Appendix 21

Portage Rock Storage Facility Closure Landform Design Report Revision 3

Portage Rock Storage Facility Closure Landform Design Report

February 22, 2023

AGNICO EAGLE

okane

Integrated Mine Closure and Relinquishment Solutions

Portage Rock Storage Facility Closure Landform Design Report

948-228-004 Rev3

February 2023

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EXECUTIVE SUMMARY

Agnico Eagle Mines Limited (Agnico Eagle) would like to assess the performance and define performance criteria for the design of the Portage rock storage facility (RSF) landform so that the information can be presented in the Meadowbank Final Closure and Reclamation Plan (FCRP), which is due one year prior to closure. Okane Consultants (Okane) previously completed thermal modelling of the Portage RSF and Agnico Eagle has requested support from Okane to demonstrate the effectiveness of the RSF cover design.

Okane was retained by Agnico Eagle to complete a review of the closure objectives, design basis, and modelling work done to support the Portage RSF cover system design, as well as regulator comments on the closure cover concept. Okane also completed review of studies and investigations completed by the Research Institute of Mines and Environment (RIME). Following the review of the aforementioned materials, the following gaps were identified (Okane, 2022a).

- Coupling of thermal oxidation and climate change for evaluation of the Portage RSF closure cover system has not been completed to date;
    - Prior to this mandate, modelling was completed prior to the availability of an add-in to the GeoStudio software which accounts for the heat generated due to oxidation reactions within the RSF, which Okane now uses for thermal modelling where oxidation reactions may influence thermal conditions. Hence, there would be value in updating the calibration model to improve its accuracy and increase confidence in its predictions.
- Examination and incorporation (if appropriate) of material properties characterized through RIME studies and investigations has not been completed to date; and
- Integration of learnings from the Whale Tail Mine has not been completed to date.

Okane proposed to update the thermal modelling of the Portage RSF closure cover system and the design basis of the cover system. The intent of the update was to increase the certainty of the modelling results and align the modelling results to better match the measured temperatures in the RSF.

Based on learnings from the Agnico Eagle Whale Tail Mine, the updated design basis of the cover system for the Portage RSF requires that performance cannot be measured alone by the depth of the active layer, it is the fulsome interaction of air and water in the intermittent non-frozen zones and the impacts (if any) that has on seepage and seepage water quality from the facility.

The cover system design for the Portage RSF is to control mechanisms which result in the potential for poor water quality from the RSF. These controls include:

- Limiting the depth of the yearly active (freeze-thaw) layer to limit the impacts on water quality;

- Promoting frozen conditions to limit acid generating reactions within the rock; and
- Promoting frozen conditions to limit mobilization of metal leaching and acid rock drainage (ML-ARD) products within the RSF.

The thermal and seepage model can also provide long-term hydrologic and thermal inputs for the site-wide water and load balances for assessing the impact of the Portage RSF on site-wide water quality should further assessment be required.

While annual thaw below the cover system is expected, the likelihood of a 4.0 m cover system thickness being insufficient, leading to unacceptable water quality in the receiver is expected to remain very low. This is due to several factors, including:

- Low volumetric water content in the thawed waste rock, resulting in low likelihood of mobilization of seepage from waste rock;
- Lower pyrite oxidation rates within the thawed waste rock compared to the cover system material (as a result of consistent near-freezing temperatures within the waste rock) resulting in low to moderate likelihood of production of metal leaching and acid rock drainage (ML/ARD) products;
- Limited volume of PAG/ML waste rock in the estimated thawed waste rock zone, resulting in low likelihood of production of ML/ARD products; and
- Limited interaction between infiltrating water and PAG/ML waste rock due to the development of ice lenses in the upper profile of the RSF and frozen conditions at the base of the RSF.

In addition, an Adaptive Monitoring Plan has been developed for the Portage RSF. The primary objective of the Adaptive Monitoring Plan is to identify a pathway for managing uncertainty and risk within the design of the Portage RSF cover system. The Portage RSF Adaptive Monitoring Plan addresses risks and uncertainties as they relate to:

- Permafrost aggradation; and
- Surface water balance and active layer development.

The Adaptive Monitoring Plan also details mitigation measures and associated management actions to be taken when specified thresholds are exceeded for parameters where uncertainty cannot be further reduced at this time (e.g. climate change). Mitigation measures may include special studies, operational changes, revised or new water and waste management systems, new or expanded conveyance systems, structures and/or facilities, or implementing mitigation activities to prevent, stabilize or reverse a change in environmental conditions or to otherwise protect the receiving environment.

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1 INTRODUCTION

1.1 Project Scope and Objectives

Okane Consultants (Okane) was retained by Agnico Eagle Mines Limited – Meadowbank Division (Agnico Eagle) to complete an update of the closure objectives and design of the Portage Rock Storage Facility (RSF) as well as address regulator comments on the closure cover concept. Through the course of normal consultation, Agnico Eagle has received concerns from regulating agencies about the current and long-term performance of the Portage closure cover concept and whether the concept would allow the water quality objective of the RSF to be reached at closure.

In response to these concerns, Okane completed a review of studies and investigations completed by the Research Institute of Mines and Environment (RIME) and Agnico Eagle, as well as updated numerical modelling of the existing closure cover system design. Additionally, a proposed adaptive monitoring plan has been developed to increase confidence in the long-term performance of the cover system as corrective actions in response to detailed monitoring have already been identified. The results of this review and updated modelling will be included in the updated Meadowbank Final Closure and Reclamation Plan (FCRP) anticipated to be submitted in 2025.

1.2 Description of Cover System

1.2.1 Summary of Closure Landform

Agnico Eagle owns and operates the Meadowbank Mine located in the Kivalliq region of Nunavut, approximately 70 kilometres north of the hamlet of Baker Lake. Mine commissioning and first gold production from the Portage open pit began in early 2010 and concluded at the Meadowbank Site in 2019. Waste rock from open pit mining operations at Meadowbank is stored at the Portage and Vault RSFs (Agnico Eagle, 2021a). The focus of this project is the Portage RSF, which is located at the north end of the main Meadowbank Mine site; adjacent to the North Cell Tailings Storage Facility (TSF) (Figure 1.1 and Table 1.1).

Table 1.1: Details of Portage Rock Storage Facility Landform.

Portage RSF Design Characteristic	Value
Storage Volume	39.3 Mm^3
Final Crest Elevation	254 m
Final Height	100 m
Maximum elevation of Adjacent Topography	192 m
Footprint Area	80.8 ha
Thermal Cover Thickness	4.0 m

Agnico Eagle, 2021a.

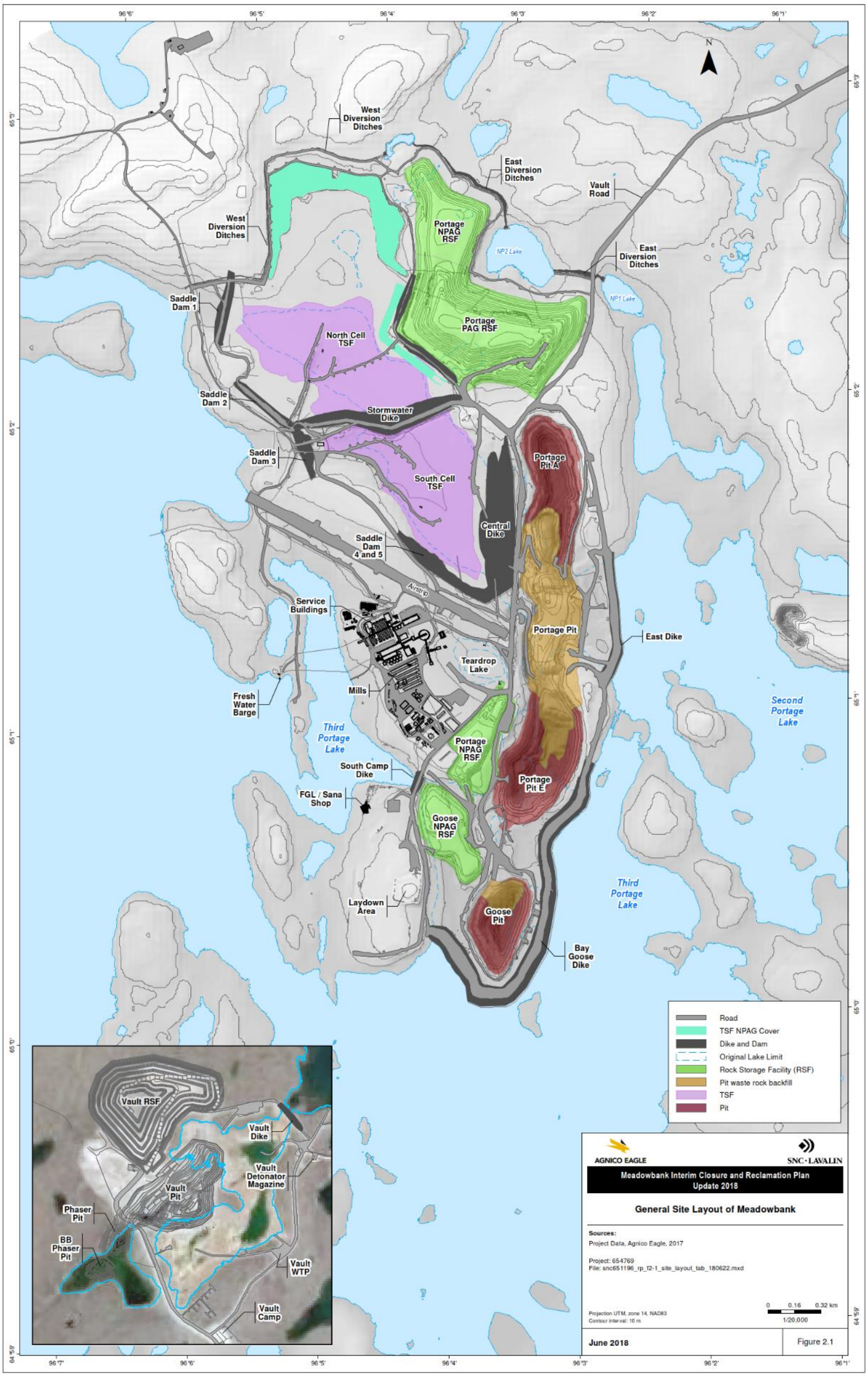

Figure 1.1: Meadowbank Site Map (Portage RSF located near top of the figure in green).

A proportion of the waste rock generated from the open pit mining has been classified as potentially acid-generating (PAG). All iron formation, quartzite and a portion of the intermediate volcanic rock are either PAG or have an uncertain potential to generate Acid Rock Drainage (ARD), while the ultramafic rocks and most of the intermediate volcanic rocks are expected to be non-potentially acid-generating (NPAG).

Placement of waste rock within the Portage RSF commenced in 2009 closest to the Portage Pit and progressed westward over the entire footprint, then upward to further benches during the development of the mine. In 2012, an extension of the Portage RSF was constructed to store NPAG material within a temporary area (Figure 1.2). Progressive reclamation of the facility with the closure cover system began in 2011.

