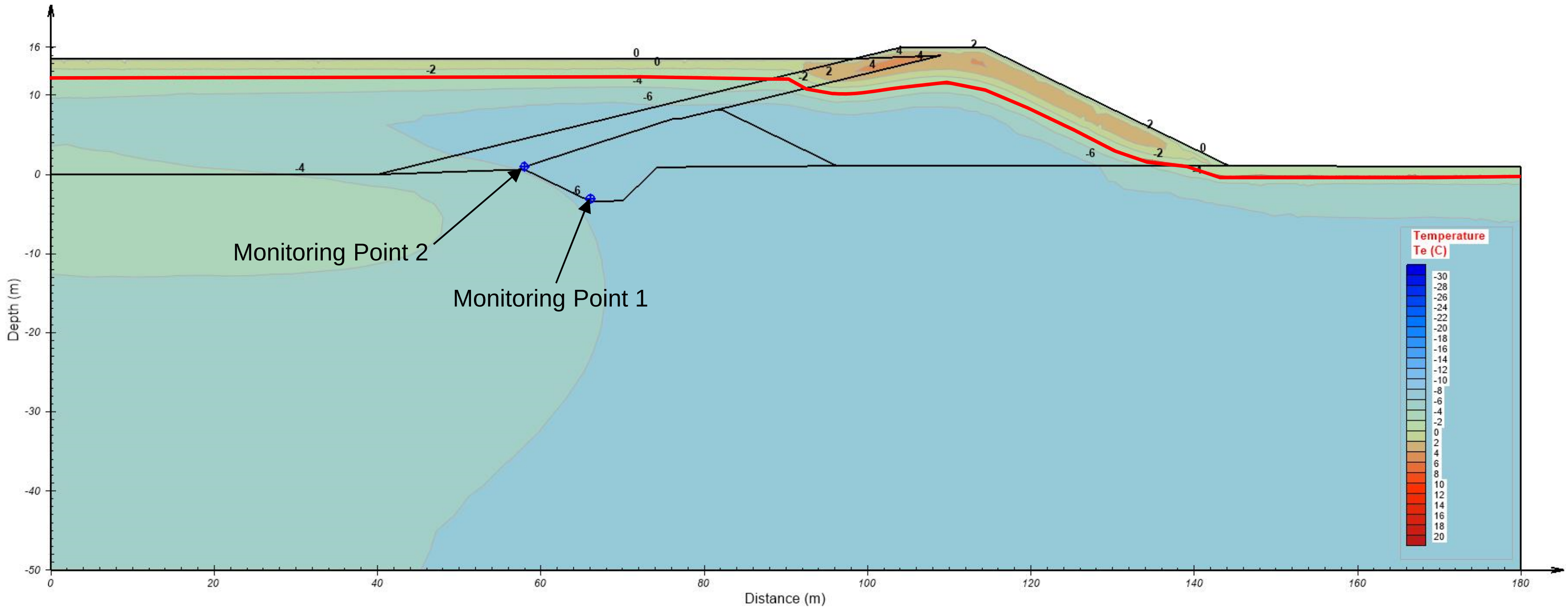
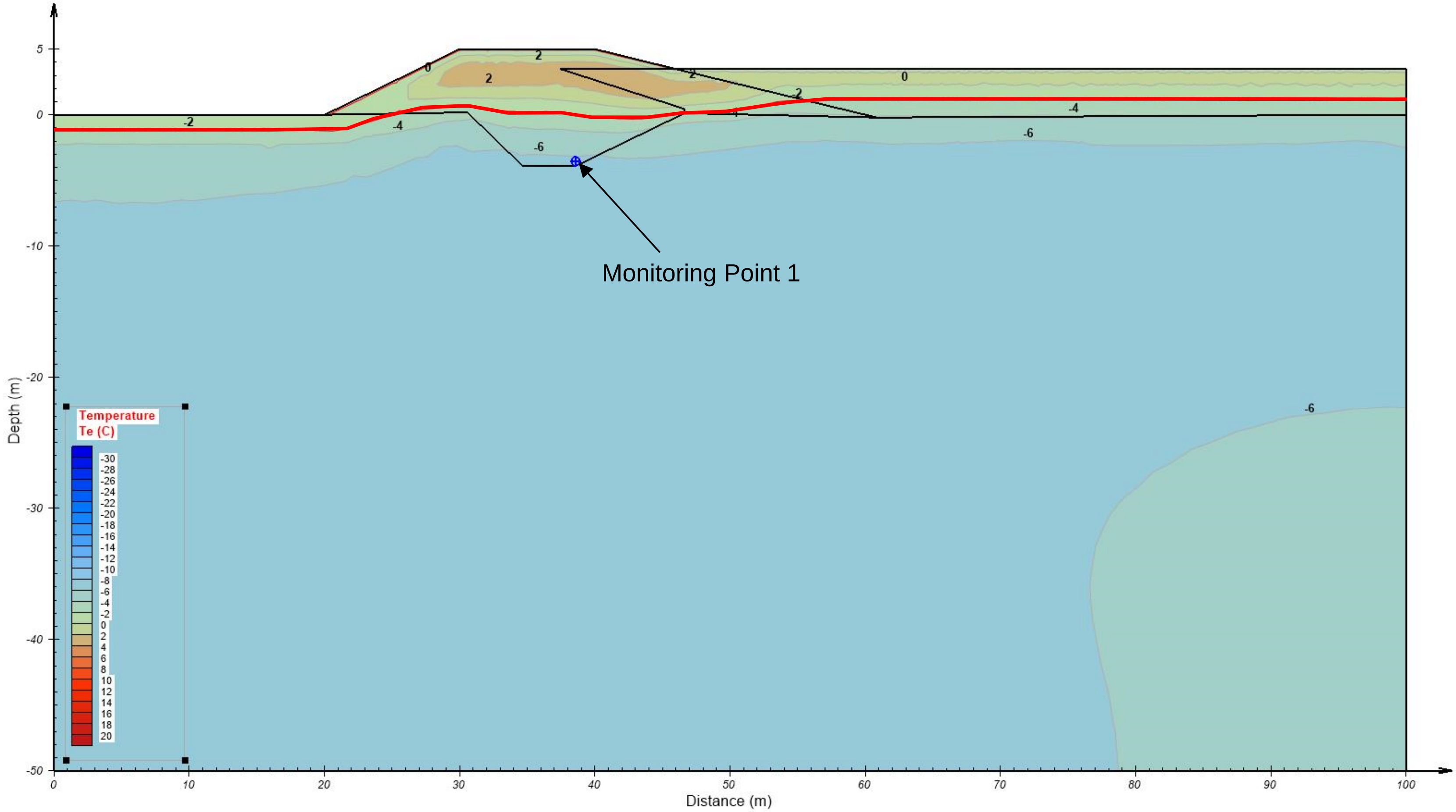


Notes:

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

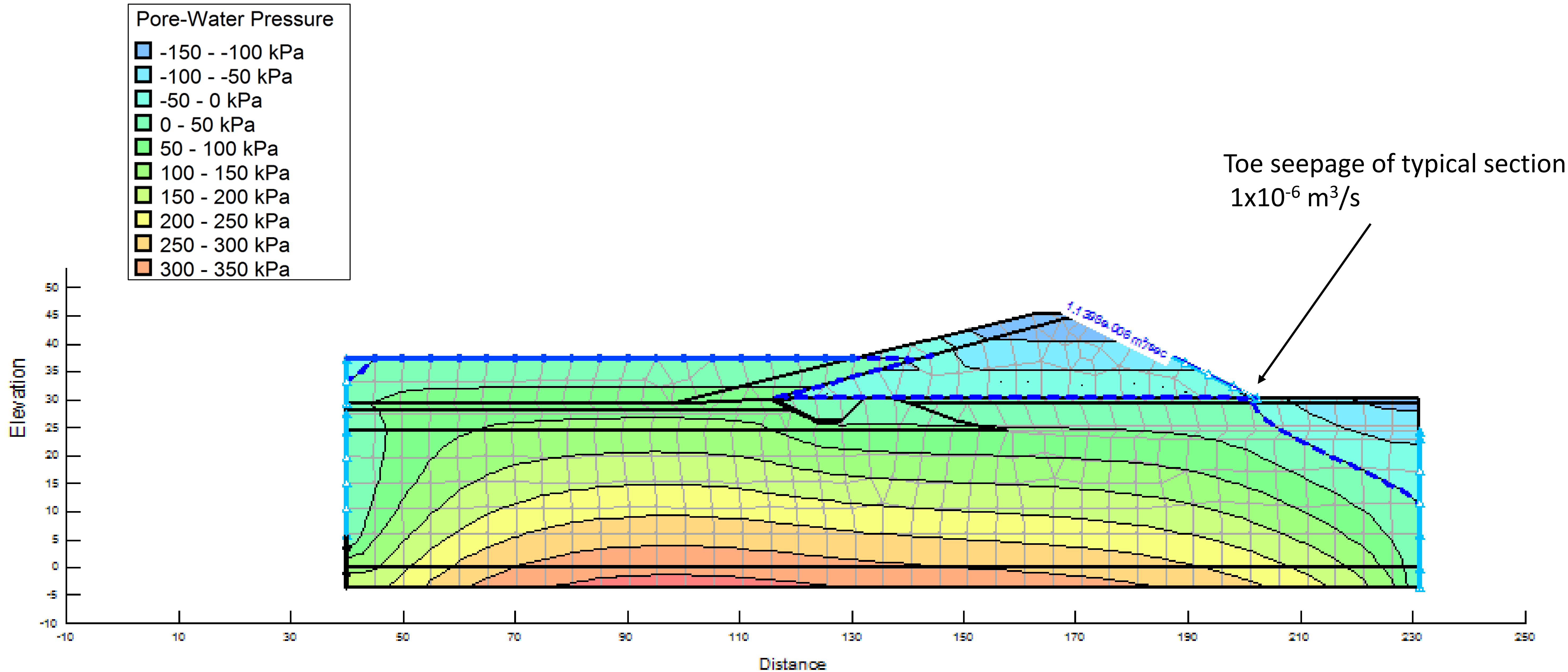
srk consulting	TMAC RESOURCES	Doris Phase 2 TIA Thermal Analysis
		Analyzed Thermal Model Results South Dam – End of Design Life
Job No: 1CT022.004.610 Filename: Figure3_SlopeStabilityMemo	TMAC Resources Inc.	Date: May 2016 | Approved: IM | Figure: **4**



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	TMAC RESOURCES	Doris Phase 2 TIA Thermal Analysis
		Analyzed Thermal Model Results West Dam – End of Design Life
Job No: 1CT022.004.610 Filename: Figure3_SlopeStabilityMemo	TMAC Resources Inc.	Date: May 2016 · Approved: IM · Figure: **5**

Attachment A
South and West Dam Seepage Analysis Results



srk consulting

TMAC RESOURCES

Job No: 1CT22.004.610

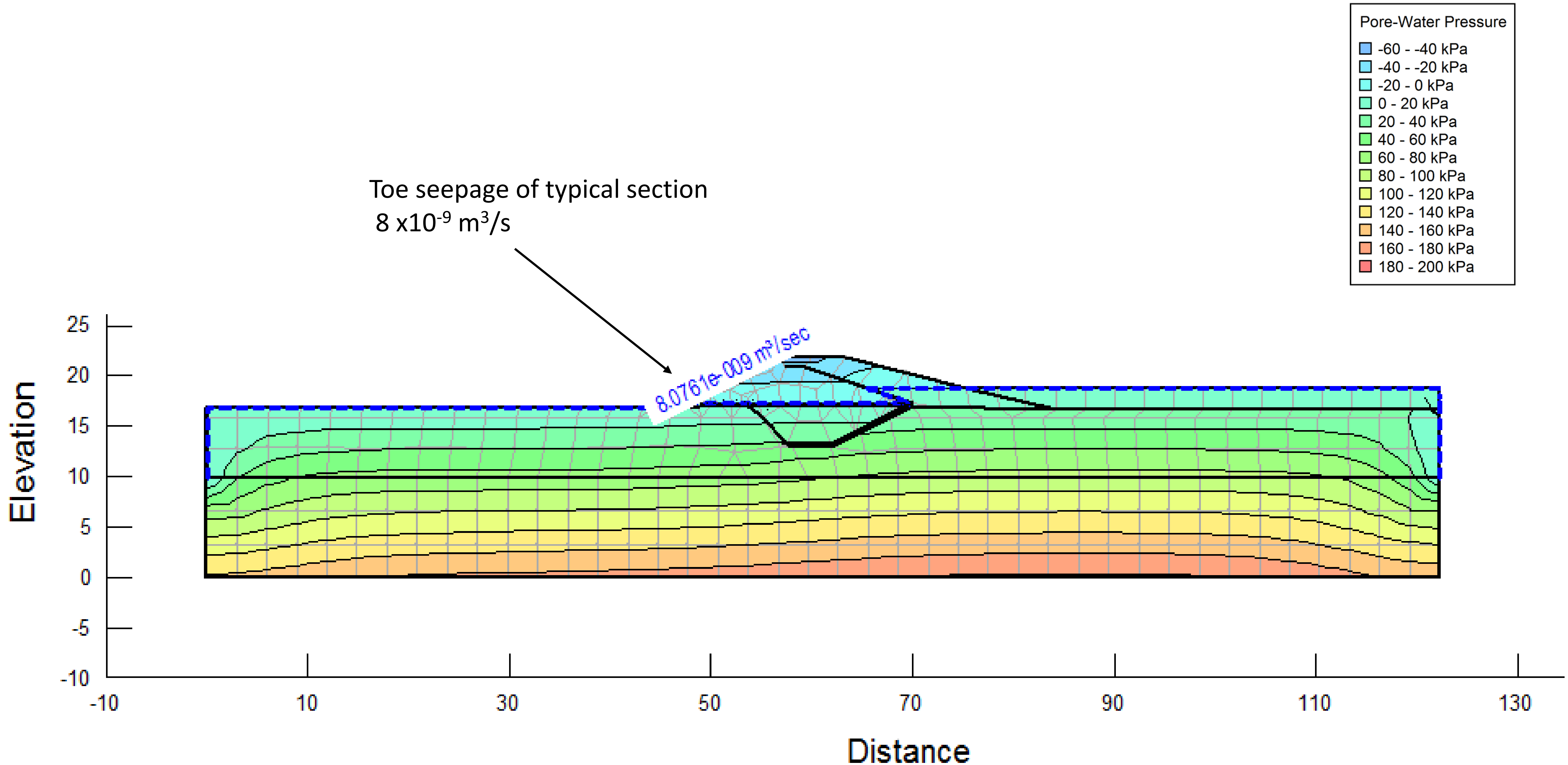
Filename: HopeBay_DorisNorth_SouthDam_SlopeStability_160407_sa

HOPE BAY PROJECT

DORIS TMS SEEPAGE ANALYSIS

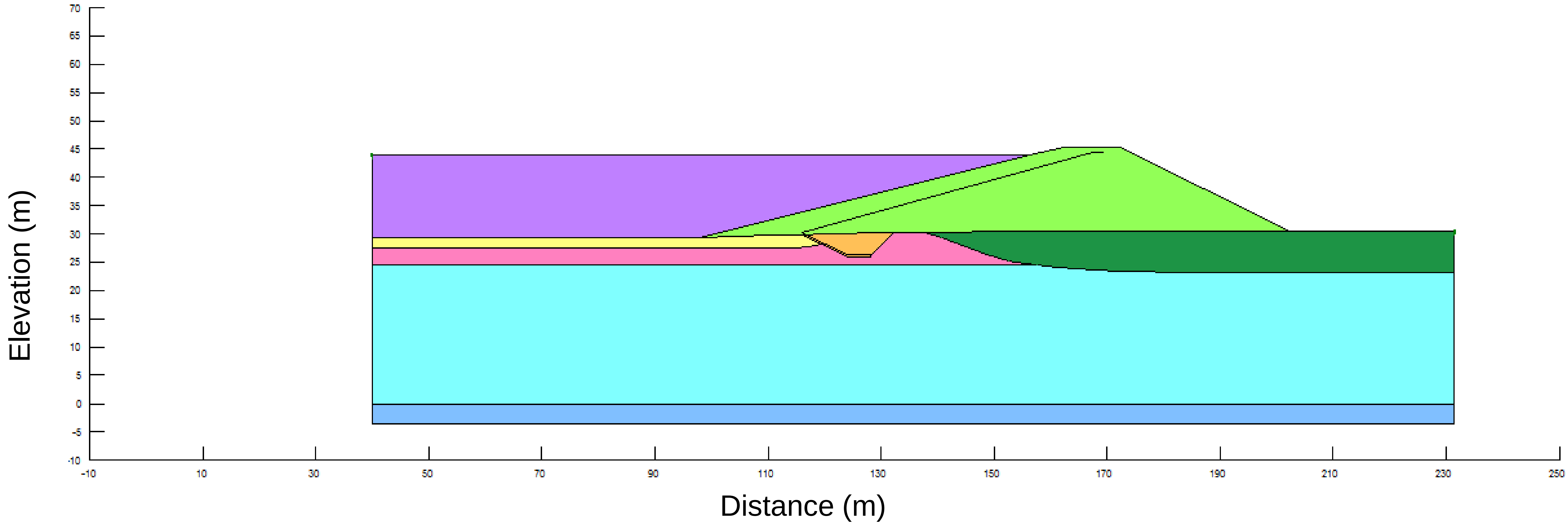
South Dam Analyzed Cross Section

Date:	Approved:	Figure:
April 2016	SA	1



srk consulting	MAC RESOURCES	DORIS TMS SEEPAGE ANALYSIS
		West Dam Analyzed Cross Section
Job No: 1CT22.004.610 Filename: HopeBay_DorisNorth_SouthDam_SlopeStability_160407_sa	HOPE BAY PROJECT	Date: April 2016 / Approved: SA / Figure: 2

Attachment B
South Dam Stability Analysis Results



LEGEND

- ROQ (Non-Frozen)
- Marine Silt and Clay (Non-Frozen)
- Marine Silt and Clay (Frozen)
- ROQ (Frozen)
- Marine Silt and Clay (Top 5m)
- Tailings
- Silt (Frozen)
- Bedrock

DORIS TIA SLOPE STABILITY

South Dam Analyzed Cross Section

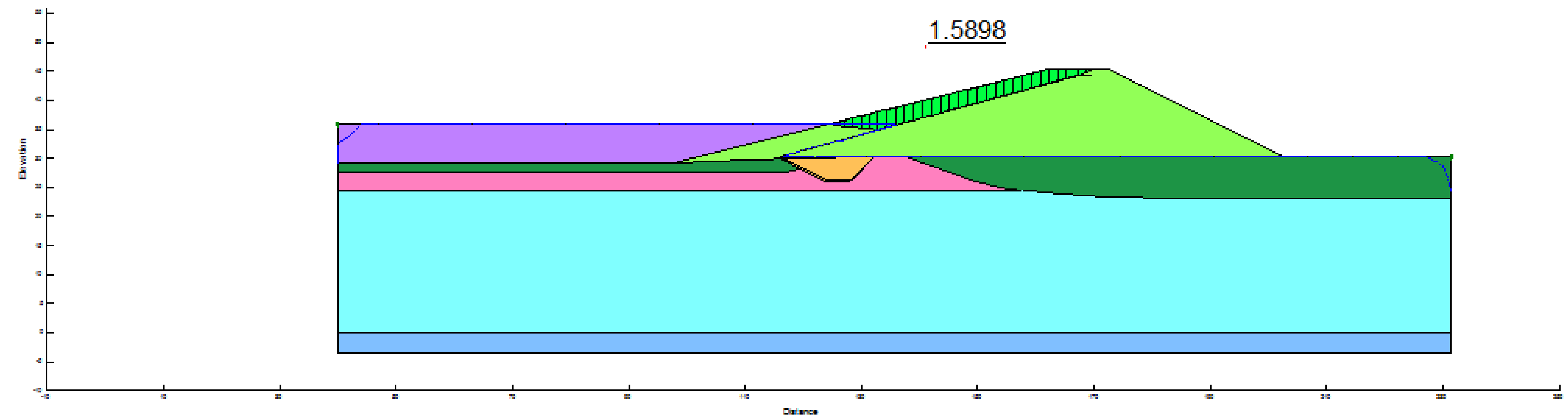
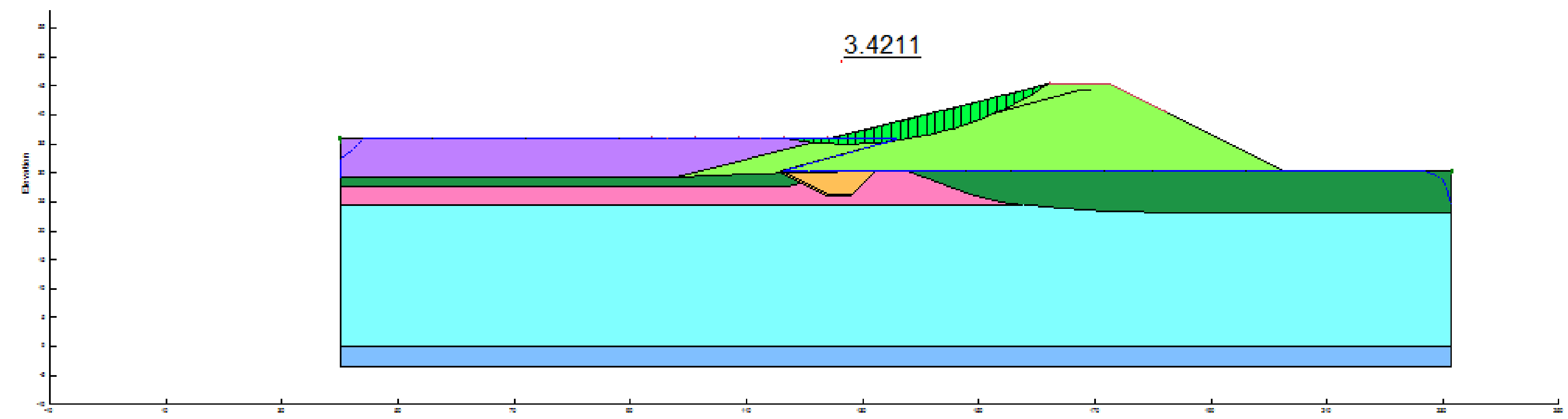
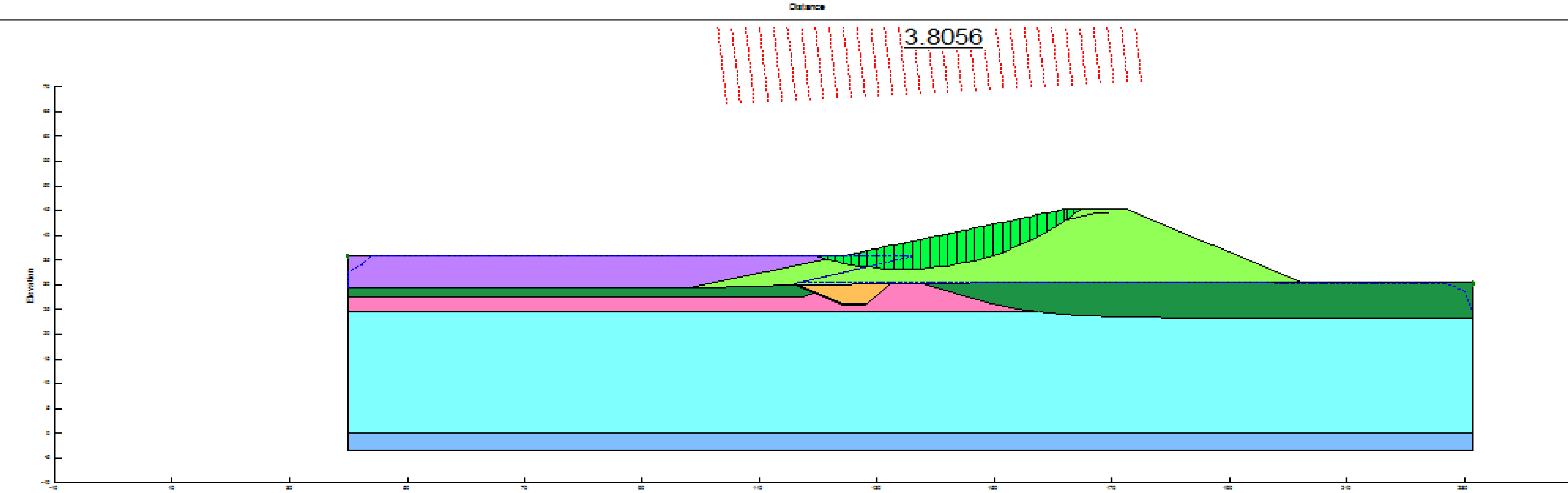
Job No: 1CT22.004.610

Filename: HopeBay_DorisNorth_SouthDam_SlopeStability_160407_sa

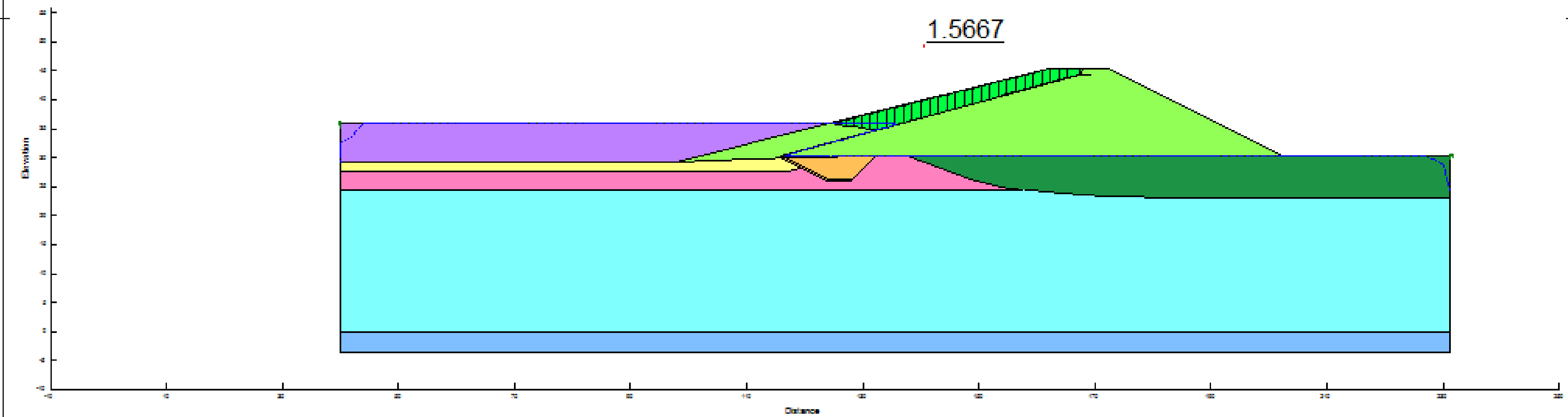
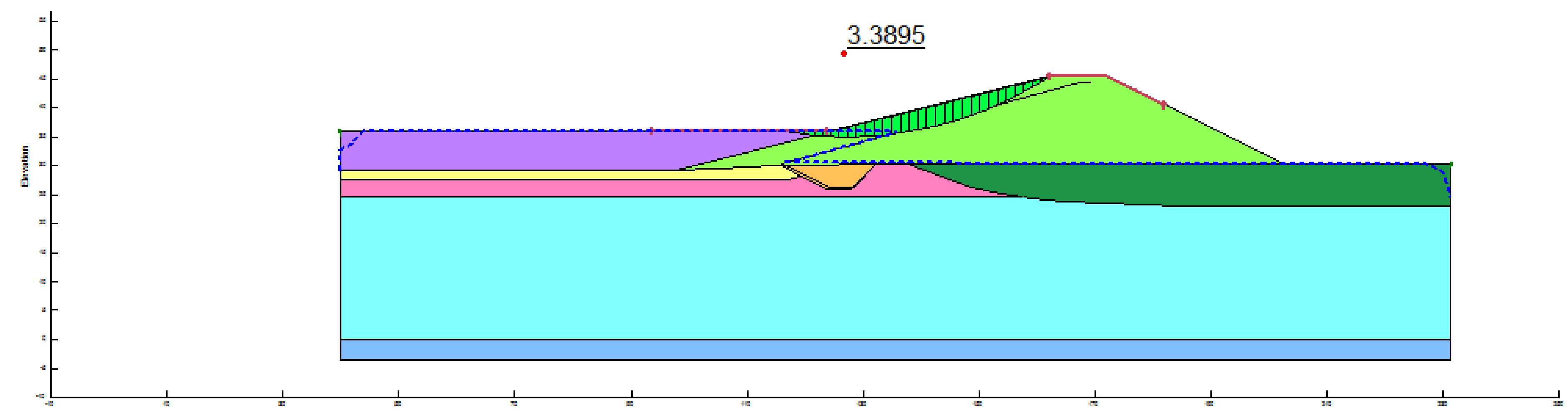
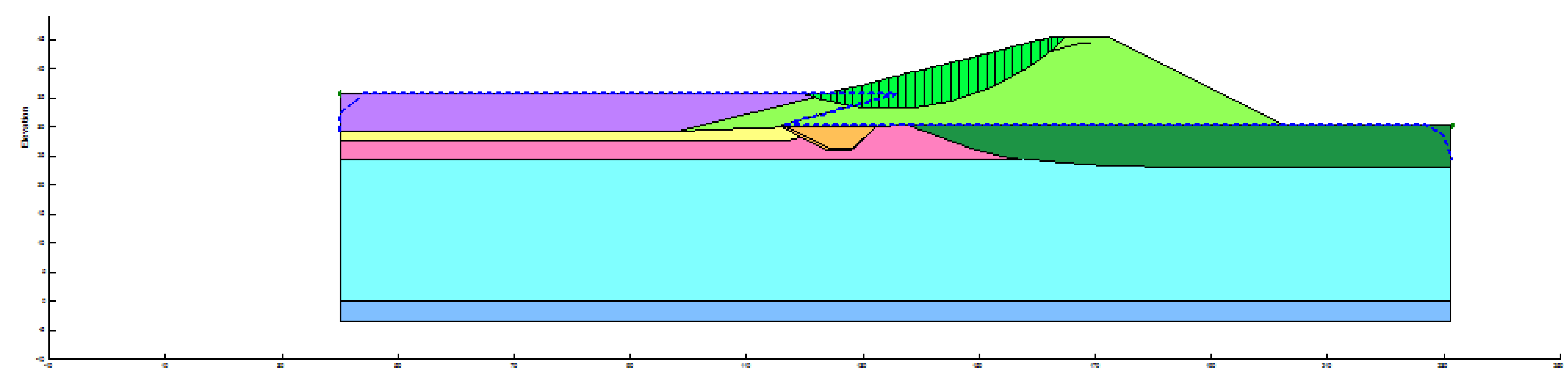
HOPE BAY PROJECT

Date:	Approved:	Figure:
April 2016		1

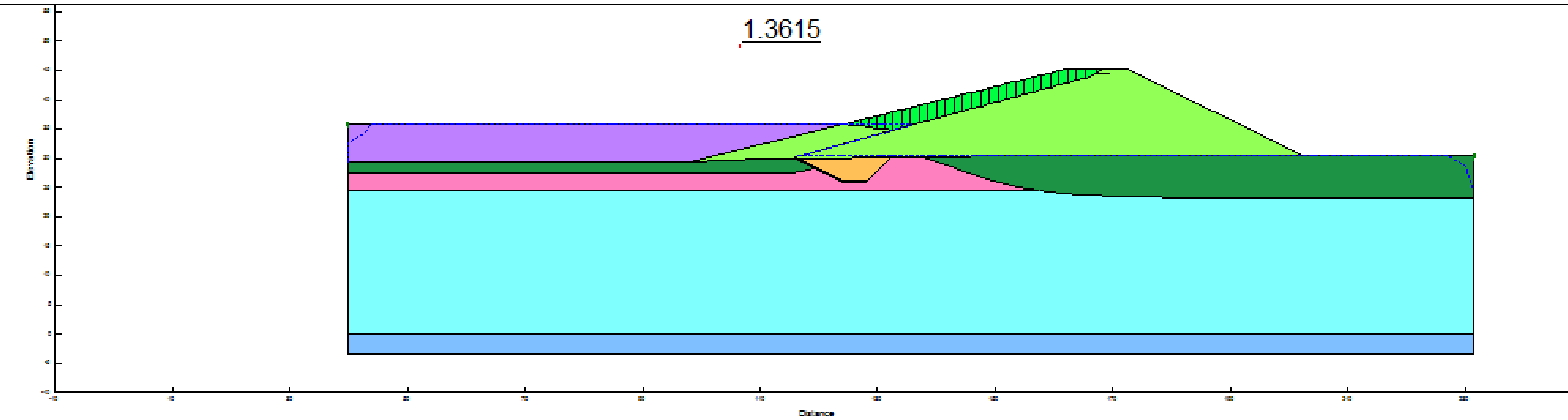
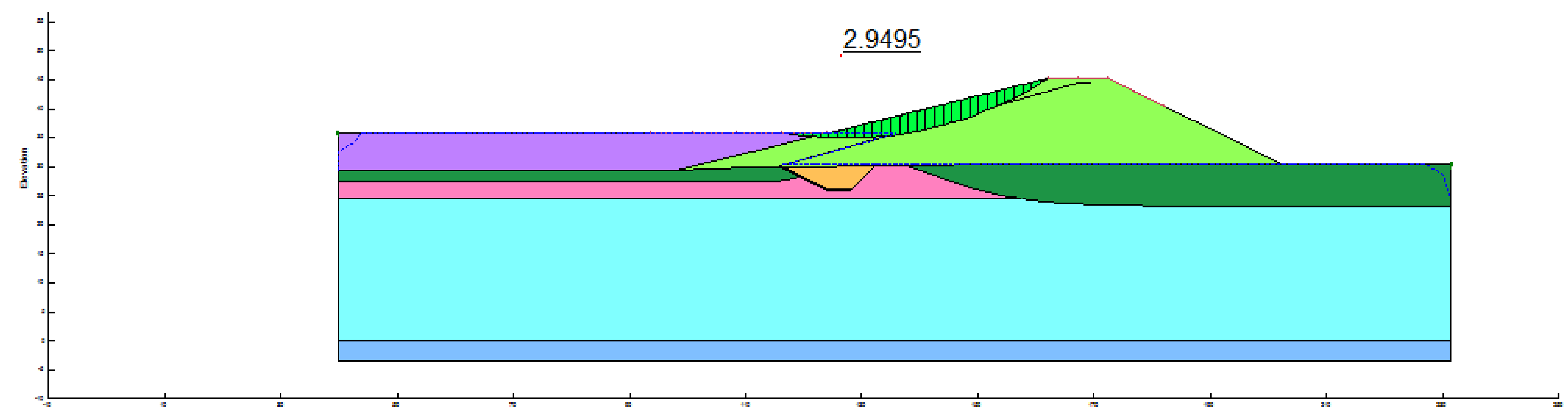
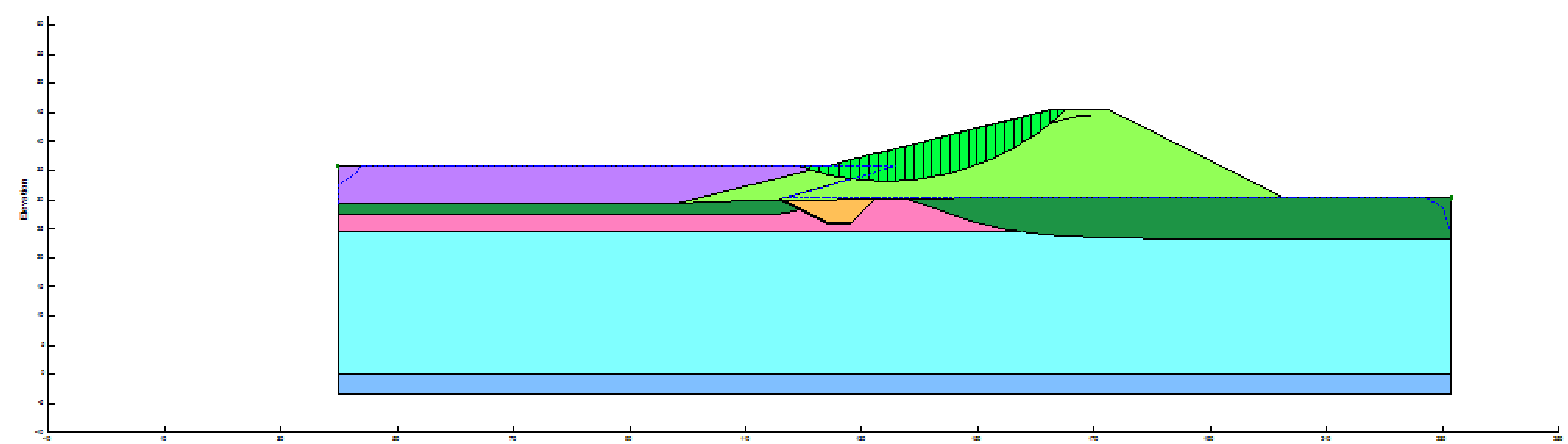
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model A-South Dam (Upstream Slope, Static, Drained, 7m AL)	1.59	Fully Defined	
	3.42	Entry Exit	
	3.81	Grid and Radius	

