Technical Memo

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File:	Lupin Gold Project - 129500081	Date:	October 15, 2019

Reference: 2 AM-LUP Technical Meeting Commitment Number 13 Response – Lupin Mine Tailings Containment Area Dams Thermal Modelling Results

Introduction

Lupin Mine Incorporated (LMI), a wholly owned subsidiary of Mandalay Resources 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 and 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. 13, shown below, which relates to thermal modelling of the long-term thaw of the Lupin Tailings Containment Area (TCA) frozen tailings containment structures or dams under multiple climate warming scenarios to support the Lupin Mine Final Reclamation and Closure Plan.

13	LMI	ECCC	LMI to use a range of emission scenarios (low to high future forcing) from multiple climate models and considering multiple parameters (precipitation, permafrost thaw, etc.), which will be determined following consultation with climate change experts, for consideration in the Final Reclamation and Closure Plan.	15-Oct-19	Technical Memo

Commitment No. 13 states that climate change experts sub-contracted by LMI will consult with Environment Canada and Climate Change (ECCC) climate change experts to determine the most applicable climate models, warming scenarios, and parameters, for the Lupin Mine site. Meetings with the ECCC climate change expert were requested by Stantec on July 31, 2019, and August 30, 2019, and ECCC responded that, in summary, email communication was preferred. Both email responses directly referenced sections of Canada's Changing Climate Report (CCCR, 2019), most specifically Chapter 8 Section 8.4.1: Changes in northern Canada. This section references two northern Canada emission scenarios and the ECCC climate change expert noted that: "the range of projected changes provided for various global emission scenarios (i.e., Representative Concentration Pathways or RCPs) in Canada's Changing Climate Report are derived from an ensemble of 29 climate models".

Details regarding the projected changes in temperature in various regions across Canada, including Canada's north, were provided in CCCR, 2019, Chapter 4, (Section 4.2.1.3 and Table 4.2). CCCR, 2019, Section 4.2.1.3, indicates that the projected increase in mean annual air temperature (MAAT) was based on a distribution of outcomes from 29 CMIP5 (Coupled Model Intercomparison Project) climate models. The climate models were used to simulate three emission scenarios (low-, medium-, and high-emissions scenarios). Stantec used the low-emissions scenario (LES) and the high-emissions scenario (HES) to fulfill the TCA thermal modelling component of Commitment No. 13 as only these two scenarios were reported in CCCR, 2019.

Thermal Modelling

Stantec performed thermal modelling to assess the potential for long-term permafrost thaw of frozen tailings containment structures (dams) under three climate warming scenarios. The median projected MAAT increase values for the North region from the two climate modelling emission scenarios (LES and HES) from CCCR, 2019, Table 4.2 (shown above) were used to establish the air temperature versus time for input to the thermal modelling. The third climate scenario was modelled using an average of the LES and HES and is termed herein as the average-emissions scenario (AES).

The thermal modelling domain was one-dimensional and represented the thermal conditions at and below the crest of the dams. The LES and HES thermal modelling scenarios considered an increase in the MAAT from the 1986-2005 time period to the 2031-2050 time period, consistent with the time periods reported in CCCR, 2019, Table 4.2. From the time period 2031-2050 to 2081-2100, a second MAAT increase rate was used, again consistent with the time periods and temperature increases reported in CCCR, 2019, Table 4.2. Table 1 below summarizes the time intervals, temperature increases, and the climate warming rates used in the LES, HES and AES thermal modelling as calculated from the projected MAAT increases reported in CCCR, 2019, Section 4.2.1.3, Table 4.2.

Table 1 – Thermal Modelling MAAT Increases and Climate Warming Rates for Emissions Scenarios

Time Period	Time Period Midpoint	Time Interval (years)	LES MAAT Increase (°C)	HES MAAT Increase (°C)	LES Climate Warming Rate (°C/year)	HES Climate Warming Rate (°C/year)	AES Climate Warming Rate (°C/year)
1986 – 2005	1995	0	--	--	--	--	--
2031 – 2050	2040	45	1.8	2.7	0.040	0.060	0.050
2081 – 2100	2090	95	2.1	7.8	0.0060	0.102	0.054
Time-Weighted Average Climate Warming Rate 1995-2100 (°C/year)					0.022	0.082	0.052

(Based on air temperature projections reported in CCCR, 2019, Section 4.2.1.3, Table 4.2)

The climate warming rates for the three emissions scenarios in Table 1 were used to ramp-increase the MAAT in the thermal modelling from 1995 to 2100 as shown in Figure 1. The temperature increases for the LES and HES scenarios shown in Table 1 and plotted in Figure 1, are based on, and are consistent with, the temperature warming projections reported in CCCR, 2019, Section 4.2.1.3, Table 4.2.

