Technical Memo

To:	Karyn Lewis, Project Manager Lupin Project	From:	Alvin Tong, P.Eng.
	Mandalay Resources Corporation Suite 330, 76 Richmond Street Toronto, ON M5C 1P1		Stantec Consulting Ltd, 200-325 25 Street, Calgary, AB T2A 7H8
File:	Lupin Gold Project – 129500081	Date:	October 15, 2019

Reference: 2AM-LUP1520 Technical Meeting Commitment Number 11 Response – Geophysical Survey Lupin Mine Tailings Containment Area Dams

INTRODUCTION

Lupin Mine Incorporated (LMI), a wholly owned subsidiary of Mandalay Resources Corporation is requesting the renewal and amendment of their existing Type "A" Water Licence No: 2AM-LUP1520, to allow for Final Closure and Reclamation of the Lupin Mine Project (Lupin). The Nunavut Water Board (NWB or Board) Water Licence Application No. 2AM-LUP1520 Technical Meeting was held June 6-7, 2019 in Kugluktuk, Nunavut. Appendix D of the June 18, 2018 Pre-Hearing Conference Decision Report outlines the agreed upon List of Commitments (Commitments). Stantec Consulting Ltd. (Stantec) was retained by LMI to support the responses to select commitments and this technical memo provides the responses to fulfill Commitment No. 11, shown below, which relates to conducting a geophysical survey along two selected Lupin Mine Tailings Containment Area (TCA) dams.

11	LMI	ECCC	One-time geophysical survey conducted along two selected dams to confirm the condition of frozen cores.	15-Oct-19	Technical Memo

Two dams were selected by Stantec for the geophysical surveys; Dam 3D representing and internal TCA dam and Dam 4 representing an external TCA dam (Figure 1). Dam 3D and Dam 4 were specifically selected since they both have thermistors installed for calibration. Aurora Geosciences Ltd. completed the surveys and the methods, results and interpretation are include in the attached memorandum titled "Lupin Tailings Dams Geophysics Survey 2019".

Reference: 2AM-LUP1520 Technical Meeting Commitment Number 10 Response

Attachment:
Aurora Geosciences Ltd. 2019. Lupin Tailings Dams Geophysics Survey 2019. Prepared for Stantec.

Stantec Consulting Ltd

Alvin Tong P.Eng.
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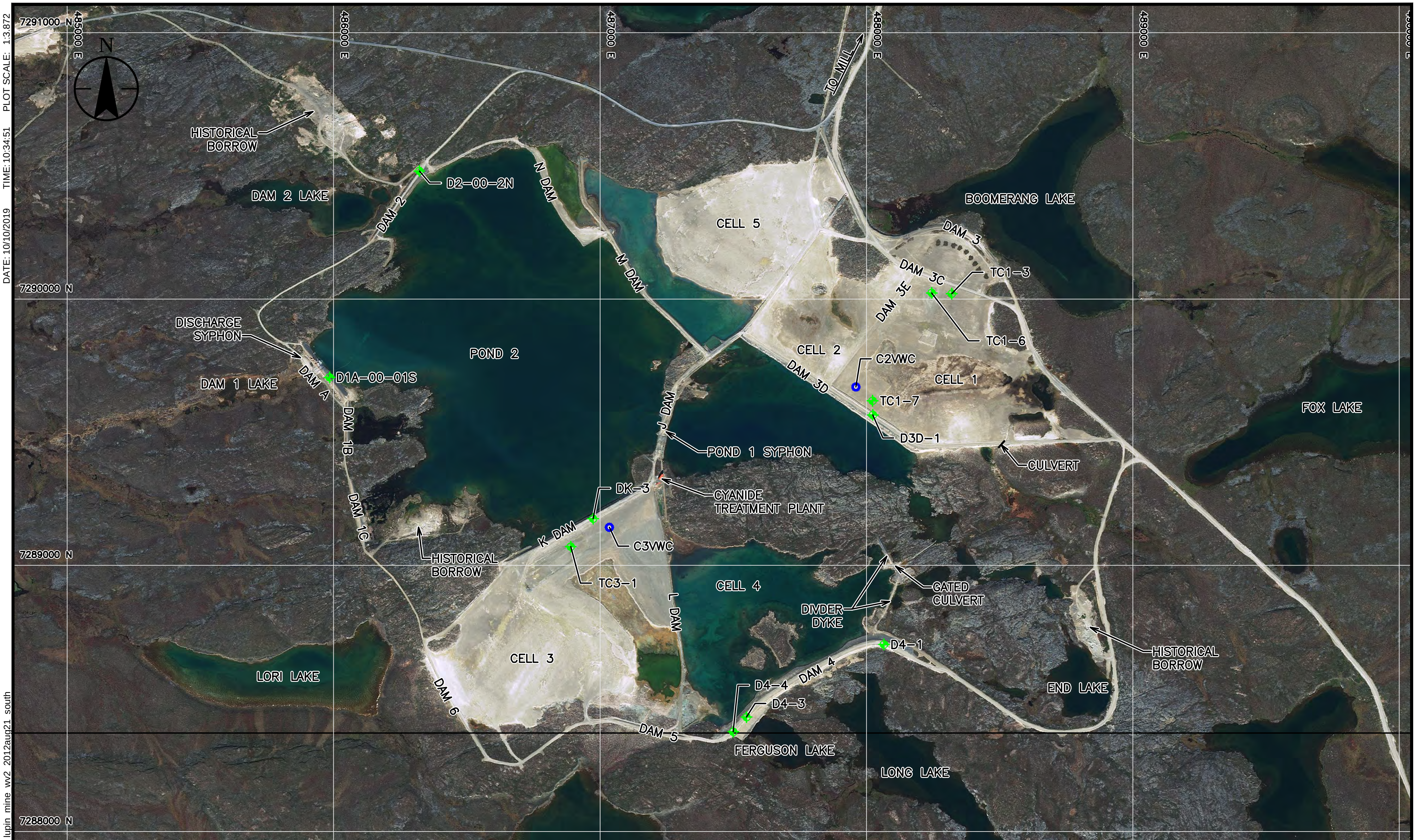


LEGEND

- ACTIVELY MONITORED THERMISTOR
- VOLUMETRIC WATER CONTENT SENSOR STRINGS

500m 0 500 1000m

SCALE 1:20,000

SCALES INDICATED BASED ON AN 8.5"x11" PLOT CONFIGURATION

LUPIN MINES INC.

2019 GEOPHYSICAL SURVEY

TAILINGS CONTAINMENT AREA

SCALE:	AS SHOWN
DATE:	2019-10-10
CO-ORD. SYS.:	UTM83-12
DRW'N BY:	KM
DSG'N BY:	--
REV'D BY:	AT
APP'D BY:	SE

Stantec

PROJECT NO.:	FIG. NO.:	REV.:
129500083	1	A

FILENAME: \\CA0200-PPFSS01\WORKGROUP\1295\ACTIVE\129500082\DISC\DRAFTING\04_TAILINGS CONTAINMENT AREA\01.TAILINGS CONTAINMENT AREA - GEOPHYSICAL SURVEY.DWG DATE: 10/10/2019 TIME: 10:34:51 PLOT SCALE: 1:3.872
XREF FILE(S):
IMAGE FILE(S): lupin_mine_wv2_2012aug21_north lupin_mine_wv2_2012aug21_south

AURORA GEOSCIENCES

NORTHERN GEOLOGICAL & GEOPHYSICAL CONSULTANTS
YELLOWKNIFE - WHITEHORSE - JUNEAU
3506 McDonald Drive, Yellowknife NT. 867.920.2729

Memorandum

To: Stantec. Inc.
Alvin Tong, P.Eng.; Sara Wilkins, P.Geol.

Date: October 15, 2019

From: Aurora Geosciences Ltd.
Troy Unrau, P.Geo

Re: Lupin Tailings Dams Geophysics Survey 2019

This memorandum report describes Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) surveys conducted at Lupin Mine for Stantec (the Client) by Aurora Geosciences Ltd. (Aurora). Lupin Mine is a remote site located in the Kitikmeot region in Nunavut, Canada. The geophysical surveys described in this report were completed on tailings dams 3D and 4. The purpose of these surveys were identify thawed ice core sections along the dam where there is a potential for the tailings to seep through the dyke.

The survey was completed between August 22nd -25th, 2019 by a crew of three operators (Darrell Epp, William Onah, Hayden Playter). Operations were based out of Lupin main camp.

Two methods were used: GPR and ERT. These were completed using: a Sensors and Software Noggin 100MHz GPR and an ABEM TerrameterLS.

Method Backgrounds

Ground Penetrating Radar (GPR)

GPR is a geophysical technique that uses electromagnetic radiation to profile subsurface layers. During operation, a pulse of electromagnetic radiation in the form of radio waves centered over a particular frequency is emitted from the instrument and a portion of the energy is reflected back to the surface by interfaces between materials with contrasting dielectric properties. Timing the arrivals of the reflected energy allows a pseudo depth section (radargram) to be constructed from data collected along a profile. The velocity at which the radar wave travels through the ground is used to determine the depths to the reflectors.

Large contrasts between dielectric properties of bedrock, water, ice and sediments can produce strong radar reflectors which make GPR a useful technique for mapping subsurface stratigraphy. See Table 1 for a list of dielectric electric properties observed in common geological materials. If two materials have similar dielectric properties, a weak reflection may be produced; if they have identical properties, no reflection will be produced.

Depth of investigation of the survey is generally dependent on a combination of the conductivity of the medium, the power of the instrument, and the frequency of the signal (Reynolds, 2017). Generally, higher conductivity corresponds to higher attenuation factors and higher frequency corresponds to a higher rate of attenuation; therefore higher conductivity and frequency result in reduced depth of investigation.

Table 1 : Typical dielectric constant, electrical conductivity & resistivity, velocity and attenuation observed in common geologic materials (Annan, 2003)

MATERIAL	*Dielectric Constant (k)*	*Electrical Conductivity (mS/m)*	*Electrical Resistivity (Ohm-m)*	*Velocity (m/ns)*	*Attenuation (dB/m)*
Air	1	0	∞	0.30	0
Fresh Water	80	0.5	2000	0.033	2x10-3
Dry Sand	3 – 5	0.01	100,000	0.15	0.01
Saturated Sand	20 – 30	0.1 – 1.0	1,000 – 10,000	0.06	0.03 – 0.3
Clays	5 – 40	2 – 1000	1 – 500	0.06	1 – 300
Silts	5 – 30	1 – 100	100 – 1,000	0.07	1 – 100
Pure Ice	3 – 4	0.01	100,000	0.16	0.01
Granite	4 – 6	0.01 – 1	1 – 100,000	0.13	0.1 – 1

Electrical Resistivity Tomography (ERT)

The ERT method uses an array of up to 61 simultaneously connected electrodes to measure the electrical resistivity of the ground. Current is injected at two electrodes to cause electricity to flow in the ground. At some distance away, electrical potential (voltage) is measured to determine where the current is flowing in the ground. By alternating which electrodes are used to inject the current, and which electrodes are used to monitor the electrical potential, variations of the electrical properties of the ground can be mapped.

