Thermal Modelling of Discovery WRSF

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AGNICO EAGLE

okane

Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

Thermal Modelling of Discovery WRSF

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Prepared for:

Agnico Eagle Mines Limited
11600 rue Louis-Bisson
Mirabel, QC
J7N 1G9

Prepared by:

Gillian Allen
Senior Engineer
gallen@okc-sk.com

Okane Consultants Inc.

112 - 112 Research Drive
Saskatoon, SK S7N 3R3
Canada

Telephone: (306) 955 0702
Facsimile: (306) 955 1596
Web: www.okc-sk.com

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EXECUTIVE SUMMARY

The Meliadine Project is comprised of six known gold deposits and development is proceeding in a phased approach (known as the Approved Project under the Water License Amendment, and the Meliadine Extension Project), until 2043. The phased approach allows for development to occur within capital constraints and during concurrent exploration. The Meliadine Extension Project will be composed of 12 additional open pits and underground workings, waste rock storage facilities, tailings storage facilities expansion, water management facilities, and construction of a haul road between Tiriganiaq and Discovery.

O'Kane Consultants Inc. (Okane) was retained by Agnico Eagle Mines Limited (Agnico Eagle) to complete a thermal assessment, which also includes evaluation of seepage conditions, of the Discovery waste rock storage facility (WRSF) at the Meliadine Extension Project. The objectives of the detailed thermal and seepage modelling are to:

- address very high-risk failure modes identified in a failure modes and effects analysis for the Discovery WRSF (Okane, 2020);
    - Quality control of potentially acid generating and metal leaching (PAG/ML) waste rock placement is insufficient, leading to increased geochemical loading from the WRSF;
- provide long-term hydrologic and thermal inputs for the site-wide water and load balances for assessing the impact of the WRSF on site-wide water quality; and
- support a basis for closure design of the WRSF, which is defendable to internal project stakeholders and regulators.

The Discovery WRSF is expected to have a much smaller proportion of overburden compared to other Meliadine WRSFs. In addition, most of the waste rock planned for the Discovery WRSF is expected to be classified as being 'uncertain' with respect to acid generating potential or be potentially acid generating and/or metal leaching (PAG/ML) (Golder, 2014a). Due to the larger proportion of PAG/ML waste rock at the Discovery WRSF, a 6 m NPAG/NML waste rock cover system has been proposed for closure to limit interaction of precipitation with PAG/ML material to the extent necessary to be protective of water quality. For the purpose of modelling presented herein, it was assumed that all waste rock beyond the 6 m cover system at Discovery WRSF is PAG/ML. It is acknowledged that the assumption that all waste rock is PAG/ML is a 'bookend' perspective with respect to potential influence of the presence of PAG/ML material within the Discovery WRSF, and that this assumption must be retained for the moment and revisited in the future once additional information with respect to waste rock composition, volumes, and schedule is developed.

A climate change scenario was modelled, representative concentration pathway (RCP) 4.5, consistent with permitted conditions for the existing Meliadine project. RCP4.5 represents a ‘medium RCP’ scenario with stabilization of radiative forcing around 2100. RCP4.5 has been selected as the base case condition for the expansion project. RCP4.5 predicts an average annual temperature of approximately -4.6°C over the last 30 years of the climate change database (2090-2120).

The Discovery WRSF is expected to have high surface infiltration capacity as a result of the physical nature of the waste rock (i.e. the coarser-textured nature). This high infiltration capacity is expected to lead to formation of ground ice at the boundary of the active layer over time. As this ice layer is established, infiltration will gradually be diverted laterally along the ice layer within the active zone, resulting in interflow reporting at the toe of the WRSFs. Interflow occurs as unsaturated flow, and thus has a long transit time for water infiltrating near the top of the WRSFs. This transit time is in the order of decades, so WRSFs will take decades to reach a pseudo steady-state hydrologic condition where most net surface infiltration reports as interflow.

The hydrologic condition described above is influenced by the depth of the active layer, which dictates the expected location of the ice layer. Regardless of climate change scenario, the majority of interflow occurs along the boundary of the ice layer which maintains pore air temperatures less than 2°C year-round. The active layer is expected to reach up to 6 m under RCP4.5 conditions, reducing the likelihood of any interaction between infiltration beyond the proposed cover system. The increased active layer depth at Discovery, compared to the Meliadine WRSFs is the result of heating from exothermic reactions from the oxidation of PAG/ML waste rock.

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1 INTRODUCTION

Agnico Eagle Mines Limited (Agnico Eagle) operates the Meliadine Gold Mine, located approximately 25 km north of Rankin Inlet, and 80 km southwest of the hamlet of Chesterfield Inlet in the Kivalliq Region of Nunavut. The Project was approved to proceed subject to Terms and Conditions of the Project Certificate No. 006. The Project is composed of five known gold deposits: Tiriganiaq, F Zone, Pump, Wesmeg, and Discovery, with approval to mine all deposits using open pit methods, and to mine Tiriganiaq with open pit and underground methods. Approved facilities include ore stockpiles, waste rock storage facilities, a tailings storage facility, and other various infrastructure.

Agnico Eagle is proposing to expand the Mine (referred to as the Meliadine Extension Project) through additional underground mining and open pit mining. The Meliadine Extension Project is proceeding in a phased approach until 2043. The phased approach allows for development to occur within capital constraints and during concurrent exploration. The Meliadine Extension Project will be composed of 12 additional open pits and underground workings, waste rock storage facilities, tailings storage facilities expansion, water management facilities, and construction of a haul road between Tiriganiaq and Discovery. O'Kane Consultants Inc. (Okane) was retained by Agnico Eagle to complete a thermal assessment of the waste rock storage facility (WRSF) at Discovery to support development of the Meliadine Extension Project for regulatory approval.

Thermal modelling will assist in developing the expected seasonal active layer through operations and post-closure and determine if permafrost conditions within the WRSF are sustainable under climate change conditions. As part of this objective, a landform water balance was also completed for the operational, closure and post closure phases, including estimates of runoff, interflow, and basal seepage rates. Results of this thermal and seepage modeling work will be used to meet requirements of the impact statement guidelines, and to inform other work such as a detailed site water quality and load balance model for operations through post-closure.

Assessment of long-term thermal stability waste rock storage, ore storage, and tailings storage was a requirement of the initial environmental impact statement and will be a requirement for any future amendments to the environmental impact statement and the Project Certificate.

1.1 Project Objectives and Scope

The objective of the detailed thermal and seepage modelling is to provide long-term hydrologic and thermal inputs for the site-wide water and load balances, as well as a basis for closure design of the Discovery WRSF that it is defendable to internal project stakeholders and regulators, and in line with findings from the FMEA (Okane, 2020b). The specific very high failure modes that are addressed, or are in part addressed through the thermal and seepage modelling (Okane, 2020b) are as follows:

- *Quality control of potentially acid generating and metal leaching (PAG/ML) waste rock placement is insufficient, leading to increased geochemical loading from WRSFs*. In this context, quality control refers to either the inadvertent placement, or greater than expected volume of PAG/ML waste rock in areas where the waste management plans indicate that only NAG/NML waste rock should be used, or the lack of a clear waste rock management guideline identifying where PAG/ML waste rock storage is acceptable. Greater load from WRSFs than anticipated could result in delays in achieving post-closure status. Long-term, this could lead to off-site effects as the system moves to passive discharge.

Based on this objective, the specific deliverables for the modelling program are:

1) Estimates of runoff, interflow, and basal seepage from the Discovery WRSF under climate change conditions scenarios agreed upon by Agnico Eagle.

2) Estimated depths of interaction and pore space temperatures for runoff, interflow, and basal seepage from the Discovery WRSF under climate change conditions scenarios agreed upon by Agnico Eagle.

3) Discussion of expected performance of thermal cover systems in limiting impacts to site water quality based on the conceptual model of performance and modelling results attained in 1) and 2) as well as recommendation to decrease potential impacts to site water quality.

1.2 Report Organization

For convenient reference, this report has been subdivided into the following sections:

- Section 2 – Provides a summary of the site background and a conceptual model of performance of the proposed Discovery WRSF;

- Section 3 – Presents the model assumptions and inputs used for the numerical modelling simulations completed;

- Section 4 – Summarizes the results of numerical models and provides a discussion on the potential implications of results on site-wide water quality; and

- Section 5 – Suggests recommendations for next steps based on the modelling results presented.

2 BACKGROUND

The Meliadine Project is comprised of six known gold deposits and development is proceeding in a phased approach (known as the Approved Project under the Water License Amendment, and the Meliadine Extension Project (Figure 2.1 and Figure 2.2)), until 2043. The phased approach allows for development to occur within capital constraints and during concurrent exploration. While the phased approach is operationally prudent, the current Type A Water Licence only applies to the Tiriganiaq deposit. The Meliadine Extension Project includes 12 additional open pits and underground workings, WRSFs, TSF expansion, water management facilities, and construction of a haul road between Tiriganiaq and Discovery.

Waste rock and overburden will be trucked to WRSFs throughout mine operations. Currently, Phase 1 has begun with development of the Tiriganiaq Underground deposit and construction of WRSF1 and WRSF3. At both facilities, overburden will be encapsulated by waste rock. It is assumed that similar construction methodology will form the base case for the Meliadine Extension Project WRSFs.

