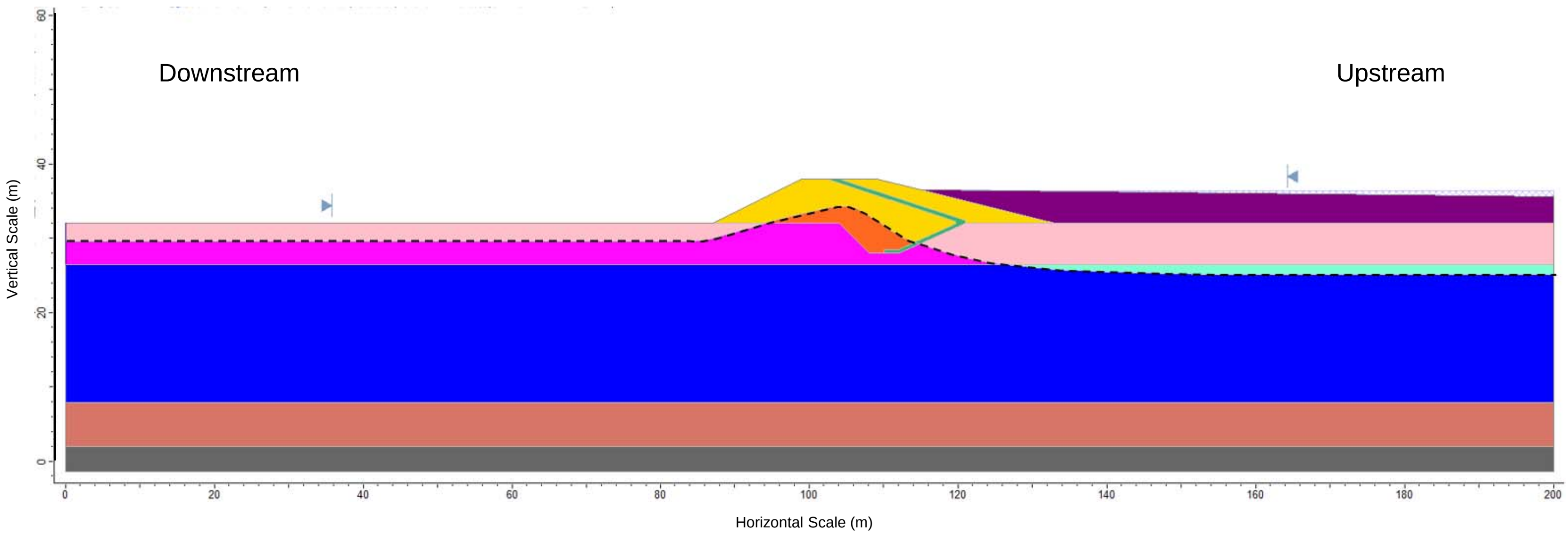


Dam ROQ (Non-frozen/Frozen)

Marine Silt (Non-frozen/Frozen)

Marine Silt and Clay (Non-frozen/Frozen)

Gravelly Till

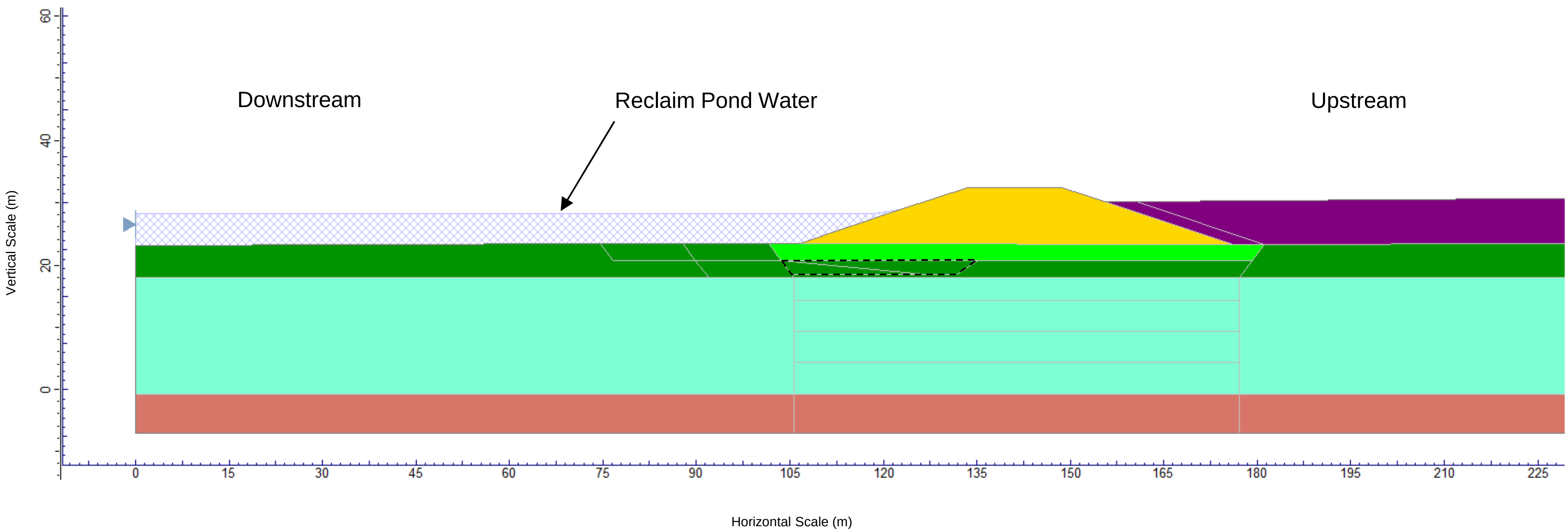
Tailings

GCL

Bedrock

Freezing Boundary (-2.3 degree Isotherm)

srk consulting	MAC RESOURCES	South Dam and Interim Dike Stability Memo **Critical South Dam Section and Model Configuration (Partially Thawed Foundation)**
Job No: 1CT022.002.200.510 Filename: 1CT022.002.200.510_StabilityFigures_PL	DORIS NORTH PROJECT	Date: 2015/04/23 · Approved: PL · Figure: 5



ROQ

Lacustrine Sediments

Mixing Zone

Marine Silt and Clay

Gravelly Till

Tailings

Referred to as the ‘deep mixing zone’

srk consulting

MAC RESOURCES

Job No: 1CT022.002.200.510

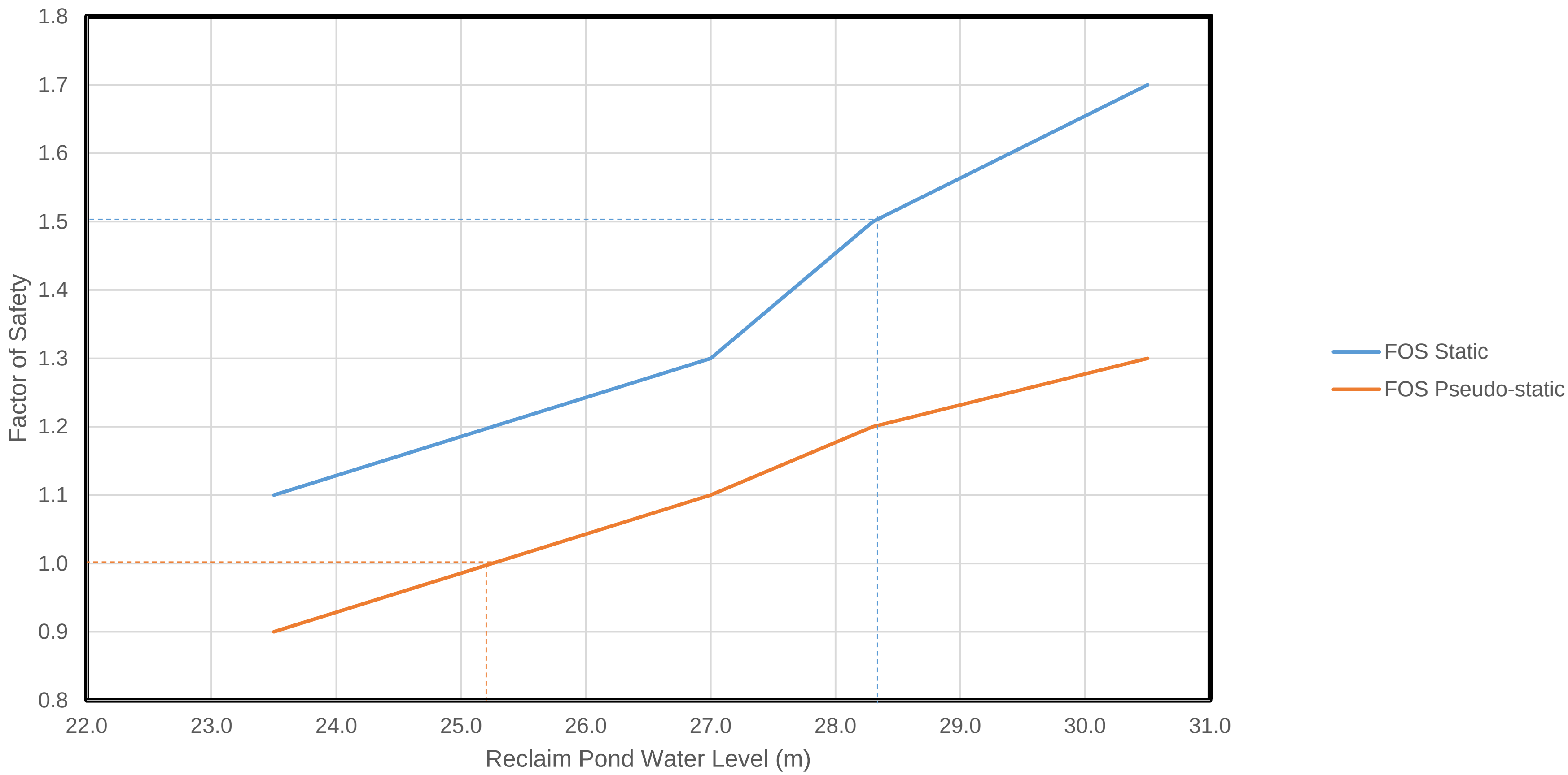
Filename: 1CT022.002.200.510_StabilityFigures_PL

