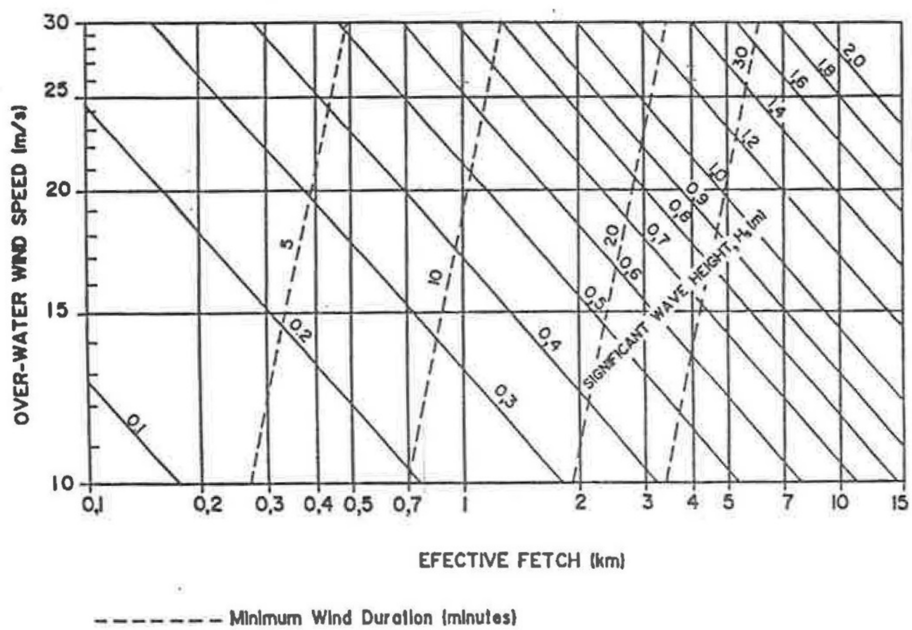


FIGURE A4 : SIGNIFICANT WAVE HEIGHTS

Reference A-1: Significant Wave Height (SANCOLD, 1990)

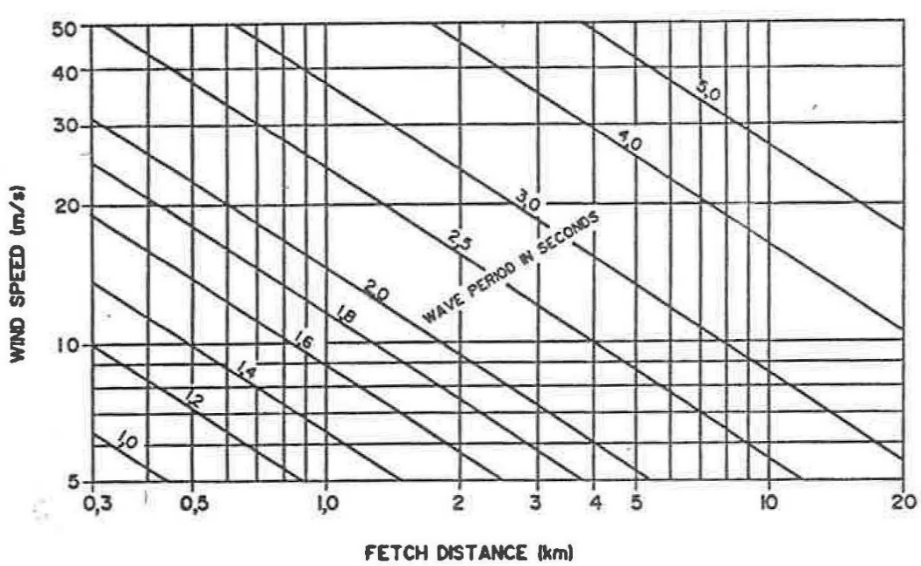
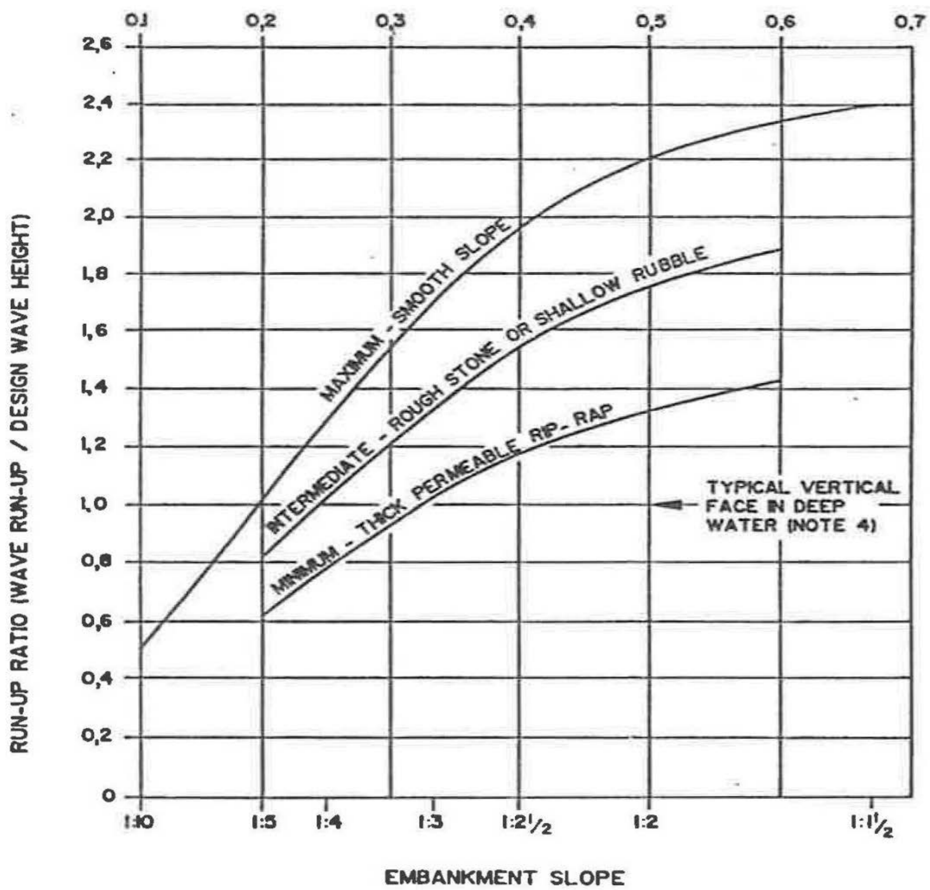


FIGURE A3 : WIND WAVE PERIODS

Reference A-2: Significant Wave Period (SANCOLD, 1990)

Fetch, km (miles)	Wind Ratio Over Water/Over Land
0.8 (0.5)	1.08
1.6 (1)	1.13
3.2 (2)	1.21
4.8 (3)	1.26
6.4 (4)	1.28
8.0 (5)	1.30

Reference A-3: Wind Over Water Correction Factors Based on Fetch Length (USACE 1997).



NOTES:

1. MAXIMUM LINE FROM SAVILLE ET AL (1962) FOR TYPICAL WAVE STEEPNESS (SIGNIFICANT WAVE HEIGHT/LENGTH) = 0,05.
2. INTERMEDIATE LINE IS 0,8 x MAXIMUM.
3. MINIMUM LINE IS 0,6 x MAXIMUM.
4. FOR FACES OFF-VERTICAL THE RUN-UP RATIO RISES ABOVE UNITY AND CAN APPROACH 2 IN SOME CIRCUMSTANCES WHERE THE DEEP WATER CONDITION IS NOT FULFILLED.

Reference A-4: Wave run-up estimation based on Run-up Ratio and Embankment Slope (SANCOLD, 1990)

Appendix G – Borehole Log (SRK 39)

PROJECT: HOPE BAY DORIS NORTH PROJECT
PROJECT NO: 1CM014.01
LOCATION: Tail Lake South
SURFACE (COLLAR) ELEVATION: 41.14 m
NORTHING: 7556391 **EASTING:** 435164
LOGGED BY: D.B.M.

HOLE NO: SRK 39
HOLE DIAMETER: 76 mm (NQ)
DATE AND TIME STARTED: 2003-07-31, 01:00
DATE AND TIME FINISHED: 2003-08-01, 06:00
DRILL CONTRACTOR: Major Midwest
DRILLING METHOD: Diamond Core

RQD ROCK QUALITY(%) = 100 x core lengths 100 mm and longer / length of run

Fracture spacing (mm): <30; 30 - 100; 100 - 300; 300 - 1000; >1000

GRADE	ROCK MASS: WEATHERING	ROCK MASS: HARDNESS	ROCK MASS: FABRIC	DISCONTINUITY: ROUGHNESS	DISCONTINUITY: SEPARATION	DISCONTINUITY: DIP
1	unweathered	v. hard	v. fine	smooth	closed	vertical
2	slightly	hard	fine	sl. rough	v. narrow	steep
3	medium	medium	medium	medium	narrow	medium
4	highly	soft	coarse	rough	wide	shallow
5	completely	v.soft	v. coarse	v. rough	v. wide	horizontal

Depth (m)	Contact (m)	Material Description	Lithology	Soil Class	RQD	Fracture Spacing	Weathering	Hardness	Fabric	Roughness	Separation	Dip (degrees)	Run	Recovery	Sample	Installations
0–7.25		OVERBURDEN Grey silty CLAY, wet, with coarse sand-sized pieces of hard dry clay which can be broken down with finger pressure. Material contains lenses of ice.		CL									1	100%	Sample 1 0.0-3.0	
													2	100%	Sample 2 3.5-5.6	
													3	100%		
													4	100%		
7.25–10	7.25	BEDROCK Green foliated BASALT with calcite veining and infilling parallel to foliation, with occacional quartz veins			49%								5	100%		
					63%								6	100%		

Depth scale: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

PROJECT: HOPE BAY DORIS NORTH PROJECT
PROJECT NO: 1CM014.01
LOCATION: Tail Lake South
SURFACE (COLLAR) ELEVATION: 41.14 m
NORTHING: 7556391 **EASTING:** 435164
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HOLE NO: SRK 39
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RQD ROCK QUALITY(%) = 100 x core lengths 100 mm and longer / length of run

Fracture spacing (mm): <30; 30 - 100; 100 - 300; 300 - 1000; >1000

GRADE	WEATHERING	HARDNESS	FABRIC	ROUGHNESS	SEPARATION	DIP
1	unweathered	v. hard	v. fine	smooth	closed	vertical
2	slightly	hard	fine	sl. rough	v. narrow	steep
3	medium	medium	medium	medium	narrow	medium
4	highly	soft	coarse	rough	wide	shallow
5	completely	v.soft	v. coarse	v. rough	v. wide	horizontal

(ROCK MASS: Weathering, Hardness, Fabric; DISCONTINUITY: Roughness, Separation, Dip)

Depth (m)	Contact (m)	Material Description	Lithology	Soil Class	RQD	Fracture Spacing	Weathering	Hardness	Fabric	Roughness	Separation	Dip (degrees)	Run	Recovery	Sample	Installations
11					92%								7	100%		
12					81%											
13																
14													8	97%		
15					90%								9	100%		
					100%											
16																
17													10	100%		
18					81%											
19													11	100%		
20																

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PROJECT: HOPE BAY DORIS NORTH PROJECT
PROJECT NO: 1CM014.01
LOCATION: Tail Lake South
SURFACE (COLLAR) ELEVATION: 41.14 m
NORTHING: 7556391 **EASTING:** 435164
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HOLE NO: SRK 39
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DRILLING METHOD: Diamond Core

RQD ROCK QUALITY(%) = 100 x core lengths 100 mm and longer / length of run

Fracture spacing (mm): <30; 30 - 100; 100 - 300; 300 - 1000; >1000

GRADE	ROCK MASS: WEATHERING	HARDNESS	FABRIC	DISCONTINUITY: ROUGHNESS	SEPARATION	DIP
1	unweathered	v. hard	v. fine	smooth	closed	vertical
2	slightly	hard	fine	sl. rough	v. narrow	steep
3	medium	medium	medium	medium	narrow	medium
4	highly	soft	coarse	rough	wide	shallow
5	completely	v.soft	v. coarse	v. rough	v. wide	horizontal

Depth (m)	Contact (m)	Material Description	Lithology	Soil Class	RQD	Fracture Spacing	Weathering	Hardness	Fabric	Roughness	Separation	Dip (degrees)	Run	Recovery	Sample	Installations
21					95%											
22													12	100%		
23																
24					93%											
25													13	99%		
26																
27					89%											
28													14	100%		
29																
30					88%											

PROJECT: HOPE BAY DORIS NORTH PROJECT
PROJECT NO: 1CM014.01
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GRADE	WEATHERING	HARDNESS	FABRIC	ROUGHNESS	SEPARATION	DIP
1	unweathered	v. hard	v. fine	smooth	closed	vertical
2	slightly	hard	fine	sl. rough	v. narrow	steep
3	medium	medium	medium	medium	narrow	medium
4	highly	soft	coarse	rough	wide	shallow
5	completely	v.soft	v. coarse	v. rough	v. wide	horizontal

Depth (m)	Contact (m)	Material Description	Lithology	Soil Class	RQD	Fracture Spacing	Weathering	Hardness	Fabric	Roughness	Separation	Dip (degrees)	Run	Recovery	Sample	Installations
31													15	98%		
32																
33					75%											
34																
35													16	97%		
36					68%											
37													17	99%		
38																
39					84%											
40																

PROJECT: HOPE BAY DORIS NORTH PROJECT
PROJECT NO: 1CM014.01
LOCATION: Tail Lake South
SURFACE (COLLAR) ELEVATION: 41.14 m
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RQD ROCK QUALITY(%)
100 x core lengths 100 mm and longer / length of run