2.1 Conceptual Model

A conceptual model describes key processes, or mechanisms, and their site-specific respective controls, which are expected to influence performance of the proposed WRSFs. It is presented at a conceptual level, using a hierarchy of climate, geology and materials, and topography, leading to an understanding of the patterns of water movement on a specific landscape (INAP, 2017). Figure 2.3 schematically describes the cover system design framework.

A thermal cover system is currently proposed for closure at the Discovery WRSF. Initial investigations of the Discovery waste rock indicated the potential for higher acid rock drainage (ARD) potential and therefore a surface layer of non-potentially acid generating and non-metal leaching (NPAG/NML) waste rock, intended to limit thaw of potentially acid generating and metal leaching (PAG/ML), has been proposed as a closure cover system.

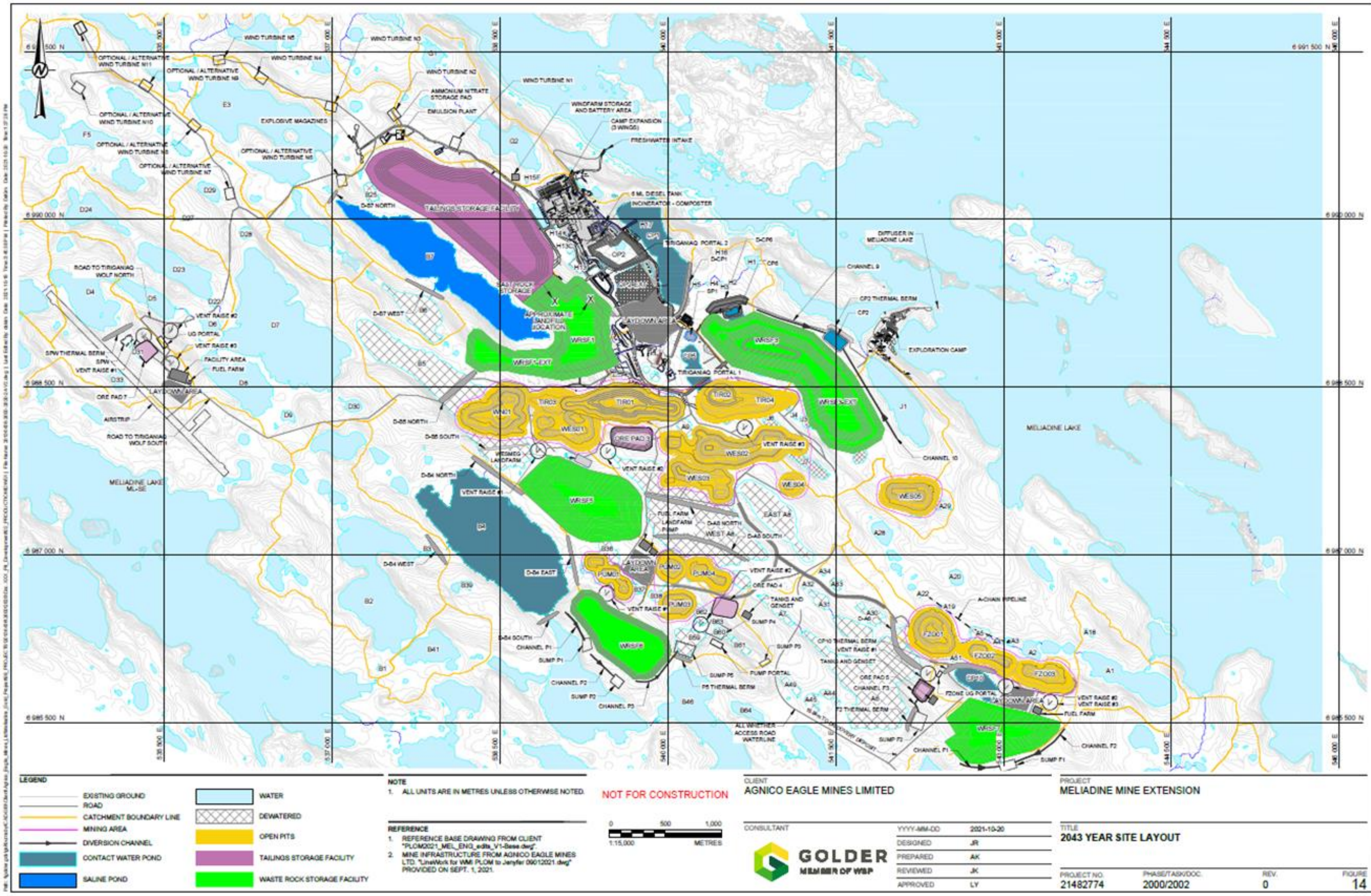

Figure 2.1 : Meliadine Extension Project site layout.

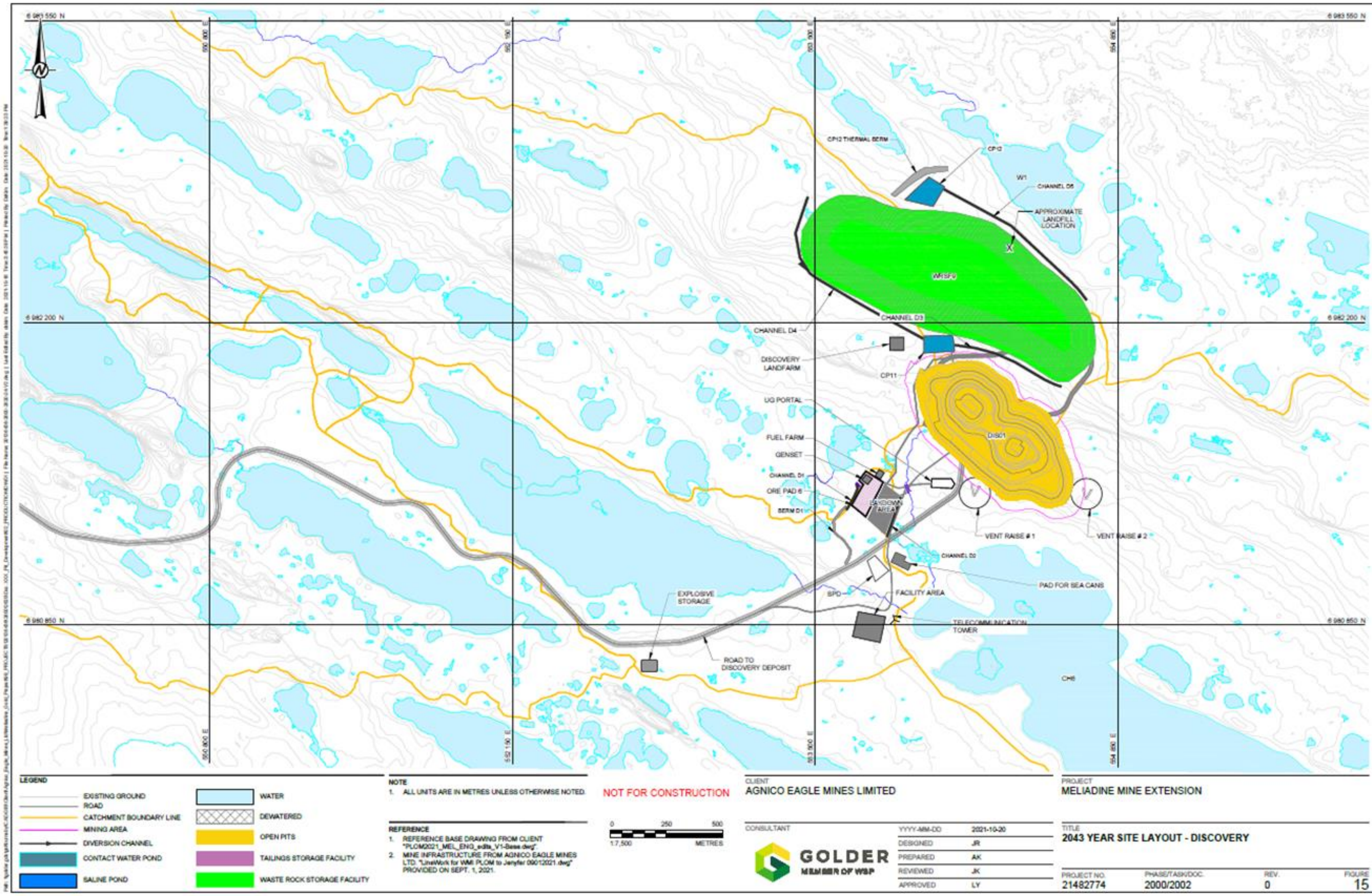

Figure 2.2 : Meliadine Discovery site layout.

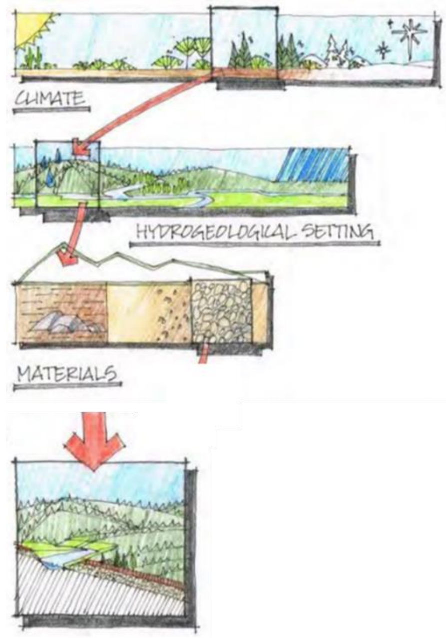

Figure 2.3: Conceptual cover system design framework with four filters for climate, hydrogeology, materials, and vegetation.