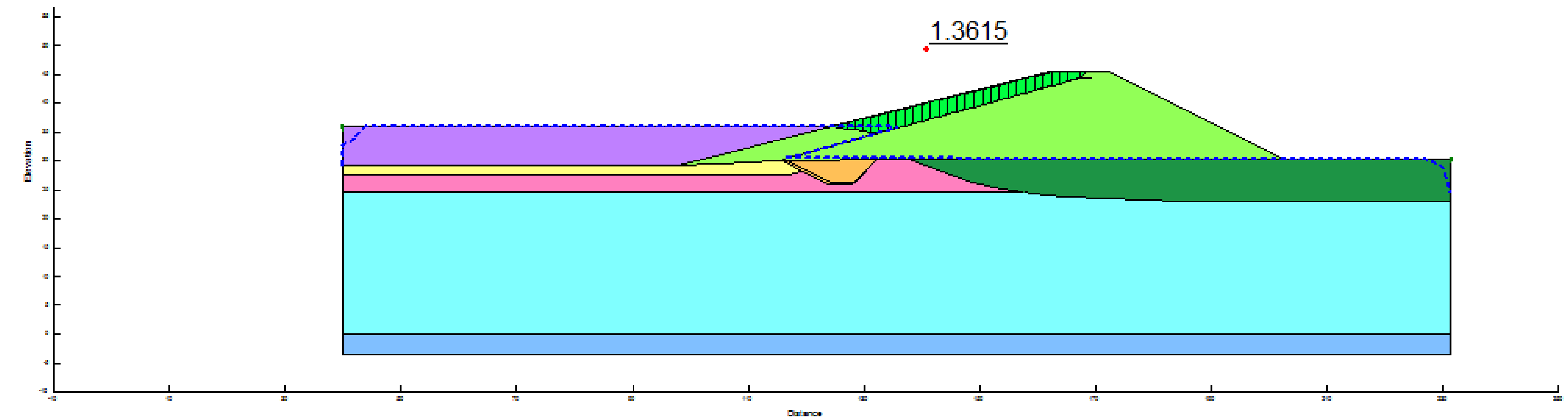
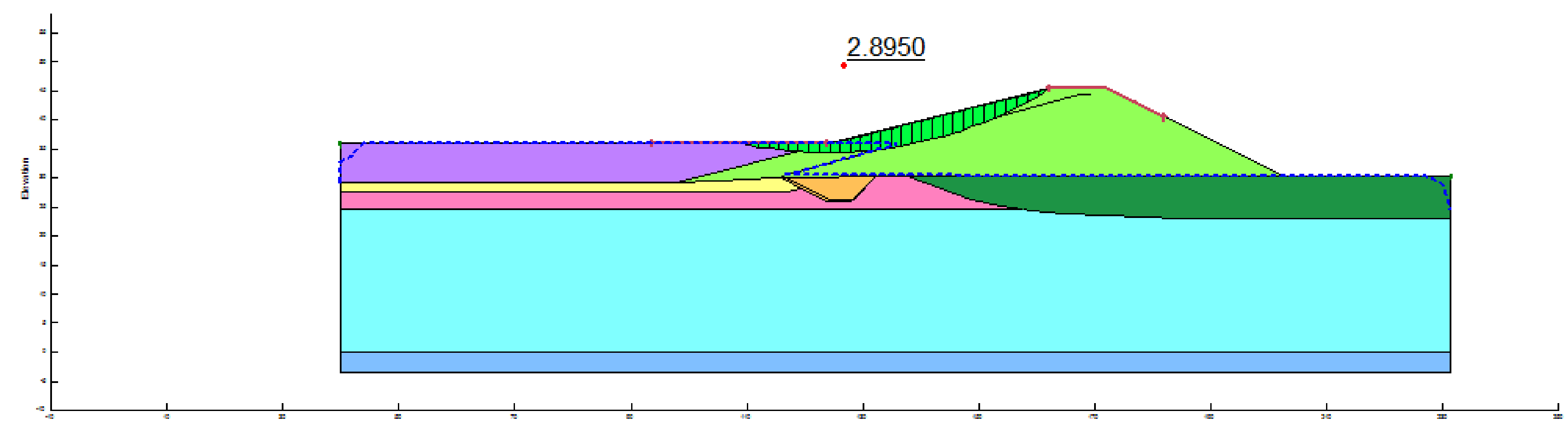
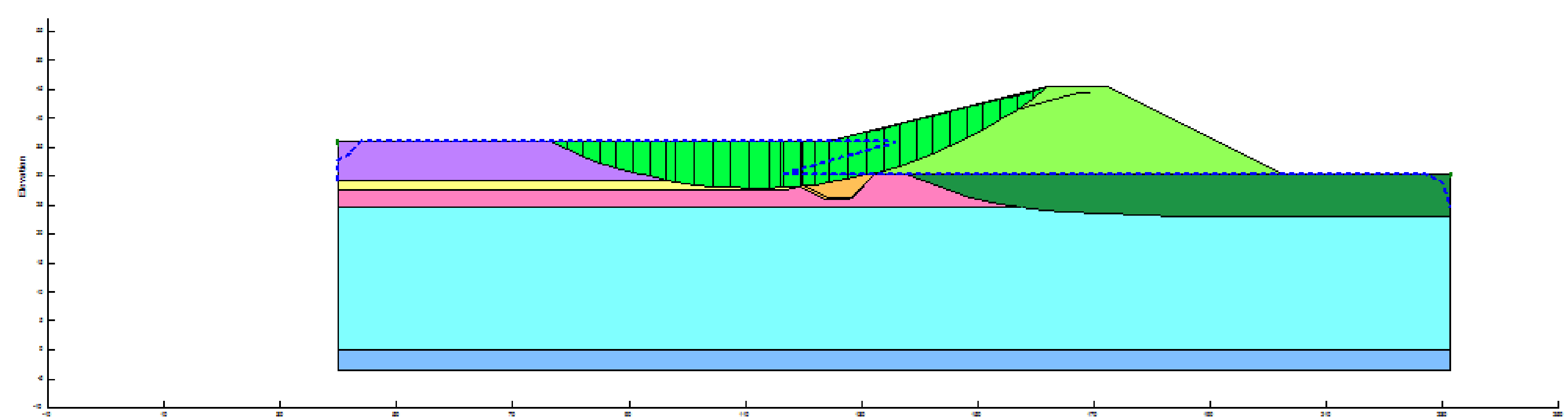
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model A-South Dam (Upstream Slope, Static, Undrained, 7m AL)	1.57	Fully Defined	
	3.39	Entry Exit	
	3.79	Grid and Radius	

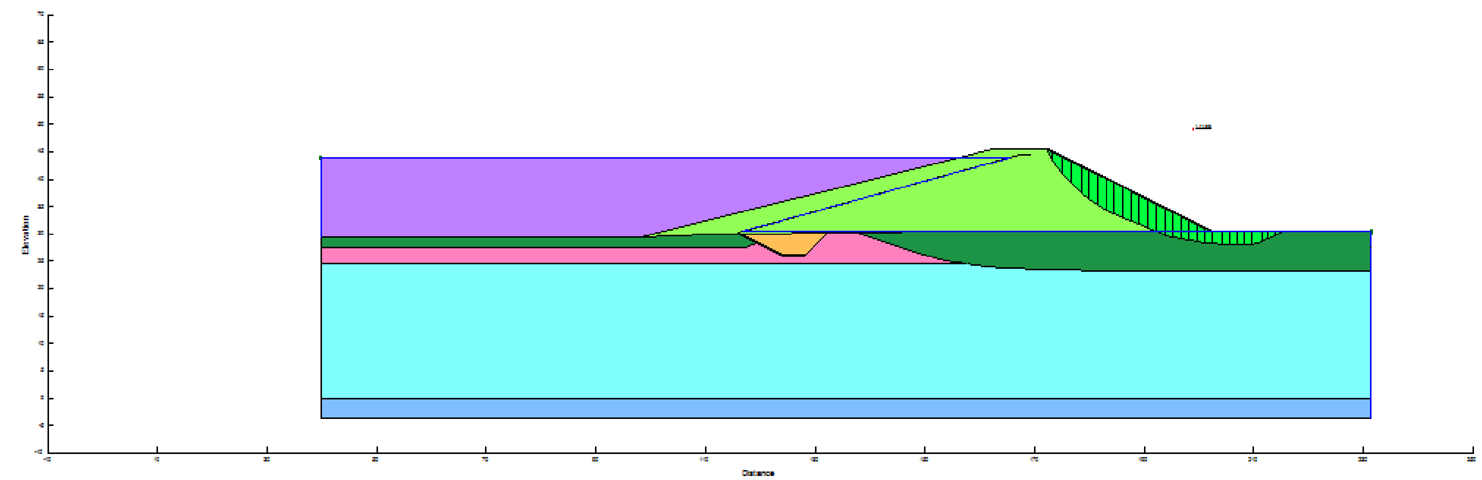
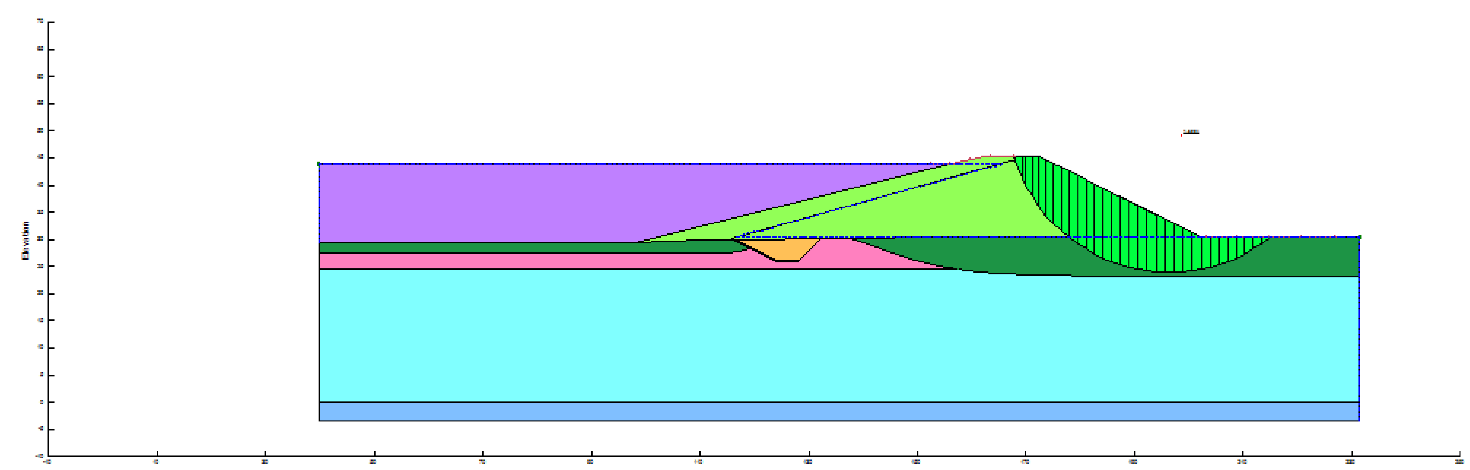
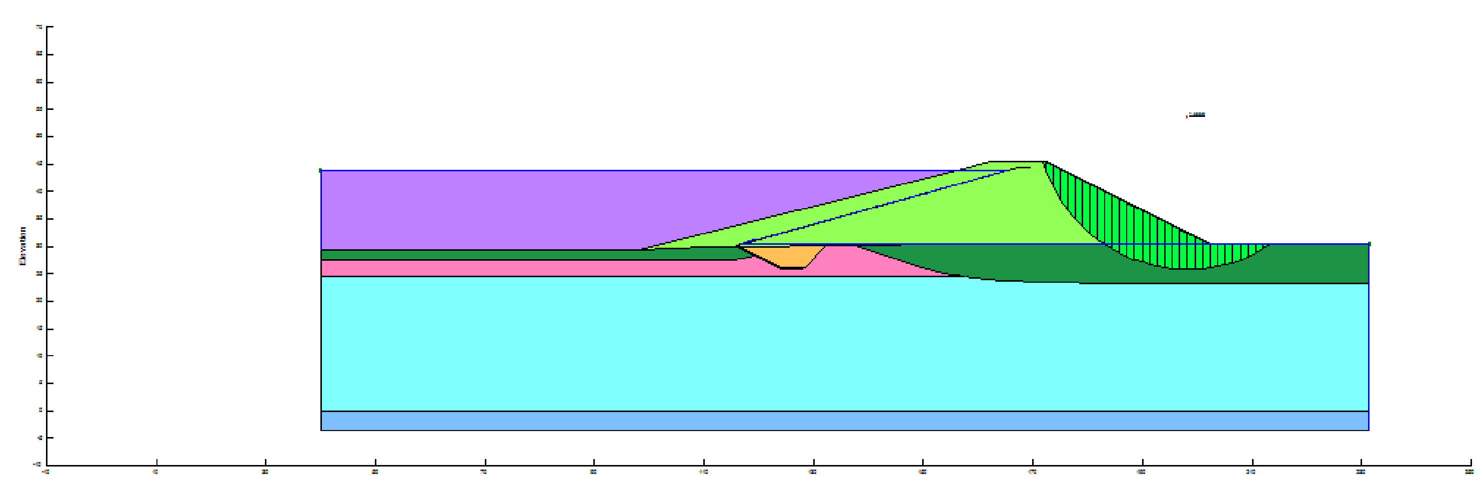
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model A-South Dam (Upstream Slope, Pseudo-Static, drained, 7m AL)	1.36	Fully Defined	
	2.94	Entry Exit	
	3.29	Grid and Radius	

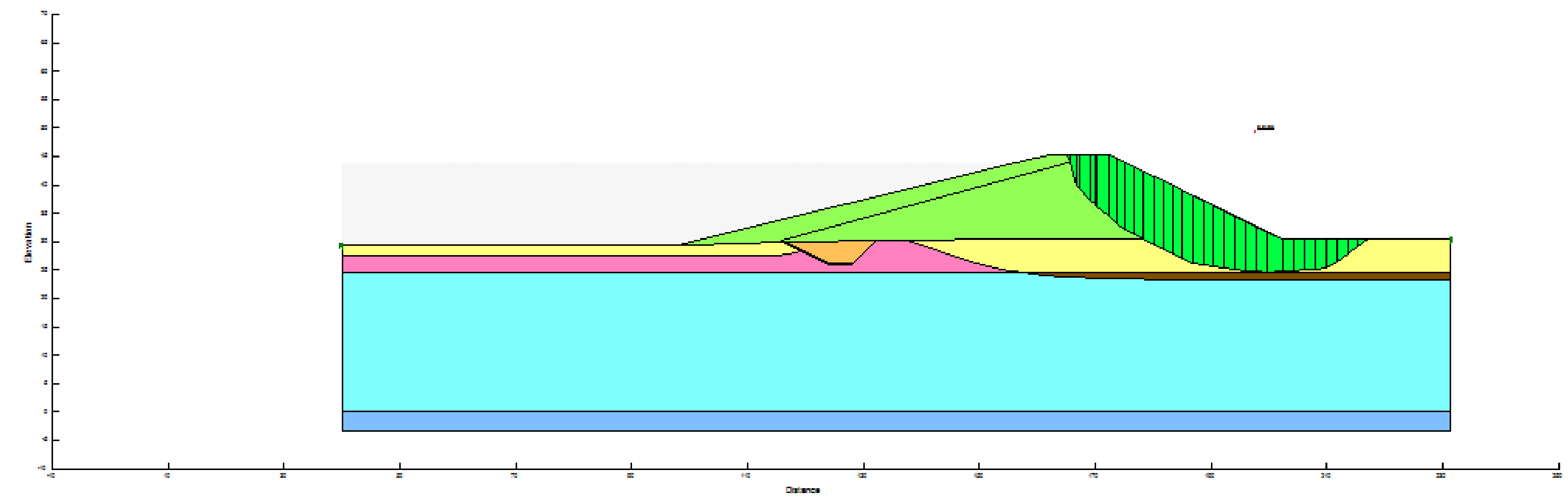
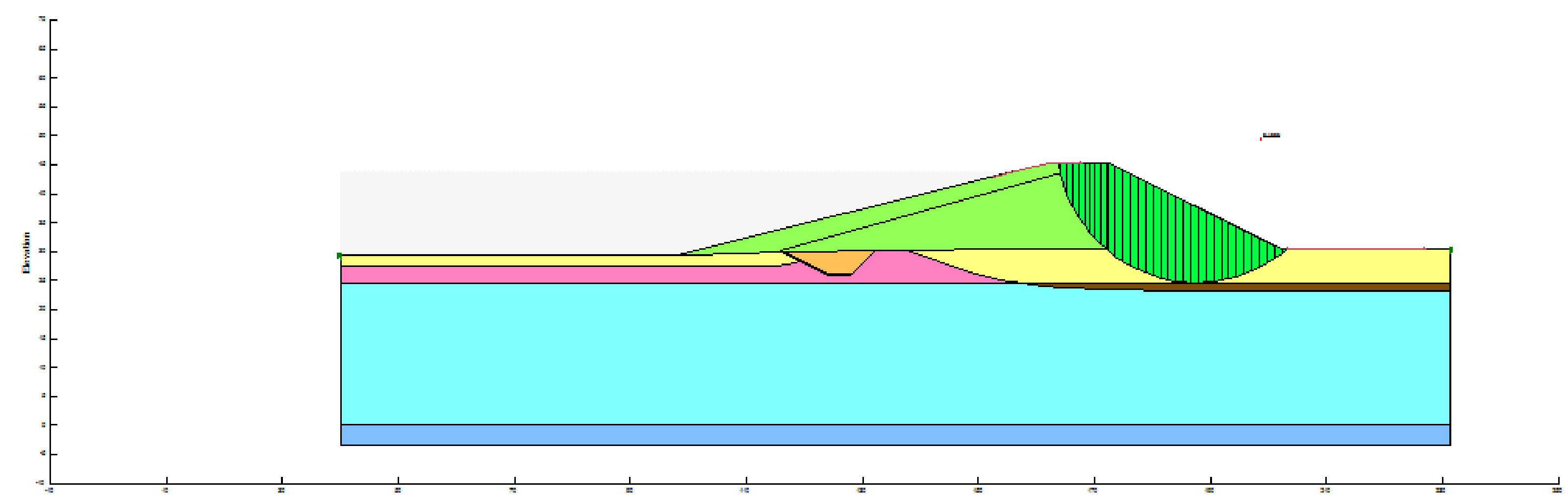
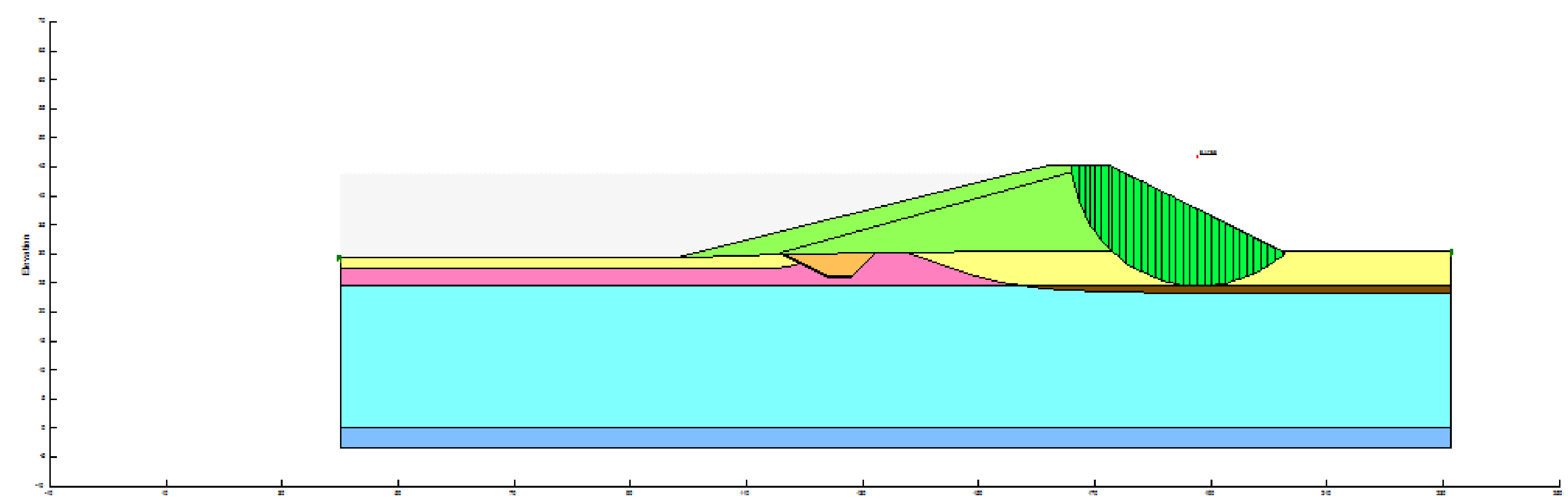
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model A-South Dam (Upstream Slope, Pseudo-Static, undrained, 7m AL)	1.36	Fully Defined	
	2.89	Entry Exit	
	3.04	Grid and Radius	

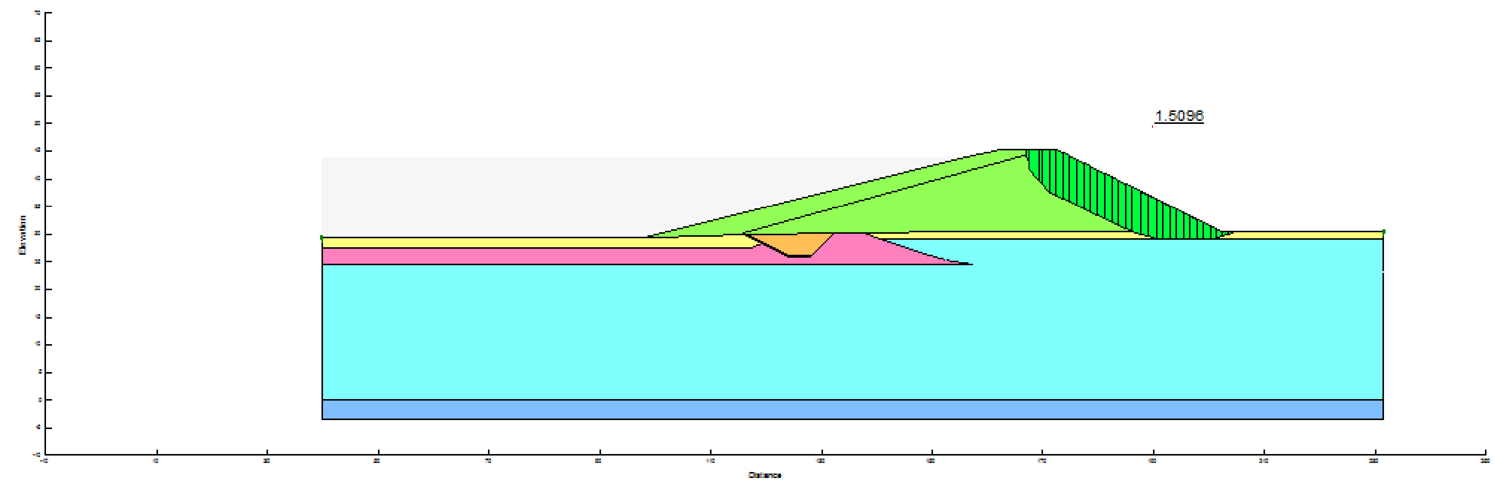
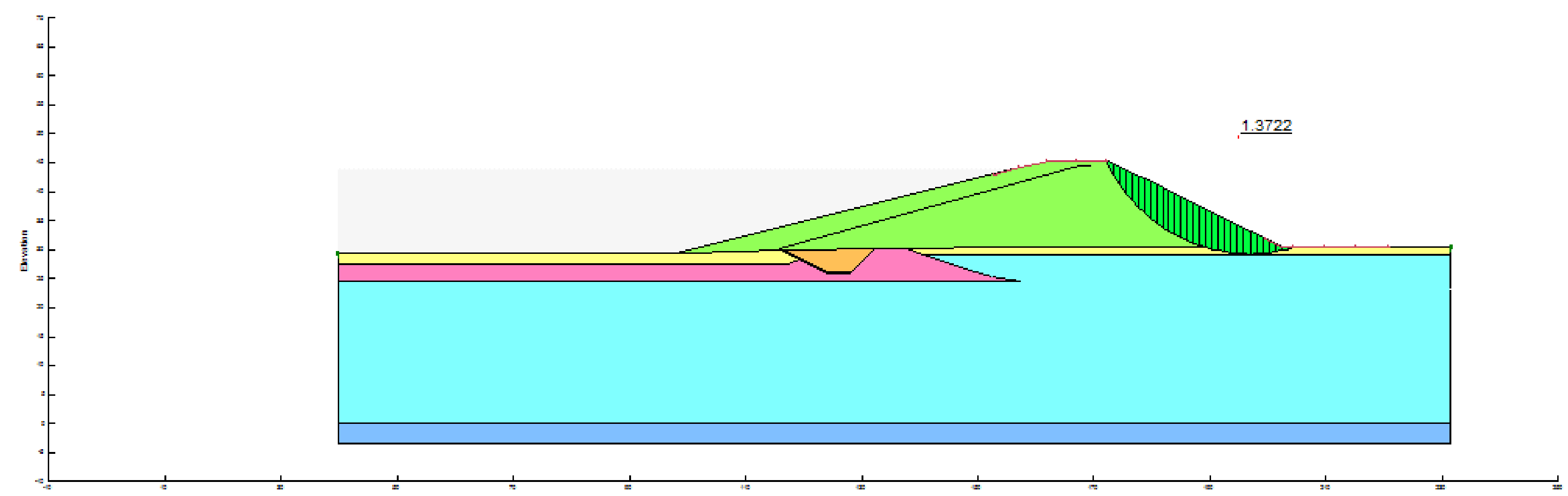
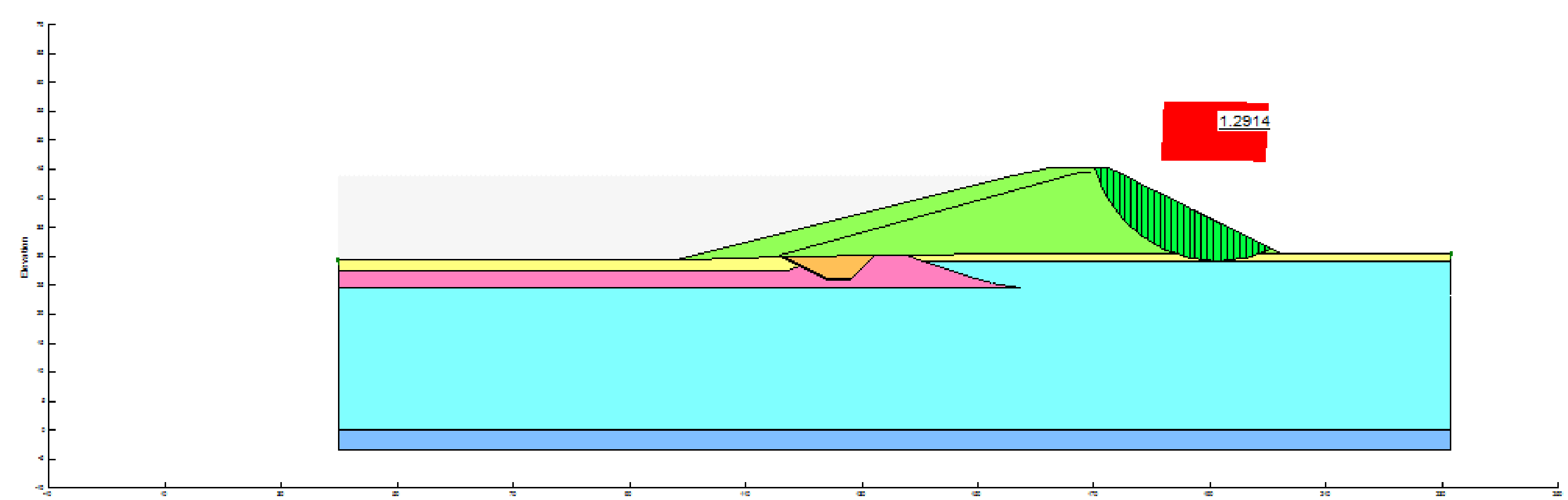
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model B-South Dam (Downstream Slope, Static, Drained, 7m AL)	1.74	Fully Defined	
	1.62	Entry Exit	
	1.57	Grid and Radius	

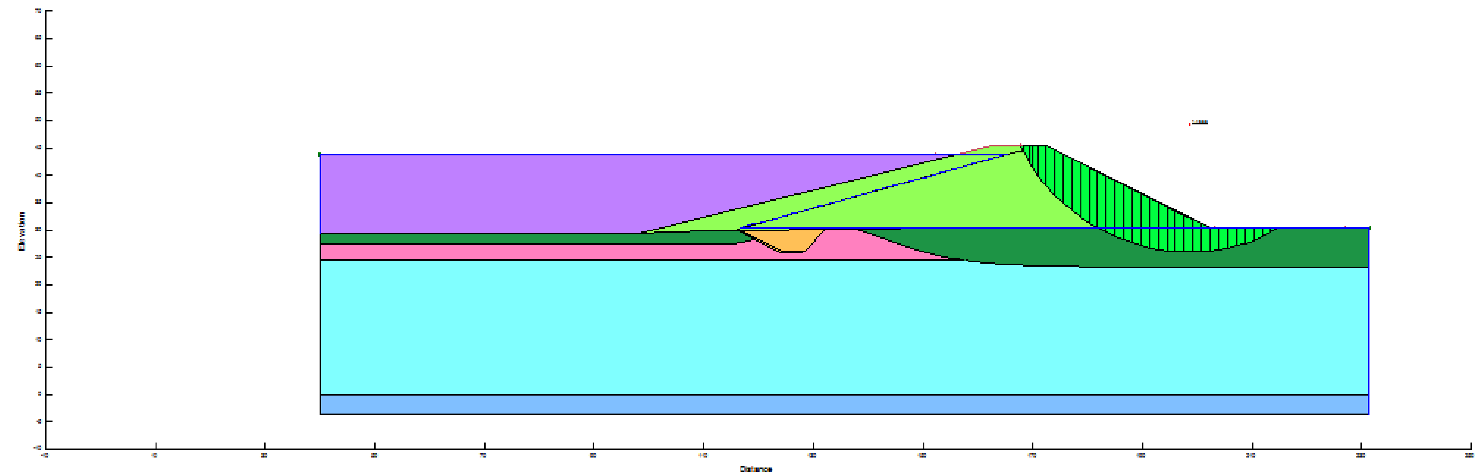
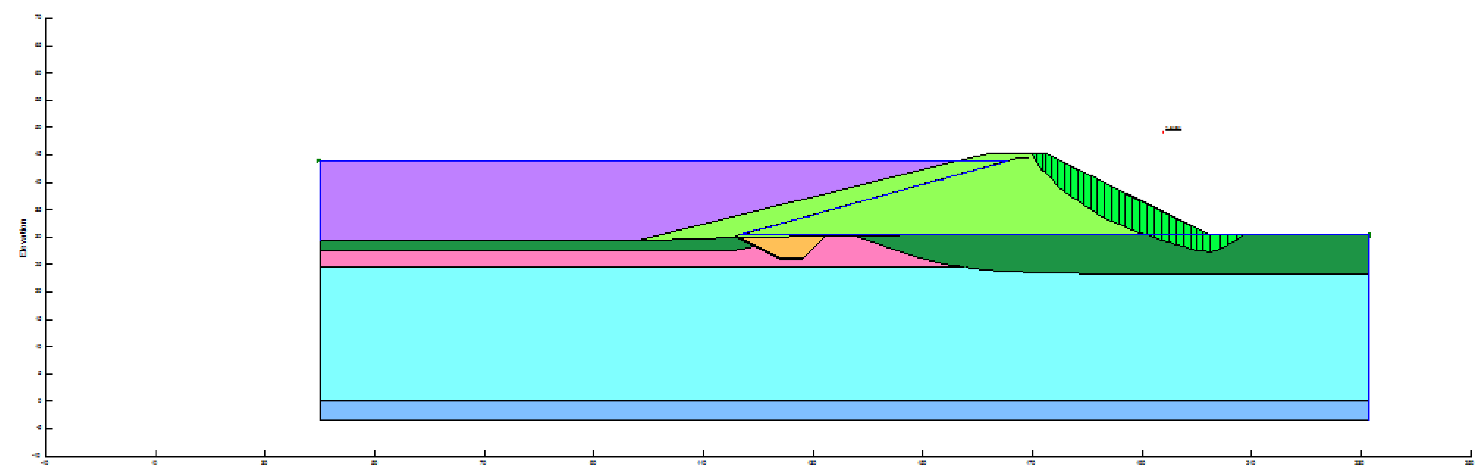
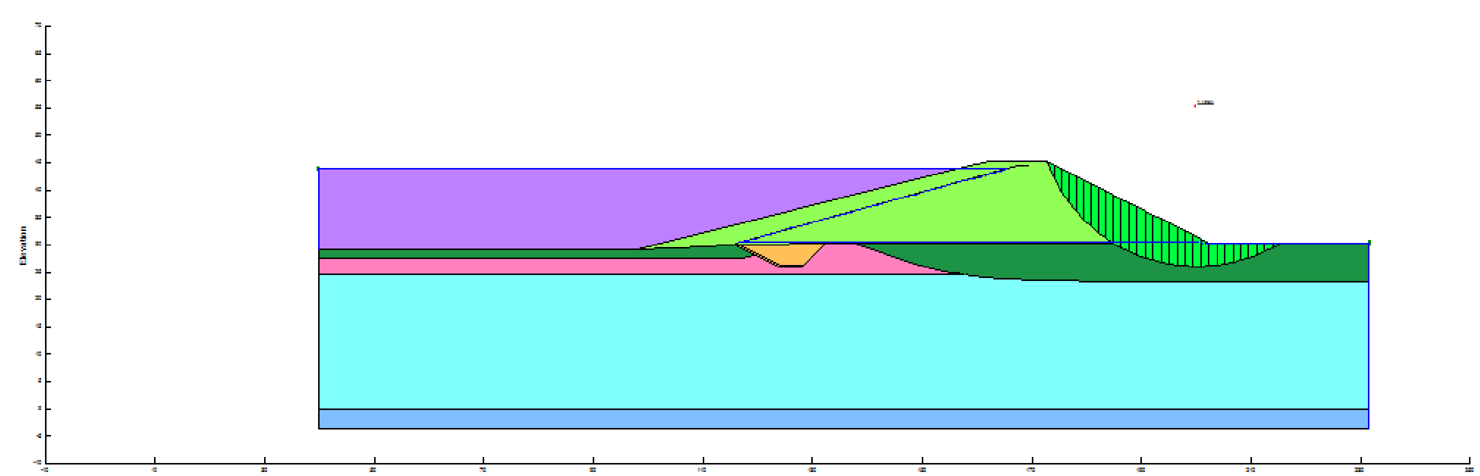
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model B-South Dam (Downstream Slope, Static, Undrained, 7m AL)	0.84	Fully Defined	
	0.50	Entry Exit	
	0.48	Grid and Radius	

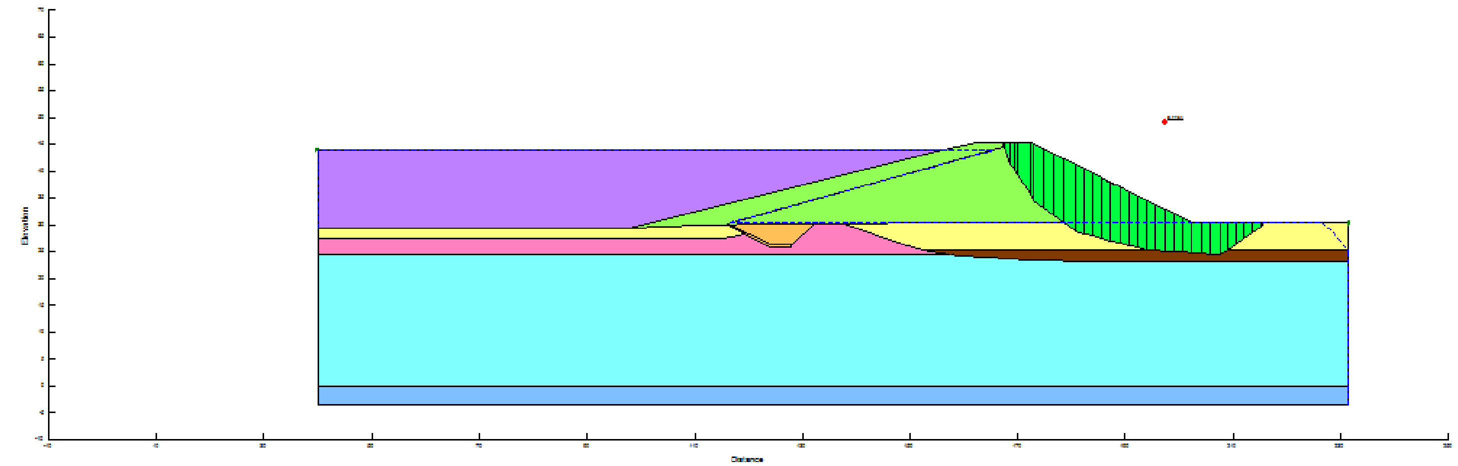
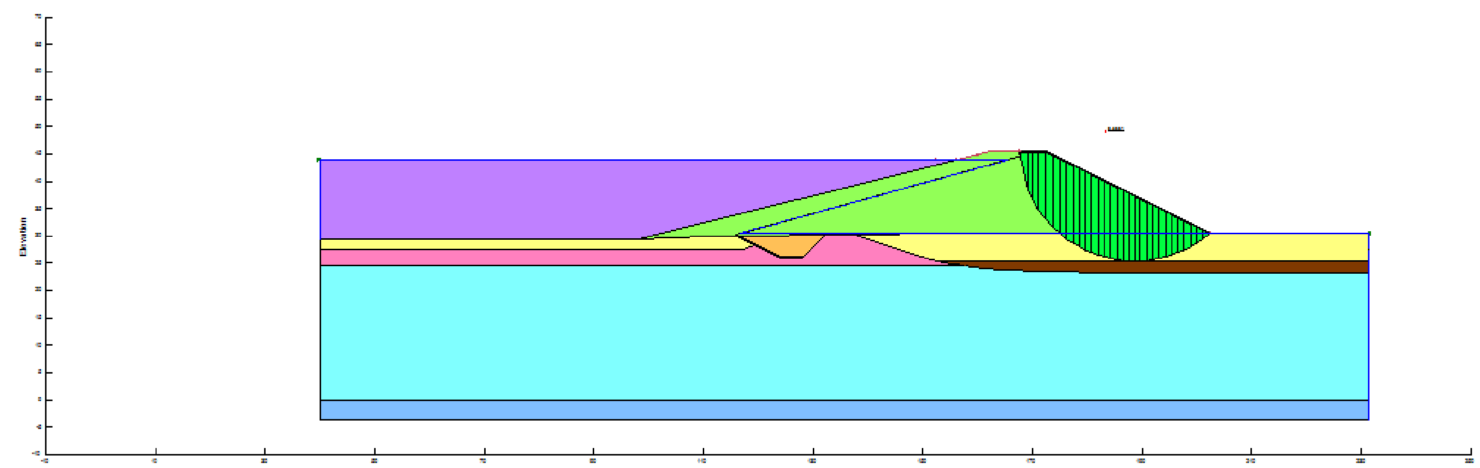
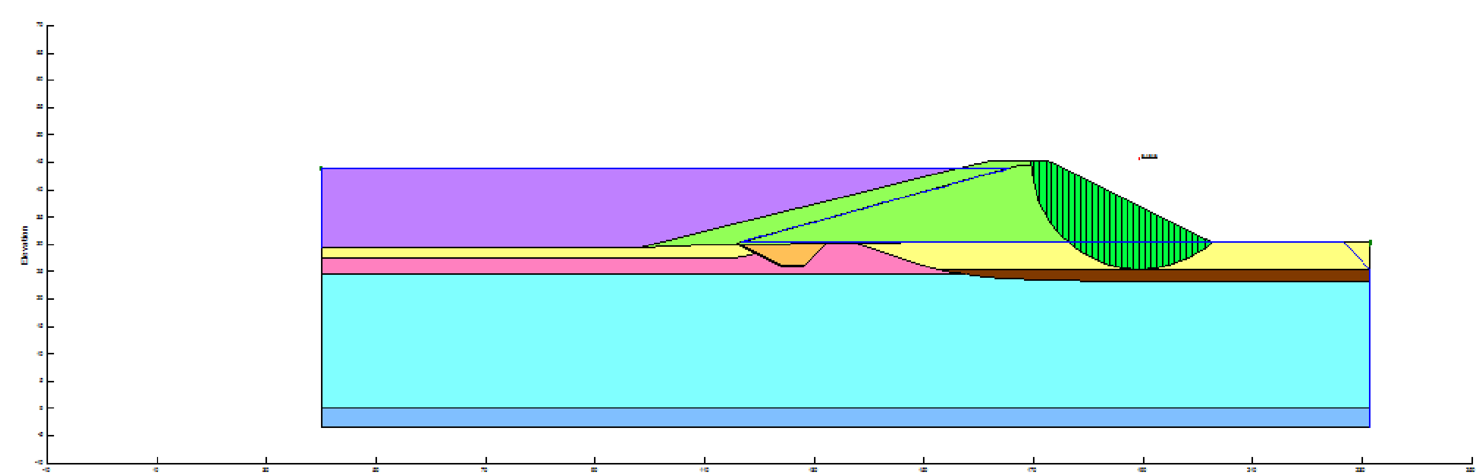
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model B-South Dam (Upstream Slope, Static, undrained, 1m AL)	1.51	Fully Defined	
	1.37	Entry Exit	
	1.29	Grid and Radius	