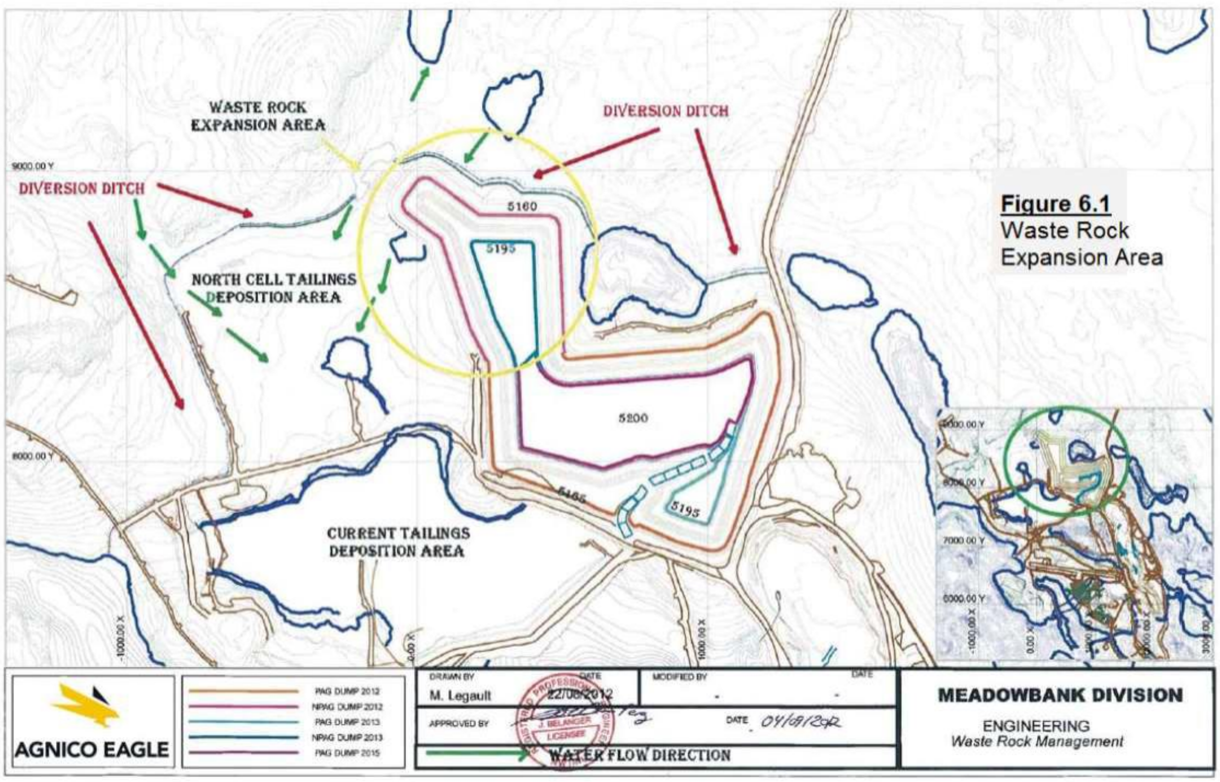

Figure 1.2: Waste Rock Expansion Area (Temporary NPAG Storage Area)

The Portage RSF closure cover system design consists of a 4.0 m NPAG waste rock cover system encapsuling PAG waste rock. The purpose of the cover system is to ensure geochemical stability of the Portage RSF by (Agnico Eagle, 2021a):

- Insulating the PAG waste rock from direct interaction with atmospheric forces; and
- Limiting oxidation by maintaining frozen conditions within the PAG waste rock.

The cover system also prevents runoff from contacting PAG waste rock material. To date, approximately 90% of the closure cover system has been constructed on the Portage RSF. No additional work on the landform is planned prior to closure as the demolition landfill is to be located on the RSF and it will not be possible to reclaim the upper most bench and plateau of the Portage RSF until the work is complete (Agnico Eagle, 2022a).

1.2.2 Summary of Information Reviewed

Okane completed a review of the closure objectives, design basis, and modelling work done to date to support the Portage RSF cover system design, as well as regulator comments received regarding the closure cover concept (Okane, 2022a). Okane has also reviewed the monitoring data Agnico Eagle has collected to date at the Portage RSF to affirm the design basis. Lastly, a review of studies and investigations completed by the RIME was completed. A summary of information reviewed follows, including the milestones and estimated schedule to complete additional studies and investigations required prior to the submission of the Meadowbank FCRP.

1.2.2.1 Design Basis Review

Summary of Thermal Modelling Inputs and Approach

A numerical modelling program to assess the expected performance of the Portage RSF cover system was completed in 2016 (Okane). The main objective of the 2016 numerical modelling was to estimate the depth of the active layer (layer of materials undergoing freeze-thaw cycles from atmospheric forcing) within the Portage RSF and to confirm that the PAG waste rock will remain frozen, and oxidation rates greatly decreased, for the next 150 years under agreed upon climate change scenarios. One-dimensional (1D) and two-dimensional (2D) soil-plant-atmosphere (SPA), thermal and air flow modelling were completed, primarily to determine internal RSF temperatures.

The 2D, 150-year climate change models predicted:

- The maximum depth of the active zone would not extend below 4 m on any slope aspect assuming climate conditions follow the RCP4.5 trend.
- If climate conditions follow the RCP6.0 trend, the model predicts that the active layer will extend beyond the 4 m cover system for infrequent time periods, with the greatest depth being over 6 m on the plateau during a period of 664 days when the model predicted an active zone greater than 4 m.

The 2016 model results were revisited by Okane (2019) to evaluate the accuracy of the thermal model by comparing the simulated results with field data collected from the thermistors in the Portage RSF in the period since the modelling was completed. The key findings of the review and comparison were:

- Decreasing trends in the active zone depth were recorded at most thermistor locations.
- The thermal model predicted colder temperatures near surface compared to recorded near surface temperatures.
- Observed temperature trends becoming more consistent with simulated temperatures over time.
- The observed active zone was generally thicker on the north slope compared to the south slope. In the conceptual model, the south slope was anticipated to be the area with the highest potential for a thicker active zone.
- Comparison of site recorded net radiation to model input net radiation showed that the model underestimated net radiation by approximately 10-15% in the summer months.
- Snow depth was not recorded at the time on the RSF.
- The cover system on the inter-bench slopes will likely have slightly different properties as it is not trafficked and would likely not have a finer-grained layer develop as a result.

Hence, the confidence in the numerical model as a predictor of future conditions was estimated as moderate to high, with further increasing confidence if the trend towards consistency continued as expected.

1.2.2.2 Closure Approach at Similar Sites

A similar non-acid generating / non-metal leaching (NAG/NML) closure thermal cover system has also been proposed and investigated at Agnico Eagle's Whale Tail Mine, specifically for the Whale Tail and IVR waste rock storage facilities (WRSFs). The intent of the Whale Tail WRSF design is to demonstrate the physical and chemical stability of the Whale Tail and IVR WRSFs while optimizing risk and cost for Agnico Eagle. The objective of the final cover system is to ensure that the overarching closure objective, specifically that water quality in the receiving environment be protected within permitted conditions, is met. The design basis of cover system design is to control mechanisms which result in the potential for poor water quality from the WRSF (Okane, 2019b).

The proposed cover system design thickness has been determined through modelling of the Whale Tail and IVR WRSFs, and monitoring efforts at the Portage WRSF. Updated thermal modelling of the Whale Tail WRSFs (Okane, 2022c) indicates that a thermal cover of NAG/NML material will limit the likelihood of risk associated with ML/ARD within the PAG/ML waste rock, by promoting frozen conditions in the Whale Tail and IVR WRSF. While thaw below the proposed cover system is expected, the likelihood of the thermal cover system thickness being insufficient, leading to unacceptable water quality in the receiver is expected to remain very low. This is due to several factors, including:

- Low volumetric water content in the thawed waste rock, resulting in low likelihood of mobilization of seepage from waste rock;
- Lower pyrite oxidation rates within the thawed waste rock compared to the cover system material (as a result of consistent near-freezing temperatures within the waste rock) resulting in low to moderate likelihood of production of metal leaching and acid rock drainage (ML/ARD) products; and
- Limited volume of PAG/ML waste rock in the estimated thawed waste rock zone, resulting in low likelihood of production of ML/ARD products.

1.2.2.3 Previous Regulating Agency Comment

Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC) has raised several concerns regarding the closure cover system for the Meadowbank Portage RSF, italicised below with details as to how these concerns will be addressed prior to the FCRP submission.

Freeze back/Capping Thickness

"CIRNAC recommended that AEM include a meaningful discussion of the results from the thermal monitoring in the Annual Report. FEIS predictions should be compared with monitoring results and be clearly presented. AEM should present the updated modeling supporting their conclusions that the conceptual plans for thermal encapsulation of the Tailings Storage Facility (TSF) and the Waste Rock Storage Facility (WRSF) remain effective to prevent and control deleterious seepage over long term. Finally, if results show discrepancies from the predicted values, AEM should discuss the management actions that should be implemented to address the risk." (Agnico Eagle, 2022c).

A review of the thermal modelling for the Portage RSF closure cover system is presented in section 1.2.2.1. Thermistor measurements and thermal model predictions are compared and analyzed in the Performance Monitoring Data section (1.2.2.4) of this memorandum.

An adaptive monitoring plan for the Portage RSF has been developed as part of this scope of work (Section 3), to be able to communicate the effectiveness of the cover system design to the regulator on a yearly basis (in operation and closure). (Agnico Eagle, 2022c).

"CIRNAC recommended that AEM provide more information on the nature and extent of research efforts, results of the research and a discussion of how the proposed cover design has been influenced by these results."

The RIME has conducted several studies and investigations at the Meadowbank Portage RSF with respect to the thermal properties and regimes of the facility. These studies have been reviewed and summarized in the RIME Studies and Investigations section (1.2.2.5) of this memorandum.

Progressive Reclamation

"CIRNAC recommended that future updates to the [Interim Closure and Reclamation plan] ICRP include more details on progressive reclamation at Meadowbank such as areas of Tailings Storage Facility (TSF) and Waste Rock Storage Facility (WRSF) facilities covered in the prior year, total areas covered to date, along with the volumes associated with these areas." (Agnico Eagle, 2022c).

To date, approximately 90% of the closure cover system has been constructed on the Portage RSF. In response to 2019-2020 Nunavut Impacts Review Board (NIRB) recommendations, Agnico Eagle has committed to include more details on progressive closure in the 2020 Annual Report. Information relevant to progressive closure can be found in Section 9.1 of the 2020 Annual Report and will continue to be updated annually. Details related to work completed and schedules of progressive reclamation is also included in the closure schedule presented in Appendix P of the ICRP which was updated in March 2020 (SNC, 2020) and provided in the 2019 Annual Report in Appendix 55. Agnico Eagle is of the opinion that the last update March 2020 version fulfills the current request. Agnico Eagle is nevertheless committed to providing more details on the progressive closure in the next iteration of the Meadowbank ICRP.

WRSF Seepage Water Quality

"CIRNAC recommended that AEM confirm whether long-term modelling of seepage from the Meadowbank Waste Rock Storage Facilities (WRSFs) is of sufficient duration to characterize seepage after breakthrough. If not, CIRNAC recommends that AEM extend the temporal scope of its WRSF seepage modelling to ensure that potential seepage impacts after breakthrough are accurately characterized." (Agnico Eagle, 2022c).

A summary of water balance results from the thermal and hydrological model is presented in Section 2.3 and Appendix B. Water balance estimates from thermal and hydrological modelling indicate that a pseudo steady-state is achieved within the time period modelled. Water balance results will subsequently be used to model the water quality from the WRSF landform at closure (to demonstrate whether long-term water quality objectives will be met) as a future scope of work.

Thermistor Measurements for the Portage RSF

"CIRNAC recommended that AEM analyze the thermistor monitoring results against early thermal modelling predictions and update its Waste Rock and Tailings Management Plans if large discrepancies are observed between the monitoring results and model predictions." (Agnico Eagle, 2022c).

Thermistor measurements and thermal model predictions are compared and analyzed in Section 1.2.2.4.

Thermal Performance of Meadowbank RSF Cover System

"CIRNAC notes that the WRSF cover concept for the Whale Tail Pit Project is generally similar to the concept used at the Meadowbank Gold Mine. The only notable difference is that thermal modelling for the Whale Tail Pit site determined that WRSF covers should have a total thickness of 4.7 m (4.2 m active freeze/thaw zone and a 0.5 m buffer). Modelling for the Whale Tail site also predicted that the freeze/thaw zone may penetrate deeper than the 4.7 m design thickness of the WRSF covers under the most conservative climate change scenario." (Agnico Eagle, 2022c).

Updated active layer thickness predictions for the Portage RSF are provided in Section 2.3.1.

1.2.2.4 Performance Monitoring Data

Summary of Installed Instrumentation

Thermistor strings have been installed to monitor temperature and permafrost aggradation within the Portage RSF. Twenty-one (21) thermistor strings were installed in the Portage RSF between 2012 and 2020 (Figure 1.3). In 2022, two (2) near surface monitoring stations (NSMS) were installed in the RSF (Agnico Eagle, 2022c) to monitor hydraulic and thermal conditions within the closure cover system. A summary of thermistor strings installed in the RSF can be found in Table 1.2 and a summary of the instrumentation installed in the NSMS can be found in Table 1.3. Additional instrumentation is planned to be installed in the Portage RSF prior to mine closure.