The depth and resolution depends on a number of factors, including: the array configuration used (which electrodes inject current, and which ones measure current), the electrode spacing, the electrical conductivity of the ground (conductive ground prevents measurement at depth), and the amount of current able to be injected into the ground. Using a 5 m electrode spacing produces a vertical model resolution of approximately 1.25 m and a horizontal model resolution of 2.5 m near the surface. This model resolution decreases with depth.

Additionally, the model is sensitive to conductors that are adjacent to the survey line as well as those below the survey line. This is due to the volume of averaging getting larger as electrodes get further apart. A deep anomaly in the model can be the result of a shallow anomaly adjacent to the survey line. Thus depth for ERT surveys should rather be interpreted as ‘distance from the survey line’.

Survey Location

The Lupin Mine is a remote site located north of Lac de Gras in Nunavut, Canada approximately 400 km northeast of Yellowknife and occupies 1:250,000 NTS map sheet 076E. Lupin is accessible year round by air and seasonally by the Tibbit to Contwoyto ice road that typically operates from February to the end of March.

The geophysical surveys described in this report were completed over the tailings dyke of dams 3D and 4 as labelled by the Client.

All coordinates described in this memo refer to UTM zone 12N, WGS84.

Field Operations

The GPR survey was conducted along the same profile as the ERT survey, pin flags are used a reference on both dams.

Figure 1. Operator performing the Ground Penetration Radar (GPR) cross profile on dam 4.

Figure 2. Electrical Resistivity Tomography setup on dam 3D.

Prior to setting up the ERT system, GPS coordinates were obtained from sections along the dam so as to plan the survey profile according to specifications given by the client. In Dam 4, the profile was conducted along the center line of the dam while at Dam 3D, it was offset upstream along the dyke (Figure 2). Where electrical contact problems occurred due to a relatively resistive ground, fresh water mixed with salt (sodium or calcium chloride) was added to the electrode location. Failing this, the electrode would be disabled from the array and located at a suitable location. This survey was conducted using both dipole-dipole and gradient-plus configurations.

Furthermore, a short profile (2.5 m electrode spacing) was conducted perpendicular to the initial profile on Dam 4 over a conductive section (pseudo depth of around 10 m) in an attempt to verify whether the deep conductivity results were coming from below the dam or adjacent to it. Similarly, a high resolution survey was conducted on Dam 3D over an anomalous region using an electrode spacing 2.5 m.

GPR Processing

GPR data requires a number of processes to be applied before it can be interpreted. These processes are described herein:

Velocity calibration: GPR data is recorded as a series of reflected radio waves. The time it takes for these reflections to arrive is noted in the raw GPR data. However, in order to convert these times into depth below the ground surface, an estimate for the radar velocity below the surface must be obtained. The simplest way to obtain this estimate is to look for hyperbolic reflectors. The best hyperbolic reflectors are single points that pass directly below the radar instrument. By fitting a theoretical hyperbola to these observed hyperbola, an estimate can be produced. Several hyperbola were fit at various spots in the data arriving at an estimate of 0.115 metres per nanosecond, plus or minus 0.005. An example of this curve fitting process is shown in Figure 3, where the GPR section crossed buried thermistor D4-4 on Dam 4.

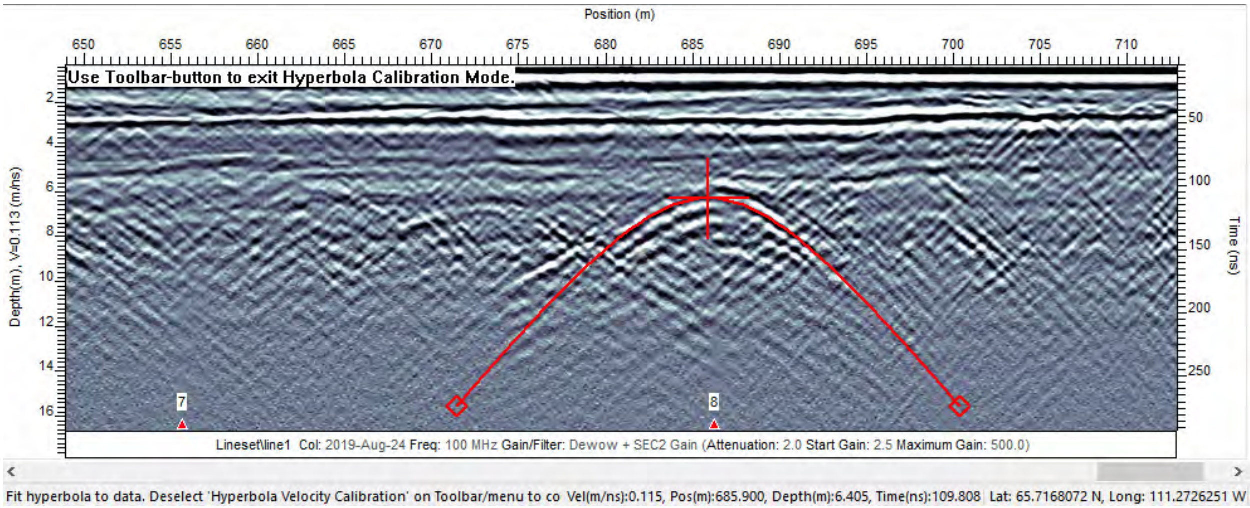
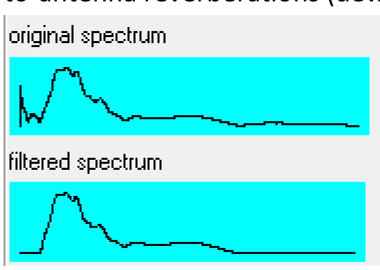


Figure 3: Hyperbola velocity calibration at thermistor D4-4 on Dam 4.

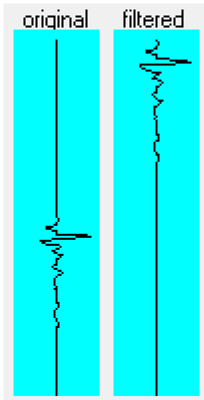
The GPR data are processed using the commercially available ReflexW software package developed by Sandmeier Scientific Software. Geosoft software are used to present the results. The following general procedures are utilized in the order that they are described:

1. Butterworth Bandpass filter, from 40 to 400 MHz. This serves to remove low frequency antenna-to-antenna reverberations (dewow), and high frequency noise unrelated to the GPR survey signals.

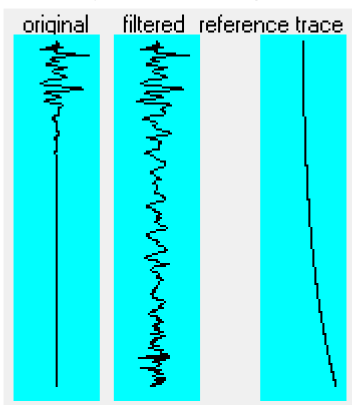


2. Background removal: Signals which persist on every trace, such as the direct airwave arrival, can be suppressed. The average of all traces is on a line subtracted from each trace on that line.

3. Set time-zero: Zero is set to be the first arrival of energy. The value used as an offset is inspected visually. Traces are moved upwards as required.



4. Time cut: The time window is trimmed to 300 ns as no coherent signal is visible beyond this point.
5. Gain function: The amplitude of reflected signals gets lower as depth increases. In order to make deep reflector easier to visually inspect and interpret, the gain is increased with depth. A gain function is applied, which increases the amplitudes of reflectors at depth exponentially. Note that this amplifies both signal and noise.



6. Horizontal Smoothing: To reduce the amount of speckle, a horizontal smoothing filter (running average) is applied across the profile. This replaces each trace with the average of the 10 nearest traces. This tends to improve clarity on horizontal features at the expense of vertical features. Noses of hyperbola are preserved while their limbs diminish. This also improves the signal to noise ratio by a factor of square root of 10.
7. The resulting data is exported as a SEGY file and imported into Geosoft Oasis Montaj for plotting as a cross section. Times are converted to depths using 0.115 m/ns, an estimate for subsurface velocity measured from hyperbola. A 10X vertical exaggeration is applied here, and a colour scheme to make the reflectors as prominent as possible is used.

ERT Processing

ERT data was archived on a nightly basis. This archived data include: raw .DAT files from the instrument, and GPS waypoints of the start, cable junctions, thermistors near the line, and end point of the profile.

Nightly data processing included: inspecting the raw ERT data for quality and a field inversion of the data to produce field preliminary results. The resulting model was used to inform the next day's survey.

The final ERT data is processed using the commercially available RES2D software package developed by Geotomo Software, an industry standard for inversion of ERT data. Geosoft Oasis Montaj is used to present the results. The following general procedures are utilized in the order that they are described:

1. Manually merge the data from the different arrays (dipole-dipole and gradient+) converting to the generalized array format; remove negative values; and incorporate GPS positions to produce a single DAT file for each line surveyed.
2. Import the resulting DAT file into RES2D and inversion modelling using default parameters.
3. Export the inversion results to XYZ.
4. Import the relevant section of the XYZ into Geosoft Oasis Montaj.
5. Create a 3D voxel from the inversion results using inverse distance gridding.
6. Sample the 3D voxel along the locations of the existing GPR profiles, already loaded into Geosoft.

Interpretation & Results

Nine section figures were generated in Geosoft Oasis Montaj. They are:

1. Section 1: Dam 3D Interpreted Electrical Resistivity and GPR Reflectors
2. Section 2: Dam 4 Interpreted Electrical Resistivity and GPR Reflectors
3. Section 3: Dam 4 Cross Line Interpreted Electrical Resistivity and GPR Reflectors
4. Section 4: Dam 3D GPR Reflectors
5. Section 5: Dam 4 GPR Reflectors
6. Section 6: Dam 4 Cross Line GPR Reflectors
7. Section 7: Dam 3D Electrical Resistivity
8. Section 8: Dam 4 Electrical Resistivity
9. Section 9: Dam 4 Cross Line Electrical Resistivity

Sections 4 through 9 are provided for clarity, should the busy colour schemes in Sections 1 through 3 cause problems. All sections provide UTM coordinates along the top of the profile, and depths below ground surface along the vertical axis. A vertical exaggeration factor of ten has been applied to all figures – which makes dipping features appear steeper than they are in reality.

