APPENDIX G.12

Update to Thermal Assessment for the Waste Rock Facility

TECHNICAL MEMORANDUM

DATE March 19, 2021 **Project No.** 20446413_Rev0

TO Christopher Murray
Baffinland Iron Mines

CC Michelle Tyldesley

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UPDATE OF THERMAL ASSESSMENT FOR THE WASTE ROCK FACILITY AT MARY RIVER PROJECT

1.0 INTRODUCTION

Potential acid generating (PAG) and non-acid generating (Non-AG) waste rock are currently being deposited in the waste rock facility (WRF) at Mary River Project, operated by Baffinland Iron Mine Corporation (Baffinland) and located on Baffin Island in Nunavut. The mitigation strategy defined for prevention of acid generation and metal leaching from the pile centers on placement of PAG rock away from the edges of the pile and progressive freezing of the pile during winter that maintains the PAG rock in frozen conditions at all times after it is frozen.

In 2019, Golder conducted a thermal assessment (Golder 2019b) to evaluate the thermal regime in the pile and support the design of a waste rock deposition plan aimed to support freezing of the pile. The 2019 study included a review of initial instrumentation data (i.e. thermistors and oxygen probes) and preparation of thermal models for the period between March and September 2019.

This document presents an update to the 2019 thermal assessment with incorporation of supplemental instrumentation data available up to November 2020 and update of thermal models. The main goal was to re-evaluate the potential influence of internal heat sources on the thermal regime of the pile.

2.0 FIELD INSTRUMENTATION

2.1 General Characteristics

Between December 2018 and February 2019, field instrumentation was installed within the waste rock pile consisting of thermistors strings, oxygen probes, vibrating-wire piezometers and a barometer. Vertical strings were installed along boreholes BH1, BH2 and BH3 up to 23 m in depth, while three 40-m long horizontal strings were installed along trenches T3, T4 and T5 at initial depth of about 1.5 m (additional waste rock has been placed on top of some areas since installation). In addition, two 5 m deep vertical thermistors were installed to monitor the thermal performance of the future WRF pond berm expansion foundation (T1) and the WRF north toe berm (T2) as presented in Golder (2019a).

Figure 1 shows the locations of boreholes BH1, BH2 and BH3, as well as locations of the horizontal thermistor strings T3, T4 and T5. Figure 1 also shows the location of a cross section defined for the thermal modelling assessment.

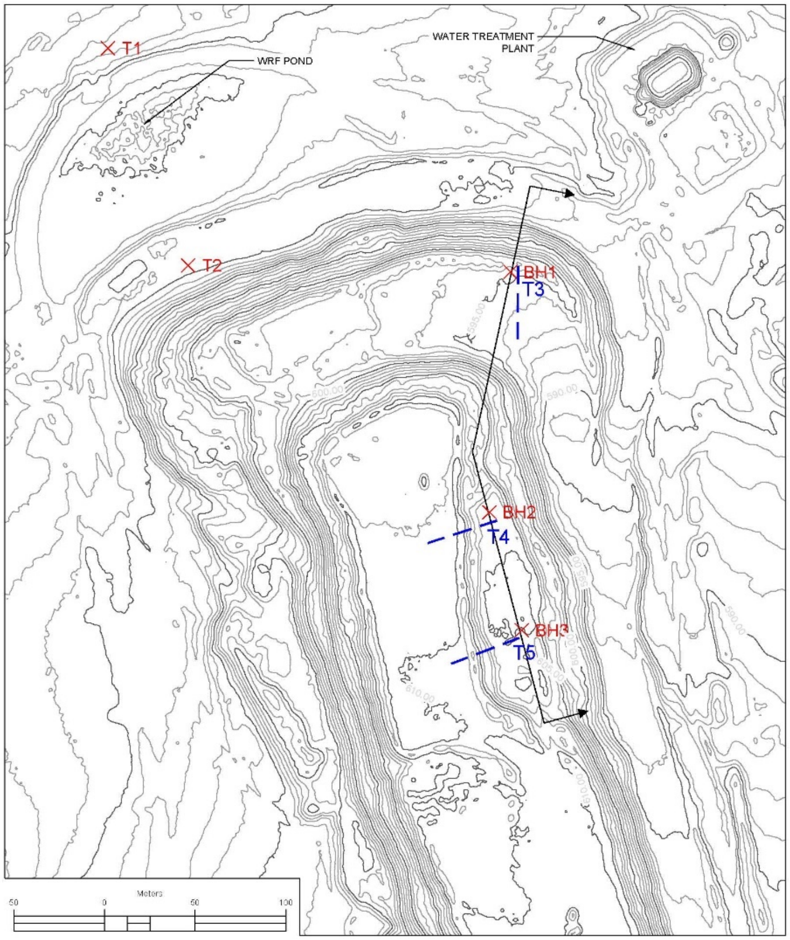

Figure 1: Locations of vertical and horizontal thermistor strings and alignment of cross section defined for the thermal models.

Since installation of the monitoring stations in February 2019, the pile has been progressively constructed with placement of Non-PAG and PAG rock at different locations. Based on survey data provided by Baffinland for the WRF from June 2019, March 2020, June 2020 and September 2020, approximately 0.2 m and 2 m of rock was placed on top of BH1 and BH3, respectively, between June 2019 and March 2020. At the location of BH2, approximately 6 m of rock was placed between March and June 2020.

Temperature data for BH2, BH3, T4 and T5 was available through November 2020 and data for BH1 and T3 was available through August 2020. Some thermistor beads were damaged, and the status of the oxygen probes are currently uncertain. A summary of instrumentation status through 2020 is presented in Table 1.

Table 1: Summary of instrumentation status during 2020.

Sensor / Station	Data Available Through	Damaged sensor	Rock placed on top
Temperature / BH1	31-August-2020	Bead at 20 m, after September 2019	≈ 0.2 m between June 2019 and March 2020
Oxygen / BH1	9-May-2020	Uncertain after May 2020	
Temperature / BH2	27-November-2020	Beads from 0.25 to 3.8 m (except for 1.3 m), after September 2019	≈ 6 m between March and June 2020
Oxygen / BH2	19-August-2019	Uncertain after August 2019	
Temperature / BH3	27-November-2020	No damaged beads	≈ 2 m between June 2019 and March 2020
Temperature / T3	31-August-2020	No damaged beads	≈ 0.2 to 1.2 m between June 2019 and March 2020
Temperature / T4	27-November-2020	No damaged beads	Yes
Temperature / T5	27-November-2020	No damaged beads	Yes

2.2 Instrumentation Trends

2.2.1 BH1 Station

The following trends and patterns have been observed from this monitoring station since installation:

- Based on available data, the active zone subject to freeze and thaw cycles is about 1.8 m deep, with the pile remaining frozen year-round below that.
- Measured rockfill temperatures have been between -1°C at depth of about 2 m and -7°C at depth of 19 m, with some seasonal variations.
- A trend of slight increase in temperature has been observed below a depth of 10 m (e.g., temperature at depth of 19 m has increased progressively from -7.7°C in March 2019 to -7°C in August 2020).
- The sensors continue to capture temporary and localized sudden increases in temperatures in late Spring and early Summer. On June 14, 2019, an increase in temperature of up to 9°C was measured down to about 7 m in depth, followed by a quick reduction in temperature of about 8°C within 24 hours (Golder 2019b). In 2020, sudden temperature increases were measured mostly along depths of 4.9 and 6.9 m between July 4 and 17, with an increase of about 4°C in temperatures that was not observed outside this depth range during that short period of time.

- Some of the oxygen sensors installed in BH1 showed temporal variation in oxygen concentration that correlated with the June 2019 event of increasing rockfill temperature. Oxygen concentrations measured at a depth of 0.9 m decreased from about 22% on June 14, 2019 to 16% by the end of June 2019. Oxygen concentrations increased after that and have been between 19.2% and 20.8%, with the latest concentration value measured in the beginning of May 2020 being around 20.2%.

- Oxygen concentrations measured at a depth of 2.42 m were erroneous between mid-June and early July 2019. Concentrations decreased progressively after that to about 5% in the beginning of October 2019, increased suddenly to 12% on October 10, 2019 and showed a trend of steady decrease after that, with the latest concentration values measured in the beginning of May 2020 being around 0.4%. This pattern of continuing reduction in Oxygen concentrations was different from what was observed at the probe installed at a depth of 0.9 m, where reduction in concentrations was temporary and values returned to background levels shortly after with O_2 replenishment associated with air diffusion and/or advection. The fact that at a depth of 2.42 m the supply of O_2 was cut off is unusual considering the relative proximity of the sensor to the surface of the pile and suggests that reduction in concentrations were related to localized circumstances around the sensor that do not reflect a general trend in the pile.

- The oxygen probes installed at depths of 4.9 m and 11.4 m showed much smaller reductions in oxygen concentration (i.e., less than 0.5% O_2) during the June 2019 event of increase in rockfill temperature, but due to sensor resolution and the influence of other factors such as air temperature and barometric pressure on sensor output, it is not clear if that small reduction in concentration was, in fact, related to sulphide oxidation. These sensors have remained with O_2 concentrations above 20% during the monitoring period between March 2019 and May 2020 in which data was available.

Figure 2 shows temperature profiles measured along BH1 during the July 2020 event of localized increase in rockfill temperature.

Figure 3 shows temporal variation in temperatures for selected depths between 0.9 and 9.9 m since March 2019. Figure 3 also shows oxygen concentrations at depths of 0.9 and 2.42 m, where variation in concentrations have been observed.