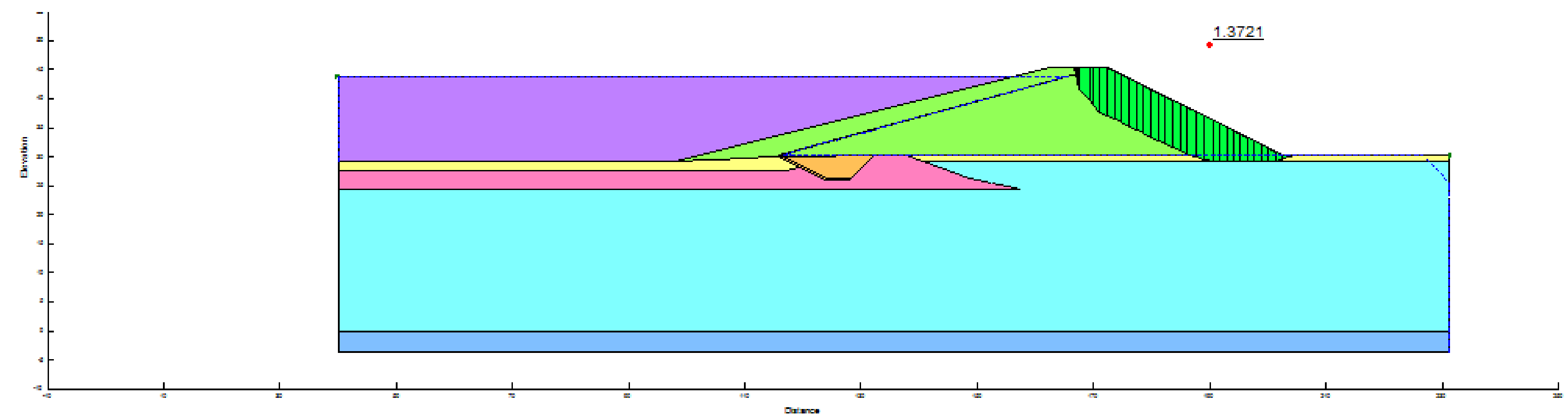
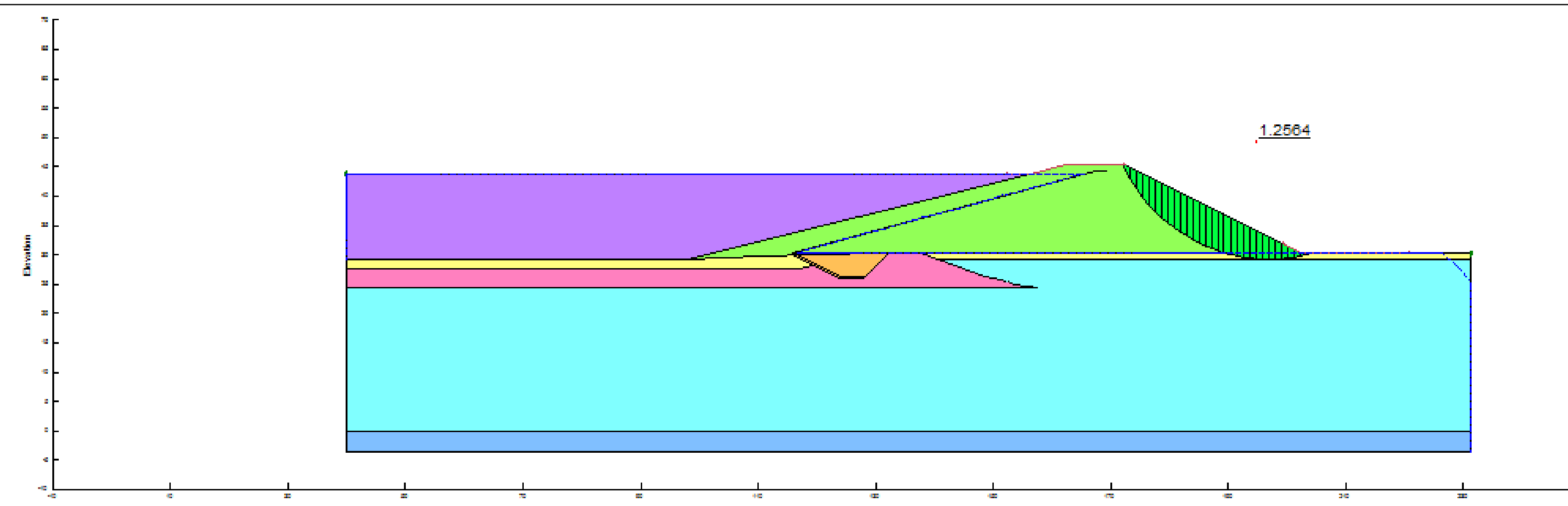
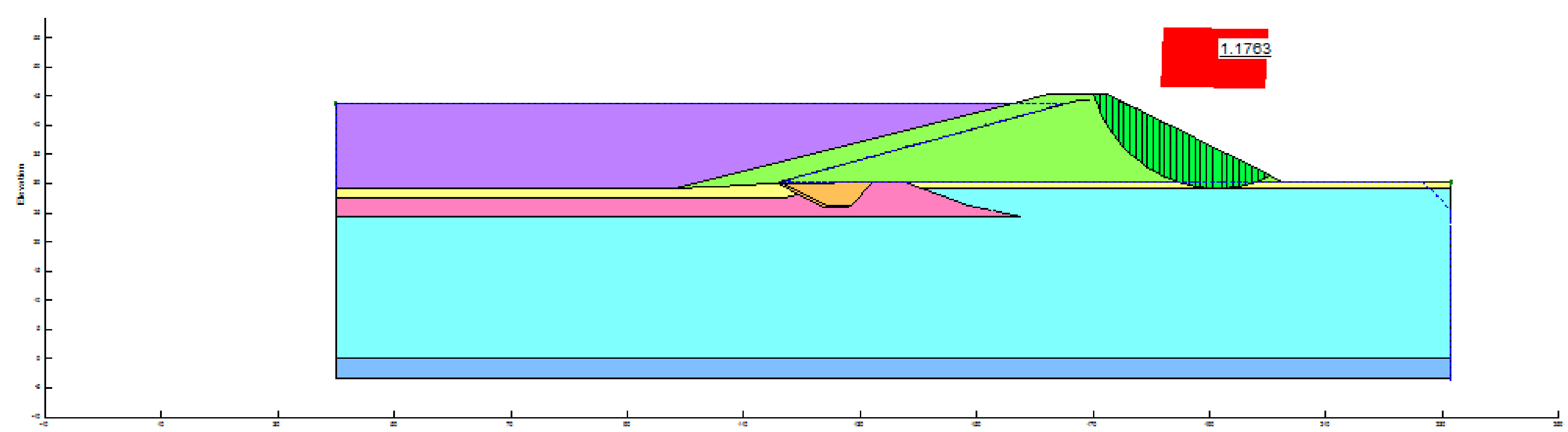
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model B-South Dam (Downstream Slope, Pseudo-Static, Drained, 7m AL)	1.55	Fully Defined	
	1.46	Entry Exit	
	1.42	Grid and Radius	

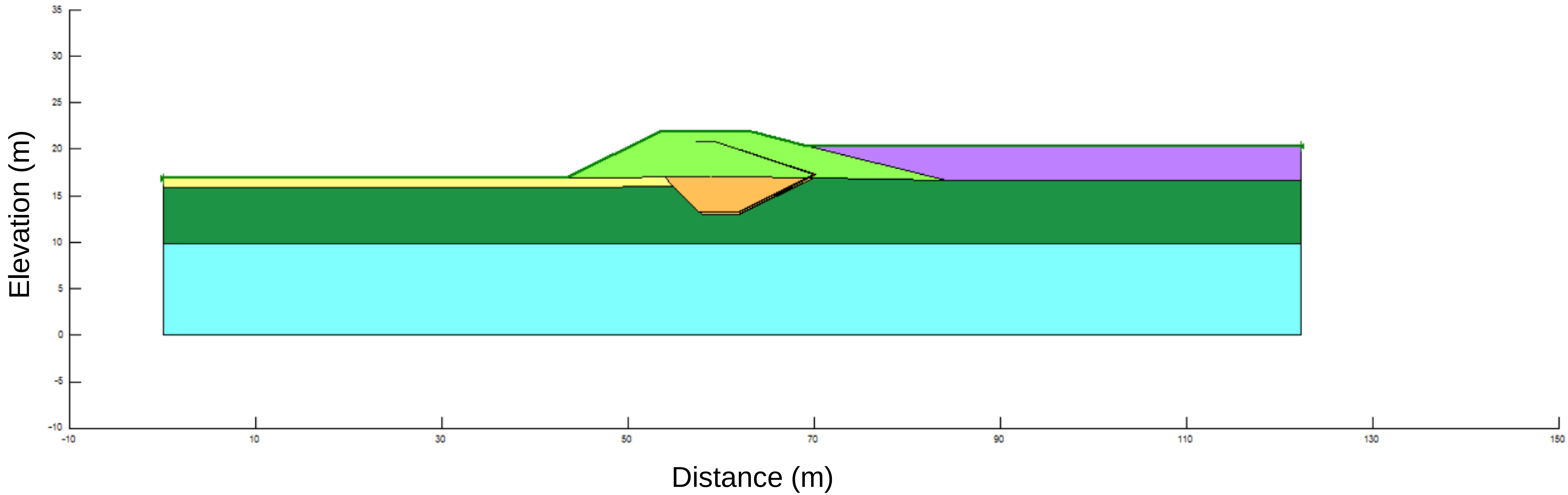
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model B-South Dam (Downstream Slope, Pseudo-Static, Undrained, 7m AL)	0.78	Fully Defined	
	0.57	Entry Exit	
	0.48	Grid and Radius	

Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model B-South Dam (Downstream Slope, Pseudo-Static, undrained, 1m AL)	1.347	Fully Defined	
	1.25	Entry Exit	
	1.18	Grid and Radius	

Attachment C
West Dam Stability Analysis Results

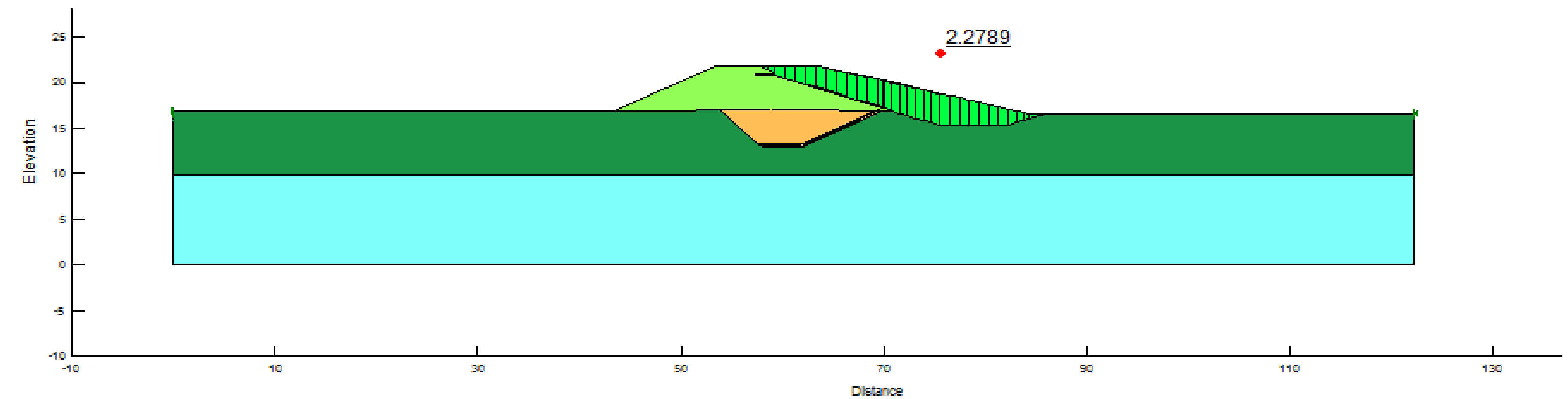
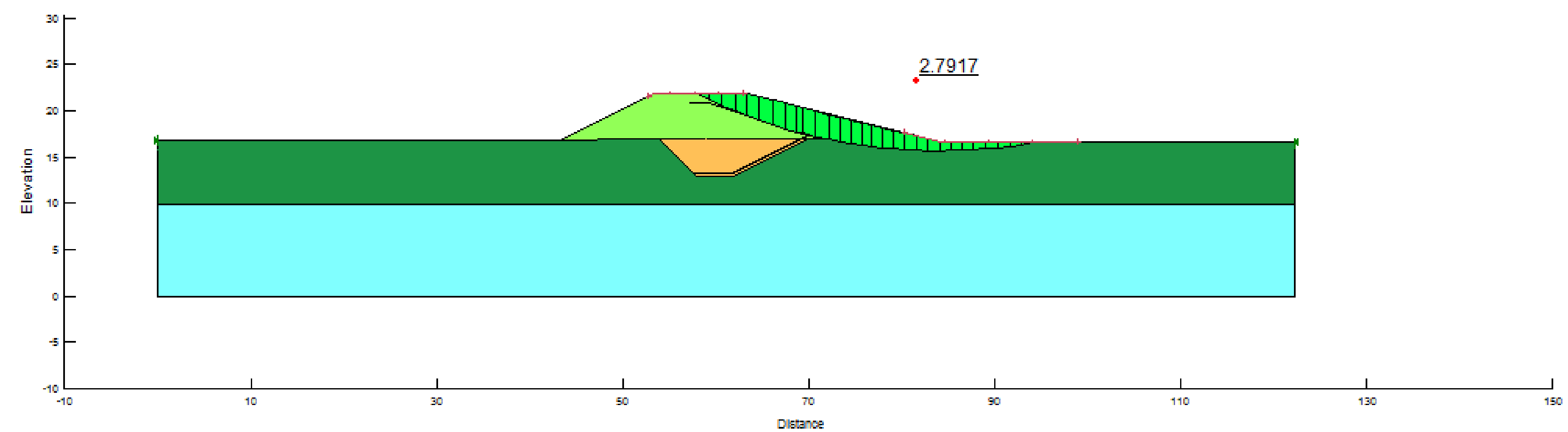
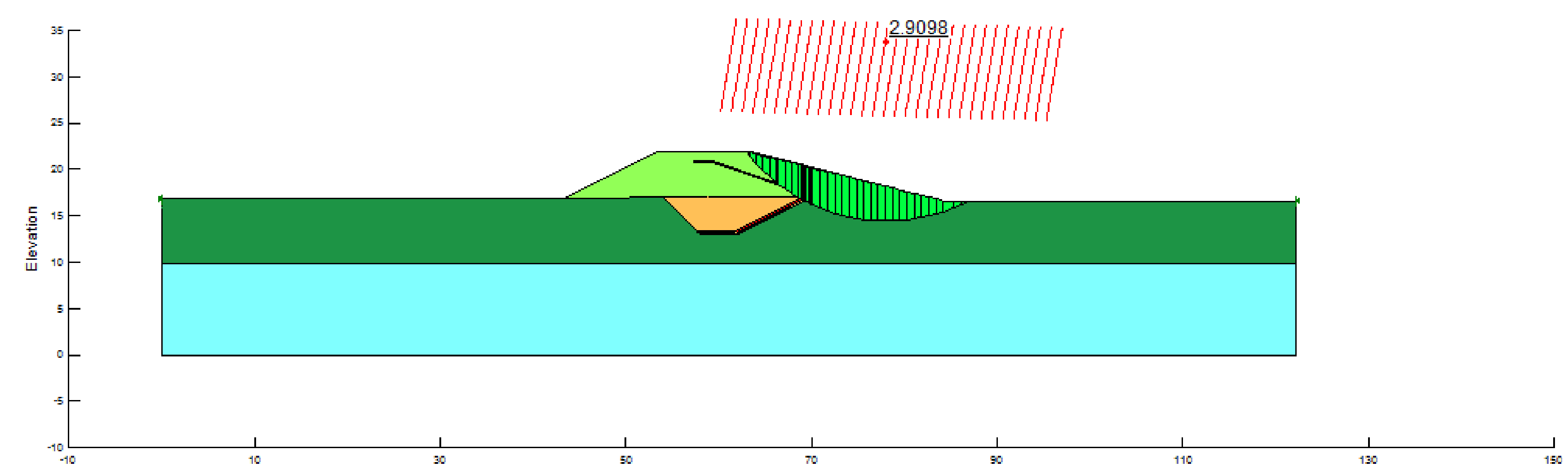


LEGEND

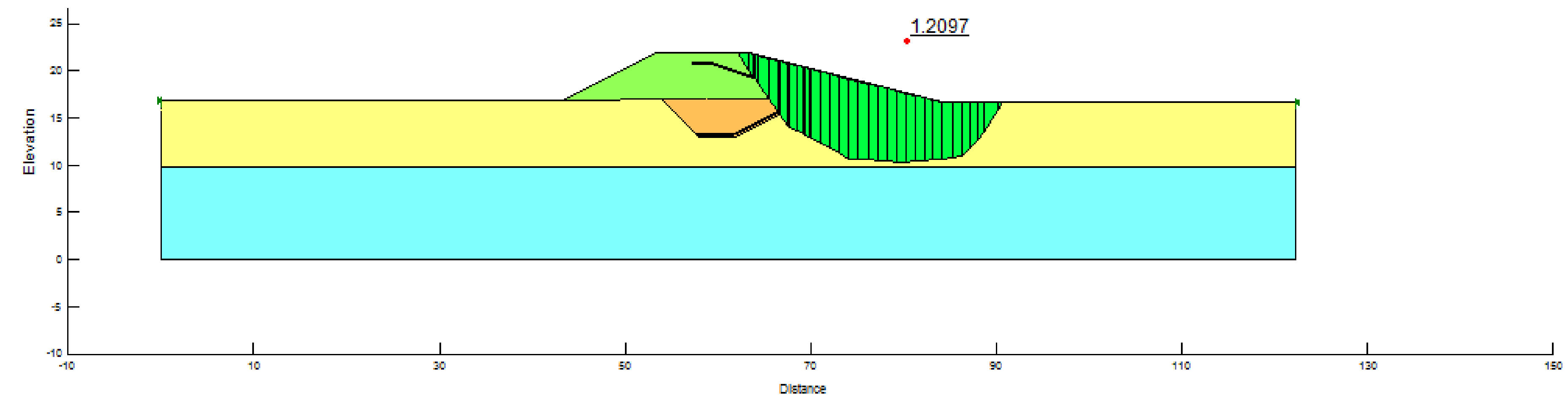
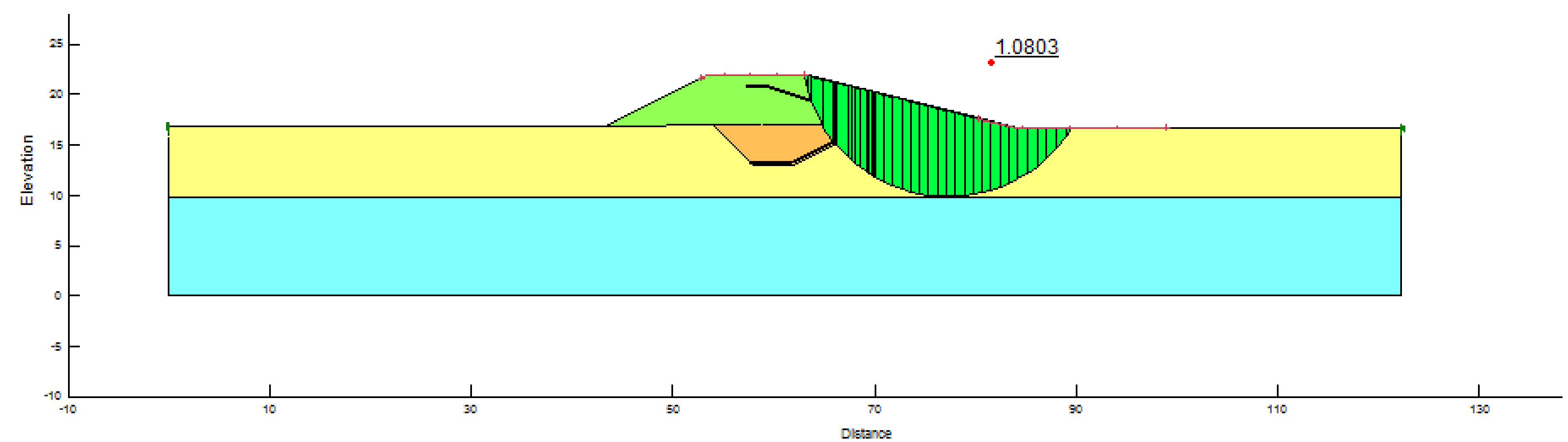
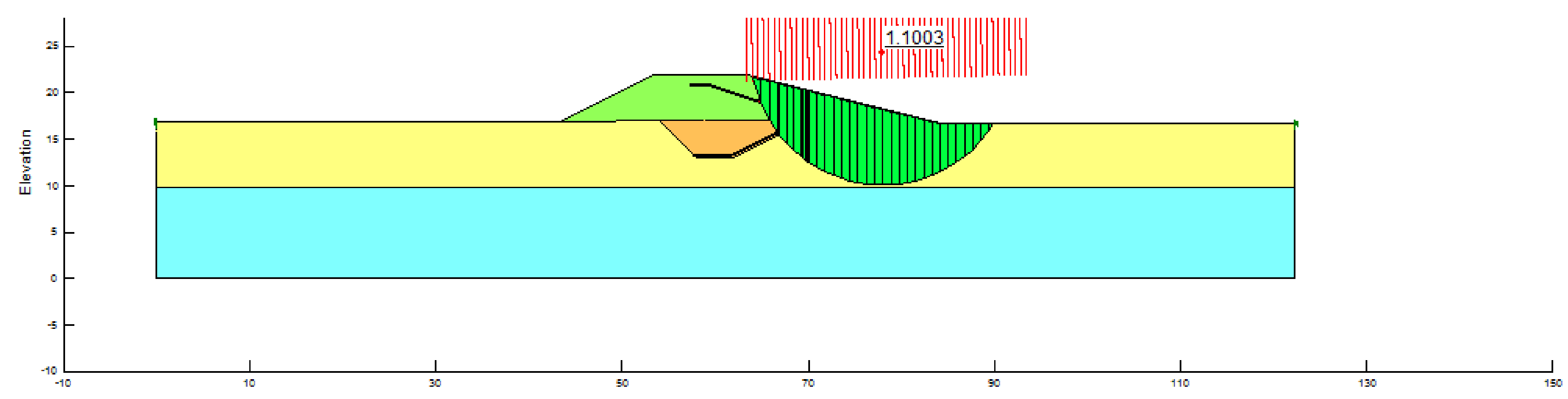
- ROQ (Non-Frozen)
- Marine Silt and Clay (Non-Frozen)
- Marine Silt and Clay (Frozen)
- ROQ (Frozen)
- Marine Silt and Clay (Top 5m)
- Tailings

srk consulting	TMAC RESOURCES	DORIS TIA SLOPE STABILITY
		West Dam Analyzed Cross Section
Job No: 1CT22.004.610 Filename: HopeBay_DorisNorth_SouthDam_SlopeStability_160407_sa	HOPE BAY PROJECT	Date: Dec 2016 / Approved: / Figure: 1

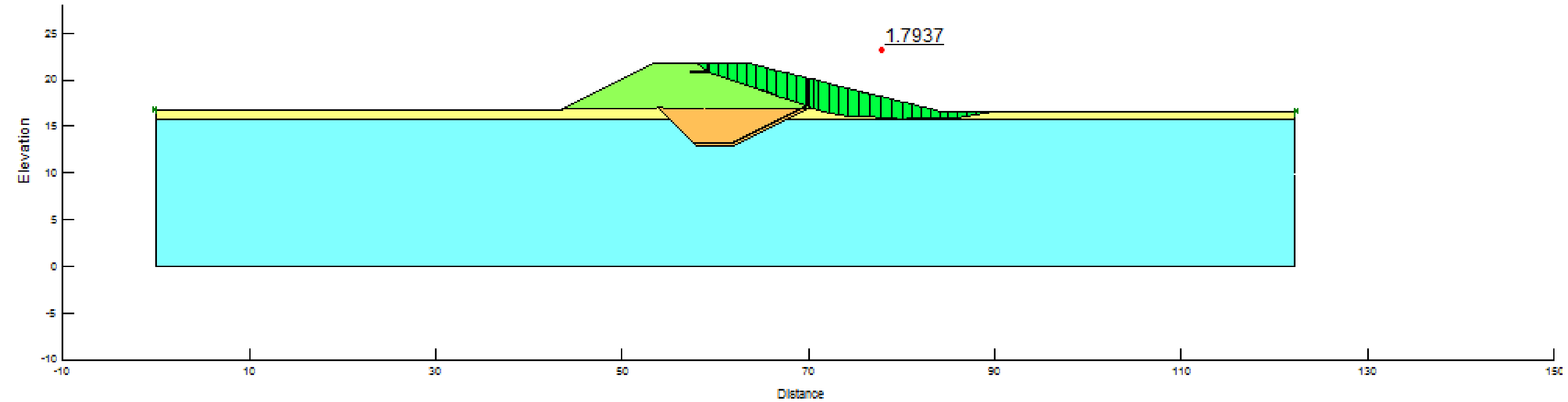
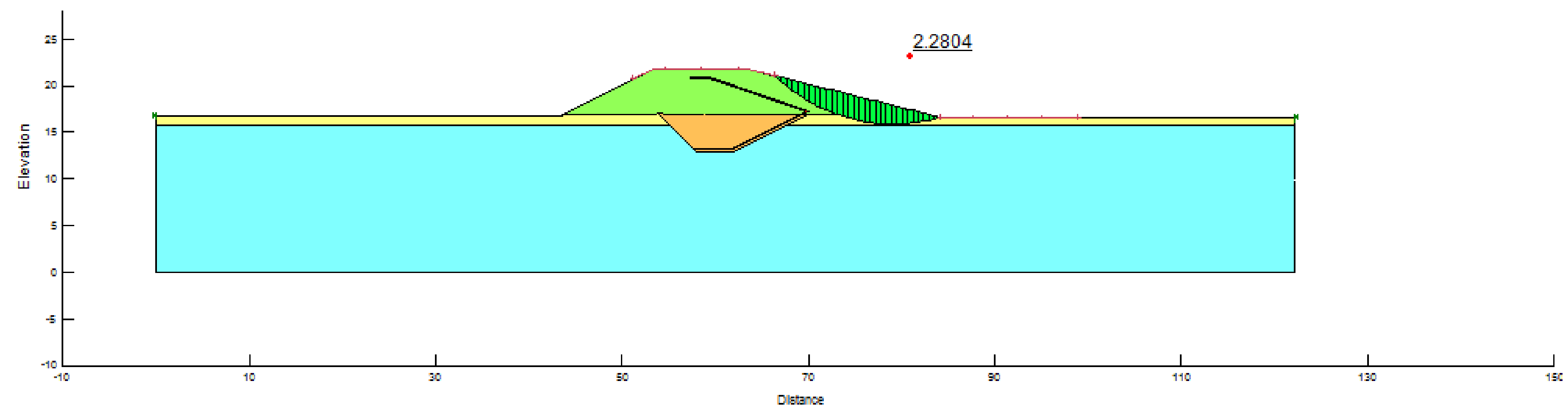
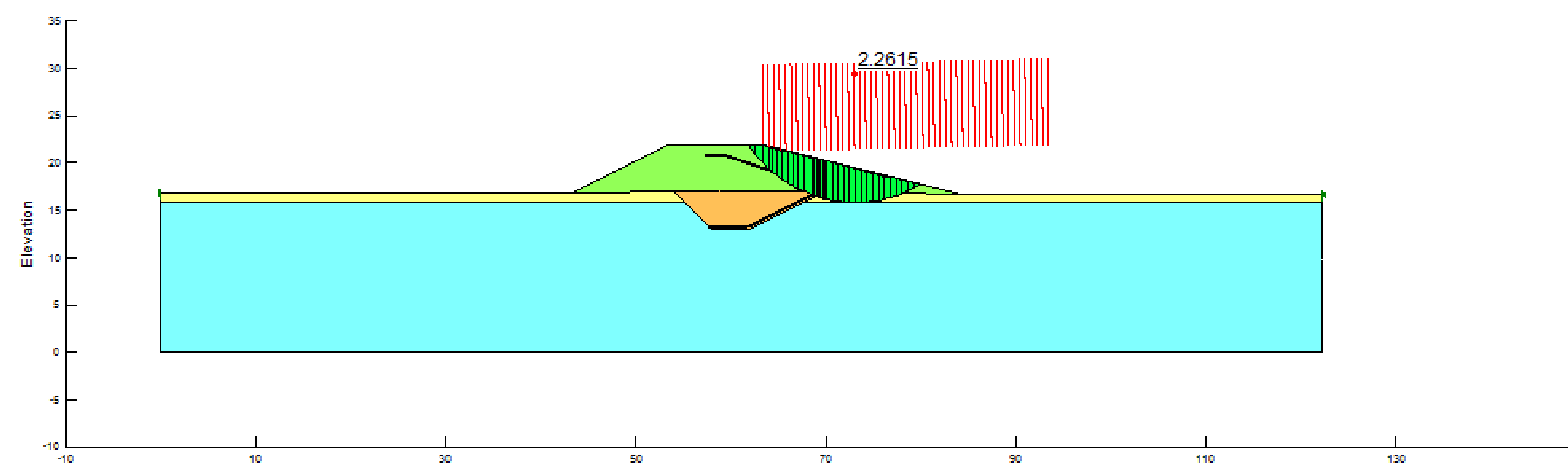
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model C- West Dam (Upstream Slope, Static, drained, 7m AL)	2.28	Fully Defined	
	2.79	Entry Exit	
	2.91	Grid and Radius	

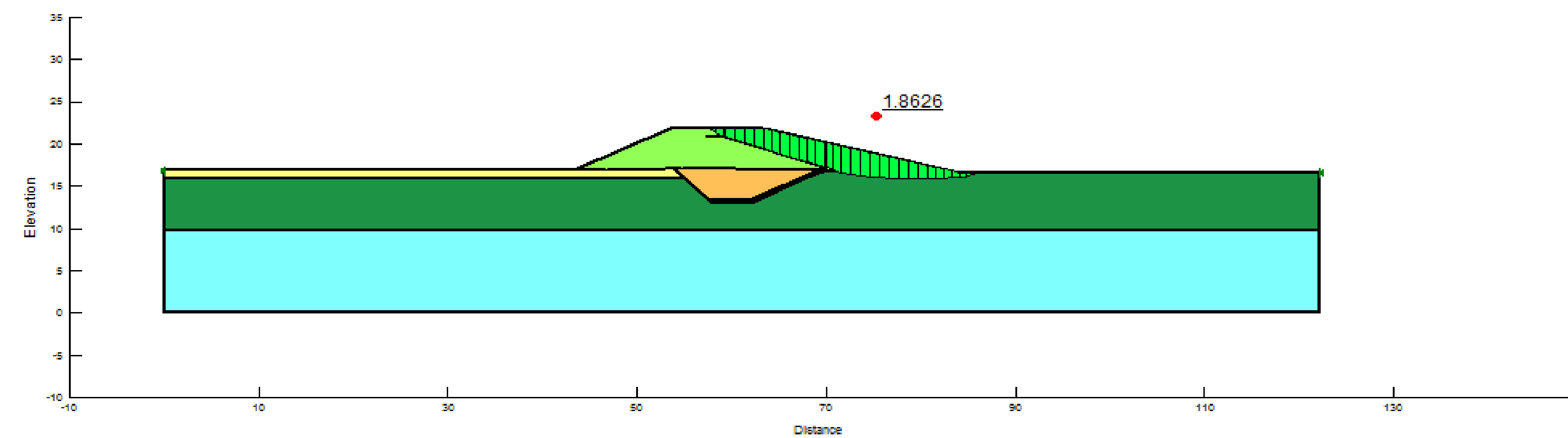
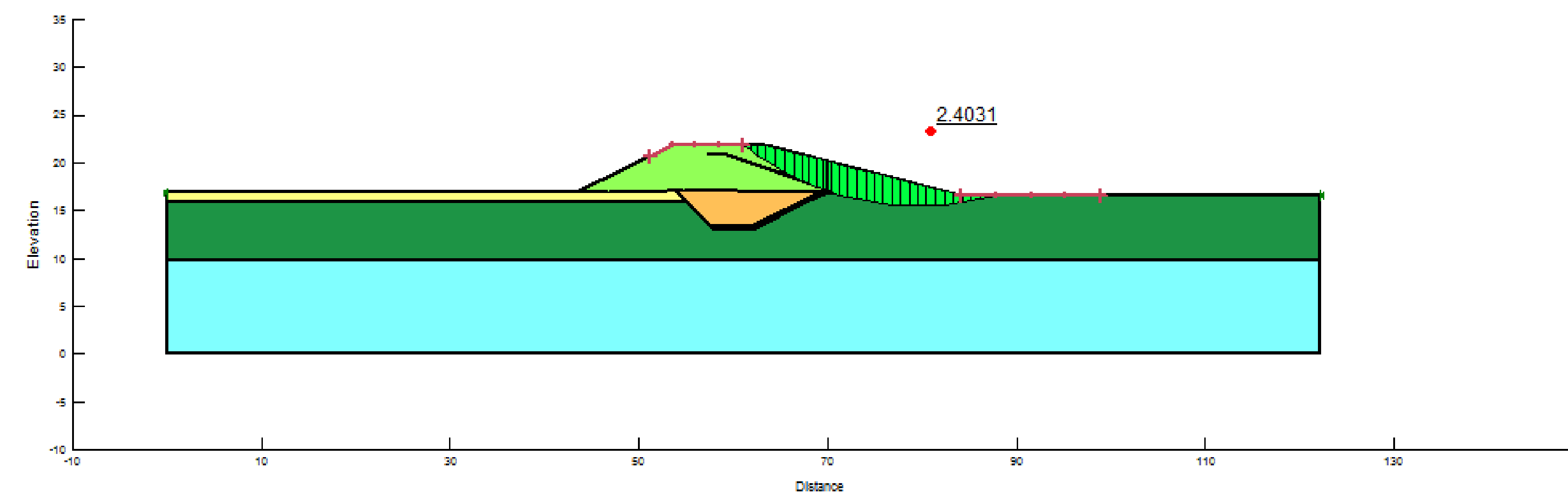
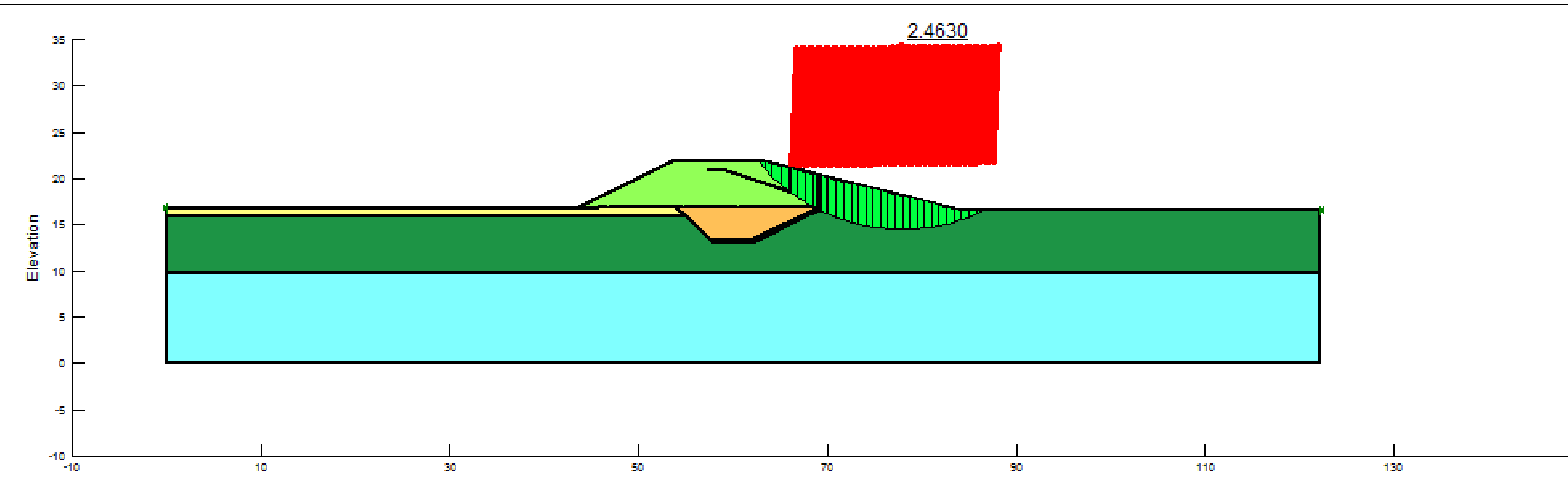
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model C- West Dam (Upstream Slope, Static, undrained, 7m AL)	1.2	Fully Defined	
	1.08	Entry Exit	
	1.10	Grid and Radius	