Fracture spacing (mm): <30; 30 - 100; 100 - 300; 300 - 1000; >1000

GRADE	ROCK MASS: WEATHERING	ROCK MASS: HARDNESS	ROCK MASS: FABRIC	DISCONTINUITY: ROUGHNESS	DISCONTINUITY: SEPARATION	DISCONTINUITY: DIP
1	unweathered	v. hard	v. fine	smooth	closed	vertical
2	slightly	hard	fine	sl. rough	v. narrow	steep
3	medium	medium	medium	medium	narrow	medium
4	highly	soft	coarse	rough	wide	shallow
5	completely	v.soft	v. coarse	v. rough	v. wide	horizontal

Depth (m)	Contact (m)	Material Description	Lithology	Soil Class	RQD	Fracture Spacing	Weathering	Hardness	Fabric	Roughness	Separation	Dip (degrees)	Run	Recovery	Sample	Installations
													18	99%		
41																
42					73%											
43													19	88%		
44																
45					71%											
46													20	100%		
47																
48					95%											
49													21	100%		
50																

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PROJECT: HOPE BAY DORIS NORTH PROJECT
PROJECT NO: 1CM014.01
LOCATION: Tail Lake South
SURFACE (COLLAR) ELEVATION: 41.14 m
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RQD ROCK QUALITY(%) = 100 x core lengths 100 mm and longer / length of run

Fracture spacing (mm): <30; 30 - 100; 100 - 300; 300 - 1000; >1000

GRADE	WEATHERING (Rock Mass)	HARDNESS (Rock Mass)	FABRIC (Rock Mass)	ROUGHNESS (Discontinuity)	SEPARATION (Discontinuity)	DIP (Discontinuity)
1	unweathered	v. hard	v. fine	smooth	closed	vertical
2	slightly	hard	fine	sl. rough	v. narrow	steep
3	medium	medium	medium	medium	narrow	medium
4	highly	soft	coarse	rough	wide	shallow
5	completely	v.soft	v. coarse	v. rough	v. wide	horizontal

Depth (m)	Contact (m)	Material Description	Lithology	Soil Class	RQD	Fracture Spacing	Weathering	Hardness	Fabric	Roughness	Separation	Dip (degrees)	Run	Recovery	Sample	Installations
51	51 EOH															
52																
53																
54																
55																
56																
57																
58																
59																
60																

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Appendix H – Hope Bay Project: Phase 2 Doris Tailings Impoundment Area South and West Dam Thermal Modeling

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Memo

To:	John Roberts, PEng, Vice President Environment	**Client:**	TMAC Resources Inc.
From:	Christopher W. Stevens, PhD	**Project No:**	1CT022.004
Reviewed By:	Maritz Rykaart, PhD, PEng	**Date:**	December 1, 2016
Subject:	Hope Bay Project: Doris Tailings Impoundment Area South and West Dam Thermal Modeling		

1 Introduction

1.1 General

The Hope Bay Project (the Project) is a gold mining and milling undertaking of TMAC Resources Inc. The Project is located 705 km northeast of Yellowknife and 153 km southwest of Cambridge Bay in Nunavut Territory, and is situated east of Bathurst Inlet. The Project comprises of three distinct areas of known mineralization plus extensive exploration potential and targets. The three areas that host mineral resources are Doris, Madrid, and Boston.

The Project consists of two phases; Phase 1 (Doris project), which is currently being carried out under an existing Water Licence, and Phase 2 which is in the environmental assessment stage. Phase 1 includes mining and infrastructure at Doris only, while Phase 2 includes mining and infrastructure at Madrid and Boston located approximately 10 and 60 km due south from Doris, respectively.

Phase 1 tailings are deposited sub-aerially in the Doris tailing impoundment area (TIA), formerly Tail Lake, located approximately 5 km from the Doris Mill. Containment would be provided by three retention structures; a water retaining frozen core dam (North Dam), a frozen foundation tailings containment dam (South Dam); and an Interim Dike situated at approximately the midpoint of the facility. Tailings would be deposited sub-aerially between the South Dam and Interim Dike, and the Reclaim Pond will be contained between the Interim Dike and the North Dam. The North Dam was constructed over two winters (2011 and 2012) and has impounded water since 2011 (SRK 2012). The South Dam and Interim Dike are scheduled for construction in 2017.

Phase 2 tailings deposition would include a continuation of the Doris TIA with raising of the South Dam and construction of a new West Dam (SRK 2016a). Phase 2 tailings deposition will see a return of the discharge spigots to the raised South Dam to form a continuous beach against the upstream side. Once the final beach elevation is reached at the South Dam, tailings deposition would shift to the West Dam to form a similar beach. Tailings beach development will result in the supernatant pond located directly against the North Dam. The Interim Dike will be completely inundated by this deposition strategy. At Closure, the North Dam would be breached to allow drainage of the pond, and a run-of-quarry (ROQ) or geochemically suitable run-of-mine (ROM) cover would be constructed over the tailings beach.

The South and West dams will rely on an impermeable liner incorporated in the dam fill and keyed into the permafrost foundation to achieve the required water retention properties. In order to ensure adequate performance of the dam, it is imperative to maintain the frozen state of the key-in trench. The North Dam will continue to operate as a frozen core dam until closure.

1.2 Objectives

This memo summarizes the assumptions and the results of numerical modeling completed to predict the thermal performance of the Doris TIA South Dam and West Dam to support Phase 2 tailings deposition. Thermal modeling completed for the North Dam is presented in SRK (2016b).

The objective of the modeling was to determine whether or not the proposed designs were suitable to maintain the liner within a frozen key-in trench. The foundation was considered to be valid if the temperature within the dam key-in trench remains colder than -2°C, which accounts for the average site-wide porewater freezing point depression of -2.1°C within natural overburden clay at the Project site (SRK 2016a). There is a negligible difference between the position of these two isotherms, and -2°C is presented for clarity of the results. The model also predicts tailings freezeback and active layer development to understand long-term geochemical loading from the facility.

2 Methods

2.1 Model Setup

Modeling was completed in a two-dimensional domain by solving for conductive heat movement in the soil, using SoilVision's SVHeat (SoilVision 2011) software package in combination with FlexPDE (FlexPDE 2014). SVHeat was utilized for the problem setup, while FlexPDE 6.35 solver was used to complete the calculation.

For the purpose of modeling, the South and West dams are divided into two periods of time; the period of active tailings deposition (*active deposition at dam*) when tailings are deposited from the dam and the period following tailings deposition (*deposition complete at dam*) when deposition is complete and a stable beach is present against the dam (Figure 1). The timeline for thermal modeling is based on the Phase 2 – Doris TIA Tailings Deposition Plan (SRK 2016d).

The South Dam was modeled with a 10 m crest width, 15 m maximum height, upstream slope of 4H:1V, and downstream slope of 2H:1V. The key trench into the in situ overburden material has a 6 m wide base with upstream slope of 2H:1V and downstream slope of 1H:1V. The key trench excavation is located near the upstream toe of the dam. Drill holes completed at the site have characterized silt and clay to a depth of 24 m which is underlain by a 10 m thick gravelly till (SRK 2016c). For simplicity, the model assumes a clay foundation. The model geometry for the South Dam during the period of active tailings deposition and following completion of deposition is presented in Figure 2 and Figure 3, respectively.

The West Dam was modeled with a 10 m crest width, 5 m maximum height, upstream slope of 4H:1V, and downstream slope of 2H:1V. The key trench excavated into overburden material has a 4 m wide base with upstream slope of 2H:1V and downstream slope of 1H:1V. The key trench excavation is located near the centre of the dam. The foundation conditions at the West Dam is inferred to consist of silt and clay based on a borehole log (SRK 2016c), and therefore the model assumes clay. Given the location of the dam alignment, it is assumed that the entire alignment of the West Dam is underlain by permafrost. The model geometry for West Dam during the period of active tailings deposition and following completion of deposition is presented in Figure 4 and Figure 5, respectively.

2.2 Model Inputs

2.2.1 Material Properties

Three material units were considered: native soil (overburden clay), dam fill (ROQ material), and tailings. Table 1 presents a summary of the material properties. No peat or organic layer was considered during the modeling. This omission is reasonable given the fact that removal of this layer from the model makes the analysis more conservative. If organic layers were to be considered in the model, the rate of thaw would be less due to latent heat required to change phase of ice to water.

Table 1: Material Thermal Properties

Material	Degree of Saturation (%)	Porosity	Thermal Conductivity, kJ/(m·day·°C)		Volumetric Heat Capacity, kJ/(m^3·°C)	
			Unfrozen	Frozen	Unfrozen	Frozen
ROQ Material	30	0.30	104	117	1,697	1,509
ROQ Material, Unfrozen Saturation 100%	100	0.30	141	117	2,576	1,509
Overburden Clay [1,2]	85	0.52	112	187	2,842	2,038
Tailings[2]	100	0.55	123	232	3,502	2,350

Notes:
1. Overburden clay includes a porewater freezing point depression of -2°C
2. Unfrozen water content curve based on grain size

The thermal properties for ROQ material were taken from previous work completed by SRK for granular pad design (SRK 2016e). The ROQ material was modified to account for unfrozen saturated thermal conductivity and heat capacity of the material located on the upstream side of the liner. The unfrozen properties for this material (*ROQ Material, Unfrozen Saturation 100%*) were estimated for 100% saturation (Table 1).

The thermal properties for natural overburden clay were based on average physical properties of the soil and a porewater freezing point depression of -2°C (SRK 2016c). An unfrozen water content curve for overburden clay was included in the model with consideration for the freezing point depression in accordance with Banin and Anderson (1974). The thermal conductivity was calculated in accordance with Cote and Konrad (2005).

The tailings thermal properties were based on physical samples of tailings sourced from the Project site. The physical properties measured in the laboratory included an average specific gravity (2.87) and a dry density (1.3 g cm^{-3}) (SRK 2016f). The measured specific gravity, dry density, and a saturation of 100% were used to calculate the porosity (55%) and gravimetric water content (42% based on dry weight of solids) of the tailings. These physical properties were in turn used to derive the tailings thermal properties shown in Table 2. The tailings thermal properties include an unfrozen water content curve based on silt size mineral soil particles. Tailings process water is not expected to have an appreciable level of dissolved ions which contribute to a freezing point depression, and no allowance was made in the model.

2.2.2 Climate Boundary Conditions

A ground surface temperature curve was developed for the Project site to represent the ground temperature immediately below surface. The boundary is defined by sinusoidal function of temperature and time based on Equation 1 and the parameters shown in Table 2.

$$T = \max(nf * \left[MAAT + (C_A * t) + Amp * Sin\left(\frac{2\pi+(t+182.5)}{365}\right)\right], \mathrm{nt} \left[MAAT + (C_A * t) + Amp * Sin\left(\frac{2\pi+(t+182.5)}{365}\right)\right] \quad \text{Eq.1}$$

Where:

- T *is the ground temperature measured in °C*
- nf *is the surface freezing n-factor*
- nt *is the surface thawing n-factor*
- $MAAT$ *is the mean annual air temperature measured in °C*
- Amp *is the air temperature amplitude measured in °C*
- C_A *is the air climate change factor in °C d^{-1}*
- t *is time measured in days*

Table 2: Current Climate Boundary Parameters

Model Parameter	Value
Mean annual air temperature *(MAAT)*	-10.7°C
Air temperature amplitude *(Amp)*	21.0°C
ROQ Surface, Thawing n-factor *(nt)*	1.52
ROQ Surface, Freezing n-factor *(nf)*	0.86
Tailings Beach, Thawing n-factor *(nt)*	1.52
Tailings Beach, Freezing n-factor *(nf)*	0.86
Natural Overburden, Thawing n-factor *(nt)*	0.55
Natural Overburden, Freezing n-factor *(nf)*	0.65

Mean annual air temperature and amplitude are based on average values for the baseline period of 1979-2005 (SRK 2016g). Seasonal n-factors are applied as multipliers of air temperature to estimate the ground surface temperature at the ground surface. The ROQ and tailings surfaces included a freezing n-factor (*nf*) of 0.86 and thawing n-factor (*nt*) of 1.52. These values are based on average published values (SRK 2016e) and considered to be reasonable base case conditions for the Project site. N-factors for natural overburden was applied downstream of the dams using values calibrated to ground temperatures measured at the Project site (SRK 2016h).

Climate change is considered in Equation 1 using the air climate change factor. This factor allows for a daily increase in air temperature within the model. Table 3 shows the daily increase in air temperature in the model which is based on the work of SRK (2016g). The model simulations are performed to the year 2100, which is 85 years beyond the year 2015.

Table 3: Summary of Doris Air Climate Change Factors Based on Climate Change Models

Year	Rate ($°C\ decade^{-1}$)	Air Climate Change Factor ($°C\ day^{-1}$)
2015 - 2040	0.74	0.000203
2041 - 2070	0.71	0.000195
2071 - 2100	0.69	0.000192

2.2.3 Initial Conditions

The initial conditions were defined by each material region in the model. The dam fill (ROQ material) was assumed to thermally adjust to the ambient air temperature during the period of winter construction. The initial temperature of the ROQ material was set to -6°C. The temperature of the ROM material would likely be colder during the winter construction period, and therefore represent a conservative input to the model. Initial ground temperature for the clay overburden was set to -7.6°C which is representative of average permafrost temperatures at the Project site (SRK 2016e). The model assumes continuous permafrost exists beneath the dam alignment prior to construction.

The vertical sides of the model space were set to a zero flux boundary and the lower boundary set to a constant flux 3.93 kJ/(m^2·day·°C) which was calculated from the average geothermal gradient (0.021°C m^{-1}) and the thermal conductivity of the clay overburden (SRK 2016e).

2.2.4 Transient Conditions

Active Deposition at Dam

For the period of active deposition, a constant temperature of +6°C was applied along the upstream face of the dam to the maximum elevation of the liner and along to the bottom of the TIA. The +6°C temperature used in the model is similar to the mean annual water temperature associated with Arctic lakes. This value is greater than the mean annual temperature resulting from heat transfer between the atmosphere and the exposed tailings surface. The boundary is considered to be conservative since a tailings beach formed against the upstream dam face will result in seasonal cooling of the tailings and gradually increase in height over the period of deposition.