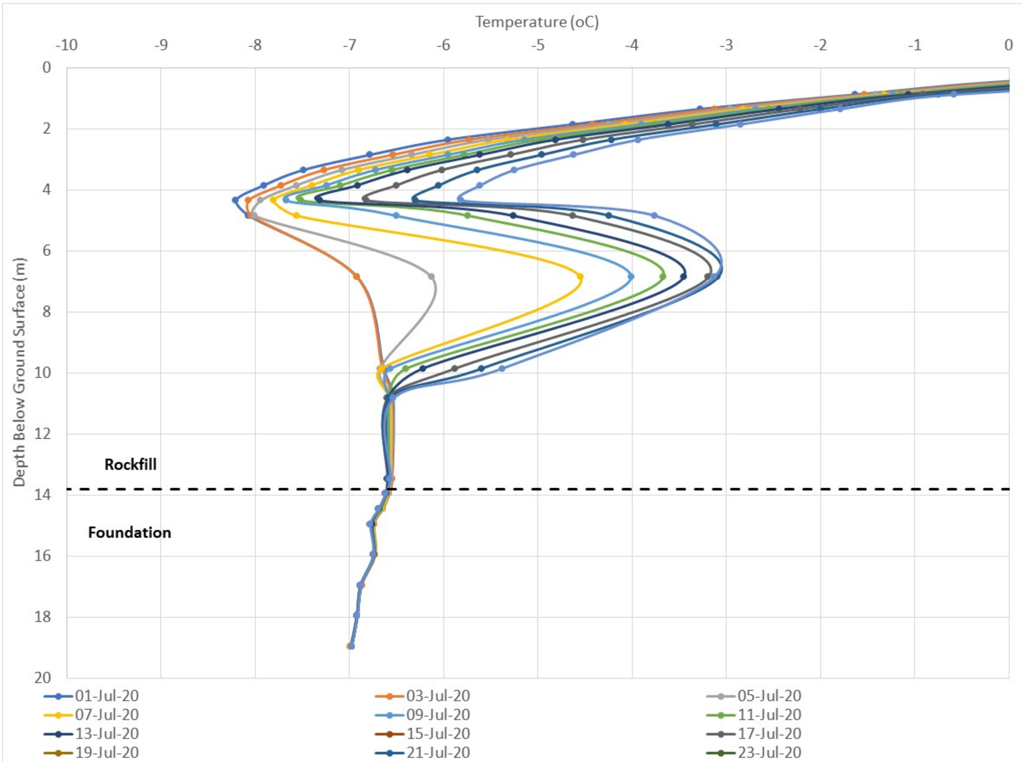

Figure 2: Localized variation in temperatures along BH1 in July 2020.

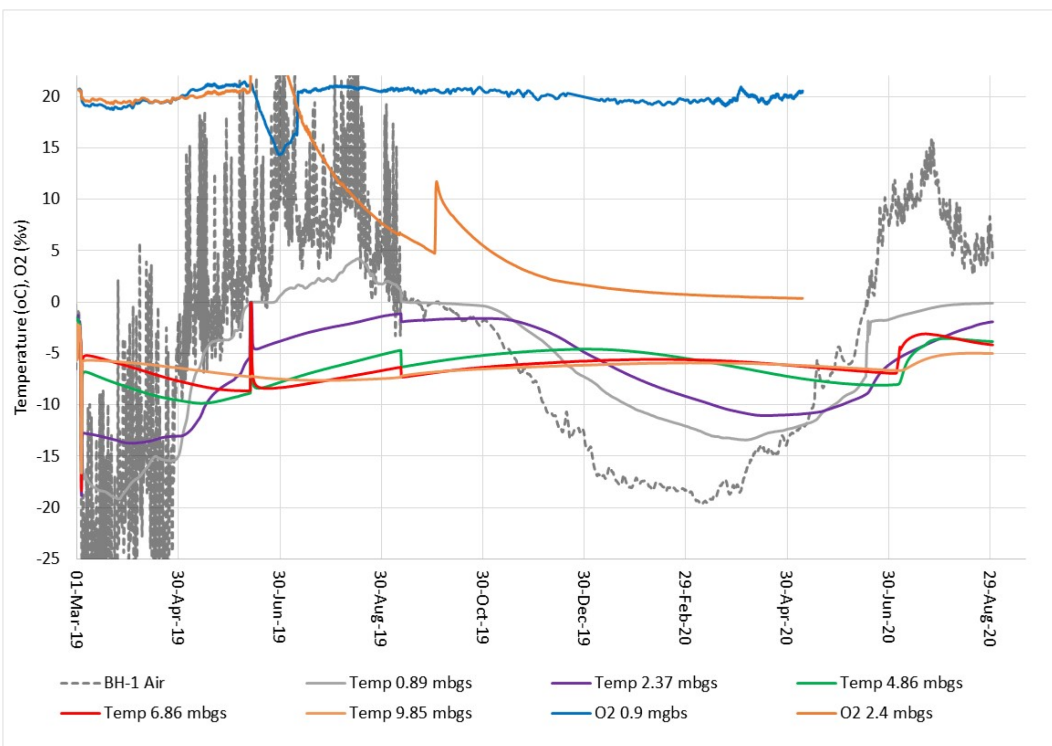

Figure 3: Variation in temperature and oxygen concentrations with time within BH1.

2.2.2 BH2 Station

About 6 m of rock was deposited on top of BH2 after March 2020 and this has caused changes in temperature patterns compared to 2019. The following trends and patterns have been observed:

- No data was available from the oxygen probes after September 2019, and therefore it is not possible to assess if the variations in oxygen concentrations observed in early Summer 2019 (Golder 2019b) continued to occur in 2020 after additional rock was placed on top of BH2.
- Sudden increases in rockfill temperature of up to 4°C were observed in July 2019 between depths of 4 m and 13 m (Golder 2019b), but in 2020 there were no events of rapid temperature increase.
- All beads that continued to be operative after September 2019 showed rockfill has been frozen below -2.5°C through the end of November 2020, which is related with additional rock placed on top of BH2 after March 2020.
- A trend of slightly cooling temperatures has been observed at beads originally installed at depths of 10 m since March 2019.

Figure 4 shows variation in temperatures with time at selected depths (i.e., original beads installation depths before placement of additional rock in March 2020).

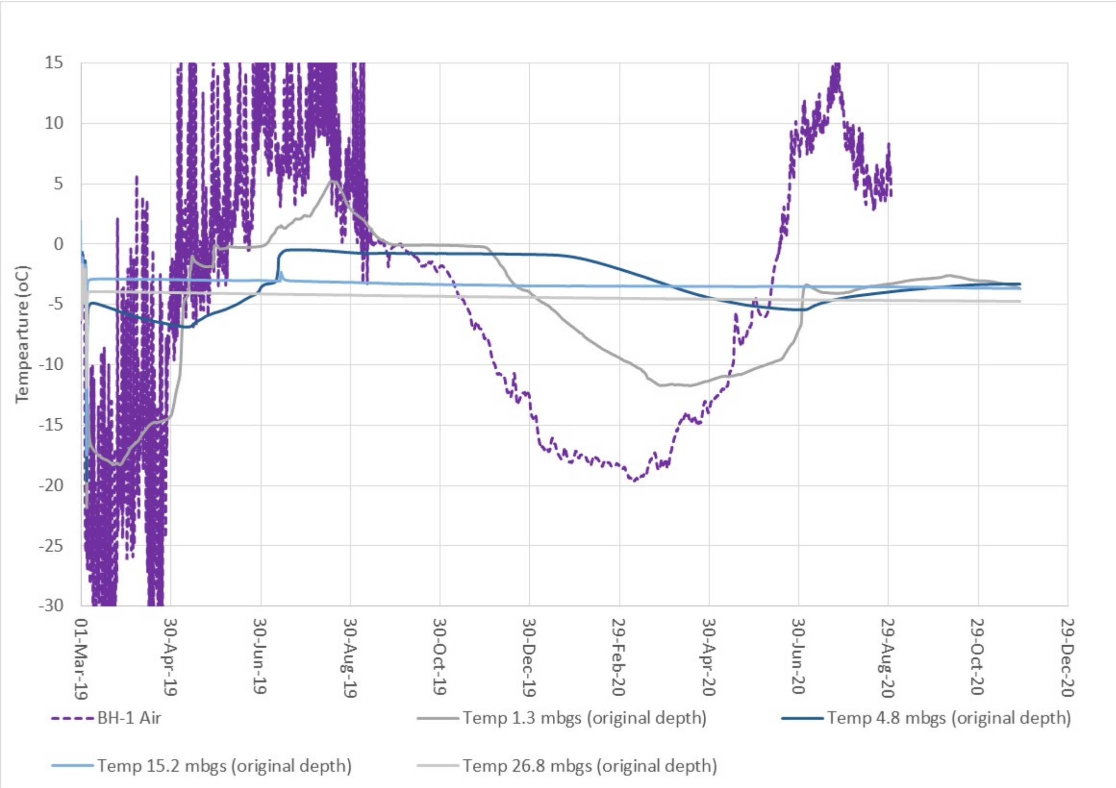

Figure 4: Variation in temperature with time along BH2.