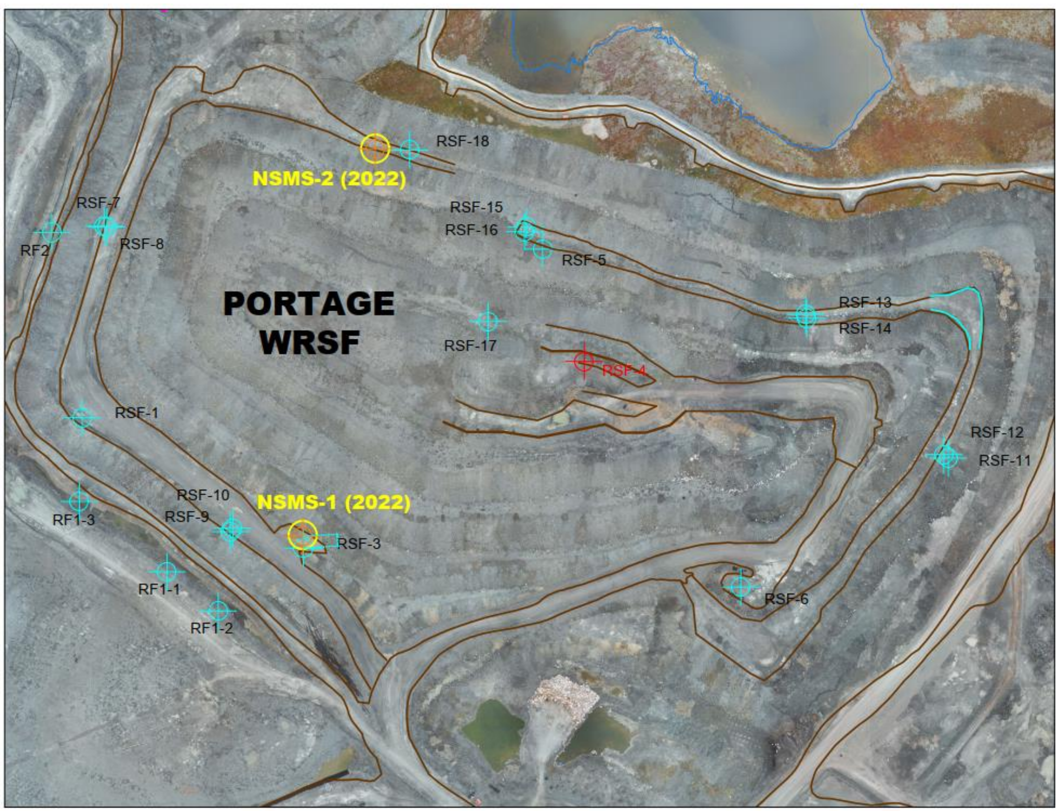

Figure 1.3: Plan view of thermistor string monitoring locations at Portage RSF.

Table 1.2: Summary of Thermistors Installed in Portage RSF between 2012 and 2020

Name	Easting	Northing	Elevation	Year Installed
RF1-1	638221.23	7215663.59	149.47	2012
RF1-2	638277.00	7215621.00	149.5	2012
RF1-3	638126.00	7215740.00	149.5	2013
RF-2	638096.00	7216032.00	149.83	2012
RSF-1	638129.00	7215831.00	172.8	2013
RSF-3	638369.59	7215689.20	173.99	2013
RSF-4	638675.00	7215892.00	210.21	2013
RSF-5	638629.81	7216014.00	193.02	2013
RSF-6	638845.40	7215647.00	197.79	2013
RSF-7	638153.00	7216039.00	173.5	2015
RSF-8	638156.00	7216038.00	173.85	2015
RSF-9	638290.00	7215707.00	171.26	2015
RSF-10	638293.00	7215711.00	171.7	2015
RSF-11	639071.00	7215787.00	193.13	2015
RSF-12	639066.00	7215791.00	193.51	2015
RSF-13	638916.00	7215943.00	191.69	2015
RSF-14	638917.00	7215939.00	191.81	2015
RSF-15	638612.00	7216038.00	192.1	2015
RSF-16	638610.00	7216033.00	192.39	2015
RSF-17	638570.442	7215935.40	233.183	2020
RSF-18	638495.212	7216111.896	172.605	2020

Table 1.3: Summary of instrumentation installed in NSMS.

Station	Location	Instrumentation
NSMS-1	South Section Portage RSF (El. 5173)	• 6 volumetric water content sensors (CS616) • 4 soil matric potential sensors (CS229) • 4 single point temperature sensors (CS107) • 1 net radiometer sensor (NR-Lite) • 1 data acquisition system
NSMS-2	North Section Portage RSF (El. 5173)	• 6 volumetric water content sensors (CS616) • 4 soil matric potential sensors (CS229) • 4 single point temperature sensors (CS107) • 1 net radiometer sensor (NR-Lite) • 1 data acquisition system

Agnico Eagle, 2022c

Observed Thermal Regime of Portage RSF

The thermal regime was evaluated using the following thermistors: RSF-3 (south slope), RSF-5 (north slope), RSF-6 (south slope), RSF-8 (west slope), RSF-10 (south slope) RSF-11 (east slope), RSF-12 (east slope), RSF-15 (north slope), RSF-17, and RSF-18 due to the completeness of the data sets collected. The remaining thermistors have data gaps that restrict the usefulness of the data sets.

The results for the aforementioned thermistors show the continued gradual shallowing of the zero isotherm through repeated years of monitoring. This would indicate that the RSF is continuing to freeze back but has not yet reached a state of equilibrium. Based on thermistor data, the depth of the active layer is approximately 3 m.

Figure 1.4 and Figure 1.5 illustrate the thermal performance of the installed thermistors RSF-3 and RSF-15. The dashed line indicates the location of the thermal cover system. Additional figures of thermistor data are included in Appendix A .

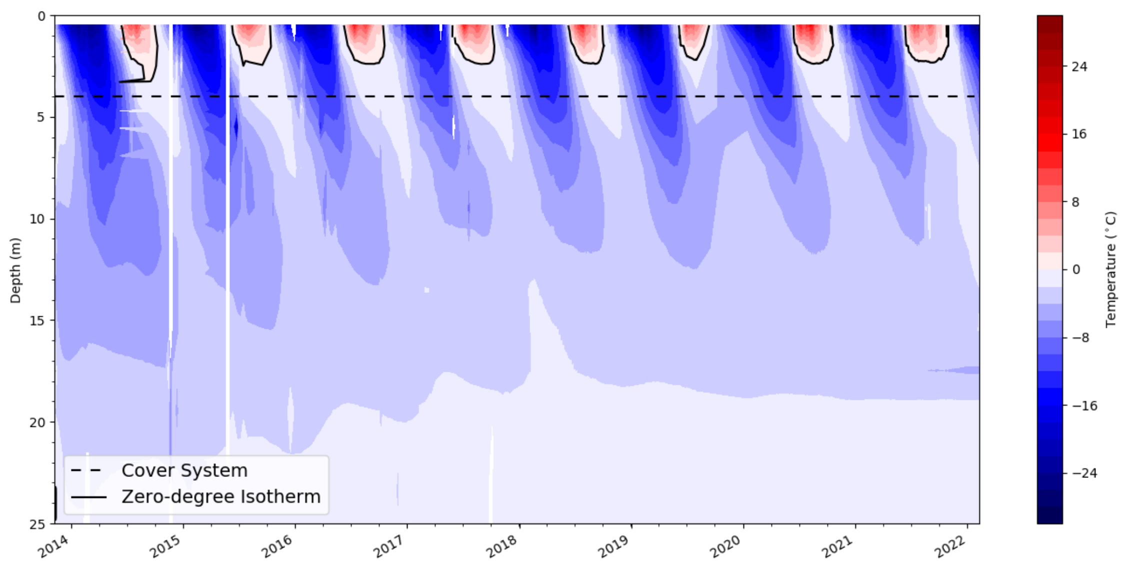

Figure 1.4: RSF-3 Thermistor String data between November 8, 2013 to February 8, 2022

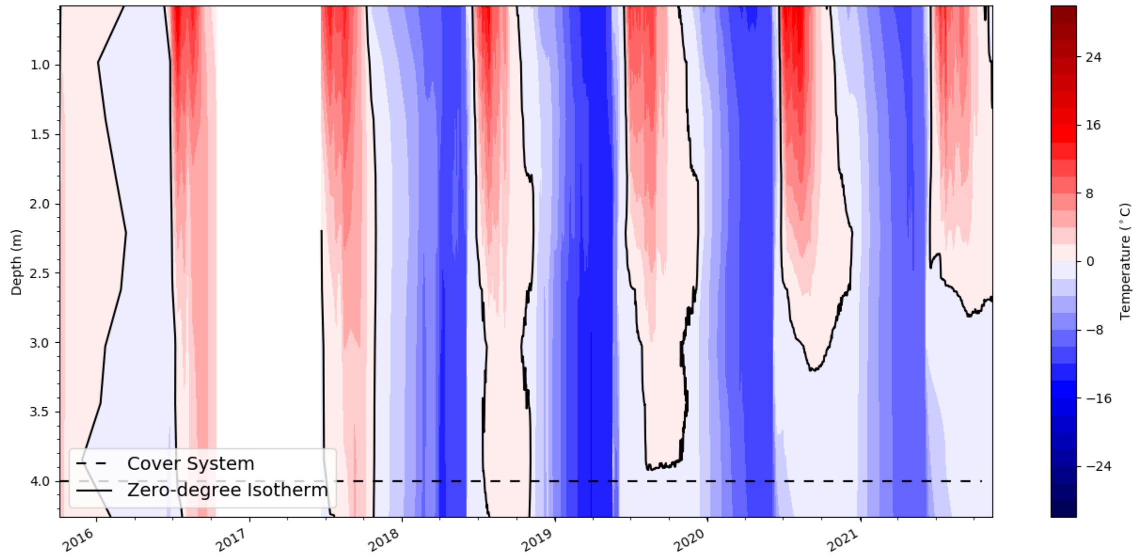

Figure 1.5: RSF-15 Thermistor String between October 4, 2014 and November 13, 2021.

Predicted Thermal Regime Comparison

Observed temperature at a depth of approximately 4 m was compared to simulated 2019 thermal model temperature for RCP4.5 and RCP6.0 to assess the accuracy of the 2019 thermal modelling (Figure 1.6 to Figure 1.8). Observed and simulated temperatures follow the same seasonal trends and have similar amplitudes of seasonal temperature fluctuations though observed temperatures are generally higher than those simulated. Observed temperatures indicate sensors are equilibrating during the initial years post-installation; therefore, comparison of observed temperature to simulated temperatures will focus on the period starting in 2017.