The GPR data shows several distinct continuous reflectors which extend the entire length of the section. These reflectors have been interpreted, from top to bottom as: transition from dry to water saturated material; transition from wet to frozen material; top of bedrock. The top of bedrock reflector is quite weak in places and its interpretation is less confident than the other two layers. The strongest reflector is the interpreted wet to frozen interface – the top of the ice core in the Dam as present on the date of the survey.

Dam 3D

All three GPR reflectors are continuous, indicating no break or absence in the ice core of the dam.

The ERT data indicates a slightly conductive surface layer (yellows), beneath which lies more resistive material (blues, greens, whites) which is consistent with the ice core of the dam and underlying bedrock. Beyond 10 m depth, the model becomes conductive again, which is interpreted as conductive features adjacent to the dam.

A single anomalous area is interpreted in the data, both in the GPR data and the ERT data. This area stretches 120 m in length and is characterized by: the interpreted top of the ice core being deeper, several strong GPR reflectors which produced strong hyperbola (circled on Section 1), and conductivity anomalies associated with those strong GPR reflectors (reddish colour within circles on Section 1). While this area is considered anomalous, it does not indicate a failure of the ice core. Rather, it is likely that the top of the ice core is depressed at this location. It is possible that the circled spots indicate wet spots that have higher total dissolved salts, fractures, or buried metal objects (i.e.: old culverts, drill casing, rebar reinforced concrete, instrumentation, etc.).

Dam 4

The top two GPR reflectors are continuous across the section, indicating no break or absence in the ice core of the dam. The bedrock reflector is discontinuous, owing to its depth – particularly on the western side of the dam.

The ERT is quite consistent across this section, showing a slightly conductive near surface region, and a more resistive region below that. The conductivity showing on this section below 10 m is interpreted to be related to the adjacent tailings pond. This interpretation is supported by the conductor disappearing at either end of the section, where the line extends past the pond.

Additionally, a short cross line was installed at dam 4 to support the interpretation that the conductivity feature at depths beyond 10 m was indeed being caused by the adjacent tailings pond. The cross line indicates that there is no conductive feature directly beneath the dam.

No anomalies on Dam 4 were identified in this data.

Final Products

The following products were delivered alongside this report, for archival purposes.

- Nine section figures in PDF format. Sections 1, 2, 4, 5, 7, and 8 will require a poster plotter to print at the correct scale. Sections 3, 6, and 9 will print on standard paper sizes.
- A zip file containing an ESRI ShapeFile and AutoCAD DXF outlining the anomalous region on Dam 3D, for use by Stantec when plotting their own maps.
- The raw data used to produce these sections. The Raw Data is quite large in size (several megabytes) and is difficult to email. It has been delivered independently from this report.

Future Work

As the chosen geophysical techniques were able to adequately detect the presence of the ice core within the dams, and independently identify regions of interest, we conclude that these methods can be used at this location in the future.

References

Annan, A.P., 2003, Ground Penetrating Radar Principles, Procedures & Applications.

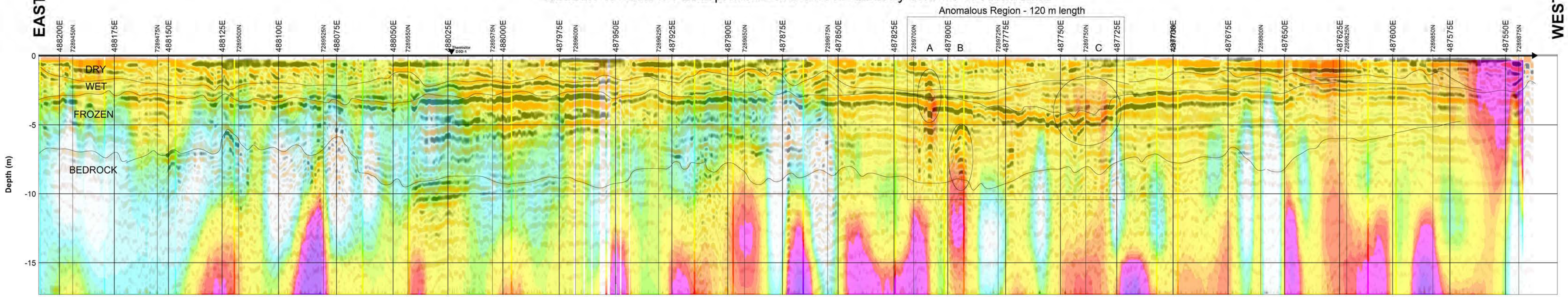
Reynolds, J.M., 1997, An Introduction to Applied and Environmental Geophysics.

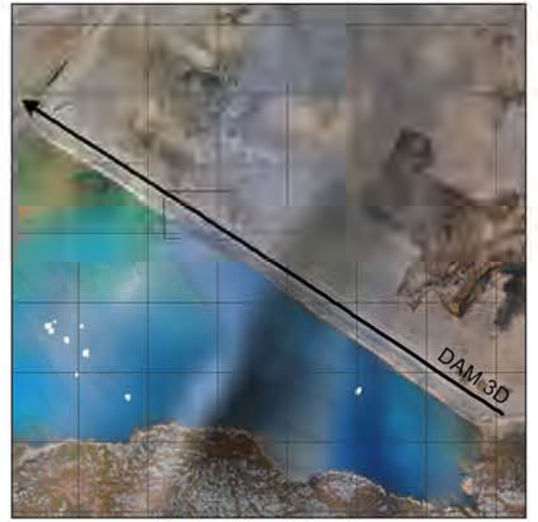
Respectfully Submitted,

Troy Unrau, P.Geo. (NAPEG #1963)

Aurora Geosciences Ltd.

Section 1: Dam 3D Interpreted Electrical Resistivity and GPR Reflectors





Section Trace Plan View

240.5 604.0 1517.2 4581.7 13836.6

Resistivity
Ω·m

Scale 1:2000

25 0 25 50
(metres)

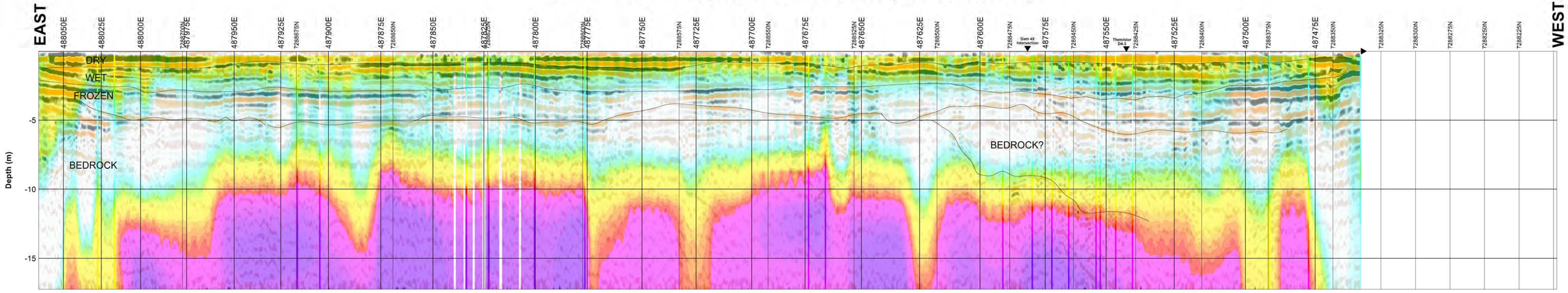
Vertical Exaggeration: 10

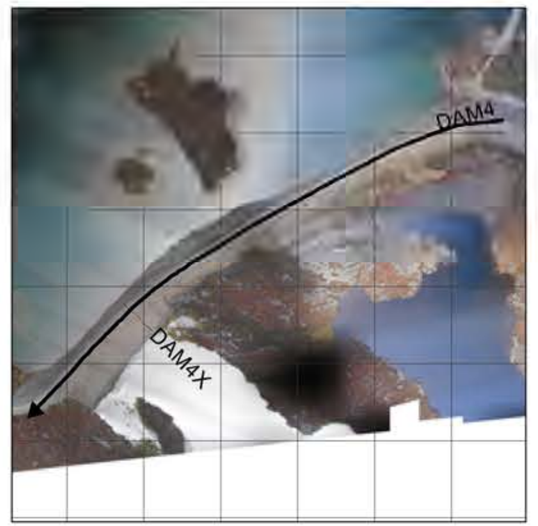
Lupin Tailings Dams Geophysics Survey 2019

Aurora Geosciences Ltd.

Drawn by TU on 2019-09-25
STN-19074-NT

Section 2: Dam 4 Interpreted Electrical Resistivity and GPR Reflectors





Section Trace Plan View

240.5 604.0 1517.2 4581.7 13836.6

Resistivity
Ω·m

Scale 1:2000

25 0 25 50
(metres)