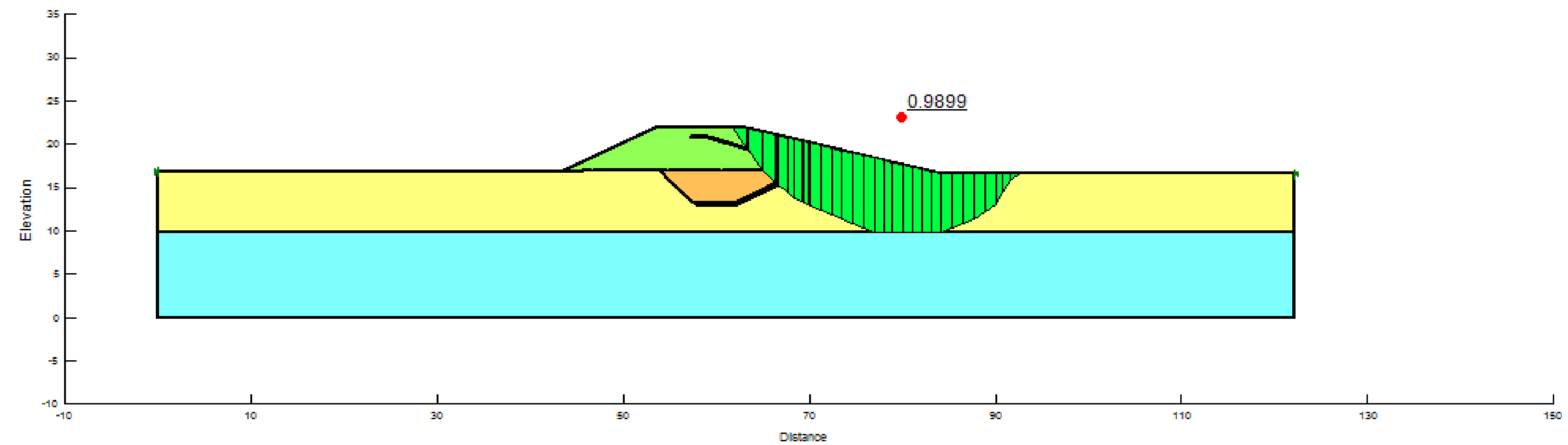
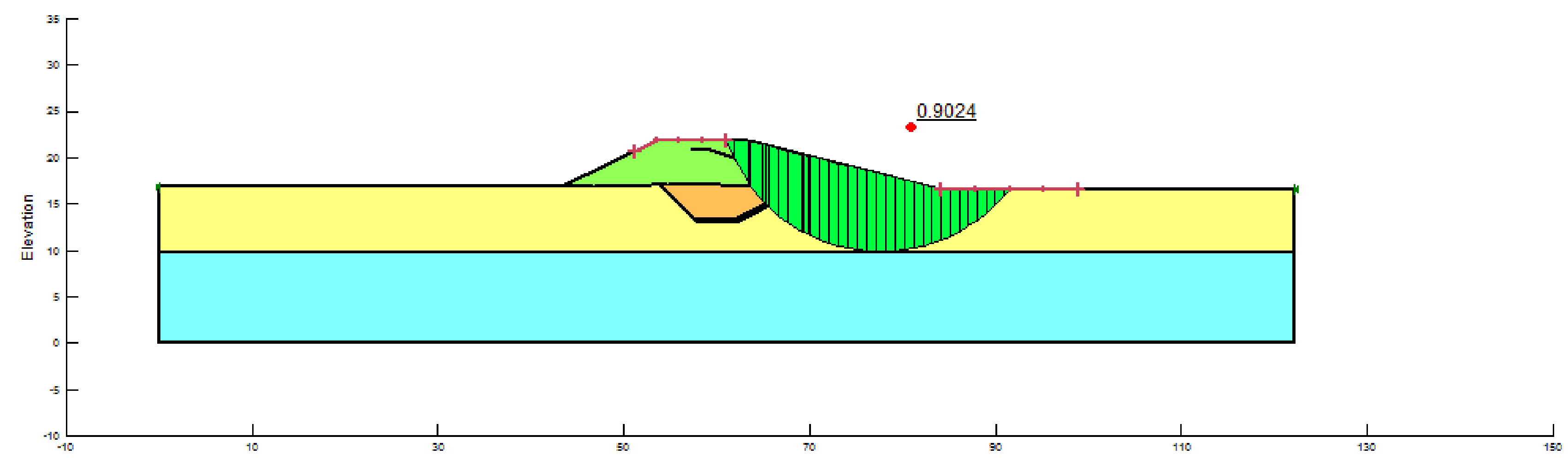
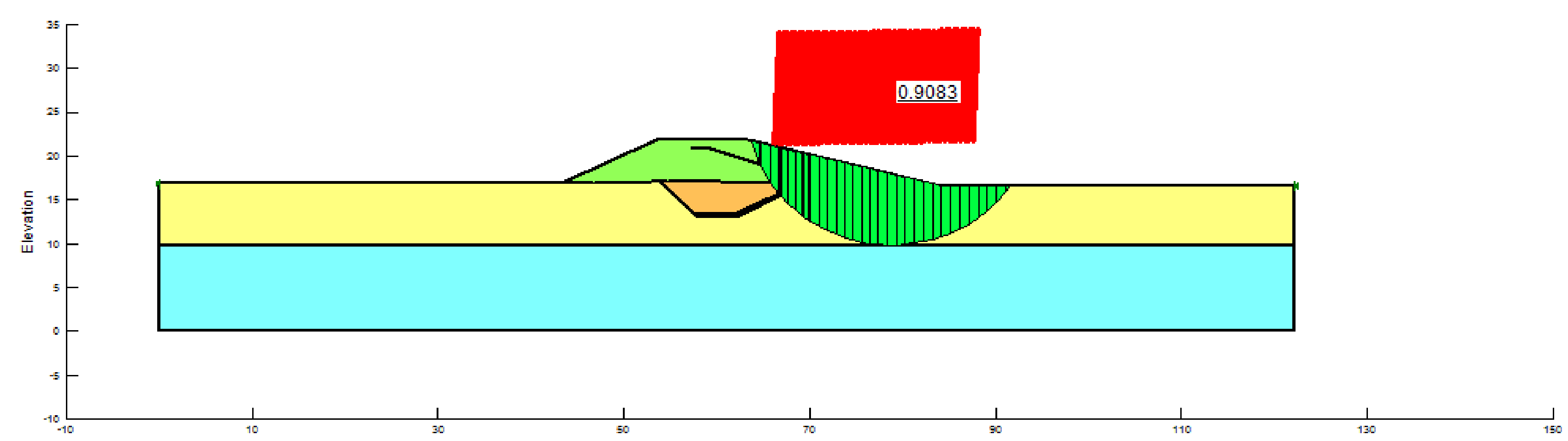
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model C- West Dam (Upstream Slope, Static, undrained, 1m AL)	1.79	Fully Defined	
	2.28	Entry Exit	
	2.26	Grid and Radius	

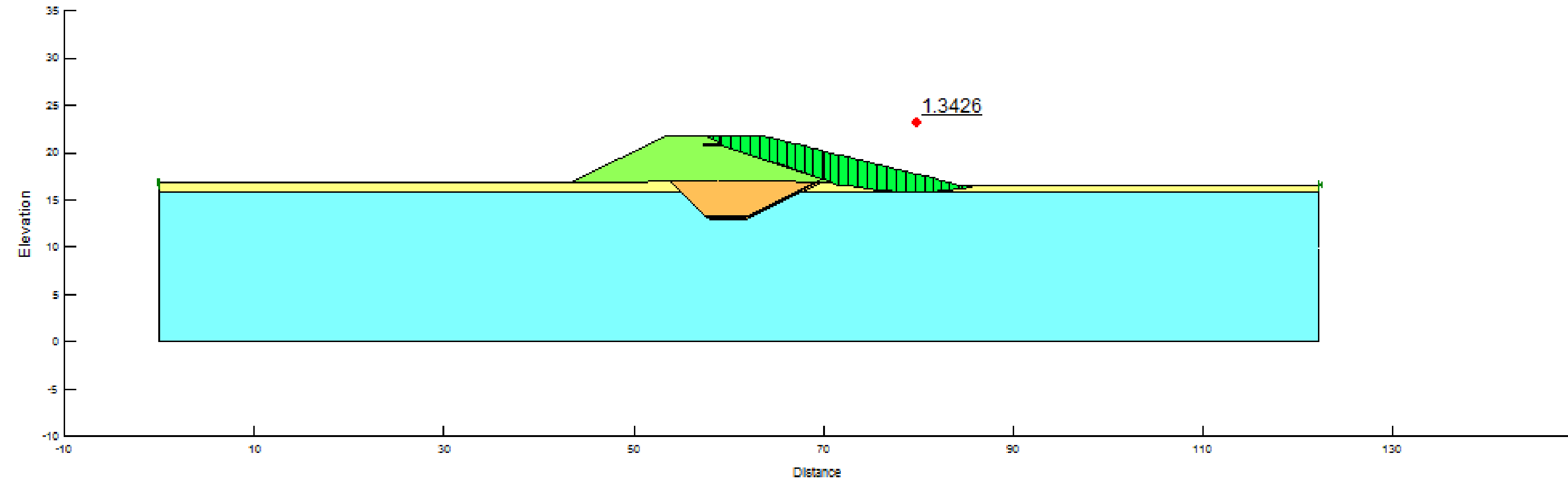
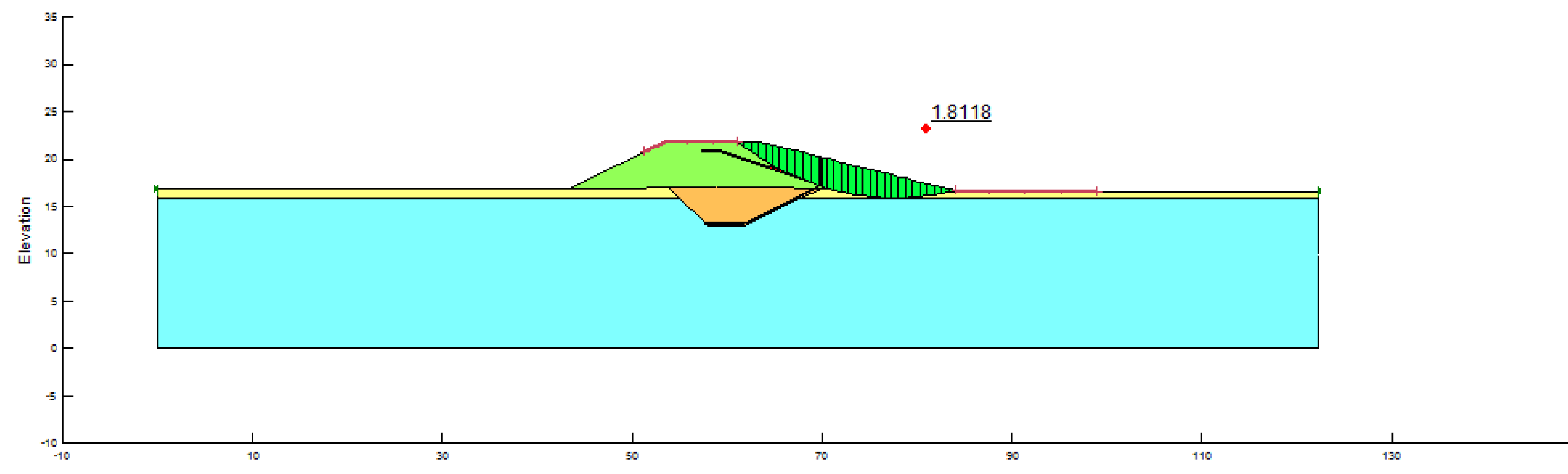
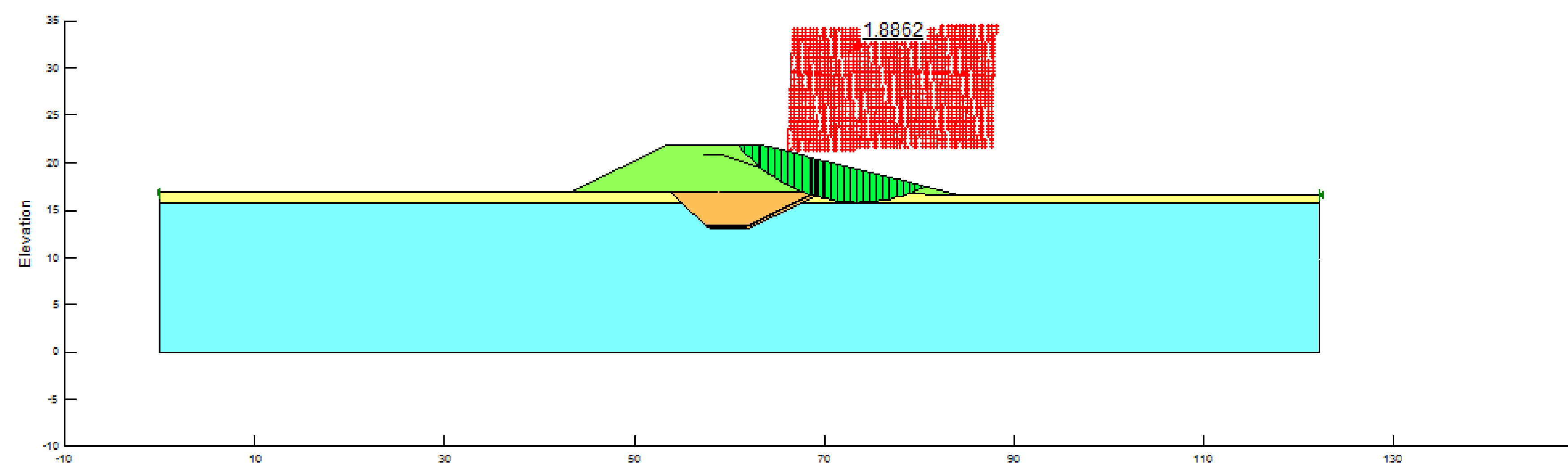
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model C- West Dam (Upstream Slope, Pseudo-Static, Drained, 7m AL)	1.86	Fully Defined	
	2.40	Entry Exit	
	2.46	Grid and Radius	

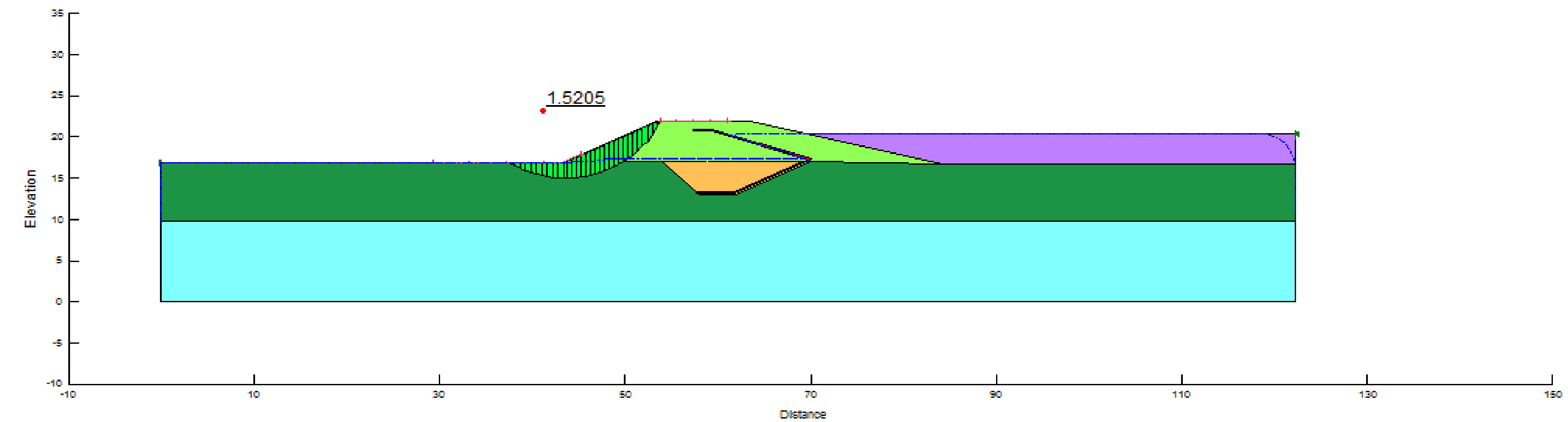
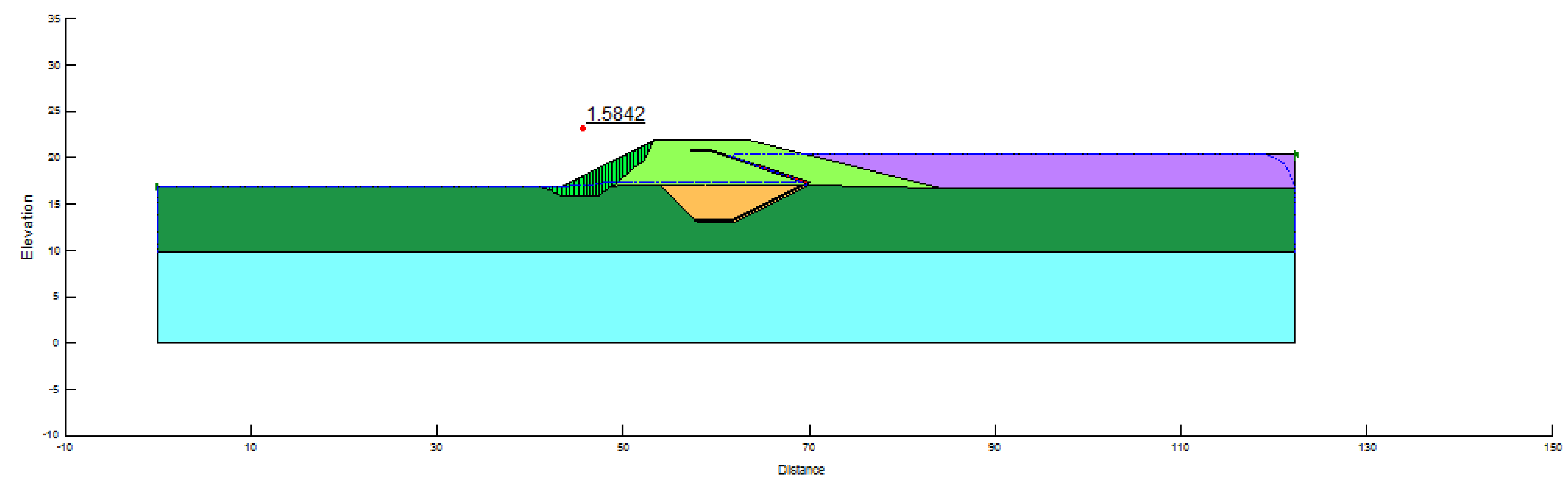
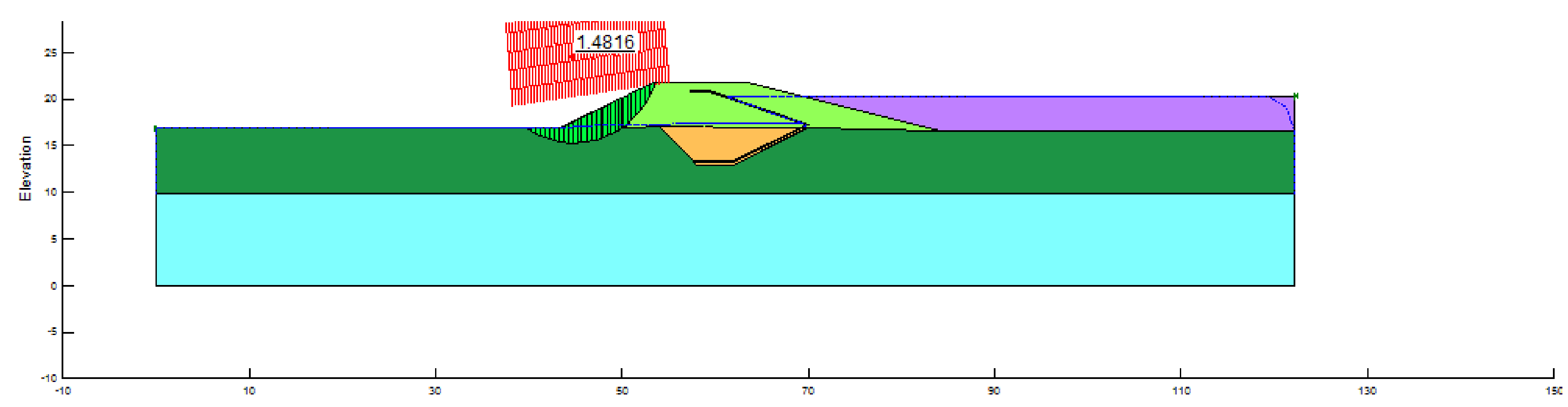
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model C- West Dam (Upstream Slope, Pseudo-Static, Undrained, 7m AL)	0.99	Fully Defined	
	0.90	Entry Exit	
	0.91	Grid and Radius	

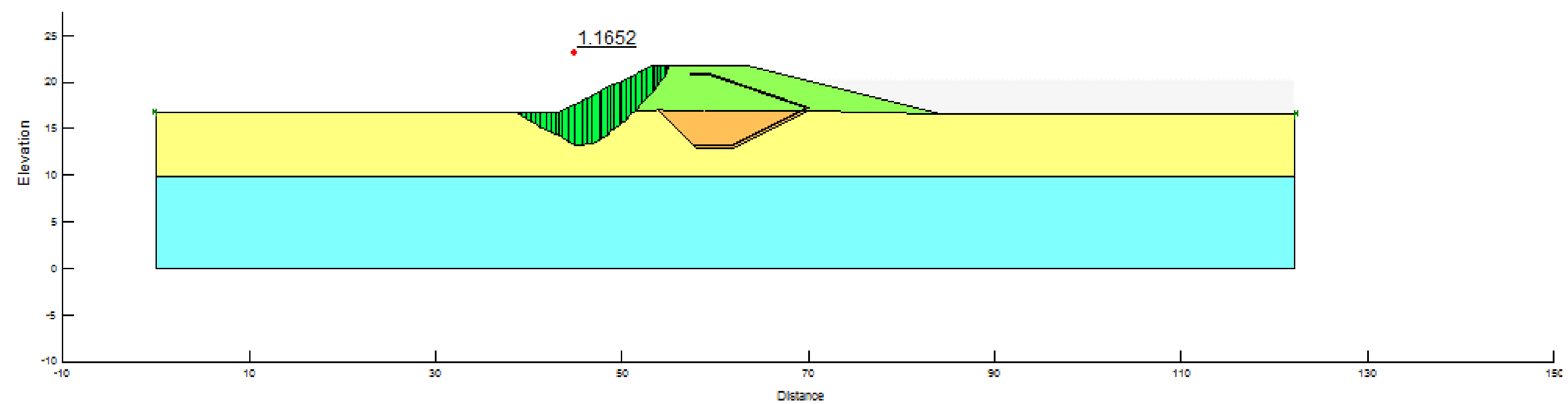
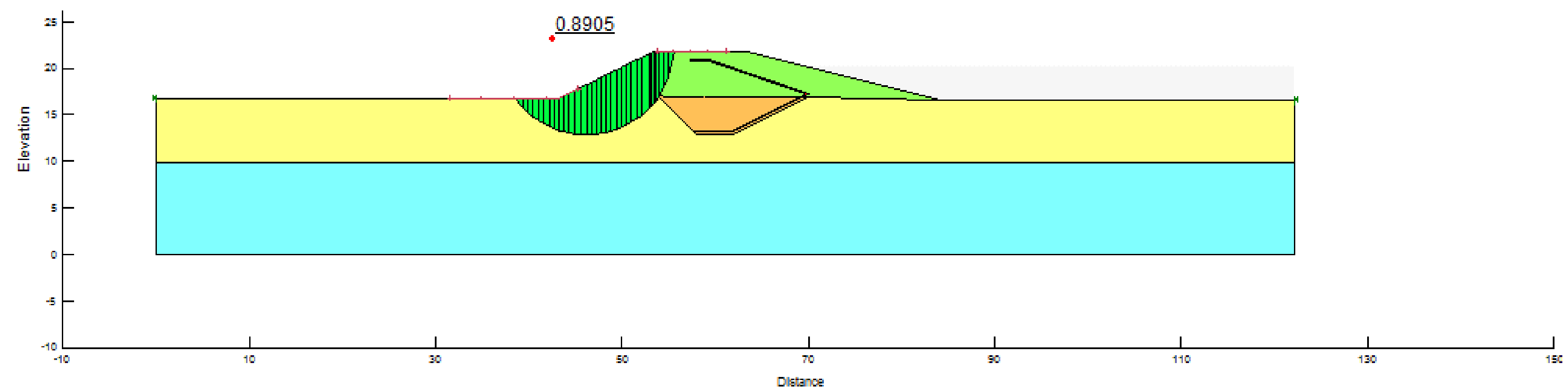
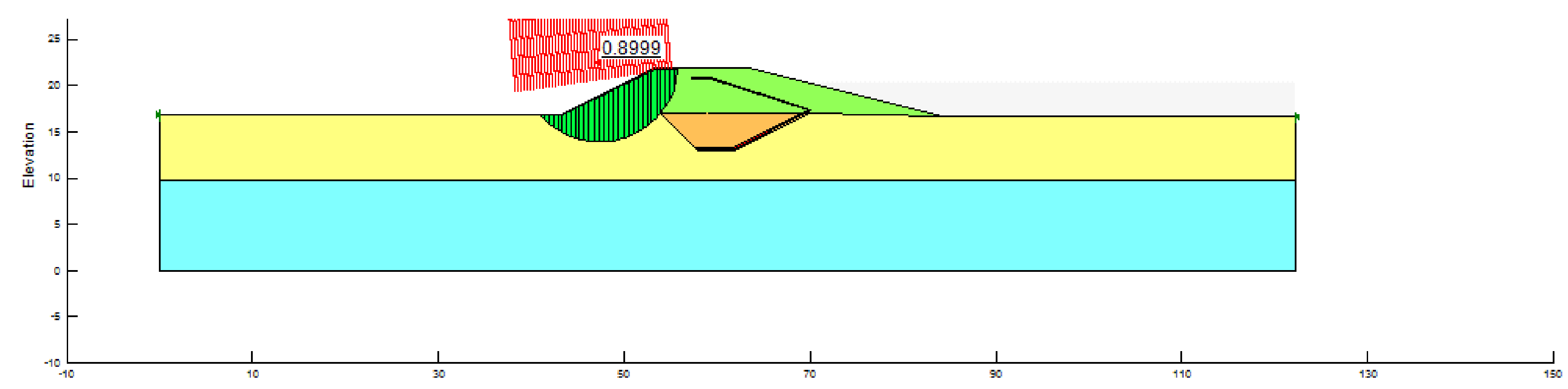
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model C- West Dam (Upstream Slope, Pseudo-Static, Undrained, 1m AL)	1.34	Fully Defined	
	1.81	Entry Exit	
	1.89	Grid and Radius	

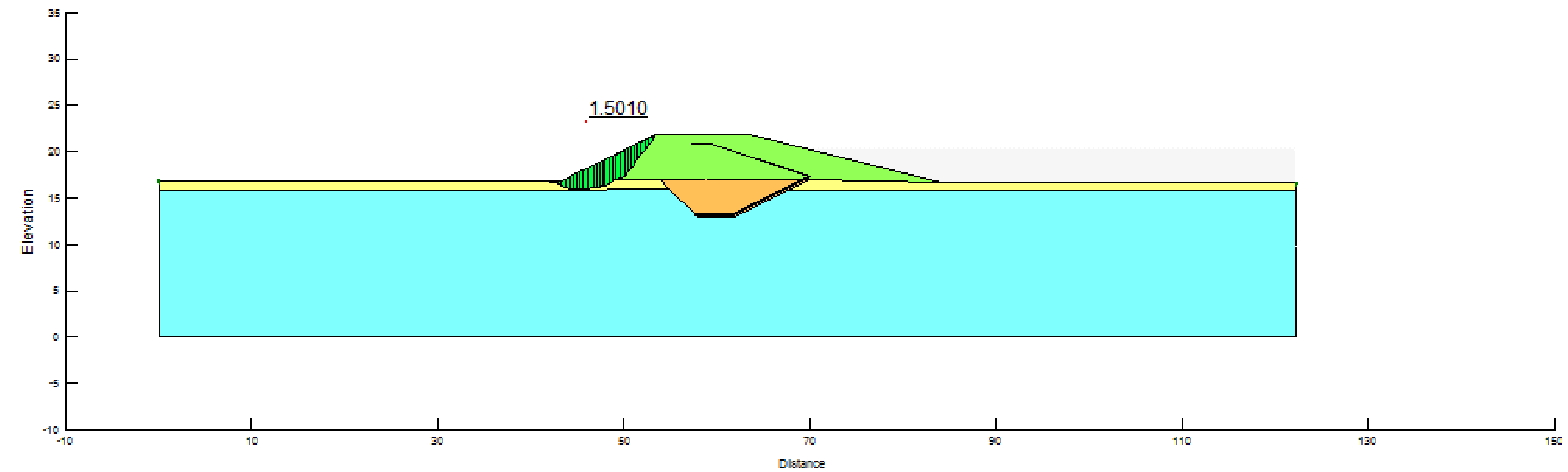
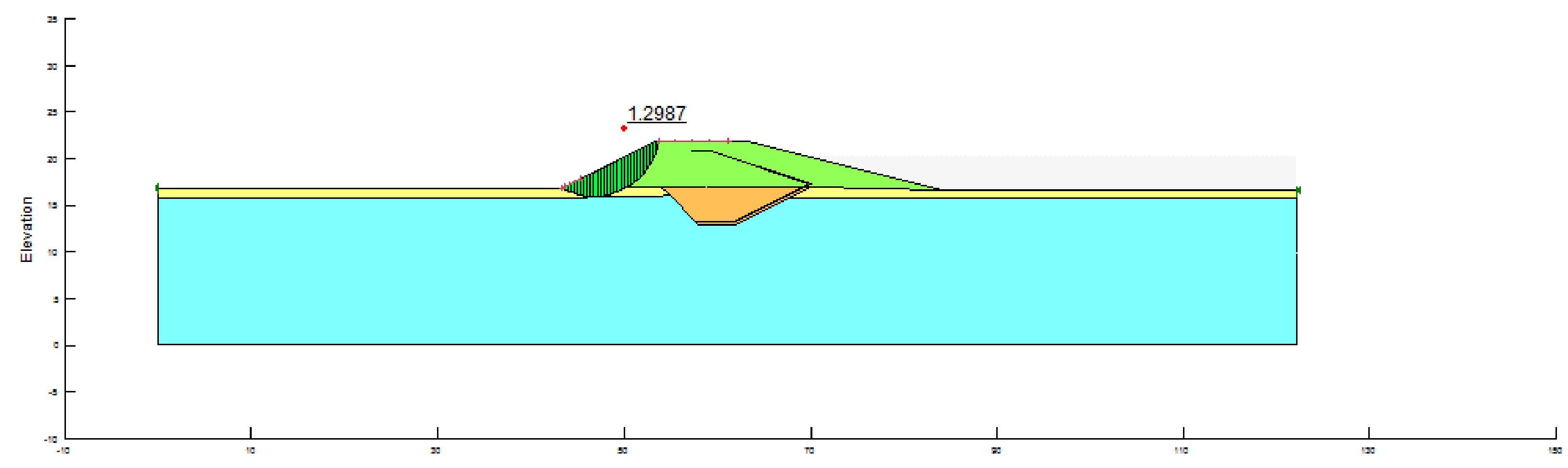
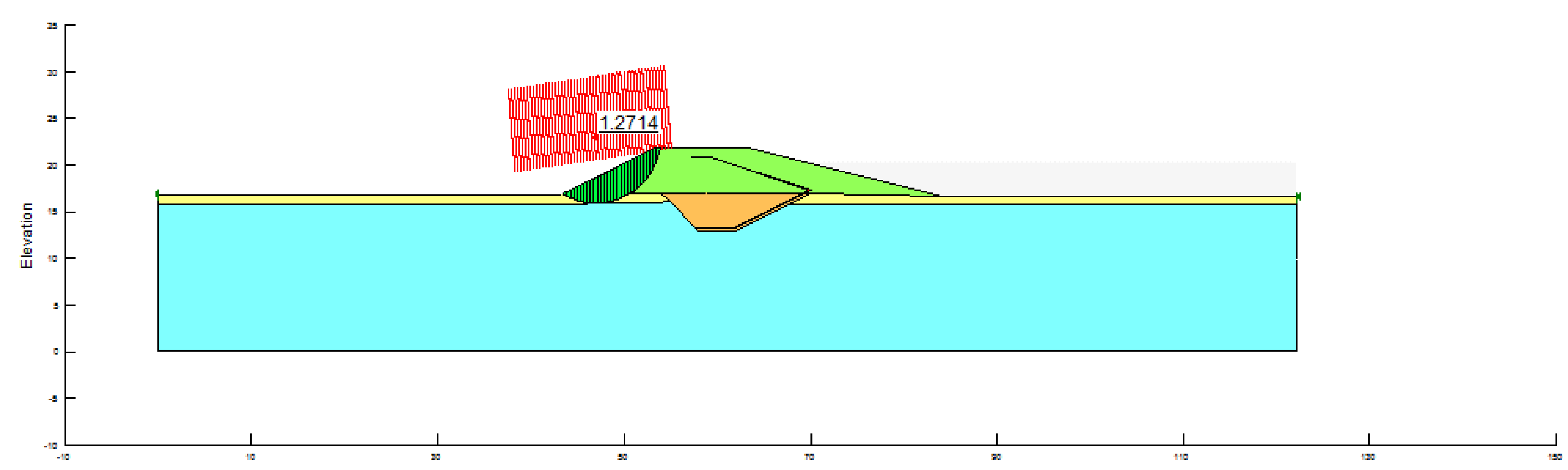
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model D- West Dam (downstream Slope, Static, drained, 7m AL)	1.58	Fully Defined	
	1.52	Entry Exit	
	1.48	Grid and Radius	