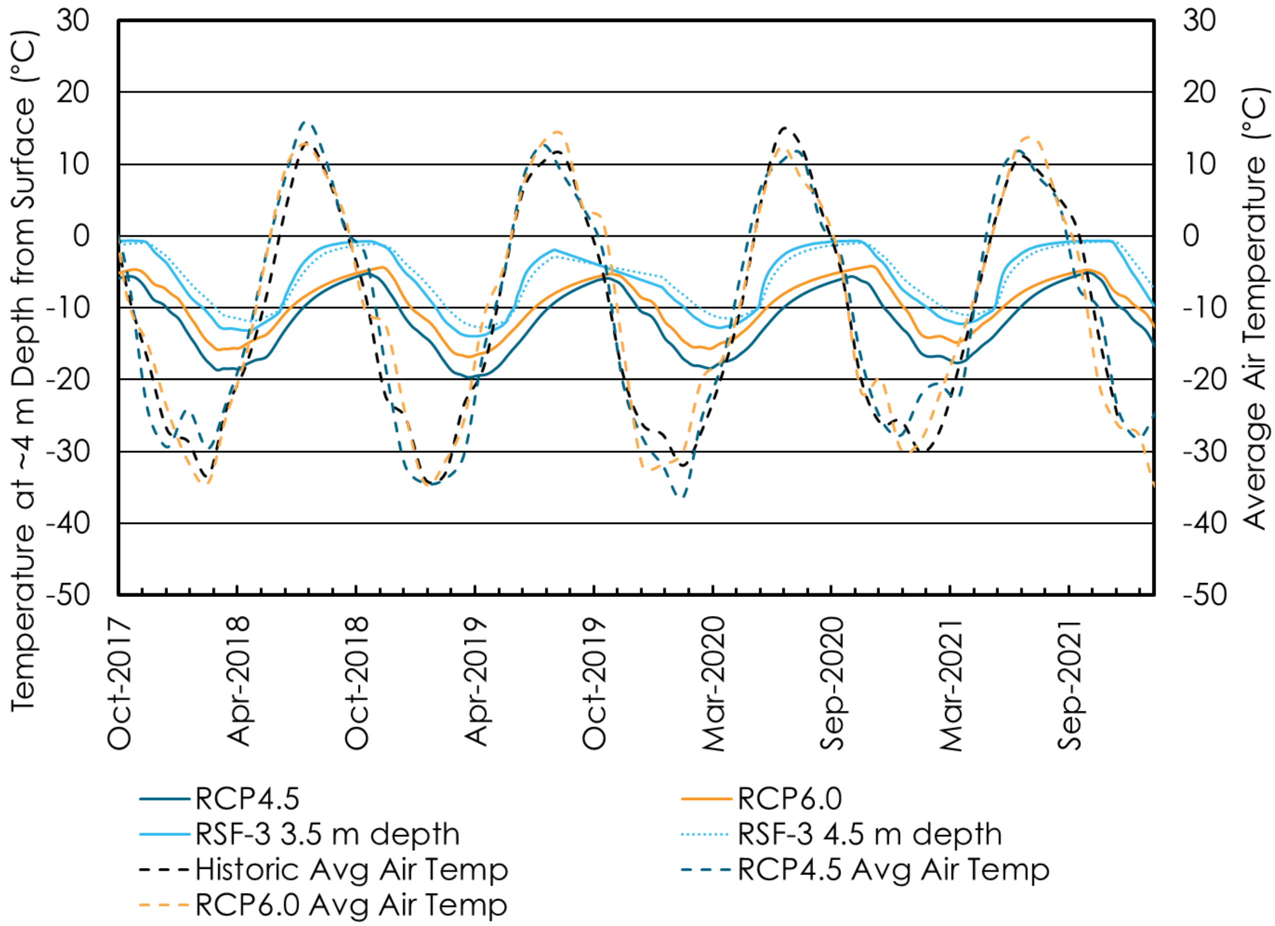

Figure 1.6: RSF-3 measured temperature at 3.5 m and 4.5 m depth compared to model predicted temperature at 4 m depth.

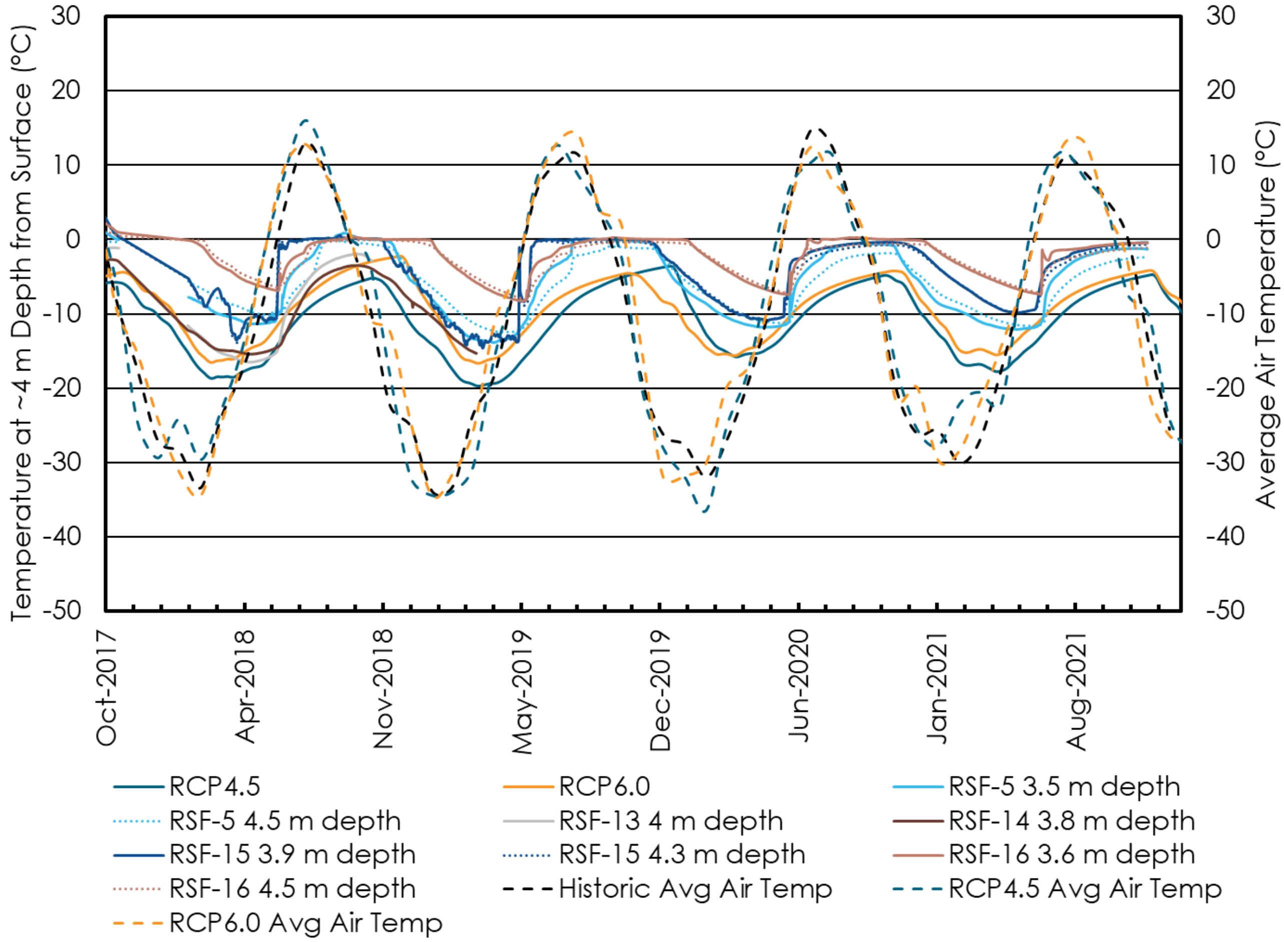

Figure 1.7: Simulated temperature at 4 m depth compared to thermistor recorded temperatures near 4 m depth at north facing slope locations.

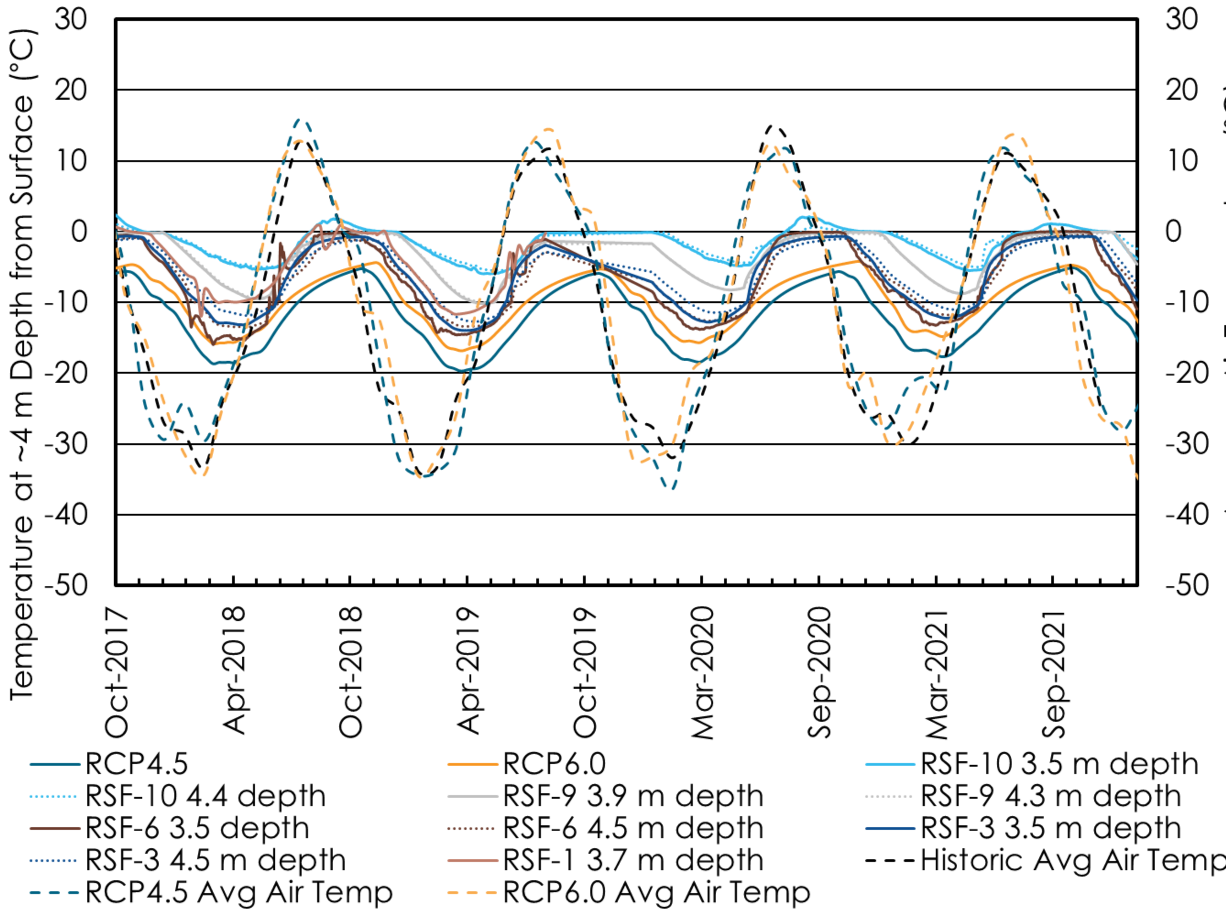

Figure 1.8: Simulated temperature at 4 m depth compared to thermistor recorded temperatures near 4 m depth at south facing slope locations.

1.2.2.5 RIME Studies and Investigations

The RIME has conducted several studies and investigations at Agnico Eagle's Meadowbank Mine and associated facilities. The following summarizes the articles pertaining to the Meadowbank facilities.

Resistance of a soapstone waste rock to freeze-thaw and wet-dry cycles: implications for use in a reclamation cover in the Canadian Arctic

Vincent Boulanger-Martel, Bruno Bussière, and Jean Côté

The durability of NPAG soapstone waste rock was investigated with respect to freeze-thaw and wet-dry cycles, to be used as a cover material for reclamation of tailings and waste rock storage facilities. No single methodology exists to accurately characterize a materials resistance to freeze/thaw and wet/dry cycles, so a series of index tests were chosen from existing literature to analyze pore space properties and static physical integrity.

Testing was completed on intact rock cores to determine the following physical properties:

- Dry mass;
- Dry density;
- Water adsorption index; and
- Apparent porosity.

Mechanical properties assessed included unconfined compressive strength (UCS), and Young's modulus (*E*) which omitted any weathering cycles, to represent initial conditions.

Results of the study indicate that the soapstone waste rock is resistant to freeze-thaw and wet-dry cycles, as well as to physical degradation. Based on site specific conditions, freeze-thaw cycles should be considered the primary weathering mechanism at Meadowbank Mine. Mass loss durability tests were also conducted on intact rock cores, rock slabs, and < 50-mm granular materials, which indicated the potential to release fine particles due to freeze-thaw weathering to be low. The soapstone waste rock is considered a suitable material for an insulation cover system at Meadowbank Mine.

Thermal behaviour and performance of two field experimental insulation covers to control sulfide oxidation at Meadowbank mine, Nunavut

Vincent Boulanger-Martel, Bruno Bussière, and Jean Côté

The proposed insulation cover for the Meadowbank mine TSF was validated *via* laboratory and field tests conducted on two instrumented experimental cells. The objectives of the study included:

- determining the materials main thermal and hydrogeological properties;
- identifying the maximum temperature for the safe storage of the Meadowbank tailings;
- assessing the thermal behaviour of 2 m and 4 m thick insulation covers after 4.5 years of monitoring; and
- assessing the in-situ performance of the cover systems with respect to limiting sulfide oxidation.

Results indicated the temperature of the tailings was significantly influenced by the insulating properties of the cover material, and that maximum and minimum temperatures at the tailings-cover interface were influenced by the thickness of the cover. Below 0°C no reactivity was observed, and at 0°C, the laboratory measured tailings' reactivity and temperature (Kr-T) relationship indicated a reduction in Kr of 93-96% relative to ambient temperatures.