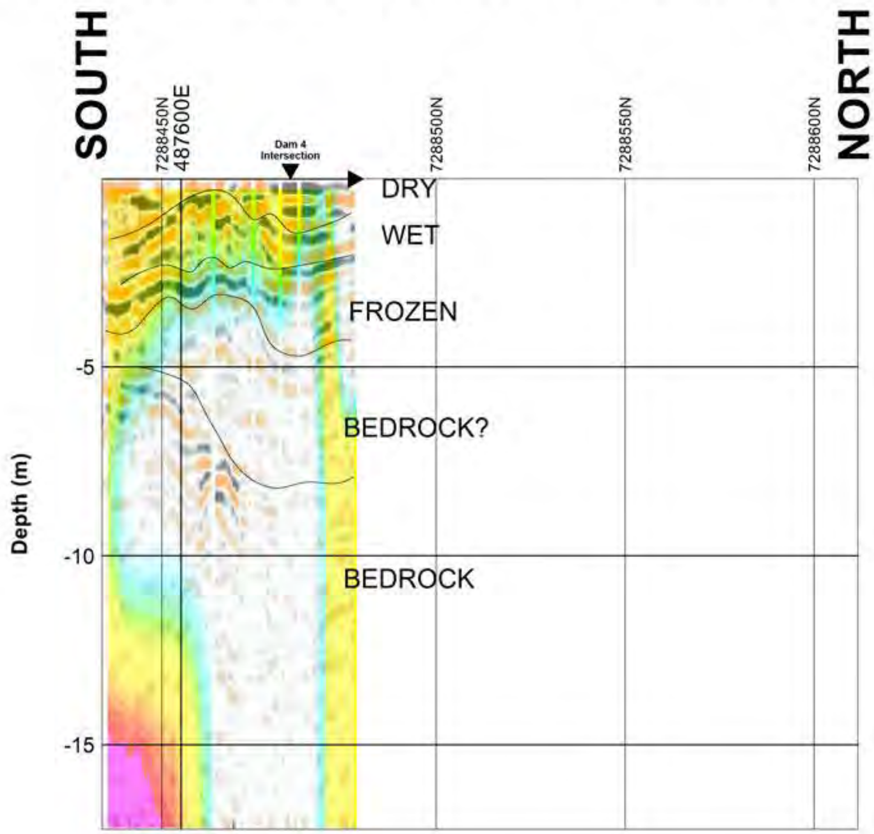
Vertical Exaggeration: 10

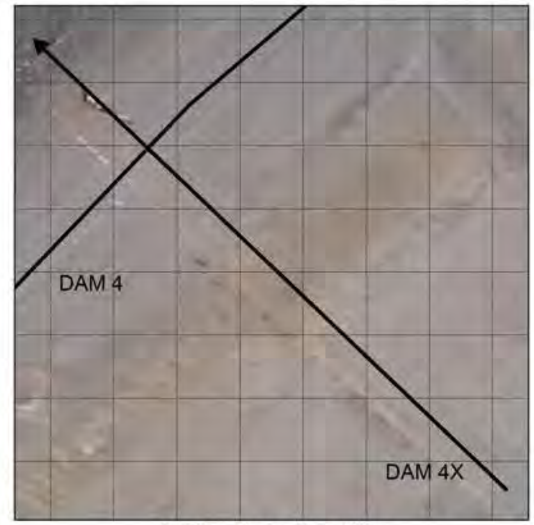
Lupin Tailings Dams
Geophysics Survey 2019

Aurora Geosciences Ltd.

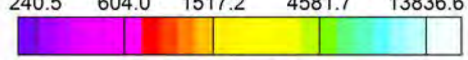
Drawn by TU on 2019-09-25
STN-19074-NT

Section 3: Dam 4 Cross Line
Interpreted Electrical Resistivity and GPR Reflectors





Section Trace Plan View



Resistivity
Ω·m

Scale 1:2000

25 0 25 50
(metres)

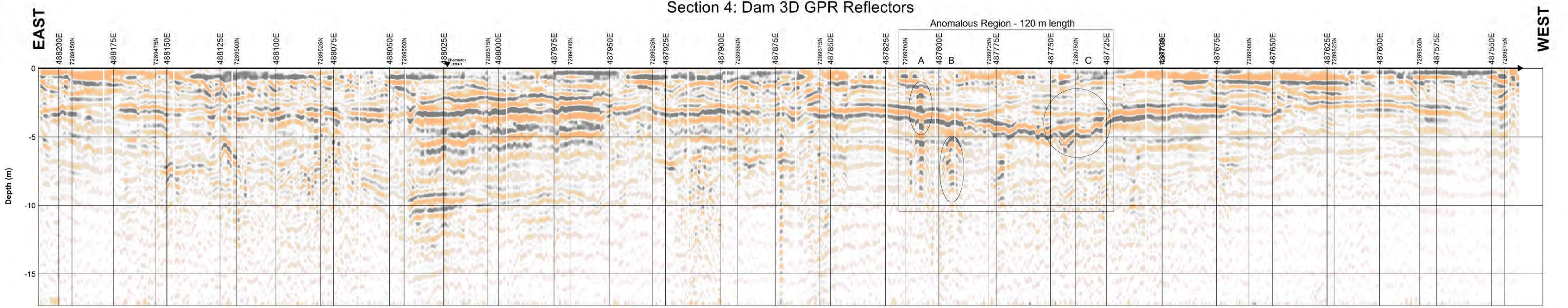
Vertical Exaggeration: 10

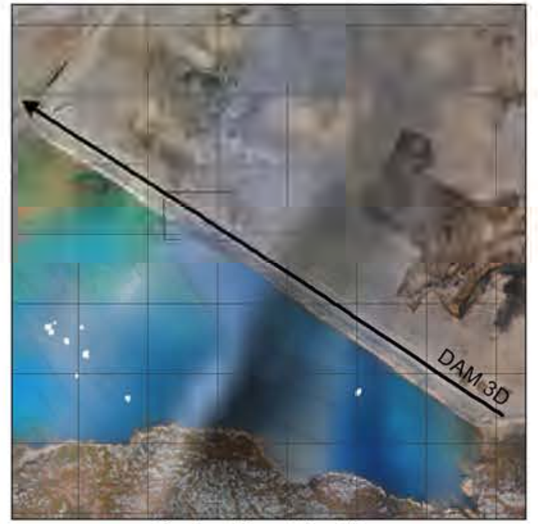
Lupin Tailings Dams Geophysics Survey 2019

Aurora Geosciences Ltd.

Drawn by TU on 2019-09-25
STN-19074-NT

Section 4: Dam 3D GPR Reflectors





Section Trace Plan View

Scale 1:2000

25 0 25 50

(metres)

Vertical Exaggeration: 10

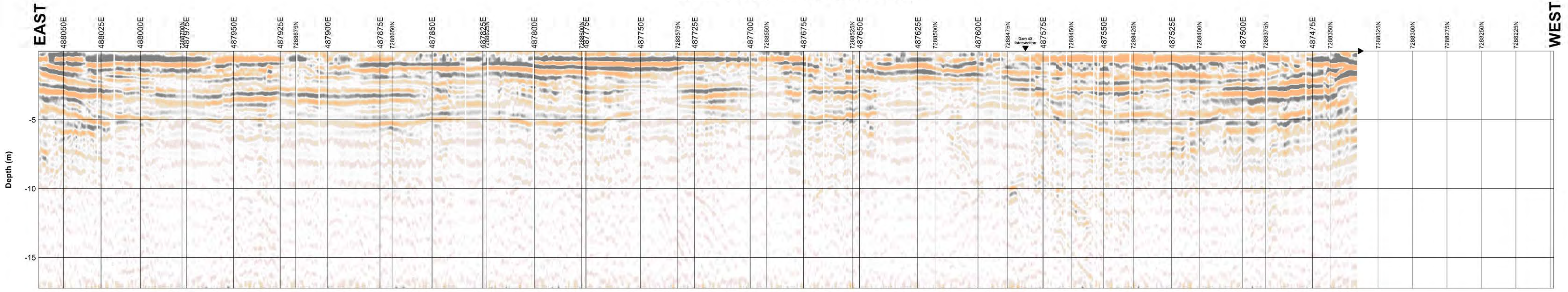
Lupin Tailings Dams Geophysics Survey 2019

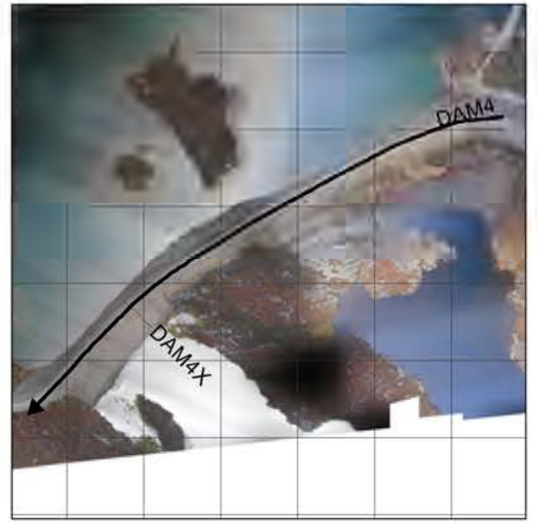
Aurora Geosciences Ltd.

Drawn by TU on 2019-09-25

STN-19074-NT

Section 5: Dam 4 GPR Reflectors





Section Trace Plan View

Scale 1:2000

25 0 25 50

(metres)

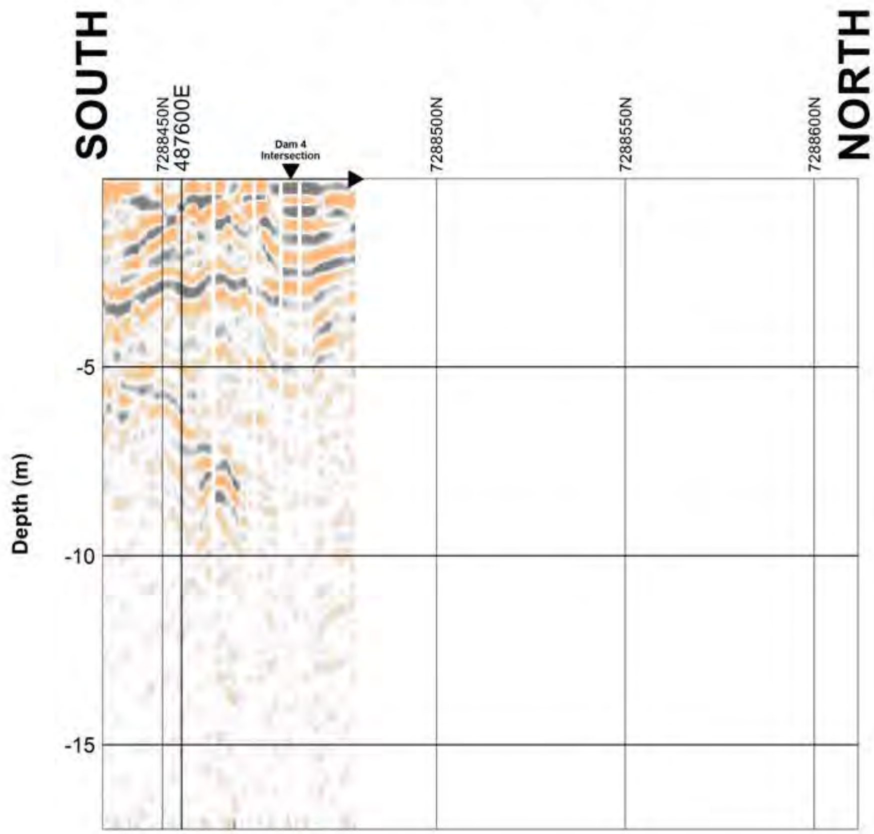
Vertical Exaggeration: 10

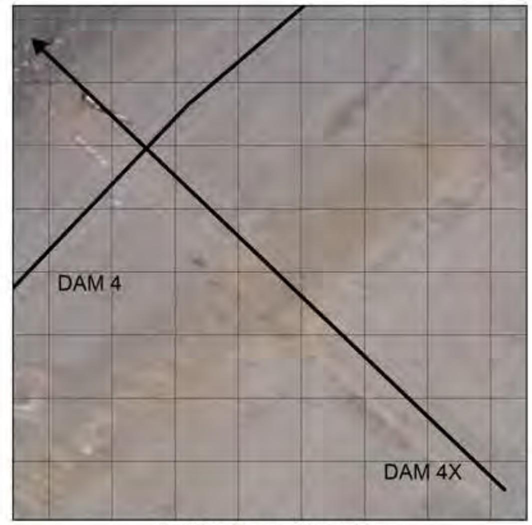
Lupin Tailings Dams Geophysics Survey 2019

Aurora Geosciences Ltd.