The period of active deposition spans 2.97 years for the South Dam and 6.42 years for the West Dam (Figure 1). It is assumed that the West Dam's construction is delayed until immediately prior to the period of active deposition.

Beached Tailings

At each dam, a stable sub-aerial beach is specified in the model after the period of active deposition is complete (Figure 1). The climate boundary with average freezing and thawing n-factors is applied to the uppermost surface of the tailings beach (Equation 1; Table 2). An exposed tailings beach surface without a material cover is assumed in the model. The initial internal temperature of the tailings is specified to be +6°C, which is conservative when considering that a portion of Phase 1 tailings will be exposed to atmospheric conditions prior to the short period of Phase 2 deposition. The initial conditions for all other regions were defined by the last time step of the Active Deposition Model.

After the maximum beach elevation is achieved at each dam, the tailings deposition will shift to adjacent positions (spigots). Lateral heat flow from areas of active deposition is not expected to thermally influence the dam and key-in trench.

3 Results

3.1 South Dam

Figure 6 shows the predicted temperature of the South Dam and foundation at the end of active deposition (Year 2.97). The constant temperature applied to the model contributes to thaw along the upstream face of the dam and bottom of the TIA. The temperature of the model at the end of the design life is shown in Figure 7.

Over the 25 year design, the South Dam key-in trench and liner remains frozen at the critical position of Monitoring Point 1 (Figure 8). The maximum temperature predicted for this location is -3.6°C over the design life. Gradual cooling is observed shortly after the tailings deposition is complete and the beached tailings are sub-aerially exposed to heat transfer with the atmosphere.

At the South Dam, the tailings are observed to freezeback over a 13-year period following completion of deposition. During this period of time, seasonal thaw exceed freezeback. Figure 9 shows the tailings active layer which increases to a maximum thickness of 2.07 m by the year 2100.

3.2 West Dam

Figure 10 shows the predicted temperature for the West Dam and foundation at the end of active deposition (Year 9.39). Similar to the South Dam, the constant temperature applied to the upstream face of the dam and bottom of the TIA contributes to thaw. Modeled temperature at the end of the design life is shown in Figure 11. The South Dam key-in trench and liner remains frozen at the critical position of Monitoring Point 1, with a maximum temperature of -5.1°C over the 25-year design life (Figure 12).

The tailings are observed to freezeback over a two (2) year period near the West Dam. The reduced time for freezeback of the tailings at this location is related to the decreased thickness when compared to tailings deposited near the South Dam. By the year 2100, tailings active layer thickness is estimated to be 2.00 m (Figure 13).

4 Conclusions

Thermal modeling of the South and West TIA dams suggests that the thickness of the bulk ROM material of the dam, acting as thermal protection over the key trench, is adequate to maintain the base of the key-in trench and liner below -2°C. The thermal results confirm that the impermeable liner will provide the intended water retaining capacity over the 25-year design life.

5 References

Banin A, Anderson DM. 1974. Effects of Salt Concentration Changes During Freezing on the Unfrozen Water Content of Porous Materials. Water Resources Research 10: 124-128.

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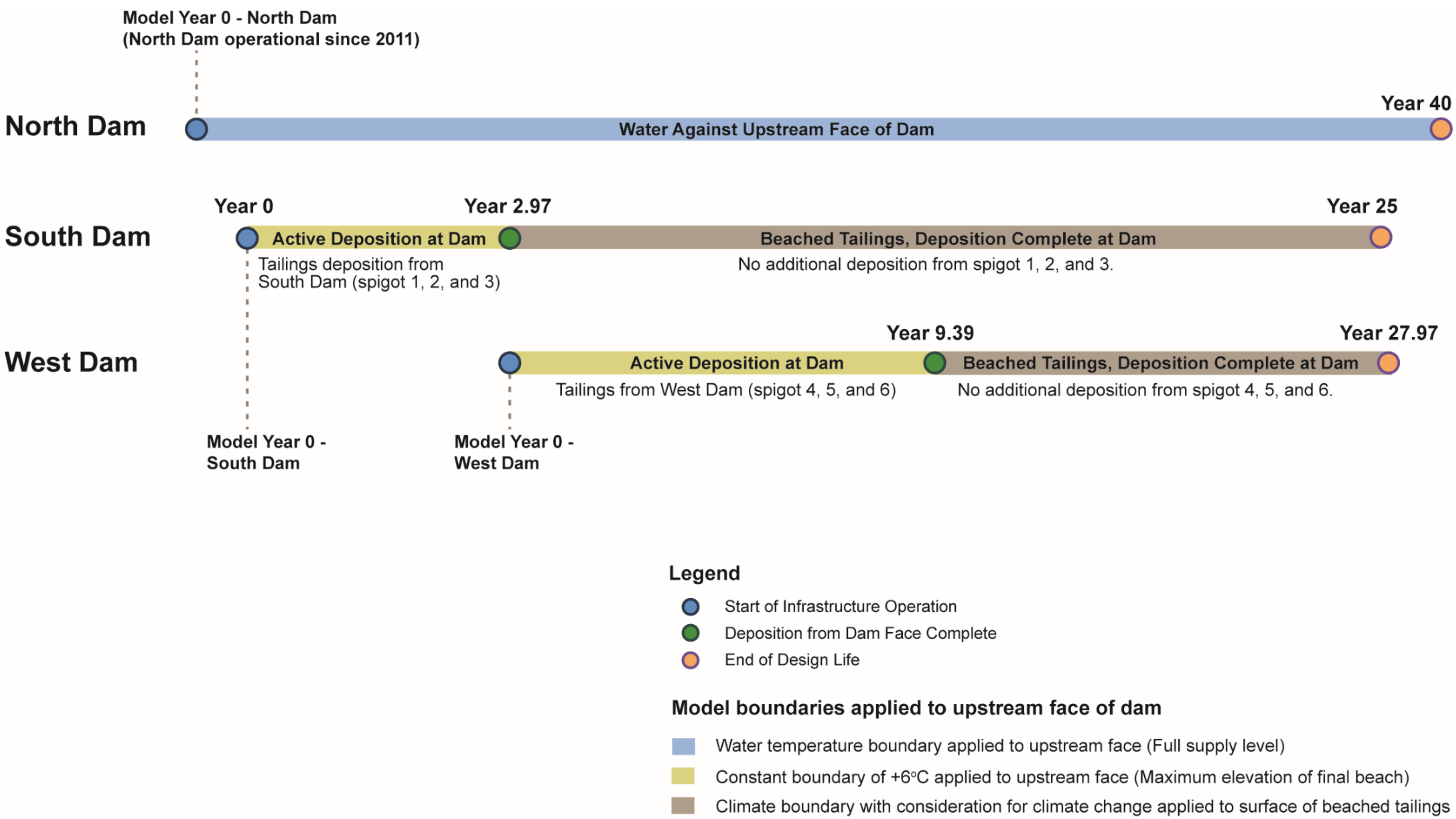
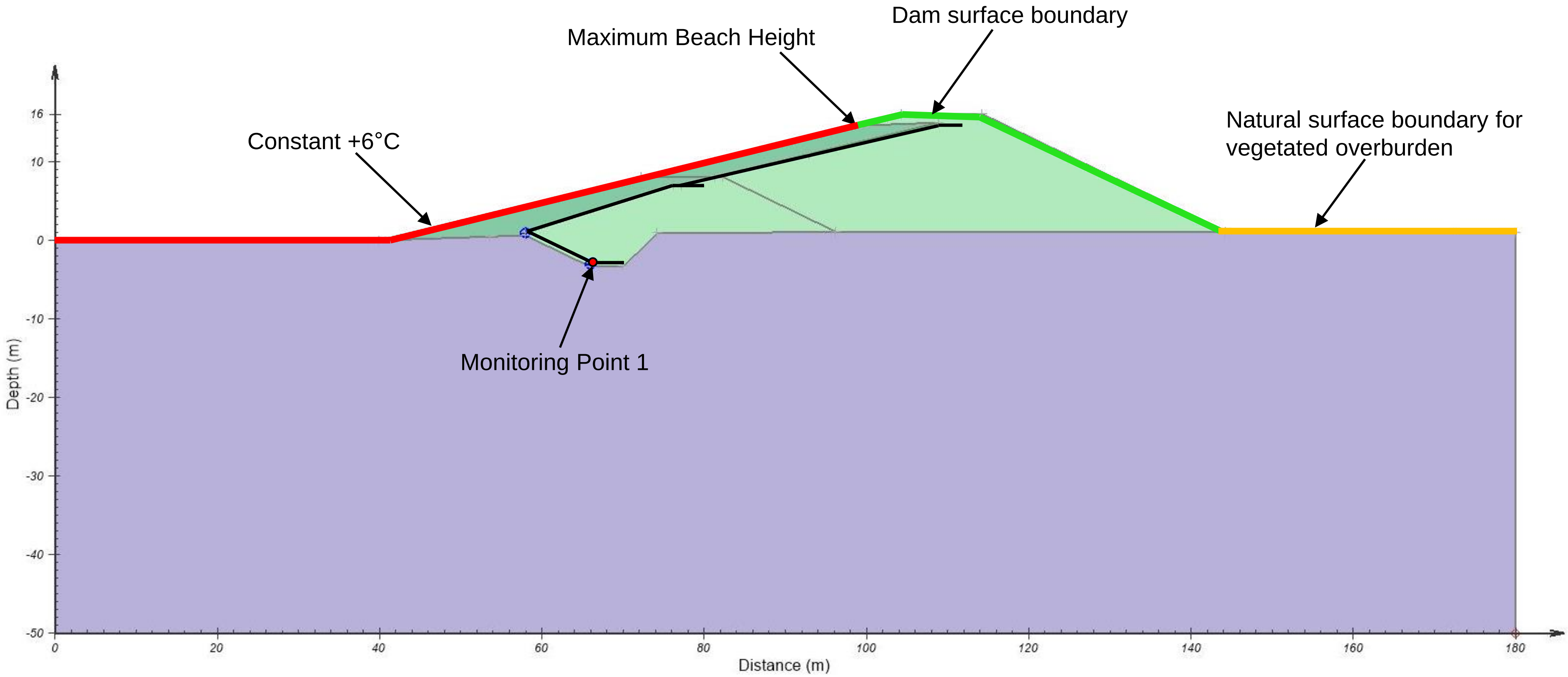
Figures



Notes:

1. Spigot numbers refer to the location of tailings deposition described in SRK (2016d)

srk consulting	MAC RESOURCES	Doris TIA Thermal Modeling
		Timeline for Thermal Models
Job No: 1CT022.004 Filename: ModelSWDams.pptx	HOPE BAY PROJECT	Date: 6/2/2016 · Approved: cws · Figure: 1



Notes:

1. Model geometry for period of active tailings deposition from South Dam
2. ROQ – Run-of-Quarry material or geochemically suitable run-of-mine (ROM) waste rock