The 4 m thick cover maintained temperatures below 0 °C at the tailings-cover interface, whereas the 2 m thick cover resulted in temperatures above 0 °C on 94-124 days out of the year. The study recommends that insulation covers be designed thick enough to maintain temperatures below the target temperature at the tailings-cover interface in the long term. Materials and construction methods that promote high degrees of saturation should also be considered to help limit thaw depth and control sulfide oxidation.

Insulation covers with capillary barrier effects to control sulfide oxidation in the Arctic

Vincent Boulanger-Martel, Bruno Bussière, and Jean Côté

The performance of a thermal cover with capillary barrier effects (CCBEs) used for reclamation of a TSF was investigated for the Meadowbank mine site in both a laboratory and field setting. The objectives of the insulation cover in a permafrost environment were to control the temperature and limit oxygen ingress of the PAG tailings.

Fine grained, compacted NPAG waste rock was evaluated as a potential candidate for construction of the moisture retention layer and was determined to be a suitable material as it has a low resistance to compaction; the waste rock easily breaks down into fine particles. The cover consisted of a 0.5 m layer protective layer of loose waste rock overlying a 0.5 m moisture -retaining layer and 1.0 m capillary break layer of loose waste rock atop approximately 15 m of tailings. Three monitoring stations were installed in the cell equipped with instrumentation to measure unfrozen volumetric water content and temperature.

The results of the investigation indicate that the active layer generally does not penetrate the PAG tailings. The maximum depth of thaw observed during the monitoring period was 15 to 25 cm into the tailings. This was typically observed in years with warmer summers, with 39 to 57 days above 0°C depending on the year. The degree of saturation in the moisture retention layer was observed to remain high even when temperatures reach above 0°C.

During periods when the tailings are below 0°C, the oxidation reactions are limited. When above 0°C, oxidation reactions were limited by the amount of available oxygen able to pass through the moisture retention layer. The annual oxygen ingress through the moisture retention layer and into the tailings was calculated to be less than 2 mol/m^2/year.

Thermal conductivity of Meadowbank's mine waste rocks and tailings

Vincent Boulanger-Martel, Andrée Poirier, Jean Côté, and Bruno Bussière

A predictive thermal conductivity model was calibrated based on laboratory data to assess the thermal conductivity of solid particles and the unfrozen/frozen thermal conductivity as a function of saturation. Materials assessed include compacted NPAG waste rock, PAG waste rock, and tailings.

The objective of the characterization program was to determine thermal conductivity (λ_s), obtain thermal conductivity measurements of the moist materials, and determine dry thermal conductivity (λ_{dry}). Unfrozen and frozen thermal conductivities as a function of saturation for each material type were determined and summarized in Table 1.4.

Table 1.4: Thermal conductivity (λ_s) summary by material type

Material Type	Number of Samples	Degree of Saturation	Porosity	λ_s (W/m K)
Compacted NPAG Waste Rock	5	33 to 90%	0.19 to 0.21	4.80
PAG Waste Rock	2	21 and 67%	0.26 and 0.21	5.27
Tailings	3	46 to 89%	0.39 to 0.40	5.80

Additional testing was conducted on NPAG waste rocks to determine structural effects on thermal conductivity, in which λ_{dry} measurements were made on grain-size fractions 0-20mm and 0-1.25 mm.

Results of XRD analyses indicate that talc and chlorite are the primary minerals in all NPAG rock samples. Field and laboratory evidence showed that the NPAG waste rock has a relatively low resistance to compaction, resulting in breakage of particles which generates finer particles after compaction.

Thermal conductivity was found to increase with increasing saturation, and higher values were measured in the frozen state relative to those measured in the unfrozen state. No major structural effects on the thermal conductivity were identified.

Design, construction, and preliminary performance of an insulation cover with capillary barrier at Meadowbank Mine, Nunavut

Vincent Boulanger-Martel, Bruno Bussière, Jean Côté, and Patrice Gagnon

This study is a preliminary report which is appropriately detailed and summarized above in 'Insulation covers with capillary barrier effects to control sulfide oxidation in the Arctic.'

Thermal-Hydrological-Chemical Modeling of a Covered Waste Rock Pile in a Permafrost Region

Xueying Yi, Danyang Su, Bruno Bussière, and K. Ulrich Mayer

A reactive transport model was developed using the MIN3P-HPC software to understand the thermal-hydrological and chemical processes governing a covered waste rock pile under permafrost conditions located in Nunavut Canada.

The long-term thermal conditions for the base case scenario indicate that the zero-degree (0°C) isotherm remains within the 4 m NPAG cover system, indicating that frozen conditions are maintained in the PAG waste rock. Frozen conditions are maintained at the core of the pile.

Sensitivity analysis was conducted on infiltration rates; simulations included a reduced infiltration rate and an increased infiltration rate in addition to the base case. Increased saturation and ponding within the cover is observed under the increased infiltration rate. In addition, the saturation and basal seepage at the toe of the pile increases with increased infiltration. The magnitude of the laterally diverted flow increases with increasing net infiltration. The simulated results indicate that net infiltration does not have a significant impact on active layer thickness as similar flow patterns and locations and ice distributions are similar for all infiltration scenarios. Overall, it was observed that saturation, ponding, and seepage is a function of the net infiltration.

Additional sensitivity analysis was run on cover thickness, including simulations with a 2 m cover system and a 6 m cover system in addition to the base case 4 m cover. Under the 2 m cover thickness, the simulated active layer extends into the PAG waste rock. Similar to the 4 m cover thickness, for the 6 m cover thickness the zero-degree (0°C) isotherm of the active layer remains within the cover system, nearing the interface of the NPAG and PAG materials.

The cover thickness and thus the resulting depth of the active layer are the main drivers affecting the geochemical processes within the RSF. For the no cover and 2 m cover scenarios, pyrite oxidation was observed in the summer months. The extent of the oxidation is greater in the no cover scenario as the entire active layer is within the PAG waste rock. In the resulting loading of sulfates in basal drainage in the 4 m and 6 m scenarios, minimal pyrite oxidation is observed as the PAG rock remains in a frozen state. As a result, basal drainage remains clean as no products of oxidation are generated.

Summary of Information of Interest

Following the review of the studies and investigations of the RIME, the following take-aways are provided below.

- NPAG waste rock is competent material for cover system construction as it is resistant to freeze-thaw and wet-dry cycles and physical degradation. As such, it would remain a physically stable cover system in closure and post-closure.

- NPAG waste rock exhibits a low resistance to compaction, leading to the formation of a finer grained material. In turn this would decrease the thermal conductivity.

- Use of an insulation thermal cover system in conjunction with a moisture retention layer can limit the oxidation reactions in tailings helping to develop and maintain frozen conditions as well as limit the amount of available oxygen.

- Thermal conductivity of NPAG waste rock was characterized through laboratory analyses. Thermal conductivity was found to increase with increasing saturation, and higher values were measured in the frozen state relative to those measured in the unfrozen state. No major structural effects on the thermal conductivity were identified.

- Thermal modelling completed by the RIME indicates that the active layer (temperatures above 0°C) is maintained with a 4 m NPAG waste rock cover system long term. This model considered the heat generated due to oxidation; however, climate change was not considered. The thermal model is in agreement with Okane's thermal modelling results which considered climate change but not heat generation due to oxidation.

- Thermal modelling completed by the RIME for the Portage RSF indicates that basal drainage remains clean as no products of oxidation are generated.

2 COVER SYSTEM DESIGN AND ASSESSMENT

2.1 Cover System Objectives

As per the 2019 Meadowbank ICRP (SNC, 2020), the Meadowbank Project specific closure principles and objectives have been defined as:

- Physically and chemically stable lands and waters at the reclaimed Meadowbank site that are safe for human, wildlife and aquatic life;
- Lands and waters at the reclaimed Meadowbank site that allow for traditional uses;
- Final landscape guided by pre-development conditions and traditional knowledge;
- Post closure conditions that, where appropriate, do not require a continuous presence of project staff until a walk-away condition is achieved.

The overarching Project closure principles and objectives were then used to develop specific objectives for the Meadowbank RSFs (SNC, 2020). These objectives are defined as follows:

- The pile is physically and geotechnically stable for human and wildlife safety in the long-term: minimize erosion, thaw settlement, slope failure, collapse, or the release of contaminants or sediments;
- Build to blend in with current topography, be compatible with wildlife use, and/or meet future land use targets;
- Generation of poor water quality has been minimized, surface runoff and seepage water quality is safe for humans and wildlife; and
- Dust levels are safe for people, vegetation, aquatic life, and wildlife in the long-term.

Based on learnings from the Whale Tail Mine, geochemical stability and minimization of generation of poor-quality water will be ensured by the implementation of a cover system for closure. The objectives of the cover system are to:

1) Limit the depth of the annual active layer within the PAG material to control impacts on water quality;
2) Promote frozen conditions to limit acid generating reactions; and
3) Limit ARD/ML migration of contaminants by promoting frozen conditions within the PAG material by limiting the mobility of water.

2.2 Cover System Design Basis

The cover system design basis and design criteria have been updated based on the refined cover system objectives and considering the additional studies completed since the original design (Section 1.2.2). Limiting the migration of contaminants (Objective #3) is largely dependant on understanding the expected landform water balance, while Objectives #1 and #2 are driven by the thermal regime. A conceptual model of performance, or the updated design basis can be largely described by understanding the high-level scientific concepts governing interactions between climate and materials. The following sections describe the high-level description of the current state of understanding of the cover system performance.

The Meadowbank 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.

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 July through August, and a slight water surplus in September, as PE decreases. Climate data suggest that net percolation, the water that moves from a cover system into a RSF when a cover system is in place, or simply just surface infiltration when there is no cover system placed, is likely to occur in the fall period when PE is low, and potentially during spring freshet.

Waste rock has very low available water holding capacity (AWHC). The AWHC 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 20-30 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%-45% of total annual precipitation.

The coarser-textured nature of the waste rock, which results in low AWHC, also results in high surface infiltration capacity (though influenced by frozen conditions), and thus low surface water runoff potential. In short, the potential for saturated overland flow is very low. 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 Meadowbank particularly at the Portage RSF, where windspeed is high and the RSF is the predominant feature within the landscape. The potential for redistribution is expected to result in a net loss of snow on the RSF (without accounting for sublimation). Previous estimates (SNC, 2015) indicated that sublimation may account for up to 70% of the total winter precipitation, or 29% of total annual precipitation. The updated average annual loss of snowpack to sublimation and snow redistribution is an estimated 40% of the total winter precipitation for between October and May (Okane, 2022b). Sublimation and snow redistribution may be higher for the wind-blown Portage RSF at Meadowbank.

Given the above drivers of the surface water balance, the initial surface infiltration into the RSF will be ‘high’, assuming no surface runoff. Given the low AWHC of the waste rock, the time for wet up of the landform will be relatively short and will have occurred during the operations period, 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 RSF will allow for additional water to be stored in the waste rock beyond its field capacity. Fully saturated ice zones will exist along the boundary of the seasonal active layer, creating a low permeability ice zone. The active layer in the Meadowbank area generally ranges from 1.3 to 4.0 m (SNC, 2020); however, the active layer will be deeper in the RSF as the thermal conductivity of waste rock is higher, and the volumetric heat capacity is lower than surrounding surficial overburden. The presence of a lower permeability ice zone coupled with the lower permeability of *in situ* surficial overburden will reduce basal seepage to negligible levels.

Once the lower permeability ice zone has formed, the RSF 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 RSF (Figure 2.1). This, however, should not be interpreted as a ‘plug flow’ condition, where a drop of water infiltrating on the plateau of the RSF reports as interflow in the same time frame as a drop of water infiltrating near the toe of the RSF. 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.