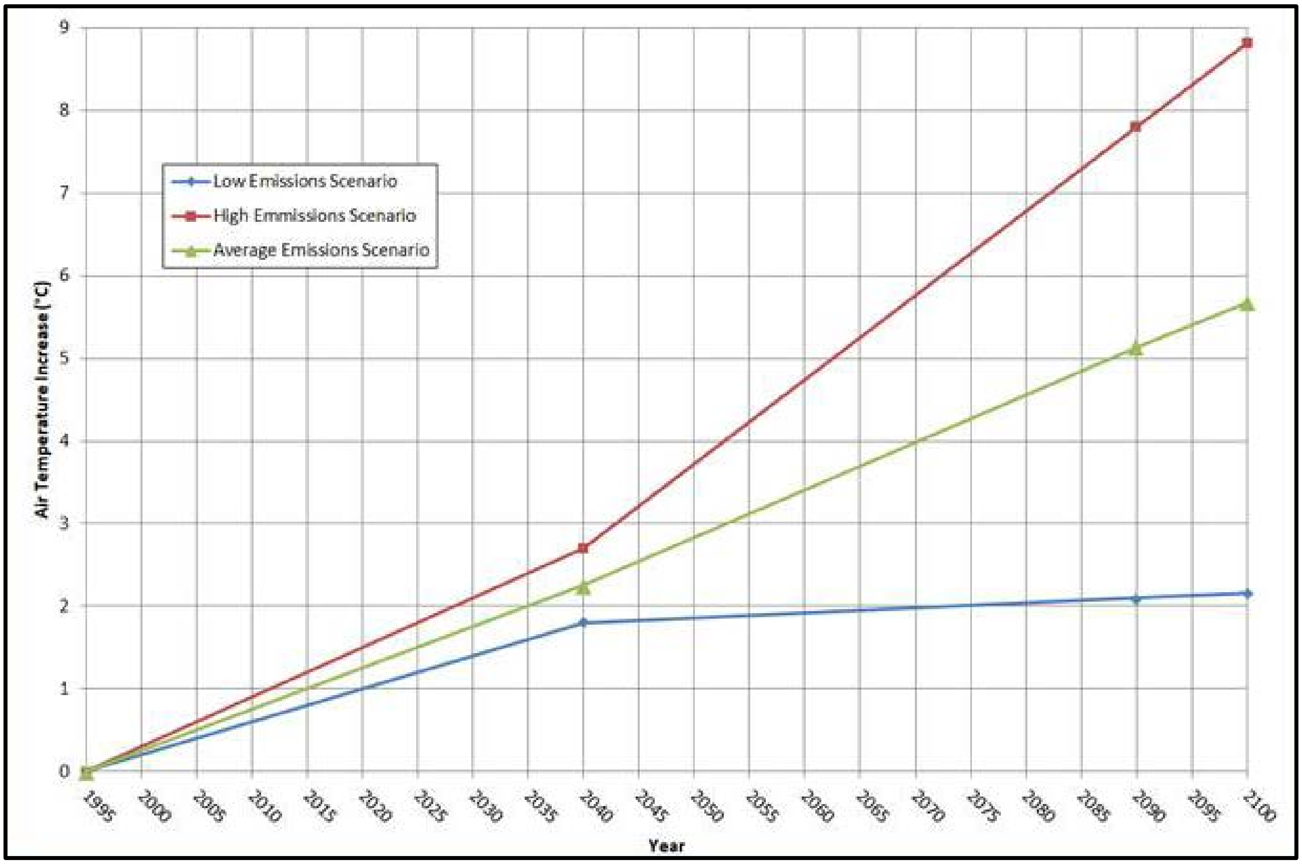

Figure 1: CCCR 2019 Climate Warming Predictions for Canada North Region

High-Emissions Scenario (HES) Thermal Modelling Results

The HES model represents the worst-case emissions scenario (i.e., highest rate of climate warming) of the three climate warming scenarios considered. Figure 2 displays the seasonal variation in air temperature used in the HES thermal modelling. The air temperature data is shown at 5-day intervals represented by red symbols. The MAAT is shown by the blue symbols and is the same air temperature data that was shown for the HES scenario in Figure 1.