DORIS NORTH PROJECT

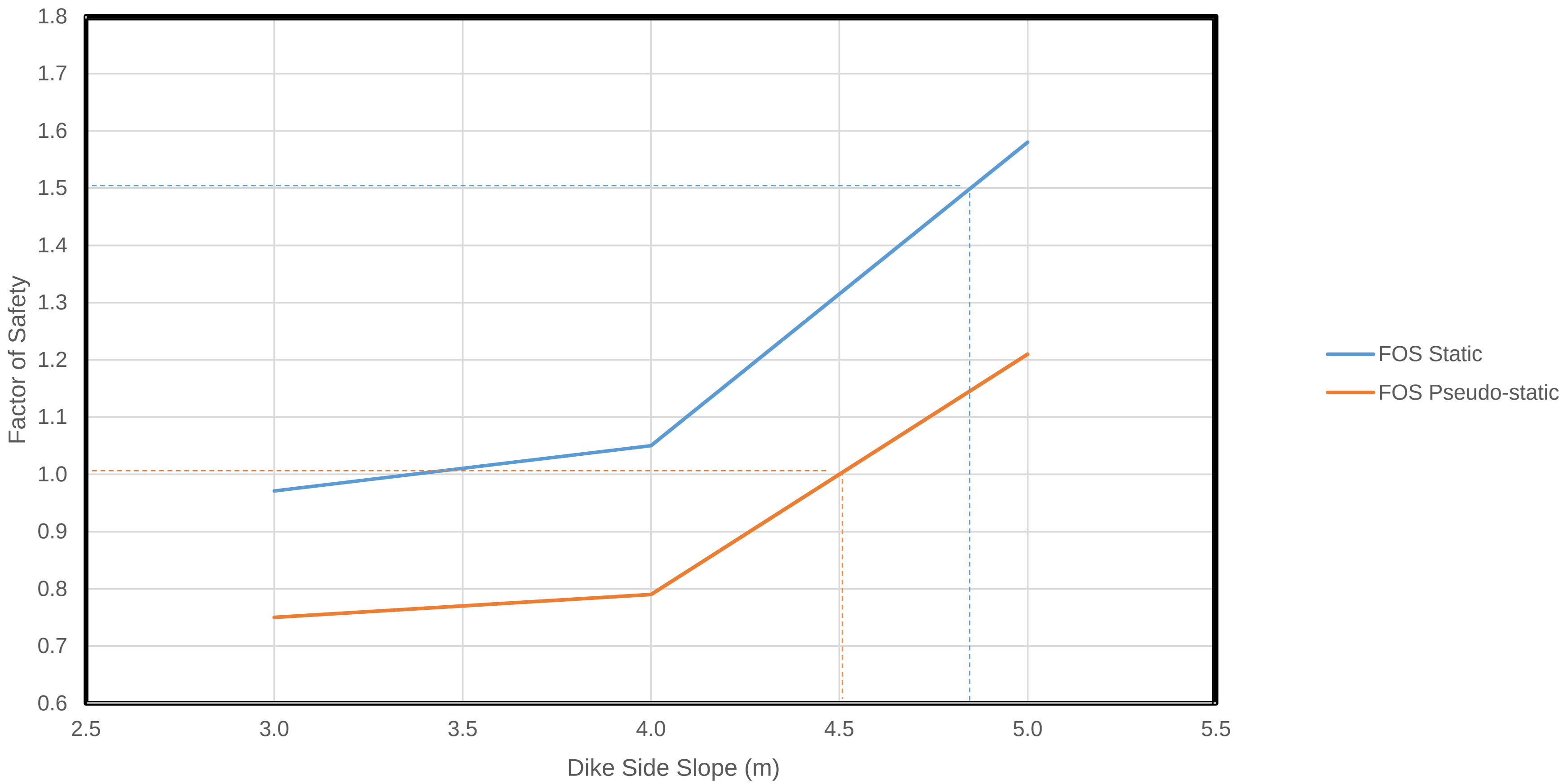
South Dam and Interim Dike Stability Memo

Critical Interim Dike Section and Model Configuration

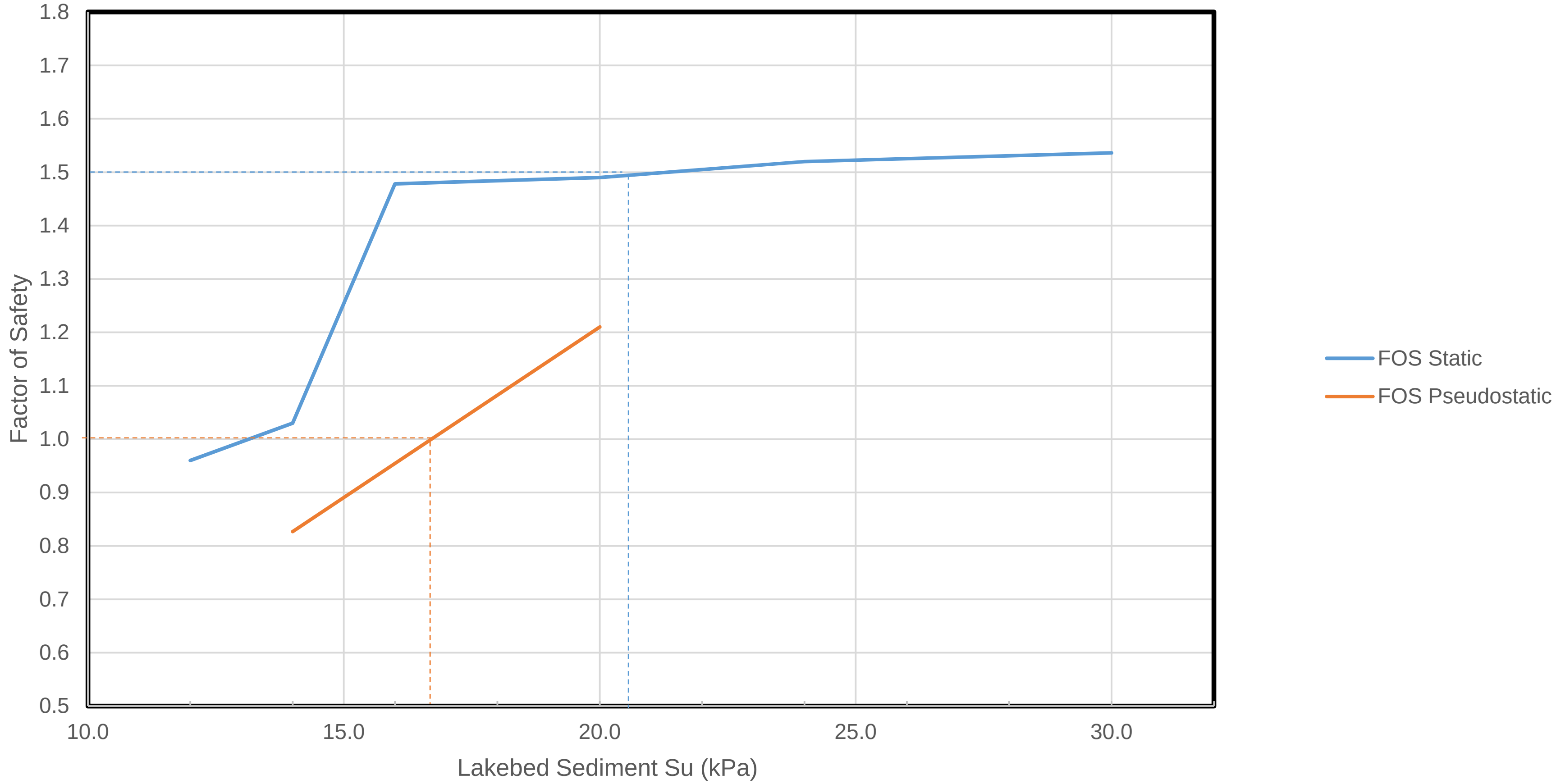
Date:	Approved:	Figure:
2015/04/23	PL	6



srk consulting	MAC RESOURCES	South Dam and Interim Dike Stability Memo
		Polishing Pond Water Level Variability Sensitivity Analysis
Job No: 1CT022.002.200.510 Filename: 1CT022.002.200.510_SensitivityAnalysis_Rev2	DORIS NORTH PROJECT	Date: 2015/05/04 · Approved: PL · Figure: 7