Materials

- ROQ
- Clay
- ROQ100Saturation

srk consulting

Job No: 1CT022.004

Filename: ModelSWDams.pptx

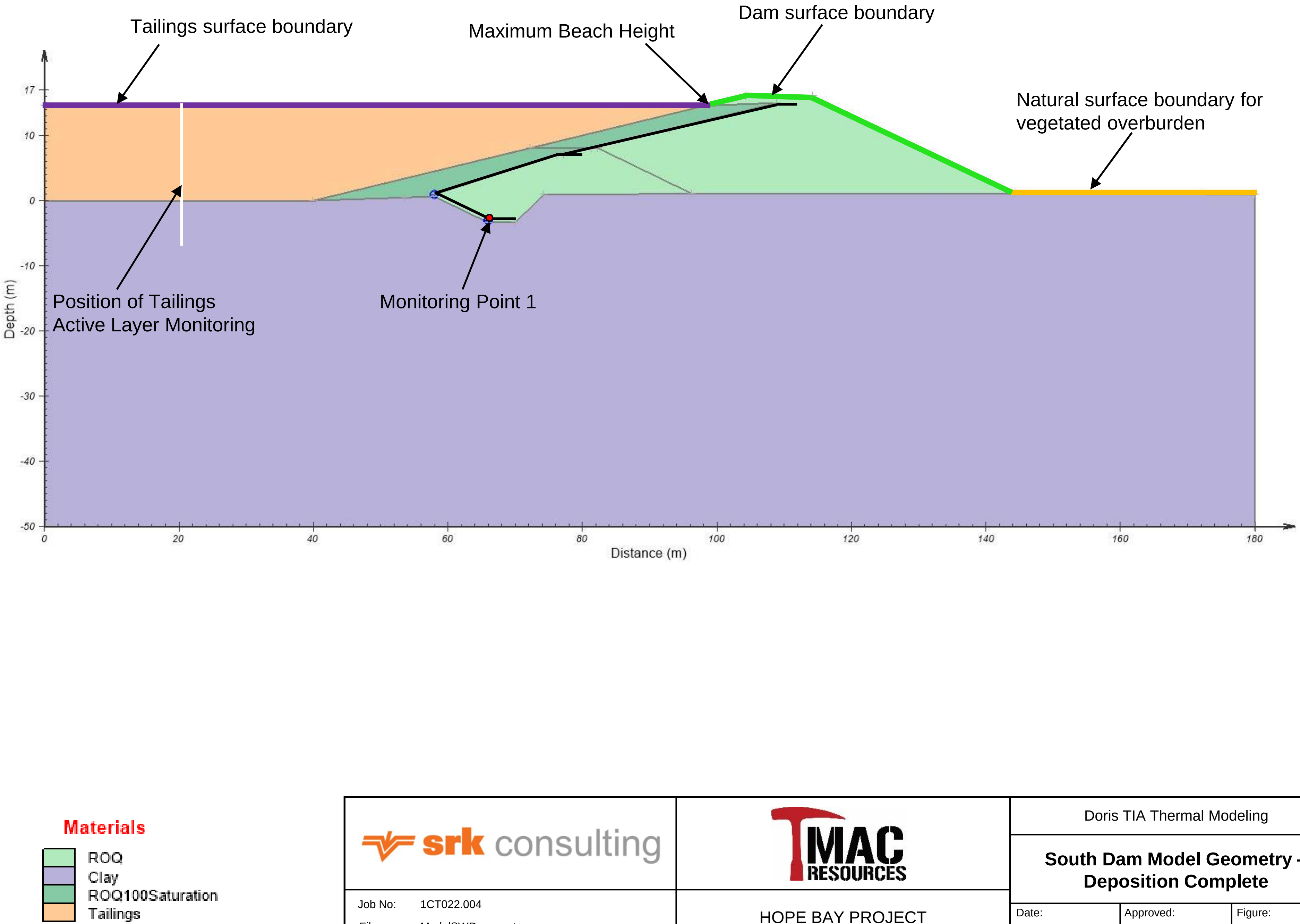
TMAC RESOURCES

HOPE BAY PROJECT

Doris TIA Thermal Modeling

South Dam Model Geometry – Active Deposition

Date:	Approved:	Figure:
6/2/2016	cws	2



srk consulting

MAC RESOURCES

Job No: 1CT022.004

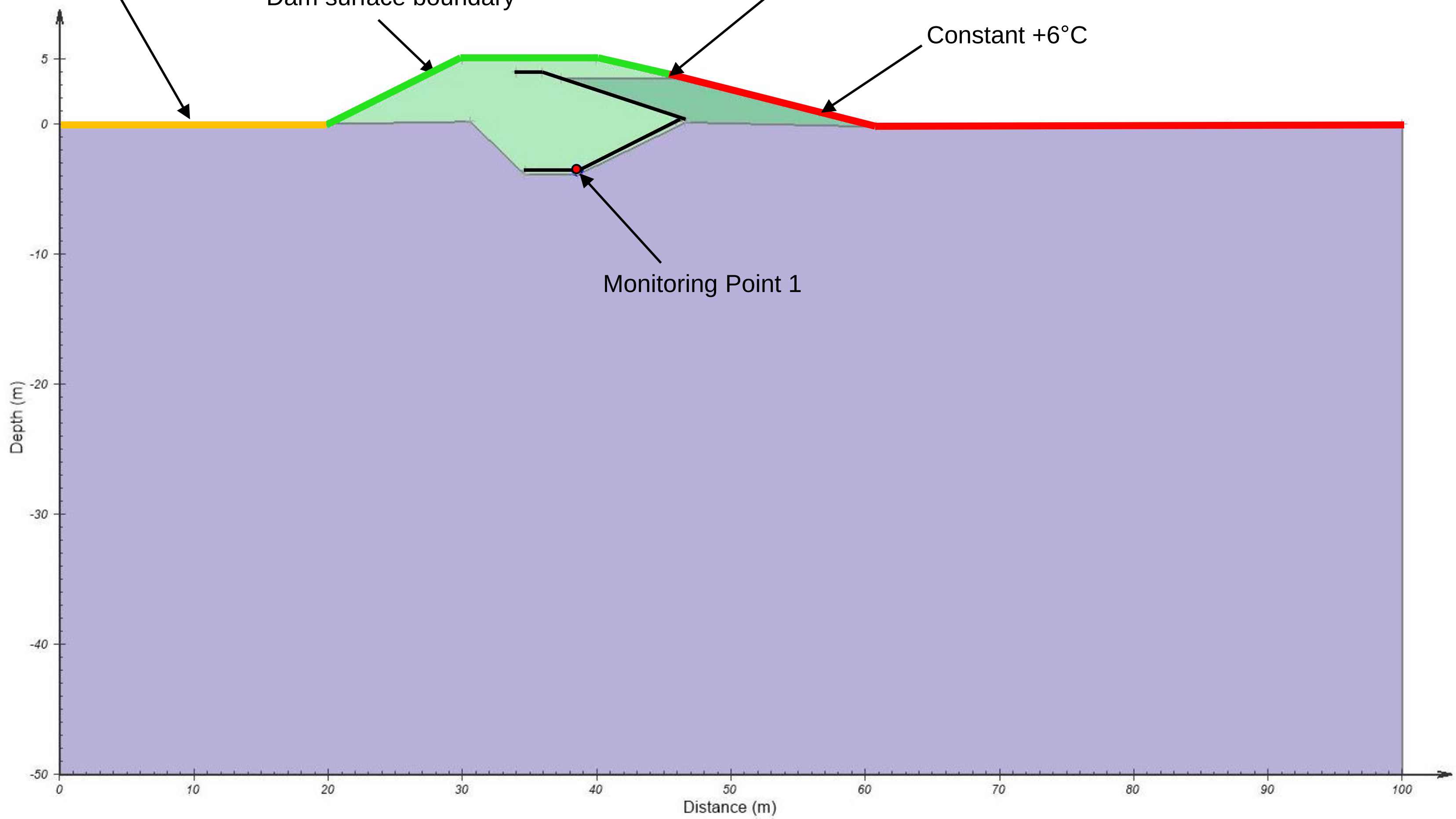
Filename: ModelSWDams.pptx

HOPE BAY PROJECT

Doris TIA Thermal Modeling

South Dam Model Geometry – Deposition Complete

Date:	Approved:	Figure:
6/2/2016	cws	3



Notes:

1. Model geometry for period of active tailings deposition from West Dam
2. ROQ – Run-of-Quarry material or geochemically suitable run-of-mine (ROM) waste rock

Materials

- ROQ
- Clay
- ROQ100Saturation

srk consulting	MAC RESOURCES	Doris TIA Thermal Modeling **West Dam Model Geometry – Active Deposition**
Job No: 1CT022.004 Filename: ModelSWDams.pptx	HOPE BAY PROJECT	Date: 6/2/2016 · Approved: cws · Figure: 4

Notes:

1. Model geometry period of beached tailings following completion of deposition from the West Dam
2. ROQ – Run-of-Quarry material or geochemically suitable run-of-mine (ROM) waste rock

Materials

- ROQ
- Clay
- ROQ100Saturation
- Tailings

srk consulting

MAC RESOURCES

Job No: 1CT022.004

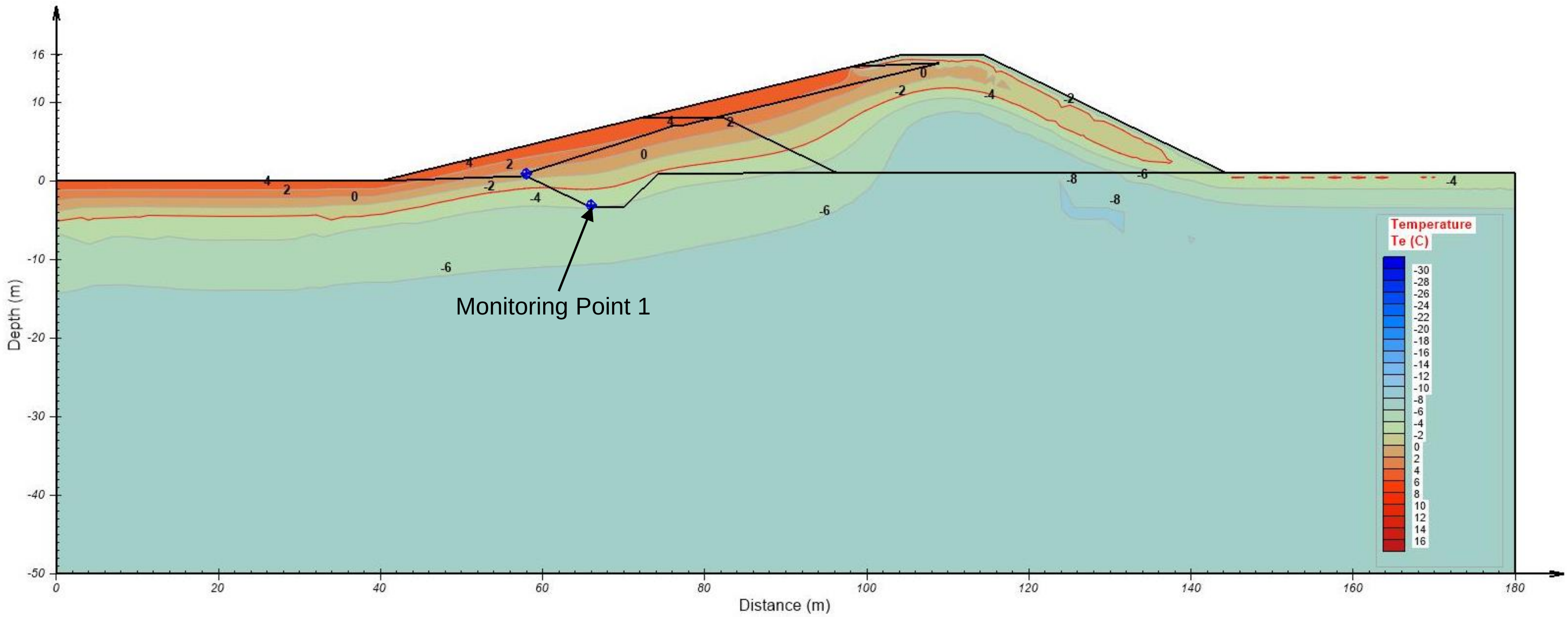
Filename: ModelSWDams.pptx

HOPE BAY PROJECT

Doris TIA Thermal Modeling

West Dam Model Geometry – Deposition Complete

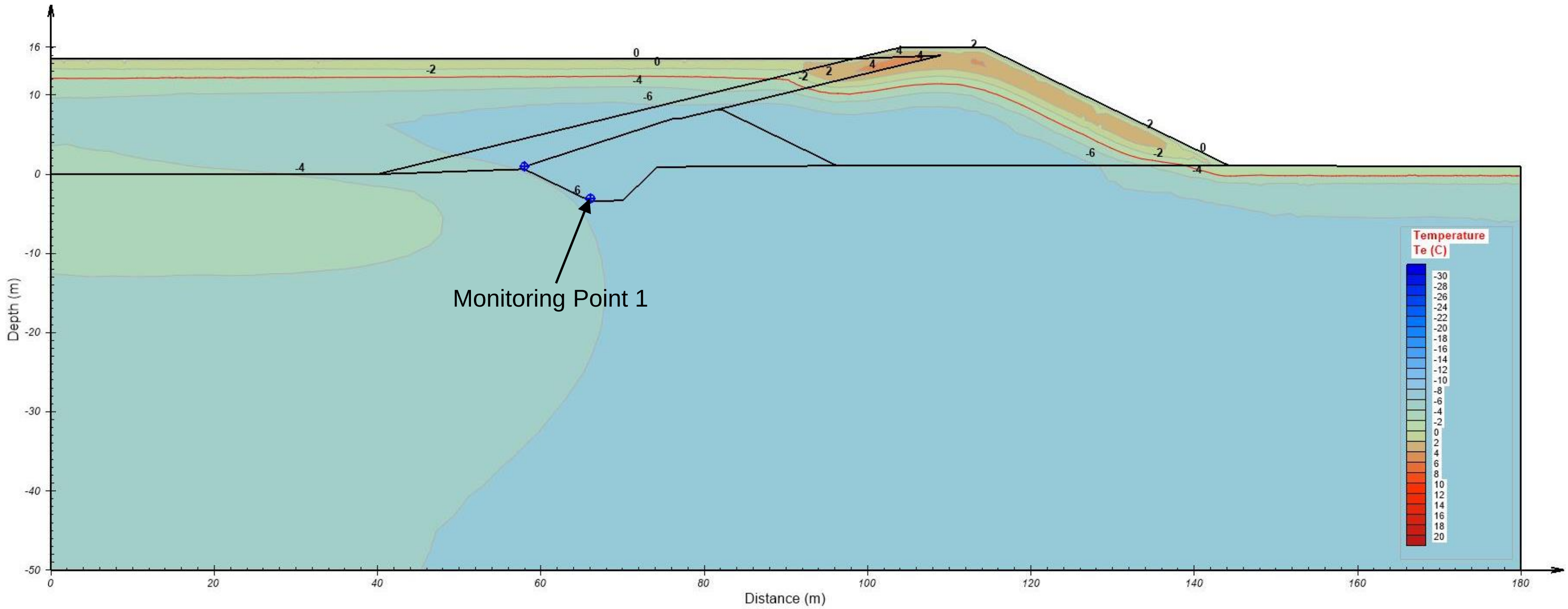
Date:	Approved:	Figure:
6/2/2016	cws	5



Notes:

1. Model results for Year 2.97 at the end of active deposition from the South Dam
2. Solid red line shows -2°C isotherm

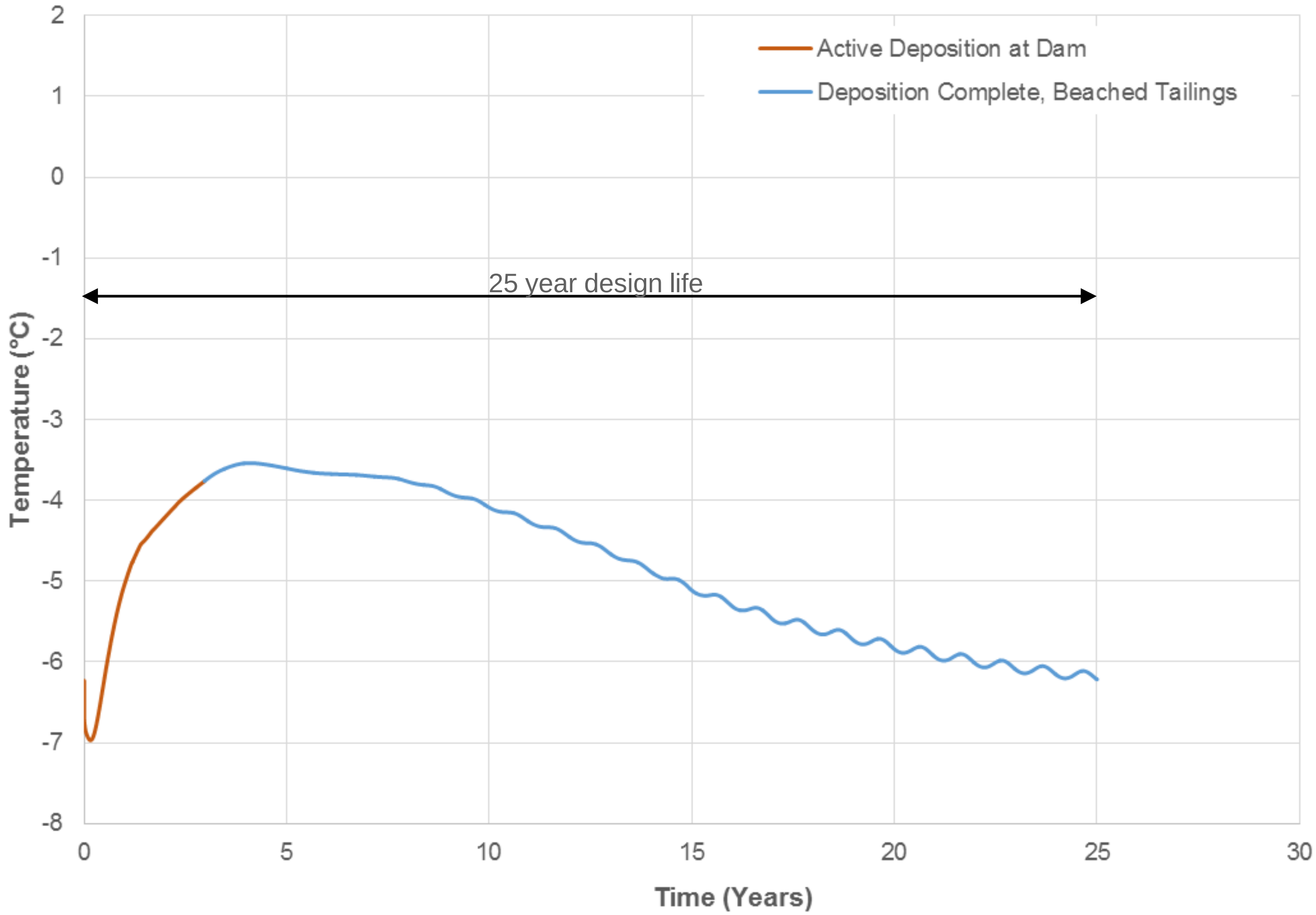
srk consulting	MAC RESOURCES	Doris TIA Thermal Modeling
		South Dam – Model Year 2.97
Job No: 1CT022.004 Filename: ModelSWDams.pptx	HOPE BAY PROJECT	Date: 6/2/2016 | Approved: cws | Figure: **6**



Notes:

1. Model results for maximum position of seasonal thaw at the end of the 25 year design life
2. Solid red line shows -2°C isotherm

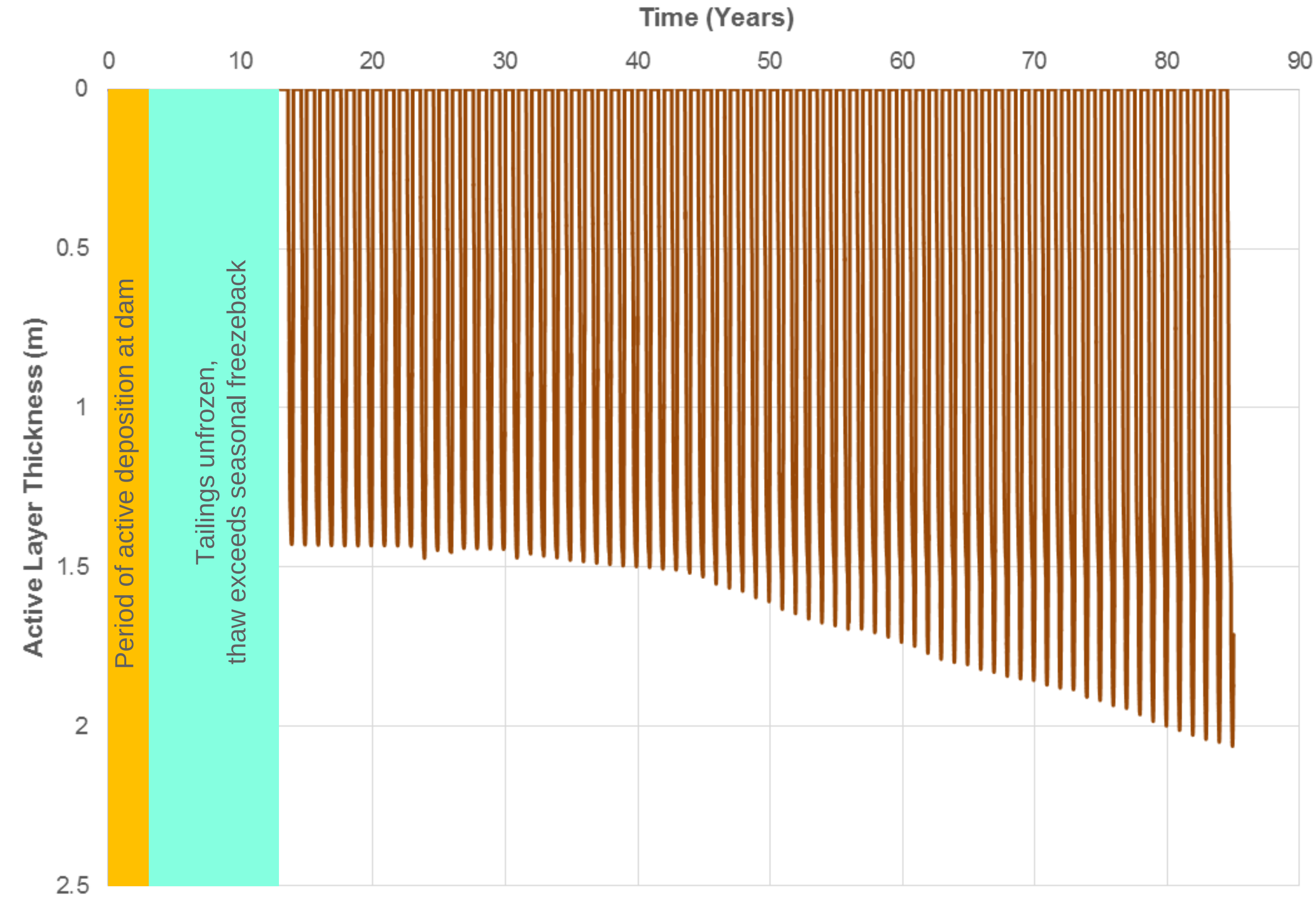
srk consulting	MAC RESOURCES	Doris TIA Thermal Modeling
Job No: 1CT022.004	HOPE BAY PROJECT	**South Dam – End of Design Life**
Filename: ModelSWDams.pptx		Date: 6/2/2016 · Approved: cws · Figure: 7



Notes:

1. Location of monitoring point 1 shown on Figures 2 and 3
2. Time express as number of years from start of South Dam operation

srk consulting	MAC RESOURCES	Doris TIA Thermal Modeling
		South Dam – Temperature at Monitoring Point 1
Job No: 1CT022.004 Filename: ModelSWDams.pptx	HOPE BAY PROJECT	Date: 6/2/2016 · Approved: cws · Figure: **8**



Year	Max depth of thaw (m)	Comment
3	17.61	Thaw exceeds freezeback
5	15.72	Thaw exceeds freezeback
10	13.22	Thaw exceeds freezeback
15	1.43	Active Layer
20	1.43	Active Layer
25	1.45	Active Layer
30	1.47	Active Layer
35	1.48	Active Layer
40	1.50	Active Layer
45	1.55	Active Layer
50	1.63	Active Layer
55	1.69	Active Layer
60	1.75	Active Layer
65	1.82	Active Layer
70	1.87	Active Layer
75	1.93	Active Layer
80	2.01	Active Layer
85	2.07	Active Layer

Notes:

1. Active layer thickness based on 0°C isotherm
2. Location of active layer thickness shown on Figure 3
3. Time express as number of years from start of South Dam operation

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MAC RESOURCES

Doris TIA Thermal Modeling

South Dam – Tailings Active Layer (Year 0 to 85)