2.2.3 BH3 Station

About 2 m of rock was deposited on top of BH3 between September 2019 and March 2020, and this has affected temperatures measured by the thermistor string. The following patterns and trends have been observed:

- Based on 2020 data, the active zone subject to freeze and thaw cycles is inferred to be about 3 m deep, which is similar to what was observed in 2019.
- All thermistor beads below the original installation depth of 1 m (i.e., approximately 3 m in depth in 2020), showed frozen rockfill throughout 2020 with temperatures ranging from -0.5ºC near the top to -5.5ºC at the bottom of the string.
- A trend of slightly cooling temperatures at beads below original installation depth of 10 m has been observed since March 2019.
- A period of sudden increase in temperatures between original installation depths of 2 and 3 m was observed in mid-June 2020.
- A period of sudden decrease in temperatures at original installation depth of 5 m was observed in mid-November 2020.

Figure 5 shows localized variation in temperatures at depths along BH3 observed in mid-June and mid-November 2020, and Figure 6 shows variation in temperature with time at selected depths (i.e. original installation depths before rock placed on top of BH3).

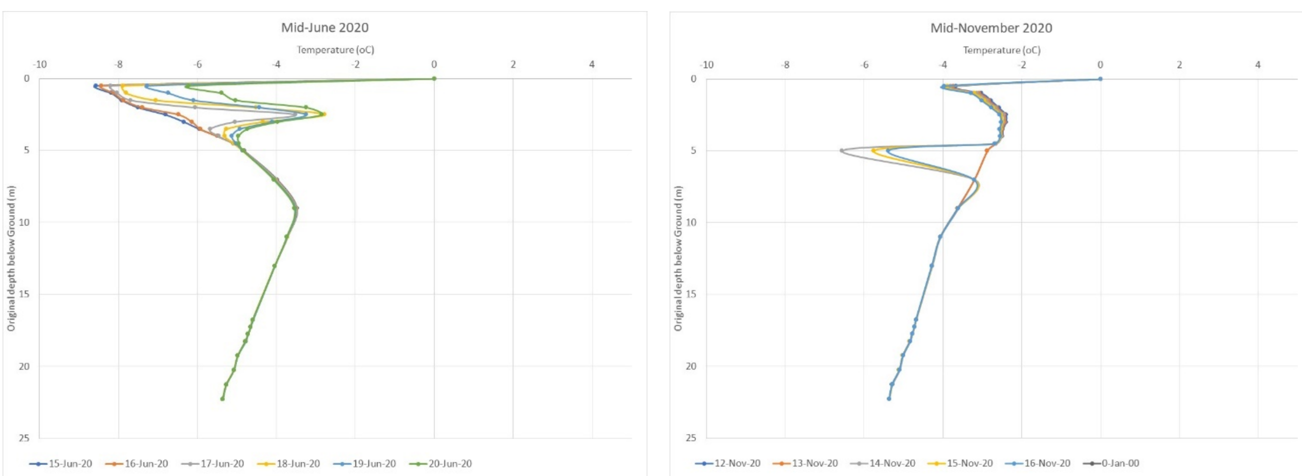

Figure 5: Sudden variation in temperatures measured along BH3 in June and November 2020.

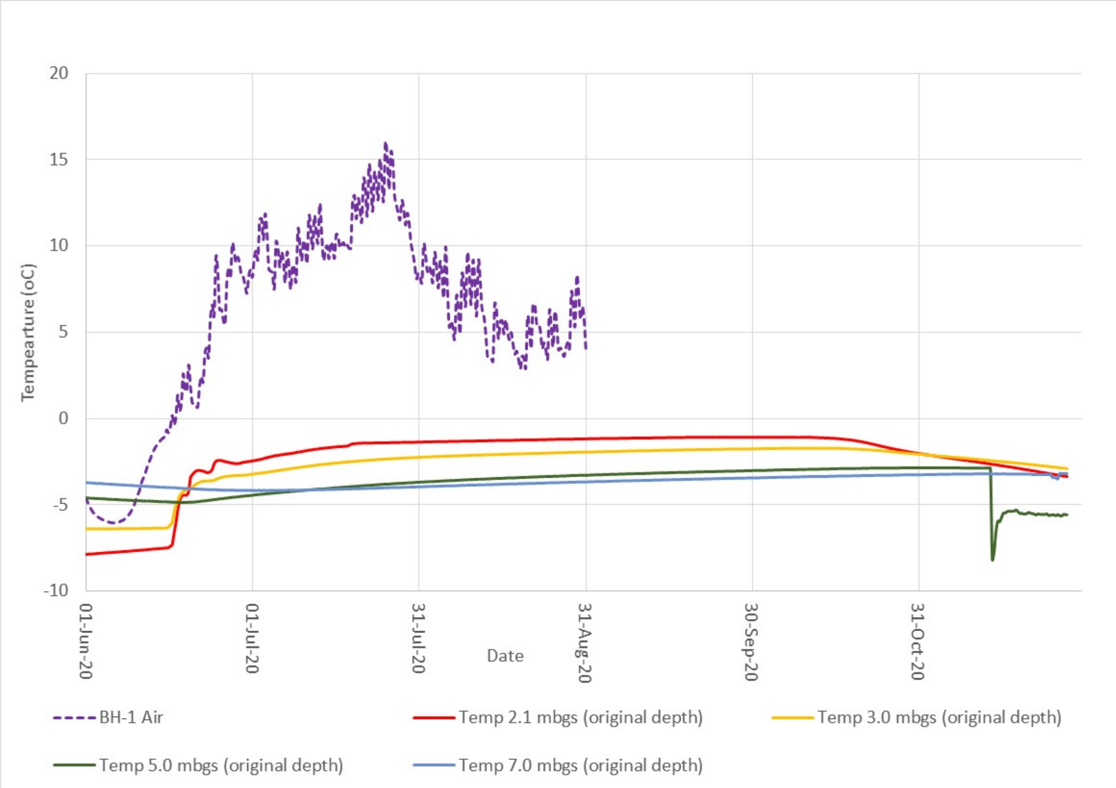

Figure 6: Variation in temperature with time at selected depths along BH3, with emphasis to the June and November 2020 sudden changes.

2.2.4 Horizontal Lines T3, T4 and T5

The following trends and patterns are observed from the horizontal lines, which run inwards for a total length of about 40 m from the edge of the pile.

- T3 is within the same area of BH1, where the least amount of rock was deposited in 2020. Other than the first 4 m in length from the edge of the pile that remained frozen year-round, the rest of the line (i.e. from 4 m to 40 m in length) has been subject to seasonal freeze and thaw cycles as the sensors are within the active zone. There have been no visible events of localized sudden variation in rockfill temperature along this line since October 2019.
- T4 runs inwards from the edge of the pile starting adjacent to BH2. The entire line remained frozen through the end of November 2020, with higher variation in temperatures from the edge of the pile to about 16 m in length. The entire thermistor string showed less variation in temperature between -1^{o}C and -3^{o}C after July 2020, probably influenced by additional deposition of rock above.
- T5 runs from the edge of the pile starting adjacent to BH3. The entire string has remained frozen from the end of 2019 through the end of November 2020. There was a localized event of high increase in temperatures of about 7^{o}C along the first 10 m from the edge of the pile in the end of June 2020. This zone normally shows a trend of higher variation in temperatures compared to the second half of the string that is farther inside the pile (i.e. from 20 to 40 m length). This period of high increase in temperature appears related to increases in the air temperature and was likely associated with air flow through the pile.

Figure 7 shows variation in temperature during 2020 along T5 for selected lengths from the edge of the pile to the end of the string about 40 m inside the pile. Variations in air temperature is also shown in Figure 7 with visible correlation with the localized June 2020 event of increase in rockfill temperature.

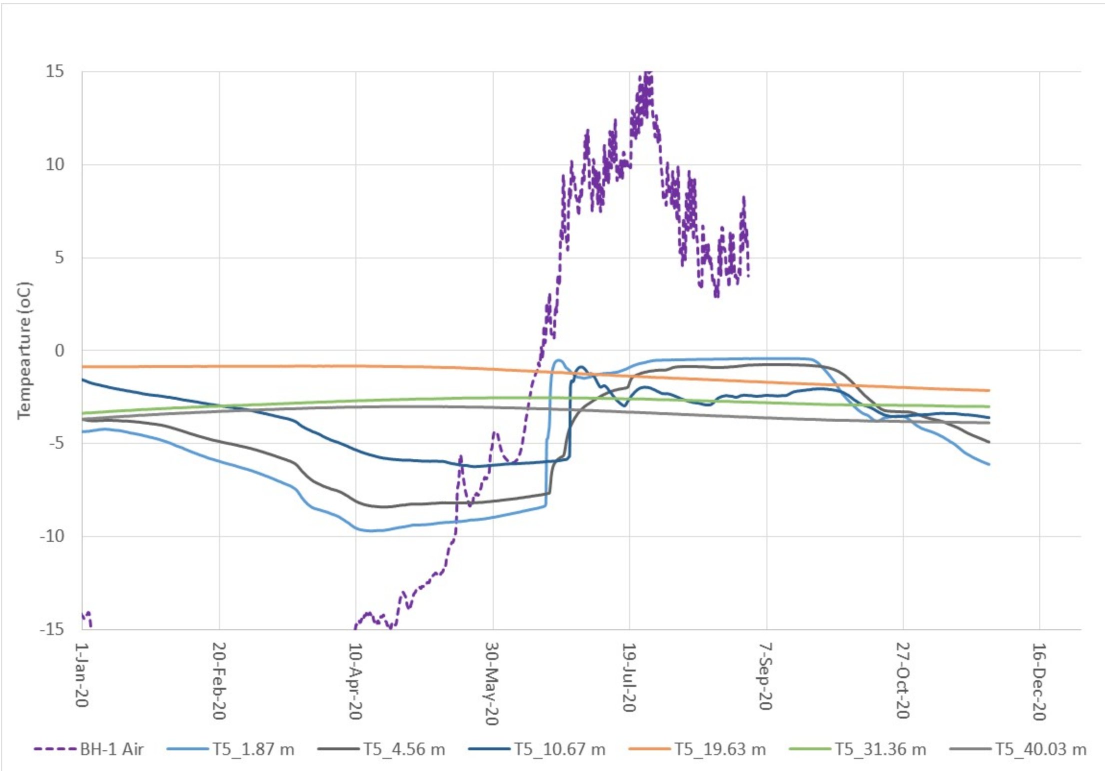

Figure 7: Variation in temperatures along T5 in 2020 from the edge of the pile (0m) to the end of the string (40 m).

