Dynamic Compaction	Yes	Medium to Low
10	Vibro-Compaction	Yes	Medium to Low
5-30	Cementation (Compaction/Chemical/Jet)	Yes	Medium
0-6 m	Excavate and Replace	No	High
6-30	Rockfill Caissons	No	Medium to High

Discussion and Conclusion

Permafrost must be a consideration in any long-term stabilization works for the Mt. Nansen Tailings Dam. Based on our assessment, the alternatives are to:

Proposed Alternative

- Alternative 1: Enhance the permafrost and utilize it as an element of the stabilization measures. If and when climate changes begin to overwhelm the permafrost and thermosyphons, ground improvement measures on unfrozen soil should be implemented

Provisional Alternatives

- Alternative 2: Eliminate reliance on permafrost by implementing long term stabilization measures through the permafrost. Appropriate techniques may include excavation and replacement, rockfill caissons or other structural reinforcing measure.

- Alternative 3: Eliminate reliance on permafrost by using an engineered process to remove or destroy the permafrost and then permanently improve the characteristics of the in-situ soil at that location. Appropriate techniques may include dynamic compaction, vibro-compaction or cementation.

Thermosyphons are considered to be a feasible means of enhancing the permafrost to provide a non-liquefiable anchor for the shear key under current climatic conditions based on the performance of the existing thermosyphons and the analysis by Naviq (2010). The thermosyphons should be able to continue performing adequately under moderately warmer environmental conditions. However, there is considerable uncertainty linked to our inability to predict climate changes accurately, and the resulting degradation of permafrost. If current warming trends continue (0.08°C/year based on Naviq (2010)), the effectiveness of thermosyphons will decrease with time, and permafrost cannot be maintained beyond the next 50-150 years (Naviq 2010). The scope of the work by Naviq was limited to a high level assessment of feasibility, and a more comprehensive assessment of potential climate conditions, existing ground conditions and design concepts would be required in future design stages.

If it is desirable to eliminate the uncertainty regarding the long term effectiveness of maintaining permafrost with thermosyphyons, then other methods of ground improvement should be considered to reduce the liquefaction potential of the foundation material. The ground improvement measures could be implemented in the near term if the permafrost is deliberately eliminated by some engineered process or at some future date.

If Closure Option 1 or Option 2 are attractive to the stakeholders based on other merits, then it would be reasonable to address the information gaps and uncertainties as an intermediate investigation phase prior to detailed design. It is our opinion that the uncertainties regarding the long term behaviour of the permafrost, and characteristics of the foundation soils under thawed conditions warrant further investigation before advancing to detailed design if either Closure Option 1 or Closure Option 2 are selected.

The following investigations would address the information gaps and provide more certainty:

- A geotechnical/geophysical site investigation is neededto identify the depth to competent ground (that is not liquefiable). This layer may be bedrock, or may be a shallower stratum of dense granular material. There are no in situ testing techniques that can be performed in frozen soil that can predict the compactness condition of that soil once thawed. Therefore, the site investigation would require that undisturbed frozen samples be collected and transported in a frozen state to a geotechnical laboratory for testing. In addition to a limited number of test holes strategically located, we would recommend a geophysical survey to provide more continuous subsurface information extrapolating with more confidence between test holes.

- An assessment of thawing technologies and preliminary design and costing of a ground thawing system would be beneficial. The costs and appropriate technologies and techniques are a function of the depth that requires thawing.

- A desktop study of climate prediction models for the Mt. Nansen area would help to understand the potential limitations of ground freezing. A linear interpretation of the mean annual temperature changes that have occurred in past 50 years cannot be reasonably extrapolated into the distant future. A study of potential climate change scenarios may be helpful in identifying the useful lifespan of thermosyphons, and could improve the estimated rate of thaw for permafrost.

As stated previously, it is our opinion that a shear key that is anchored with permanently frozen ground is still a feasible and economical means of ensuring the stability of the dam at the present time.

Please contact the undersigned with comments or questions.

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REFERENCES

AECOM 2010
Geotechnical Assessment and Costing of the Mt. Nansen Mine Closure Alternatives, November 2010.

Andersland, O. B., and Ladanyi, B. 2004
Frozen Ground Engineering. American Society of Civil Engineers and John Wiley & Sons Inc.

EBA 2002
Dam Safety Assessment: Mount Nansen Tailings Facility near Carmacks, YT. May 2002.

Higgs, T.W. and Associates, 1994,
Initial Environmental Evaluation, Mt. Nansen Development (prepared for B.Y.G. Natural Resources Inc.).

Klohn Leonoff 1988,
Mt. Nansen Gold Project: Tailings Dam Preliminary Design Report.

Olsen S. M., and Stark, T. D.,2002.
Liquefied strength ratio from liquefaction flow failure case histories. Canadian Geotechnical Journal. 39: 629-647.