Figure 3 displays the model-calculated variation in the thaw depth versus time at the dam crest for the HES. As with Figure 2, the data points are evenly spaced at 5-day intervals. In the thermal model, the maximum annual thaw depth (termed the active layer depth) in 1995 is 2.3 m. Climate warming causes small incremental increases in the depth of the active layer each year until about 2075. After 2075, the annual winter frost depth does not penetrate to the base of the active layer (top of permafrost), and long-term progressive permafrost thaw deepening begins after that point in time. By the year 2100, the top of the permafrost is located 14 m below ground surface. Of the three emissions scenarios considered, the HES is the most extreme given that the observed MAAT in Canada increased by 8.8°C from 1995 to 2100.

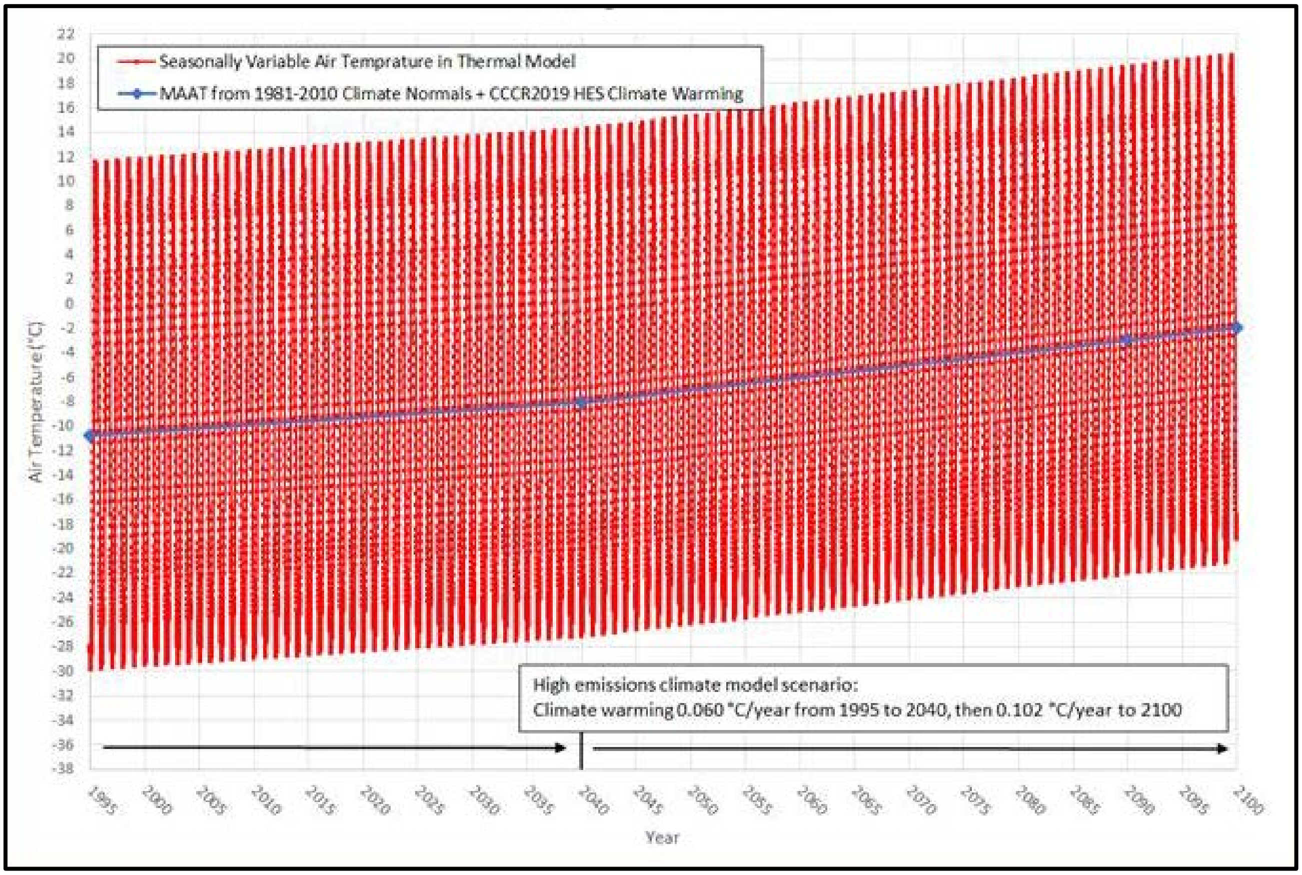

Figure 2: HES Scenario – Lupin Thermal Modelling with Climate Warming, Air Temperature Input Data