Adapted from INAP, 2017.

2.1.1 Conceptual Model of Surface Water Balance

The Meliadine site falls near the intersection of the ET (polar tundra) and Dfc (subarctic climate) classification of the Köppen-Geiger climate classification system where:

- E – 'polar' where average temperature of the warmest month is < 10°C;
- T – 'tundra' where the average temperature of the warmest month is < 10°C, but > 0°C;
- D – 'continental' where average temperature of the coolest month is < -3°C, and average temperature of warmest month > 10°C;
- f – 'without a dry season' where precipitation is relatively evenly distributed throughout the year; and
- c – 'cold summer' where one to three months average temperature reach < 22°C but > 10°C.

Annual precipitation is approximately 430 mm, distributed relatively evenly as snowfall and rainfall. Climate data suggest that the site has a relatively balanced annual surface water budget, or slight water deficit, where the ratio of potential evapotranspiration (PET), sublimation, and snow redistribution is approximately equal to total annual precipitation. There is expected to be a water deficit throughout the summer as potential evaporation (PE) exceeds rainfall in June through August, and a water surplus in September, as PE decreases. Climate data suggest that net percolation, the water that moves from a cover system into a WRSF is likely to occur in the fall period when PE is low, and potentially during spring freshet.

Waste rock is expected to have very low available water holding capacity (AWHC) (<3 mm). The available water holding capacity refers to the volume of water held within a granular material that may be available for evapotranspiration. Given high evaporative conditions in July through August, this available water holding volume may be 'recycled' several times, as the volume of water held in the waste rock increases following a rainfall event, then is evapotranspired in the following period when it is no longer raining (or evaporates if/when there is little to no vegetation present). Climate data indicates there are typically 50-60 days where precipitation occurs between July to August. Based on the assumption that evapotranspiration is limited to non-rainfall days and is limited to the surficial metre of material, the maximum probable volume of water lost to evapotranspiration is approximately between 55 mm to 165 mm. This depth of evapotranspiration represents roughly 15%-40% of total annual precipitation.

The coarser-textured nature of the waste rock, which results in low available water holding capacity, also results in high surface infiltration capacity (though influenced by non-frozen conditions), and thus low surface water runoff potential. In short, the potential for saturated overland flow is very low. As noted, frozen conditions in the waste rock during spring freshet will both decrease the permeability of the waste rock and reduce viscosity of the water as it approaches its freezing point, leading to the potential for a small volume of runoff to occur in the freshet period.

The last parameter influencing surface infiltration is the portion of snowfall that is sublimated or redistributed. Conditions for sublimation and redistribution are high at Meliadine, particularly at the WRSFs, where windspeed is high and WRSFs are the predominant feature within the landscape. The potential for redistribution is expected to result in a net loss of snow on the WRSF (without accounting for sublimation). Previous estimates (Golder, 2014b) indicated that sublimation may account for up to 50% of the total winter precipitation, or 25% of total annual precipitation. This proportion may be even higher for the wind blown WRSFs at Meliadine.

Given the above drivers of the surface water balance, surface infiltration into the WRSF is expected to be 'high', between approximately 30% to 50% of total annual precipitation (130 mm to 215 mm). Given the low AWHC of the waste rock, the time for wet up of the landform is expected to be relatively short, as the *in situ* water content of the waste rock is likely similar to its drained field capacity. However, the permafrost conditions which exist within the WRSF will allow for additional water to be stored in the waste rock beyond its field capacity.

Fully saturated ice zones are expected to form along the boundary of the seasonal active layer, creating a low permeability ice zone. The active layer in the Meliadine area is generally between 1.0 m to 3.0 m (Golder, 2014b); however, the active layer is expected to be deeper in the WRSF as the thermal conductivity of waste rock is higher, and the volumetric heat capacity is lower than surrounding surficial overburden. The formation of a low permeability ice zone is anticipated to occur in the order of decades.

High salinity porewater (approximately 57 ppt) in waste rock emanating from underground workings will delay freeze back of the WRSFs, but more importantly is expected to increase the depth of the active layer if high salinity material is placed near surface.

The presence of a lower permeability ice zone coupled with the lower permeability of *in situ* surficial overburden and waste overburden or waste rock is expected to reduce basal seepage to negligible levels.

Once the lower permeability ice zone has formed, the WRSF will largely reach a pseudo steady-state condition where, from a hydraulic performance perspective, surface infiltration will report as toe seepage (or interflow along the lower permeability ice zone) from the WRSF (Figure 2.4). This, however, should not be interpreted as a 'plug flow' condition, where a drop of water infiltrating on the plateau of the WRSF reports as interflow in the same time frame as a drop of water infiltrating near the toe of the WRSF. The 'age' of interflow observed will increase over time as areas further away from the toe begin to report, finally reaching a pseudo 'steady-state' condition from a geochemical perspective. This process is also expected to occur in the order of decades. Lastly, interflow water quality is expected to evolve over the life of mine as buffering capacity of PAG/ML waste rock may be exceeded, and available reactive minerals are slowly exhausted.

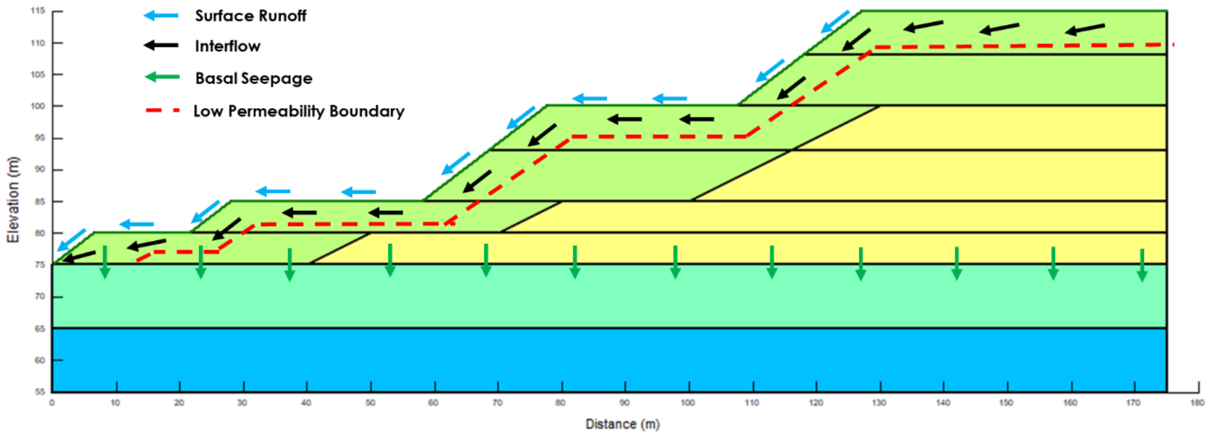

Figure 2.4: Conceptual sketch of landform water balance at Meliadine WRSFs.

Climate change in the region is expected to result in a warmer and wetter climate. The anticipated rise in average annual temperature is likely to increase the thickness of the active layer, potentially thawing a portion of the lower permeability ice layer already in place or increasing its depth within the WRSF. The increase in temperature is likely also to increase evaporative conditions; however, this is expected to be similar in proportion to the increase in precipitation resulting in a similar proportion reporting as net percolation (and surface infiltration).

2.1.2 Conceptual Model for Oxygen Ingress

Oxygen availability throughout the WRSFs is not expected to be limited in the short term as the waste rock has very high air permeability (coarser-textured material of relatively low water content when placed). Air permeability can be estimated based on the intrinsic permeability derived from the estimated hydraulic conductivity for a given material, which can be measured in laboratory, or estimated based on material texture (Fredlund et al., 2012). The waste overburden, however, has much lower air permeability. The lower air permeability of the waste overburden is not expected to limit oxygen availability, as the overburden is assumed to have low reactivity (i.e. the consumption of oxygen due to oxidation reactions in the waste overburden is likely lower than the air permeability). The low volume of waste overburden will not inhibit formation of convective cooling cells or oxygen availability at the Discovery WRSF. High bulk air permeability at the Discovery WRSF will allow exothermic sulphide oxidation reactions to proceed uninhibited as a result of the continuous re-supply of oxygen, resulting in some internal heating. However, the permafrost expected to develop within the WRSF (as described above) will likely limit oxidation rates, which are temperature dependent. Internal heating may delay onset of freeze back of the WRSFs but is not expected to drive the thermal regime of the Discovery WRSF under current climatic conditions.

The presence of ice zones at the boundary of the active layer are expected to reduce air permeability. This may delay freeze back of the WRSFs. At the Discovery WRSF, where waste rock is expected to have greater reactivity, the lower air permeability layers may be sufficient to reduce oxygen availability; however, reaction rates are already expected to be relatively low due to low air temperatures in the pile. Thus, the lower permeability ice layers are not expected to limit sulphide oxidation under current climatic conditions.

2.2 Description of Numerical Modelling Program

GeoStudio Version 10 was used to conduct the modelling for this project. A detailed description of GeoStudio Version 10 and its limitations related to this modelling effort is described in greater detail in Okane (2022).

3 MODEL INPUTS

Model inputs for Meliadine and Discovery WRSFS can be divided into five types:

1) Climate / Upper Boundary Conditions;
2) Materials;
3) Geometry;
4) Lower and Edge Boundary Conditions; and
5) Initial Conditions.