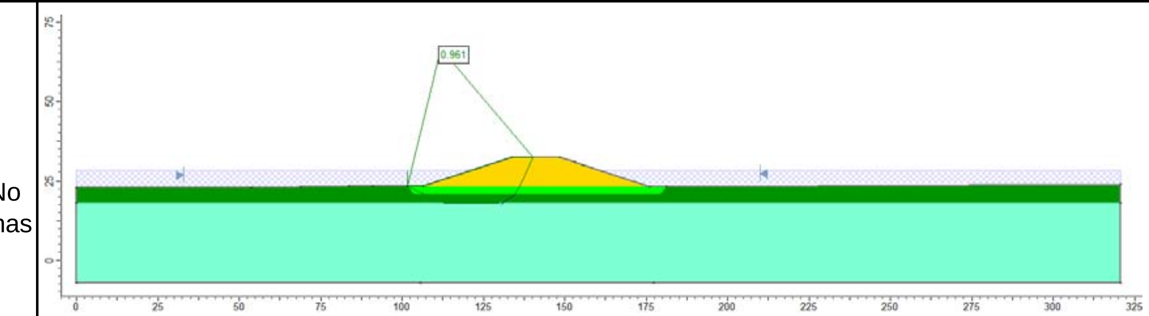
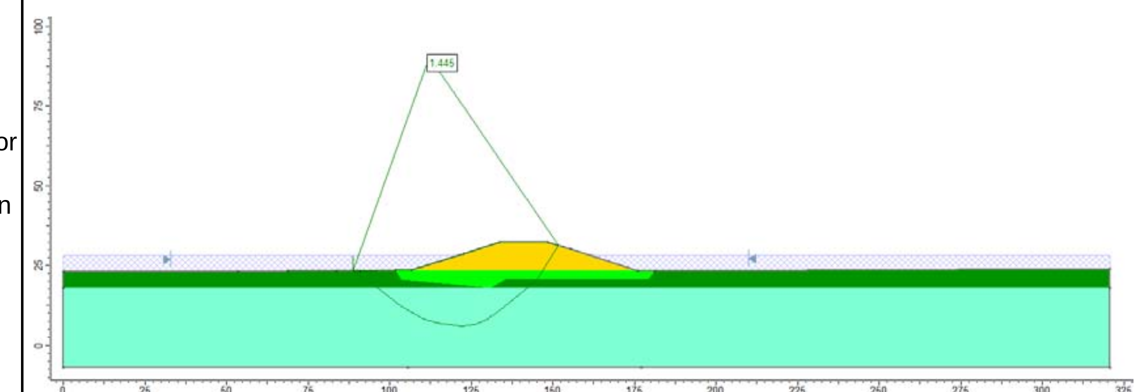
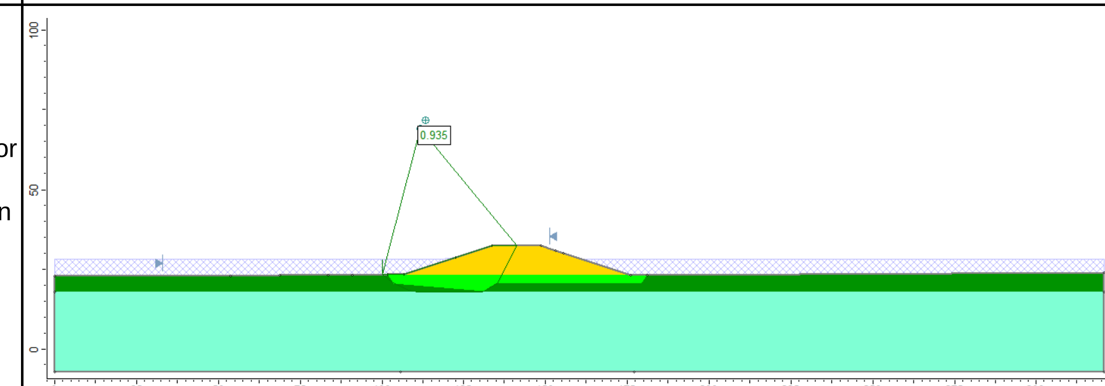
srk consulting	MAC RESOURCES	South Dam and Interim Dike Stability Memo
		Interim Dike Side Slope Variability Sensitivity Analysis
Job No: 1CT022.002.200.510 Filename: 1CT022.002.200.510_SensitivityAnalysis_Rev2	DORIS NORTH PROJECT	Date: 2015/05/04 · Approved: PL · Figure: 8

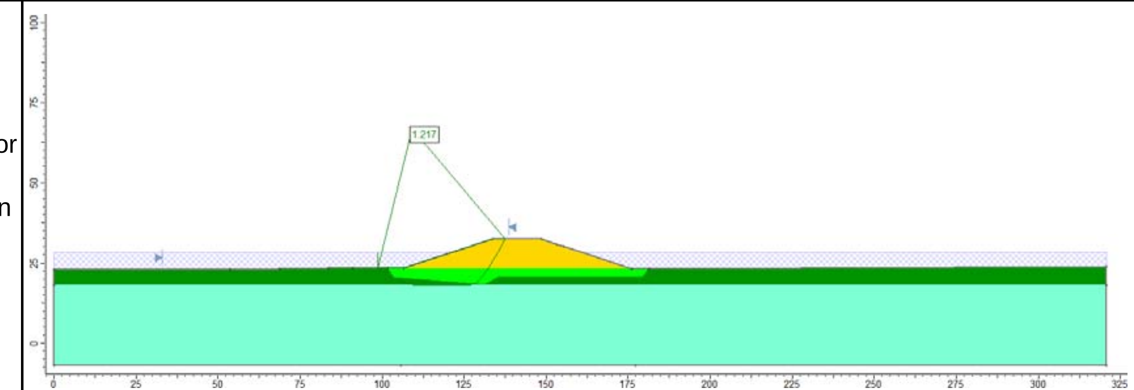
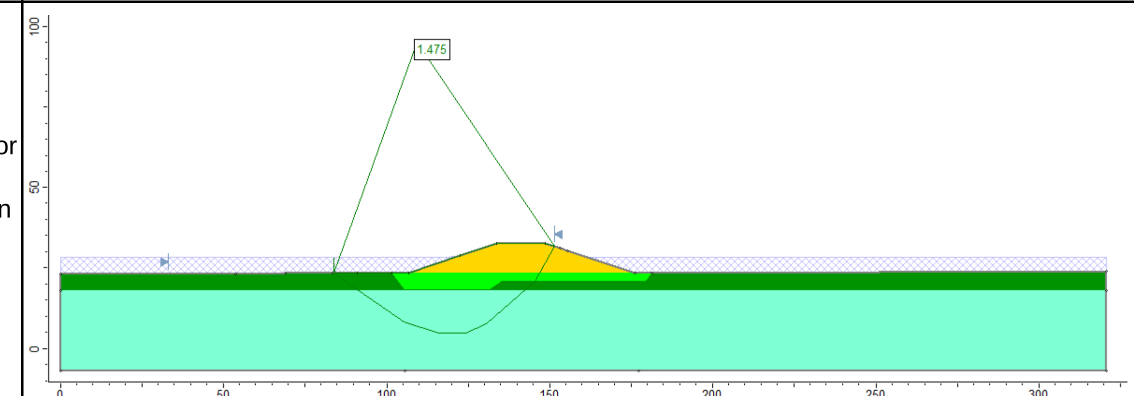
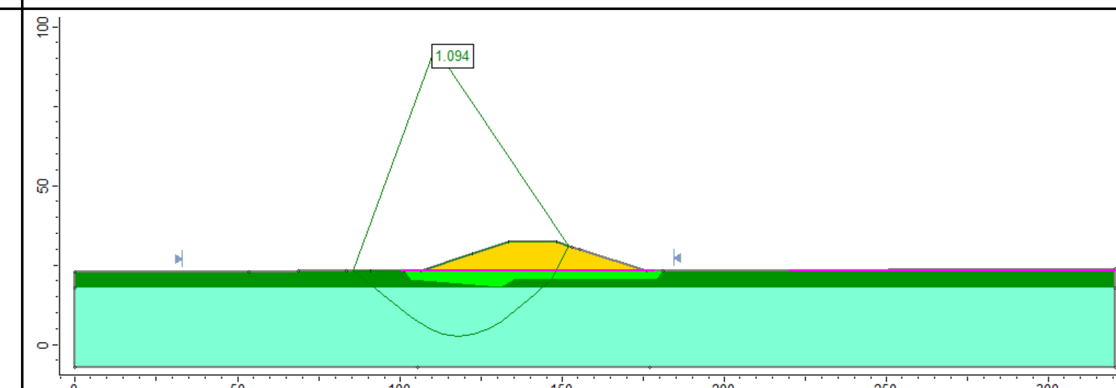


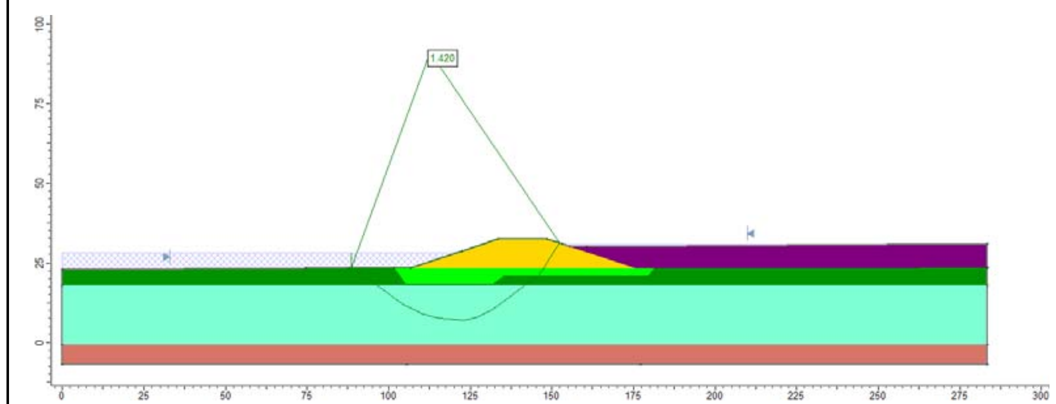
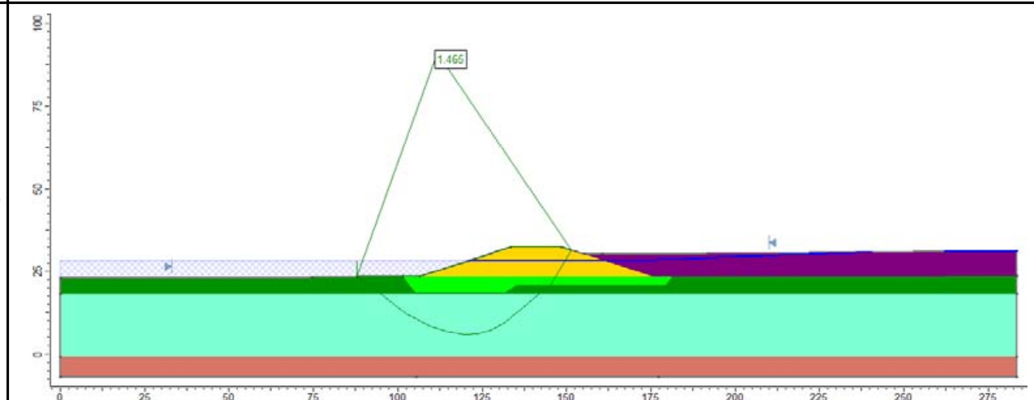
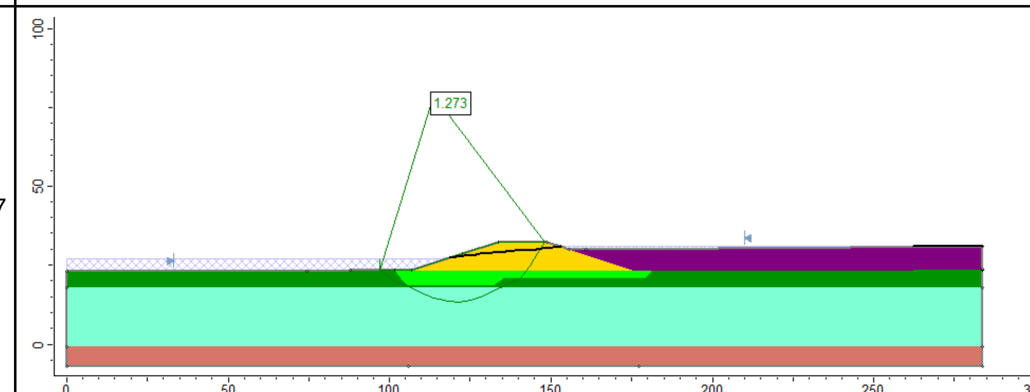
srk consulting	MAC RESOURCES	South Dam and Interim Dike Stability Memo
		Dike Lake Bed Sediment Undrained Shear Strength Variability Sensitivity Analysis
Job No: 1CT022.002.200.510 Filename: 1CT022.002.200.510_SensitivityAnalysis_Rev2	DORIS NORTH PROJECT	Date: 2015/05/04 · Approved: PL · Figure: 9