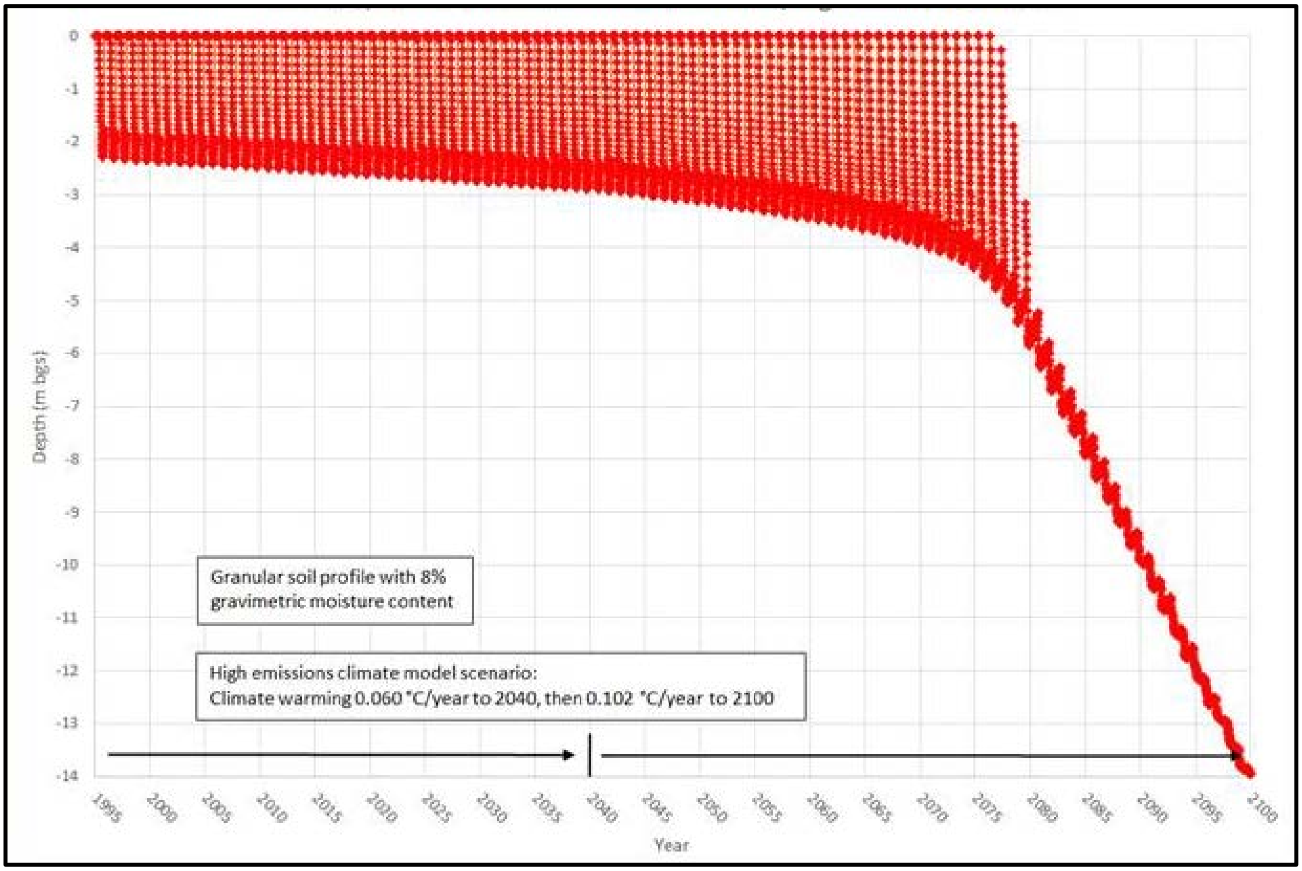

Figure 3: HES Scenario – Lupin Thermal Modelling with Climate Warming, Long-Term Thaw Depth

Low-Emissions Scenario (LES) Thermal Modelling Results

The air temperature data used in the modelling for the LES thermal modelling is shown in Figure 4. The LES scenario uses a MAAT increase of 2.2°C from 1995 to 2100. CCCR, 2019, states that the warming trend observed in Canada from 1948 to 1996 was 1.2°C, representing an average warming rate of 0.025°/yr. Accordingly, the LES is considered to be more realistic than the HES.