The following sections describe model inputs particular to the Discovery WRSF where they differ from those described in Okane (2022).

3.1 Geometry

The Discovery WRSF idealized cross-section (Figure 3.1) was selected for long term modelling. Typical geometry for the idealized cross-sections is provided in Table 3.1. The cross-section was 'built-up' over time in 2D to simulate conditions at placement (Appendix A). Previous thermal modelling work at Whale Tail showed the slope aspect had limited effect on the depth of thaw but that freeze-back would take longer along the southern aspects than the northern aspects. A southern exposure is expected to show conservative freeze-back through the WRSF due to increased solar radiation and less convective cooling from the leeward slope.

Table 3.1: Typical cross-section geometry.

Parameter	Value
Initial Bench Height	15 m
Maximum Bench Height	15 m
Setback	15 m
Interbench Slope (Waste Rock)	1.3H:1V
Interbench Slope (Overburden)	2H:1V
Overall Slope (Ultimate toe to ultimate crest)	2H:1V
Cover Thickness	6 m

It was assumed that the first lift of overburden is to be placed only in winter to maintain frozen conditions within the WRSF foundation materials.

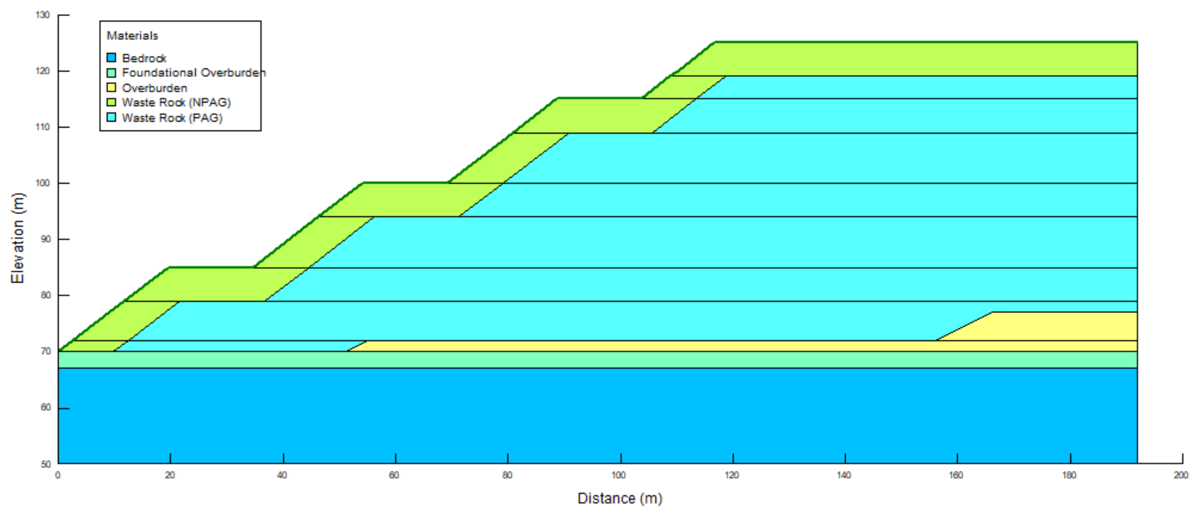

Figure 3.1: Southwest facing cross-section of proposed Discovery WRSF.

3.2 Boundary Conditions

3.2.1 Air and Gas Boundary Conditions

A barometric air pressure condition referenced to site elevation (70 masl) and adjusted for daily air temperature was applied to the exterior of the cross sections. A constant oxygen concentration representing atmospheric conditions (280 g/m^3) was also applied to the exterior of the cross sections.

3.2.2 Temperature Boundary Conditions

A depth of zero amplitude condition of -5°C was assumed to exist at the base of the bedrock in the model geometry (approximately 20 mbgl) (Tetra Tech, 2019). To simulate exothermic reactions from the oxidation of waste rock, the Gas Consumption and Exothermic Reaction boundary condition was applied to the PAG waste rock material at the Discovery WRSF. This boundary condition couples the oxygen consumption due to mineral oxidation to heat generated by the associated exothermic reactions. Optimal oxidation rates were calculated from the advanced customizable leach column (ACLC) test program (Okane, 2020a) as 0.004 kg O_2/t/year for the waste rock material. These rates represent the oxidation rate under optimal conditions. The add-in adjusts the reaction rate at each timestep and node based on the current temperature and oxygen concentration.

3.3 Initial Conditions

3.3.1 Temperature Conditions

Cover system material at Discovery WRSF was assumed to be placed in the same season as neighbouring waste rock, indicative of progressive reclamation of the WRSF.

4 MODEL RESULTS

Modelling of the Discovery WRSF was completed in two major steps: short term sensitivity modelling and long-term climate modelling. Short term sensitivity modelling was completed to assess the range of expected performance under conditions where uncertainty exists. Short-term sensitivity was completed using the base case climate RCP4.5 described in Okane (2022).

Following completion of the sensitivity models (Okane, 2022), modelling of the long-term 2D cross section at the Discovery WRSF (Figure 3.1) was completed to develop long-term thermal active layer depths, estimates of pore air temperature within the active layer, and a landform water balance. A 100-year period (2020-2120) was modelled under RCP4.5 including construction of the WRSF, using six-hour timesteps saved daily. The following sections summarize the results of the long-term 2D modelling.

4.1 Active Thermal Layer Depth

In permafrost environments, thaw of the active layer occurs as a unidirectional process from the surface. During the summer months, when air temperatures are the warmest, the active layer absorbs and transfers heat from the atmosphere downwards toward the thawing front. This transfer of heat occurs predominantly through conduction but infiltrating water can contribute to the heat transfer via convection.

Freezing in autumn occurs first as a unidirectional process from the bottom of the active layer at the freezing front. As the ambient air temperature declines, the temperature gradient driving conduction also declines, resulting in freezing upwards from the permafrost. Once the air temperature becomes negative, a freezing front develops at the surface and progresses into the active layer, creating bidirectional freezing. The cold air temperatures rapidly cool the surficial material, allowing the upper freezing front to quickly progress downward, while the lower freezing front moves slowly upwards. The thawed portion between the two freezing fronts is at or near 0°C, creating isothermal or zero-curtain conditions, where water and ice can coexist in equilibrium. Unfrozen pore water migrates both upwards and downwards toward the freezing fronts until all pore water is frozen and the zero-curtain closes.

The primary mechanism responsible for thaw, conduction, is typically constrained within the upper 4 m before colder air temperatures decrease the thermal gradient. Freezing from the surface progresses rapidly, while freezing from the bottom is a slower process. Freezing from the bottom is further inhibited by potential exothermic heating from oxidation reactions if the thawing front has reached PAG/ML waste rock. Zero-curtain conditions are created, slowing the upper freezing front, until all pore water is frozen.

The following figure**Error! Reference source not found.**s illustrate annual average near-surface thermal conditions at several locations along the slope (Figure 4.1)

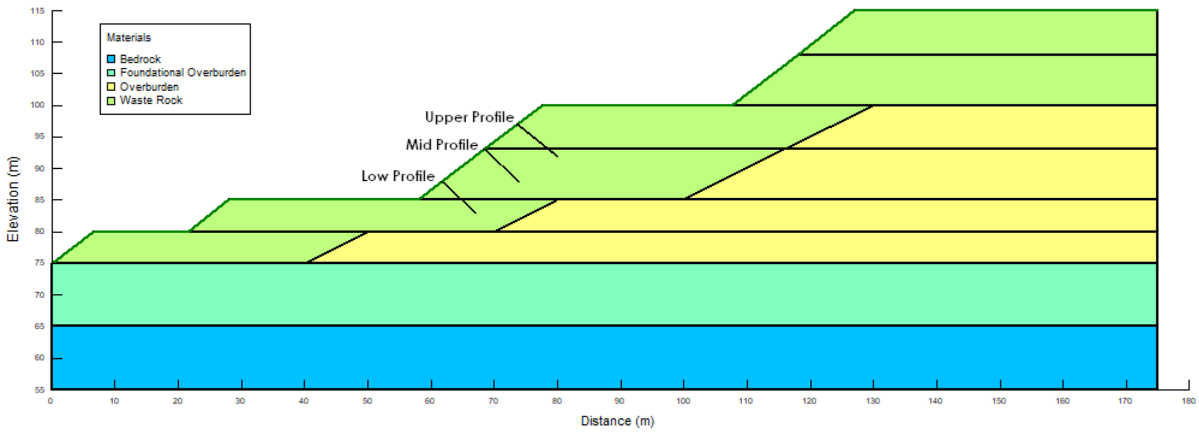

Figure 4.1: Section view of typical thermal locations rendered below.

The long-term thermal modelling predicts a deepening of the active layer with time. The average active layer depth over the last 30 years of modelling (2090-2120) indicates an active layer of approximately 5 m to 6 m under RCP4.5 conditions (Figure 4.2).