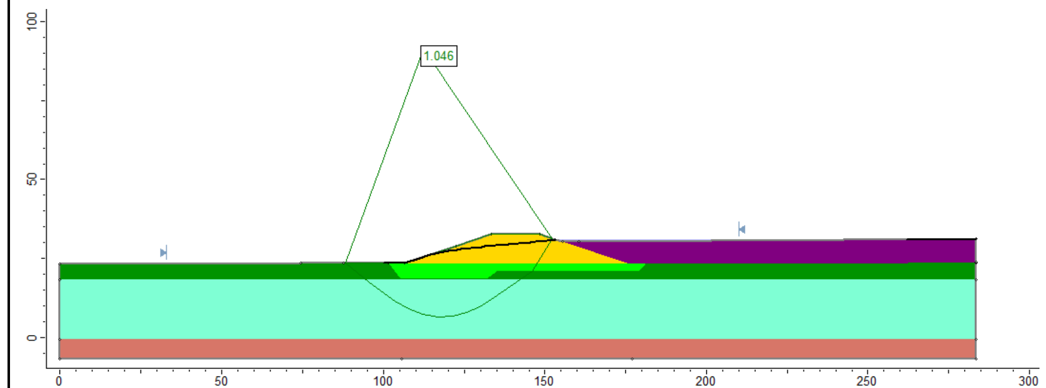
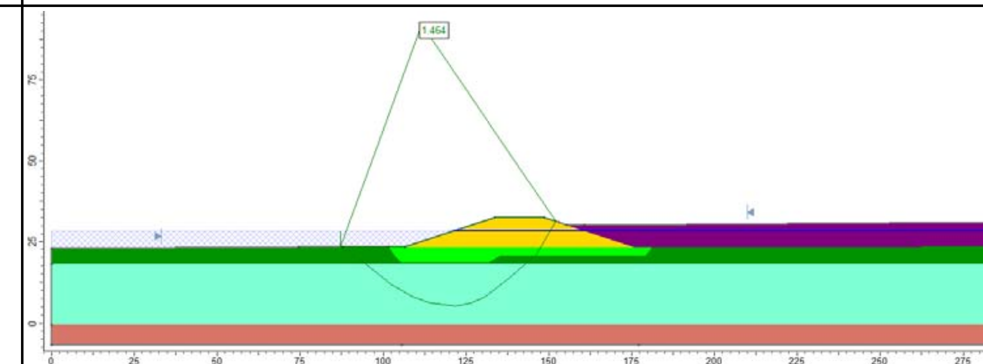
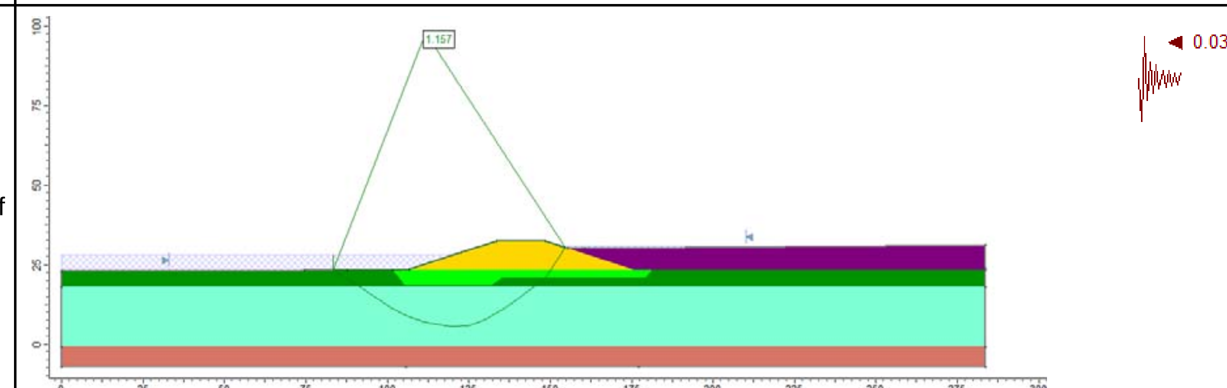
Attachment 1: Interim Dike Stability Analysis Runs

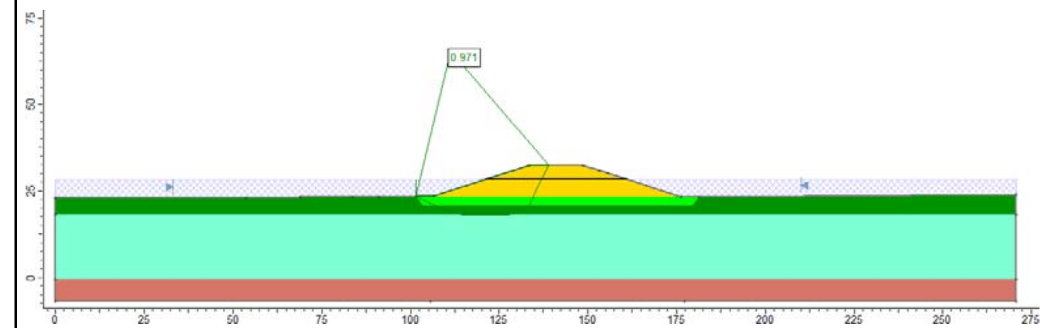
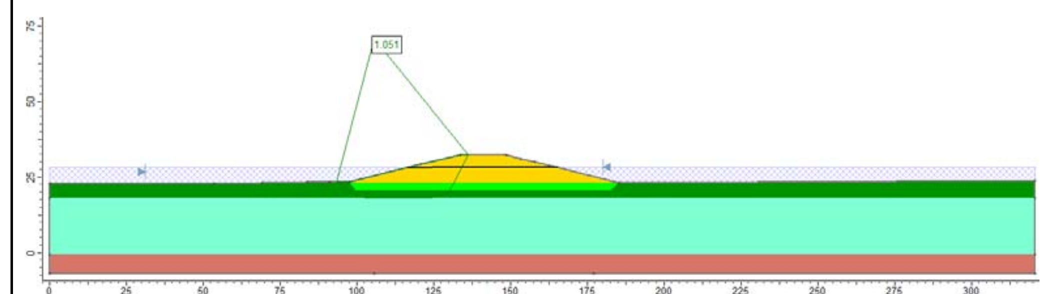
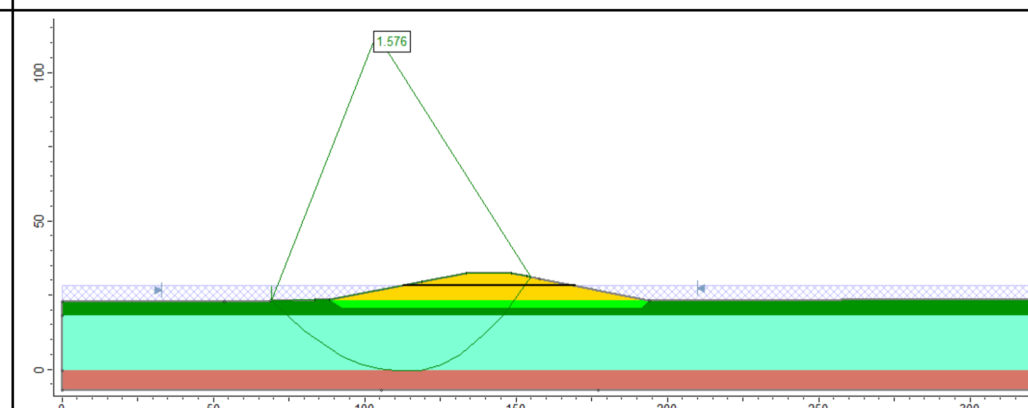
TIA Interim Dike Stability Analyses.