2.3 Summary and Discussion

Combined, instrumentation deployed along the six monitoring locations indicates the following patterns and trends:

- The portions of the pile monitored by the temperature probes remained entirely frozen throughout the monitoring period, except for the active zone within 2 to 3 m in depth, which is subject to seasonal freeze and thaw cycles.
- Reduction in oxygen concentration in some of the oxygen probes installed in BH1 (up to May 2020) and BH2 (up to September 2019) suggests that temporary and localized sulphide oxidation is occurring in the pile. However, based on correlations of rockfill temperature and oxygen concentrations, it appears that increases in temperature associated solely with internal heat generation is linked to sudden spikes in temperature followed by rapid decreases, as observed in BH1 between depths of 2.5 and 6 m in mid-June 2019 (Figure 3).
- All events of sudden increases in rockfill temperatures observed so far have occurred between June and July, when air temperature typically rises above the freezing mark and snowmelt and freshet occur. This suggests that localized flow of warmer air, and likely water flow associated with snowmelt during freshet, through preferential paths in the pile is playing a role in the pile's thermal regime (see Figure 3). The effect of air flow

through the pile was also evidenced by an event of sudden reduction in temperature measured at a depth of 5 m (original installation depth) in BH3 in mid-November 2020 (see Figure 5).

- Direct correlation of rockfill temperature and oxygen concentrations measured by probes installed in BH1 and BH2 at different depths and times suggests that rockfill temperatures are mostly influenced by variations in air temperature and air flow through the pile rather than heat release from sulphide oxidation. The patterns of variation in rockfill temperature do not show any significant deviation from the pattern of variation in air temperature.
- It is probable that the thermal regime of the pile is affected by a combination of seasonal variations in air temperature, preferential air flow through the pile and temporary localized heat generation associated with sulphide oxidation and/or mineral dissolution, but the fact that, other than the active zone subject to seasonal freezing and thawing, the pile remained frozen during all times indicates that the site cold climatic condition is the prevailing mechanism governing the thermal regime in the pile, as intended in the design.

3.0 NUMERICAL MODELLING

3.1 Thermal Model Update

The thermal model prepared previously (Golder 2019b) was based on limited instrumentation data available for the period between March and September 2019. Calibration of the 2019 model in portions of the waste rock pile adjacent to BH2 and BH3 using this limited data set was only attained with inclusion of continuous and widespread assumption of internal heat generation that was further assumed to correlate with sulphide oxidation. The main purpose of this model update was to recalibrate the thermal model based on an expanded instrumentation dataset to evaluate if, in fact, internal heat generation is affecting the thermal regime of the pile.

Transient two-dimensional (2D) thermal modelling was carried out using the finite element software TEMP/W of GeoStudio 2020, developed by GEO-SLOPE international Ltd. Update of the thermal model was conducted using the same waste rock pile cross section defined in 2019 along the alignment of boreholes BH1, BH2 and BH3 as shown in Figure 1. Data from thermistors installed along these boreholes for the period between September 2019 and November 2020 was used for model recalibration purpose.

The models were run for the period between September 11, 2019 and November 31, 2020, with the patterns of temperature profiles predicted along boreholes BH1, BH2 and BH3 being compared to values measured in the field for selected dates to validate the model input parameters. The model recalibration process consisted of adjusting model boundary conditions, timing of additional rock deposition on the pile, and running trials with and without the inclusion of heat generation until the predicted patterns of temperature variations were in general agreement with measured values.

The model geometry was adjusted to incorporate rockfill placed in the pile after September 2019 based on surveys provided by Baffinland for different dates in 2019 and 2020. Using sensitivity trials, the calibrated model scenario included instant placement of rock on top of BH1 and BH3 in November 2019, and instant placement of rock on top of BH2 in March 2020. Figure 8 shows the updated model geometry.

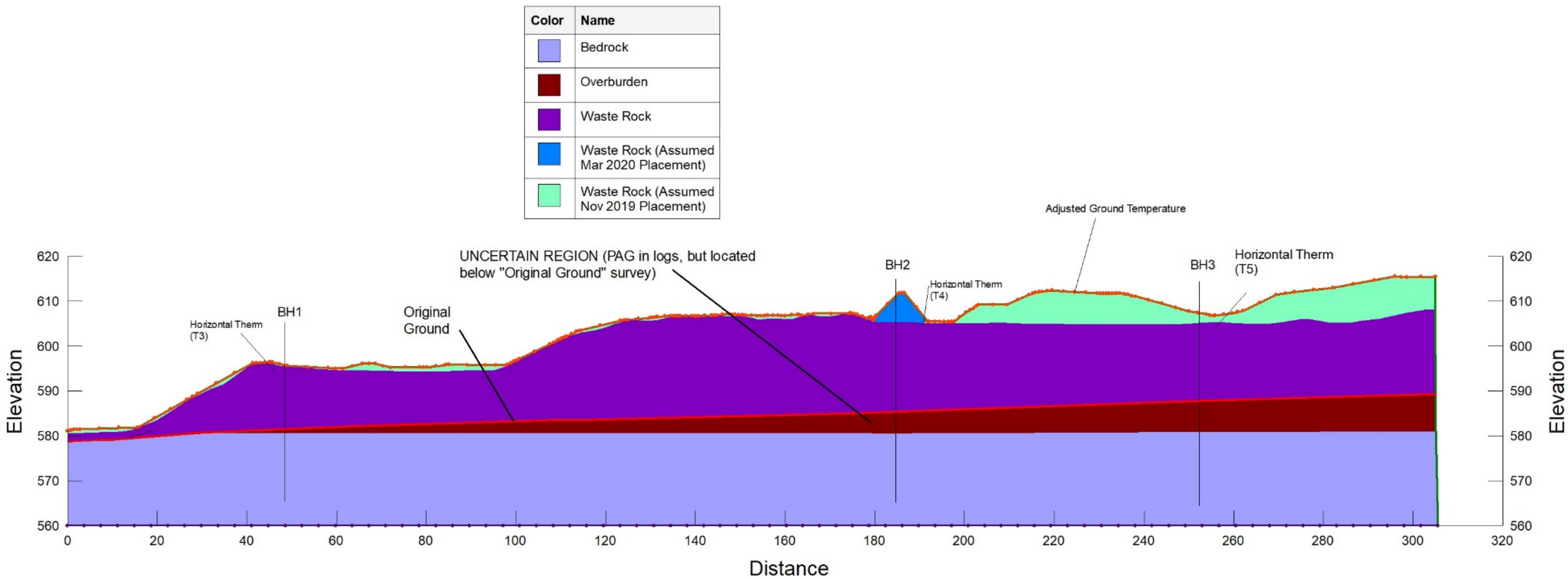

Figure 8: Updated cross section of the Waste Rock Facility defined for the thermal models.

3.2 Material Properties

The thermal properties of waste rock used in the models were the same defined in the 2019 study, based primarily on the results of laboratory testing conducted as part of the 2019 thermal assessment (Golder 2019b). Table 2 summarizes the material thermal properties used in the models.

Table 2: Thermal properties of materials included in the thermal models.

Material	Volumetric Water Content	Thermal Conductivity (W/m-°C)		Volumetric Heat Capacity (MJ/m3-°C)	
		Frozen	Unfrozen	Frozen	Unfrozen
Waste Rock	8%	1.95	1.8	1.7	2.0
Overburden	35%	2.1	1.5	2.2	2.8
Bedrock	1%	2.9	2.9	2.4	2.4

3.3 Boundary Conditions

Boundary conditions in the model were mostly like those used in the 2019 study, but with adjustments made to the ground surface temperature to reflect 2020 conditions.

An initial model scenario was run using the general ground surface temperature boundary condition created for the 2019 thermal models. These models did not produce results in agreement with measured data from 2020 suggesting the ground surface temperature function needed to be adjusted. When comparing the 2019 and 2020 climate records from thermistor beads at or above surface at BH1, it was observed that the 2019 air temperature was up to 5°C colder than 2020 in winter months, and up to 6°C warmer than 2020 in summer months. As such, a new ground surface temperature boundary condition was created based on data obtained from the thermistor bead installed at a depth of 0.1 m in BH1 for the period between September 2019 and August 2020 as shown in Figure 9. Figure 10 shows a comparison of the 2019 and 2020 ground surface temperature functions.