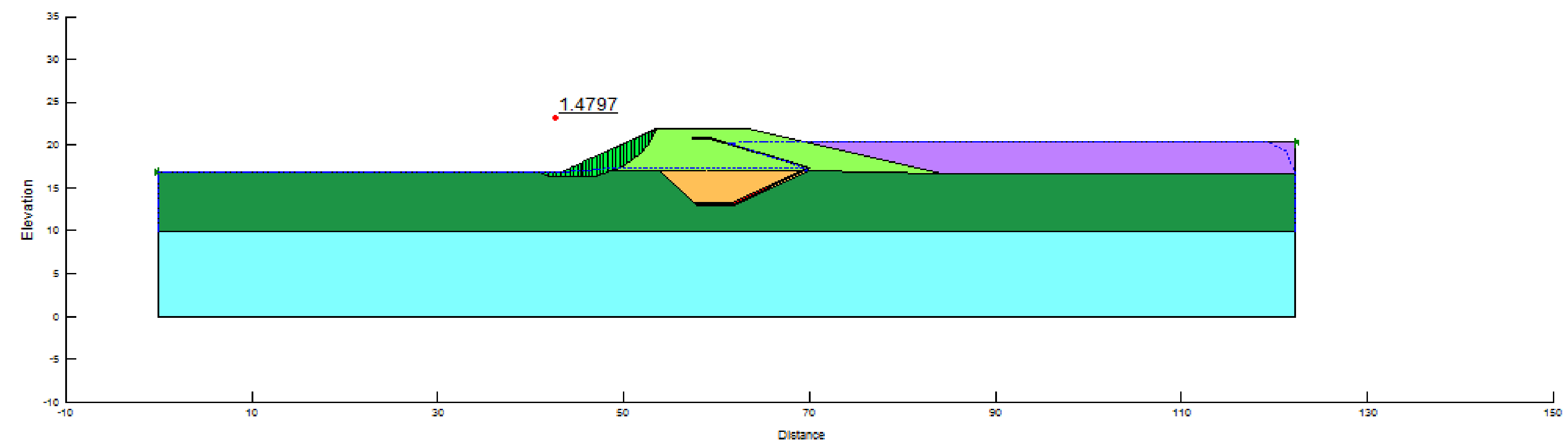
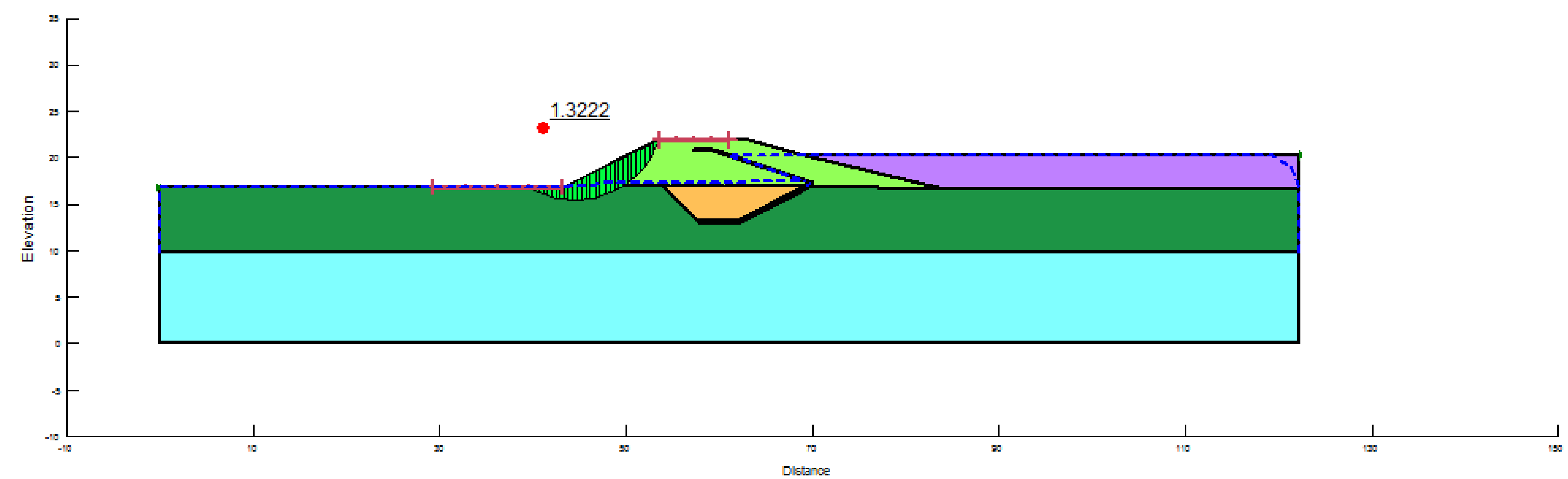
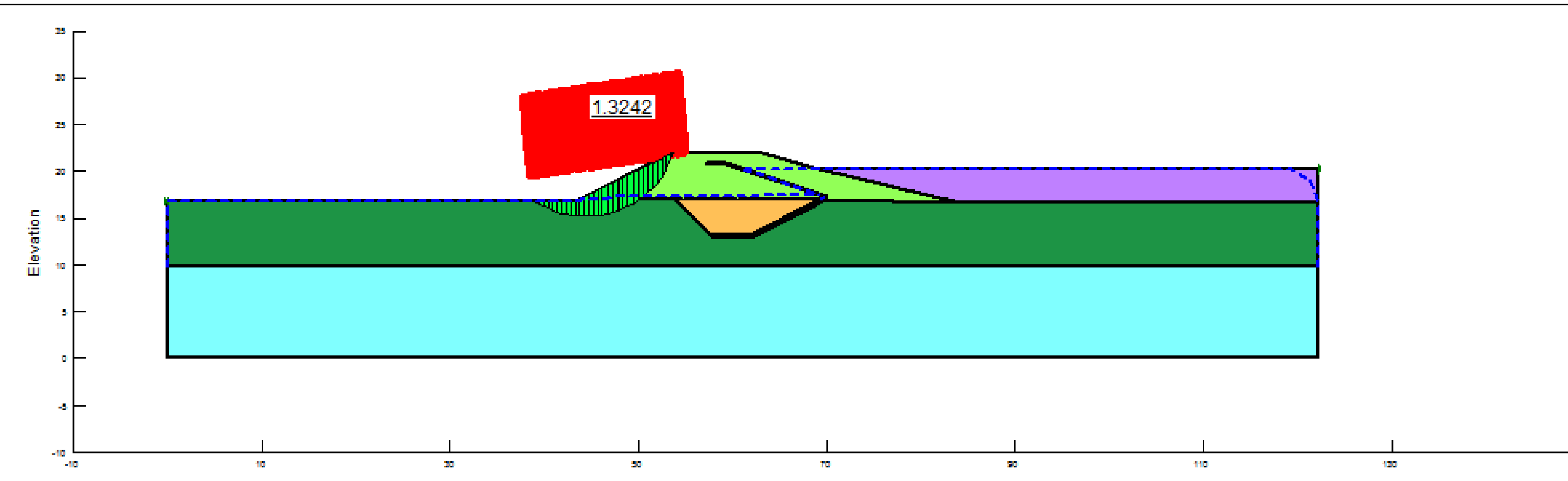
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model D- West Dam (downstream Slope, Static, undrained, 7m AL)	1.16	Fully Defined	
	0.89	Entry Exit	
	0.9	Grid and Radius	

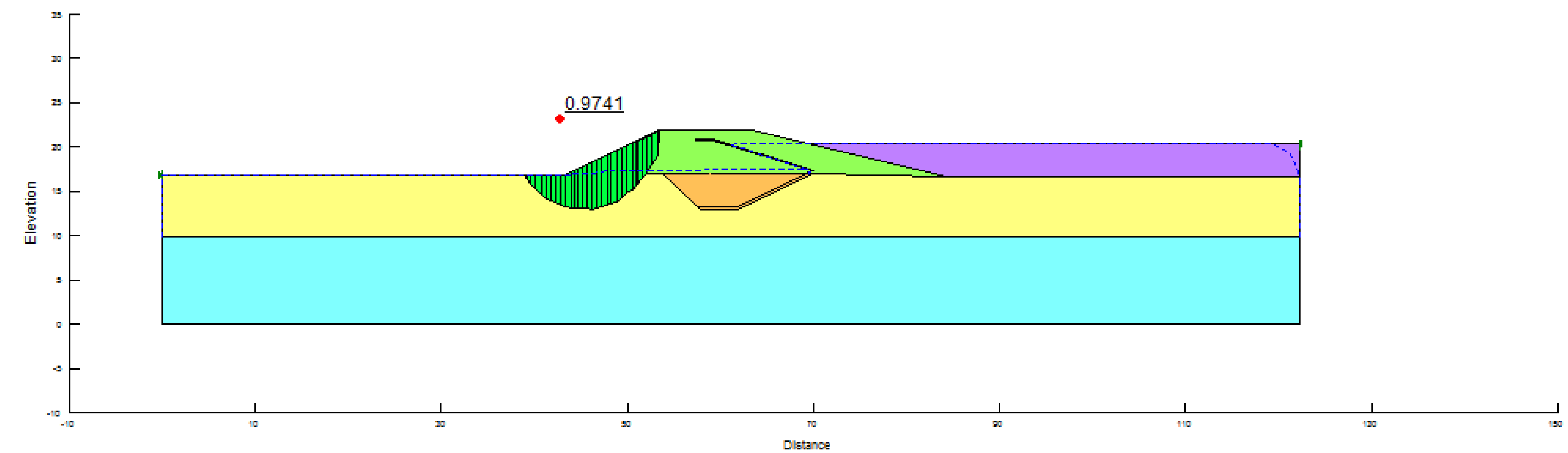
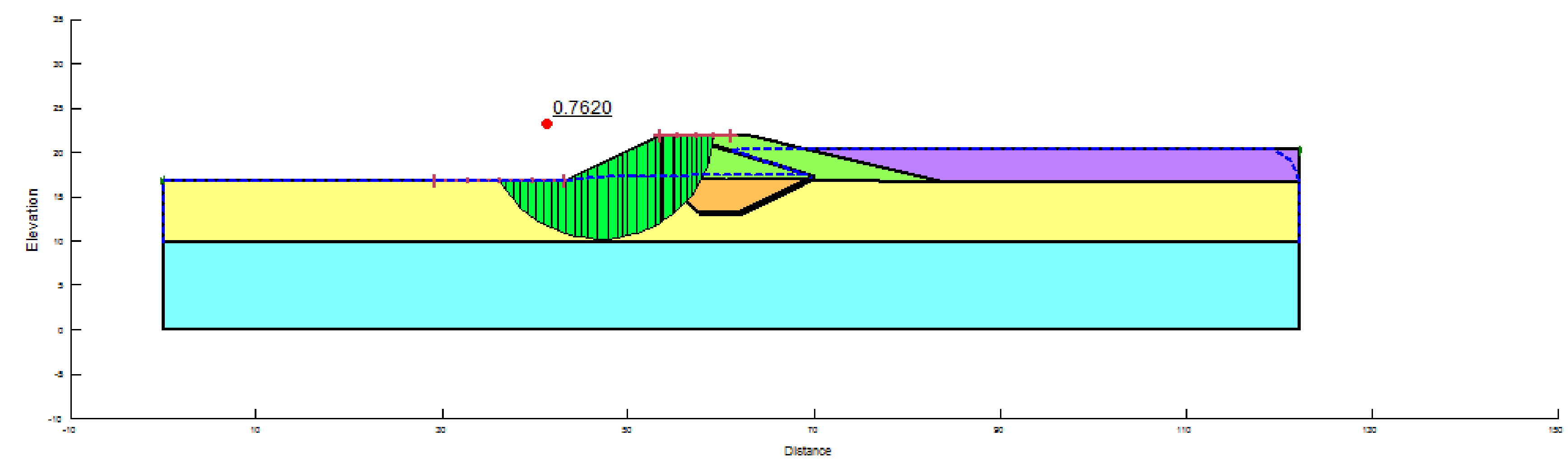
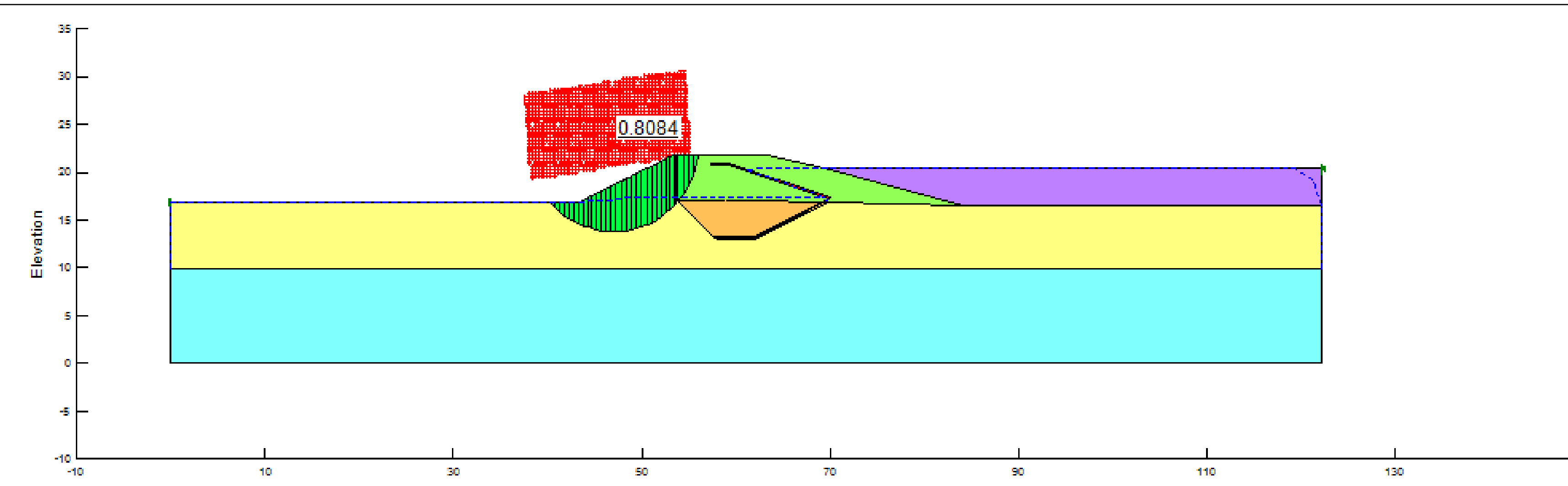
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model D- West Dam (downstream Slope, Static, undrained, 1m AL)	1.50	Fully Defined	
	1.30	Entry Exit	
	1.27	Grid and Radius	

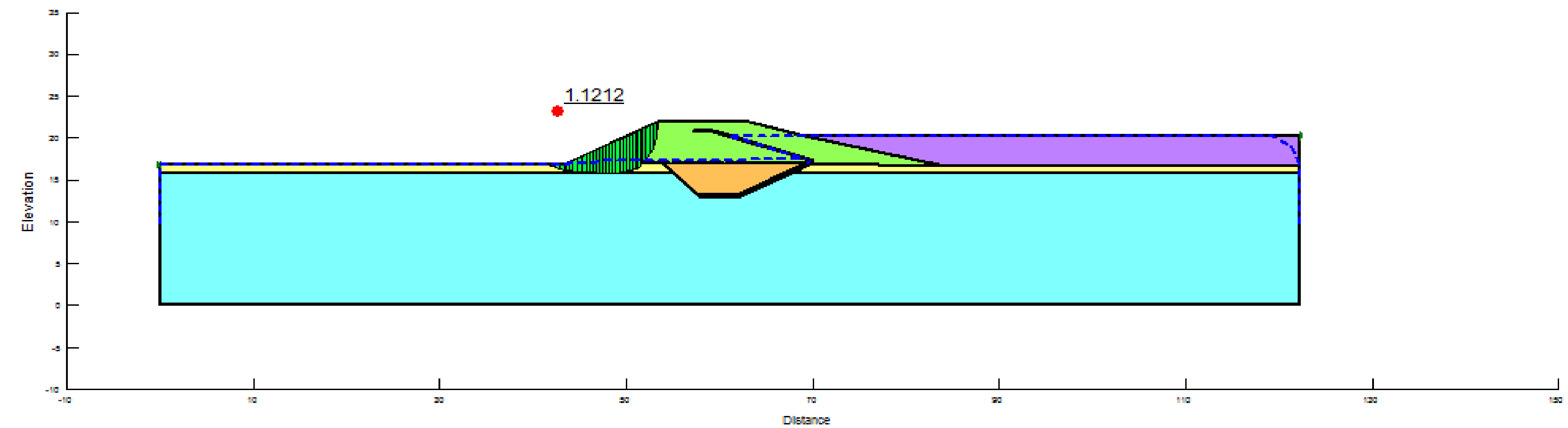
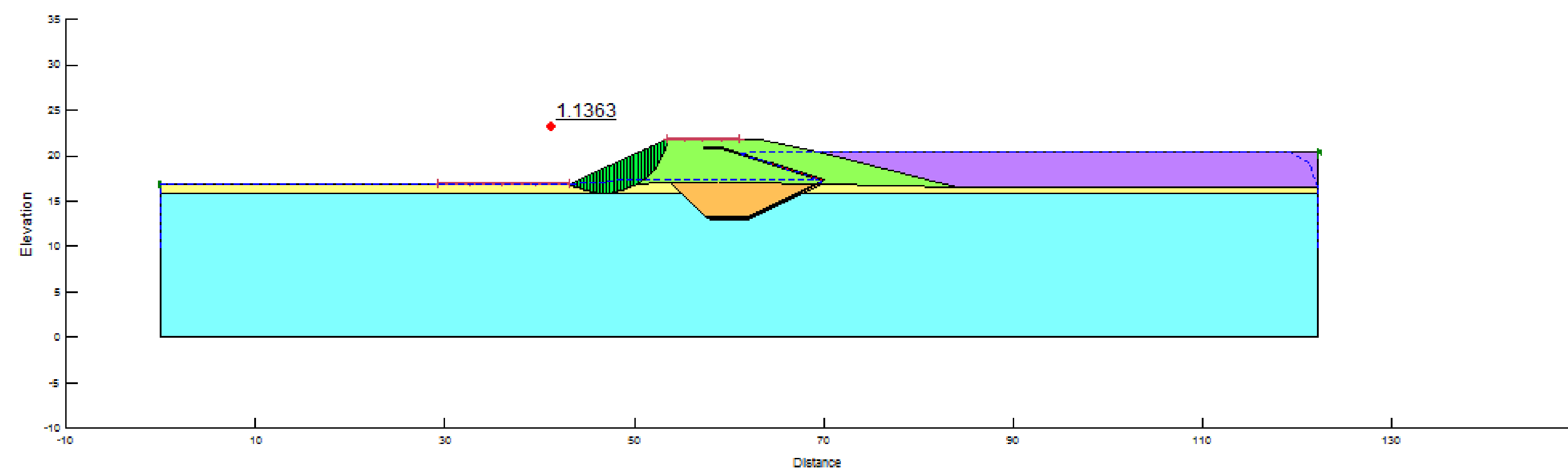
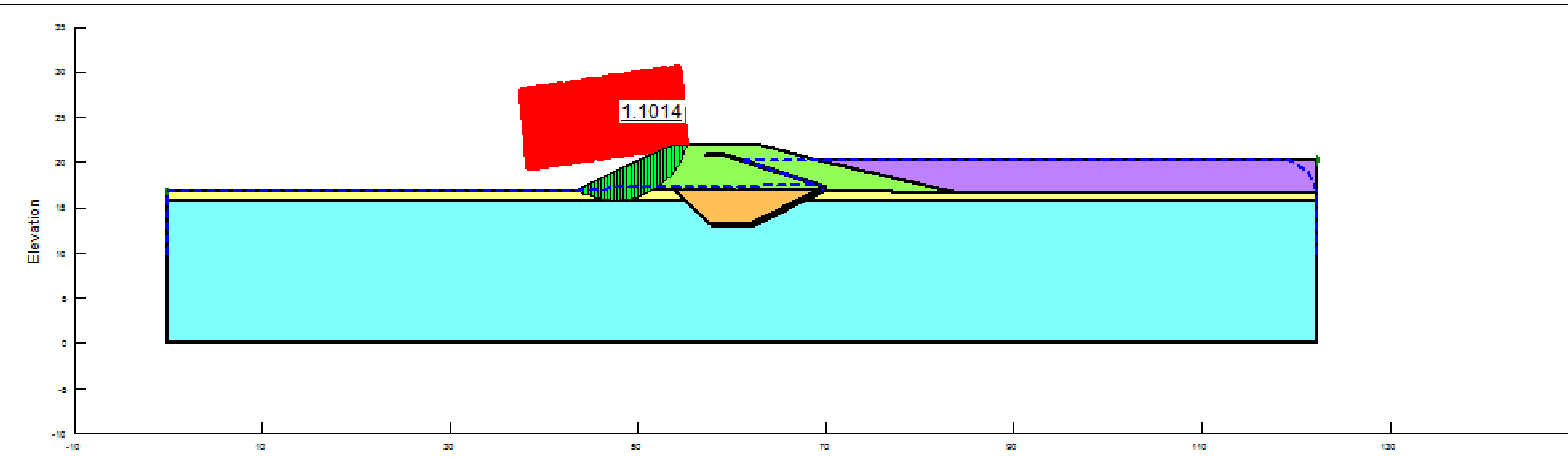
Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model D- West Dam (Downstream Slope, Pseudo-Static, Drained, 7m AL)	1.48	Fully Defined	
	1.32	Entry Exit	
	1.32	Grid and Radius	

Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model D- West Dam (Downstream Slope, Pseudo-Static, undrained, 7m AL)	0.97	Fully Defined	
	0.76	Entry Exit	
	0.81	Grid and Radius	

Slope Stability Results

Model	Factor of Safety	Slip Surface Option	Figure
Model D- West Dam (Downstream Slope, Pseudo-Static, undrained, 1m AL)	1.12	Fully Defined	
	1.14	Entry Exit	
	1.10	Grid and Radius	

Appendix C – Hope Bay Project: Phase 2 Doris Tailings Impoundment Area North 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 13, 2016
Subject:	Hope Bay Project: Doris Tailings Impoundment Area North 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 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 (Figure 1). 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). Thermal analysis completed for the South Dam and West Dam is reported in SRK (2016b).

The North Dam relies on a frozen ice-saturated core and foundation to achieve the required water retention properties. A geosynthetic clay liner (GCL) was installed along the upstream side of the frozen core to provide secondary water-retaining capability in case cracks develop in the core caused by thermal expansion or creep deformation. In order to ensure adequate performance of the dam, it is imperative to maintain the frozen state of the core and foundation over the design life.

The original design life of the North Dam was 25 years (SRK 2007). As part of Phase 2 tailings deposition, the North Dam design life would be extended to 2041 (30 years from 2011). This timeline assumes a period of nominal water impoundment prior to start of tailings deposition in 2017, active tailings deposition between 2017 and 2036, and a five-year post closure period prior to breaching of the dam in 2041.

1.2 Modeling Objective

The objective of the North Dam modeling was to determine if the current configuration of the North Dam is suitable to maintain the thermal design criteria over a 40-year design life, which is ten years greater than the actual planned design life of 30 years. The thermal conditions at the end of the planned design life is also used to conduct a creep analysis for the North Dam (SRK 2016c).

The North Dam was modeled along two critical cross sections; Section 0+85, located at the thickest section of the dam, and Section 0+40 near one of the thinnest sections of the dam (Figure 2). Ground temperature measurements are collected at both these sections, which allows for model calibration.

2 North Dam Details

2.1 As-built Overview

2.1.1 General

The North Dam is located across the Tail Lake outlet and extends approximately 200 m long and 10 m high, with upstream and downstream slopes of 6H:1V and 4H:1V, respectively (Figure 1 through Figure 3). The dam as-built report, drawings, and quality control and quality assurance documentation is provided in SRK (2012).

2.1.2 Foundation

The overburden soils are up to 20 m thick at the base of the valley and thin out at the dam abutments. About two-thirds of the dam longitudinal section is characterized by ice-saturated sand of approximately 10 m to 15 m thick. The sand deposit is overlain by a silt and clay layer that is less than 3 m thick. The remaining one-third portion of the dam alignment is characterized by marine clayey silt that is up to 15 m thick. The fine-grained materials are also ice-saturated and contain excess ground ice. At the North Dam, the average porewater salinity is 39 ppt, with a freezing point depression of -2.2°C (Geometric mean of 30 ppt. and -1.7°C). The average site-wide freezing point depression is -0.8°C for sand and -2.2°C for silt and clay, with an average of -2.1°C for all samples collected at the Project site (SRK 2016d). Bedrock is generally competent basalt.

2.1.3 Dam Construction

The North Dam was constructed over the winters of 2011 and 2012, and consists of three major regions; the frozen core, transition zone, and dam shell (Figure 3).

The key trench was excavated in 2011 using drill and blast methods. A hyper-saline zone comprised of clayey silt with an average porewater salinity of 45 ppt. and a freezing point of -2.6°C was encountered between key trench Station 1+00 and Station 1+20. The trench was over-excavated to remove as much hyper-saline material as practical. Further detail of key trench excavation, testing, and conditioning of the surface for material placement is provided in SRK (2012).

The central frozen ice-saturated core was constructed of a 2:3 blend of 20 mm minus material to fines (SRK 2012). This blend was tested on-site to obtain the moisture retention required for placement during construction. The blend material was moisture conditioned in the frozen core mixing plant using freshwater sourced from Doris Lake, with routine testing to ensure no elements in the water would affect the frozen material. A Geosynthetic Clay Liner (GCL) was installed over the upstream side of the frozen core to function as a secondary water retention system.

The transition zone was constructed of 150 mm (6 inch) minus crushed material and placed over the top of the frozen core and GCL (SRK 2012). The transition material was observed to be clean with little fines and no sand and gravel. The external dam shell (Shell) was constructed of run-of-quarry (ROQ) material. Finer crushed rock transition material was placed over a portion of the dam crest to serve as an access road.

2.1.4 Ground Temperature Cables

A total of 24 ground temperature cables (GTCs) (*aka* thermistor strings) have been installed within the North Dam to monitor temperature every six hours. GTCs were installed to ensure the dam core and foundation remain within the design operating temperature (Section 2.2).

GTCs were installed during construction and include; horizontal thermistor strings (HTS) installed in the upper (Upper Core), middle (Middle Core), and lower (Lower Core) region of the frozen core (Figure 4). The horizontal Lower Core GTCs also measure ground temperature near the buried evaporator pipes. For practical purposes, thermistor nodes (sensors or beads) near the buried pipes are used to measure the evaporator pipe temperature. Vertical temperature strings (VTS) were installed in the foundation below the key-trench (KT), and upstream (US) and downstream (DS) of the dam toe (Figure 4).

2.1.5 Thermosyphons

Thermosyphon evaporator pipes located at the base of the key trench provide passive cooling during the winter to ensure that the core and foundation remain frozen throughout the year.

Thermosyphons are pressurized sealed pipes, charged with a two-phase working gas that vaporizes and condenses to move heat without the need of a mechanical pump. A typical passive thermosyphon consists of an evaporator pipe buried in the ground and radiator exposed at the surface. The radiator section is manufactured with fins attached to the radiator pipe to enhance heat transfer with the atmosphere.

Heat is extracted from the ground when the air temperature at the radiator is colder than the ground temperature adjacent to the evaporator pipe. The temperature differential allows for the pressurized gas to condense within the radiator section of the pipe and lowers the pressure-boiling point within the evaporator which causes the lower gas to vaporize. The condensed fluid flows under gravity to the bottom of the evaporator pipe, and the process is repeated until the air temperature becomes warmer than the ground temperature.

Thermosyphon heat transfer is a function of composition and physical properties of the working gas, radiator and evaporator design, temperature difference between the upper and lower sections of pipe, ground thermal properties, and exposure of the radiators to advective cooling from the wind.

North Dam thermosyphons were procured and installed by Arctic Foundations of Canada Inc. Thermosyphon installation included one series of six evaporator pipes installed from the north end of the key trench and another six installed from the south end. The evaporator pipes extend to Section 0+85 which is the lowest point of the key trench. The north and south evaporator pipes are sloped at 4.6° and 8°, respectively.

Two thermosyphon radiators were attached to each evaporator pipe, with a total radiator surface area of 39 m^2. The North and South radiators are exposed at the surface and unobstructed by surface infrastructure to allow for effective heat loss from the radiator (Figure 1). Each pipe is charged with a carbon dioxide working gas and considered to have similar performance. General function of the thermosyphons is assessed in the winter by comparing the temperature differential between the air and the evaporator pipe directly below the ground surface.

2.2 Thermal Design Criteria

The thermal criteria for the extended design life is based on the original criteria proposed by EBA (2006), and requires:

- The top of the frozen core remain higher than the maximum operating level of the water within the TIA;
- The frozen core maintain a temperature at or below -2°C with a width that is at least twice the head of water impounded against the dam. For the Phase 2 tailings deposition a maximum head is approximately 7.9 m, resulting in a required frozen core width of 15.8 m; and
- The frozen foundation maintain a temperature at or below -8°C for a width equal to the required width of the frozen core (15.8 m) and extend to the base of the overburden soil (i.e. top of bedrock).

The critical section for applying the thermal criteria is shown as a yellow bounding box in Figure 3. The section is to ensure a sufficiently wide area of the core and foundation remain nearly ice-saturated impervious barrier to seepage over the design life.

The thermal criteria for the critical section of foundation was selected to reduce the unfrozen water content of the saline marine clayey silt and thus decrease creep of the dam. The low porewater salinity of sand beneath the dam alignment suggests a lower potential for creep at the equivalent temperature to that of the marine clayey silt. The thermal modeling is therefore based on a marine clayey silt foundation which presents the greatest sensitivity to deformation.

2.3 Current Conditions

Annual inspections and review of monitoring data suggest the dam is performing in accordance with the design expectations. The North Dam has impounded water since the first winter of construction in 2011. The operating water level impounded against the upstream face of the dam has averaged 29 m, with a maximum level of 29.5 m over the period from September 2011 to September 2015. The original water level of Tail Lake prior to construction of the North Dam was 28.3 m.

Annual review of ground temperature monitoring data collected at the North Dam indicates (SRK 2016e):

- All horizontal GTCs were measuring temperatures well below the core design temperature of -2°C.
- Foundation temperatures were less than the foundation design temperature of -8°C, as measured by all nodes of GTC ND−VTS−085−KT.
- Foundation temperatures for the top six meters below the key trench at Section 0+175, as measured by GTC ND-VTS-175-KT, were warmer than the foundation design temperature of -8°C. However, a cooling trend is observed, with the maximum measured temperature decreasing approximately 1°C between 2014 and 2015.
- The maximum measured temperatures of near surface thermistor nodes for vertical GTCs on the upstream and downstream sides of the North Dam were between -1°C and -2°C.
- All thermosyphons are currently working with the exception of North 2 located along the north panel of thermosyphons. The evaporator pipe for North 2 is the second pipe from the downstream side of the core.

Figure 5 shows the thermosyphon evaporator temperature of one pipe measured at Section 0+85. The temperature record shows the heat extraction (cooling) period extends from mid-to-late October to late March. The thermosyphon ceases to extract heat from the spring when air temperatures are equal or greater than the ground temperature. During this period of time, the ground gradually warms near the evaporator pipe until the air temperature becomes colder than the ground in the fall.

Figures 6 and 7 show the thermosyphon evaporator temperature for Section 0+85 and 0+40, respectively. Evaporator temperature at Section 0+40 is observed to have a greater amplitude (minimum and maximum value). Section 0+40 is characterized by a thinner section of the dam with less thermal mass, which results in greater magnitude of warming and cooling over one year.

However, similar average annual evaporator pipe temperature is measured at these two sections of the dam.

Figure 8 shows the foundation temperature directly beneath the key trench at Section 0+85. Ground temperatures are observed to be consistently less than -8°C with a decreasing trend in temperature. Figures 9 and 10 show the foundation temperature beneath the upstream and downstream toe of the dam, respectively. Warmer foundation temperatures are expected beneath the toe due to decreased fill thickness and impoundment of water against the upstream face of the dam.

3 Methods

3.1 Model Setup

Modeling was completed in a two-dimensional domain by solving for conductive heat movement 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.

As-built survey information was used for the 2D model sections of the dam. Section 0+85 was modeled with a 14 m wide crest, 11 m height, upstream slope of 6H:1V, and downstream slope of 4H:1V. Section 0+40 was modeled with a 13 m wide crest, 4 m height, upstream slope of 4H:1V, and downstream slope of 2H:1V. The model geometry for Section 0+85 and Section 0+40 is presented in Figure 11 and Figure 12, respectively.

Thermosyphon evaporator pipes and thermistor node locations were included in the model using available as-built survey information. Thermosyphon evaporator pipes act as a location for heat extraction in the model and thermistor nodes represent locations for comparing measured and modeled temperature.

3.2 Model Inputs

3.2.1 Material Properties

Five material regions were considered in the model: shell, transition zone, core, natural clay foundation, and bedrock. Table 1 presents a summary of the materials and thermal properties for each material region. The GCL was not physically represented in the model, which is a reasonable omission considering the nominal thickness of the liner (approximately 15 mm).

The thermal properties for ROQ material were taken from previous work completed by SRK for granular pad design (SRK 2016f). The thermal conductivity and heat capacity of the ROQ and transition materials were also calculated for 100% saturation to simulate infiltration of water on the upstream side of the frozen core and liner (Table 1).

The thermal properties for foundation-soil was based on natural clayey silt located beneath a portion of the dam. The average physical properties of the clayey silt was based laboratory measurements from field samples at the site (SRK 2012). A porewater freezing point depression of -2°C was based on average site-wide conditions which is reported to be -2.1°C (SRK 2016d). There is a negligible difference between the position of these two isotherms, and -2°C is presented for clarity of the results. The material property includes an average unfrozen water content curve for natural clay (Andersland and Ladanyi 2004) which has been adjusted for the freezing point depression in accordance with Banin and Anderson (1974). The thermal conductivity and head capacity were calculated in accordance with Cote and Konrad (2005) and Newman (1995), respectively.

Average physical properties of the frozen core material and transition zone material (SRK 2012) were used to calculated representative thermal properties. The core is not expected to have an appreciable level of dissolved ions within the porewater and no allowance was made in the model for a freezing point depression.

Table 1: Material Thermal Properties

Region of Model	Material	Degree of Saturation (%)	Porosity	Thermal conductivity, kJ/(m·day·°C)		Volumetric Heat Capacity, kJ/(m³·°C)	
				Unfrozen	Frozen	Unfrozen	Frozen
Shell	ROQ	30	0.30	104	117	1,697	1,509
Saturated Shell	ROQ	100	0.30	142	211	2,776	2,147
Transition	150 mm (6 inch) minus	40	0.21	172	174	1,821	1,646
Saturated Transition	150 mm (6 inch) minus	100	0.21	208	274	2,347	1,911
Core	20 mm minus: 5 mm minus (2:3 blend by volume)	88	0.26	184	231	2,827	2,351
Clay Foundation [1,2]	Clayey Silt	85	0.52	112	187	2,842	2,038
Bedrock	Basalt	100	0.05	260	260	2,380	2,133

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

3.2.2 Climate Boundary Conditions

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

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

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}
α is phase lag of the sine wave
t is time measured in days

Mean annual air temperature and amplitude are based on average values for the baseline period of 1979-2005 (SRK 2016g). Seasonal n-factors were applied as multipliers of air temperature to estimate the temperature at the ground surface. The upstream and downstream face of the dam (dam face) was based on a freezing n-factor (*nf*) of 0.86 and thawing n-factor (*nt*) of 1.52. These values are based on average published values for crushed rock and gravel (SRK 2016f), and considered to be reasonable base case conditions for the Project site. The n-factors applied to the crest of the dam were calibrated to match measured temperature for the upper core. The calibration reduced the thaw n-factor and increased the freezing n-factor which results in cooler ground temperatures when compared to the average published values applied to the side slopes. The n-factors for natural overburden was applied downstream of the dam using values calibrated to ground temperatures measured at the Project site (SRK 2016h).

Table 2: Current Climate Boundary Parameters

Parameter	Value
Mean Annual Air Temperature $(MAAT)$	-10.7°C
Air Temperature Amplitude (Amp)	21°C
Dam Crest, Thawing n-factor (nt)	1.30
Dam Crest, Freezing n-factor (nf)	0.90
Dam Face[1], Thawing n-factor (nt)	1.52
Dam Face[1], Freezing n-factor (nf)	0.86
Natural Overburden Downstream, Thawing n-factor (nt)	0.55
Natural Overburden, Freezing n-factor (nf)	0.65
Water Temperature Boundary	Figure 8

Notes:

1. Dam face refers to both the downstream side and upstream side of the dam above the water level

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 which is based on the work of SRK (2016g). Table 3 shows the daily increase in air temperature in the model applied to the thermal models.

Table 3: Summary of Doris Air Climate Change Factors Applied to Thermal Models

Year	Rate (°C $decade^{-1}$)	Air Climate Change Factor (°C day^{-1})
2011 – 2040	0.74	0.000203
2041 – 2051	0.71	0.000195

3.2.3 Water Boundary Condition

The thermal effect of water against the upstream face of the dam was simulated using a time dependent temperature boundary (Figure 13). The temperature is similar to average monthly lake bottom temperature for Arctic waterbodies (Burn 2002; Ensom *et al*. 2012) and are conservative when compared to the average lake water temperatures measured at lakes located within the Project site (SRK 2016i). The potential change in water temperature due to climate change was not consider due to conservatism considered in the boundary.

3.2.4 Thermosyphon Boundary Condition

Thermosyphons were included as a heat flux boundary in the model:

$$Q = Hq\ (Tg - Ta) for\ Ta < Tg \qquad \text{Eq.2}$$

$$Q = 0\ for\ Ta > Tg \qquad \text{Eq.3}$$

$$h = (A + B \cdot V^C)A_{rad} \qquad \text{Eq.4}$$

$$Hq = (h\ \cdot S)\ /\ A_{Evap} \qquad \text{Eq.6}$$

$$Ta = \left[MAAT + (C_A * t) + Amp * Sin\left(\frac{2\pi + (t+\alpha)}{365}\right)\right] \qquad \text{Eq.7}$$

Where:

- Q *is the total heat flux (J* s^{-1}*)*
- h *is the thermosyphon performance (J* s^{-1} *°*C^{-1})
- Tg *is the evaporator temperature in the ground (°C*)
- Ta *is the ambient air temperature (°C*)
- V is the wind speed (m s^{-1})
- $A, B, and\ C$ are heat transfer coefficients (Table 4)
- A_{rad} is the surface area of the radiator
- A_{Evp} is area of the evaporator pipe in the model
- S is the number of second per day
- Hq is the daily heat flux per metre of pipe

Heat transfer coefficients for a sloped evaporator were based on experimental results provided by Zarling and Haynes (1985) (Table 4). The heat flux boundary condition in the model extracts heat for the period of time when the air temperature is less than the ground temperature at the location of the evaporator pipe in the model (Eq. 2). The heat flux is prescribed to be zero for periods of time when the air temperature is greater than the ground temperature (Eq. 3) which agrees with the function of a thermosyphon (Figure 5).

Table 4: Passive Thermosyphon Heat Transfer Coefficients

Parameter	Value	Units
A	2.72	W m^{-2} C^{-1}
B	7.04	W m^{-2} C^{-1}
C	0.273	-
V	4.81	m s^{-1}

Notes:
1. Average wind speed (V) for climate change baseline period (SRK 2016g)

Climate change was applied to the air temperature boundary used to determine thermosyphon heat extraction. The average wind speed based on baseline climate conditions was used in the model, which is predicted to increase by 0.2 m s^{-1} over the design life (SRK 2016g). The predicted increase in wind speed would result in an increase in thermosyphon heat extraction, and for conservatism the constant baseline wind speed was used (Table 4).

3.2.5 Initial Conditions

The initial conditions were defined by each material region in the model. The frozen core temperature was set to -11°C which is the average temperature measured within the middle of the core (GTC ND-HTS-085-294). The transition material and shell were set to a constant temperature of -8°C and -7°C, respectively.

An initial temperature of -7.6°C was applied to overburden and bedrock which is representative of average permafrost temperatures at the Project site (SRK 2016f). The applied temperature is consistent with the average annual ground temperature measured in 2012 from the deepest thermistor node installed within the foundation at ND-VTS-085-KT (-7.6°C), ND-VTS-085-US (-7.6°C), and ND-VTS-085-DS (-6.2°C).

The vertical sides of the model space were set to a zero flux boundary and the lower boundary set to a constant flux 5.46 kJ/(m^2·day·°C) which was calculated from the average geothermal gradient of 0.021°C m^{-1} and the thermal conductivity of the bedrock (SRK 2016i).

3.3 Model Scenarios

3.3.1 Calibration Model

North Dam ground temperature measurements between August 12, 2012 and April 11, 2016 was used for model calibration of the two Sections 0+40 and 0+85. Table 5 summarizes the calibration model objectives and applied boundary conditions.

Table 5: Summary of Calibration Model Objectives and Boundary Conditions

Model	Objectives	Boundary Conditions
1	Confirm: • Thermosyphon heat transfer coefficients used to calculate heat extraction (Eq. 4)	• Measured Doris Meteorological Station daily air temperature and wind speed • Thermosyphon applied using SVHeat's thermosyphon option built into modeling package with calculated heat transfer coefficients
2	Confirm: • Climate boundary (Eq. 1). • Thermosyphon flux boundary (Eq. 2)	• Generalize climate boundary with average wind speed • Thermosyphon flux boundary

Notes:
1. Calibration models were run from Aug 12 of 2012 to April 11 of 2016

Model 1 was run to confirm reasonable heat extraction from the thermosyphons based on the calculated heat transfer coefficients and thermal properties. Doris Meteorological Station air temperature and wind speed measured over the calibration period was applied to the model (Figures 14 and 15).