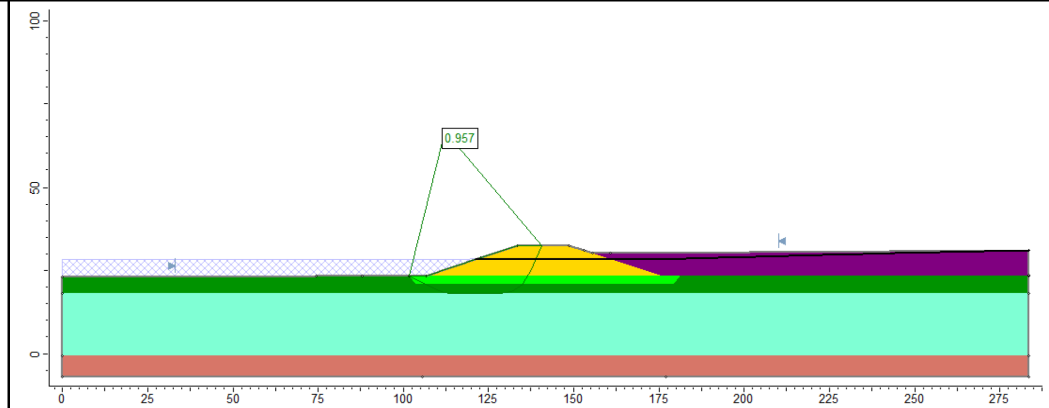
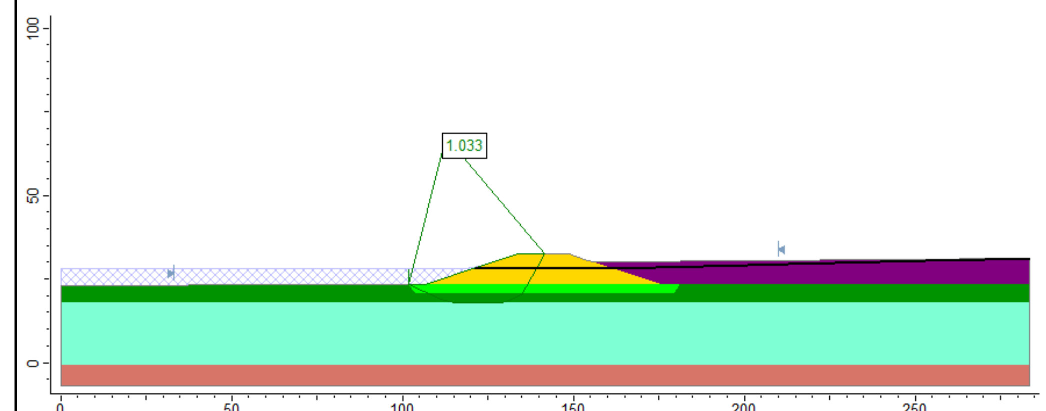
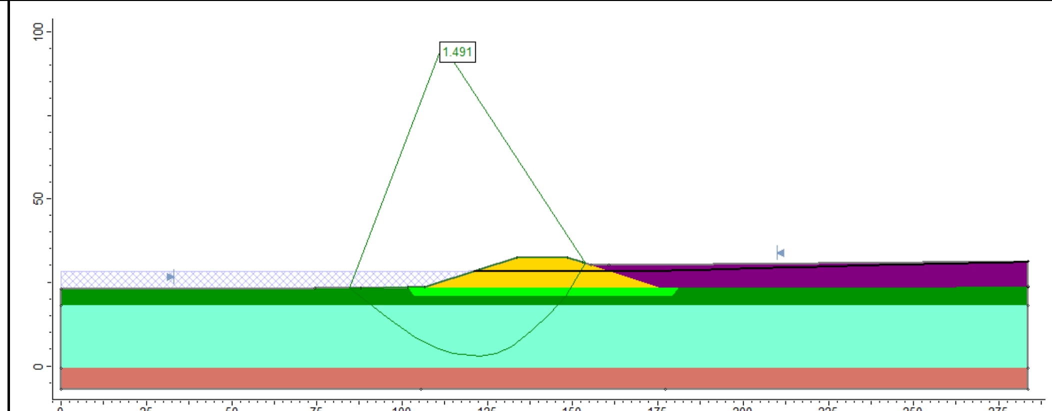
Run #	Stability Condition	Limit equilibrium Method	Minimum FoS	Search Function	Drainage condition (For Lake Bed and Silt/Clay Material)	Other Notes	Critical Slip Surface
1	Short Term (Construction)	Spencer	1.0	Optimized Auto-Refine (Non-circular)	Undrained	Stage 1 of construction. No additional self-butressing has occurred	
2	Short Term (Construction)	Spencer	1.5	Optimized Auto-Refine (Non-circular)	Undrained	Stage 2, due to the low factor of safety in stage 1, additional material has been added during construction creating a deeper mixing zone	
3	Short Term (Construction)	Spencer	0.9	Simulated Annealing	Undrained	Stage 2, due to the low factor of safety in stage 1, additional material has been added during construction creating a deeper mixing zone	

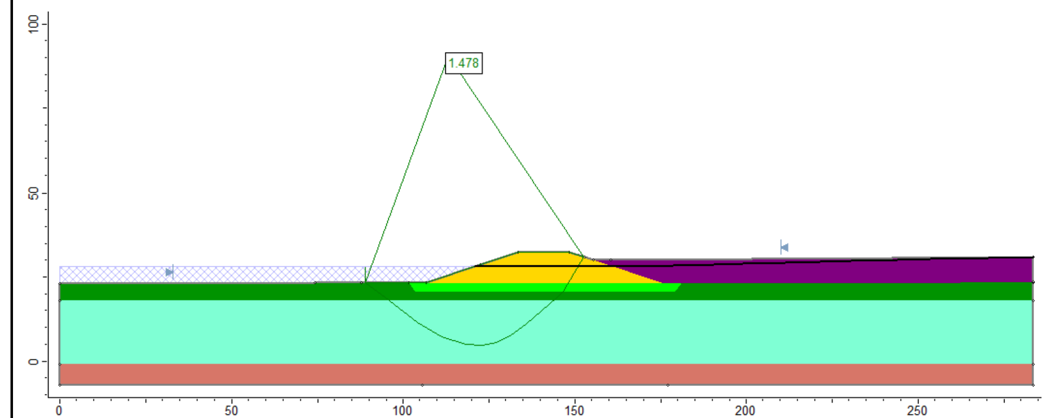
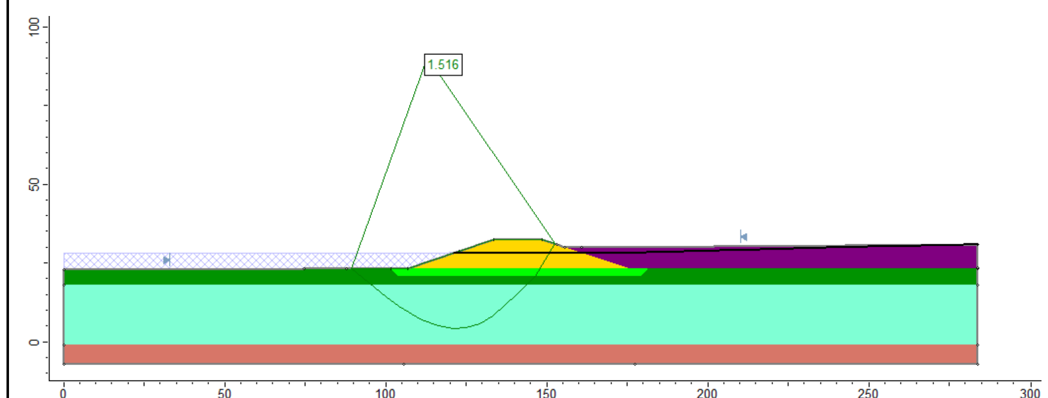
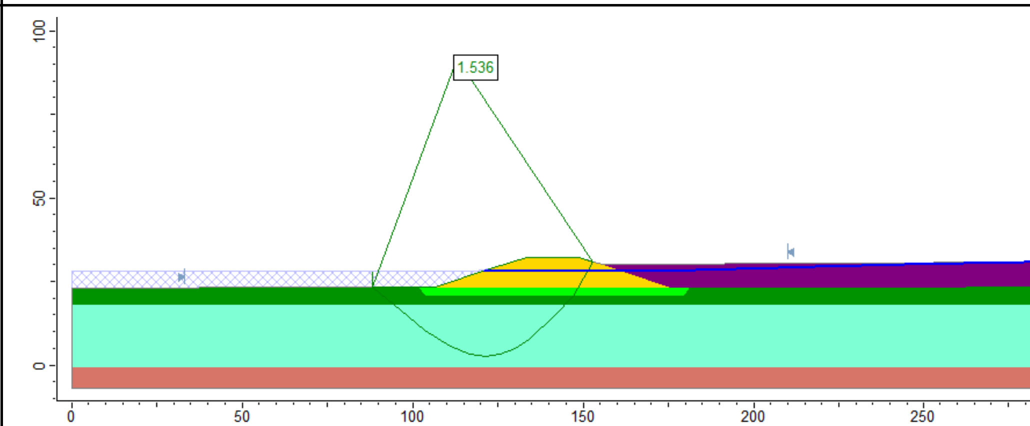
Run #	Stability Condition	Limit equilibrium Method	Minimum FoS	Search Function	Drainage condition (For Lake Bed and Silt/Clay Material)	Other Notes	Critical Slip Surface
4	Short Term (Construction)	Spencer	1.2	Optimized Auto-Refine (Non-circular)	Undrained	Stage 2, due to the low factor of safety in stage 1, additional material has been added during construction creating a deeper mixing zone	
5	Short Term (Construction)	Spencer	1.5	Simulated Annealing	Undrained	Stage 3, due to the low factor of safety in stage 2, additional material has been added during construction creating a deeper mixing zone	
6	Short Term (Construction)	Spencer	1.1	Optimized Auto-Refine (Non-circular)	Undrained	No Lake Present During Construction	

Run #	Stability Condition	Limit equilibrium Method	Minimum FoS	Search Function	Drainage condition (For Lake Bed and Silt/Clay Material)	Other Notes	Critical Slip Surface
7	Long Term (Undrained Foundation)	Spencer	1.4	Optimized Auto-Refine (Non-circular)	Undrained	Tail Lake at 28.3 masl; upstream pond formed	
8	Long Term (Undrained Foundation)	Spencer	1.5	Optimized Auto-Refine (Non-circular)	Undrained	Tail Lake at 28.3 masl; water level below tailings surface	
9	Partial Drawdown	Spencer	1.3	Optimized Auto-Refine (Non-circular)	Undrained	Drawdown of Tail Lake to 27 masl	