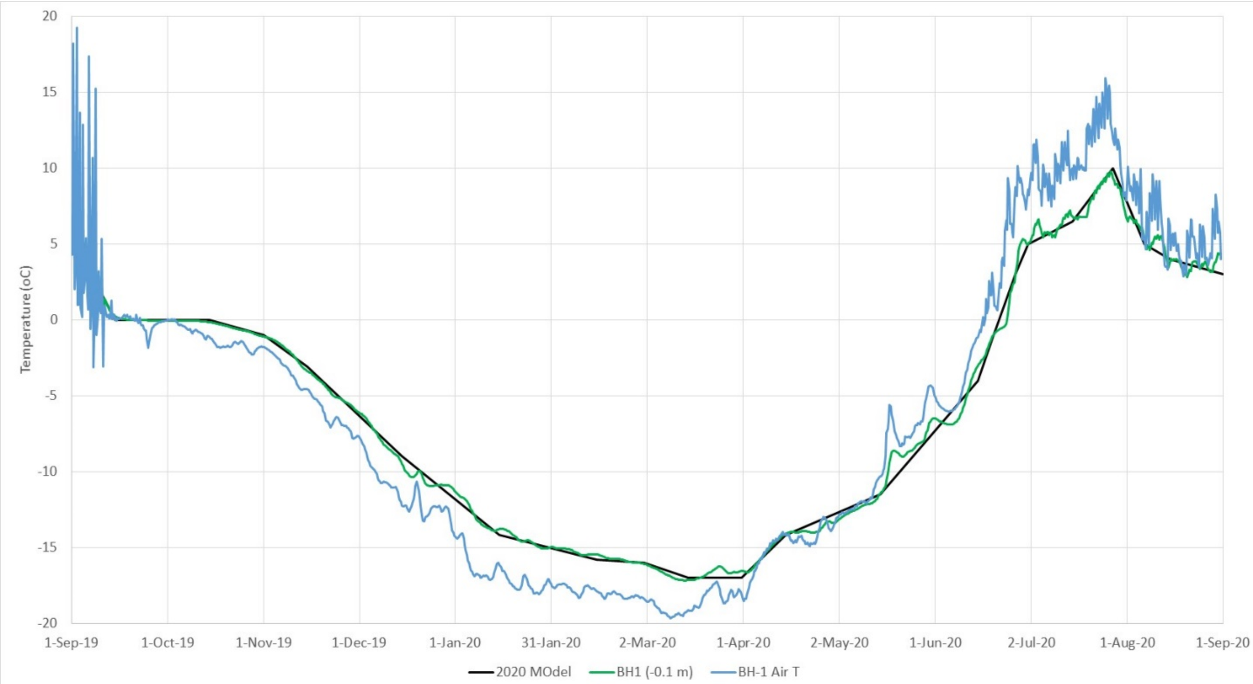

Figure 9: Variation in air and ground surface temperatures used as reference for the 2020 thermal model update.

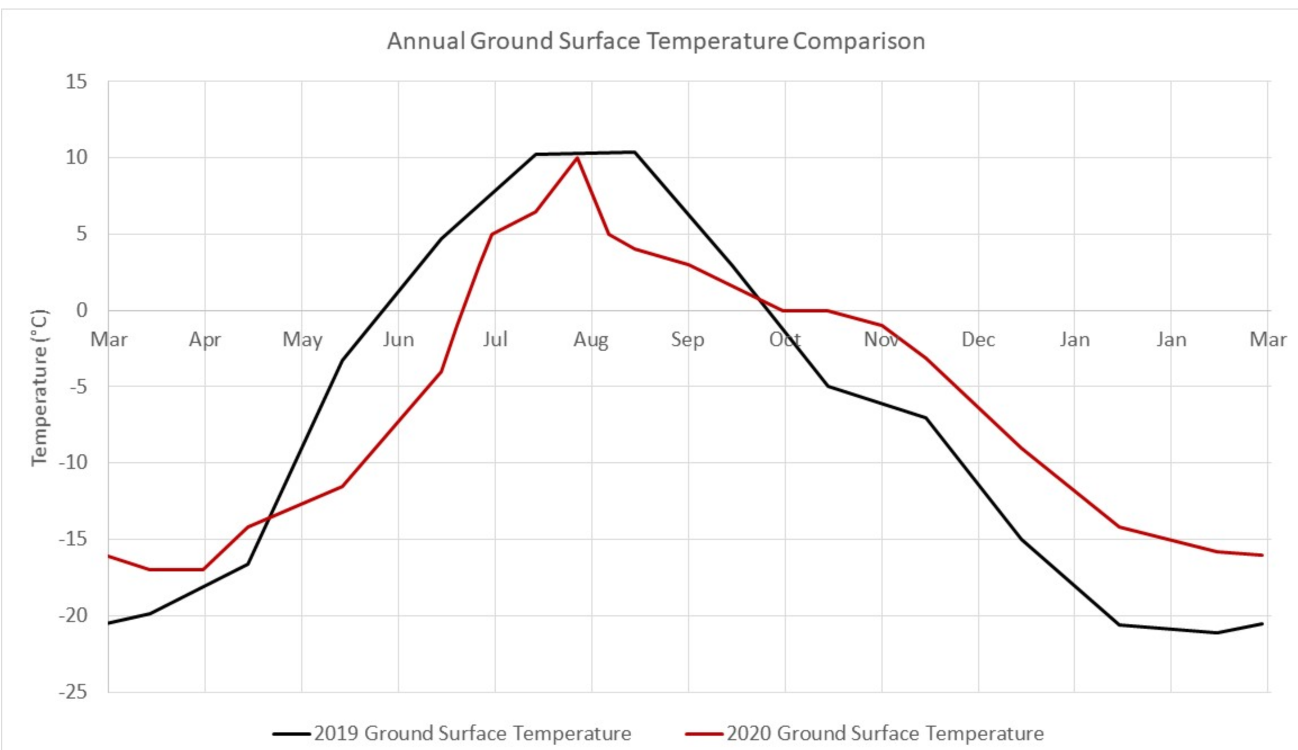

Figure 10: Comparison of ground surface temperature functions defined for the 2019 and updated for the 2020 modelling exercise.

A constant temperature of -8ºC was defined as boundary condition at the base of the model geometry at elevation of 560 m, between 20 to 30 m below the original ground surface along the location of the model cross section. This value was defined based on thermal gradients estimated from the deepest beads of thermistors installed along boreholes BH-1, BH-2 and BH-3.

For the base case model scenario, a heat flux boundary condition was not incorporated in the model.

3.4 Sensitivity Model Scenarios

In addition to the base-case model scenario without incorporation of internal heat generation, a model scenario with inclusion of localized internal heat at a depth of 2.4 m along BH1 (where reference oxygen and temperature probes are installed) was prepared to evaluate conceptually how much impact on rockfill temperature a localized event of heat generation could have.

The oxidation of sulphide minerals such as Pyrite occurs through exothermic reactions like the one below.

$$4FeS_2\ (pyrite) + 15O_2 + 2H_2O \rightarrow 2Fe_2(SO_4)3 + 2H_2SO_4$$

The oxidation of 1 mole (120 g) of Pyrite releases approximately 1409 kJ of heat and uses about 3.75 moles (120 g) of O_2.

The amount of heat generation included in the model as an internal heat flux boundary condition was defined based on the mass relationship between O_2 and Pyrite consumptions described above, and the estimated amount of pyrite oxidation that would have been associated with reduction in oxygen concentrations as measured between July 2019 and January 2020 by the oxygen probe installed in BH1 at a depth of 2.4 m. Although it is not clear what process cut off the supply of oxygen to this sensor, it is the one that showed continuous reduction in oxygen concentrations for the longest period of time compared to the other sensors, and therefore was considered a good reference for a conceptual evaluation of the impact of localized internal heat generation for a prolonged period of time.

Assuming an average air density of 1292 g/m^3 at 0ºC temperature (approximately 298 g of O_2/m^3) and using oxygen consumption rates as measured at a depth of 2.4 m in BH1, it was estimated that a total of 3.1 moles of Pyrite / m^3 would have been oxidized during two periods between July 2019 and January 2020. This amount of pyrite oxidation would release a total of approximately 4368 kJ of heat at an estimated maximum rate of 31.7 kJ/day, as illustrated in Figure 11.

The estimated maximum heat generation rate was incorporated in the model geometry between depths of 2 and 3 m along BH1 for a period between November 2019 and March 2020, and results were then compared to the base case model scenario (without internal heat) to assess changes in temperatures associated with the localized internal heat generation modelled.

In addition, a second sensitivity model scenario was run that incorporated widespread heat generation in portions of the pile adjacent to BH2 and BH3 for a period of three months between June and August 2020. Results of this second sensitivity scenario were compared to the base case model without heat to assess the potential impact in the thermal regime of the pile.