Drawn by TU on 2019-09-25
STN-19074-NT

Section 6: Dam 4 Cross Line
GPR Reflectors





Section Trace Plan View

Scale 1:2000

25 0 25 50

(metres)

Vertical Exaggeration: 10

Lupin Tailings Dams Geophysics Survey 2019

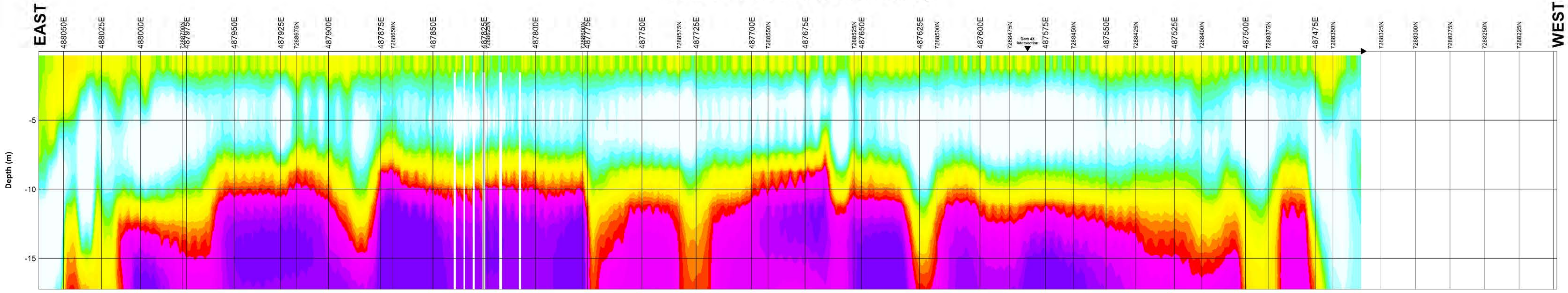
Aurora Geosciences Ltd.

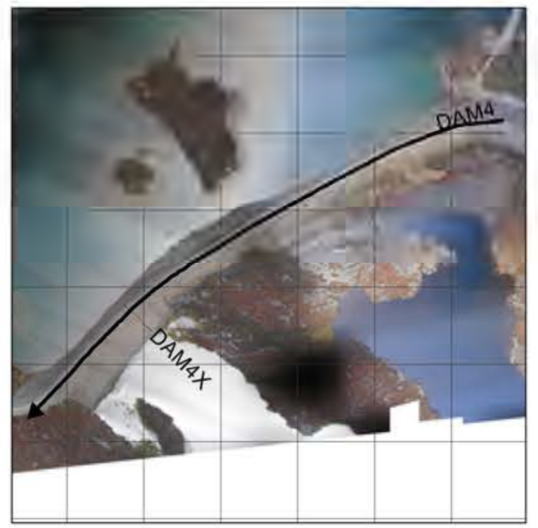
Drawn by TU on 2019-09-25
STN-19074-NT

AURORA GEOSCIENCES


Section 7: Dam 3D Electrical Resistivity
EAST
WEST
Anomalous Region - 120 m length
488200E
7289450N
488175E
7289475N
488150E
488125E
7289500N
488100E
7289525N
488075E
488050E
7289550N
488025E
Thermistor
7289575N
488000E
487975E
7289600N
487950E
7289625N
487925E
487900E
7289650N
487875E
7289675N
487850E
487825E
7289700N
487800E
B
7289725N
487775E
487750E
7289750N
C
487725E
487700E
487675E
7289800N
487650E
487625E
7289825N
487600E
7289850N
487575E
487550E
7289875N
0
-5
-10
-15
Depth (m)
DAM 3D
Section Trace Plan View
240.5
604.0
1517.2
4581.7
13836.6
Resistivity
Ω·m
Scale 1:2000
25
0
25
50
(metres)
Vertical Exaggeration: 10
Lupin Tailings Dams
Geophysics Survey 2019
Aurora Geosciences Ltd.
Drawn by TU on 2019-09-25
STN-19074-NT

Section 8: Dam 4 Electrical Resistivity





Section Trace Plan View

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Resistivity
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25 0 25 50
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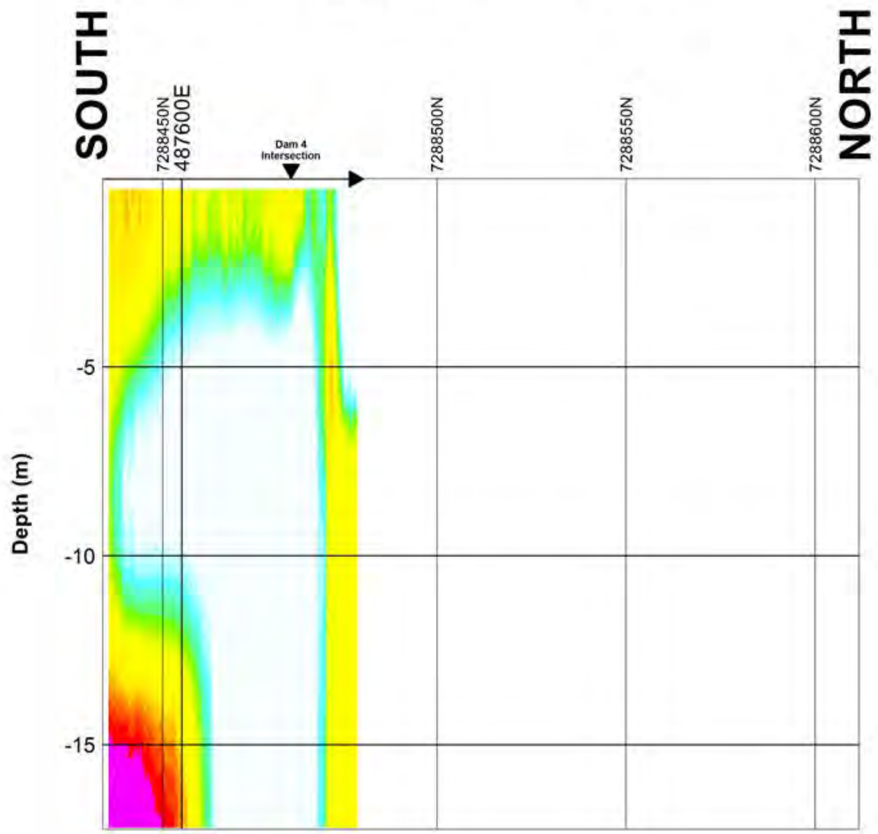
Vertical Exaggeration: 10

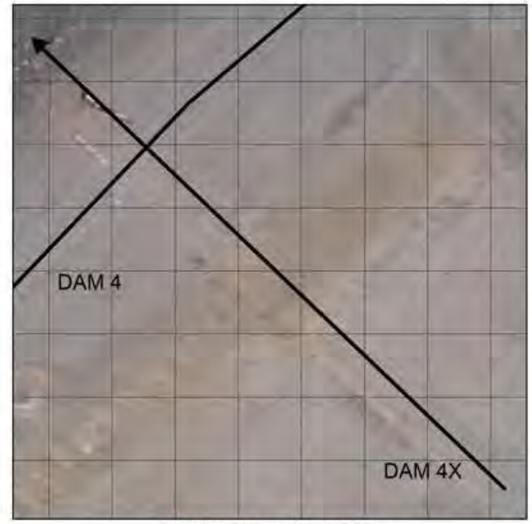
Lupin Tailings Dams Geophysics Survey 2019

Aurora Geosciences Ltd.

Drawn by TU on 2019-09-25
STN-19074-NT

Section 9: Dam 4 Cross Line
Electrical Resistivity





Section Trace Plan View

240.5 604.0 1517.2 4581.7 13836.6

Resistivity
Ω·m

Scale 1:2000

25 0 25 50

(metres)

Vertical Exaggeration: 10

Lupin Tailings Dams Geophysics Survey 2019

Aurora Geosciences Ltd.

Drawn by TU on 2019-09-25
STN-19074-NT

AURORA GEOSCIENCES

Stantec

Technical Memorandum

To:	Karyn Lewis, Project Manager Lupin Project	From:	Alvin Tong
	Mandalay Resources Corporation, Suite 330, 76 Richmond Street Toronto, ON M5C 1P1		Stantec Consulting Ltd., 1100 – 111 Dunsmuir Street Vancouver, BC V6B 6A3
File:	Lupin Gold Project - 129500081	Date:	November 13, 2019

Reference: 2 AM-LUP Technical Meeting Commitment Number 12 Response – Risk Assessment on Two Dams in the Lupin Tailings Containment Area

Lupin Mine Incorporated (LMI), a wholly owned subsidiary of Mandalay Resources Corporation is requesting the renewal and amendment of their existing Type “A” Water License No: 2AM-LUP1520 (License), to allow for Final Closure and Reclamation of the Lupin Mine Project (Lupin). The Nunavut Water Board (NWB or Board) Water License Application No. 2AM-LUP1520 Technical Meeting was held June 6-7, 2019 in Kugluktuk, Nunavut. Appendix D of the June 18, 2018 Pre-Hearing Conference Decision Report outlines the agreed upon List of Commitments (Commitments). Stantec Consulting Ltd. (Stantec) was retained by LMI to support the responses to select commitments and this technical memorandum provides the responses to fulfill Commitment No. 12, shown below, which relates to conducting a risk assessment on select dams at the Lupin Tailings Containment Area (TCA).

12	LMI	ECCC	Risk assessment of the two dams selected under item #11, based on the results of the thermal modelling provided on October 15, 2019, and representing both perimeter and internal dam types.	15-Nov-19	Technical Memo

The two dams selected for risk assessment in the response to Commitment No. 11 (Stantec 2019a) are Dam 3D and Dam 4, representing both perimeter and internal dam types. The risk assessment is based on the geotechnical stability results from Commitment No. 6. (Stantec 2019b), surface geophysical results from Commitment No. 11, and potential thawing of the frozen material in the TCA dams under multiple climate warming scenarios from the thermal modelling completed for Commitment No. 13 (Stantec 2019c). This technical memorandum will summarize risk on the dams in terms of geotechnical stability and the potential for impact to downstream water quality due to seepage from the Lupin TCA, based on the current thermal modeling results.