Model 2 was run to confirm that reasonable results were obtained using the generalized climate boundaries for air temperature and ground surface temperature, and the flux boundary used to simulate heat extraction from the thermosyphon evaporator pipes.

For the calibration models, the water temperature boundary was applied to upstream face of the dam and based on the average water level (29 m) measured during the calibration period. The calibration models used six working thermosyphons for direct comparison with the current conditions at the south panel of thermosyphons.

3.3.2 Thermal Performance Model

A long-term thermal performance of the dam and foundation were predicted over the design life using:

- Climate boundary with consideration for climate change increase in air temperature (Eq. 1 and Table 2 and 3);
- Thermosyphon flux boundary (Eq. 2) with consideration of climate change (Table 4) and five working thermosyphons to meet conservative conditions along the north panel of thermosyphons;
- Water temperature boundary conditions applied along the upstream dam face to the top of the frozen core over the entire design life (Figures 13 and 14). This represents a conservative input to the model as the full supply level will be 34 m (SRK 2016a);
- Clayey silt foundation to represent thermal conditions for which the dam is physically sensitive;
- Average geothermal heat flux and calculated thermal properties; and
- Design life of 40 years from 2011 to 2051, which extends beyond the expected period of mining and subsequent closure, for at least ten years.

4 Results

4.1 Calibration Period

Model results for the calibration period are shown for Section 0+85 (Figures 16 through 25) and Section 0+40 (Figures 26 through 32).

Calibration Model 1 uses measured daily air temperature and wind speed to confirm the thermal behavior and heat extraction of the thermosyphon is achieved in the model. For Section 0+85 (Figures 16 through 21) and Section 0+40 (Figures 26 through 31), the modeled evaporator pipe temperature closely match the measured values. In particular, the modeled temperature agrees with the timing of heat extraction from the thermosyphon evaporator which is observed as a rapid decrease in temperature, and the timing of warm and maximum temperature reached when the thermosyphons is seasonally shutdown. Short term fluctuation in temperature is also captured when using daily measured air temperature and wind speed. In general, the thermosyphon heat extraction and resulting change in temperature does not exceed the measured minimum temperature or maximum temperature.

Calibration Model 2 uses the modeled climate boundary and average wind speed to confirm the generalized boundary conditions and the thermosyphon heat flux boundary produce comparable results to Model 1 and measured temperatures. A similar change in evaporator temperature results from Model 2 when compared to the more specific inputs used in Model 1; i.e. the input of measured daily air temperature and wind speed. Figures 16 through 21 show the Model 1 and Model 2 comparison for Section 0+85. Equivalent figures for Section 0+40 are shown in Figures 26 through 31. Results from Model 2 confirm the generalized climate boundary and thermosyphon flux boundary are suitable and conservative for predicting long-term thermal performance of the dam over the extended design life.

Measured and modeled temperature for the upper core (Figure 22), middle core (Figure 23), and foundation (Figures 24 and 25) all show good agreement for Section 0+85. Figure 32 shows modeled and measured temperatures for the middle core of Section 0+40. Measured ground temperatures are not available for the upper core of Section 0+40. Modeled temperature below the key trench in the foundation also shows good agreement with measured temperature over the calibration period (Figures 24 and 25).

4.2 Thermal Performance Period

The North Dam thermal regime was modeled over the 40-year design life to evaluate its thermal performance based on the thermal design criteria described in Section 2.2. The critical section of the dam used to assess performance is shown as a yellow bounding box in Figure 3. The critical section defined by the box is 15.8 m wide and extends from the FSL (34 m level) to the top of bedrock.

Figures 33 through 37 show the modeled temperature for Section 0+85 at years 2, 10, 20, 30, and 40, respectively. For Section 0+85, the thermal criteria is met over the design life, with the core remaining below -2°C and the foundation below -8°C (Figure 37). The core and foundation temperatures are observed to increase in response to the surface climate boundary and the water temperature boundary applied to the upstream face of the dam. The warming of the foundation directly below the key trench is mainly caused by the length of time water is applied to the upstream face of the dam. Temperature at the base of the key trench and within the foundation is shown in Figure 38.

Figures 39 through 43 show the modeled temperature for Section 0+40 at years 2, 10, 20, 30, and 40, respectively. The core temperature over the critical section remains below -2°C for the design life and most, but not all of the foundation remains at or below -8°C. A portion of the critical section warms to -6°C by the end of the design life (28% of section) while the remaining 72% is colder than the -8°C. A smaller portion of the foundation (8%) is warm -8°C at the end of 30 years which is the actual expected design life of the dam.

Temperature at the base of the key trench and within the foundation is shown in Figure 44. The predicted warming for the foundation would result in a higher unfrozen water content of the frozen clay. However, little change in the unfrozen water content over the same range in temperature (-8°C to -6°C) would be expected for the foundation consisting of sand; i.e. coarser-grained soils, such as sand with fresh porewater exhibit a small change in the unfrozen water content for this temperature range.

5 Conclusions

Thermal modeling of the North Dam has been completed for a 40-year design life, which is 10 years greater than the actual planned design life of 30 years. The model was validated with measured temperature from the dam, and long-term performance modeling was completed with consideration for climate change and the use of conservative inputs. The model results indicate the frozen core will remain below -2°C. Towards the end of the 40-year design life, the foundation over a portion of the critical section is expected to exceed the -8°C beneath the thinnest sections of the dam. The warmer foundation conditions will result in a higher fraction of unfrozen water and a greater potential for creep deformation. The thermal criteria is met over the 40-year design life for the thickest section of the dam which impounds the greatest head of water.

At the end of the planned design life of 30 years, the thermal criteria of the foundation is met beneath the thickest section of the dam. A small portion of the foundation does not meet the thermal criteria beneath the thinnest sections of the dam (8% of the foundation), with 92% of the area below -8°C. Over this period of time the frozen core temperature is below -2°C.

These results are based on conservative inputs to the model with consideration for increasing air temperature due to climate change, a constant wind speed which is expected to increase and improve thermosyphon performance, a constant head of water applied to the full supply level for the entire design life, a clay foundation, and five working evaporator pipes.

Annual inspections and monitoring to date indicate the North Dam is performing in accordance with the design expectations. Continued monitoring of the North Dam will allow for assessment of its thermal performance over time and the need for any mitigation, such as maintaining the downstream dam face clear of snow to enhance cooling, construction of a coarse rock convective cover over the downstream dam face, placement of added thermal protection at the upstream dam surface, or installation of vertical thermosyphons to reduce foundation temperatures. The existing thermosyphons may also be retrofitted with chilling coils on the surface radiators to increase heat extraction. Thermal responses in the dam will be very slow and trends will be easily identified through monitoring, allowing for ample time to implement any of the mitigation strategies.

6 References

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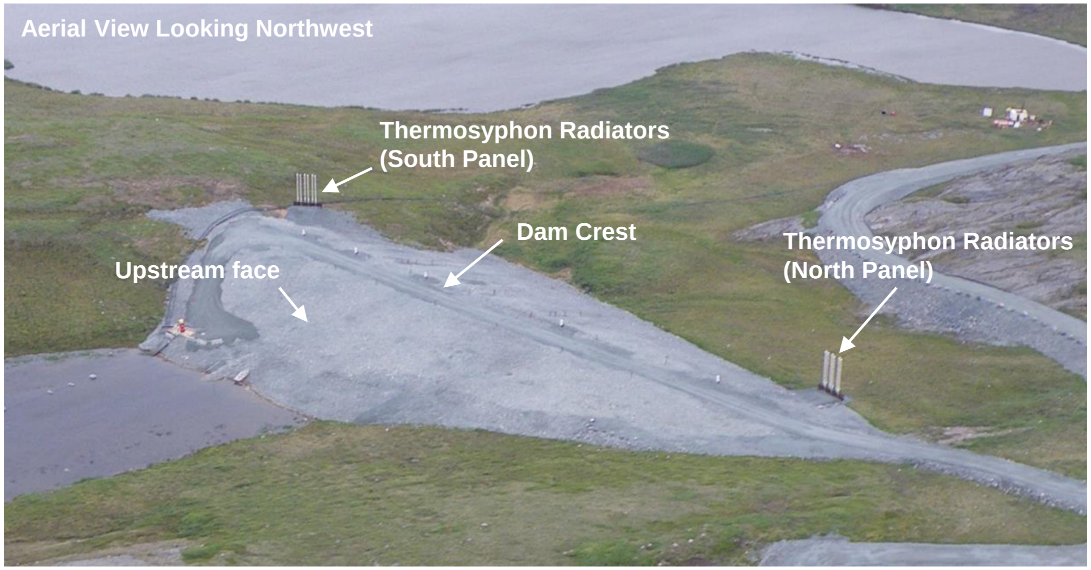
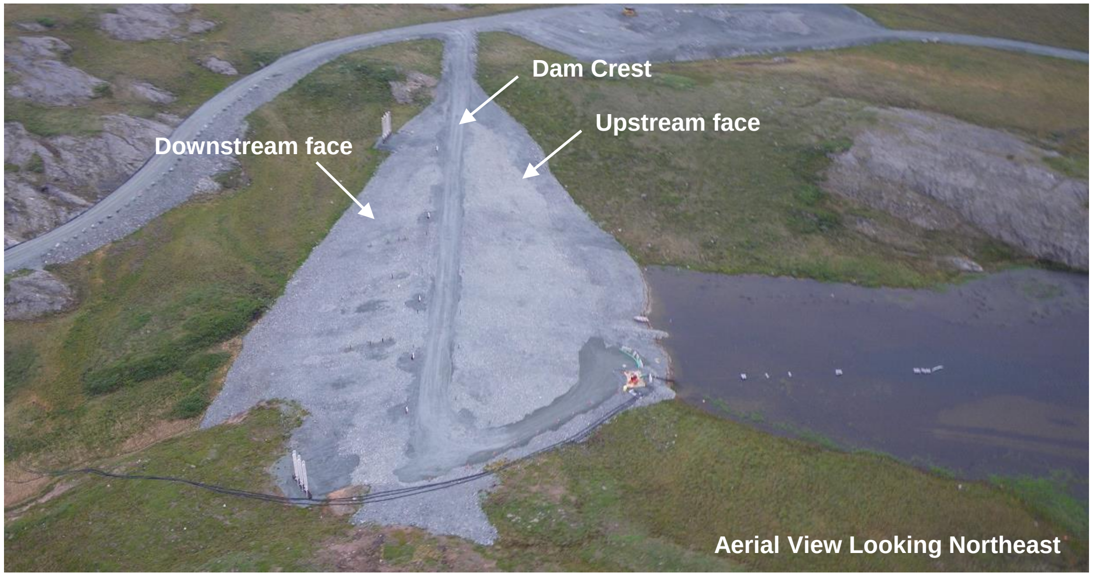
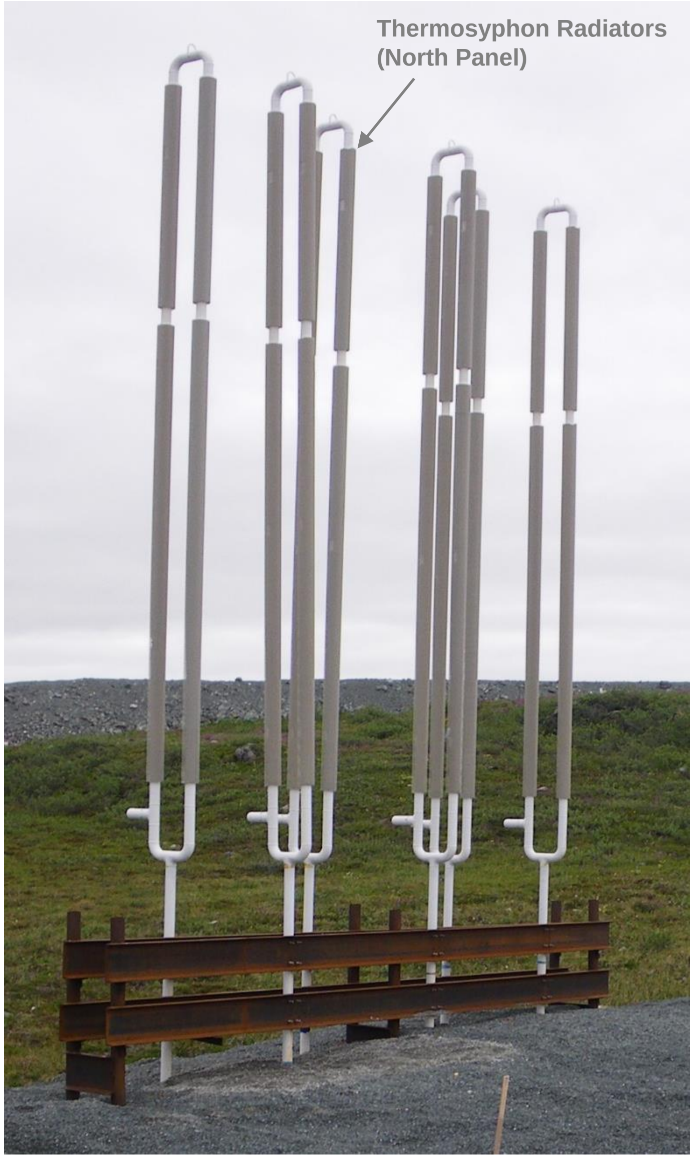
Figures



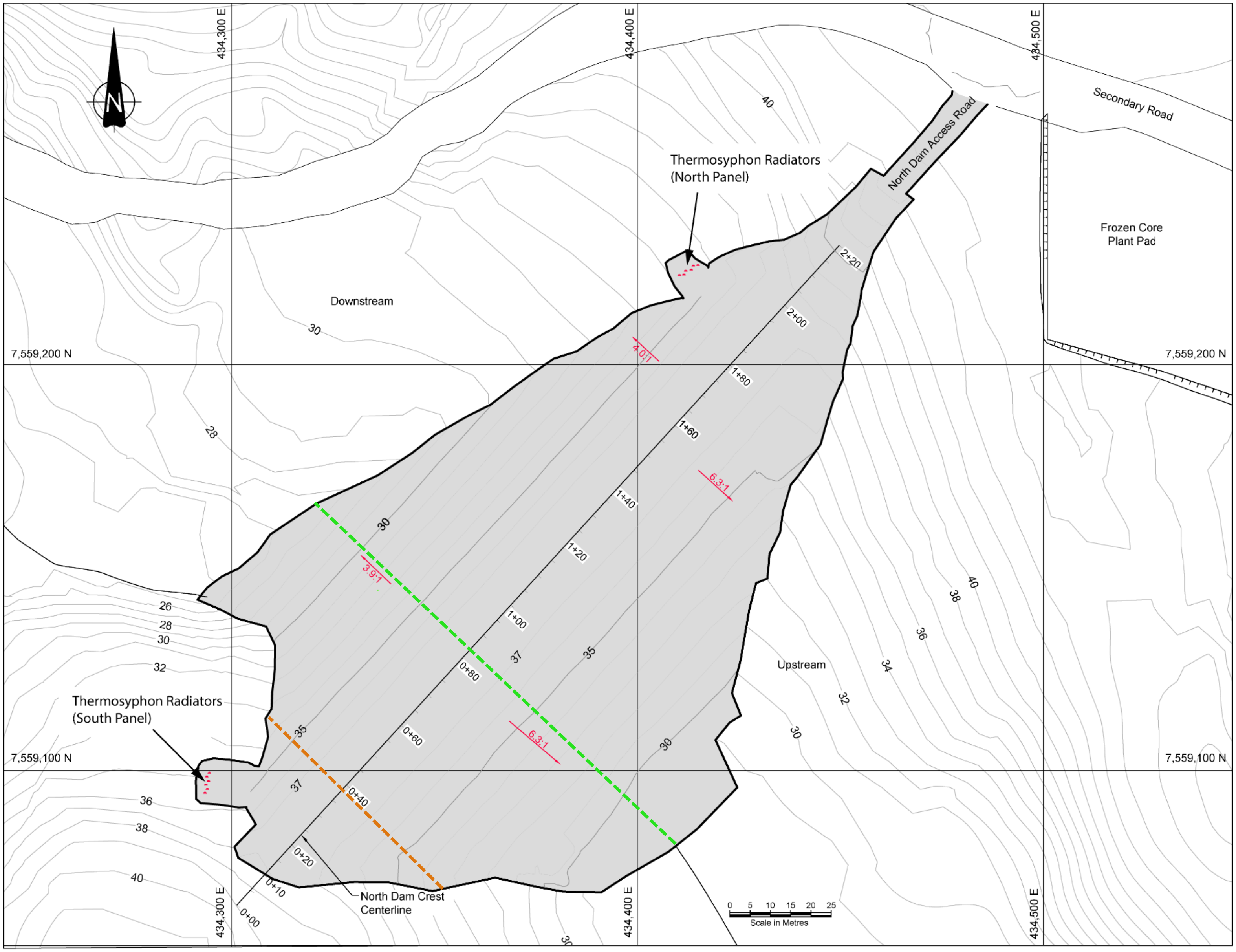




Notes:

1. Field photographs taken July 18th and July19th of 2014

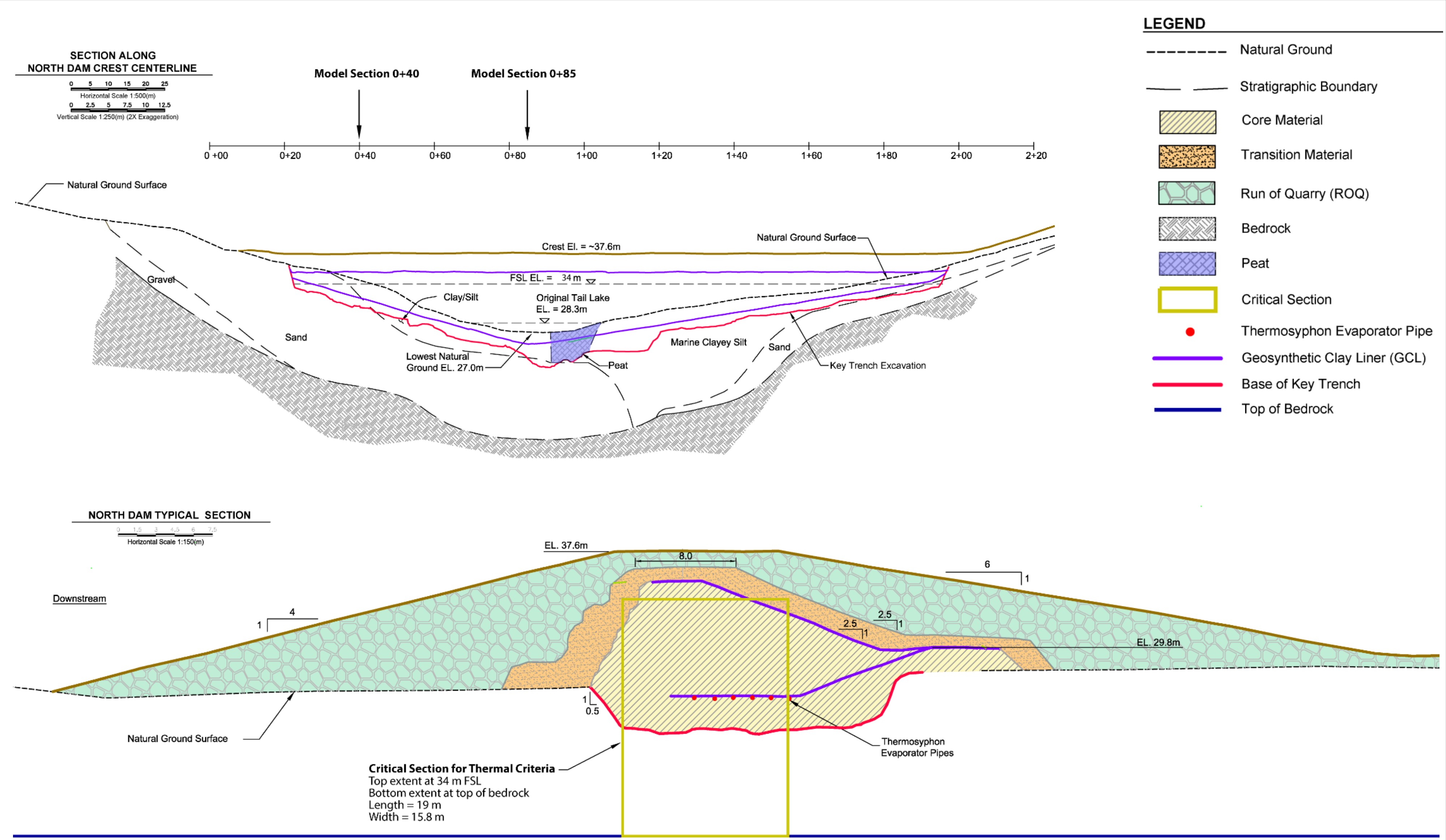
srk consulting	TMAC RESOURCES	Doris North Dam Thermal Modeling
		North Dam – Field Photograph
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 · Approved: cws · Figure: 1



Notes:

1. Dashed orange line indicates Dam Section 0+40
2. Dashed green line indicates Dam Section 0+85

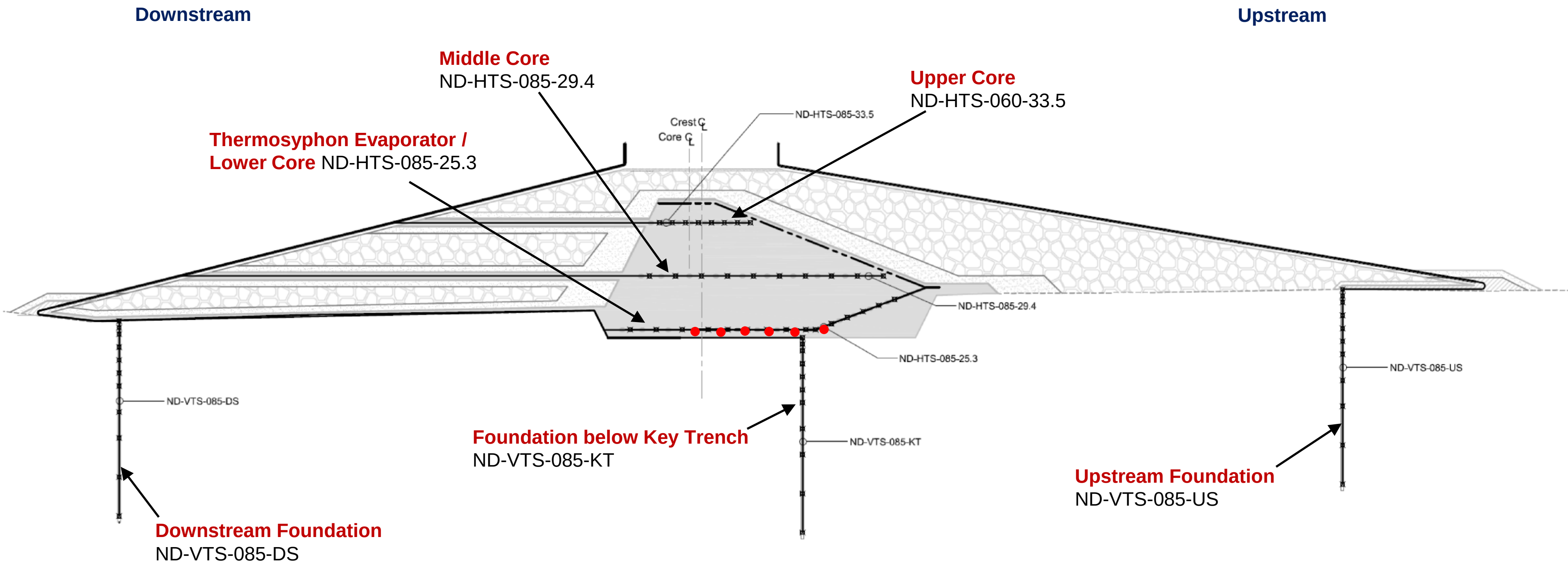
srk consulting	MAC RESOURCES	Doris North Dam Thermal Modeling
		North Dam General Arrangement
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 | Approved: cws | Figure: **2**



Notes:

1. The subsurface geology has been extrapolated from a series of geotechnical investigations and geological unit contacts are therefore likely to vary somewhat.

srk consulting	MAC RESOURCES	Doris North Dam Thermal Modeling
		North Dam Typical As-Built Section
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 · Approved: cws · Figure: 3



Notes:

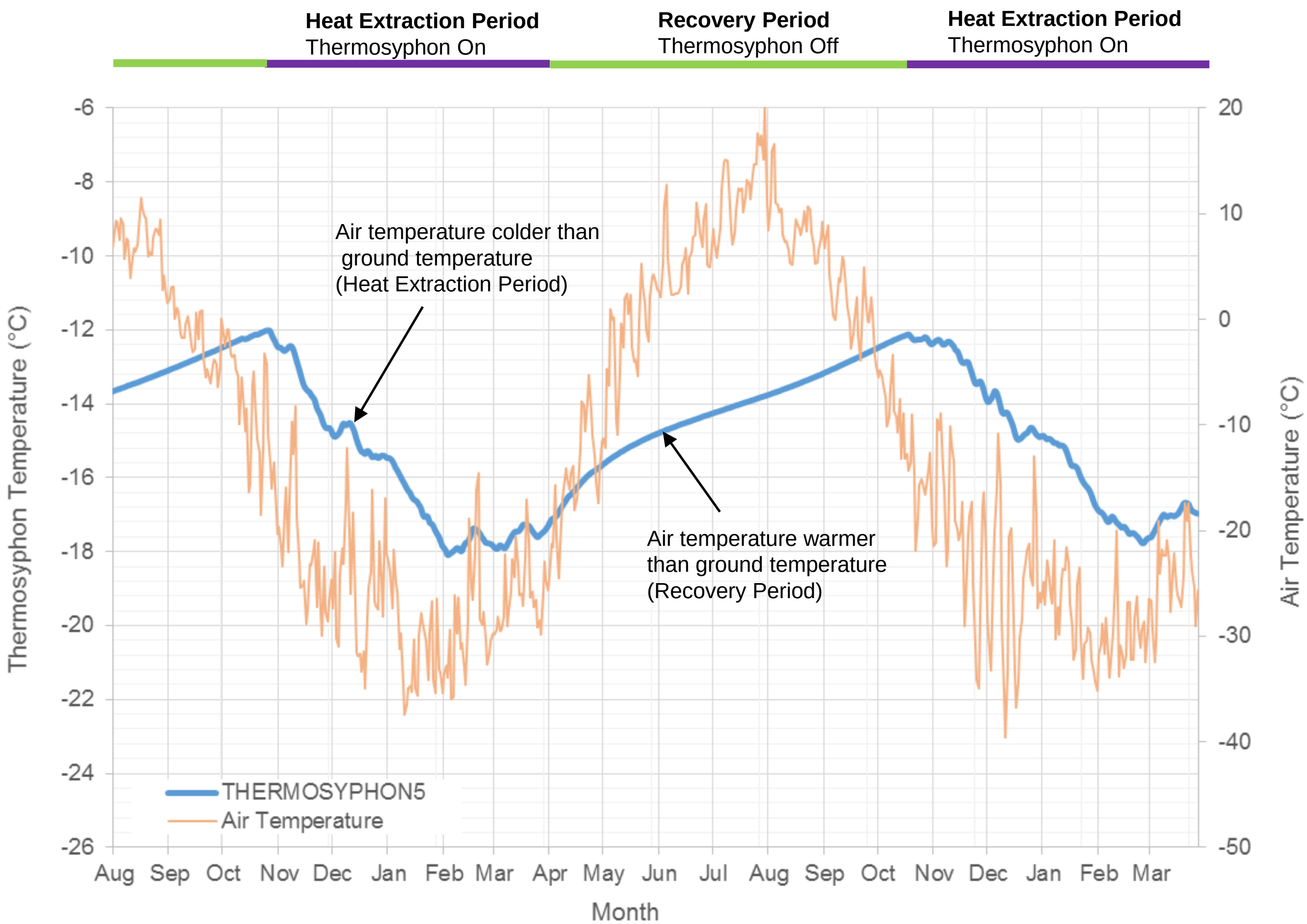
1. Red dots indicate evaporator pipes
2. Black dots indicate thermistor nodes
3. Horizontal thermistor strings (HTS)
4. Vertical thermistor strings (VTS)
5. Key trench (KT)
6. Upstream (US) and downstream (DS)

Doris North Dam Thermal Modeling

North Dam
Temperature Cable Arrangement

HOPE BAY PROJECT

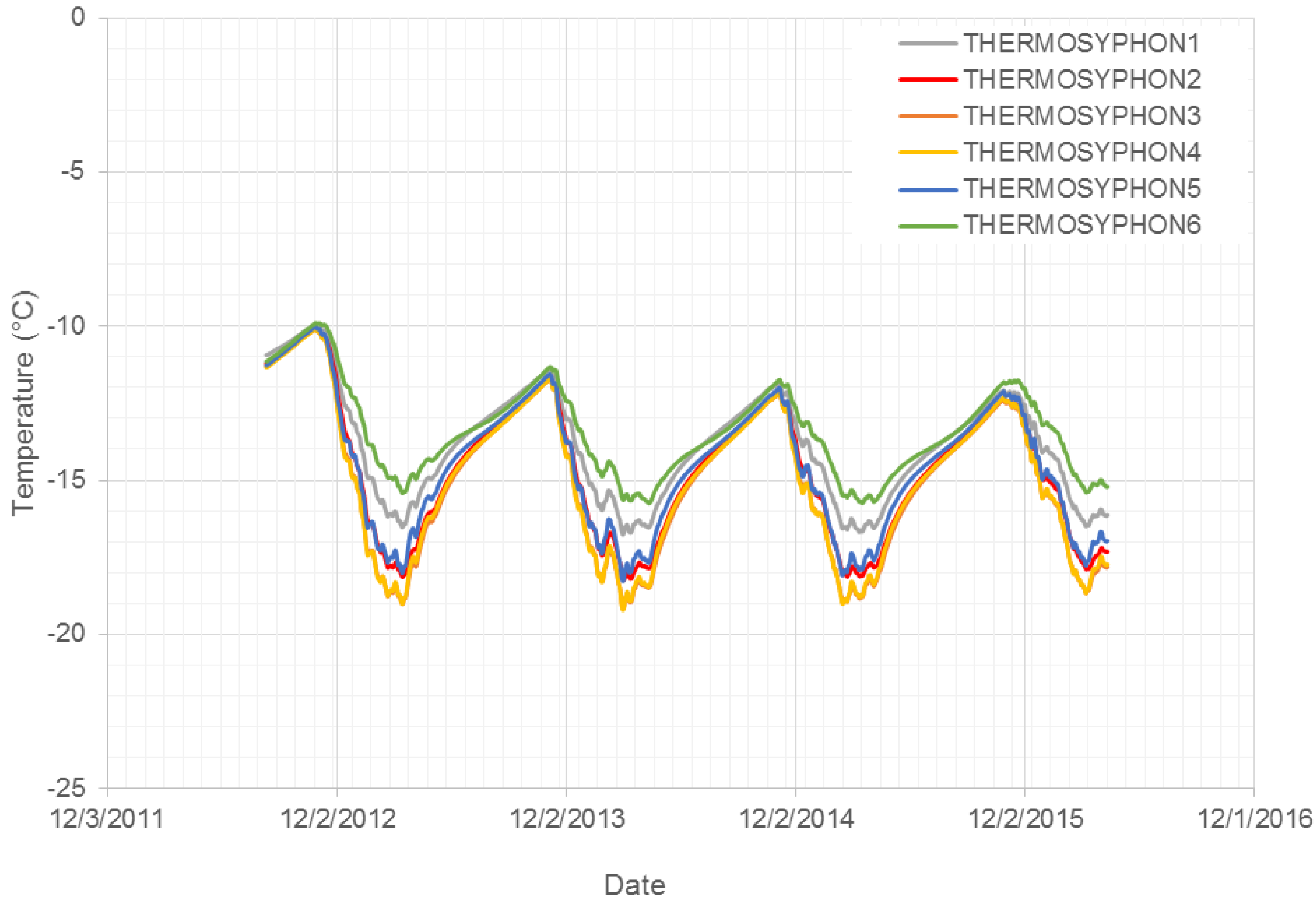
Job No: 1CT022.004	Date: 5/2/2016	Approved: cws	Figure: 4
Filename: NorthDam.pptx			



Notes:

1. Blue line represents thermosyphon evaporator temperature
2. Orange line represents Doris Metrological Station air temperature

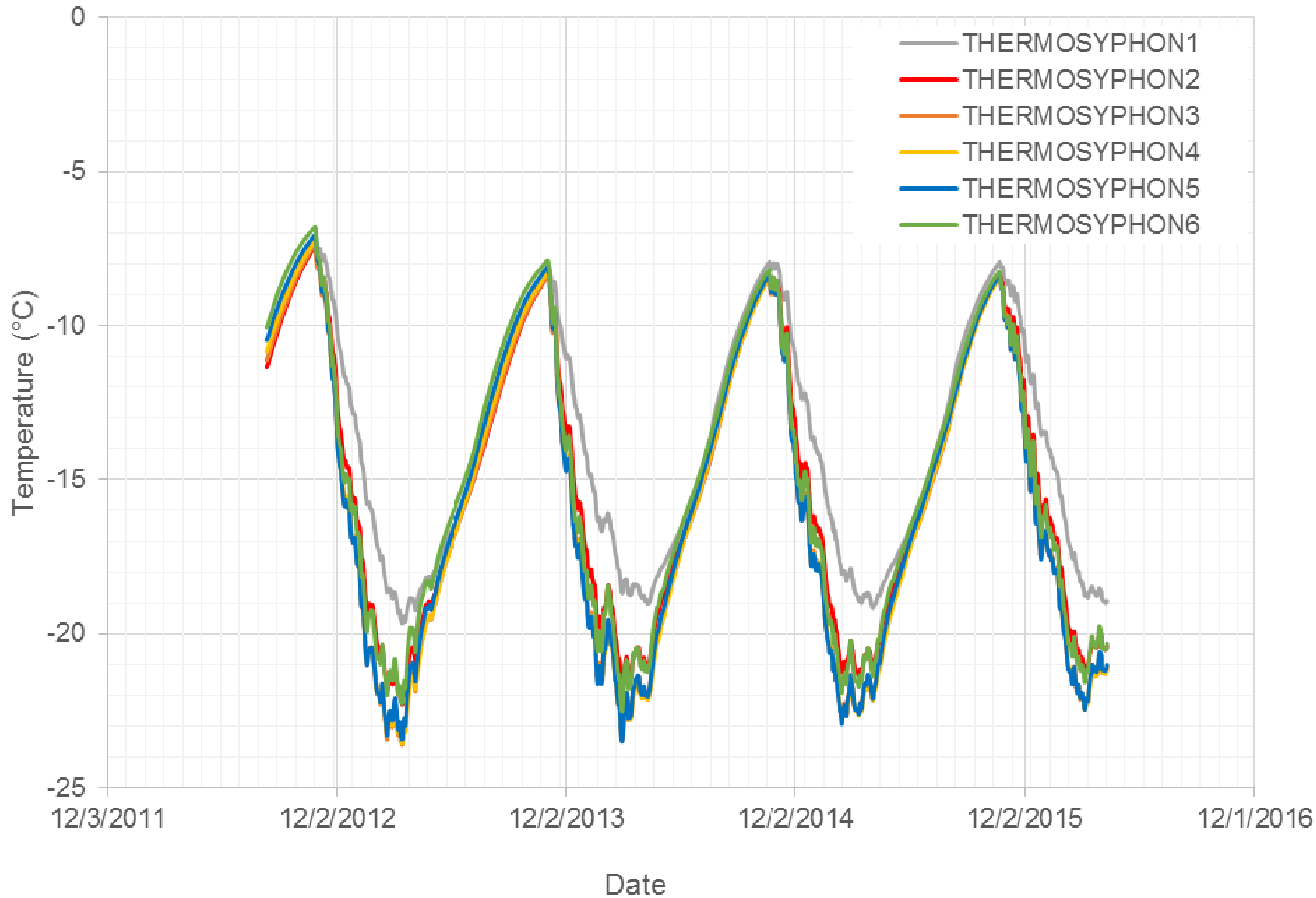
srk consulting	TMAC RESOURCES	Doris North Dam Thermal Modeling **Thermosyphon Evaporator – Thermal Behavior**
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 | Approved: cws | Figure: **5**



Notes:

1. Ground temperature measurements from thermistor string ND-HTS-085-25.3 (see Figure 4)
2. Thermistor nodes located near evaporator pipe
3. Data from Section 0+85