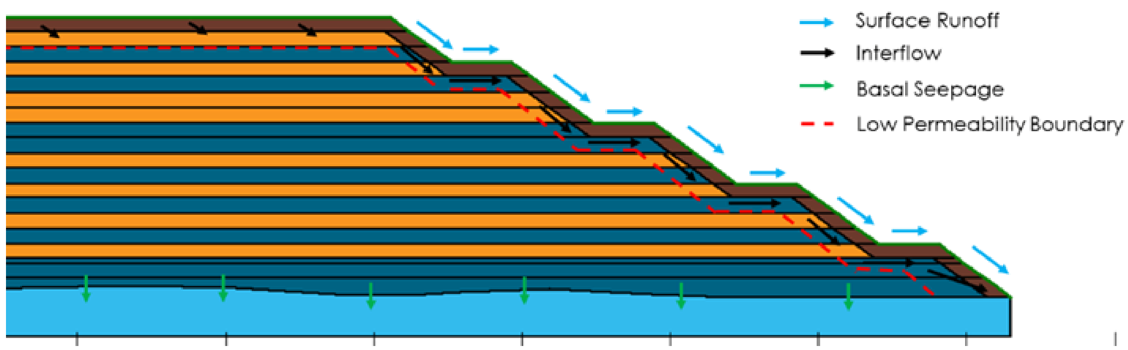

Figure 2.1: Sketch of landform water balance of an RSF.

Climate change in the region will result in a warmer and wetter climate. The rise in average annual temperature will increase the thickness of the active layer, thawing a portion of the lower permeability ice layer already in place or increasing its depth within the RSF. The increase in temperature will also 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).

Oxygen availability throughout the RSF will not 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 formation of large-scale convective airflow cells are known to encourage freezing of coarser-textured RSF in cold climates (Pham et. al, 2013). The presence of ice zones at the boundary of the active layer are expected to reduce air permeability over time.

2.2.1 Climate

The Project is located in an arid arctic environment that experiences extreme winter conditions, with an annual mean temperature of -11.3 °C. The monthly mean temperature ranges from -31.5 °C in January to 11.5 °C in July, with above-freezing mean temperatures from June to September.

Although the Project is located in an area of continuous permafrost, the depth of the permafrost and active layer will vary based on proximity to waterbodies, overburden thickness, vegetation, climate conditions, and slope aspect. Based on measurements of ground temperatures, the depth of permafrost at the site is estimated to approximately 425 m outside the influence of water bodies (Golder, 2018).

Annual precipitation at the site is 359 mm, with 169 mm falling as rain, and 190 mm falling as snow. Mean annual temperatures and precipitation are provided in Table 2.1.

Table 2.1: Summary of average climate parameters for 59-year Meadowbank and Whale Tail historical climate database (1963-2021).

Month	Temperature (°C)		Relative Humidity (%)		Wind (m/s)	Precipitation	
	Maximum	Minimum	Maximum	Minimum		(mm)	(days)
January	-27.8	-34.8	71.7	60.7	6.3	15	7
February	-27.9	-35.0	70.5	60.0	6.3	14	7
March	-22.5	-31.1	73.3	61.3	6.0	19	8
April	-12.7	-22.1	81.4	68.0	5.8	25	9
May	-2.7	-9.8	90.1	76.0	5.6	22	9
June	9.1	0.6	90.0	61.6	4.7	27	13
July	16.8	6.3	88.9	52.5	4.6	43	14
August	14.3	5.5	92.0	58.8	5.0	47	17
September	6.1	-0.3	93.2	68.3	5.5	51	17
October	-3.6	-9.8	91.4	77.8	6.1	44	16
November	-15.7	-23.2	81.2	68.4	6.1	32	11
December	-23.5	-30.6	74.5	62.9	6.1	20	9
Annual	**-7.4**	**-15.2**	**83.3**	**64.7**	**5.7**	**359**	**137**

2.2.1.1 Climate Change

The expected warming caused by climate change has the potential to influence the expected performance of the thermal cover system at Portage RSF over time. Climate change was therefore included in the thermal and seepage modelling described in Section 2.4.

A climate change database from to 2170 was developed based on the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (AR5) which describes four representative concentration pathways (RCPs) (RCP2.6, RCP4.5, RCP6.0 and RCP8.5). RCP4.5 was selected as the scenario for the Base Case simulations, with RCP6.0 completed as a Climate Sensitivity. The climate change database for Meadowbank and Whale Tail was developed following the recommendations outlined on the Canadian Climate Data and Scenarios (CCDS) website, which is wholly supported by ECCC (CCDS, 2018). Figure 2.2 and Figure 2.3 show the annual temperature and precipitation, respectively, estimated for the RCP4.5 and RCP6.0 100-year climate databases developed for Whale Tail and Meadowbank.

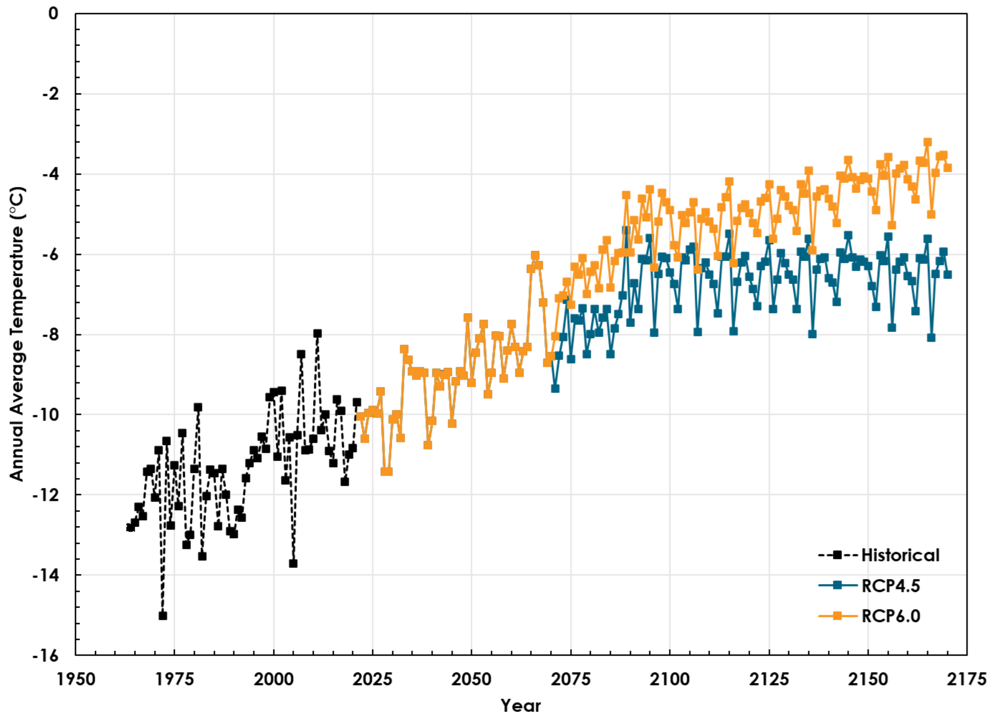

Figure 2.2: Annual average temperature estimated for the RCP4.5 and RCP6.0 climate change scenarios. Historical temperature at Baker Lake is also shown.

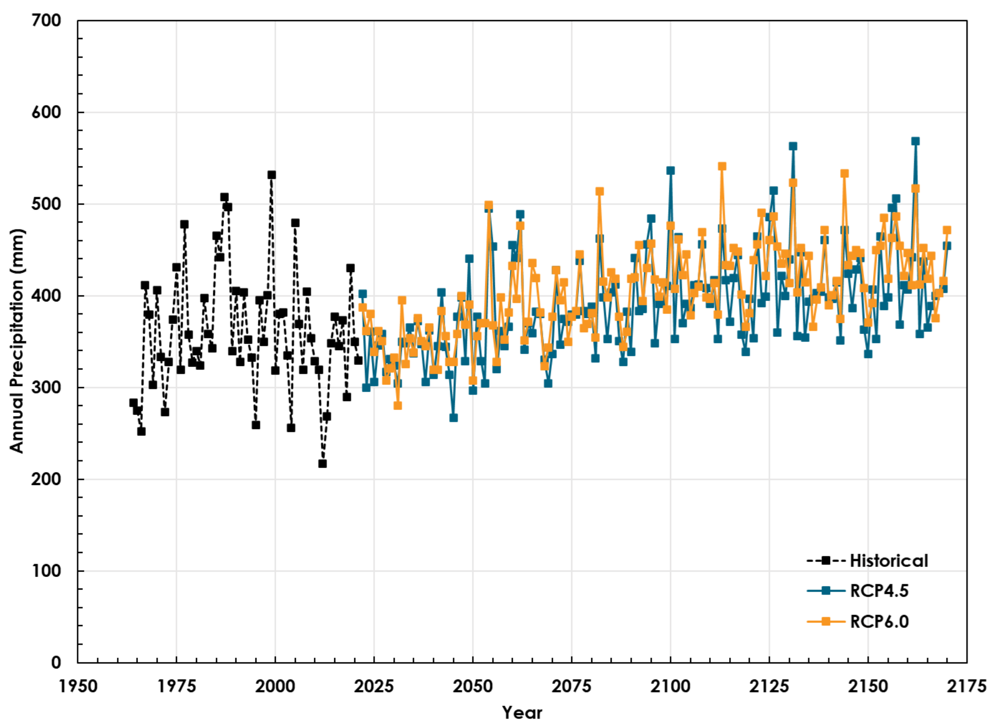

Figure 2.3: Annual precipitation estimated for the RCP4.5 and RCP6.0 climate change scenarios. Historical precipitation at Baker Lake is also shown.

Beyond temperature and precipitation, other climate variables (wind speed and direction, net radiation, and relative humidity) were developed as part of the climate change database to complete numerical modelling (Section 2.4). Temperature and precipitation were derived from the Pacific Climate Impact Consortium output (PCIC, 2018), while the other climate variables (i.e., relative humidity and net radiation) were downscaled using the Statistical Downscaling Model (SDSM) (Wilby et al., 2002; 2013; 2014), with the exception of wind speed due to the lack of climate change predictors. A detailed description of the methodology followed in developing the climate change database is found in Appendix B.

2.2.2 Materials

The thermal and hydrological behaviour of granular materials is dependant on the material texture, material temperature, water content, and material composition. The relationship between these parameters was developed in support of thermal and seepage modelling described in Section 2.4. Figure 2.4 shows the range of all particle size distributions (PSDs) measured based on fragmentation analyses for the NPAG and PAG waste rock for the Portage RSF. The PSDs show:

- The run-of-mine (ROM) NPAG waste rock (of which only three Split PSD results were available) falls almost on the average of the range of the 314 PAG waste rock fragmentation PSD samples; therefore, the ROM NPAG and PAG waste rock will be simulated initially with the same material inputs (with the exception of geochemical reactivity).
- The ROM waste rock can all be classified as very coarse-textured (Figure 2.5). Any additional crushing and weathering will result in the formation of a finer-textured layer, mostly on highly trafficked surfaces.