CURRENT CONDITIONS

Geophysical surveys were carried out on Dam 3D and Dam 4 in response the Commitment No. 11. The survey indicated that frozen material was encountered at a depth of approximately 2.5m within the dams. This depth corresponds to sub-zero temperature readings from the existing thermistors in the dams. Both the survey and the thermistor readings indicated that the TCA dams contain a continuous frozen core as licensed, which is intended to control seepage from the TCA cells. The geotechnical stability evaluation done in response to Comment No. 6 concluded that Dam 3D and Dam 4 meet the stability criteria shown in Table 1.

Reference: 2 AM-LUP Technical Meeting Commitment Number 12 Response – Risk Assessment on Two Dams in the Lupin Tailings Containment Area

Table 1: Summary of Stability Criteria

Failure Mode	Condition	Factor of Safety (Limit-Equilibrium)
Local	Static	1.3
Global		1.5
Global	Seismic	1.1

Overall, the survey results, thermistor readings, and the stability evaluation all indicate that the dams are currently performing as licensed.

RISK ASSESSMENT

To complete the risk assessment, the current dam conditions were used as a starting point and the results of the thermal modeling were applied to evaluate potential changing dam conditions outlined in the climate scenario. The thermal modeling completed in response to Comment No. 13 (Stantec 2019c) was completed using the low emission scenario (LES) and the high emission scenario (HES). The LES model results suggested only a partial thaw of the frozen core and some degradation of the permafrost, while in contrast the HES model results suggested a complete thaw of the frozen core and significant degradation of the permafrost. As such, this risk assessment will focus on the HES scenario as it is more conservative and will be the critical potential failure mode.

GEOTECHNICAL STABILITY

Stability analyses were completed in the same manner as the work completed in response to Comment No. 6. The only difference is the frozen core was replaced with thawed material, and a phreatic surface was assumed between the top of tailings adjacent to the upstream side of the dam to the downstream toe of the dam. This assumed phreatic surface is more conservative than the expected condition during HES thawing. Realistically, as the frozen core recedes downwards to lower elevations according to the HES model, the phreatic surface is expected to drop accordingly within the dam and recede upstream into the tailings deposit, resulting in a more gradual gradient over a minimum 30m distance in to the tailings (Holubec, 2006) than the assumed phreatic surface next the upstream dam face. Figure 1 shows the typical seepage section for the TCA dams (Holubec, 2006).

Reference: **2 AM-LUP Technical Meeting Commitment Number 12 Response – Risk Assessment on Two Dams in the Lupin Tailings Containment Area**

Figure 1: Schematic of Seepage Analyses Results (Holubec 2006)

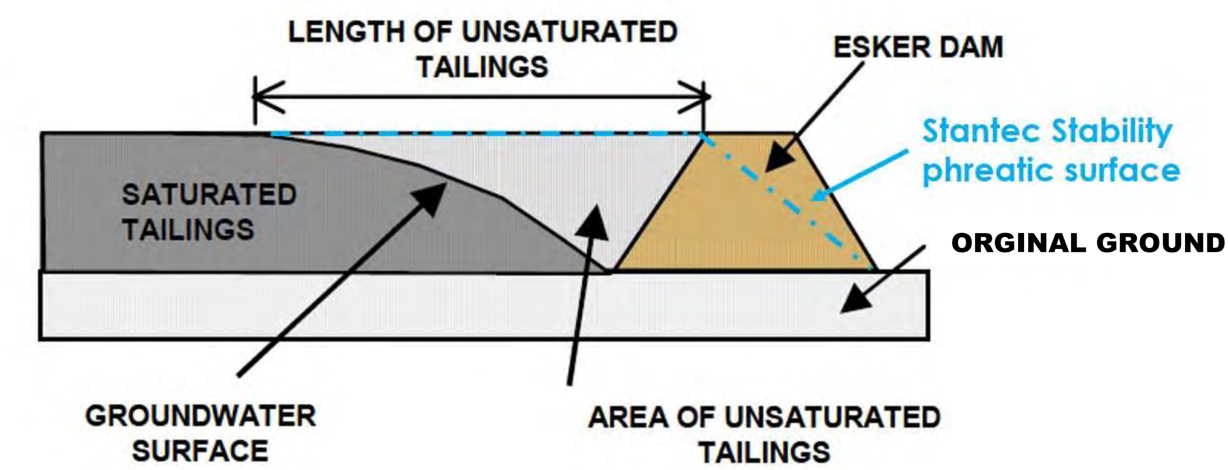


Table 2 shows the material properties used in the analyses and the Figure 1 shows the locations of the stability sections.

Table 2: Material Properties

Material	Unit Weight (kN/m^3)	Effective Stress Parameters
Esker (dam and cover fill)	30	c' = 0, φ' = 35°
Gravelly Sand	30	c' = 0, φ' = 35°
Rockfill	20	c' = 0, φ' = 39°
Tailings (Drained)	18	c' = 0, φ' = 30°
Tailings (Undrained)	18	Minimum strength: 20 kPa, Su/σ'v = 0.24
Till	18	c' = 0, φ' = 30°
Bedrock	Impenetrable	

Reference: 2 AM-LUP Technical Meeting Commitment Number 12 Response – Risk Assessment on Two Dams in the Lupin Tailings Containment Area

Figure 2: Tailings Containment Area Stability Section Locations

The results of the stability analyses are shown in Table 3 and provided in Appendix A. The factor of safety of the dams with the unfrozen core under the HES meet the closure criteria.

Table 3: Summary of Stability Analyses Results

Cross-section	Configuration	Scenario		
		Thawed Condition		Seismic
		Local	Global	Global
3D	As-built	1.3	3.6	3.2
4	As-built	2.9	5.9	4.7

POTENTIAL IMPACT ON THE WATER QUALITY DUE TO SEEPAGE

The potential impact on downstream water quality in the receiving environment due to seepage from the TCA in the scenario where the frozen core of the dam is thawed has been analyzed in previous geotechnical, seepage and water balance studies (Holubec 2006; EcoMetrix 2006). In general, the studies concluded that the current TCA closure plan provides adequate water quality protection in post-thaw conditions. More specifically, the studies concluded the following:

- *If permafrost thaws in the future, the unsaturated tailings adjacent to the dams will continue to retain high degrees of water saturation. The fine-grained nature of the tailings, enhanced infiltration and prevention of the evaporation associated with the esker cover will likely keep the saturation of the tailings high.*

- *Majority of the tailings areas beyond the small unsaturated areas adjacent to the dams will remain fully saturated and thereby exhibit similar very low to negligible oxidation rates that occur under current saturated conditions.*

To further mitigate the seepage risks, the existing perimeter dam, including Dam 4, incorporate a geosynthetic liner to provide additional seepage control.

CONCLUSION

Based on the existing instrumentation and survey data, the dams have a continuous frozen core and are deemed to be performing as licensed. Further evaluation indicated that in the event of the HES scenario where the frozen cores would thaw due to climate change, the dams will remain geotechnically stable. Based on previous work completed (Holubec 2006 and EcoMetrix 2006) as part of the TCA closure plan, the potential water quality impacts to the downstream receiving environment due to TCA seepage was generally estimated to be low, as the predicted increase in concentration in the discharge is estimated to be very low based on small unsaturated areas and the overall runoff dilution. The overall risks to Dam 3D and 4 associated with the HES thermal model are deemed low, and in turn, the risks associated with the LES thermal model are deemed very low.

Stantec Consulting Ltd.

Alvin Tong P. Eng.
Senior Geotechnical Engineer

Phone: 604 630 5833
Fax:
alvin.tong@stantec.com

Attachment: Appendix A - Stability Results Figures

Reference

Stantec Consulting Ltd., 2019 (Stantec 2019a). 2AM-LUP Technical Meeting Commitment Number 11 Response – Geophysical Survey Lupin Mine Tailings Containment Area Dams, Technical Memorandum submitted to Lupin Mine Incorporated, October 15, 2019.

Stantec Consulting Ltd., 2019 (Stantec 2019b). 2AM-LUP Technical Meeting Commitment Number 6 Response – Geotechnical Review on the Long-Term Stability of the TCA Dams, Technical Memorandum submitted to Lupin Mine Incorporated, November 15, 2019.

Stantec Consulting Ltd., 2019 (Stantec 2019c). 2AM-LUP Technical Meeting Commitment Number 11 Response – Lupin Mine Tailings Containment Area Dam Thermal Modelling Results, Technical Memorandum submitted to Lupin Mine Incorporated, October 15, 2019.

Holubec Consulting Inc., 2006 (Holubec 2006). Volume 1 and 2 of Geotechnical, Seepage and Water Balance for Reclaimed Tailings Containment Area, Lupin Operation, reports submitted to Kinross Gold Corporation, March 2006.