Job No: 1CT022.004

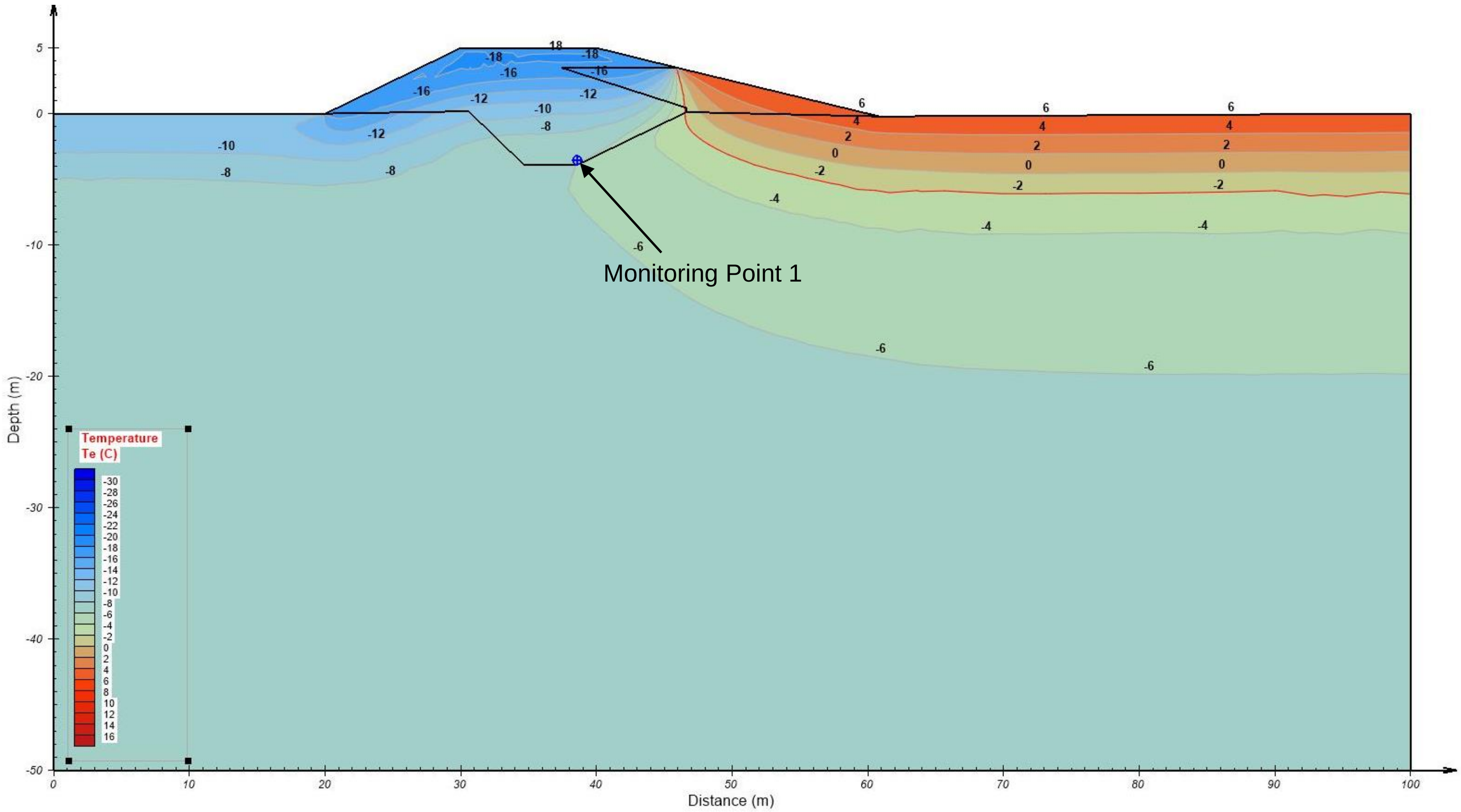
Filename: ModelSWDams.pptx

HOPE BAY PROJECT

Date: 6/2/2016

Approved: cws

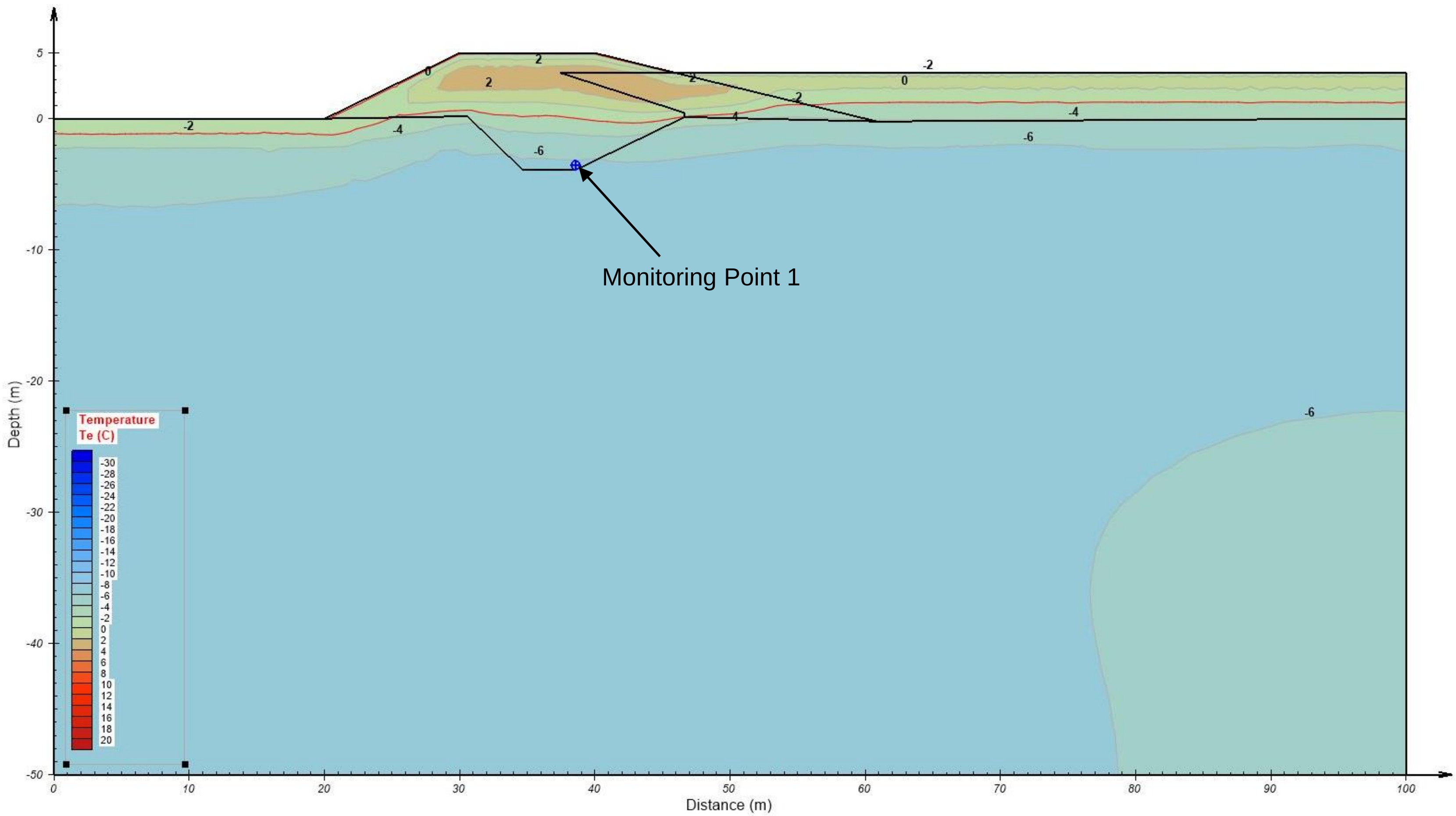
Figure: 9



Notes:

1. Model results for Year 9.39 at the end of active deposition from the West Dam
2. Solid red line shows -2°C isotherm

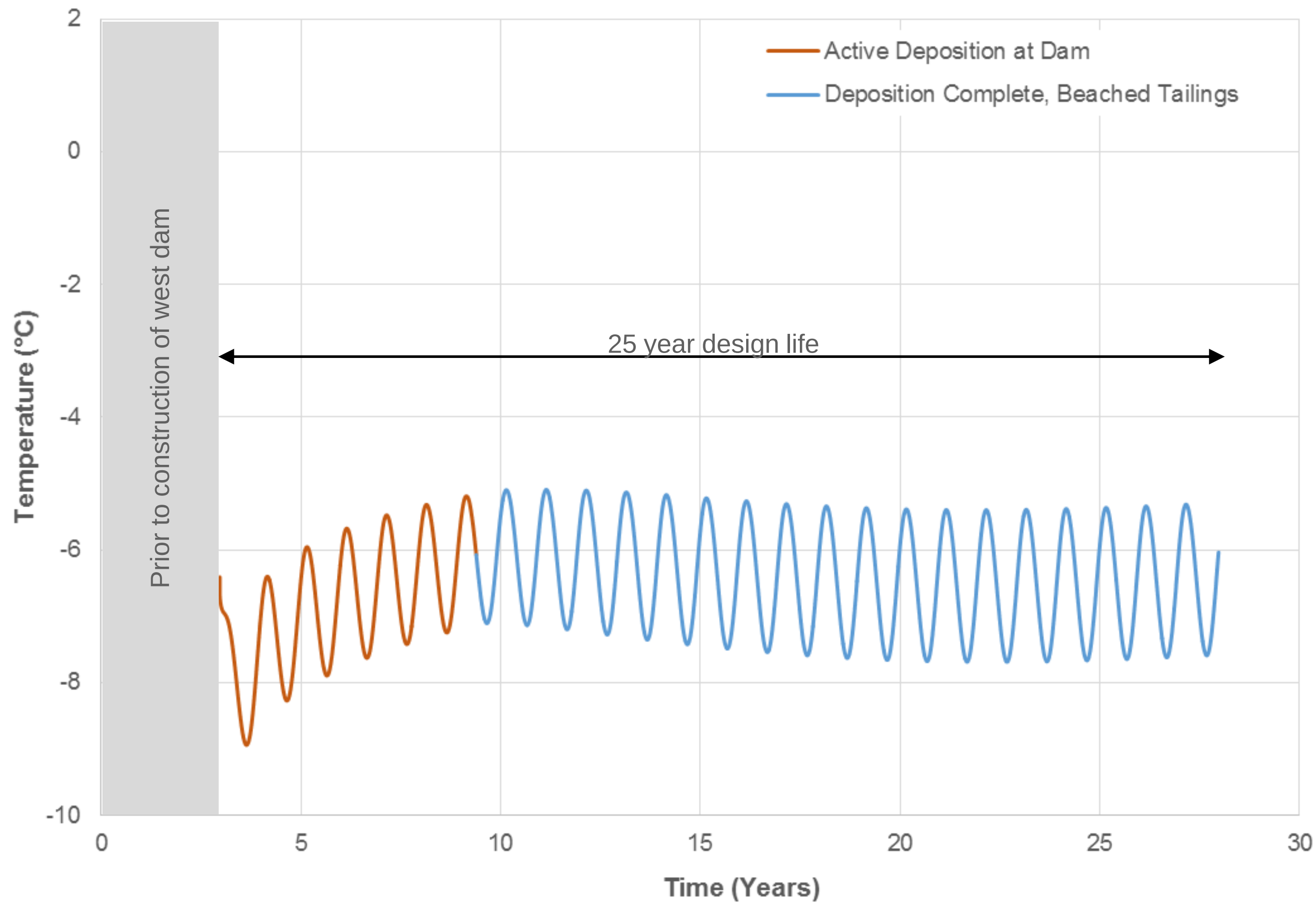
srk consulting	MAC RESOURCES	Doris TIA Thermal Modeling
		West Dam – Model Year 9.39
Job No: 1CT022.004 Filename: ModelSWDams.pptx	HOPE BAY PROJECT	Date: 6/2/2016 · Approved: cws · Figure: **10**



Notes:

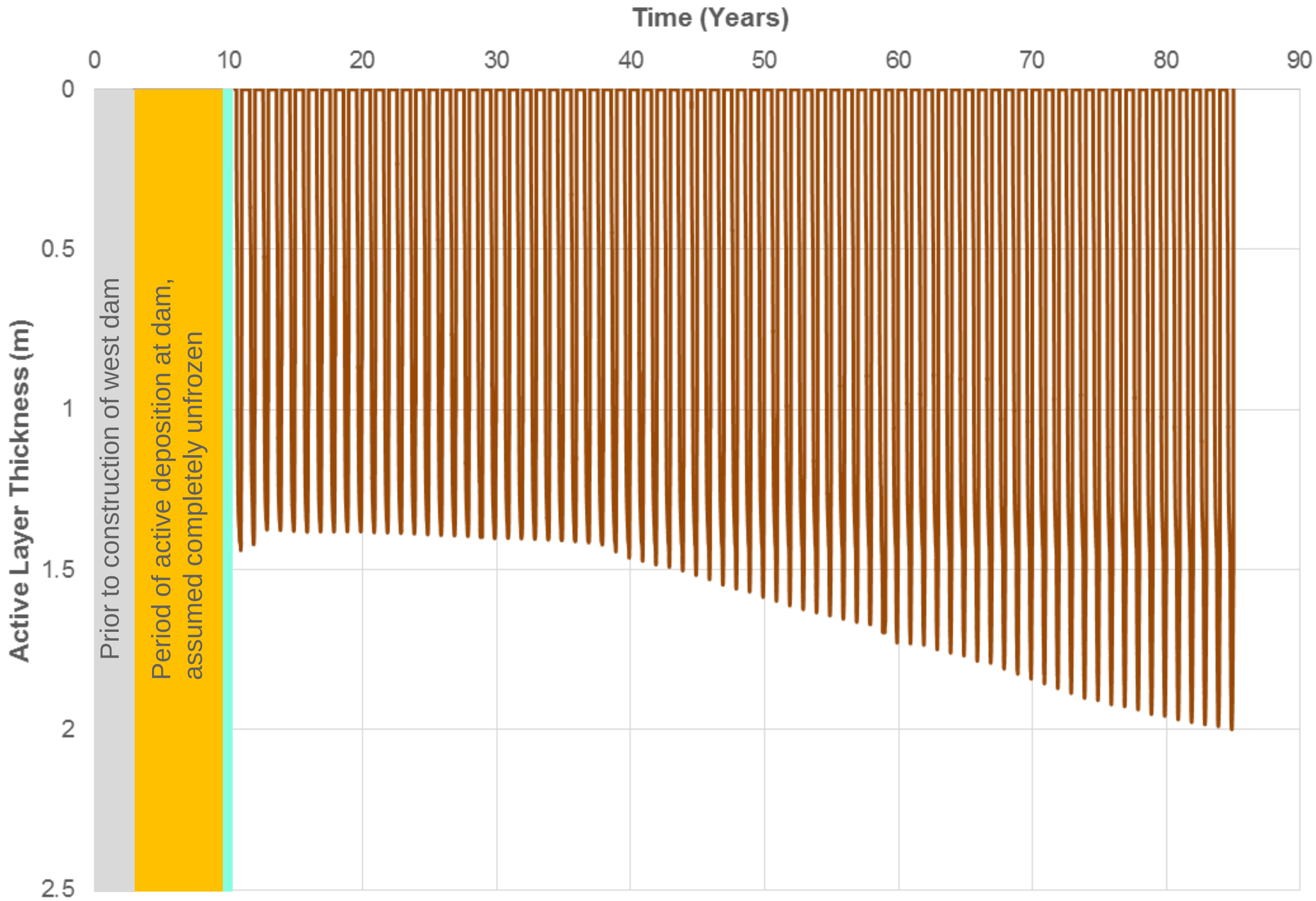
1. Model results for maximum position of seasonal thaw at the end of the 25 year design life
2. Solid red line shows -2°C isotherm

srk consulting	MAC RESOURCES	Doris TIA Thermal Modeling
		West Dam – End of Design Life
Job No: 1CT022.004 Filename: ModelSWDams.pptx	HOPE BAY PROJECT	Date: 6/2/2016 Approved: cws Figure: **11**



Notes:
1. Location of monitoring point 1 shown on Figures 4 and 5
2. Time express as number of years from start of South Dam operation

srk consulting	TMAC RESOURCES	Doris TIA Thermal Modeling **West Dam – Temperature at Monitoring Point 1**
Job No: 1CT022.004 Filename: ModelSWDams.pptx	HOPE BAY PROJECT	Date: 6/2/2016 · Approved: cws · Figure: **12**



Year	Max depth of thaw (m)	Comment
10	8.07	Thaw exceeds freezeback
11	5.90	Thaw exceeds freezeback
15	1.38	Active Layer
20	1.38	Active Layer
25	1.39	Active Layer
30	1.40	Active Layer
35	1.41	Active Layer
40	1.46	Active Layer
45	1.52	Active Layer
50	1.59	Active Layer
55	1.64	Active Layer
60	1.73	Active Layer
65	1.77	Active Layer
70	1.84	Active Layer
75	1.91	Active Layer
80	1.96	Active Layer
85	2.00	Active Layer

Notes:
1. Active layer thickness based on 0°C isotherm
2. Location of active layer thickness shown on Figure 11
3. Time express as number of years from start of South Dam operation

srk consulting

MAC RESOURCES

Doris TIA Thermal Modeling

West Dam – Tailing Active Layer (Year 0 to 85)

Job No: 1CT022.004
Filename: ModelSWDams.pptx

HOPE BAY PROJECT

Date: 6/2/2016
Approved: cws
Figure: 13

Appendix I – Hope Bay Project: Phase 2 Tailings Impoundment Area, South Dam and West Dam Settlement, and Tailings Frost Heave Evaluation

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Memo

To:	John Roberts, PEng, Vice President Environment	**Client:**	TMAC Resources Inc.
From:	Tia Shapka-Fels Peter Luedke, EIT Iozsef Miskolczi, MASc, PEng	**Project No:**	1CT022.004
Reviewed:	Arcesio Lizcano, PhD Maritz Rykaart, PhD, PEng	**Date:**	December 8, 2016
Subject:	Hope Bay Project: Phase 2 TIA, South and West Dam Settlement and Tailings Frost Heave Evaluation		

1 Introduction

1.1 General

The Hope Bay Project (the Project) is a gold mining and milling undertaking of TMAC Resources Inc. (TMAC). The Project is located 705 km northeast of Yellowknife and 153 km southwest of Cambridge Bay in Nunavut Territory, and is situated east of Bathurst Inlet. The Project comprises of three distinct areas of known mineralization plus extensive exploration potential and targets. The three areas that host mineral resources are Doris, Madrid, and Boston.

The Project consists of two phases; Phase 1 (Doris project), which is currently being carried out under an existing Water Licence, and Phase 2 which is in the environmental assessment stage. Phase 1 includes mining and infrastructure at Doris only, while Phase 2 includes mining and infrastructure at Madrid and Boston located approximately 10 and 60 km respectively due south from Doris.

Phase 1 tailings are deposited sub-aerially in the Doris Tailings impoundment Area (TIA), formerly Tail Lake, located approximately 5 kilometres from the Doris Mill. Containment is provided by three retention structures; a water retaining frozen core dam (North Dam), a frozen foundation tailings containment dam (South Dam); and an Interim Dike situated at approximately the midpoint of the facility.

