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Memo

To:	John Roberts, PEng	**Client:**	TMAC Resources Inc.
From:	Iozsef Miskolczi, PEng Arcesio Lizcano, PhD	**Project No:**	1CT022.002
Reviewed By:	Maritz Rykaart, PhD, PEng	**Date:**	December 4, 2015
Subject:	Response to NRCan IR #1c – Stability of Tailings Cover with respect to Frost Heave		

1 NRCan Information Request 1 (NRCan IR-1)

1.1 Subject

Design and stability of the proposed Tailings Impoundment Area (TIA)

1.2 Reference

Package 2 (3.5), Package 6 (P6-13), Package 5 (P5-2 sec 2.9, 3.7, 5.9; P5-3 sec 2.4, 2.6, 2.8)

1.3 Rationale

A significant modification to the Project is the design of the TIA. The approved Project consisted of subaqueous disposal of tailings and a water cover at closure. The planned extension of underground mining means that a greater volume of tailings will be produced and these cannot be accommodated in the TIA that was originally approved. Subaerial deposition (slurry deposition) of floatation tailings is now proposed. Tailings will be deposited in the south end of the TIA between the South Dam and an Interim Dike (new feature). Closure will include a dry cover. Leach tailings which are potentially acid generating will be disposed of as mine backfill.

It is NRCan's understanding that the approved TIA was considered to be a walk-away-solution for tailings disposal with no need to ensure integrity of the dams in perpetuity. Under the revised plan for the TIA, the dams and dikes will need to remain in perpetuity. It is therefore not clear whether a site presence and monitoring will be required over the long-term following closure to ensure stability of the TIA including dams and dikes.

Freezing of the tailings pile and the foundation (i.e. current unfrozen lake bed sediments) is anticipated and will enhance performance of the TIA. It is unclear whether the potential for frost heave within the tailings (or the foundation materials) and its potential effect on performance of the protective cover (due to deformation) and the pile stability has been considered in the impact analysis. It is also not clear whether pore water expulsion during freezing of the tailings and potential migration of contaminants into the underlying talik and shallow groundwater has been considered in the impact analysis.

1.4 Information Request

a) Please clarify whether frozen conditions in the tailings pile and foundation are required to ensure long-term performance of the TIA.

b) Please clarify whether a site presence and ongoing monitoring beyond closure is required to ensure the integrity of the TIA, including dams and dikes, over the long-term.

c) Please clarify whether the potential for frost heave, associated with freezing of the tailings and the underlying foundation materials, has been considered in the stability analysis including the potential for deformation and impacts on performance of the protective cover.

d) Please clarify whether pore water expulsion during freezing of tailings and potential impacts on shallow groundwater has been considered in the impact analysis.

2 TMAC Response

2.1 Context

The response relates specifically item c) of the information request.

The potential for frost heave associated with freezing of the tailings and underlying foundation materials was not discussed explicitly in document P6-13 Tailings Management System Design. This memo presents an analysis of the frost heave due to freezing of tailings and underlying foundation materials followed by a conclusion on the likely impacts on the final tailings closure cover.

2.2 Potential Frost Heave Associated with Freezing of Tailings

2.2.1 Tailings Deposit Description

As described in Document P6-13, Tailings Management System Design, tailings will be deposited in the TIA through a series of spigots (Figure 1 of document 6-13) over an active deposition period of 4 years and 5 months. Deposition will start at the South Dam, and will progress toward the Interim Dike. In practical terms, the tailings deposited during the warm season is expected to freeze back completely over the following winter, and will subsequently be covered by a layer of fresh tailings acting as thermal protection over the following summer. Seasonal thaw will occur to the depth of the active zone, estimated to be a maximum of 2 m thick as per the thermal analysis presented in P6-13. At conclusion of operations in the TIA the tailings deposit will reach a maximum thickness of about 10 meters, as shown in Figure 2 of document P6-13.

2.2.2 Tailings Properties

A complete description of the tailings properties is provided P6-13. A subset of these properties relevant to frost heave are included in Table 1 below.

Table 1: Tailings Properties

Parameter	Notation	Value
Void ratio (at deposition)	e_0	1.1 (unitless)
Dry density	ρ_d	1,290 (kg/m^3)
Degree of saturation (at deposition)	S	100 (%)
Specific Gravity	SG	2.7 (unitless)

2.2.3 Phase Change of Water to Ice

When freezing, a unit volume of liquid water will experience an increase in volume of about 9%. Under the conservative assumption of full saturation, the tailings material will therefore experience a volume increase of 9% compared to the initial (unfrozen) pore volume.

2.2.4 Frost Heave Analysis

The Interim Closure Plan (document P5-2) consider the TIA, which includes construction of a run-of-quarry rock cover. This cover can only be constructed in the winter following closure of the facility at the earliest. By that time, the tailings will be completely frozen and the deeper zones of tailings will remain perennially frozen (i.e. become part of the permafrost), while the active layer will experience annual freeze-thaw cycles. Therefore, given the annual freezing cycles that the tailings are subject to, it is expected that any related volume change in the tailings will have already occurred by closure. Permafrost tailings will retain their frozen density indefinitely with no further influence on the deformation of the tailings surface.