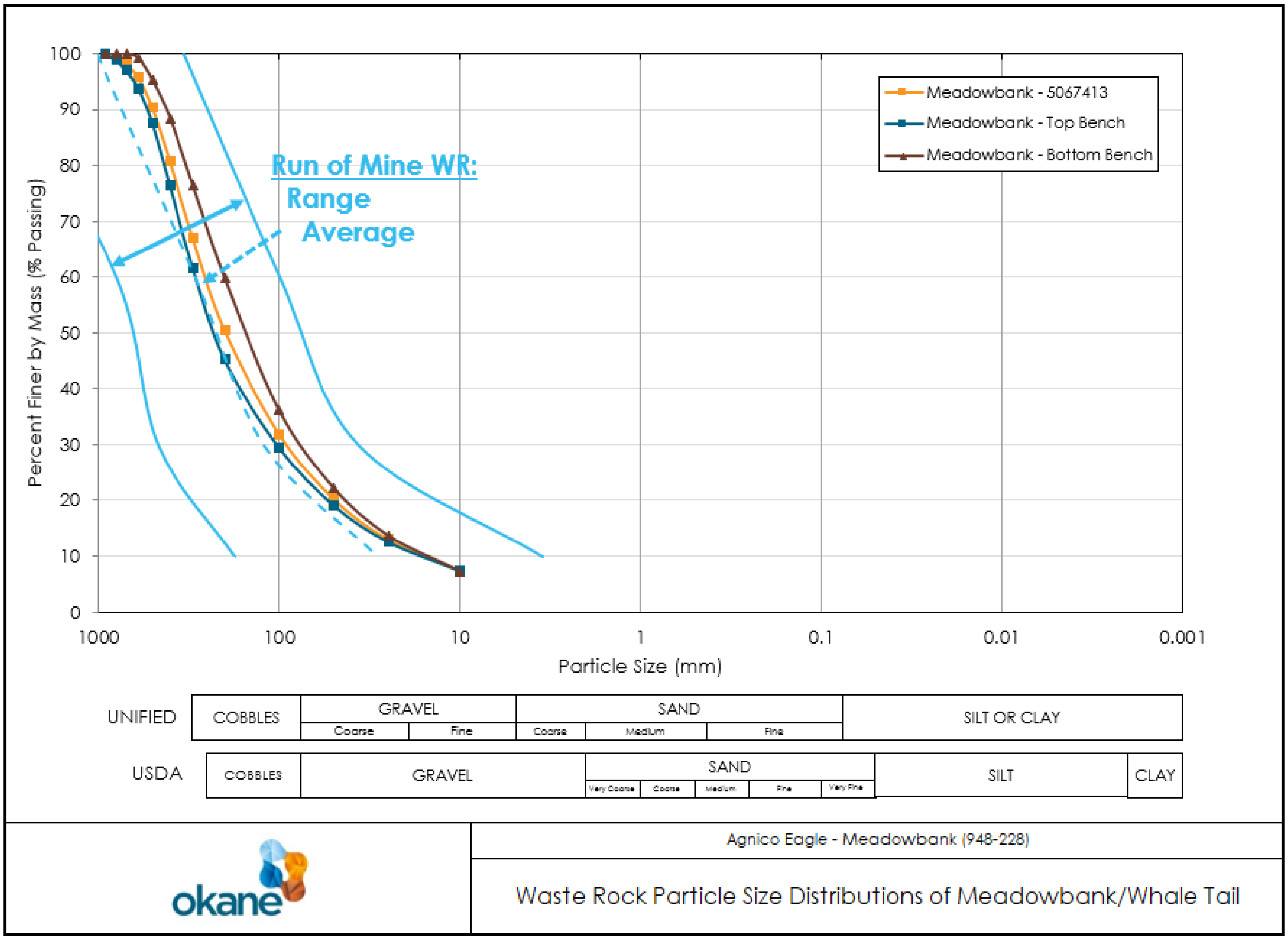

Figure 2.4: Particle size distributions for range of Portage waste rock samples.

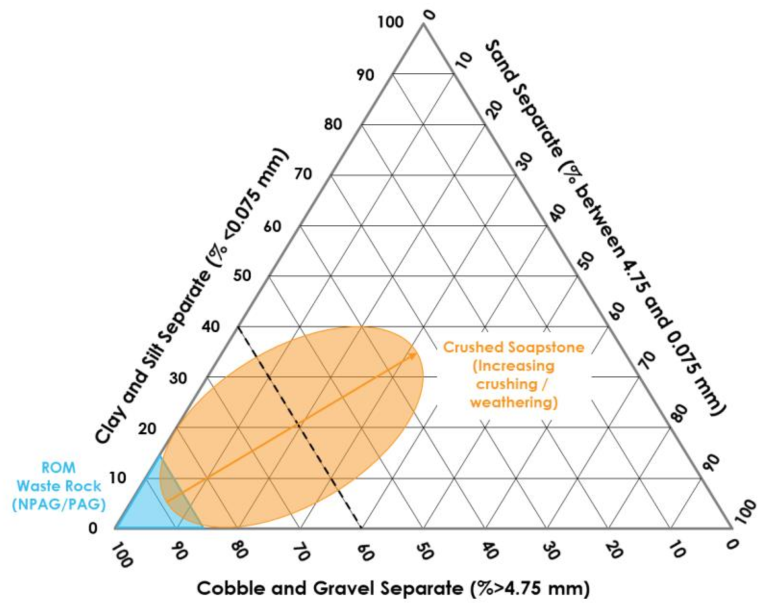

Figure 2.5: Textural Triangle of Portage waste rock samples.

A set of material properties were estimated for the following four materials: crushed (from vehicular traffic) soapstone (NPAG); run-of-mine (ROM) soapstone; till; and bedrock. All material properties were estimated based on previous work completed by Golder Associates Ltd. (2008) and, for the crushed soapstone, ROM soapstone, comparisons of particle size distribution (PSD) data to materials in the SoilVision database with similar PSDs and known material properties.

The NPAG and PAG materials are initially to be simulated with the same material properties (i.e., soapstone). However, AEM has indicated that the PAG material is likely to have less fines that the NPAG cover system material. Refinement of the PAG material properties will be made by calibrating the initial models to current conditions using thermistor strings data. Additional estimates for sensitivity will be made for NPAG and PAG materials to evaluate performance for a range of parameters. A summary of calibrated material properties is provided in Appendix B.

2.3 Thermal and Hydrological Model

Updated thermal and hydrological modelling was completed for the Portage RSF to update predictions of performance using the coupling of thermal oxidation and climate change for evaluation of the Portage RSF closure cover system.

Modelling of the RSF was completed in three major steps: historical calibration modelling, one-dimensional boundary condition modelling, and long-term two-dimensional climate change modelling. Following completion of 1D calibration modelling, long term climate modelling was completed using the RCP4.5 and RCP6.0 climate database described previously. The range of long-term climate scenarios were included in long term modelling to generate the range of expected thermal and hydraulic performance of the RSF in closure and post-closure. Long term climate modelling was competed for the idealized cross-section (Figure 2.6). Detailed information on the thermal modelling is provided in Appendix B.

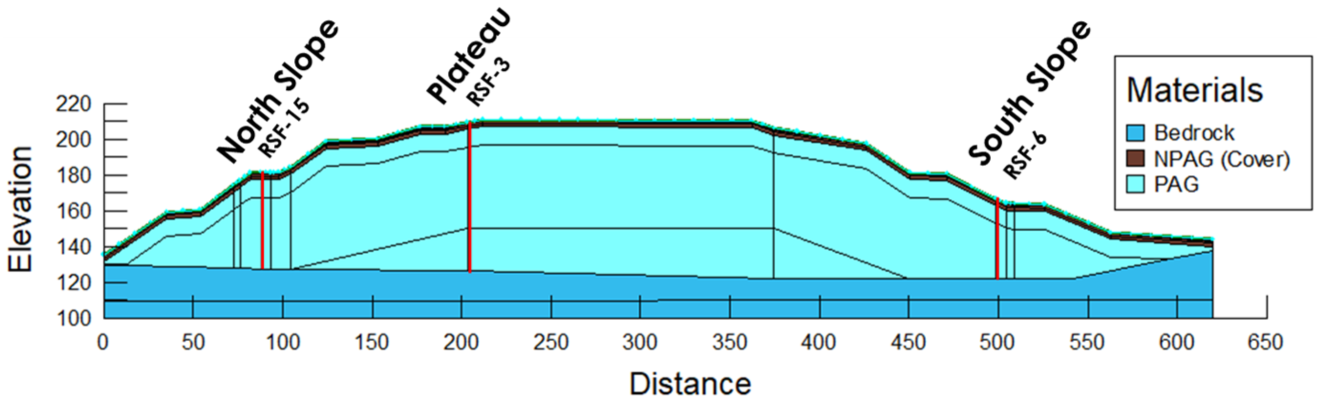

Figure 2.6: Section view of N-S cross section and typical thermal locations rendered below.

2.3.1 Active Thermal Layer Depth

The long-term thermal modelling predicts a deepening of the active layer with time (Table 2.2). The average active layer depth over the last 30 years of modelling (2090 to 2120) indicates an active layer of approximately 6 m in the base case climate scenario (RCP4.5). The following figures (Figure 2.7 and Figure 2.8) illustrate annual average near-surface thermal conditions at several locations on the RSF between 2090 to 2120 under the Base Case and Climate Sensitivity scenarios, respectively.

Table 2.2: Annual average active layer depths for the 30-year period 2090 to 2120.

Profile	Corresponding Thermistor	Base Case (RCP4.5)	Climate Sensitivity (RCP6.0)
North Slope	RSF-15	3.8 m	5.7 m
Plateau	RSF-3	5.7 m	6.5 m
South Slope	RSF-6	10.6 m*	8.3 m

***Note:** Highlights the difference in the shape/location of the active layer between climate change scenarios at the RSF-6. Not necessarily indicative of overall degree of thaw for the RSF.

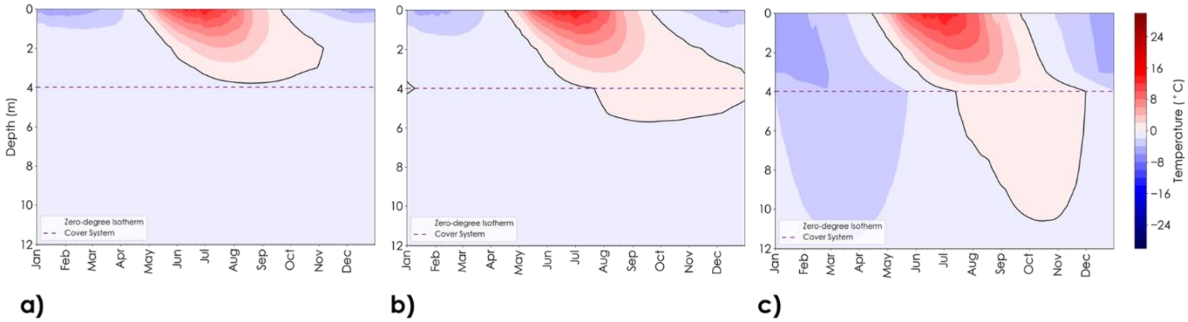

Figure 2.7: Annual long term near surface temperature along the slope of the idealized cross section at the a) north slope, b) plateau, and c) south slope under the Base Case (RCP4.5) climate conditions.

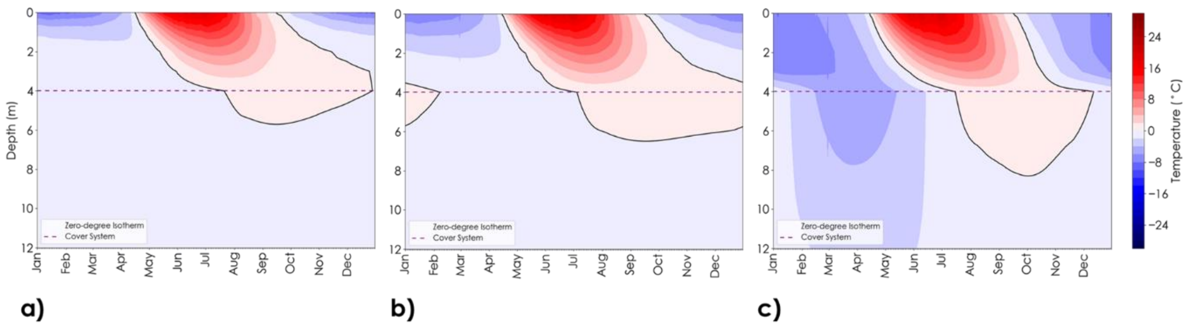

Figure 2.8: Annual long term near surface temperature along the slope of the idealized cross section at the a) north slope, b) plateau, and c) south slope under Climate Sensitivity (RCP6.0) climate conditions.

While the thermal regime is governed by two separate mechanisms, conduction and convection, the hydrologic regime must be accounted for to fully understand the effect of the depth of thaw on cover system performance. Figure 2.9 compares the unfrozen volumetric water content, or the portion of pore water available to be mobilized, compared to thaw depth at the same location. Figure 2.9 illustrates that the warming beyond the cover system does not equate to the mobilization of water through the RSF. For very low volumetric water content (less than 0.04 m^3/m^3), the hydraulic conductivity of the waste rock material is less than 1 x 10^{-7} m/s. This very low hydraulic conductivity limits the movement of moisture in the thawed zone below to cover system to the range of <1 m/year.