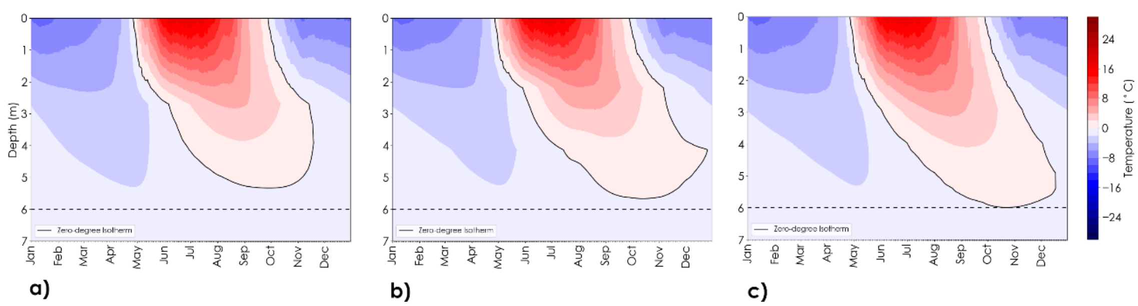

Figure 4.2: Annual long term near surface temperature along the slope of the Discovery model and the a) low profile, b) mid profile and c) upper profile under RCP4.5 climate conditions with the proposed cover system interface shown by the black dashed line.

The progression of the thaw front continues until the thermal gradient driving conduction decreases due to the decrease in air temperature. The active layer reaches its maximum depth at this stage, after which the downward thawing front becomes an upward freezing front.

4.2 Active Layer Pore Temperature

Pore air temperature is required to estimate reaction rates and loading rates from the Discovery WRSF. As temperatures are expected to stabilize under both climate change scenarios modelled, an asymptotic regression was used to estimate typical pore air temperatures over time based on the modelling results. Detailed pore air temperature results by month and depth are summarized in Appendix B.

4.3 Landform Water Balance

A landform water balance was completed to aid in the thermal modelling of the Discovery WRSF. This work includes estimates of runoff, interflow and basal seepage rates. A summary of the 100-year surface water balance for Discovery WRSF plateau and slope are provided in Table 4.1 for the long-term models under RCP4.5.

Table 4.1: Summary of average water balance for the plateau and slope of the long-term models under RCP4.5.

Water Balance Parameters	RCP4.5	
	Plateau	Slope
Total Precipitation (mm)	439 mm	439 mm
Rainfall (% of Total Precipitation)	55-60%	55-60%
Snow (% of Total Precipitation)	40-45%	40-45%
Actual Evaporation (% of Total Precipitation)	40-45%	40-45%
Runoff (% of Total Precipitation)	1-5%	<1-5%
Surface Infiltration (% of Total Precipitation)	15-20%	15-20%
Sublimation (% of Total Precipitation)	30-35%	30-35%

Runoff is assumed to interact with surficial materials to a depth of 30 cm (Sharpley, 1985; Zhang, 2009). Table 4.2 summarizes the runoff distribution by month for the Discovery WRSF.

Table 4.2: Runoff distribution by month under RCP4.5.

Month	RCP4.5	
	Plateau	Slope
January	0%	0%
February	0%	0%
March	0%	0%
April	23%	23%
May	75%	76%
June	1%	1%
July	<1%	<1%
August	0%	0%
September	0%	0%
October	0%	0%
November	<1%	0%
December	0%	0%

4.3.1.1 Basal Seepage

The high infiltration capacity of the waste rock material results in a propensity for incident precipitation to become surface infiltration, rather than runoff (Table 4.1). As water infiltrates into the surficial materials, net percolation flows vertically through the WRSF, eventually freezing back at depth. The base layer of the WRSF is consistently frozen from the time of placement. As a result, basal seepage from the landform is negligible in all long-term models.

4.3.1.2 Interflow

Interflow occurs as lateral flow within the active layer on the plateaus and slopes. During construction and freeze back, water can percolate into the WRSF beyond the active layer, resulting in increased storage and consequently lower interflow. As time progresses, a zone of high saturation, ice-rich frozen waste rock develops below the active layer and prevents further percolation, resulting in the lateral diversion of infiltrating water and greater interflow Unsaturated interflow will occur near the boundary of the freezing front (Figure 4.3), meaning that following initial infiltration, lateral flow will only occur within the waste rock at low temperature conditions (<2°C).

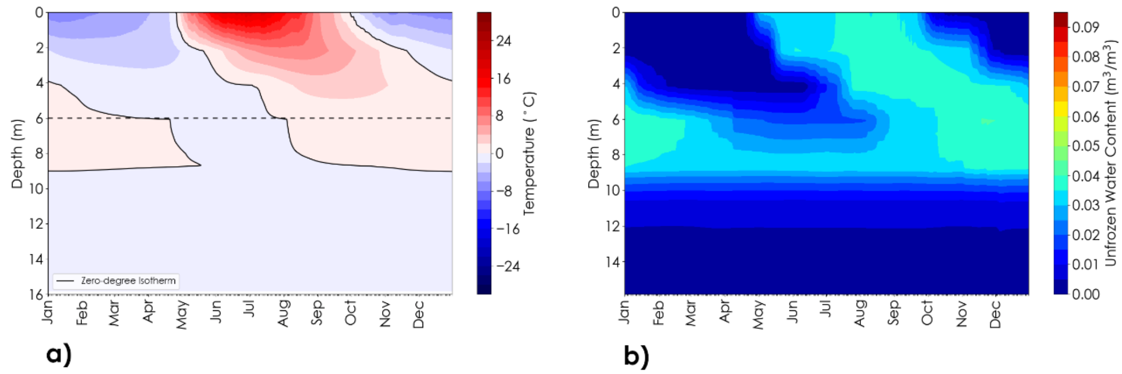

Figure 4.3: a) Annual long term near surface temperature along the mid slope of the Discovery WRSF; b) annual long term near surface unfrozen water content along the mid slope of the Discovery WRSF.

Table 4.3 shows the progression of interflow with time as a percent of total precipitation. The monthly distribution of interflow is shown in Table 4.4.

Table 4.3: Interflow for the Discovery WRSF as a percent of total precipitation.

	RCP4.5	
	0-45 Years	**45-90 Years**
Interflow (% of Total Precipitation)	10-15%	15-20%

Table 4.4: Interflow distribution by month for the Discovery WRSF as a percent of total interflow (2031-2120).

Month	Percent of Interflow Occurring by Month (RCP4.5)	
	0-45 Years	**45-90 Years**
January	0%	0%
February	0%	0%
March	0%	0%
April	0%	2%
May	8%	11%
June	11%	10%
July	14%	14%
August	22%	25%
September	29%	26%
October	14%	11%
November	2%	1%
December	<1%	0%

5 CONCLUSIONS

The thermal modelling of the proposed Discovery WRSF presented herein is intended to provide long-term hydrologic and thermal inputs for the site-wide water and load balances, as well as a basis for closure design which is defendable to internal project stakeholders and regulators by addressing material risk to the project related to the WRSFs. Potential failure modes deemed to be of higher risk identified for the WRSFs relate to the potential for geochemical loading from the WRSF resulting in poor water quality, and uncertainty surrounding the effect of climate change on geochemical loading from the WRSFs. Long term thermal models were completed for long term climate models RCP4.5 to assess the potential effects of climate change on geochemical loading.

The major component of the surface water balance, which has the potential to result in geochemical loading from the WRSF, is net percolation, that results in interflow. Runoff and basal seepage are expected to be nearly negligible. Under RCP4.5 conditions, the active layer at the Discovery WRSF is generally maintained within the 6 m proposed NPAG/NML cover system, limiting interaction with potential PAG/ML materials.

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Appendix A

Model Geometry Evolution

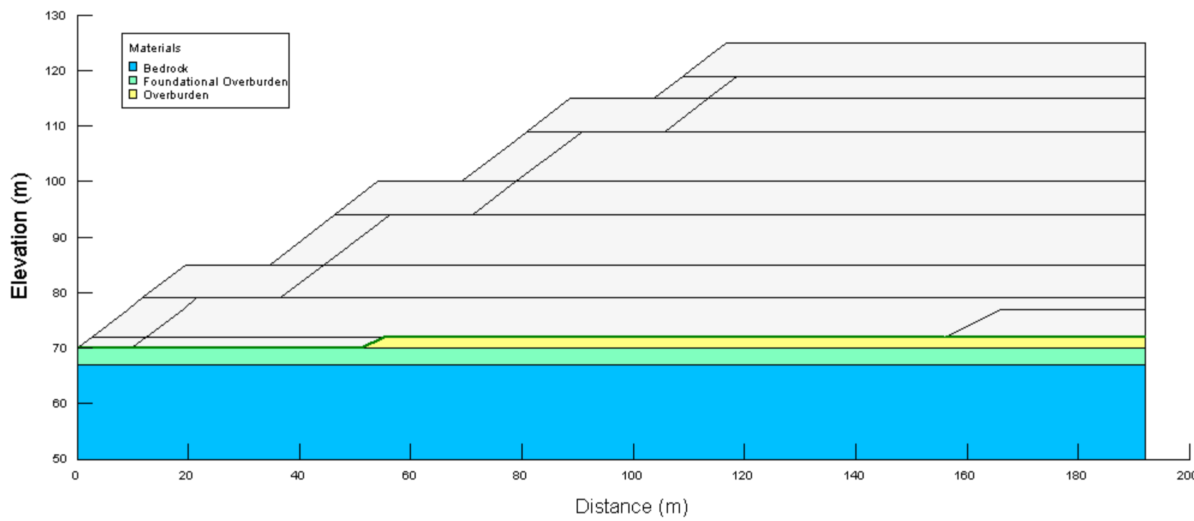

Figure A.1: Discovery WRSF construction – Winter 2031.