Figure 5 shows the model-calculated thaw depth for the LES from 1995 to 2100. The model begins with an active layer depth of 2.3 m in 1995, which deepens to 2.8 m by year 2100, indicating an active layer thickness increase of 0.5 m. The LES does not result in long-term progressive permafrost thaw.

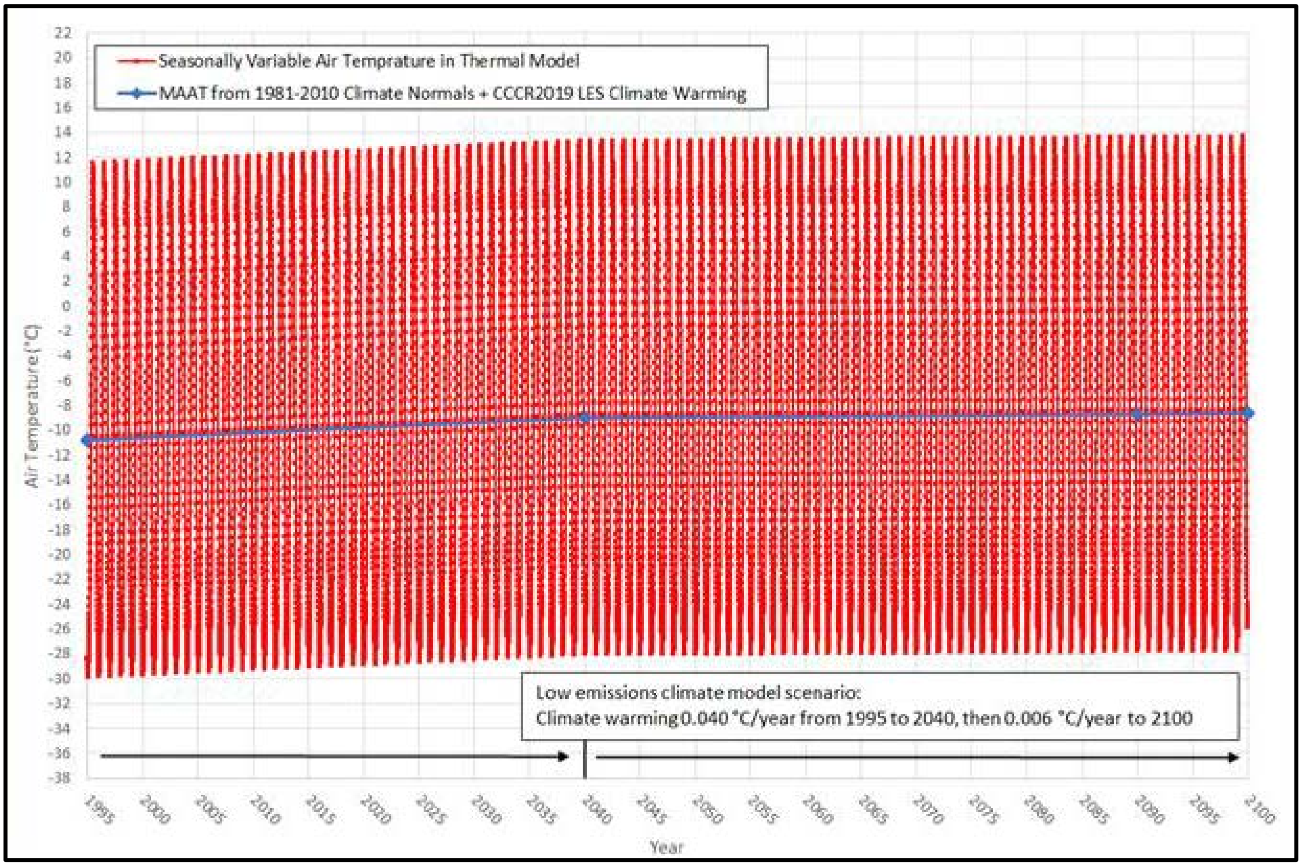

Figure 4: LES Scenario – Lupin Thermal Modelling with Climate Warming, Air Temperature Input Data