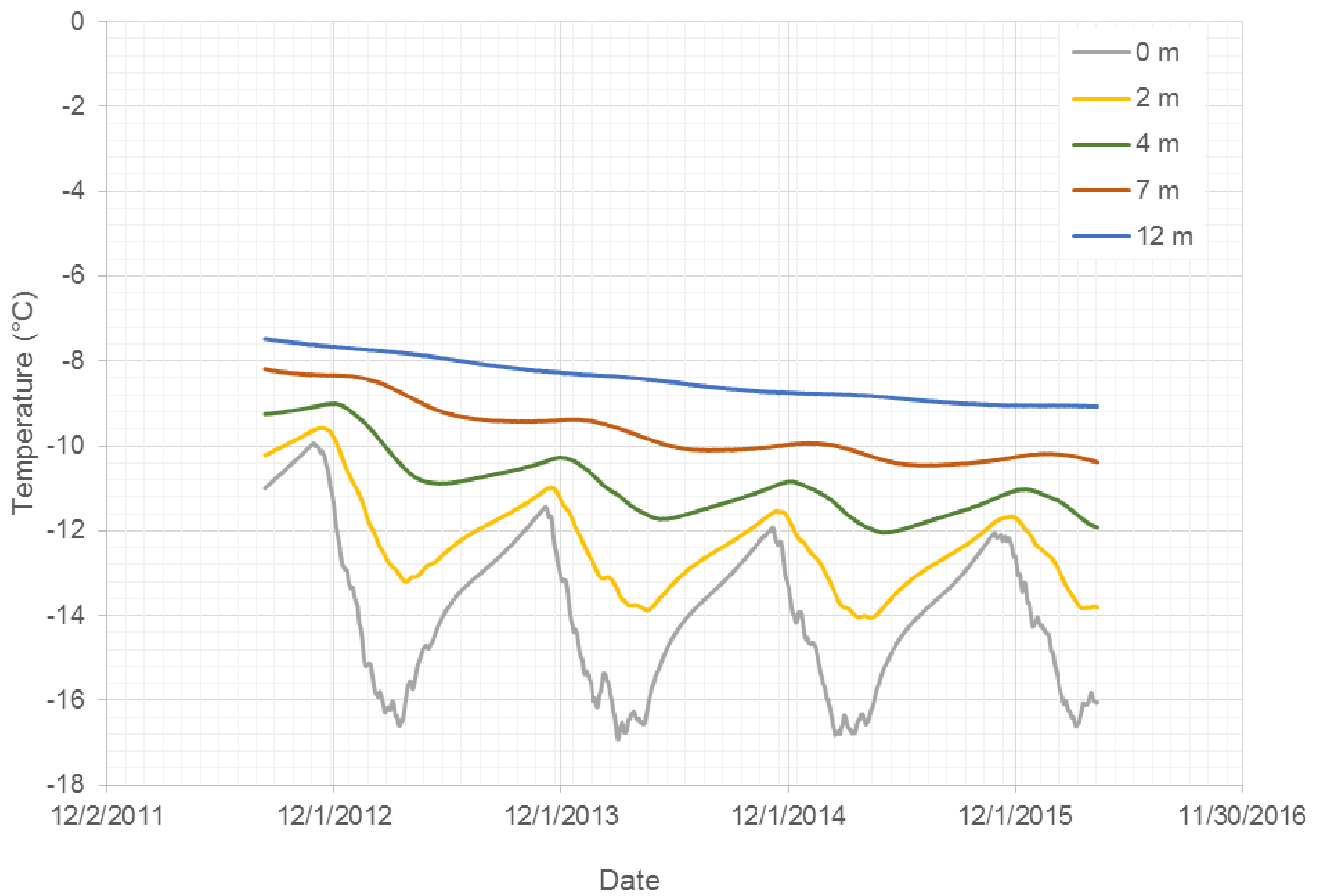
srk consulting	MAC RESOURCES	Doris North Dam Thermal Modeling
		Measured Temperature – Thermosyphon Evaporator (0+85)
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 · Approved: cws · Figure: 6



Notes:

1. Ground temperature measurements from thermistor string ND-HTS-040-31.5 (see Figure 4)
2. Thermistor nodes located near evaporator pipe
3. Data from Section 0+40

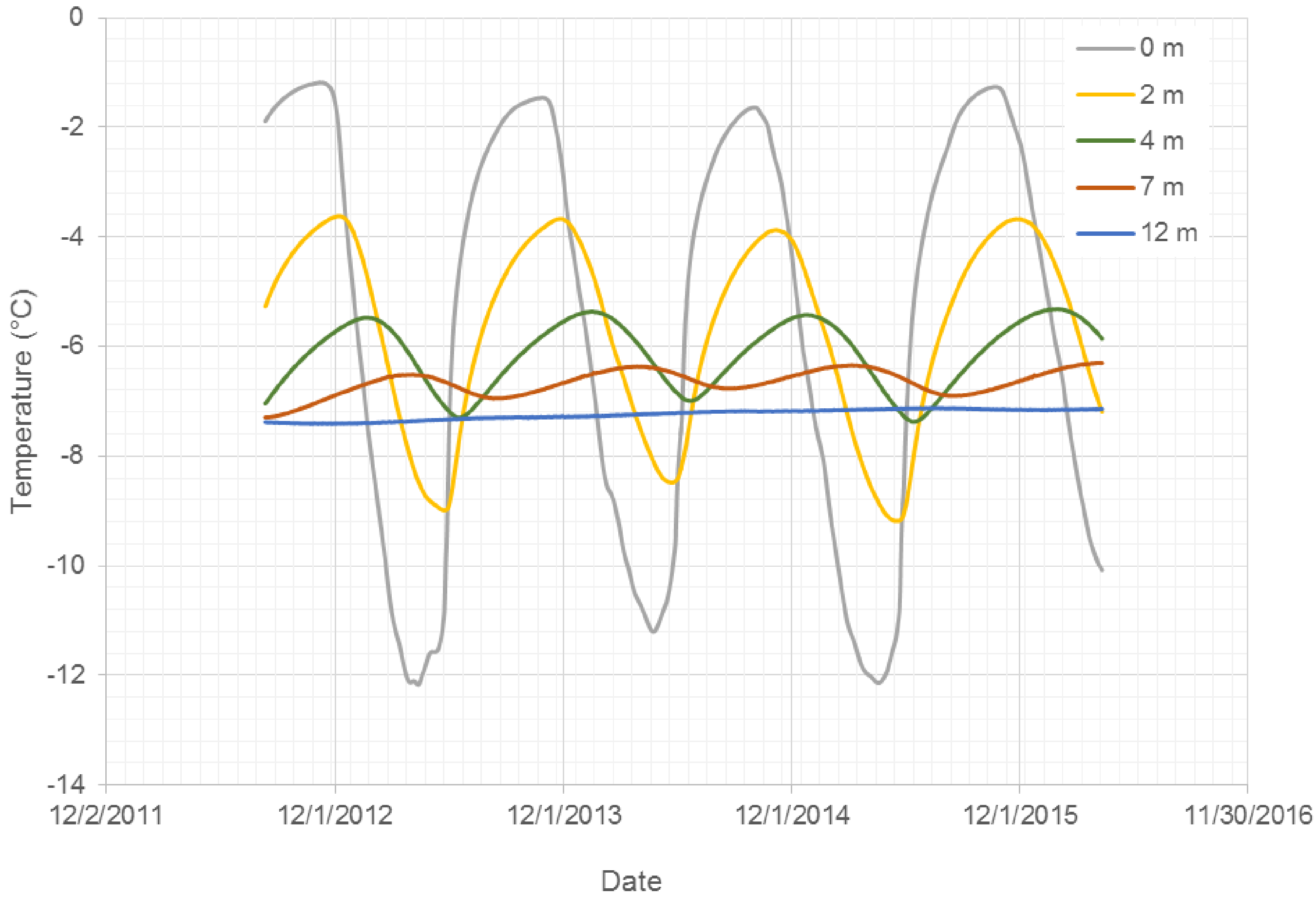
srk consulting	TMAC RESOURCES	Doris North Dam Thermal Modeling
		Measured Temperature – Thermosyphon Evaporator (0+40)
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 · Approved: cws · Figure: 7



Notes:

1. Ground temperature measurements from thermistor string ND-VTS-085-KT (see Figure 4)
2. Data shown for select thermistor nodes for graphical clarity
3. Depth referenced from top thermistor node

srk consulting	MAC RESOURCES	Doris North Dam Thermal Modeling
		Measured Temperature – Below Key Trench (0+85)
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 · Approved: cws · Figure: **8**



Notes:

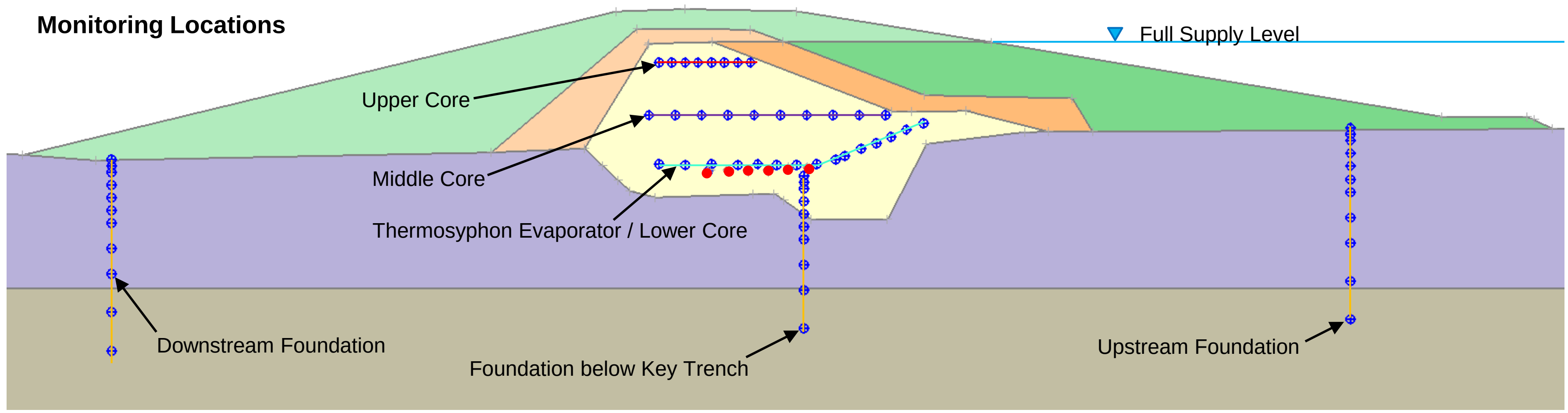
1. Ground temperature measurements from thermistor string ND-VTS-085-US (see Figure 4)
2. Data shown for select thermistor nodes for graphical clarity
3. Depth referenced from top thermistor node

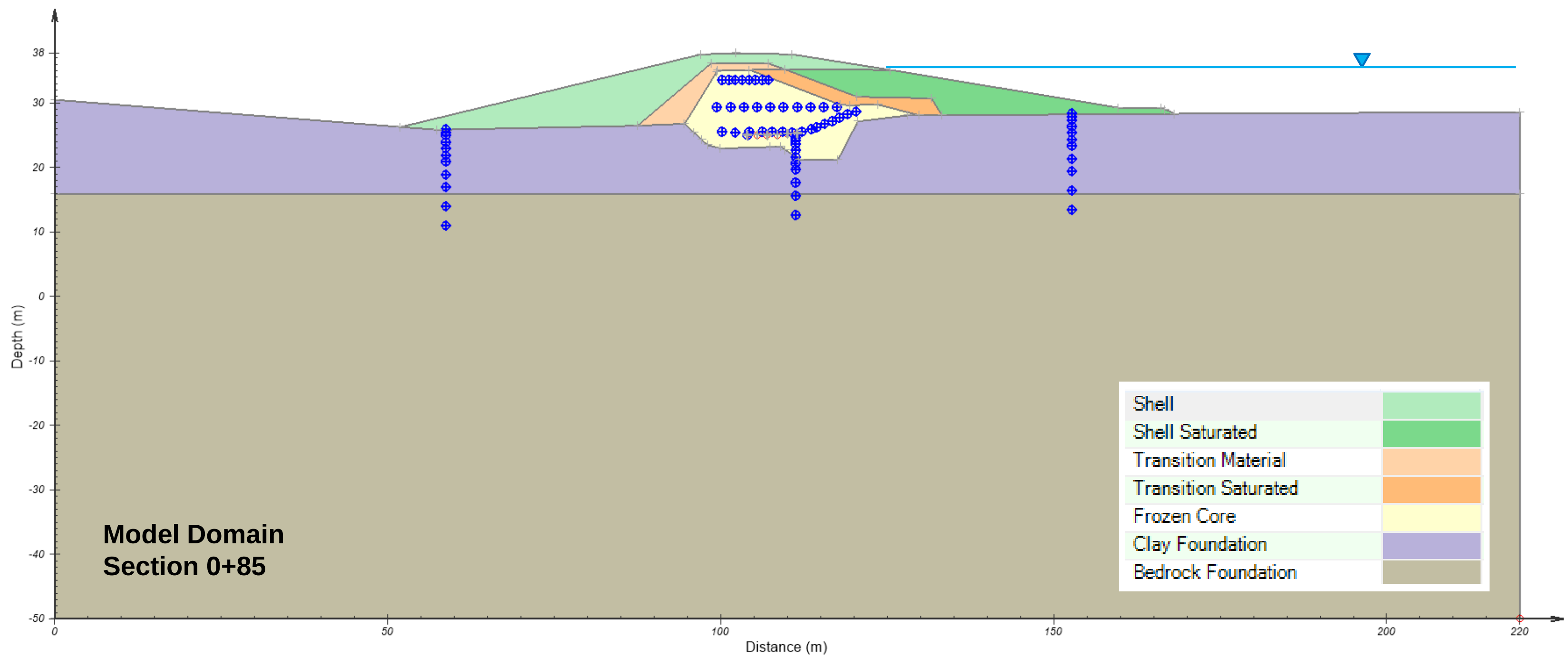
srk consulting	MAC RESOURCES	Doris North Dam Thermal Modeling
		Measured Temperature – Upstream Foundation (0+85)
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 | Approved: cws | Figure: **9**

Notes:

1. Ground temperature measurements from thermistor string ND-VTS-085-DS (see Figure 4)
2. Data shown for select thermistor nodes for graphical clarity
3. Depth referenced from top thermistor node

srk consulting	TMAC RESOURCES	Doris North Dam Thermal Modeling
		Measured Temperature – Downstream Foundation (0+85)
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 | Approved: cws | Figure: **10**

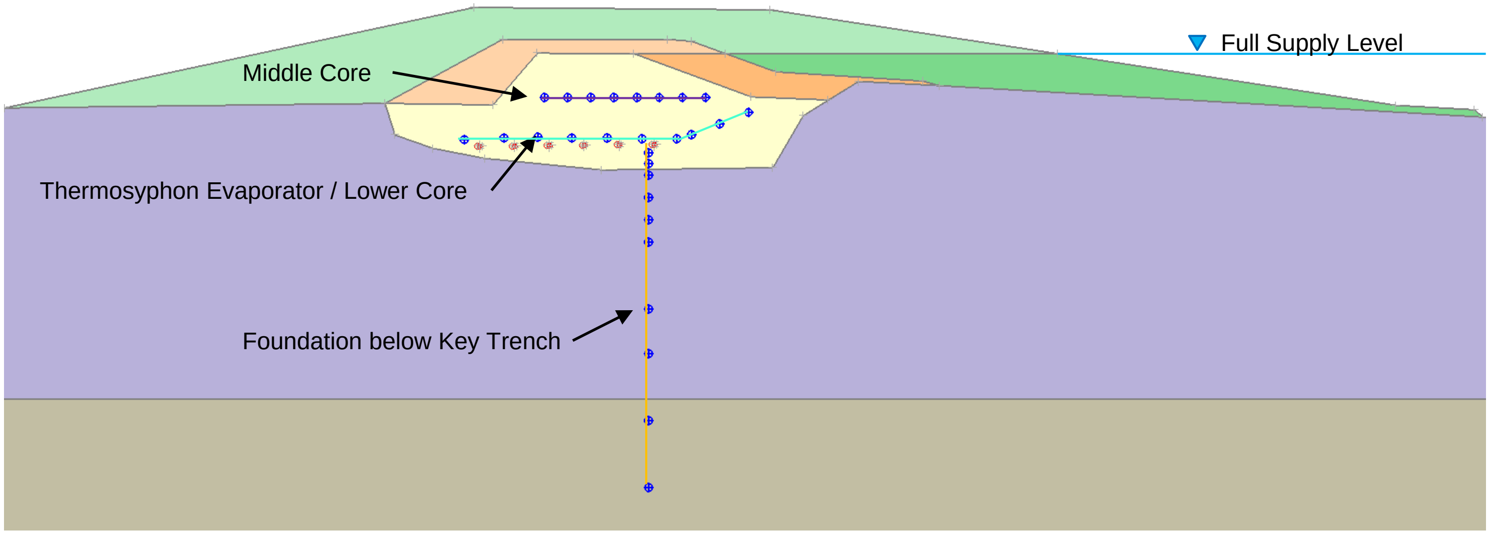


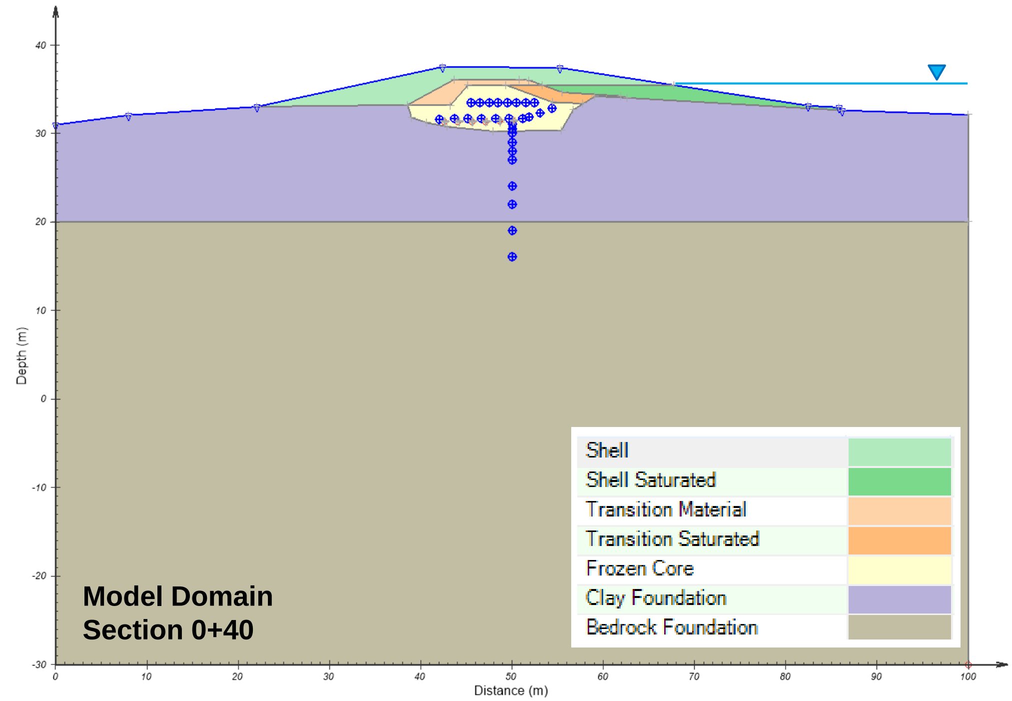


Notes:

1. Red dots indicate evaporator pipes
2. Blue dots indicate thermistor nodes

srk consulting	MAC RESOURCES	Doris North Dam Thermal Modeling
		North Dam Model Domain (0+85)
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 — Approved: cws — Figure: **11**

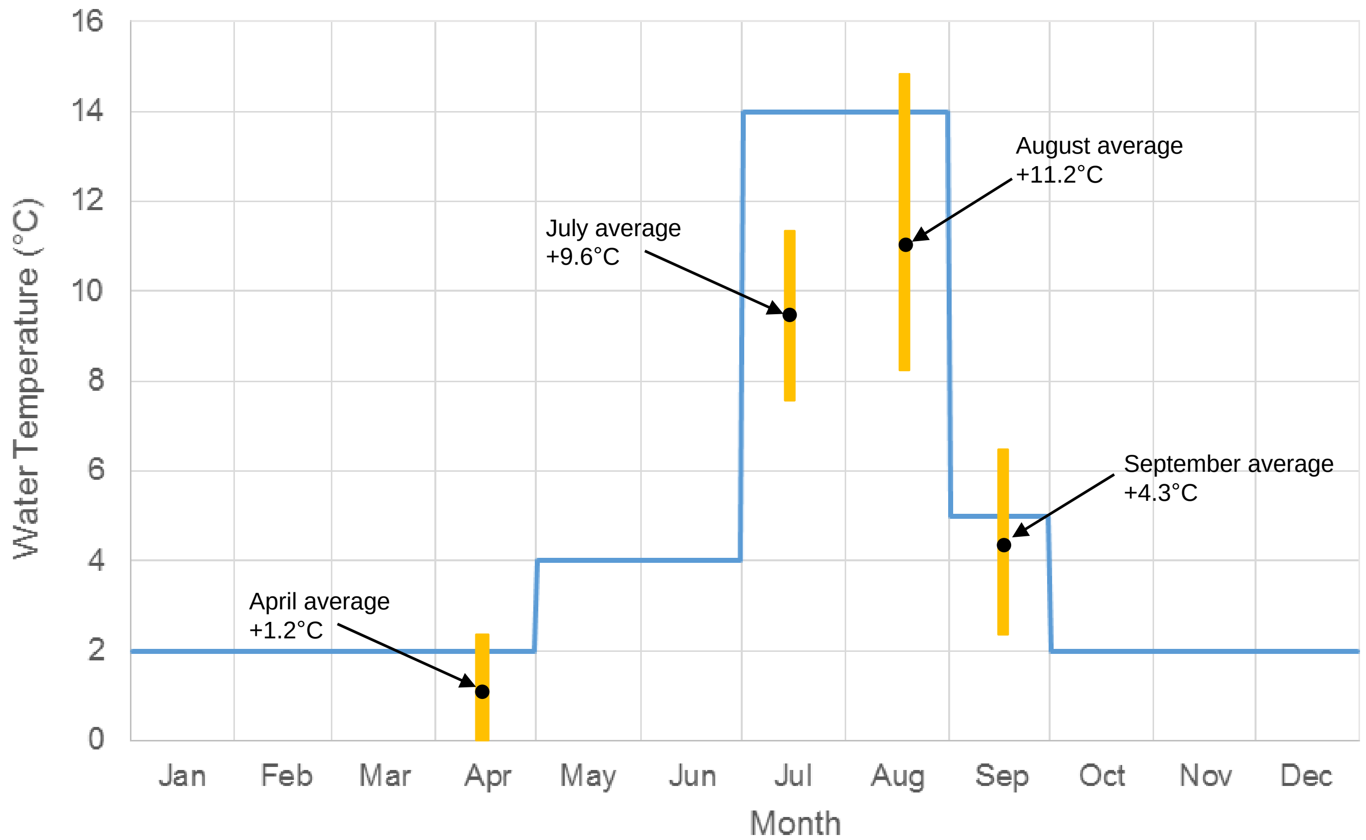




Notes:

1. Red dots indicate evaporator pipes
2. Blue dots indicate thermistor nodes

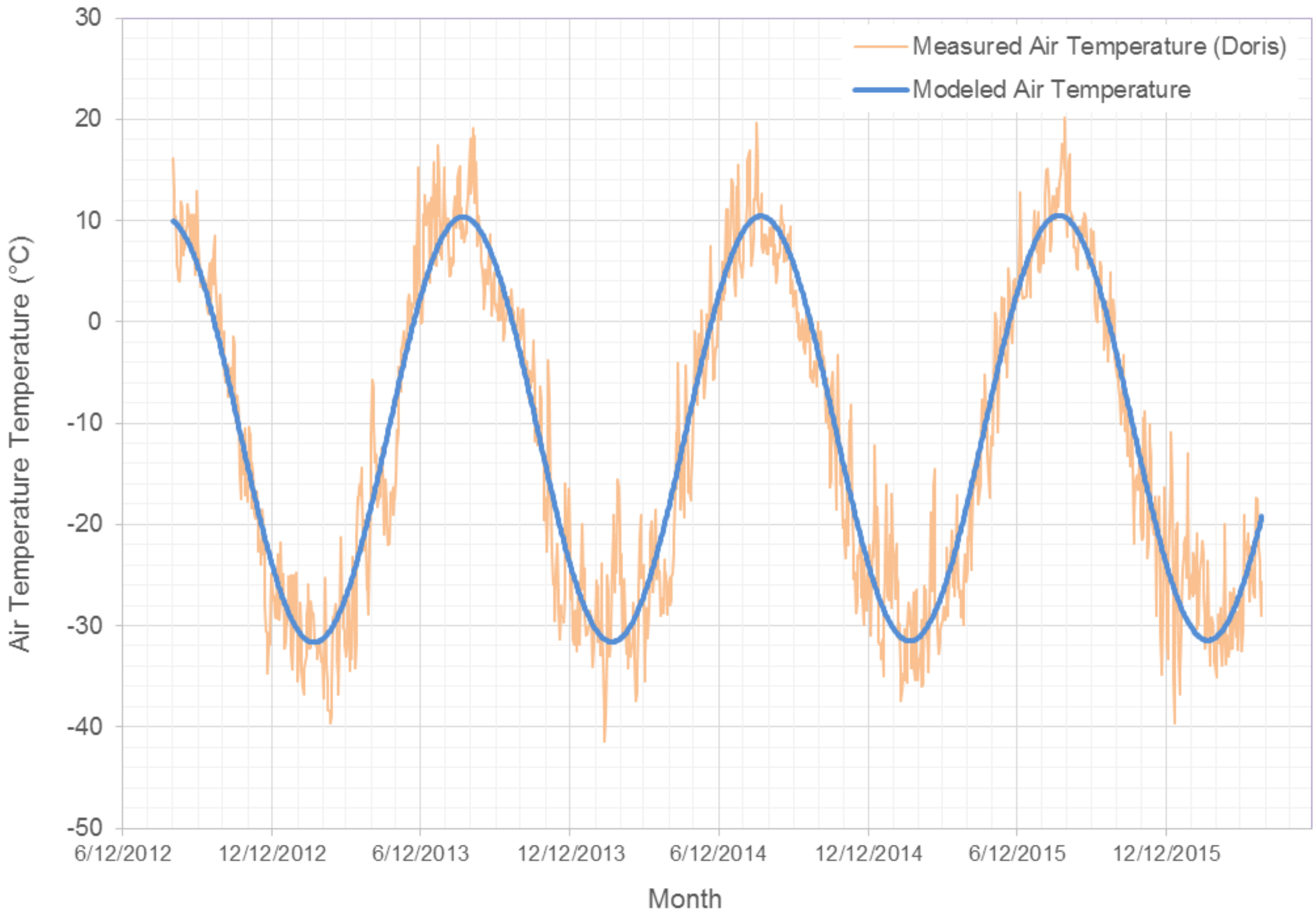
srk consulting	MAC RESOURCES	Doris North Dam Thermal Modeling
		North Dam Model Domain (0+40)
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 | Approved: cws | Figure: **12**



Notes:

1. Solid blue line represents water temperature used in the thermal model
2. Yellow bars represent range of lake water temperature measured at Property

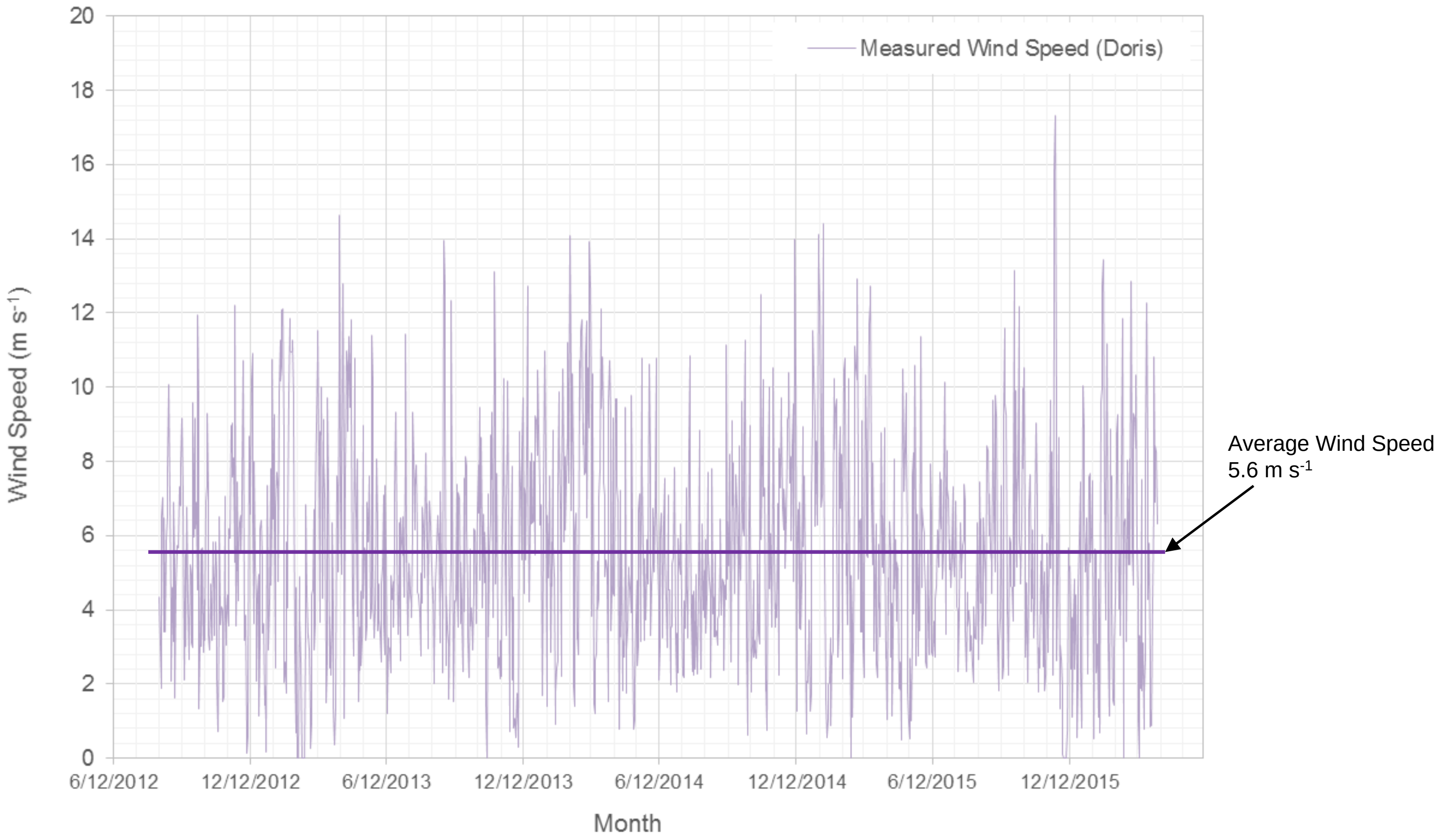
srk consulting	MAC RESOURCES	Doris North Dam Thermal Modeling
		Model Input – Water Temperature
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 · Approved: cws · Figure: **13**



Notes:

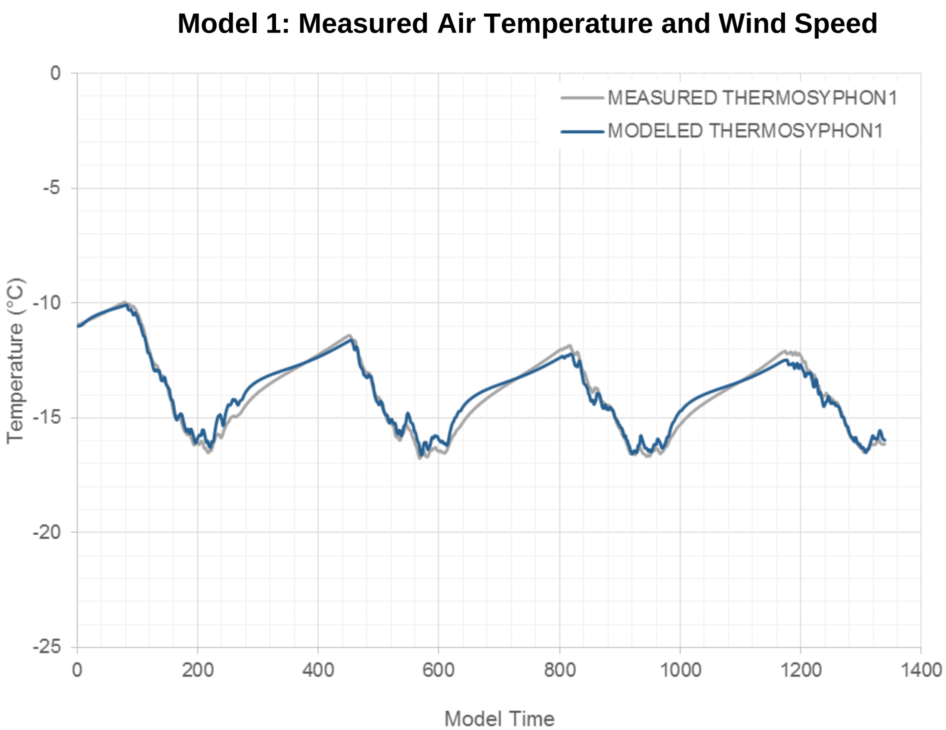
1. Daily air temperature measured at Doris Meteorological Station
2. Modeled air temperature used in the thermal model

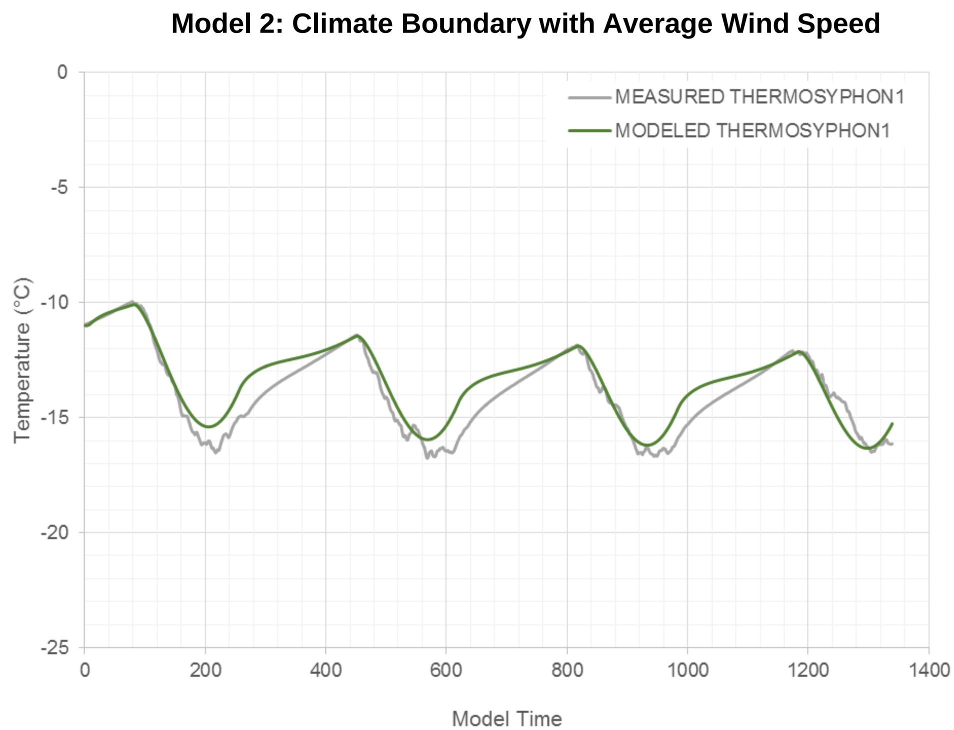
srk consulting	MAC RESOURCES	Doris North Dam Thermal Modeling **Model Input – Air Temperature**
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 | Approved: cws | Figure: **14**



Notes:
1. Daily wind speed measured at Doris Meteorological Station
2. Wind speed data used for model calibration

srk consulting	MAC RESOURCES	Doris North Dam Thermal Modeling
		Model Input – Wind Speed
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 · Approved: cws · Figure: **15**



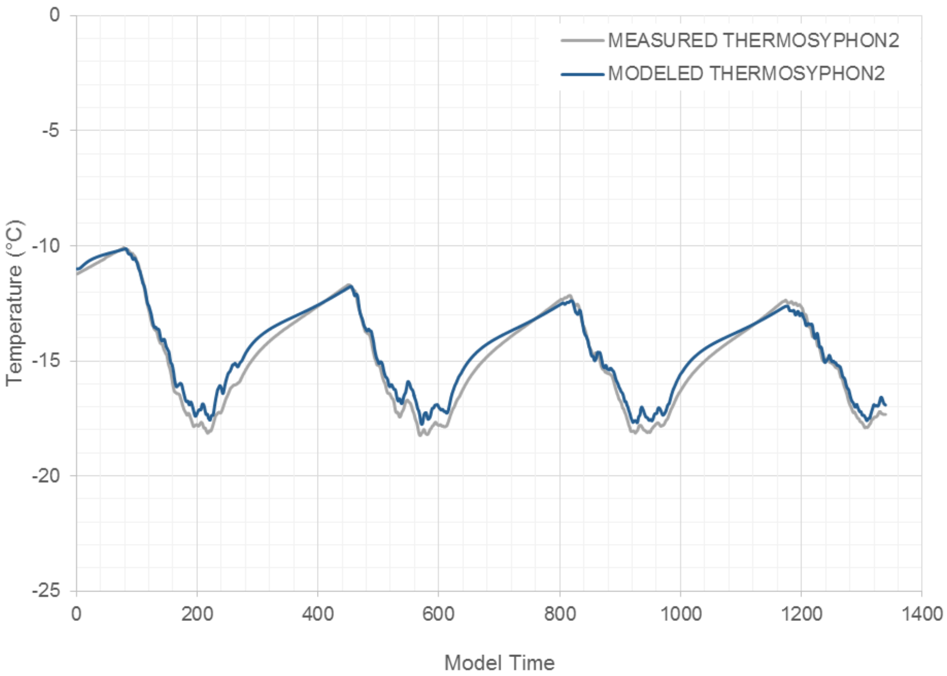


Notes:

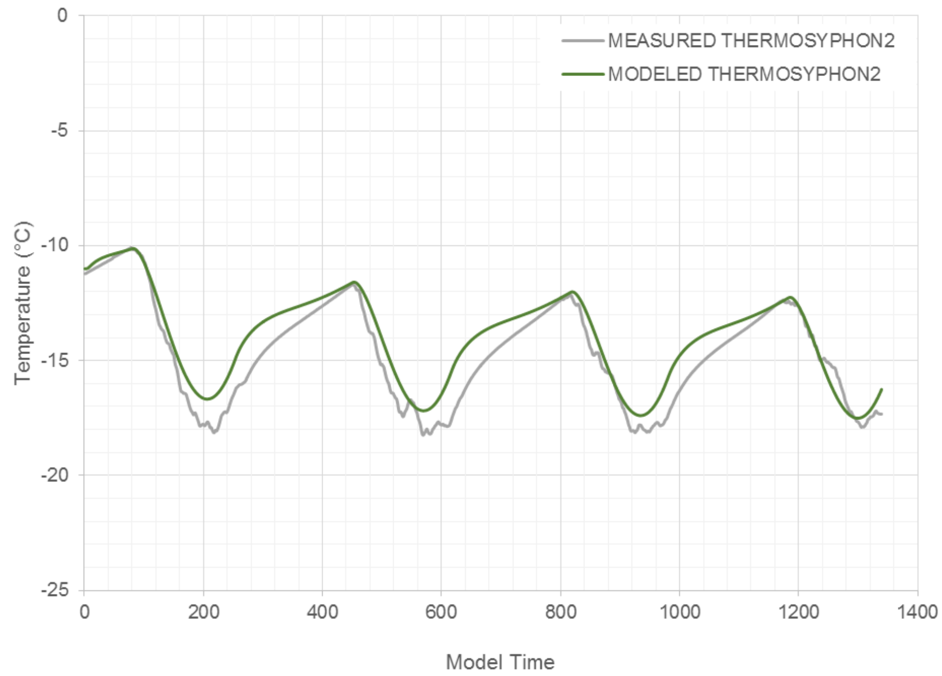
1. Ground temperature measurements from thermistor string ND-HTS-085-25.3
2. Thermistor node located near thermosyphon evaporator 1, Dam Section 0+85

srk consulting	TMAC RESOURCES	Doris North Dam Thermal Modeling
		Model Calibration – Thermosyphon Evaporator 1 (0+85)
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 | Approved: cws | Figure: **16**