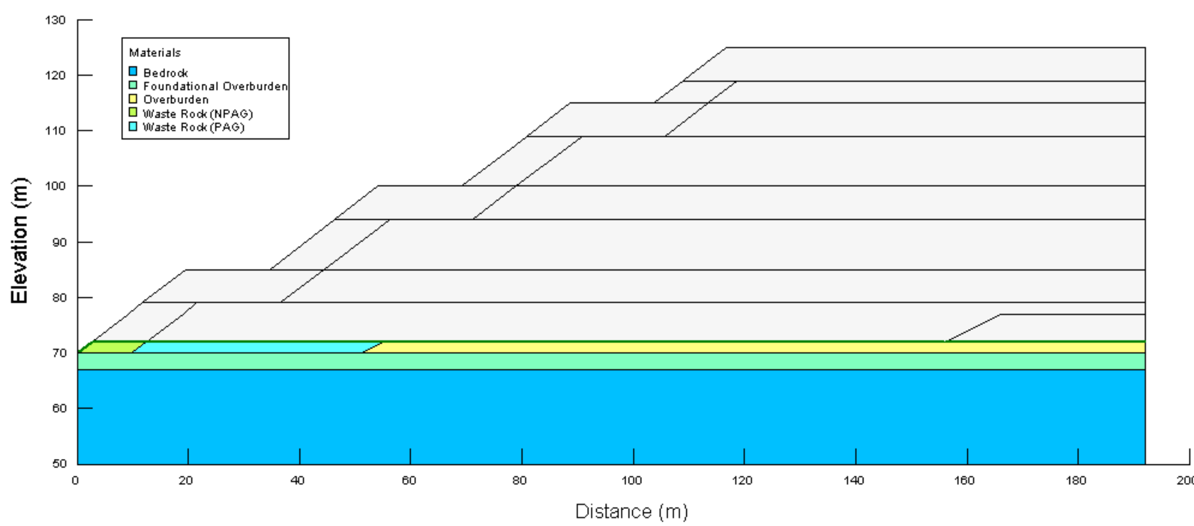

Figure A.2: Discovery WRSF construction – Summer 2031.

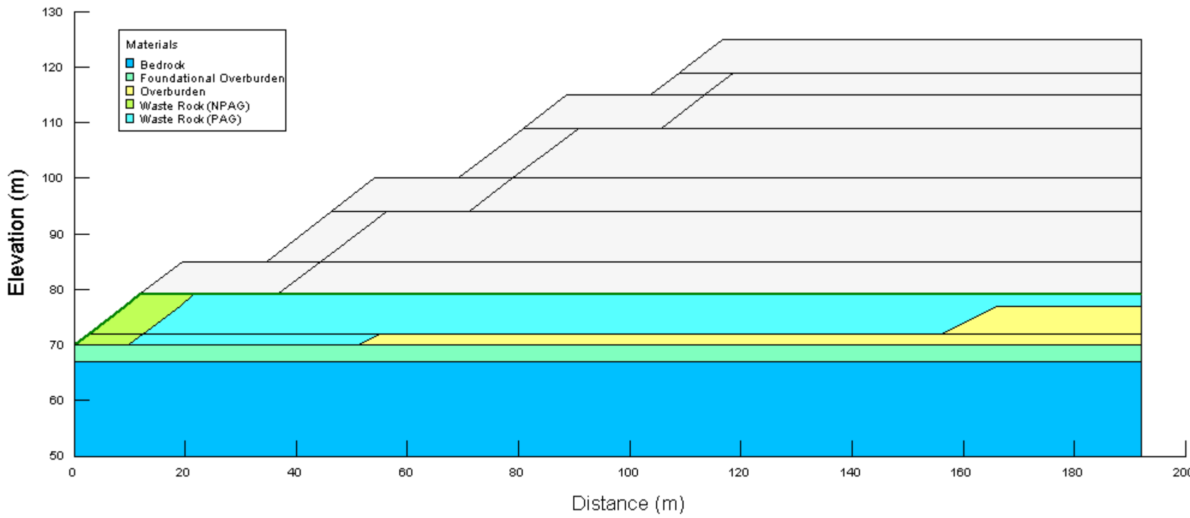

Figure A.3: Discovery WRSF construction – Winter 2032.

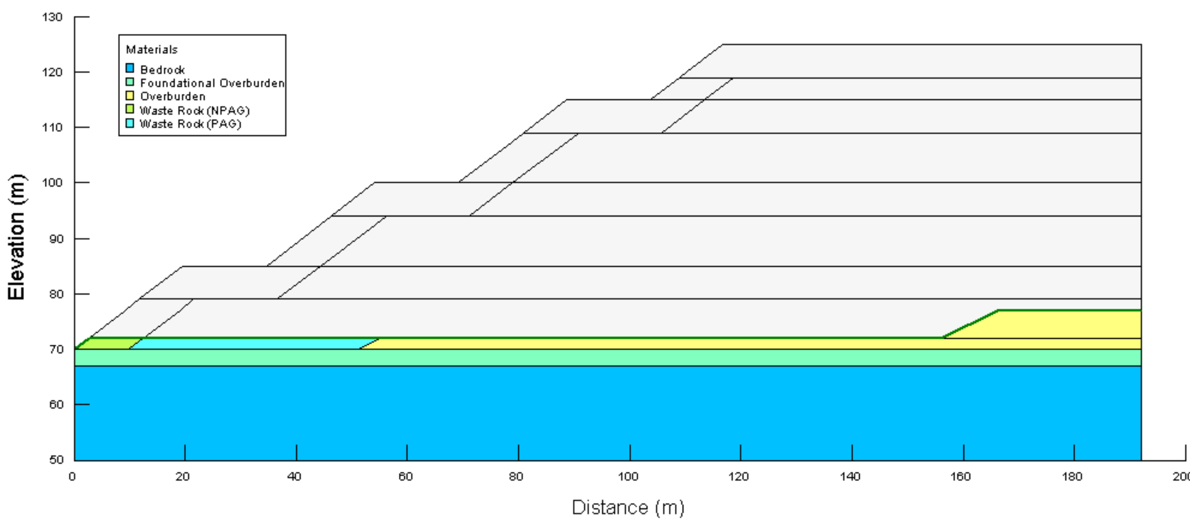

Figure A.4: Discovery WRSF construction – Summer 2032.

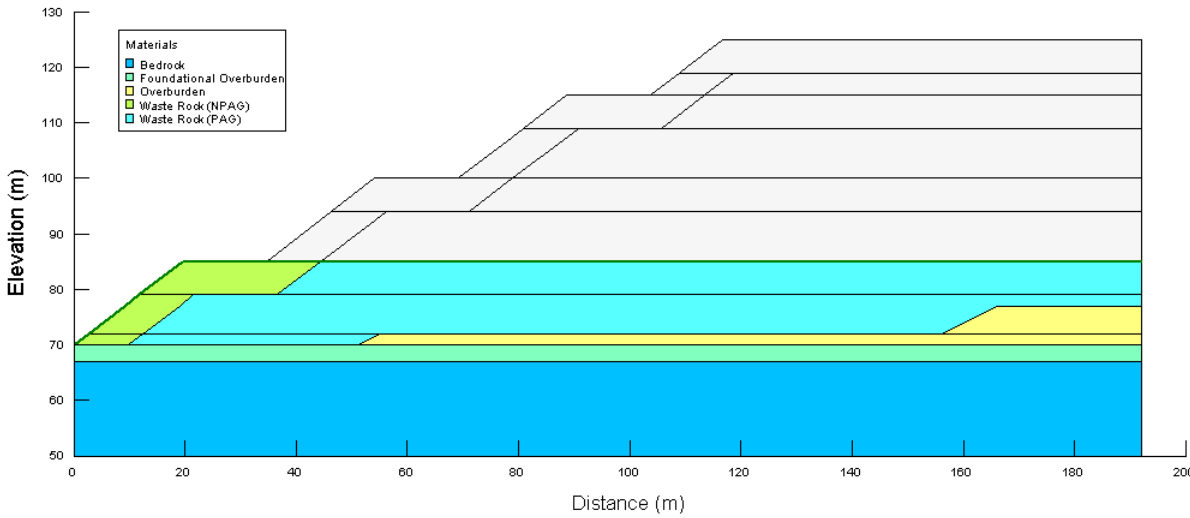

Figure A.5: Discovery WRSF construction – 2033.

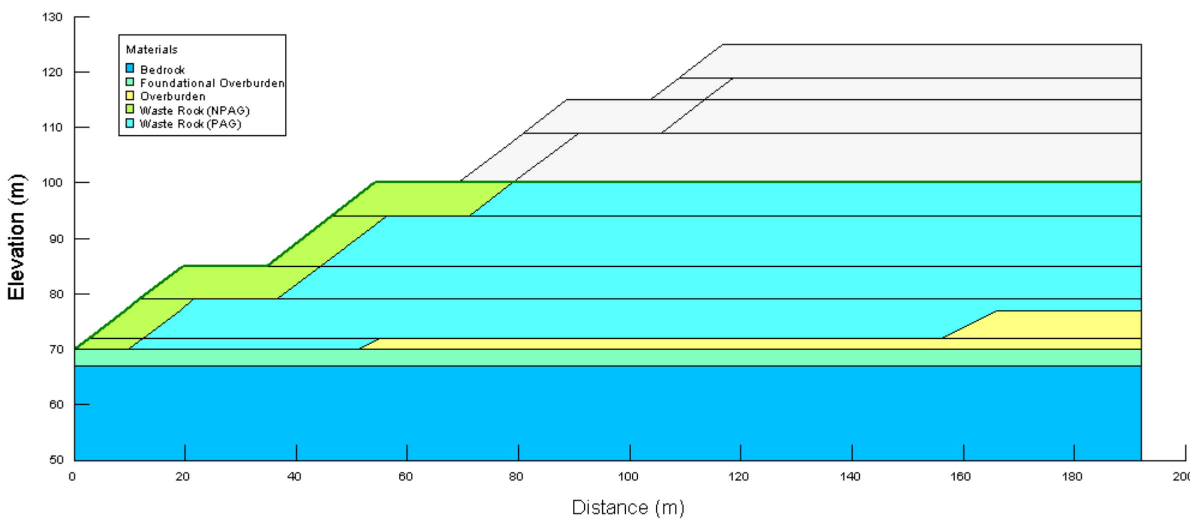

Figure A.6: Discovery WRSF construction – 2034.