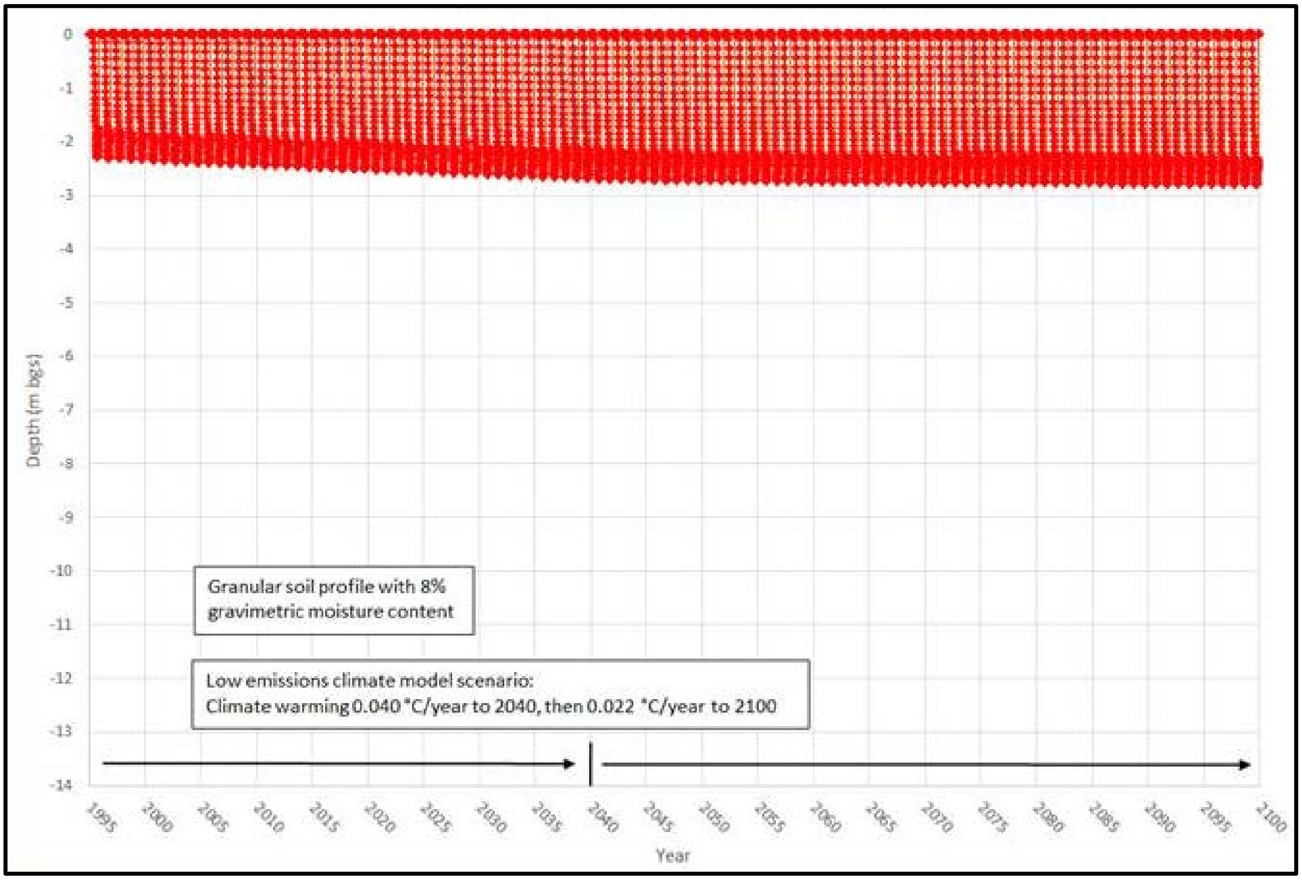

Figure 5: LES Scenario – Lupin Thermal Modelling with Climate Warming, Long-Term Thaw Depth

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Average-Emissions Scenario (AES) Thermal Modelling Results

The AES scenario is an average of the LES and HES MAAT warming rates. Figure 6 shows the seasonally variable temperature together with the MAAT for the AES. The overall climate warming rate in this scenario is 0.052 °C/yr.