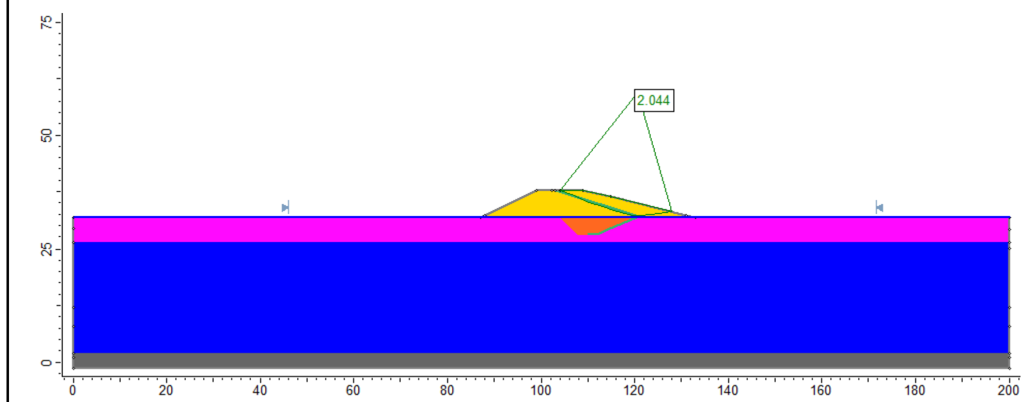
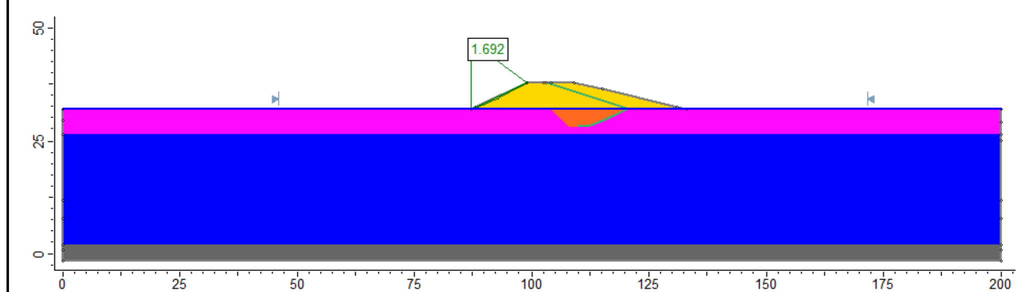
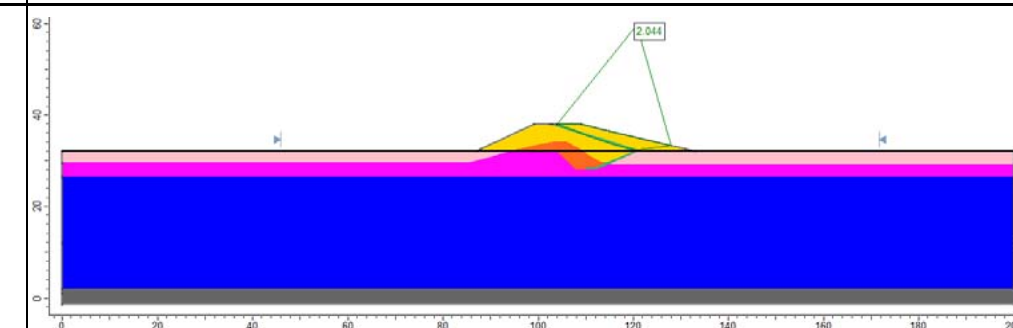
Run #	Stability Condition	Limit equilibrium Method	Minimum FoS	Search Function	Drainage condition (For Lake Bed and Silt/Clay Material)	Other Notes	Critical Slip Surface
10	Drawdown	Spencer	1.0	Optimized Auto-Refine (Non-circular)	Undrained	Rapid Drawdown of Tail Lake to 23.5 masl (extreme case)	
11	Drawdown	Spencer	1.5	Optimized Auto-Refine (Non-circular)	Undrained	Static Water Level at 28.3 masl (After ND Breach)	
12	Pseudo-static	Spencer	1.2	Optimized Auto-Refine (Non-circular)	Undrained	Seismic: PGA, Drawdown of Tail Lake to 28.3 masl	

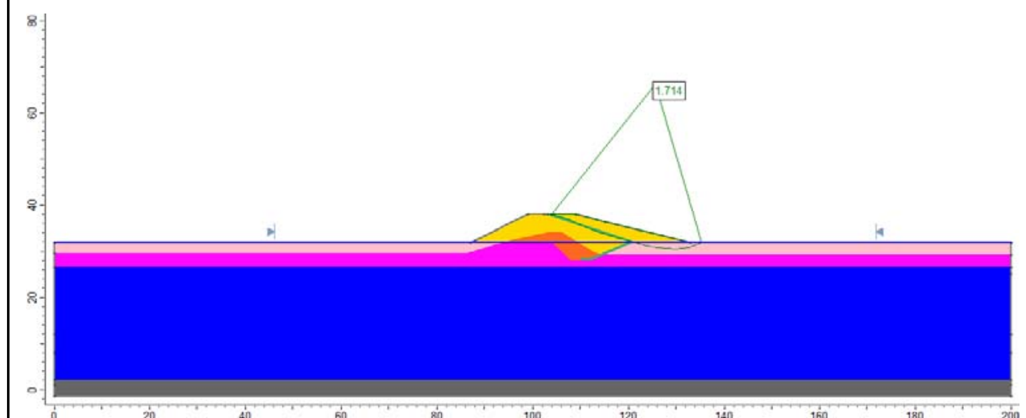
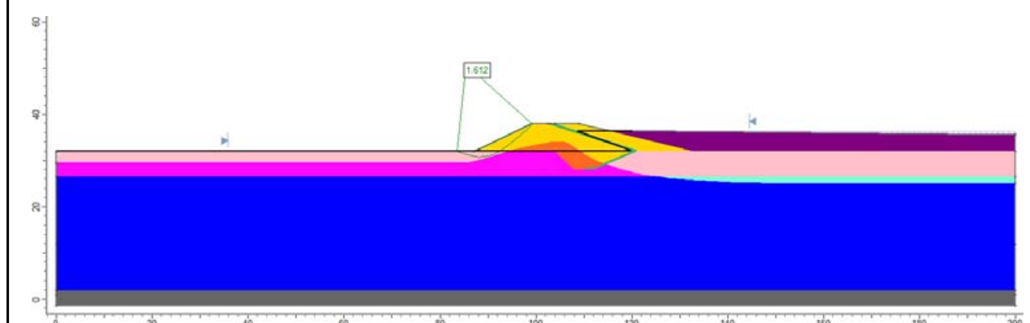
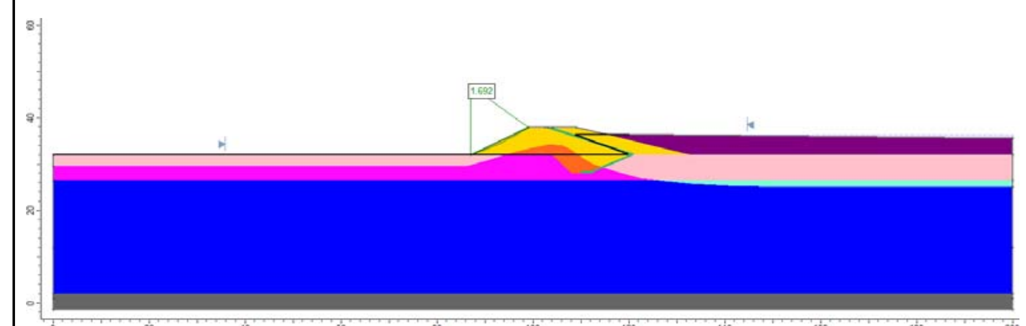
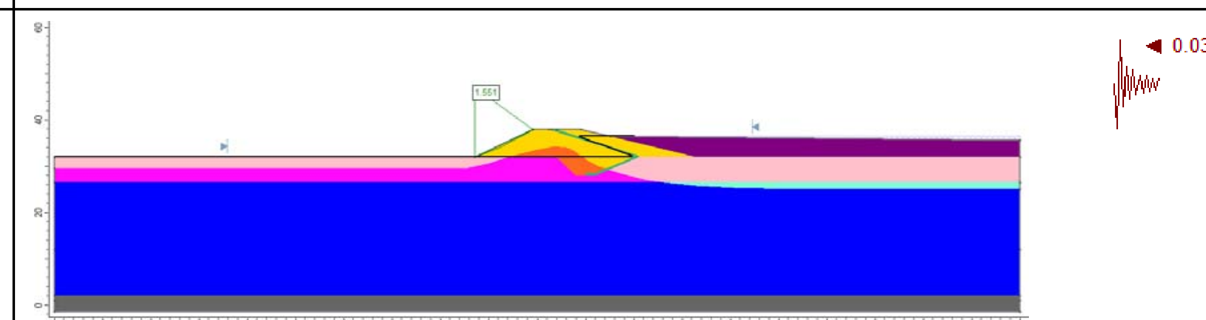
Run #	Stability Condition	Limit equilibrium Method	Minimum FoS	Search Function	Drainage condition (For Lake Bed and Silt/Clay Material)	Other Notes	Critical Slip Surface
13	Sensitivity (Slope Angle)	Spencer	1.0	Optimized Auto-Refine (Non-circular)	Undrained	3 to 1 side slopes; Lake at 28.3 masl	
14	Sensitivity (Slope Angle)	Spencer	1.1	Optimized Auto-Refine (Non-circular)	Undrained	4 to 1 side slopes; Lake at 28.3 masl	
15	Sensitivity (Slope Angle)	Spencer	1.6	Optimized Auto-Refine (Non-circular)	Undrained	5 to 1 side slopes; Lake at 28.3 masl	