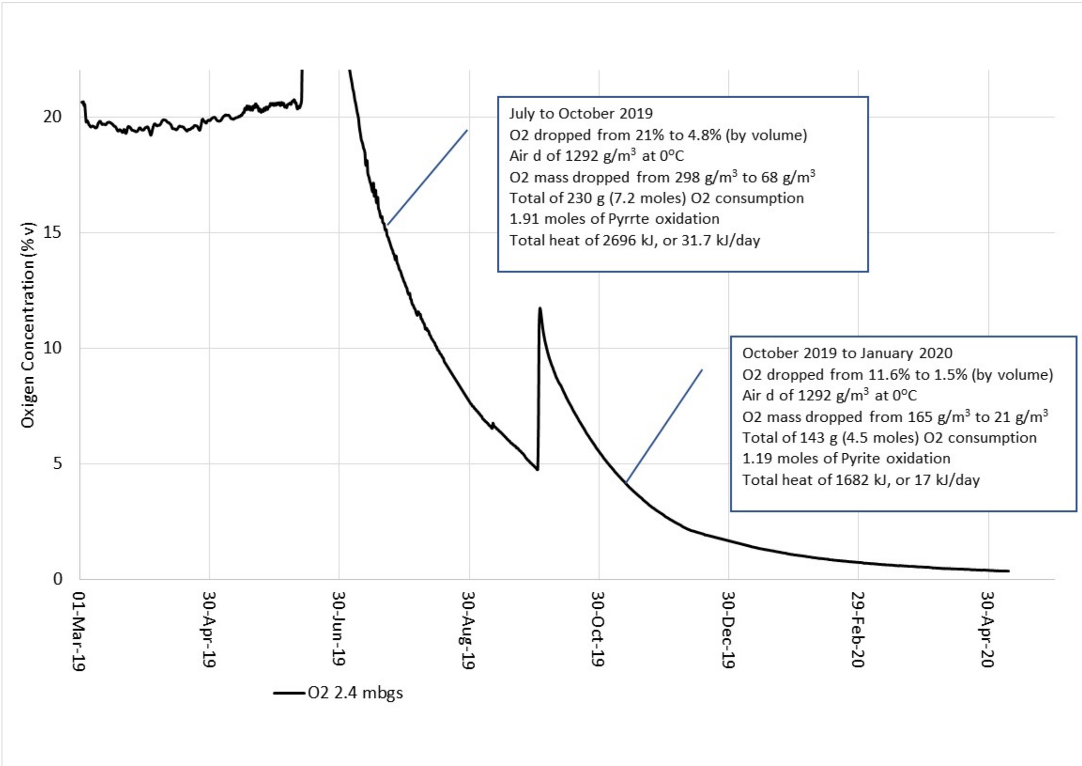

Figure 11: Estimated heat generation rate based on reduction in oxygen concentrations measured in BH1 at depth of 2.4 m.

3.5 Model Limitations

The models prepared for this study constitute a simplification of the field reality and carry assumptions and limitations that shall be taken into consideration during interpretation of model results. The most important model limitations are as follows:

- The models consider a homogeneous waste rock mass with no spatial variation in waste rock properties. Waste rock piles typically present zones of segregated materials, densification and layering that affect the thermal and hydraulic characteristics of the pile, as well as can work as preferential pathways for air flow that can impact internal temperatures.
- The updated model geometry considered instant placement of additional waste rock in the pile in November 2019 (around BH1 and BH3) and March 2021 (over BH2), based on survey data. Waste rock is placed progressively throughout the year and the timing and sequence of waste rock deposition affect the thermal regime.
- The thermal models compute variation in temperature associated only with conduction and is not set to incorporate the impact of heat transfer associated with air and water flow through the pile. Instrumentation data suggest that air flow is an important component affecting the thermal regime of the pile, and snowmelt during the freshet season can also have an effect.

- The two-dimensional nature of the thermal models can only capture heat transfer along the cross section and does not incorporate three-dimensional heat transfer coming from adjacent areas.

4.0 MODEL RESULTS

4.1 Base Case (No Internal Heat)

Figure 12 shows temperature contours computed for the end of August 2020 within the model cross section, indicating that the pile was mostly frozen, except for the upper 2-3 m layer of active zone.

Figures 13 to 15 show a comparison of predicted and measured temperature profiles for selected dates along BH1, BH2 and BH3, respectively.

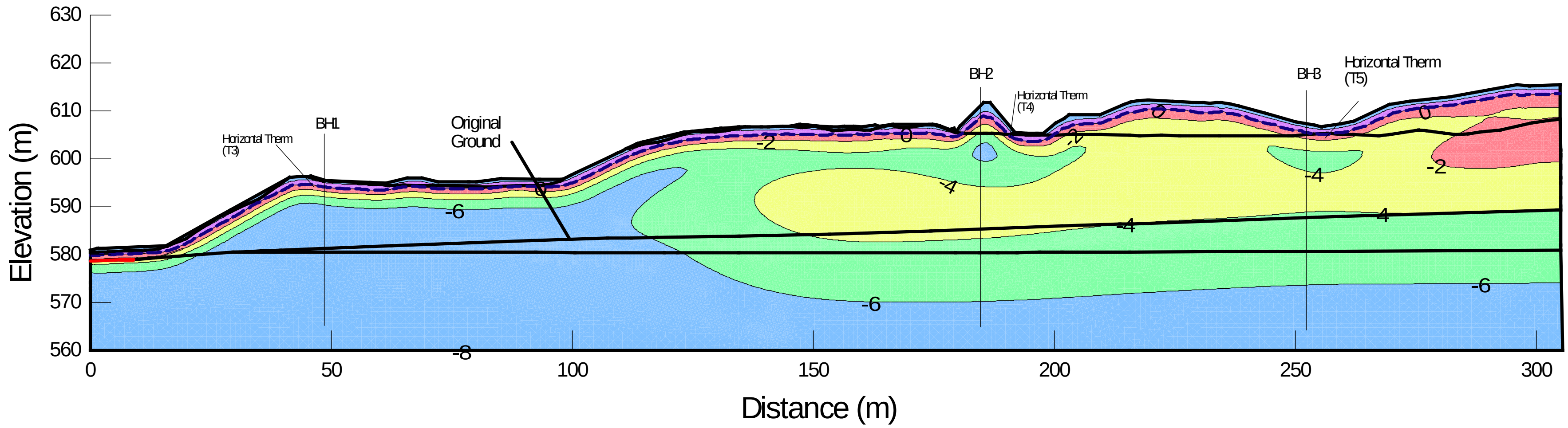

Figure 12: Temperature contours within the model cross section predicted for the end of August 2020.

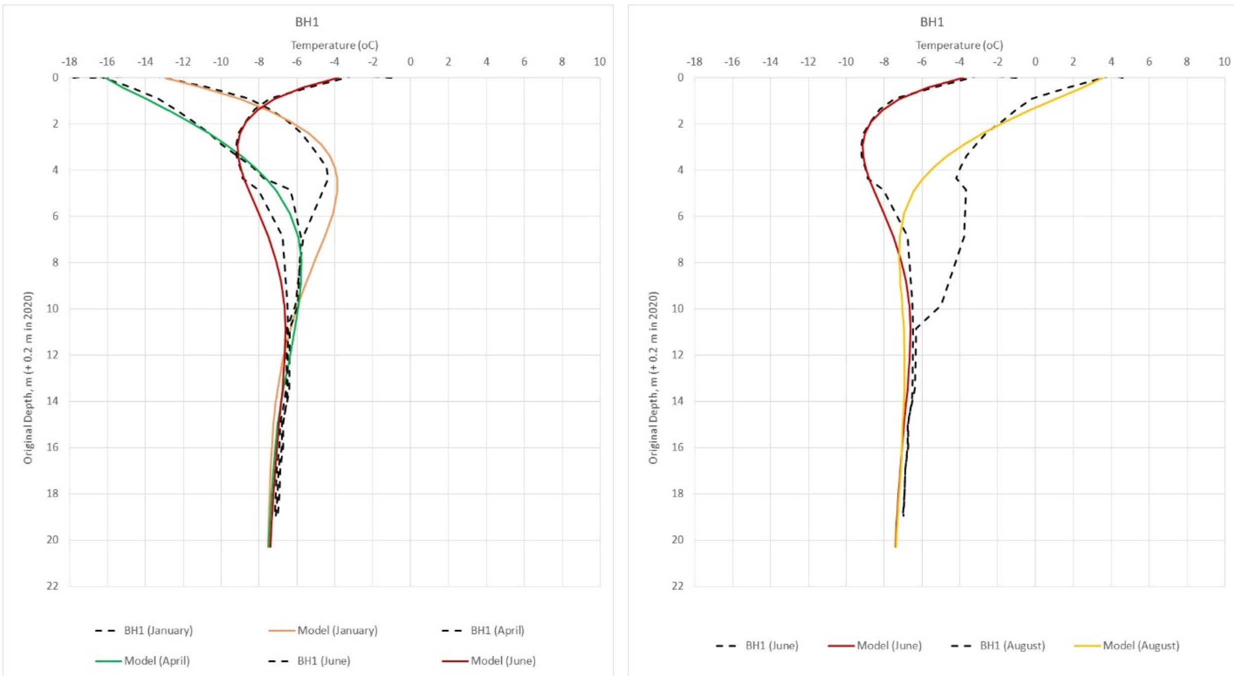

Figure 13: Comparison of measured and predicted temperature profiles along BH1 in 2020 (no internal heat added).

For BH1, the predicted temperature profiles for January, April and June 2020 in general represent well the patterns measured by the thermistor string, except for depths between 6 and 7 m, where predicted temperatures were warmer than measured in January 2020 and colder than measured in June 2020.

The predicted temperature profile for August 2020 was much colder than measured at depths between 3 and 10 m, and this is because the model is unable to capture sudden and localized variations in temperatures like measured in BH1 between depths of 4.5 and 9 m in July 2020.