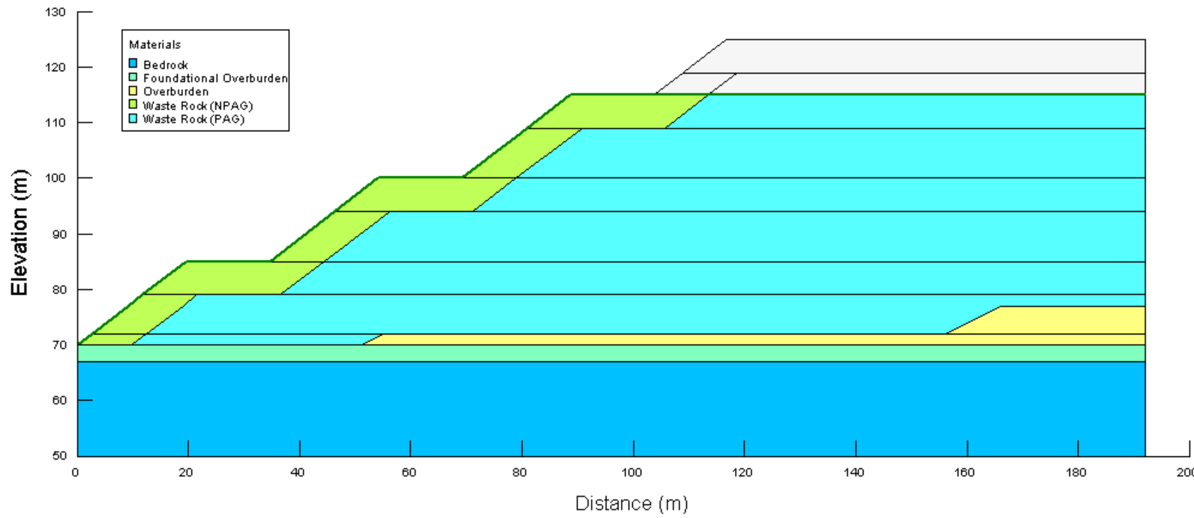

Figure A.7: Discovery WRSF construction – 2035.

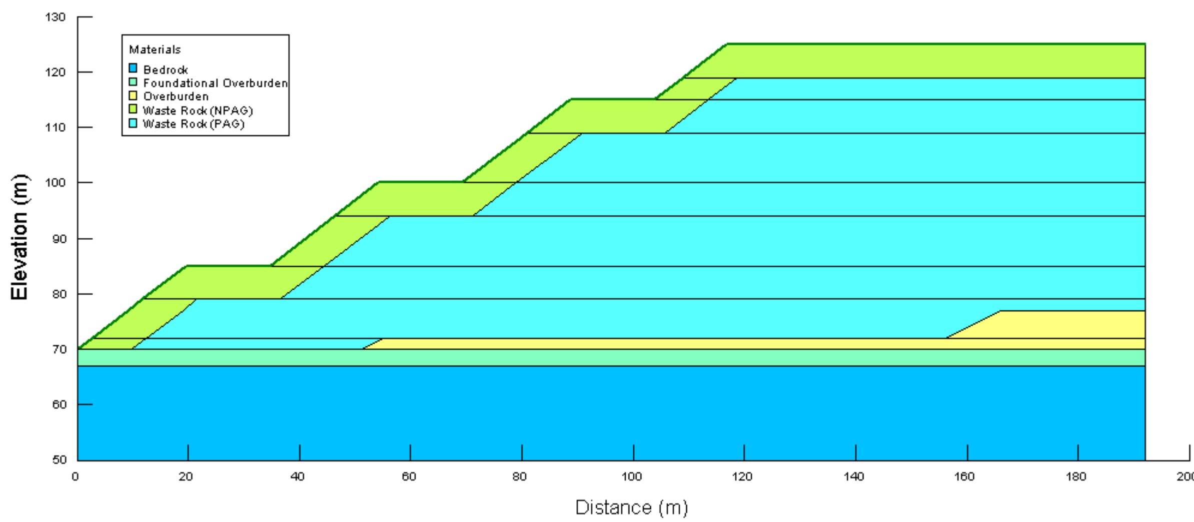

Figure A.8: Discovery WRSF construction – 2036.

Appendix B

Active Layer Pore Space Temperature

Figure B.1: Average pore space temperature for the Discovery WRSF under RCP4.5 conditions from 0 m to 2 m depth.

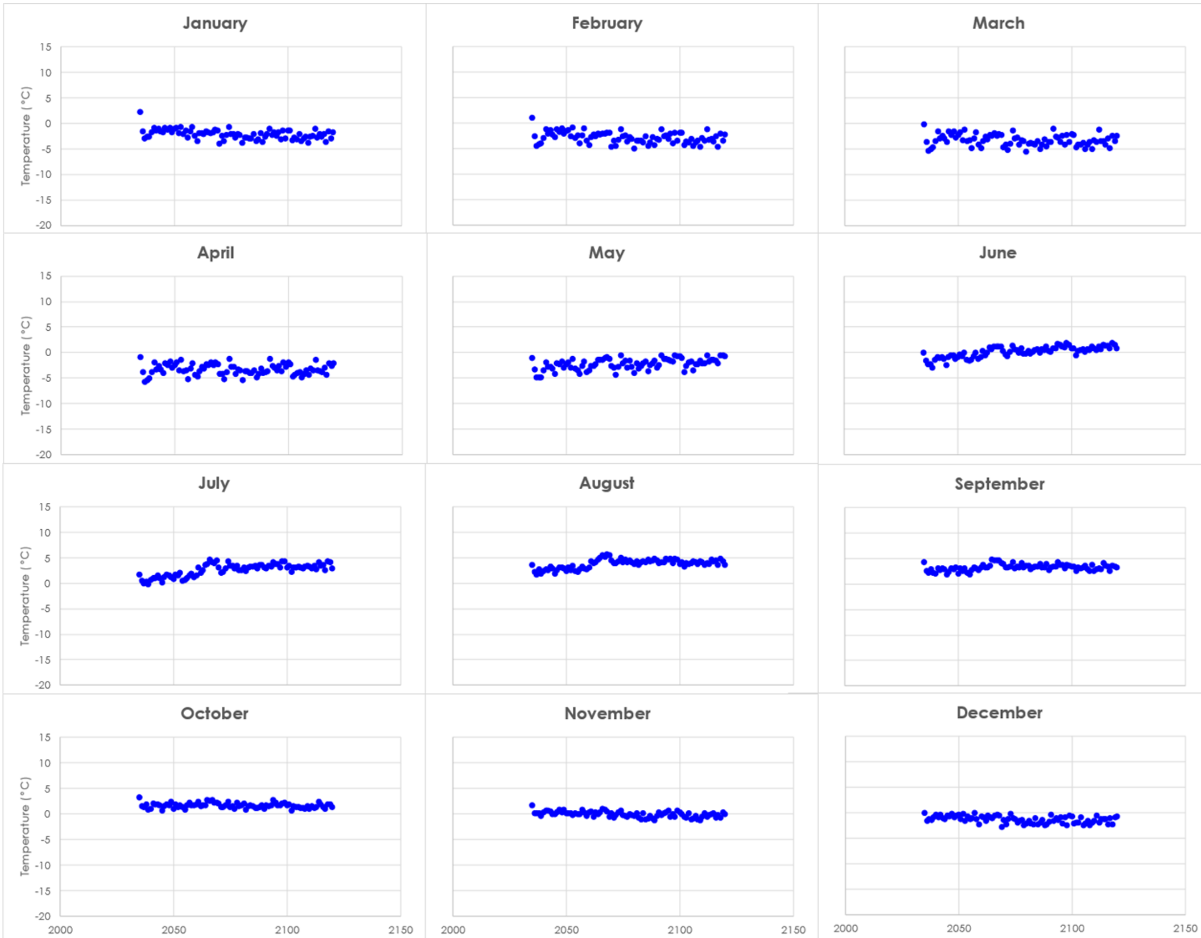

Figure B.2: **Average pore space temperature for the Discovery WRSF under RCP4.5 conditions from 2 m to 4 m depth.**