Model 1: Measured Air Temperature and Wind Speed



Model 2: Climate Boundary with Average Wind Speed

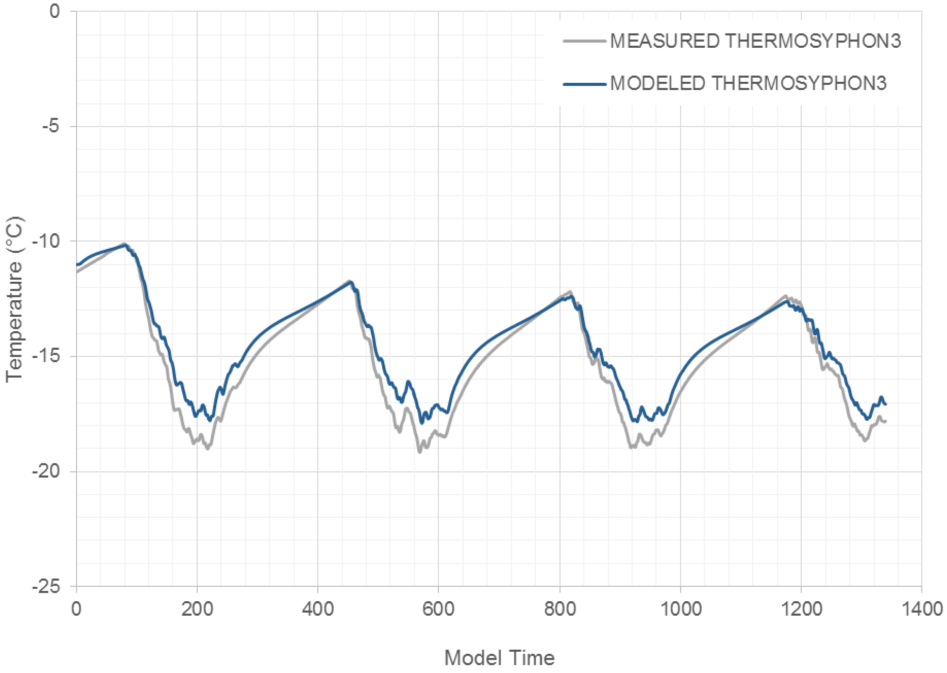


Notes:

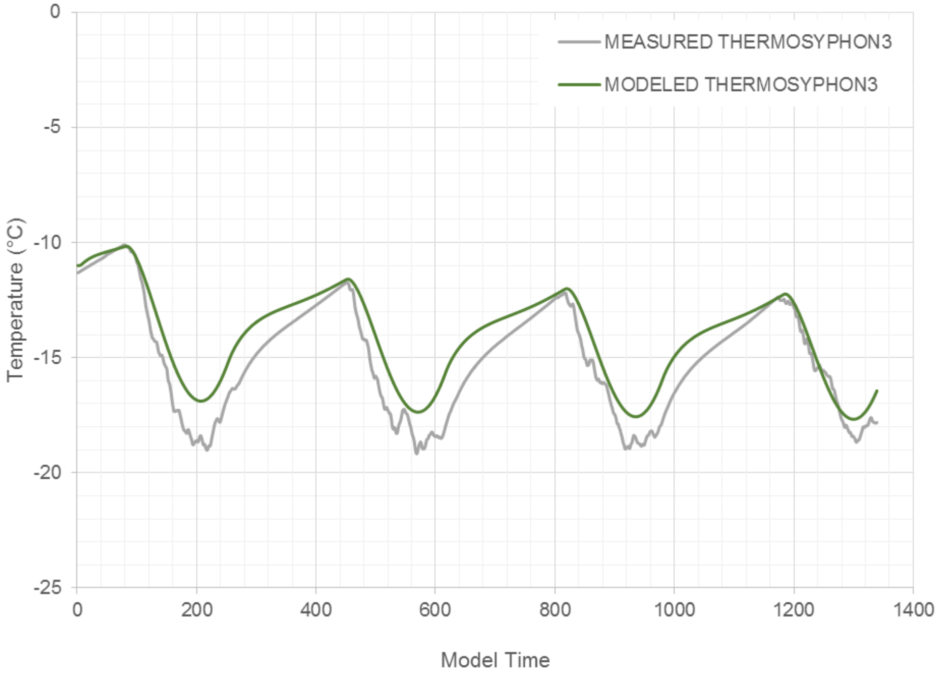
1. Ground temperature measurements from thermistor string ND-HTS-085-25.3
2. Thermistor node located near thermosyphon evaporator 2, Dam Section 0+85

srk consulting	TMAC RESOURCES	Doris North Dam Thermal Modeling
		Model Calibration – Thermosyphon Evaporator 2 (0+85)
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 / Approved: cws / Figure: **17**

Model 1: Measured Air Temperature and Wind Speed



Model 2: Climate Boundary with Average Wind Speed

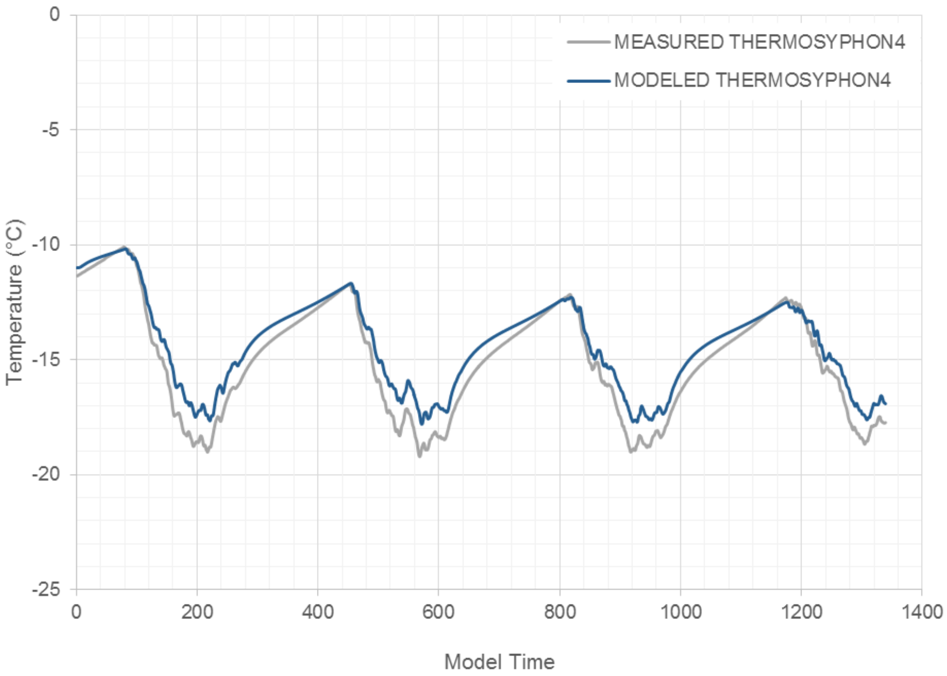


Notes:

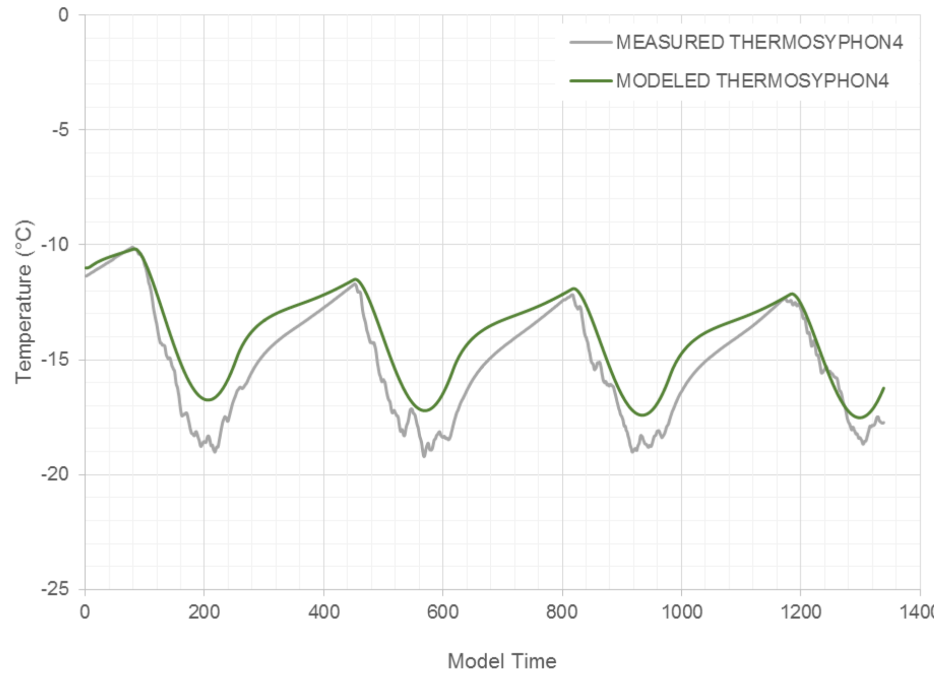
1. Ground temperature measurements from thermistor string ND-HTS-085-25.3
2. Thermistor node located near thermosyphon evaporator 3, Dam Section 0+85

srk consulting	TMAC RESOURCES	Doris North Dam Thermal Modeling
		Model Calibration – Thermosyphon Evaporator 3 (0+85)
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 · Approved: cws · Figure: **18**

Model 1: Measured Air Temperature and Wind Speed



Model 2: Climate Boundary with Average Wind Speed

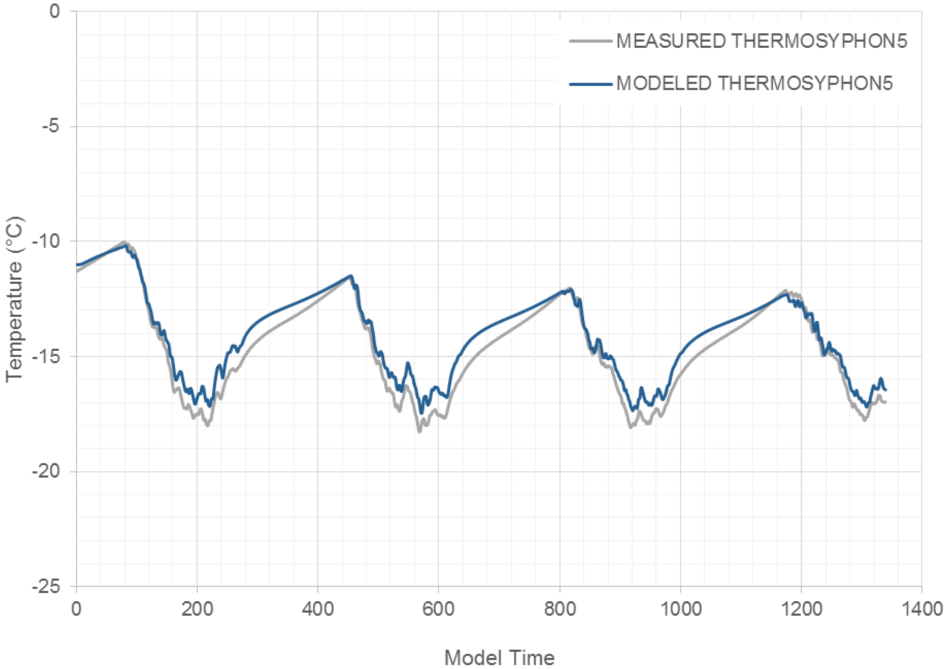


Notes:

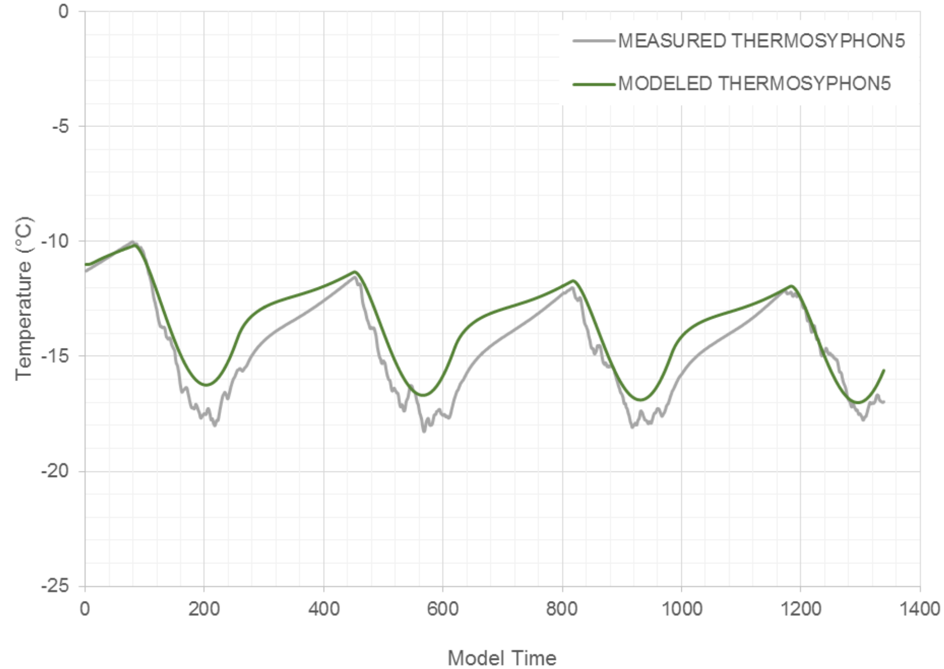
1. Ground temperature measurements from thermistor string ND-HTS-085-25.3
2. Thermistor node located near thermosyphon evaporator 4, Dam Section 0+85

srk consulting	MAC RESOURCES	Doris North Dam Thermal Modeling
		Model Calibration – Thermosyphon Evaporator 4 (0+85)
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 / Approved: cws / Figure: **19**

Model 1: Measured Air Temperature and Wind Speed



Model 2: Climate Boundary with Average Wind Speed

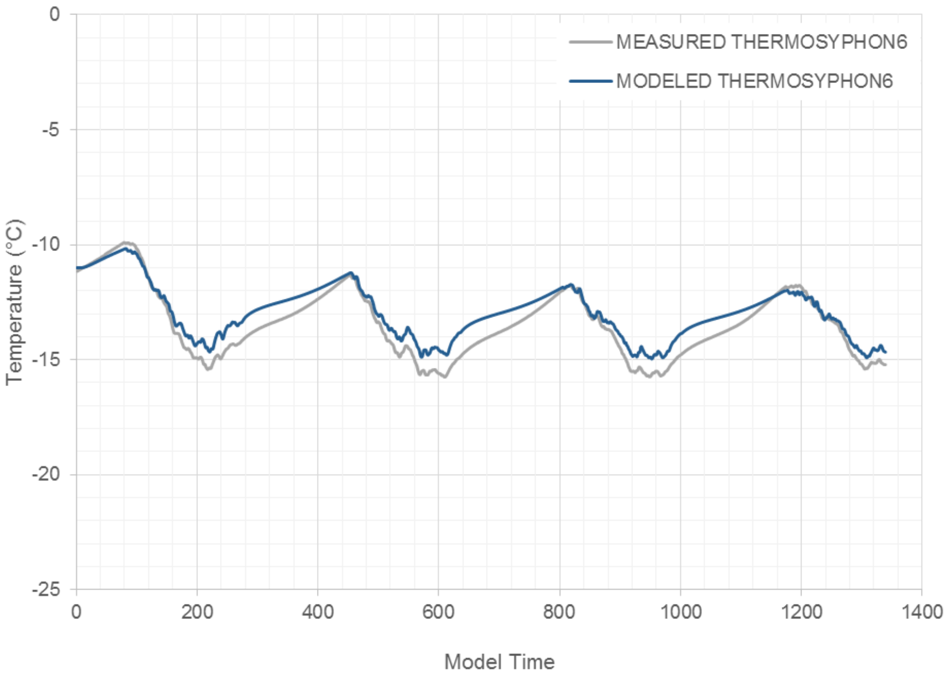


Notes:

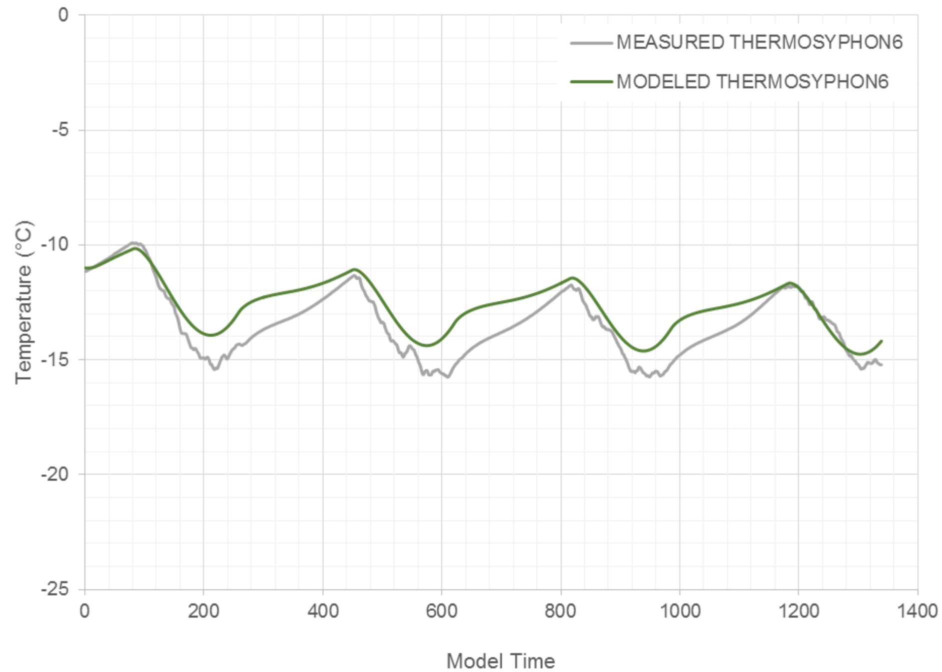
1. Ground temperature measurements from thermistor string ND-HTS-085-25.3
2. Thermistor node located near thermosyphon evaporator 5, Dam Section 0+85

srk consulting	TMAC RESOURCES	Doris North Dam Thermal Modeling
		Model Calibration – Thermosyphon Evaporator 5 (0+85)
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 | Approved: cws | Figure: **20**

Model 1: Measured Air Temperature and Wind Speed



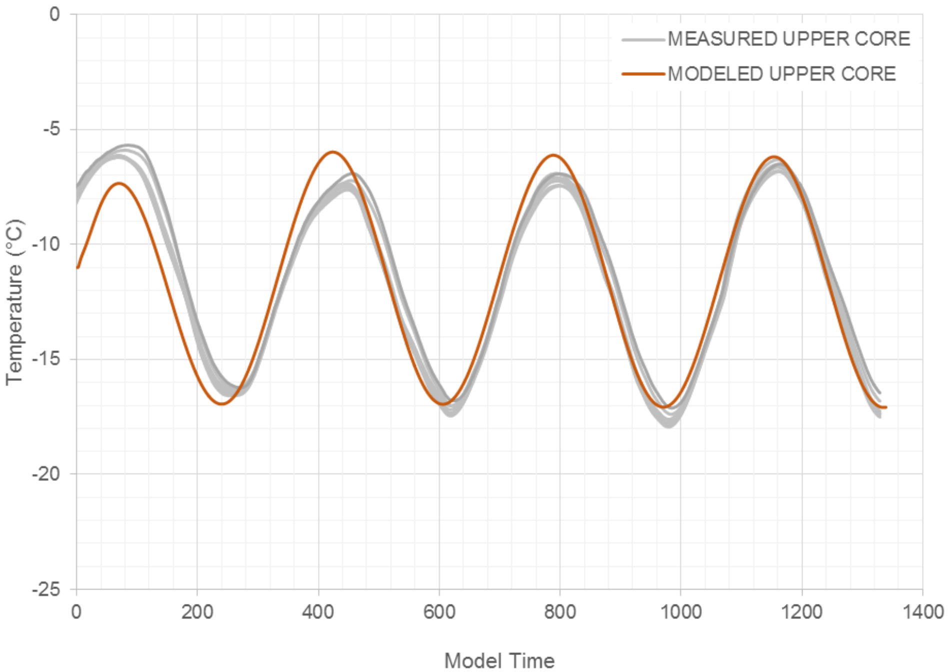
Model 2: Climate Boundary with Average Wind Speed



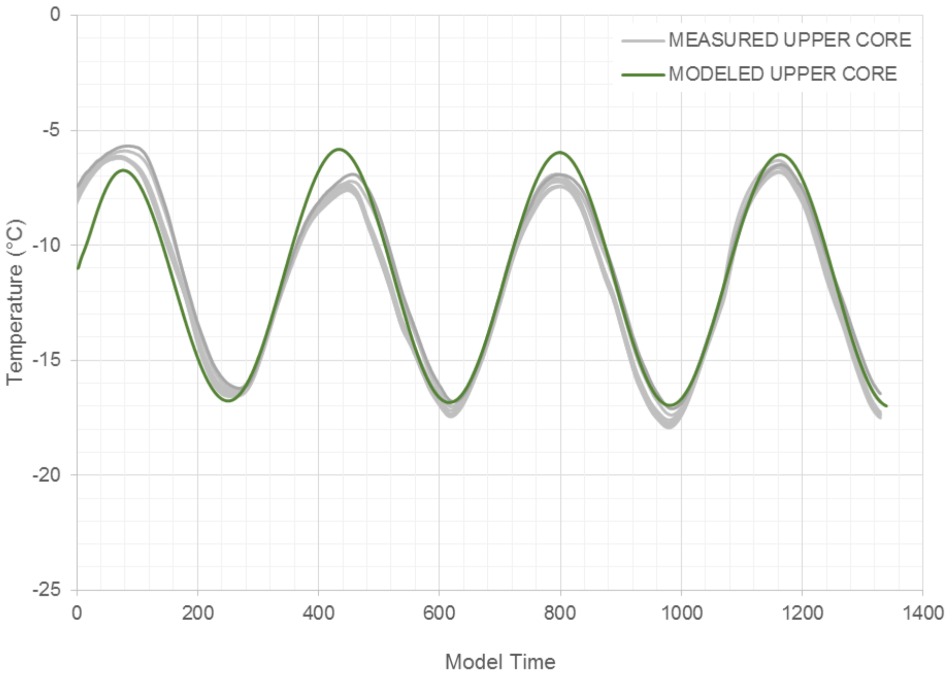
Notes:
1. Ground temperature measurements from thermistor string ND-HTS-085-25.3
2. Thermistor node located near thermosyphon evaporator 6, Dam Section 0+85

srk consulting	TMAC RESOURCES	Doris North Dam Thermal Modeling
		Model Calibration – Thermosyphon Evaporator 6 (0+85)
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 | Approved: cws | Figure: **21**

Model 1: Measured Air Temperature and Wind Speed



Model 2: Climate Boundary with Average Wind Speed

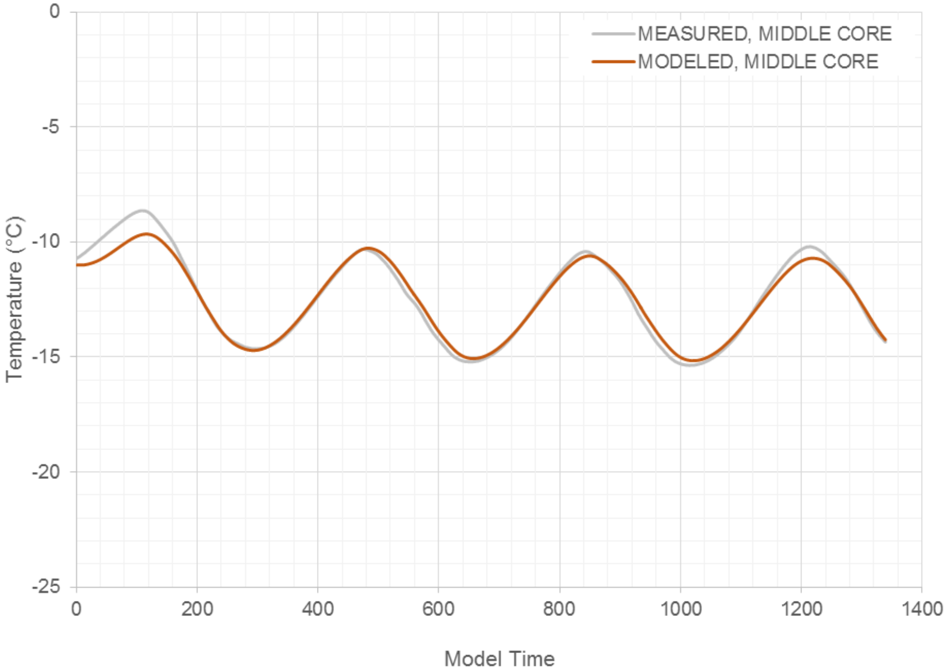


Notes:

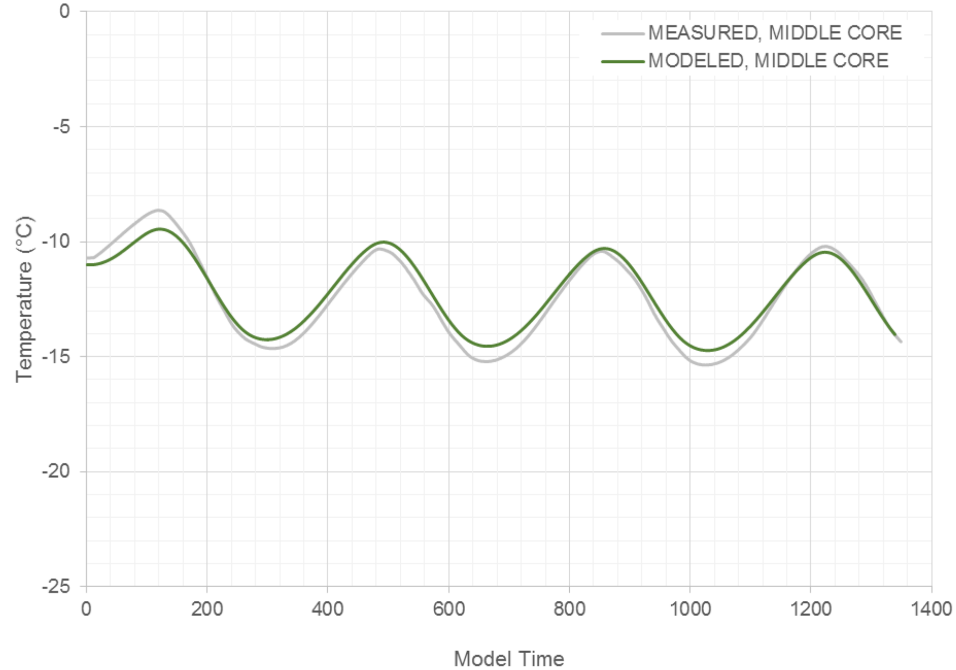
1. Ground temperature measurements from thermistor string ND-HTS-085-33.5
2. Thermistor cable is located near the top of the frozen core, Dam Section 0+85

srk consulting	TMAC RESOURCES	Doris North Dam Thermal Modeling
		Model Calibration – Upper Core (0+85)
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 | Approved: cws | Figure: **22**

Model 1: Measured Air Temperature and Wind Speed



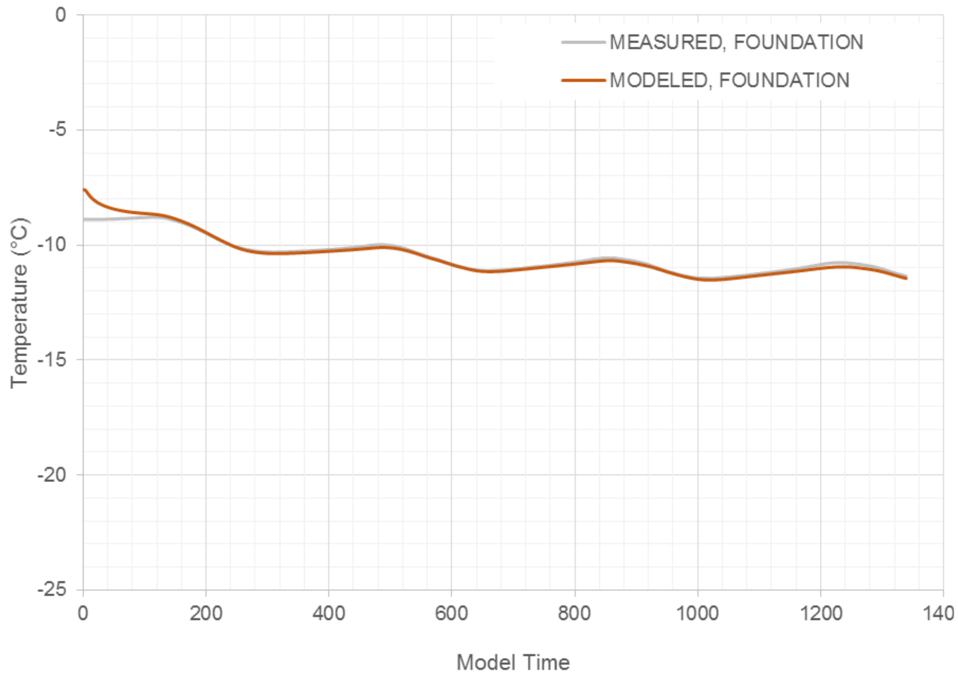
Model 2: Climate Boundary with Average Wind Speed



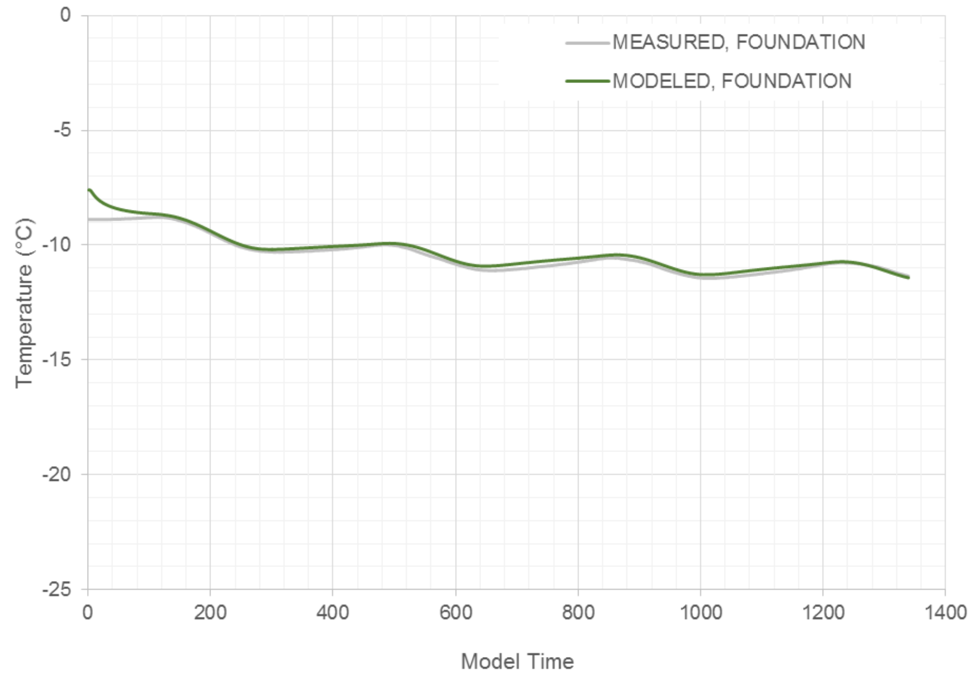
Notes:
1. Ground temperature measurements from thermistor string ND-HTS-085-29.4
2. Thermistor cable is located near the middle of the frozen core, Dam Section 0+85

srk consulting	MAC RESOURCES	Doris North Dam Thermal Modeling
		Model Calibration – Middle Core (0+85)
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 · Approved: cws · Figure: **23**

Model 1: Measured Air Temperature and Wind Speed



Model 2: Climate Boundary with Average Wind Speed

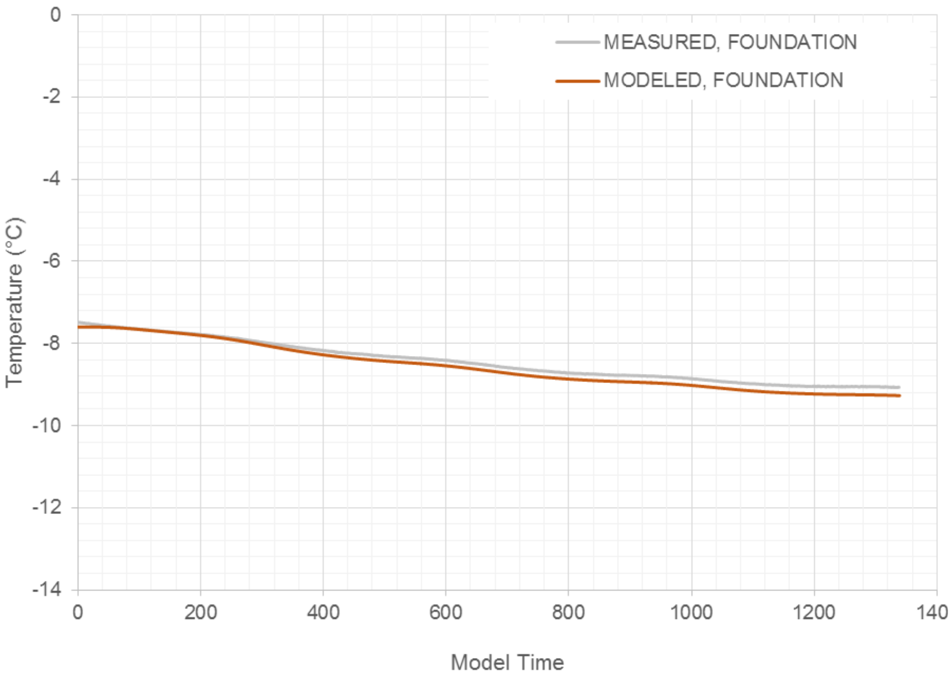


Notes:

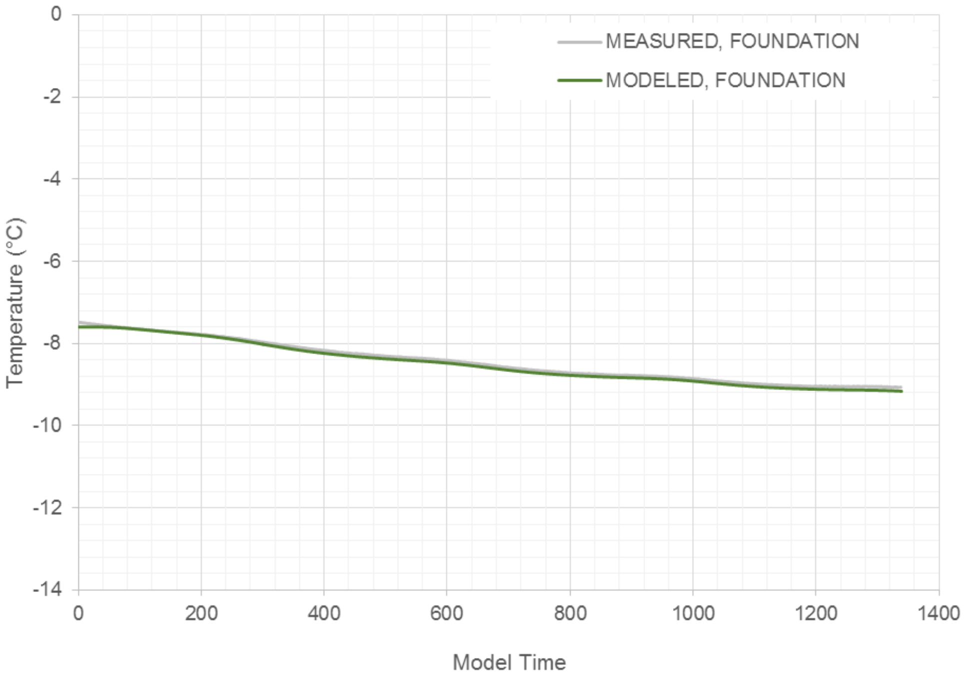
1. Ground temperature measurements from thermistor string ND-VTS-085-KT
2. Thermistor node located 2 m below base of key trench, Dam Section 0+85
3. Depth referenced to uppermost thermistor node at base of key trench

srk consulting	MAC RESOURCES	Doris North Dam Thermal Modeling
		Model Calibration – Foundation 2 m Below Key Trench (0+85)
Job No: 1CT022.004 Filename: NorthDam.pptx	HOPE BAY PROJECT	Date: 5/2/2016 · Approved: cws · Figure: **24**

Model 1: Measured Air Temperature and Wind Speed



Model 2: Climate Boundary with Average Wind Speed



Notes:

1. Ground temperature measurements from thermistor string ND-VTS-085-KT
2. Thermistor node located 9 m below base of key trench, Dam Section 0+85
3. Depth referenced to uppermost thermistor node at base of key trench

srk consulting

MAC RESOURCES

Doris North Dam Thermal Modeling

Model Calibration – Foundation 9 m Below Key Trench (0+85)

Job No: 1CT022.004

Filename: NorthDam.pptx

HOPE BAY PROJECT

Date: 5/2/2016

Approved: cws

Figure: 25