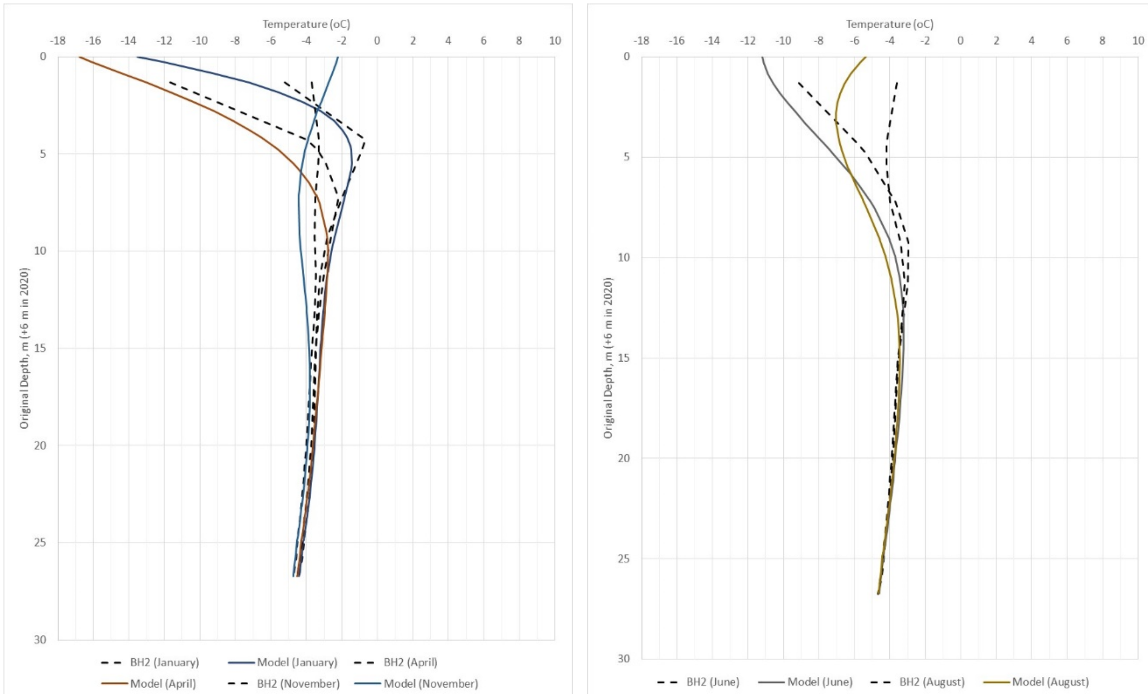

Figure 14: Comparison of measured and predicted temperature profiles along BH2 in 2020 (no internal heat).

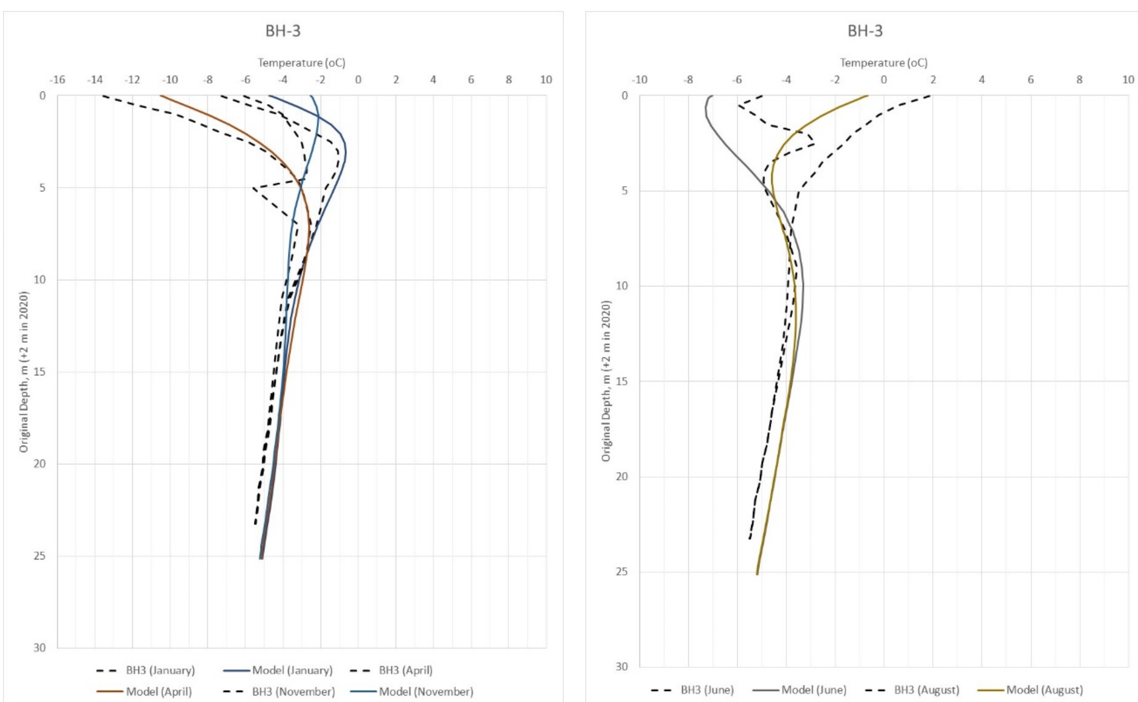

Figure 15: Comparison of measured and predicted temperature profiles along BH3 in 2020 (no internal heat).

For BH2, although the predicted pattern of variation in temperature with time followed the trends measured on site, the predicted temperature profiles were in general colder than measured. Calibration of temperatures along BH2 was difficult because about 6 m of rock was placed on top between March and June 2020. The model assumed instant placement of 6 m of rock in March, but progressive deposition or deposition of rock later in spring would have affected the pattern of temperature change. Although model trials were run with instant deposition of rock on BH2 at different times, none of the scenarios was able to replicate conditions measured on site.

The same difficulty was faced for calibration of BH3, where some 2 to 4 m of rock was placed immediately adjacent to BH3 between June 2019 and March 2020, and the actual sequence and timing of rock deposition would have affected the pattern of variation in temperature profiles. Similar to what was done for BH2, different deposition dates were tried adjacent to BH3, with the best results attained for a scenario considering instant placement of rock in November 2019.

The calibrated model results for BH3 (Figure 15) for January, April, June and November 2020 in general represent well the patterns measured on site, although the model was unable to capture the localized sudden variations in temperatures measured in June and November 2020 between depths of 3 and 5 m (i.e. original beads installation depths). The temperature profile predicted for August was colder than measured and calibration was not attained for that specific date.

4.2 Sensitivity Scenarios With Internal Heat

Results obtained for the two sensitivity scenarios including a) localized internal heat between 2 and 3 m in depth along BH1 and, b) widespread internal heat along areas adjacent to BH2 and BH3 are summarized below.

4.2.1 Localized Heat in BH1

Figure 16 shows computed temperature profiles along BH1 for April 2020 and June 2020 comparing results of model scenarios without internal heat (base case) and with addition of localized internal heat generation between depths of 2 and 3 m following the trends measured by the oxygen probe installed in BH1 at depth of 2.4 m, as described in Section 3.4 and illustrated in Figure 11.

Figure 17 shows variation in predicted temperatures with time in BH1 at depth of 2.4 m between September 2019 and the end of March 2020 for the model scenarios with and without internal heat.

The model results suggest that, while localized progressive generation of internal heat can increase rockfill temperatures, the increase would be small using the level of internal heat generation estimated based on oxygen consumptions measured in BH1 (see Figure 11).

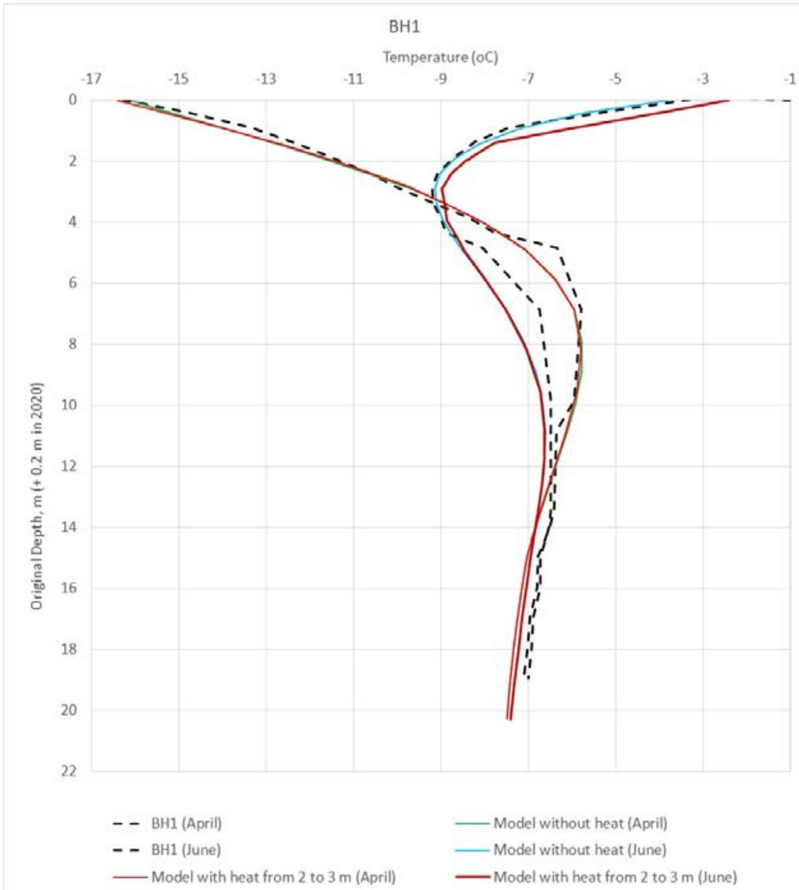

Figure 16: Comparison of temperature profiles along BH1 for model scenarios with and without internal heat.