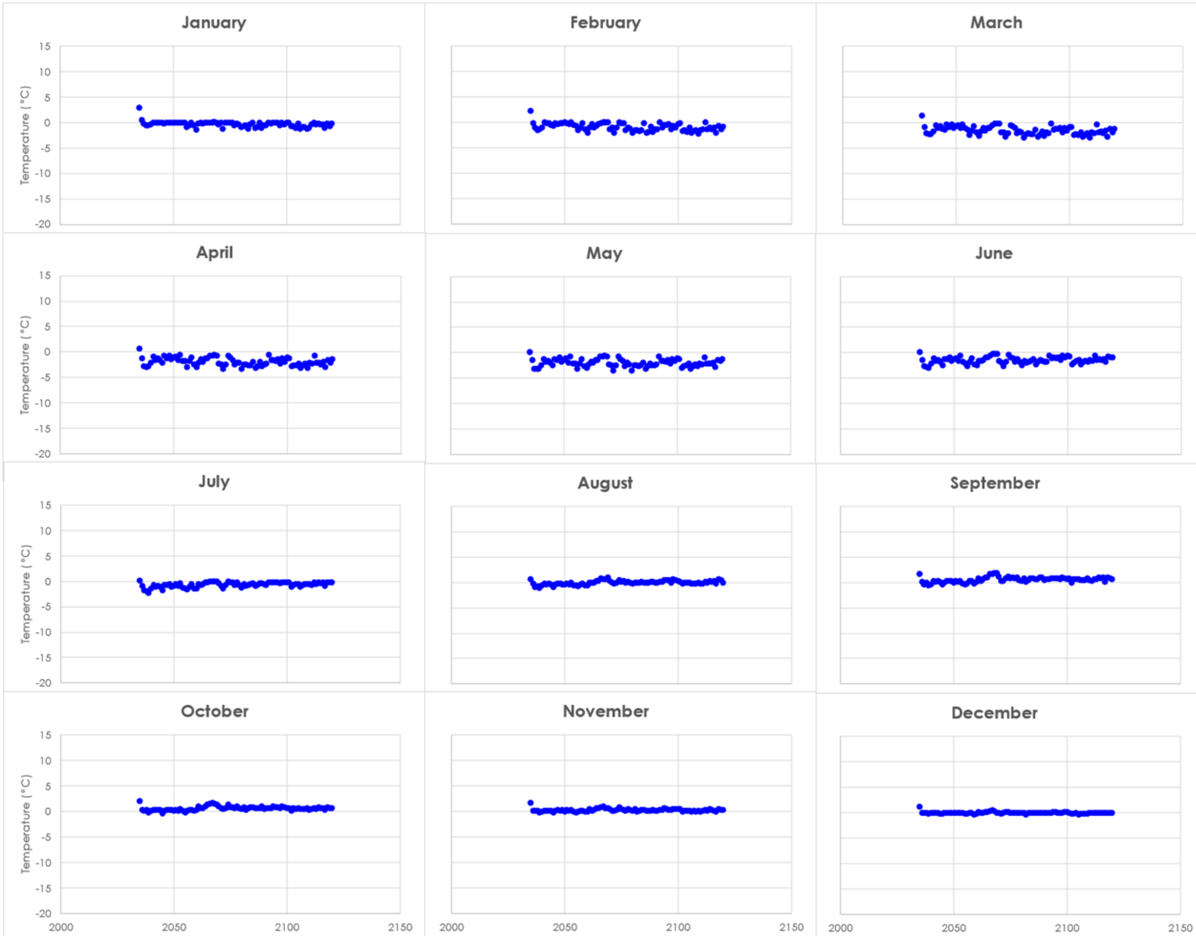

Figure B.3: Average pore space temperature for the Discovery WRSF under RCP4.5 conditions from 4 m to 6 m depth.

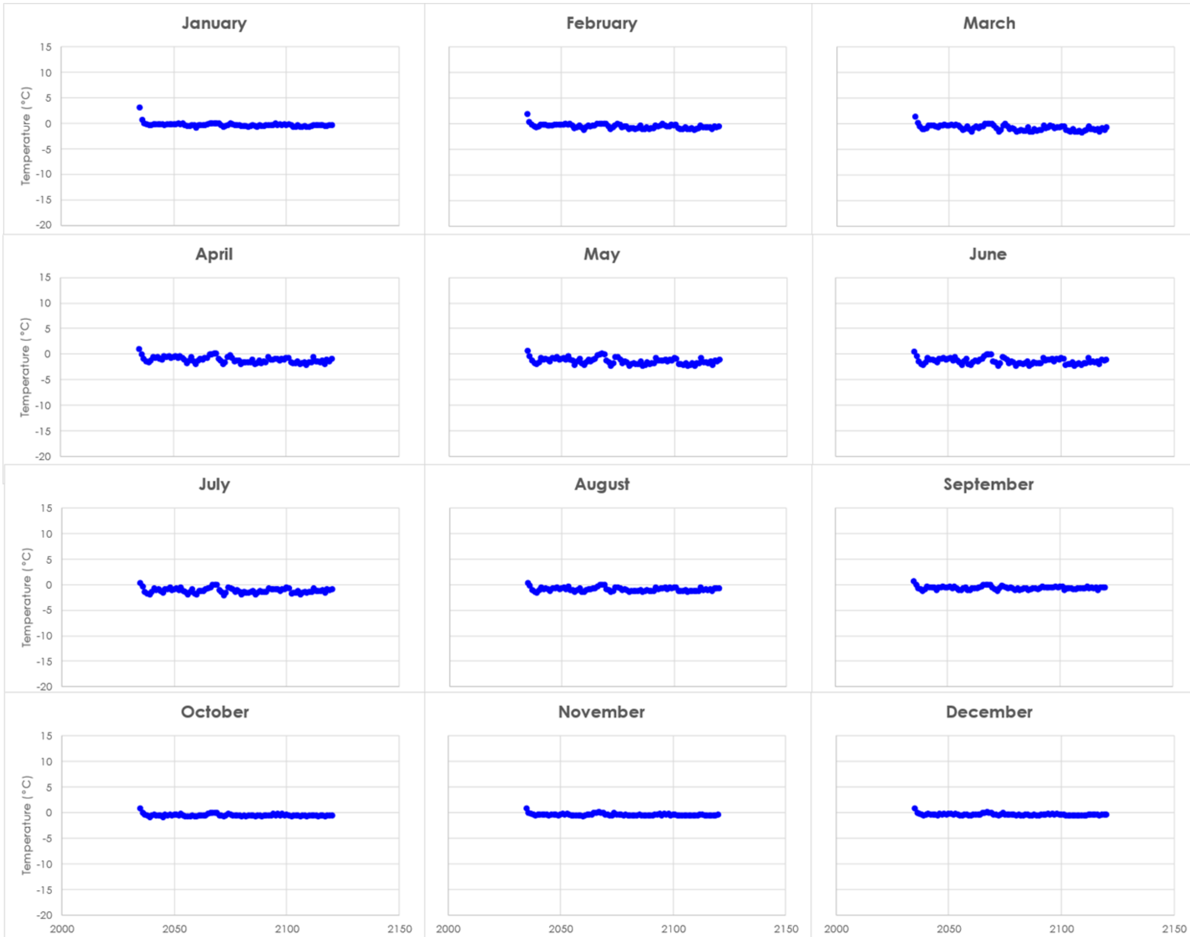

Figure B.4: Average pore space temperature for the Discovery WRSF under RCP4.5 conditions from 6 m to 8 m depth.

Table B.1: Summary of average pore space temperatures for the Discovery WRSF under RCP4.5 conditions.

Depth	Parameter	January	February	March	April	May	June	July	August	September	October	November	December
0m to 2m	A	3.98	-7.44	-1.52	48.6	183	162	114	-44.6	-48.3	-95.8	7.39	5.31
	B	0.108	-680	13.1	196	753	593	260	-66.7	-126	-225	0.017	141
	C	-0.002	0.003	0.0006	0.0006	0.0007	0.0007	0.0004	0.0001	0.0004	0.0004	-0.003	0.001
2m to 4m	A	-28.4	-26.0	0.71	-3.38	37.6	60.7	105	47.5	20.9	-0.425	-13.1	2.58
	B	-93.7	-85.5	0.0366	1.85E+48	115	220	227	127	47.1	-10.7	-63.8	0.0168
	C	0.0006	0.0006	-0.002	0.1	0.0005	0.0006	0.0004	0.0005	0.0005	0.0008	0.0008	-0.003
4m to 6m	A	-12.8	-46.0	3.01	-1.96	-8.64	5.83	10.0	13.2	26.1	13.4	-0.192	-0.435
	B	-48.4	-83.3	0.0158	1.77E+28	-18.9	27.0	59.7	39.6	46.1	23.8	-0.869	-2.21
	C	0.0007	0.0003	-0.003	0.1	0.0005	0.0006	0.0008	0.0005	0.0003	0.0003	0.0003	0.0008
6m to 8m	A	-15.7	-21.0	-18.8	-30.3	-28.0	1.14	-6.07	-5.88	-3.70	-0.01	0.039	0.032
	B	-39.1	-51.7	-63.1	-64.6	-57.5	0.0167	-18.8	-17.4	-10.0	0.003	4.83E-06	4.05E-03
	C	0.0004	0.0004	0.0006	0.0004	0.0004	-0.002	0.0006	0.0006	0.0006	-0.002	-0.005	-0.002

Temperature = $A\text{-}Be^{-C*YEAR}$

For further information contact:

Gillian Allen
Senior Engineer
gallen@okc-sk.com

Okane Consultants Inc.

112 - 112 Research Drive
Saskatoon, SK S7N 3R3
Canada

Telephone: (306) 955 0702
Facsimile: (306) 955 1596
Web: www.okc-sk.com