Figure 7 shows the model-calculated thaw depth for the AES from 1995 to 2100. The model begins with an active layer thaw depth of 2.3 m in 1995, which deepens to 3.9 m by year 2100, indicating an active layer thickness increase of 1.6 m. As with the LES, there is no long-term progressive permafrost thaw.

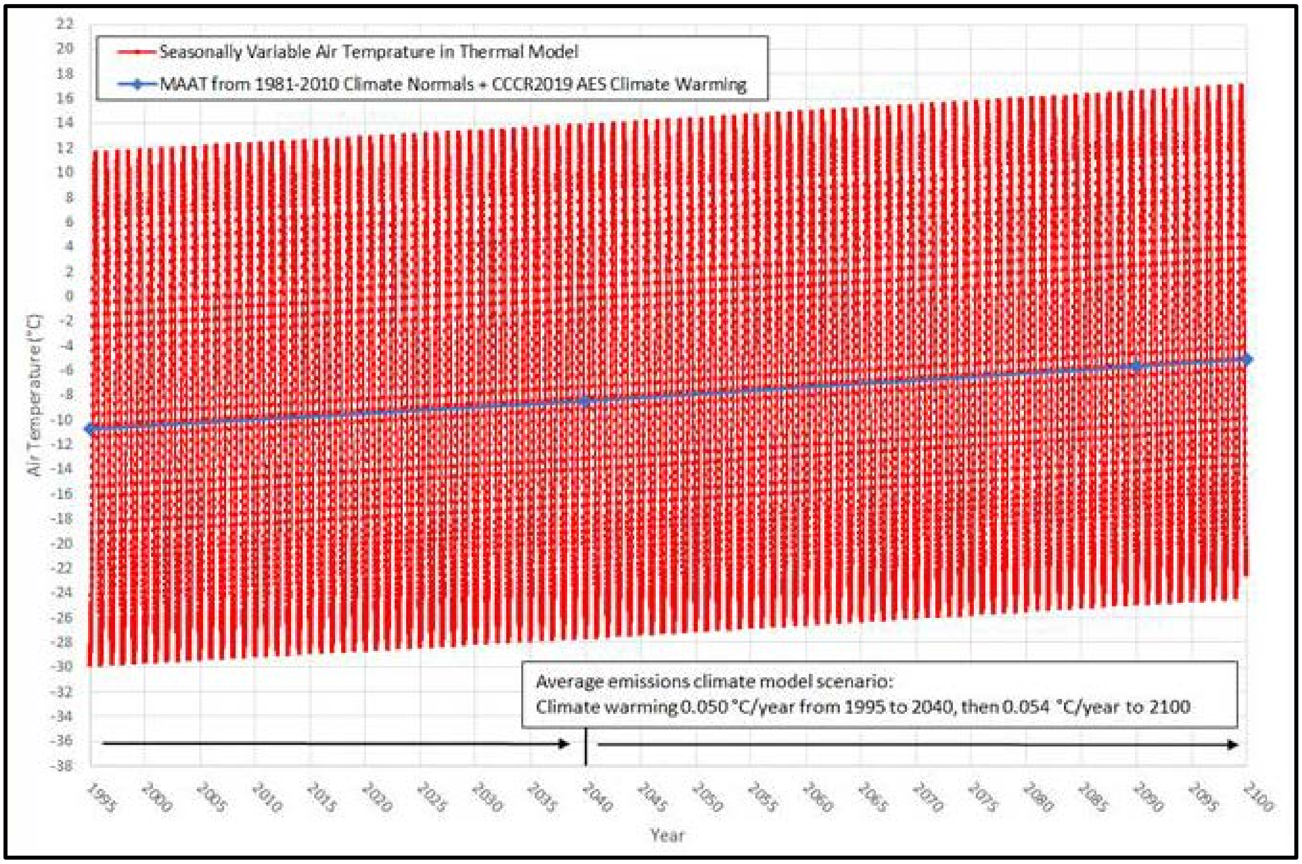

Figure 6: AES Scenario – 1D Model of Climate Warming Air Temperature

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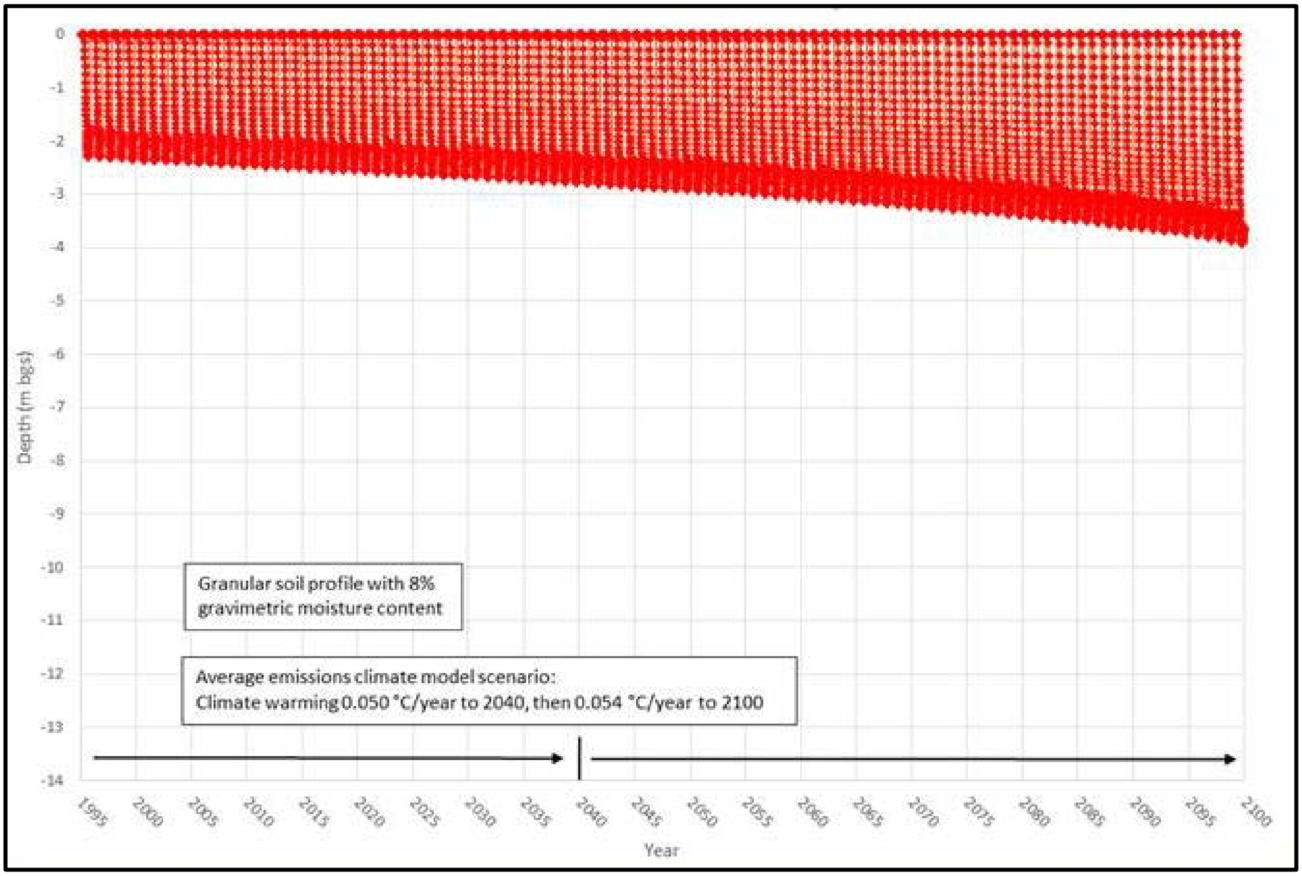

Figure 7: LES Scenario – Lupin Long-Term Thaw Depth with Climate Warming

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Conclusions

The thermal modelling conducted by Stantec found that the LES and AES did not result in long-term progressive permafrost thaw within the Lupin Mine TCA dams. The LES and AES are considered to be more realistic climate warming emission scenarios compared to the HES, based on reported observations of temperature changes in the latter half of the 20th century in Canada. Thermal modelling showed that the HES emission scenario resulted in long-term progressive permafrost thaw which is not expected to begin until the latter quarter of the 21st century, and which would result in a permafrost thaw depth of 14 m below ground by the year 2100.

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