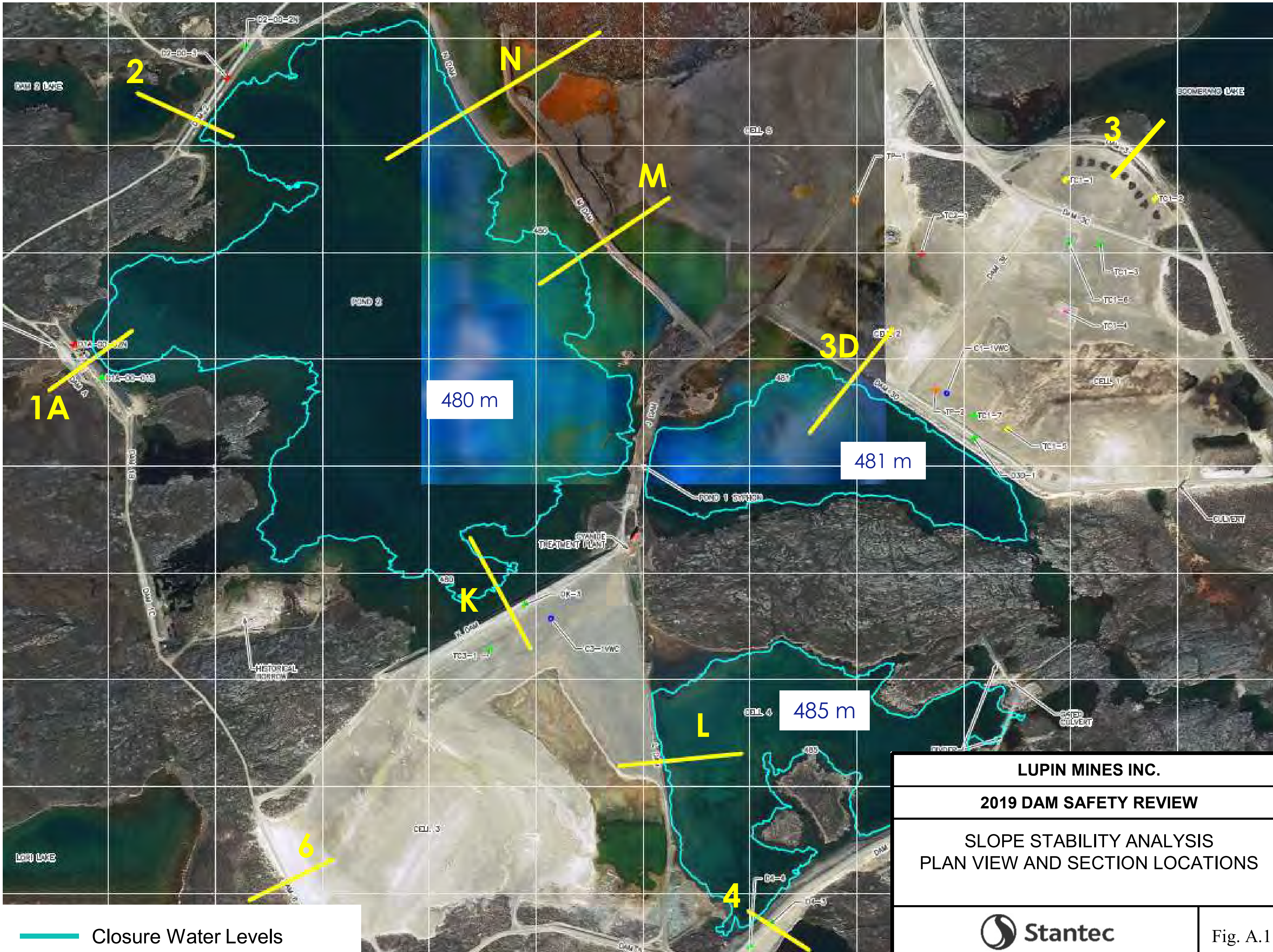
EcoMetrix Incorporated., 2006 (EcoMetrix 2006). Geochemistry and Water Quality, Volume 3 of Seepage and water Quality for Reclaimed Tailings Containment Area, Lupin Operation, report submitted to Kinross Gold Corporation, April, 2006.

Appendix A

Lupin Mines Inc.
2019 Dam Safety Review
Tailings Containment Area

Slope Stability Analysis
Thawed Scenario
(Rev 0)

November 13, 2019



LUPIN MINES INC.	
2019 DAM SAFETY REVIEW	
SLOPE STABILITY ANALYSIS PLAN VIEW AND SECTION LOCATIONS	
Stantec	Fig. A.1

Fig. A1	Plan View Section Locations
Fig. A2	List of Analyses
Fig. A3	Section 3D - Thawed Scenario, Static Case – Local Failure
Fig. A4	Section 3D - Thawed Scenario, Static Case – Global Failure
Fig. A5	Section 3D - Thawed Scenario, Pseudo-Static Case – Global Failure
Fig. A6	Section 4 - Thawed Scenario, Static Case – Local Failure
Fig. A7	Section 4 - Thawed Scenario, Static Case – Local Failure
Fig. A8	Section 4 - Thawed Scenario, Pseudo-Static Case – Global Failure

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PHC Comment Response

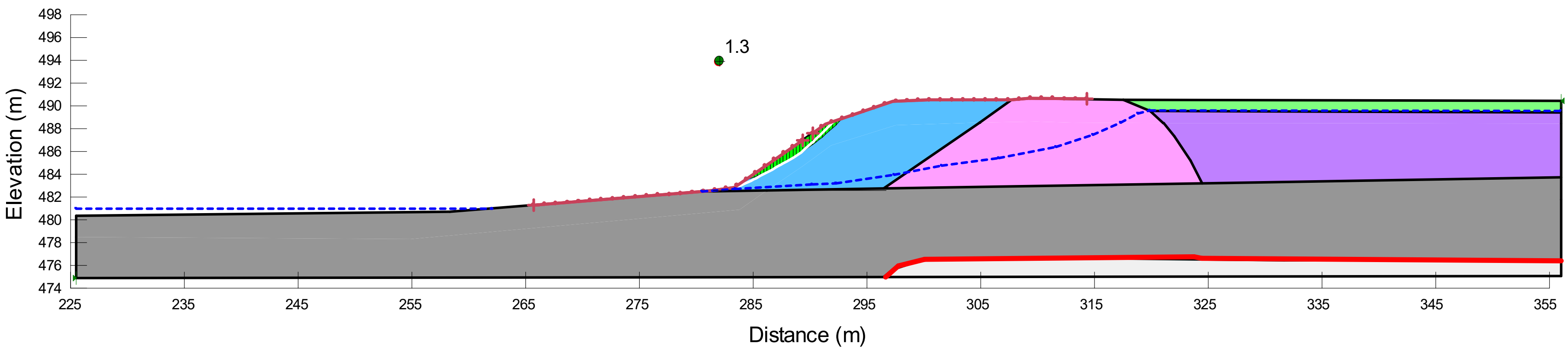
SLOPE STABILITY ANALYSIS
LIST OF ANALYSES
THAWED SCENARIO

Stantec

Fig. A.2

Details:
Thawed Scenario: based on High-Emissions Scenario where permafrost is present at depth 14m below ground surface

Material		Unit Weight (kN/m³)	Drained Parameters		Undrained Parameters	
			Friction Angle (°)	Cohesion (kPa)	Minimum Strength (kPa)	Tau/Sigma Ratio
	Esker	30	35°	0	N/A	
	Gravelly Sand	30	35°	0	N/A	
	Rockfill	20	39°	0	N/A	
	Tailings (Drained)	18	30°	0	N/A	
	Tailings (Undrained)	18	N/A		20	0.24
	Till	18	30°	0	N/A	
	Bedrock	Impenetrable				
	Permafrost	N/A				
	Geotechnical Liner	N/A				



Notes:
1. FOS is for optimized slip surface using Spencer method in SLOPE/W (GeoStudio 2018, version 9.0.4).

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SLOPE STABILITY ANALYSIS
SECTION 3D – THAWED SCENARIO
STATIC CASE – LOCAL FAILURE

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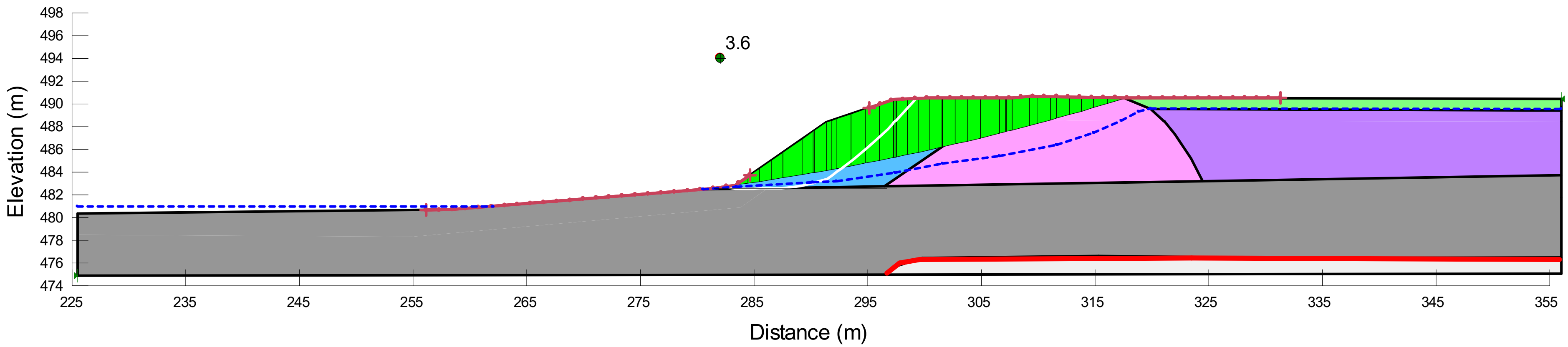
Fig. A.3

Details:

Thawed Scenario: based on High-Emissions Scenario where permafrost is present at depth 14m below ground surface

	Material	Unit Weight (kN/m³)	Drained Parameters		Undrained Parameters	
			Friction Angle (°)	Cohesion (kPa)	Minimum Strength (kPa)	Tau/Sigma Ratio
	Esker	30	35°	0	N/A	
	Gravelly Sand	30	35°	0	N/A	
	Rockfill	20	39°	0	N/A	
	Tailings (Drained)	18	30°	0	N/A	
	Tailings (Undrained)	18	N/A		20	0.24
	Till	18	30°	0	N/A	
	Bedrock	Impenetrable				
	Permafrost	N/A				
	Geotechnical Liner	N/A				



Notes:

1. FOS is for global failure that breaches the dam using Spencer method in SLOPE/W (GeoStudio 2018, version 9.0.4).

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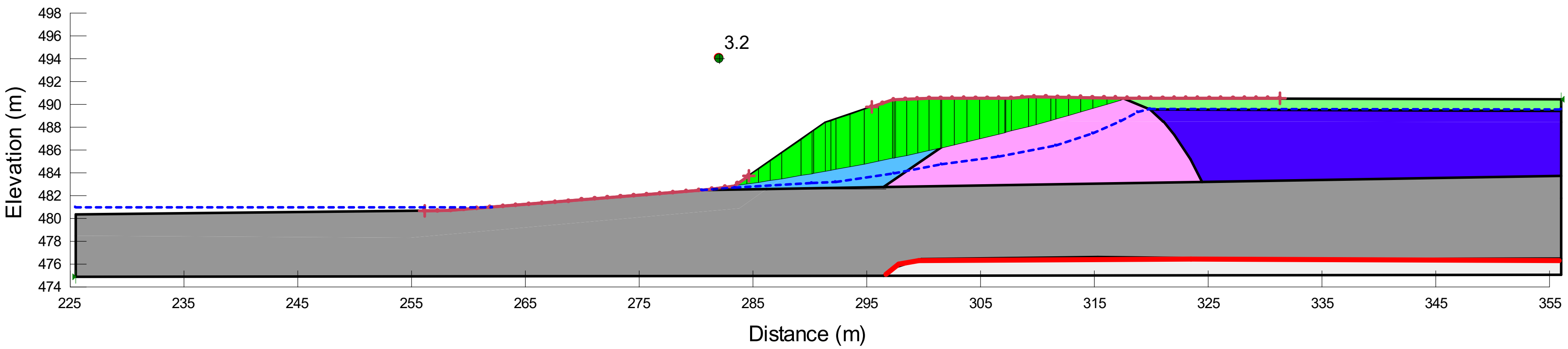
SLOPE STABILITY ANALYSIS
SECTION 3D – THAWED SCENARIO
STATIC CASE – GLOBAL FAILURE

Stantec

Fig. A.4

Details:
Thawed Scenario: based on High-Emissions Scenario where permafrost is present at depth 14m below ground surface

Material	Unit Weight (kN/m³)	Drained Parameters		Undrained Parameters	
		Friction Angle (°)	Cohesion (kPa)	Minimum Strength (kPa)	Tau/Sigma Ratio
Esker	30	35°	0	N/A	
Gravelly Sand	30	35°	0	N/A	
Rockfill	20	39°	0	N/A	
Tailings (Drained)	18	30°	0	N/A	
Tailings (Undrained)	18	N/A		20	0.24
Till	18	30°	0	N/A	
Bedrock	Impenetrable				
Permafrost	N/A				
Geotechnical Liner	N/A				



Notes:
1. FOS is for global failure that breaches the dam using Spencer method in SLOPE/W (GeoStudio 2018, version 9.0.4).