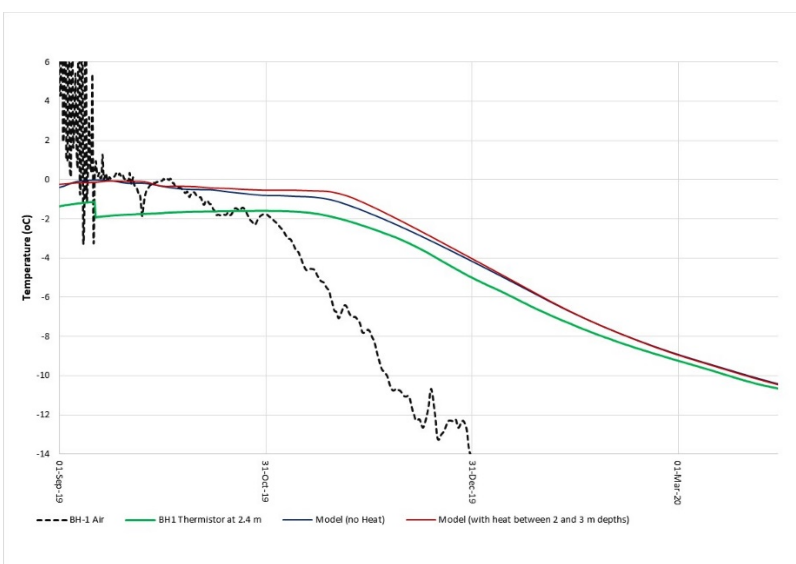

Figure 17: Variation in temperatures in BH1 at 2.4 m depth for model scenarios with and without heat generation.

4.2.2 Widespread Heat Adjacent to BH2 and BH3

Figure 18 shows temperature profiles along BH3 computed for June and August 2020 for the sensitivity model scenario that included widespread heat generation adjacent to BH2 and BH3 for the period between June and August 2020. Temperature profiles computed for the base case model scenario without inclusion of heat are also shown in Figure 18.

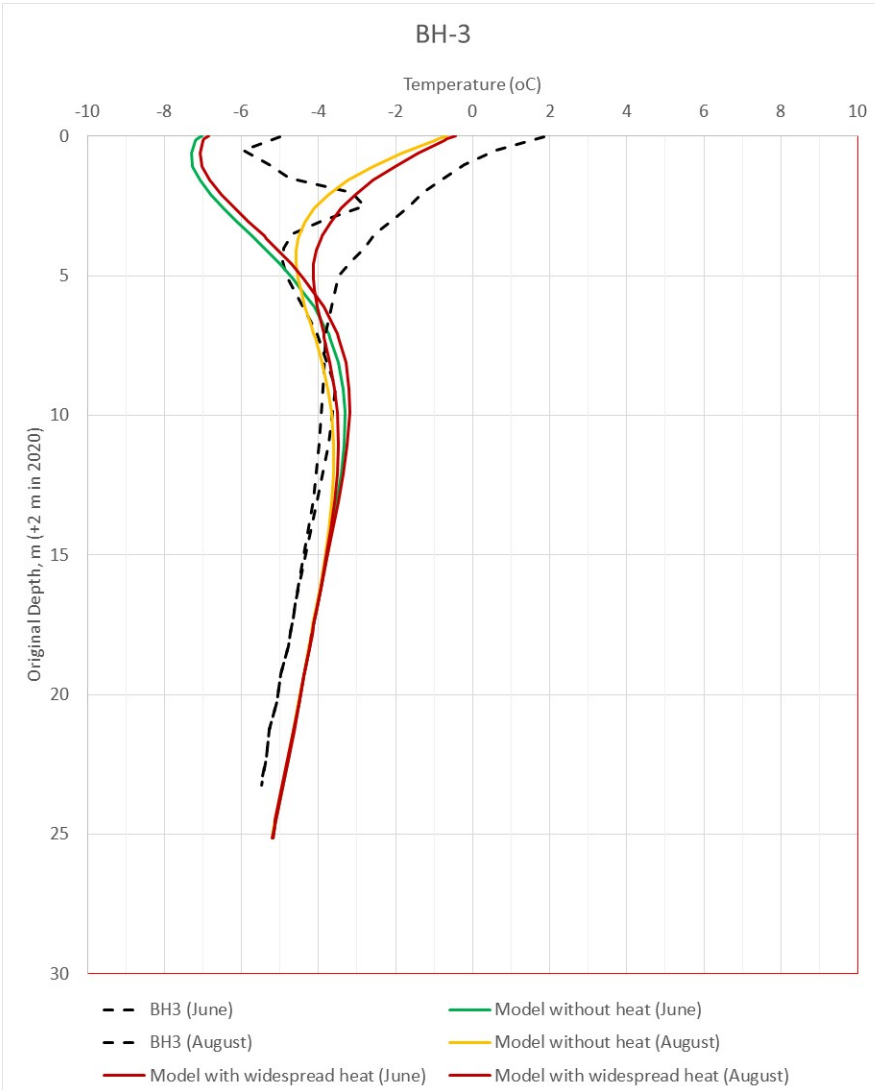

Figure 18: Temperature profiles along BH3 computed for the sensitivity model scenario with widespread heat generation between June and August 2020.

Results of the second sensitivity model scenario showed that even with the inclusion of widespread heat generation during summer time in 2020, predicted temperature profiles along the mid and upper portions of BH3 were still much colder than measured, indicating that heat generation associated with sulphide oxidation alone would not be enough to cause the variation in temperatures observed in summer, and that air flow must be playing a major role. Predicted temperatures at the lower portion of BH3 were warmer than measured for model scenarios with and without incorporation of widespread internal heat, suggesting that this discrepancy must not be related to internal heat.

5.0 CONCLUSIONS AND RECOMMENDATIONS

An update of the thermal assessment conducted in 2019 was carried out based on supplemental instrumentation data available for the period between September 2019 and November 2020. The following trends were observed from the instrumentation data:

- The areas of the pile monitored by the six monitoring stations remained frozen between March 2019 and November of 2020 (latest data available), except for the active zone within the upper 2-3 m of the pile that is subject to seasonal freeze and thaw cycles. This confirms that the design objective of maintaining the pile in frozen conditions during operations is being met.
- Some of the probes at different locations recorded localized rapid increases in temperatures in late Spring and early Summer of 2019 and 2020. In addition, a localized decrease in temperature was recorded about 5 m in depth along BH3 in November 2020. This suggests that air flow through preferential paths is occurring that temporarily affects temperatures in the pile. However, the fact the pile has remained frozen indicates the cold nature of the climatic site conditions is the main driver governing the pile thermal regime.
- Reduction in oxygen concentrations were recorded by the upper probes (i.e. 0.9 m and 2.4 m deep) in BH1 between June 2019 and January 2020. This indicates that sulphide oxidation, and the associated heat generation, may be occurring near the surface of the pile. However, other than a short period (i.e. a day or two) of sharp increase in rockfill temperatures followed by decrease in temperatures back to seasonal values, the evolution of temperatures with time during the period when reduction in oxygen concentrations occurred did not appear to have been affected by internal heat generation, and followed the trend of variation in air temperature, indicating that sulphide oxidation is not the main driver governing the thermal regime of the pile.

Thermal models were updated based on the instrumentation data available. The main trends observed in the models were as follows:

- Based on recalibrated models, the predicted patterns in variation in temperature profiles for the model scenario without consideration of internal heat within the monitoring locations BH1 and BH3 in general represented well the trends measured by the thermistor strings. However, predicted temperatures in the models were colder in summer compared to measured values.
- A sensitivity model scenario prepared with inclusion of localized internal heat generation at depths of 2 to 3 m along BH1 showed that, although an increase in rockfill temperature in that zone was predicted to occur, the increase was very small, reflecting the localized nature of internal heat, and not enough to interfere with the trend of rockfill temperature following seasonal variations in air temperature.
- A second sensitivity scenario with inclusion of widespread internal heat generation in portions of the pile adjacent to BH2 and BH3 from June to August 2020 resulted in larger increase in rockfill temperatures down to about 5 to 7 m beneath the original pile surface level in 2019, but even with the widespread heat generation, predicted temperature profiles were colder than measured on site.
- The results of these sensitivity scenarios suggest that flow of warmer air in late spring and summer is probably the main driver behind spikes in temperature that have been measured in the pile during that period. The influence of airflow was also evidenced by the sudden and localized decrease in rockfill temperature that was observed in mid-November 2020 about 5 to 7 m in depth in BH3. At any event, the models predict the pile will

continue to be frozen except for the active zone. As is evidenced by the instrumentation data, these localized variations in temperature are not preventing the pile from freezing as per the design intent.

The following recommendations are offered to help improve understanding of the factors affecting the thermal regime of the pile.

- Monitoring of the pile through instrumentation should continue to expand the dataset and validate the patterns identified so far.
- Instrumentation data constitute the primary means for evaluation of the thermal regime of the pile. Currently, only partial data is available from BH1 and the oxygen probes in BH2 have not recorded data since September 2019. It is strongly recommended that the monitoring stations be inspected and serviced regularly to ensure continuation of data acquisition. In addition, it is recommended that dates when rock is placed on top of the stations, and the amount of rock placed, be recorded to facilitate data interpretation.
- It is recommended that supplemental instrumentation stations be installed in the pile at different locations to expand the portion of the pile that is monitored and generate supplemental data for continual evaluation of the thermal regime of the pile.

6.0 CLOSURE

We trust the information provided in this document meet your expectation and needs. Should you have any question or requests, please do not hesitate to contact Golder.

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