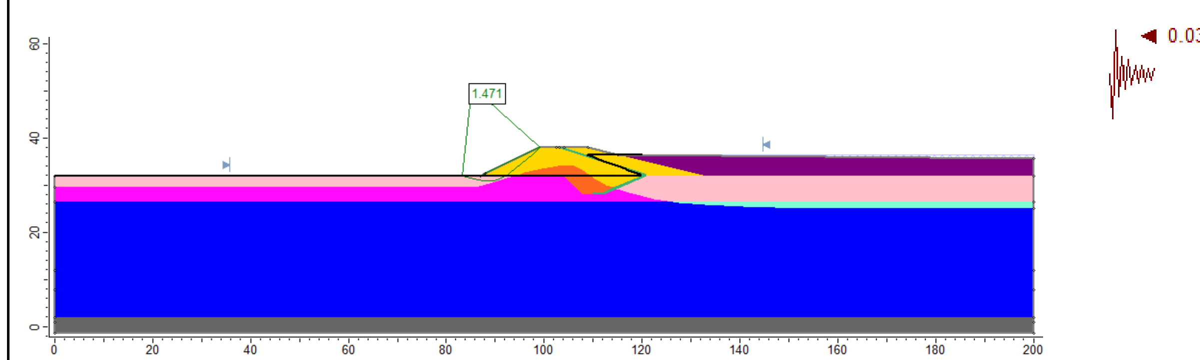
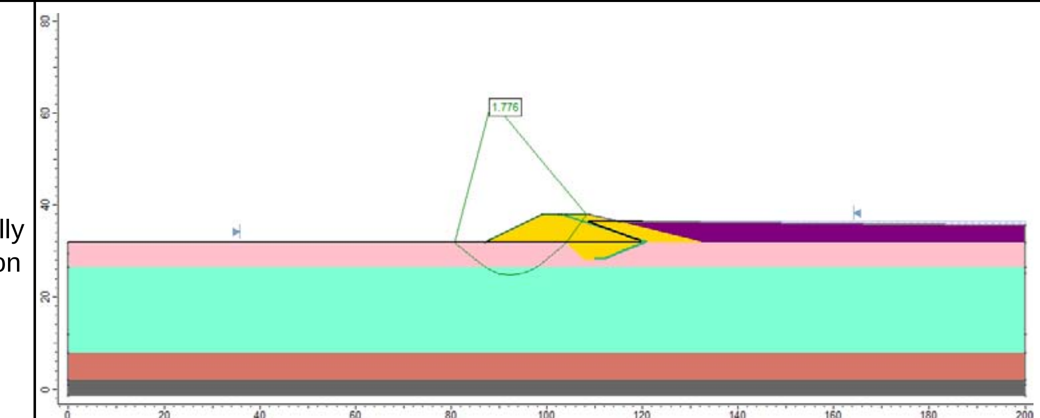
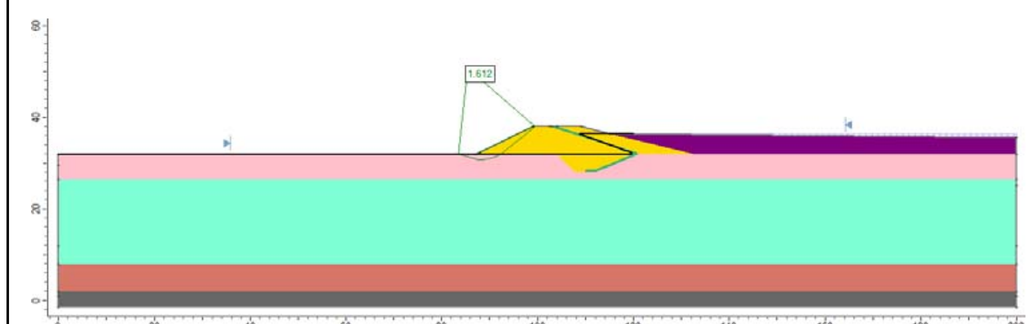
Run #	Stability Condition	Limit equilibrium Method	Minimum FoS	Search Function	Drainage condition (For Lake Bed and Silt/Clay Material)	Other Notes	Critical Slip Surface
16	Sensitivity (Lakebed Su)	Spencer	1.0	Optimized Auto-Refine (Non-circular)	Undrained	Lake bed sediments: Su =12kPa	
17	Sensitivity (Lakebed Su)	Spencer	1.0	Optimized Auto-Refine (Non-circular)	Undrained	Lake bed sediments: Su =14kPa	
18	Sensitivity (Lakebed Su)	Spencer	1.5	Optimized Auto-Refine (Non-circular)	Undrained	Lake bed sediments: Su =20kPa	

Run #	Stability Condition	Limit equilibrium Method	Minimum FoS	Search Function	Drainage condition (For Lake Bed and Silt/Clay Material)	Other Notes	Critical Slip Surface
19	Sensitivity (Lakebed Su)	Spencer	1.5	Optimized Auto-Refine (Non-circular)	Undrained	Lake bed sediments: Su =16kPa	
20	Sensitivity (Lakebed Su)	Spencer	1.5	Optimized Auto-Refine (Non-circular)	Undrained	Lake bed sediments: Su =24kPa	
21	Sensitivity (Lakebed Su)	Spencer	1.5	Optimized Auto-Refine (Non-circular)	Undrained	Lake bed sediments: Su =30kPa	

Attachment 2: South Dam Stability Analysis Runs

TIA South Dam Stability Analyses							
Run #	Stability Condition	Limit equilibrium Method	Minimum FoS	Search Function	Failure Direction	Other Notes	Critical Slip Surface
1	Short Term (Construction)	Spencer	2.0	Optimized Auto-Refine (Non-circular)	Upstream	Frozen ground surface	
2	Short Term (Construction)	Spencer	1.7	Optimized Auto-Refine (Non-circular)	Downstream	Frozen ground surface	
3	Short Term (Construction)	Spencer	2.0	Optimized Auto-Refine (Non-circular)	Upstream	Assumes surface layer is thawed, GWT at ground surface. (Silt Su = 40kPa)	

Run #	Stability Condition	Limit equilibrium Method	Minimum FoS	Search Function	Failure Direction	Other Notes	Critical Slip Surface
4	Short Term (Construction)	Spencer	1.7	Optimized Auto-Refine (Non-circular)	Upstream	Assumes surface layer is thawed, GWT at ground surface. (Silt ϕ' = 32°)	
5	Long Term (Downstream)	Spencer	1.6	Optimized Auto-Refine (Non-circular)	Downstream	Minimum depth of failure (0.5m) (Silt Drained)	
6	Long Term (Downstream)	Spencer	1.7	Optimized Auto-Refine (Non-circular)	Downstream	Minimum depth of failure (0.5m) (Undrained Foundation su=40 kPa)	
7	Pseudo-static (Downstream)	Spencer	1.6	Optimized Auto-Refine (Non-circular)	Downstream	Minimum depth of failure (0.5m) (Undrained Foundation su=40 kPa)	

Run #	Stability Condition	Limit equilibrium Method	Minimum FoS	Search Function	Failure Direction	Other Notes	Critical Slip Surface
8	Pseudo-static (Downstream)	Spencer	1.5	Optimized Auto-Refine (Non-circular)	Downstream	Minimum depth of failure (0.5m) (Drained, thawed silt)	
9	Long Term (Downstream)	Spencer	1.8	Optimized Auto-Refine (Non-circular)	Downstream	Minimum depth of failure (0.5m) (Undrained Foundation su=40 kPa), fully thawed foundation condition	
10	Long Term (Downstream)	Spencer	1.6	Optimized Auto-Refine (Non-circular)	Downstream	Minimum depth of failure (0.5m) (Drained Foundation), fully thawed foundation condition. Silt and Clay (30 degrees, 0 kPa), Silt (32 degrees, 0kPa)	

Appendix F – South Dam and Tailings Freeze-Back Thermal Analysis

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Memo

To:	Project File	**Client:**	TMAC Resources Ltd.
From:	Murray McGregor, EIT	**Project No:**	1CT022.002.200.535
Reviewed by:	Maritz Rykaart, PhD, PEng	**Date:**	May 29, 2015
Subject:	Doris North Project: South Dam and Tailings Freeze-Back Thermal Analysis		

1 Introduction

1.1 Tailings Management Concept

TMAC Resources Ltd. plan to revise their tailings management plan to accommodate a greater volume of tailings at the Doris North project, located in Nunavut, approximately 160 km southwest of Cambridge Bay. The revised volume of tailings exceeds the amount that can sub-aqueously be deposited in the Tailings Impoundment Area (TIA) with a permanent water cover after the North Dam gets breached.

The tailings management plan has subsequently been redesigned to incorporate a sub-aerial deposition strategy starting at the south end of the TIA. The approximately 2.5 Mt of tailings will be deposited along the southern end of the TIA and will be contained by a new Interim Dike about 1,500 m north of the South Dam. The remaining portion of the TIA between the Interim Dike and existing North Dam will not contain any tailings, and will act as a Reclaim Pond. Tailings will be spigotted from a number of points along the eastern perimeter of the TIA and from the South Dam creating a landscape that drains towards the Interim Dike at an average slope of about 1%. Figure 1 presents a plan layout of the proposed configuration.

The South Dam was originally designed as a frozen core dam (SRK 2007), as it was intended to retain water for a period of up to 20 years. With the proposed revised tailings deposition strategy, the South Dam is not required to retain water since tailings will be beached from the face of the dam from the start of operations. As a result, the South Dam design has been changed to a frozen foundation dam consisting of a compacted rock fill dam with a geosynthetic clay liner (GCL) keyed into the permafrost overburden foundation. Details of the South Dam are provided in Figure 2.