Phase 2 tailings deposition would include a continuation of the Doris TIA with raising of the South Dam and construction of a new West Dam. Tailings would be deposited sub-aerially starting at spigot points along the crest of the raised South Dam and the West Dam, as well as additional spigot points along the eastern perimeter.

At closure, once water quality discharge criteria are met within the Reclaim Pond, the North Dam would be breached returning the pond water level to the pre-mining elevation of 28.3 m. The tailings surface will be covered with a nominal geochemically suitable waste rock cover of 0.3 m thickness. The function of the cover is to prevent dust and to minimize direct contact by animals and humans.

1.2 Objectives

1.2.1 Settlement Evaluation

The South and West dams will be constructed on frozen foundation soils and are designed as frozen foundation dams. Thermal modeling shows that the key trench and liner of both dams remain frozen at critical elevations over their 25 year design life (SRK 2016a). This technical memorandum provides details of the settlement that would occur should the foundation sediments thaw under the entire structure.

1.2.2 Frost Heave Evaluation

Tailings will be deposited from spigot points along the South and West Dams, and along the eastern perimeter. The maximum thickness of the final tailings deposit will be about 20 m, tapering off around the perimeter and toward the North Dam. This memorandum provides details on the expected magnitude of frost heave due to talik freeze-back and the effect of frost heave on the integrity of the proposed closure cover.

2 Site Conditions

2.1 South and West Dam Geometry

The South and West Dams are frozen foundation dams with a geosynthetic clay liner (GCL) keyed into the permafrost overburden foundation. The dams will not have ponded water against them as tailings will be beached from the crest of the dams pushing the supernatant pond water, i.e. Reclaim Pond, away from the dams. To accommodate Phase 2 tailings, the Phase 1 South Dam will be raised, and the West Dam will be a new structure.

The Phase 2 raise of the South Dam will be a downstream raise following the same geometry as the Phase 1 design. The final crest width will be 10 m, the upstream slope 4H:1V, and the downstream slope 2H:1V (Figure 1). The crest elevation is raised 8 m from 38.0 to 46.0 m and results in a maximum dam height of 15 m and total dam length of 520 m. The key trench will be about 4 m deep, have a base width of 4 m with 2H:1V, and 1H:1V upstream and downstream slopes respectively. The GCL previously installed as part of the Phase 1 South Dam will be extended vertically to reach an elevation of 45.0 m at a slope of 4H:1V.

The West Dam was designed with the same cross section as the South Dam. This dam will be constructed in a single stage, and will be about 470 m long with a maximum height of 5 m.

2.2 Foundation Conditions

2.2.1 South Dam

Sub-surface investigations has been completed along the foundation of the Phase 1 South Dam (SRK 2003, 2005, 2007), but not along the footprint of the Phase 2 raise. It is however reasonable to assume that foundation conditions under the raise would be similar to those under Phase 1.

Foundation conditions are variable, with the overburden at its maximum thickness along the center of the proposed alignment, thinning towards the abutments. The upper, approximately 5.5 m of the profile, consists of marine silt which transitions to marine silt and clay to a depth of about 24 m below ground surface (i.e. about 18.5 m thick). Beneath these sediments is a layer of gravelly till of about 10 m thick overlying basalt bedrock.

The entire profile is cold permafrost (-8˚C near-surface temperature), with an active layer thickness of about 1 m. The marine silt and clay are ice rich with clear ice lenses present. Salinity results from samples collected in the footprint of the South Dam foundation indicate salinity ranges from 6 ppt to 86 ppt, with an average of about 47 ppt. This results in a depressed freezing point of about -2.6˚C (Andersland 2004).

Thermal modeling of the South Dam (SRK 2016a) confirms that the foundation soils beneath the dam will remain frozen. At the end of the design life, the active layer downstream of the dam (-2°C isotherm) is approximately 1 m below the ground surface. The isotherm roughly follows the profile of the dam, and as such, rises toward the crest into the dam fill. With this thermal profile, the critical foundation beneath the key trench and crest does not thaw, thus any thaw effects will be limited and localised to the downstream toe (SRK 2016a).

2.2.2 West Dam

Sub-surface characterization at the West Dam is limited to a single drill hole (SRK-39), completed in 2003 (SRK 2003). This drill hole suggests a layer about 7 m thick of marine silty clay overlying basalt bedrock. Bedrock outcrops at both abutments suggests thinning of the overburden towards the abutments, similar to the South Dam. Ice content in the overburden soil formations was assumed to be consistent with the ice content of the South Dam foundation soils.

Similarly, at the end of the design life, the active layer (based on the -2°C isotherm) was assumed to be approximately 1 m below the ground surface near the downstream toe of the West Dam. The isotherm roughly follows the profile of the dam, and as such, rises towards the crest, into the dam fill. With this thermal profile, the critical foundation beneath the key trench and crest does not thaw and any thaw effects will be limited and localized to the downstream toe (SRK 2016a).

2.2.3 Tailings Area

Site characterization and thermal analysis (SRK 2016a) suggest a closed talik beneath the TIA (formerly Tail Lake). The overburden profile underneath the TIA can be inferred from site characterization under the North and South Dams, as well as drill hole completed through the TIA

(SRK 2016b). The overburden thickness ranges from about 15 m at the North Dam to about 34 m at the South Dam, and consists of predominantly marine silt and clay, overlying gravelly till and basalt bedrock.

Thermal modelling (SRK 2016a) confirms that tailings freeze back will occur and that permafrost will extend into the foundation soils underlying the deposited tailings, ultimately removing the closed talik.

2.3 Material Properties

Material properties for the analysis was based on the North Dam (SRK 2007), and Phase 1 South Dam (SRK 2015b) designs, supplemented with the site wide geotechnical design properties (SRK 2016b). Table 1 summarize the properties used in the analysis.

Table 1: South and West Dam Foundation and Material Properties

Parameter	Run-of-Quarry Rock (Dam Fill)	Thawed Marine Silt and Clay	Tailings
Dry Unit Weight (kN/m^3)	19.12[1]	12.67[1]	12.75[9]
Saturation (%)	30.0[2]	84.7[3]	100.0[7]
Gravimetric Water Content (%)	4.6[1]	34.2[2]	41.8[9]
Moist Unit Weight (kN/m^3)	20.0[2]	17.0[4]	18.1[9]
Specific Gravity	2.80[5]	2.70[2]	2.85[8]
Void Ratio	0.44[1]	1.09[1]	1.20[8]
Compression Index	-	0.3[6]	0.1[7]

Notes:

[1]Calculated value based on sources 2,4,5 below.
[2]SRK 2011
[3]Assumed value based on location and high excess ice content prior to thaw.
[4]SRK 2015
[5]EBA 2011
[6]Assumed value based on range of laboratory testing data and expected average value of silts and clays.
[7]Assumed at deposition
[8]SRK 2016c
[9]Calculated based on sources 7 and 8

3 Settlement Evaluation

3.1 Approach

3.1.1 Analysis Assumptions

The settlement evaluation assumes that settlement at each dam site will only occur if the foundation thaws. If that happens the settlement will occur as a result of consolidation in the foundation soils, and as a result of the ice content in the foundation soils. The analysis assumes the following:

- Marine silt and clay underlie the structures;

- The partial thaw depth considered in this analysis was 1 m, and was assumed to occur uniformly across the entire dam footprint. 1 m is a conservative depth as the predicted thaw is only 1 m at the toe of the dams (SRK 2016d);
- The maximum thaw depth considered in this analysis was 7 m, and was assumed to occur uniformly across the entire dam footprint (SRK 2016d);
- Following foundation thaw, the marine silt and clay is in a normally consolidated state prior to the application of the full load induced by the entire dam structure;
- After foundation thaw, the excess of pore water pressure is equal to the contact pressure at the ground surface exerted by the entire dam structure; and
- Consolidation of the underlying frozen marine silt and clay is negligible.

3.1.2 Settlement due to Foundation Consolidation

Consolidation settlement, δ_c, was evaluated using the one-dimensional consolidation theory from Terzaghi (1943):

$$\delta_c = \frac{H}{1+e_0} C_c \log\left(\frac{\sigma' + \Delta\sigma'}{\sigma'}\right) \quad (1)$$

where:

C_c = compression index of the marine silt and clay (dimensionless);
e_0 = initial void ratio of the marine silt and clay (dimensionless);
H = thickness of the consolidation layer (m);
σ'= Average in-situ effective stress in the consolidations layer (kPa); and
$\Delta\sigma'$= Stress increment in the consolidation layer due to the weight of the dam (kPa).

3.1.3 Settlement due to Foundation Ice Content

Settlement due to the foundation ice content considers both excess (i.e. massive) and non-visible ice. Andersland (2004) attributes settlement from thaw of non-visible ice to 9% of the total thaw depth. Settlement associated with thaw of excess ice is calculated as the percentage of excess ice in the foundation soil multiplied by the thaw depth.

3.2 Results

The settlement results are summarized in Table 2. To account for uncertainty associated with the actual foundation conditions under the structures, a sensitivity analysis was completed with foundation ice content values of 10%, 20% and 30%.

Table 2: Total Settlement with Foundation Thaw of 1 m and 7 m

	Excess Ice (%)	Excess Ice Settlement (m)		Non-Visible Ice Settlement (m)		Consolidation Settlement (m)		Total Settlement (m)	
Structure / Thaw Depth		**1 m**	**7 m**	**1 m**	**7 m**	**1 m**	**7 m**	**1 m**	**7 m**
South Dam	10%	0.10	0.70	0.09	0.63	0.28	1.12	0.47	2.45
	20%	0.20	1.40	0.09	0.63	0.28	1.12	0.57	3.15

	30%	0.30	2.10	0.09	0.63	0.28	1.12	0.67	3.85
West Dam	10%	0.10	0.70	0.09	0.63	0.21	0.70	0.40	2.03
	20%	0.20	1.40	0.09	0.63	0.21	0.70	0.50	2.73
	30%	0.30	2.10	0.09	0.63	0.21	0.70	0.60	3.43

This simplified analysis provides a conservative range of settlement that could occur over time. Based on the thermal modelling completed by SRK, the dam settlement by the year 2100 will be less than the 1 m case as the foundation is not expected to fully thaw. The 7 m thaw case represents a long term potential settlement case that is not plausible under the expected long term field conditions, and is only used as a theoretical absolute limit (on a millennial time scale).

4 Frost Heave Analysis

Frost heave is a common phenomenon in cold regions resulting in a rise in elevation of a structure or facility due to massive ice lens formation or volume change associated with the freezing of pore water. Frost heave could occur in the foundation or within the rock fill structures. If not managed frost heave has the potential to cause damage to structures and facilities.

4.1 Approach

4.1.1 Analysis Assumptions

The South and West Dams will be constructed on frozen overburden foundations, well outside of the former Tail Lake footprint, and thus outside of the influence of the lake talik. Frost heave of the dams associated with foundation freeze back will therefore not occur. Furthermore the dams are constructed with non-frost susceptible materials and therefore frost heave within the dam structure will not occur.

The Doris TIA will be constructed in the basin of the former Tail Lake, and the tailings will be displacing the lake water and occupy the former lake bed. The thermal modelling completed for the TIA (SRK 2016a) indicates that complete talik freeze-back will occur. Freeze-back of the pore water in the lake sediments and foundation soils within talik will cause frost heave of the tailings deposit and the overlying closure cover. Likewise the tailings are placed in a thawed and saturated state, and as the tailings freezes back frost heave will be experienced.

4.1.2 Heave Assessment of Tailings

Two mechanisms of frost heave were identified as potentially impacting the structures associated with the Doris TIA, as follows:

- Freezing of pore water; and
- Segregated ice formation.

Differential heave resulting from massive ice lens formation could compromise the physical integrity of the cover, while generalized uniform heave over large areas as in the case of pore water freeze-back would not necessarily cause undue differential deformations.

A relative upper bound of deformation due to pore water freeze-back was calculated based on the fact that a unit volume of liquid water will experience an increase in volume of about 9%. The one-dimensional deformation was computed using the following equation:

$$s = \frac{H}{1+e_0}\Delta e \qquad (2)$$

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); $e_0 = 1.2$
Δe: Void ratio increase due to freezing of tailings pore water (unitless); $\Delta e = 0.09e_0$

Estimating the potential and the magnitude for segregated ice is difficult, and due to lack of relevant data was not completed for this stage of project planning; however, a qualitative analysis is presented in this section. 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 underlying the Reclaim Pond.

4.2 Results and Discussion

4.2.1 Frost Heave due to Freezing of Pore Water

Tailings pore water will freeze relatively fast following deposition, and mostly within the period of active tailings deposition. Therefore, by the time the closure cover will be constructed, there will be no further frost heave associated with the actual tailings freeze back. The active layer within the tailings will initially be about 1.5 m, and by the year 2100, accounting for climate change, the tailings active layer would have increased to about 2.0 m (SRK 2016a). Freeze and thaw of this active layer will result in minor frost heave and thaw settlement changes on an annual cycle.

Under the conservative assumption that the tailings of the active layer, before cover construction, have the same void ratio as at time of deposition and are completely saturated, the maximum magnitude of frost heave was calculated to be 9.8 cm, considering pore water in the foundation soils will freeze in time as the talik closes. 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 upper bound 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.

The upper bound of the heave expected due to pore water freezing is expected to be about 1.6 m. Furthermore, the heave is expected to be widely distributed, with little differential surface deformation and gentle transition zones.

4.2.2 Frost Heave due to Segregated Ice

Because complete tailings freeze back is expected prior to cover construction, the active layer is 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 in the active layer, with little segregated ice development.

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 deposit based on drill holes completed in other lakes on the Hope Bay property (SRK 2009). This in turn will cause frost heaves of similar magnitude, resulting in little differential heave transmitted to the tailings surface. It is expected that heave will be most pronounced in the deepest part of the tailings deposit, tapering to zero toward the edges.

4.2.3 Effect of Frost Heave on the Closure 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 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.