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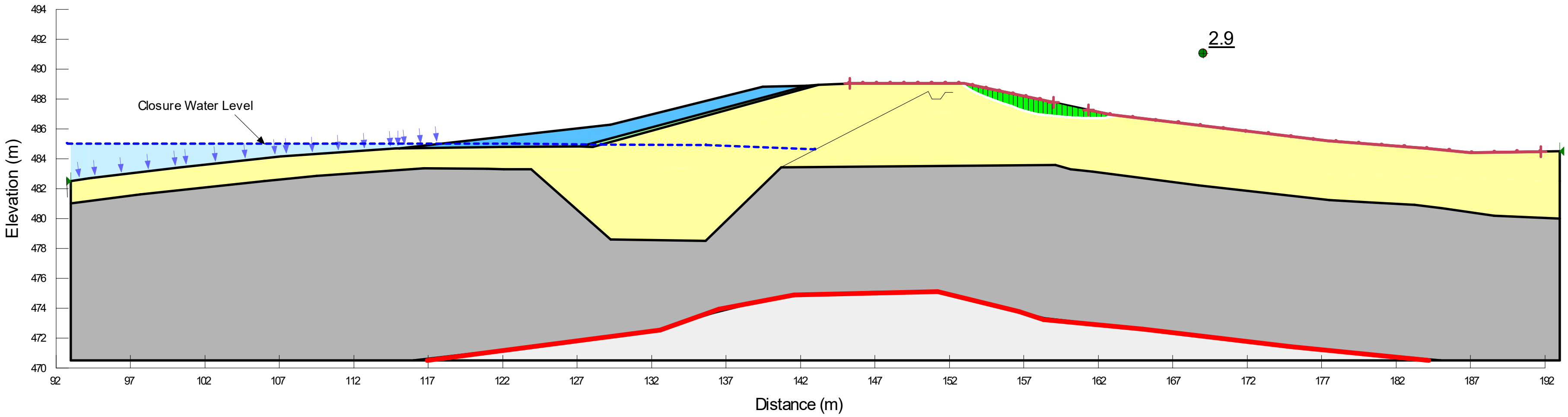
SLOPE STABILITY ANALYSIS
SECTION 3D – THAWED SCENARIO
PSEUDO-STATIC CASE – GLOBAL FAILURE

Stantec

Fig. A.5

Details:
Thawed Scenario: based on High-Emissions Scenario where permafrost is present at depth 14m below ground surface

Material		Unit Weight (kN/m³)	Drained Parameters		Undrained Parameters	
			Friction Angle (°)	Cohesion (kPa)	Minimum Strength (kPa)	Tau/Sigma Ratio
	Esker	30	35°	0	N/A	
	Gravelly Sand	30	35°	0	N/A	
	Rockfill	20	39°	0	N/A	
	Tailings (Drained)	18	30°	0	N/A	
	Tailings (Undrained)	18	N/A		20	0.24
	Till	18	30°	0	N/A	
	Bedrock	Impenetrable				
	Permafrost	N/A				
	Geotechnical Liner	N/A				



Notes:
1. FOS is for optimized slip surface using Spencer method in SLOPE/W (GeoStudio 2018, version 9.0.4).

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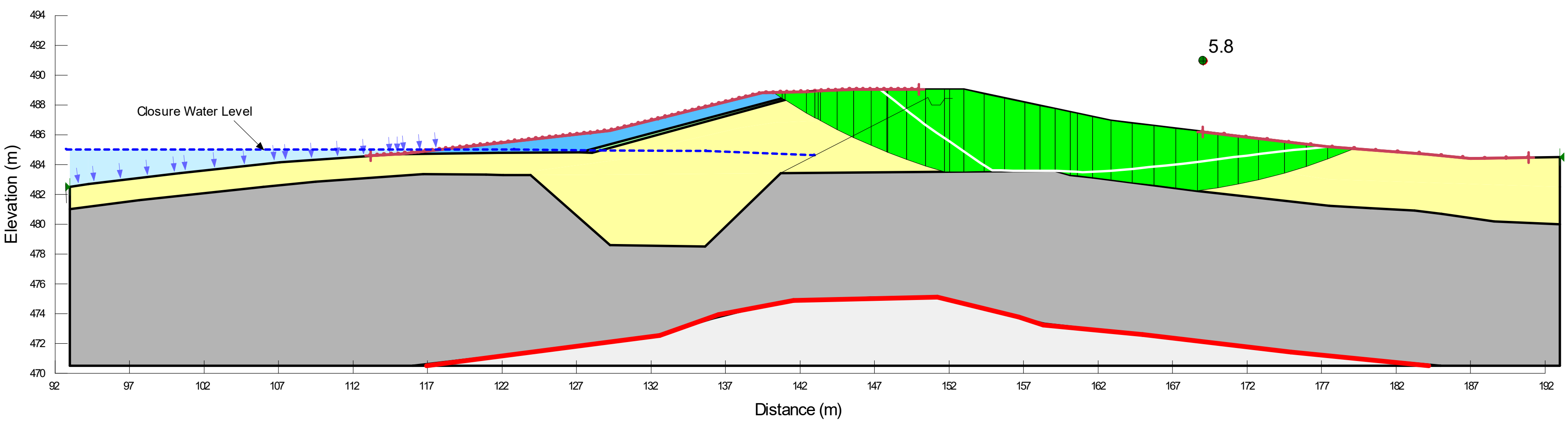
SLOPE STABILITY ANALYSIS
SECTION 4 – THAWED SCENARIO
STATIC CASE – LOCAL FAILURE

Stantec

Fig. A.6

Details:
Thawed Scenario: based on High-Emissions Scenario where permafrost is present at depth 14m below ground surface

Material		Unit Weight (kN/m³)	Drained Parameters		Undrained Parameters	
			Friction Angle (°)	Cohesion (kPa)	Minimum Strength (kPa)	Tau/Sigma Ratio
	Esker	30	35°	0	N/A	
	Gravelly Sand	30	35°	0	N/A	
	Rockfill	20	39°	0	N/A	
	Tailings (Drained)	18	30°	0	N/A	
	Tailings (Undrained)	18	N/A		20	0.24
	Till	18	30°	0	N/A	
	Bedrock	Impenetrable				
	Permafrost	N/A				
	Geotechnical Liner	N/A				



Notes:
1. FOS is for global failure that breaches the dam using Spencer method in SLOPE/W (GeoStudio 2018, version 9.0.4).

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PHC Comment Response

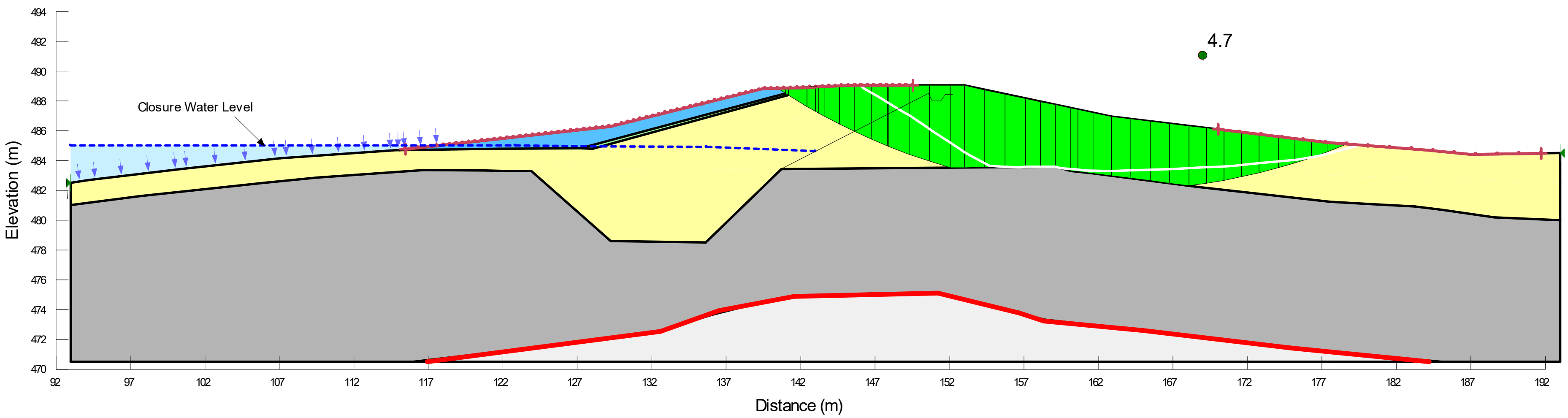
SLOPE STABILITY ANALYSIS
SECTION 4 – THAWED SCENARIO
STATIC CASE – GLOBAL FAILURE

Stantec

Fig. A.7

Details:
Thawed Scenario: based on High-Emissions Scenario where permafrost is present at depth 14m below ground surface

Material	Unit Weight (kN/m³)	Drained Parameters		Undrained Parameters	
		Friction Angle (°)	Cohesion (kPa)	Minimum Strength (kPa)	Tau/Sigma Ratio
Esker	30	35°	0	N/A	
Gravelly Sand	30	35°	0	N/A	
Rockfill	20	39°	0	N/A	
Tailings (Drained)	18	30°	0	N/A	
Tailings (Undrained)	18	N/A		20	0.24
Till	18	30°	0	N/A	
Bedrock	Impenetrable				
Permafrost	N/A				
Geotechnical Liner	N/A				



Notes:
1. FOS is for global failure that breaches the dam using Spencer method in SLOPE/W (GeoStudio 2018, version 9.0.4).

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PHC Comment Response

SLOPE STABILITY ANALYSIS
SECTION 4 – THAWED SCENARIO
PSEUDO-STATIC CASE – GLOBAL FAILURE

Stantec

Fig. A.8