Upon closure, the tailings surface will be covered with a nominal waste rock cover of 0.3 m thick. The function of the cover is to prevent dust and to minimize direct contact by terrestrial animals. The cover will terminate at the Interim Dike, and the Interim Dike will be levelled to match the elevation of the cover. Once the water quality in the Reclaim Pond has reached the required discharge criteria, the North Dam will be breached as originally intended. Should there be any exposed shoreline erosion these areas will be covered as described in the original project closure plan.

1.2 Thermal Modelling Objectives

Even though the South Dam will not be required to retain water, during the operational stage, there may be short periods, especially during the early project stages when the tailings beach has not yet been fully developed, where water may be in close proximity to the dam. To ensure environmental containment, the South Dam has therefore been designed to include a GCL keyed into the permafrost overburden foundation. A key design criteria for the South Dam is therefore to ensure that this connection remains frozen under all foreseeable conditions. To demonstrate this, thermal analysis has been completed along a critical section of the South Dam (i.e. along its maximum height) as illustrated in Figure 3.

Given the climatic conditions it is expected that the tailings will freeze once deposited, providing an additional form of environmental containment. Thermal modelling to demonstrate how this freeze-back will occur are presented along a critical tailings section (Figure 4) representing the expected maximum tailings profile thickness of 10 m in height.

The methods, assumptions and results of these thermal analyses are presented in this memo.

2 Modelling Setup

2.1 Modelling Code

Thermal modelling was completed in a two-dimensional domain by solving for conductive and convective heat movement in the soil, using SoilVision's SVHeat (SoilVision 2011) software package in combination with FlexPDE (FlexPDE 2014). SVHeat version 6 was utilized for the problem setup, while FlexPDE 6.35 completed the calculations.

2.2 Modelling Geometry

The South Dam has been designed with a crest width of 10 m and an upstream slope of 4:1 H:V and downstream slope of 2:1 H:V. The crest elevation is set at 38 masl and results in a maximum dam height of 6 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 will be placed along the entire base of the key trench, along the upstream face of the key trench and then slope back within the center of the dam at a slope of 3H:1V.

2.3 Conceptual Model

Figures 3 and 4 present the conceptual models for the two completed thermal analysis models. The critical section of the South Dam represented by Figure 3, presents a cross section of the dam at its location of maximum height. The base case model assumes a tailings beach against the dam face. The ground profile consists of three layers as informed by rigorous geotechnical investigations (SRK 2007). Approximately the upper 5 m consist of silty sands, while the lower sediments consist of marine silts and clays (15 m thick), overlaying about 10 m of till. The underlying bedrock is basalt. All of these materials have been confirmed to be permafrost.

The critical tailings section, analysed to assess the freeze-back rate of the tailings, consist of a 100 m wide zone of tailings overlying 20 m of marine silts and clays, 10 m of till with a basalt bedrock foundation. It is assumed that any lakebed sediments will have thermal properties consistent with the marine silts and clays; therefore, no lakebed sediment layer was added to the freeze-back model. Two models were completed, one taking into consideration the talik present under the TIA while the other assumes a permafrost foundation. The modelling does not account for the temporal effect of placing tailings, but rather assumes that all of the tailings are placed in a single lift, with no ponded water present. This is a conservative assumption since in reality, freeze-back will occur seasonally.

2.4 Material Properties

The material properties were selected from two previous works on the Hope Bay project: the geotechnical design parameters report (SRK 2011) and the original thermal modelling (SRK 2007). Several materials were considered and are presented in Table 1 below.

Table 1: Material Thermal Properties

Material	Degree of Saturation	Porosity	Thermal Conductivity (KJ m-1 day-1 °C-1)		Volumetric Heat Capacity (KJ m-3 °C)	
Run of Quarry	100	0.30	163	244	2,751	2,123
Run of Quarry	30	0.30	104	117	1,697	1,509
Silty sand	100	0.35	122	195	2,715	1,982
Marine clay/silt	100	0.35	122	195	2,715	1,982
Tailings	100	0.36	99	216	3,271	2,071
Till	100	0.35	122	195	2,715	1,982
Basalt	100	0.05	260	260	2,238	2,133

2.5 Climate Conditions

Climate data was obtained from (SRK 2007). The correlated data was obtained from Environment Canada weather stations over a 30-year period. Although there is site specific data available, the record is not sufficiently long to be representative for long term modeling. Regional air temperatures indicate that the mean annual air temperature is -12.1°C with an air freezing index of 748°C-days, and air freezing index of -5,135°C-days.

The annual cycle ground response was developed based on the three warmest years over the 30-year period analyzed. The mean annual air temperature was set at -10°C, with an amplitude of 22°C. This has been modelled as a sinusoidal function of temperature-time relationship based on Equation 1 and the parameters shown in Table 2.

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

Where:

- T *is the ground response temperature measured in °C*
- nf *is the surface freezing index*
- nt *is the surface thawing index*
- $MAAT$ *is the mean annual air temperature measured in °C*
- Amp *is the air temperature amplitude measured in °C*
- t *is time measured in days*

Table 2 summarizes the model inputs used to create a synthetic sinusoidal weather cycle.

Table 2: Climate Model Parameters

Model Parameter	Value
Mean annual air temperature $(MAAT)$	-10°C
Air temperature amplitude (Amp)	22°C
Surface thawing index (nt)	2.0
Surface freezing index (nf)	1.0

The mean annual ground response temperature was calculated to be -7.2°C based on this relationship. The freezing and thawing indices were found to provide a good fit based on recorded temperature readings of roughly -8°C in the subsurface. The ground response curve is presented in Figure 5.

2.6 Initial Conditions

2.6.1 South Dam

The initial conditions for the South Dam model are presented in Figure 6. These conditions were determined by a series of conditioning runs for the subsurface within the model. The expected ground surface temperature regimes were imposed as boundary condition in a 10-year long model. This allowed the model domain to equilibrate with the boundary conditions. The dam was modelled at a constant temperature of -8°C.

Since it has been assumed that the dam will be constructed from run of quarry during the winter season, the -8°C starting temperature is considered conservative since actual winter temperature is expected to be much colder.

2.6.2 Tailings Freeze-Back

Tailings are assumed to have been placed instantaneously at a temperature of +4°C. This presents a conservative assumption, since significant freeze-back is expected during operations as a result of continual deposition throughout all seasons.

For the tailings freeze-back model, two initial conditions were used for the foundation conditions. The first (Case A) involved conditioning runs as described for the South Dam, while the second

(Case B) model had ground temperatures equal to +4°C to acknowledge the presence of the TIA talik. These initial conditions are presented in Figure 7.

2.7 Boundary Conditions

The boundary conditions are consistent for both the South Dam and tailings freeze-back models. Climate conditions were simulated using an equation that correlates ground response temperature to the average daily air temperature recorded on the project site as described in Section 2.5. Climate change has been estimated as an average increase in temperature of 4.1°C per 100 years (Charron 2014).

The sides of the model are fixed as zero flux boundaries. The lower boundary of each model was set to a constant thermal flux of 2,964 Joules/day/meter, equivalent to 0.0114°C/m in bedrock which represents the geothermal gradient observed in the project area (SRK 2007).

3 Results

3.1 South Dam

Three select years were shown in order to understand the evolution of the thermal profile following tailings deposition at the South Dam. The thermal profile for the South Dam model is presented for the start of winter for years 2, 4, and 6 in Figure 8.

The results of the South Dam thermal model indicate that the foundation remains below -3°C throughout the deposition period, which has been estimated at less than five years.

3.2 Tailings Freeze-Back

3.2.1 Freeze-Back in Areas without Talik (Case A)

Three select years were shown in order to understand the evolution of the thermal profile following tailings deposition in areas where no talik exist (Case A). The thermal profile for the tailings is presented for the start of winter for years 4, 6, and 8 in Figure 9.

The thermal profiles presented in Figure 9 indicate that freeze-back occurs within the first four years, while a quasi-equilibrium is reached closer to six years, when the change in thermal profile becomes much less pronounced.

3.2.2 Freeze-Back in Areas with Talik (Case B)

Three select years were shown in order to understand the evolution of the thermal profile following tailings deposition. The thermal profile for the tailings is presented for the start of winter for years 4, 6, and 8 in Figure 10.

The thermal profiles presented in Figure 10 indicate that freeze-back occurs within the first six years.

3.3 Long Term Active Layer within Tailings

The tailings freeze-back model was used to assess the long-term active layer thickness within the tailings surface. For the first decade the active layer is about 2.0 m thick, but as a result of climate change the active layer thickness increases to about 2.4 m over the first 100 years.

4 Discussion and Conclusions

Salinity results from samples collected in the footprint of the South Dam foundation indicate salinity ranges from 30 to 46 ppt with an average of 41 ppt. This results in freezing temperatures of approximately -2.3ºC. Figure 6 suggests that freezing temperatures are maintained throughout the design life for the dam. Upon closure, the upstream portion of the dam will begin to freeze back when tailings deposition ends, and therefore environmental containment is ensured at all times.

The tailings are not expected to have a high salinity; therefore, a 0ºC freezing temperature has been adopted. Based on this freezing temperature, the time to complete tailings freeze back has been estimated at less than four years where the ground surface is exposed and six years where lake talik has developed. These estimates are based on the very conservative assumption that the tailings will maintain at 4ºC throughout the deposition period. The actual freeze-back time is likely to be significantly less and may be measured in months rather than years due to progressive freeze-back over the life of project.

The active layer over the first decade is approximately 2 m deep based on the results presented in Figure 11. The long-term thermal model, which was run for 100 years with an average temperature increase of +4.1ºC over 100 years indicates an increase in active layer depth to 3 m.

The results of the thermal models have implications for stability, consolidation and seepage analyses. The frozen foundation of the South Dam indicates that frozen material properties can be used for the stability analysis, while the Interim Dike assumes thawed foundation conditions due to the lake talik. For the seepage analysis, it has been assumed that no flow passes through frozen ground.

Consolidation is dependent on pore water pressure release. The refreezing of tailings removes the shortest drainage path, which would greatly increase consolidation time. Eventually the ground will freeze through to the foundation and eliminate all settlement altogether where lake taliks do not exist.

5 References

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Figures