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Appendix J – Tailings Impoundment Area Dust Control Strategy

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Memo

To:	Project File	**Client:**	TMAC Resources Inc.
From:	Iozsef Miskolczi, PEng	**Project No:**	1CT022.004
Reviewed By:	Maritz Rykaart, PhD, PEng	**Date:**	December 13, 2016
Subject:	Hope Bay Project: Tailings Area Dust Control Strategy for Doris TIA		

1 Introduction

The Hope Bay Project (the Project) is a gold mining and milling undertaking of TMAC Resources Inc. The Project is located 705 km northeast of Yellowknife and 153 km southwest of Cambridge Bay in Nunavut Territory, and is situated east of Bathurst Inlet. The Project comprises of three distinct areas of known mineralization plus extensive exploration potential and targets. The three areas that host mineral resources are Doris, Madrid, and Boston.

The Project consists of two phases; Phase 1 (Doris project), which is currently being carried out under an existing Water Licence, and Phase 2 which is in the environmental assessment stage. Phase 1 includes mining and infrastructure at Doris, while Phase 2 includes mining and infrastructure at Madrid and Boston located approximately 10 and 60 km due south from Doris, respectively.

Two tailings storage areas are planned for Phase 2. The existing Doris tailings impoundment area (TIA) will be expanded, and a new Boston tailings management area (TMA) will be developed. The Doris TIA tailings deposition will consist of subaerial tailings deposition, while the Boston TMA will be comprised of filtered tailings developed as a dry-stack. This memo is addressing dust management strategies for the Doris TIA.

Two tailings streams will be produced; flotation tailings, comprising approximately 92-94% of the overall volume, and detoxified leach tailings (following cyanidation, and subsequent cyanide destruction), comprising about 6-8% of the overall volume. Only flotation tailings will be deposited in the Doris TIA. The detoxified leach tailings will be filtered, mixed with mine waste rock and used for underground mine backfill.

Upon closure, the tailings surface of the Doris TIA will be covered with a nominal waste rock cover of about 0.3 m thick. The function of the cover is to prevent dust and to minimize direct contact by terrestrial animals. Once the water quality in the Reclaim Pond has reached the required discharge criteria, the North Dam will be breached allowing the TIA to return to its pre-mining elevation of 28.3 m.

Throughout the operational phase, portions of the tailings surface will be exposed, and sufficiently inactive such that they would dry out and pose a dusting risk. This memo describes alternative dust management strategies that have been considered and presents the rationale for selection of the preferred strategy.

2 Definition of Dust

2.1 Fugitive Dust

Fugitive dust is particulate matter suspended in air by wind action and human activities. Within the Doris TIA, tailings will be deposited by hydraulic placement of a tailings slurry which does not generate any fugitive dust. Fugitive tailings dust will however be generated during the period when the tailings closure cover is being constructed.

2.2 Aeolian Dust

Aeolian dust is defined as particles that are transported as suspended load due to wind action on a surface. Although tailings are discharged wet, the surface eventually dries out as a result of evaporation or freezing of the tailings surface. As a result, at any given time, large areas of the tailings surface would expose dry tailings. Aeolian tailings dust is expected because the Project site is prone to high winds and the moderate surrounding topography does not offer effective protection from wind.

3 Typical Dust Control Methods

3.1 State of Practice

Dust control from operating and closed tailings impoundments is a significant concern in the mining industry, and as a result, the state of practice is quite advanced. There are three primary dust control strategies for fugitive and aeolian dust from exposed tailings areas: natural dust control, physical dust control and chemical dust control. Natural dust control specifically relies on maximizing the benefits offered by nature in the form of precipitation (rain and snow). While highly effective, these benefits are opportunistic and may not always be available at the times when it may be needed.

Physical dust control is by far the most effective strategy, as it relies on creating a physical barrier, such as a cover, that would preclude dusting. This may however not be a cost efficient strategy for an operating tailings impoundment, since any interim cover would occupy space within a tailings impoundment that would otherwise be required for tailings.

Chemical dust control relies on modification of the tailings surface that generates the dust. The effectiveness of this method is temporary, but its application is typically simple, making it a very good alternative for managing dust from an operating tailings impoundment.

The sections that follow provide a detailed description of all the dust control methods that are currently being used in the industry, with a specific focus towards their potential applicability for this Project.

3.2 Natural Methods

3.2.1 Snow Cover

If early in the fall season, wet snow falls directly on the exposed tailings surface and subsequently freezes, it will remain in place all winter protecting the tailing surface from dusting. Snow that falls later in the season is typically drier and more powdery and it tends to be subject to wind transport and redistribution (drifting). This means that portions of the tailings surface will become exposed and opportunity for dust release increases. This is exacerbated by the fact that during the winter the tailings surface gets extremely dry as a result of freezing, making it highly susceptible to dusting.

To maximize the potential benefits offered by snow as a natural dust control method, any snow that does fall on the tailings surface can be track compacted in areas where the tailings surface is trafficable. By mechanically compacting the snow, it will stay in place longer and will melt at a much slower rate in the spring, extending the useful life of the snow as a dust control method.

It is however important to minimize the amount of tailings that gets deposited over the compacted snow. If the compacted snow does not melt during the subsequent summer season due to the insulating blanket of the overlying tailings, ice lenses within the tailings impoundment are created which result in a loss of tailings storage space and possible instability.

There is sufficient snowfall at the Project site that this dust control method could be effectively used. In addition, there is a requirement at the Project site for snow removal in specific areas. Snow that is removed could be hauled to the TIA and used specifically for the purpose of creating a compacted snow cover over any temporarily inactive tailings surface areas. Due to the temporary nature of this dust control method, it will not be a complete solution, but would be a practical and complementary method.

3.2.2 Ice Cover

Similar to compacted snow, an ice cover will remain in place for the duration of the winter and thus temporarily mitigate dust migration. Ice cover on exposed tailing surfaces can be achieved by various methods, including ponding water during freezing weather and mechanical placement of ice blocks imported from a different source (contact water ponds).

Water can be held back in specified locations and retained there during the shoulder seasons when freezing weather will create an ice cap. Once the ice cap is achieved the open water beneath the ice can be drained off, leaving an ice cap.

The ice cap can also be created mechanically by loading ice from contact water ponds (or fresh water streams) into haul trucks and dumping the ice on the tailings surface.

Similar to compacted snow, care must be taken to ensure that the amount of tailings deposited over an ice cover is limited to avoid entraining long-term ice in the TIA.

There are several contact water ponds throughout the Project site all of which must be managed such that they are normally empty. Contact water ponds are; therefore, unable to provide a reliable source of water to use to create an ice cover. Fresh water cannot be readily hauled to the TIA to create an ice cover as the use of fresh water is governed by the Water License (2AM-DOH1323); therefore, creating an ice cover for dust control is not considered a viable practical alternative for application at the Project.

3.3 Physical Methods

3.3.1 Water – Surface Wetting

Water is by far the most common temporary dust control measure used in areas where water shortage is not of concern. The exposed surface is wetted up, preventing particles from becoming airborne. Since the water rapidly evaporates (in a matter of hours or days), it needs to be reapplied at a frequent interval to be effective. The surface wetting can be done using a conventional water truck, a water cannon fitted to a water truck, or a stationary sprinkler system. Naturally this dust control method is only applicable during non-freezing periods of the year.

For the Project, water could readily be obtained from the Reclaim Pond or can be hauled via water truck from other site contact water ponds. The tailings surface is however not expected to be trafficable in the short term and the only viable means of frequent tailings wetting would be via a water cannon, or a sprinkler system. While both of these methods are viable, the short useful life of every wetting cycle makes this a very labor intensive dust control method which is not preferred. This method will however be reserved as a last line of defence should any of the other dust control methods prove to be ineffective.

3.3.2 Water – Flooding

Flooding the tailings surface will naturally preclude any dust concerns. This is however not a viable strategy for the Project since the objective is to place tailings subaerially. At Doris, TIA portions of the tailings may be seasonally flooded as the water level in the Reclaim Pond rises; however, the water level will be managed such that a perpetual water cover will not be present.

3.3.3 Permanent Dry Cover

The most effective permanent dust control system is a permanent physical dust cover. Typically this is in the form of a layer of soil, or other suitable readily available cover material. This is however not practical until the tailings surface has reached its final elevation. In order to facilitate placement of a final dust cover as expediently as possible, any tailings deposition plan should be designed taking into consideration all opportunities for progressive reclamation.

In the context of the Doris TIA, the tailings deposition plan provides limited opportunity for progressive reclamation during the early Project life. This is predominantly driven by the surface topography and as a result there are no practical means to improve the design. The only viable permanent dust cover would be geochemically suitable waste rock, or quarry rock. Since all the Project waste rock is designated for use as structural underground backfill, only quarry rock can be considered a viable source for a permanent dust cover. While this will be the final closure dust control method, it is not considered a viable method during the operational phase of the Project.

3.3.4 Sacrificial Dry Cover

In extreme cases, nominal sacrificial covers such as a layer of sand or gravel are used to manage tailings dust when the final tailings surface has not yet been reached, but the period until tailings deposition might resume at any particular spot may be extensive. When tailings deposition eventually returns to the covered area, these materials are not removed and tailings deposition proceeds to overtop the sacrificial cover. This can be very cost intensive and will only be practical if the tailings surface is readily trafficable.

There are no suitable natural sacrificial cover materials readily available at the Project site. Gravel could be produced from quarry rock; however, at great cost. This is therefore not considered a viable dust control strategy for the Project TIA.

3.3.5 Biodegradable Cover

Biodegradable material such as hay, wood mulch or sewage treatment sludge can be applied over exposed tailings surfaces to mitigate dust for a limited period (i.e. requiring occasional reapplication). Naturally this option is only economically viable if the organic source is readily available. The tailings surface must also be sufficiently trafficable to allow equipment to spread these materials. As these materials biodegrade and dry out, they themselves become prone to being part of the dust hazard.

There is no viable source of biodegradable materials at the Project site, and therefore this is not considered a viable dust control strategy for the Project.

3.3.6 Wind Barriers

A wind barrier (aka windbreak or shelterbelt) is a physical structure used to reduce the wind speed, which will reduce tailings from being re-mobilized from the TIA. Typically, a wind barrier consists of one or more rows of trees or shrubs. Trees and shrubs don’t grow at the Project site (at least not to the size where they would be effective wind barriers), therefore, any wind barriers would have to be engineered structures. The efficiency of wind barriers is also a function of wind speed, and often, at very high wind speeds, wind barriers can fail since it is simply not cost effective to design and build these structures to withstand large wind velocities. As well, wind barriers only work effectively over a very narrow range of wind directions. Multiple wind barriers would need to be installed to cover all of the Project’s prevalent wind directions so as to provide a comprehensive dust management system for the TIA.

Given the very high wind speeds and the multiple wind directions, experienced at the Project’s TIA, engineered wind barriers are not be considered a viable dust control strategy for the Project’s TIA.

3.3.7 Vegetation

Revegetating an exposed tailings surface is a very effective way to mitigate dust. In an arctic setting such as at the Project site, this is not a practical option since the growth season is simply too short to allow for rapid onset of effective vegetation. In addition, the tailings material may not be amenable to supporting vegetation without the addition of supplemental nutrients, which might preclude establishment of natural successional vegetation species. This is therefore not a viable dust control method for the Project.

3.4 Chemical Methods

3.4.1 Salt (Calcium Chloride)

"Salted" sand will not freeze at temperatures above -10˚C, and can be spread in a thin layer over exposed frozen tailings surfaces during the shoulder seasons when frost penetration is enough to support the spreader truck (or other suitable spreader mechanism). The calcium chloride in the sand acts to melt the frost on the exposed tailing surface and stops the fine particulate dust particles from becoming airborne.

There are no sources of sand at the Project site, requiring that both sand and salt would have to be imported at great cost. As runoff occurs from the tailings surface, the salt will dissolve reducing the efficiency; however, since this mitigation method is best used during freezing conditions this risk is limited. However, during freshet the salt is washed off towards the Reclaim Pond which results in an increased salt load to the TIA, which may limit the use of TIA reclaim water to the mill. This is therefore not a viable dust control strategy for the Project TIA.

3.4.2 Chemical Suppressants

There are many environmentally safe commercial chemical dust suppressants on the market. Although originally developed for other forms of fugitive dust management, they are routinely used for dust control on tailings surfaces. These products work in different ways, but principally they all either chemically bind dust, or alternately facilitate towards development of a crust to prevent particles from separating and becoming airborne.

The chemical suppressants are normally supplied in concentrated liquid form in containers of various sizes. They are typically water based and are diluted before application at a ratio of about nine parts water to one part suppressant. The solution is applied by means of a spray cannon mounted on a modified water truck, but can also be done via hand held sprayers. The application rate is typically about four liters per square metre.

Chemical suppressants have a useful life which is dependent on the concentration applied and local weather conditions. Normally, products are applied at a concentration which would render a useful life of approximately one year.

Of all the dust control methods, chemical suppressants offer the greatest flexibility for application at the Project TIA. The concentrated liquid can be shipped to site on an annual basis and solution can be mixed an applied on site as required. The relatively long useful life limits the amount of effort that needs to be exerted and therefore makes the dust control method practical.

4 Dust Control Procedures for Tailings

The primary dust control measures of the Project site tailings facilities will be the use of environmentally suitable chemical dust suppressants. The application of these suppressants will be reviewed on an ongoing basis to ensure that any areas that may be at risk will be adequately covered. Generally, annual application of chemical suppressants will be applied; however it is recognized that more frequent applications may be required as discharge locations are changed throughout any year.

In addition to chemical dust suppressants, natural dust control in the form of packed snow when available will be used as far as practical. Again, the effectiveness will vary on a year by year basis depending on how deposition points vary for any given winter season.

Finally, if for any reason, any of the above dust control methods prove to be temporally ineffective, a suitable water cannon will be available to allow for dust suppression in the form of spraying of the areas of concern.