Annual freeze-thaw cycles are responsible for frost heave followed by thaw settlement in the active layer. Therefore the magnitude of surface displacement will be a consequence of volume changes occurring in the 2 m top layer only, equivalent to the active layer depth.

Because the tailings underneath the seasonal active layer are frozen at the time of the cover construction, the active layer becomes a closed system, i.e. excess water is not available for segregated ice formation. Frost heave is therefore limited to the volumetric change of the tailings pore water contained in the active layer only.

Under the conservative assumption that the tailings of the active layer, before cover construction, have the same void ratio as in deposition and are completely saturated, the maximum magnitude of frost heave was calculated to be 9.4 cm, considering one-dimensional deformation and using the following equation:

$$s = \frac{H}{1 + e_0} \Delta e$$

where:

s: Magnitude of deformation (m)

H: Thickness of the active zone (m); $H = 2.0$ m

e_0: Initial void ratio in the active zone by the time of cover construction (unitless); $e_0 = 1.1$

Δe: Void ratio increase due to freezing of tailings pore water (unitless); $\Delta e = 0.09e_0$

2.3 Potential Frost Heave Associated with Foundation Soils

2.3.1 Foundation Soils Characterization

The site characterization performed during the design stage of the TIA suggest the existence of a closed talik underneath the TIA; however, the full extent of the talik is unknown (SRK 2006). The overburden underlying the TIA is typical of the region-wide overburden, with a marine silt and clay stratum over till formations. The thickness of overburden varies from 15 m underneath North Dam to about 30 m under South Dam as described in document P6-13 Tailings Management System Design.

Once the deposited tailings displace the water south of the Interim Dike, the talik will begin freezing back. The thermal model presented in Document P6-13 indicates that permafrost will extend into the foundation soils underlying the deposited tailings. The model was not set up to study the extents of the talik freeze-back or the time associated with this freeze-back.

2.3.2 Frost Heave due to Freezing of Pore Water

As described in Section 2.2.4, the frost heave due to freezing of the pore water is limited to about 9% of the pore volume. Detailed soil properties for the soils underlying the TIA are not available, therefore soil properties obtained from Doris Lake samples will be used for this assessment. Assuming a conservative overburden thickness of 30 m, and an average void ratio of 1.14 (SRK 2009), the magnitude of the frost heave is estimated to not exceed 1.5 m.

2.3.3 Frost Heave due to Segregated Ice in Foundation Soils

Frost heave due to segregated ice in the foundation soils was not estimated for this stage of the design. A qualitative analysis is presented in this section in response to the Information Request.

Segregated ice causing frost heave can form in fine-grained soils if a constant supply of water is available. At the beginning of the cover construction, the talik under the TIA will be bounded on three sides (east, south, and west) and will have an ample water supply from the unfrozen portion of the talik and the overlying Reclaim Pond (see Figures 1 and 2 of document P6-13).

Although the properties of foundation soils may exhibit spatial variations, the significant properties with respect to segregated ice lens formation (segregation potential, hydraulic conductivity and the thermal conductivity) are expected to be similar for the TIA foundation materials based on drill holes completed in other lakes of the site (SRK 2009). This in turn will cause frost heave of similar magnitude across the surface area of the TIA, resulting in little differential heave transmitted to the tailings surface.

2.4 Effect of Frost Heave on the Cover

The magnitude of the frost heave due to freezing of pore water and segregated ice lenses that could potentially form in the foundation soils is anticipated to be of similar magnitude over a relatively large area of the tailings surface. Therefore, differential frost heave due to foundation freeze-back will result in gentle undulations of the tailings surface, rather than step-type transitions.

The low-gradient vertical displacement of the tailings surface can be easily accommodated by the protective cover due to its granular nature. The particles of the cover will rearrange to adjust to the gentle changes caused by frost heave in the tailings surface. The function of the cover as protection against wind and run-off erosion will therefore be maintained. Additionally, the low-gradient vertical displacement of the tailings surface will not compromise the stability of the cover as the friction angle in the cover-tailings interface is at least 40° (SRK 2006), sufficient to avoid the slide of the cover over a tailings surface slope of 1.2H:1V.

3 References

SRK Consulting (Canada) Inc. (2006). Design of the Tailings Containment Area – Doris North Project, Hope Bay, Nunavut, Canada. Report submitted to Miramar Hope Bay Ltd October, 2006. SRK Project No. 1CM014.008.165.

SRK Consulting (Canada) Inc. (2009). Hope Bay Gold Project: Stage 2 Overburden Characterization Report, Hope Bay, Nunavut, Canada. Report submitted to Hope Bay Mining Ltd September, 2009. SRK Project No. 1CH008.002.