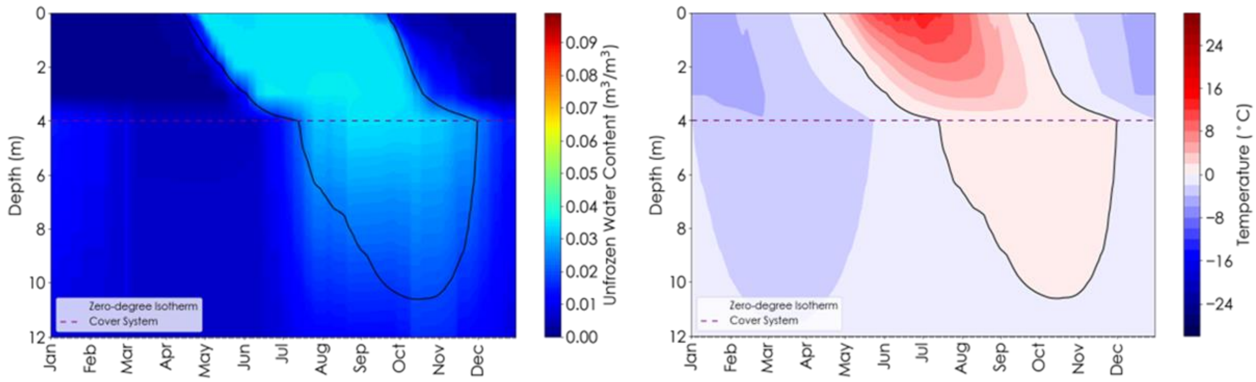

Figure 2.9: Annual long term near surface unfrozen volumetric water content (left) and temperature (right) for the Base Case along the south slope of the cross section at RSF-6 with the cover system interface shown by the purple dashed lines.

2.3.2 Landform Water Balance

A landform water balance was completed for the Portage RSF. This work included estimates of runoff, interflow, and basal seepage rates for the Base Case and Climate Sensitivity analyses of the Portage RSF (Table 2.3) for the water year (October 1 to September 30).

Table 2.3: Summary of average surface water balance for the Portage RSF under different climate scenarios (2022-2120).

Water Balance Parameter	Base Case (RCP4.5)	Climate Sensitivity (RCP6.0)
Total Precipitation (mm)	378 mm	389 mm
Rainfall (% of Total Precipitation)	45-50%	45-50%
Snow (% of Total Precipitation)	50-55%	50-55%
Actual Evaporation (% of Total Precipitation)	40-45%	40-45%
Runoff (% of Total Precipitation)	10-15%	5-10%
Surface Infiltration (% of Total Precipitation)	5-10%	10-15%
Sublimation (% of Total Precipitation)	35-40%	35-40%

Runoff is an important component with respect to the site-wide water balance as it is considered to be contact water. 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.

The high infiltration capacity of the waste rock material results in a preference for precipitation to result in surface infiltration, rather than runoff (Table 2.3). As water infiltrates into the surficial materials, net percolation flows vertically through the RSF, eventually freezing back at depth. The base layer of the RSF is consistently frozen from the time of placement. As a result, basal seepage from the landform is negligible under the base case and sensitivity scenario.

Interflow occurs as lateral flow within the active layer on the plateaus and slopes. During construction and freeze back, water can percolate into the RSF 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 (Figure 2.10).

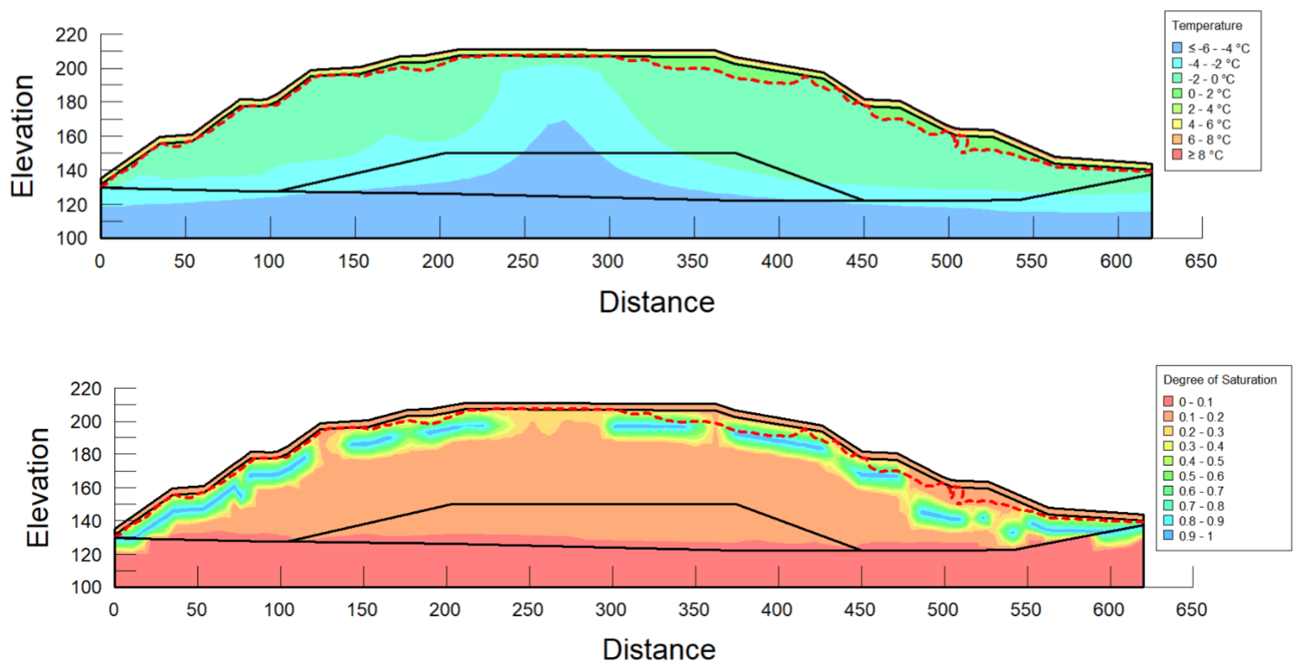

Figure 2.10: Temperature and saturation profiles for the Base Case (RCP4.5) at 2120 with the zero-degree isotherm indicated by the red dashed line.

Table 2.4 shows the estimated interflow as a percent of total precipitation for the Portage RSF.

Table 2.4: Interflow for the Portage RSF cross section as a percent of total precipitation.

	RCP4.5	RCP6.0
Interflow (% of Total Precipitation)	1-5%	5-10%

2.3.3 Thermal and Hydrological Modelling Conclusions

Based on learnings from the Agnico Eagle Whale Tail Mine and the updated thermal modelling of the Portage RSF cover system described in this report, the performance of the Portage RSF cannot be measured alone by the depth of the active layer; it is the fulsome interaction of air and water in the intermittent non-frozen zones and the impacts (if any) that has on seepage and seepage water quality from the facility.

While thaw below the cover system is expected as per the updated thermal modelling, the likelihood of a 4.0 m cover system thickness being insufficient, leading to unacceptable water quality in the receiver is expected to remain low. This is due to several factors, including:

- Low volumetric water content in the thawed waste rock, resulting in low likelihood of mobilization of seepage from waste rock;
- Lower pyrite oxidation rates within the thawed waste rock compared to the cover system material (as a result of consistent near-freezing temperatures within the waste rock) resulting in low to moderate likelihood of production of metal leaching and acid rock drainage (ML/ARD/) products;
- Limited volume of PAG/ML waste rock in the estimated thawed waste rock zone, resulting in low likelihood of production of ML/ARD products; and
- Limited interaction between infiltrating water and PAG/ML waste rock due to the development of ice lenses in the upper profile of the RSF and frozen conditions at the base of the RSF.

Updated thermal modelling of the Portage RSF indicates that a 4.0 m thermal cover of NPAG/NML material will reduce the risk to water quality in the receiving environment, associated with ML/ARD generated from the PAG/ML waste rock, by promoting frozen conditions within the RSF. Whether the reduction in risk achieved is sufficient in preventing poor water quality must however still be assessed through a site-wide water quality model.

3 ADAPTIVE MONITORING PLAN

The primary objective of the Adaptive Monitoring Plan is to identify a pathway for managing uncertainty and risk within the design of the Portage RSF cover system. Specifically, mitigation measures and associated management actions to be taken when specified thresholds are exceeded for parameters where uncertainty cannot be further reduced at this time (e.g., climate change). Mitigation measures may include special studies, operational changes, revised or new water and waste management systems, new or expanded conveyance systems, structures and/or facilities, or implementing mitigation activities to prevent, stabilize or reverse a change in environmental conditions or to otherwise protect the receiving environment.

As indicated in Figure 3.1, an adaptive monitoring plan is cyclical in nature. The Adaptive Monitoring Plan will be reviewed periodically to account for the dynamics of mine construction, operations, and policy changes, and to adjust the adaptive monitoring strategy as needed.

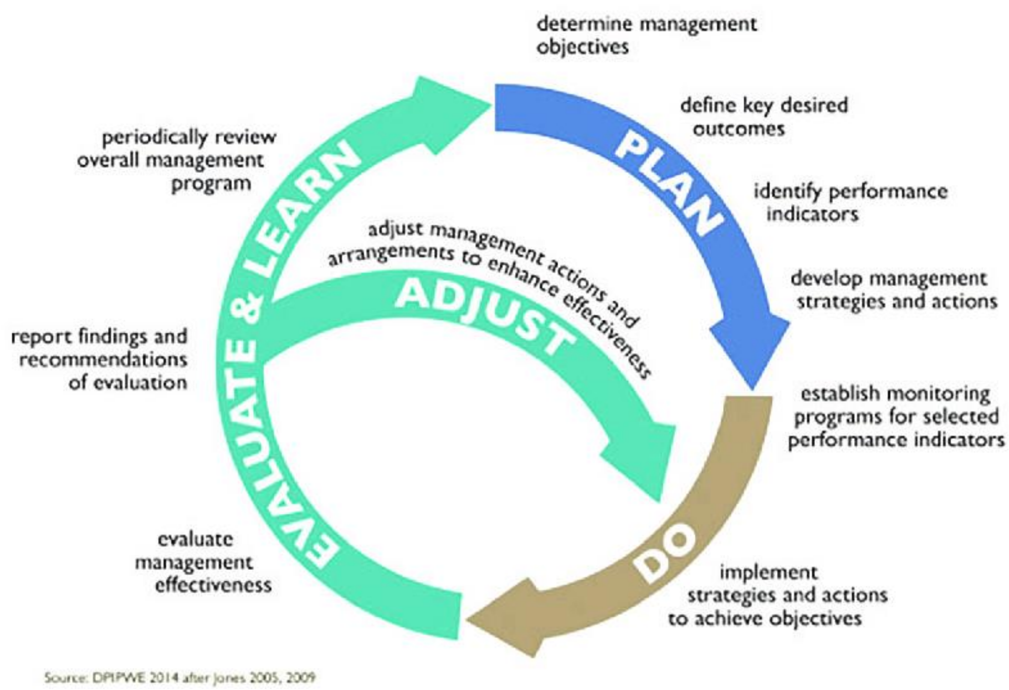

Figure 3.1: The adaptive monitoring cycle.

3.1 Key Performance Indicators

The objective of the final cover system is to ensure that the overarching closure objective, specifically that water quality in the receiving environment be protected within permitted conditions, is met. The design basis of cover system design is to control mechanisms which result in the potential for poor water quality from the WRSF by:

1) Limiting depth of yearly active layer to control impacts on water quality;

2) Promoting frozen conditions to limit acid generating reactions; and

3) Limiting ARD/ML migration of contaminants by promoting frozen conditions within the PAG material by limiting mobility of water.

In order to ensure that the aforementioned objectives are met, the performance (key performance indicators) of the facility will be evaluated by:

- Ensuring water quality collected through water management strategies meets discharge criteria; and

- Monitoring permafrost development (depth of thaw and permafrost aggradation) as well as active layer progression.

3.2 Permafrost Aggradation

Performance of the RSF is in part defined by its ability to achieve geochemical stability. Promoting development of permafrost conditions within PAG/ML waste rock will inhibit leaching of acidic drainage or metal contaminated waters.

Permafrost aggradation into the RSF from the surrounding bedrock will be monitored to verify frozen conditions at depth are developing and being maintained over time. Permafrost aggradation is defined within this Adaptive Monitoring Plan by the point of zero amplitude (i.e., the depth at which seasonal temperature fluctuations no longer influence ground temperature) moving upwards into the RSF until a post-construction thermal equilibrium is reached. Monitoring to date (Figure 3.2) indicates that thermal equilibrium has not yet been reached as the point of zero amplitude is continuing to move upwards in the RSF. Should the point of zero amplitude move downwards, Table 3.1 summarizes specific mitigation measures and associated management actions to be taken.

When using Table 3.1 to assess the adaptive monitoring response required, some preliminary assumptions should be considered:

- The zero-amplitude points heights are determined during the Annual Report.

- The thresholds are referring to an average of thermistors or two spatially consecutive thermistor beads for localized effects (i.e., two thermistors within 20 m of one another or two consecutive thermistors beads located on a single thermistor).

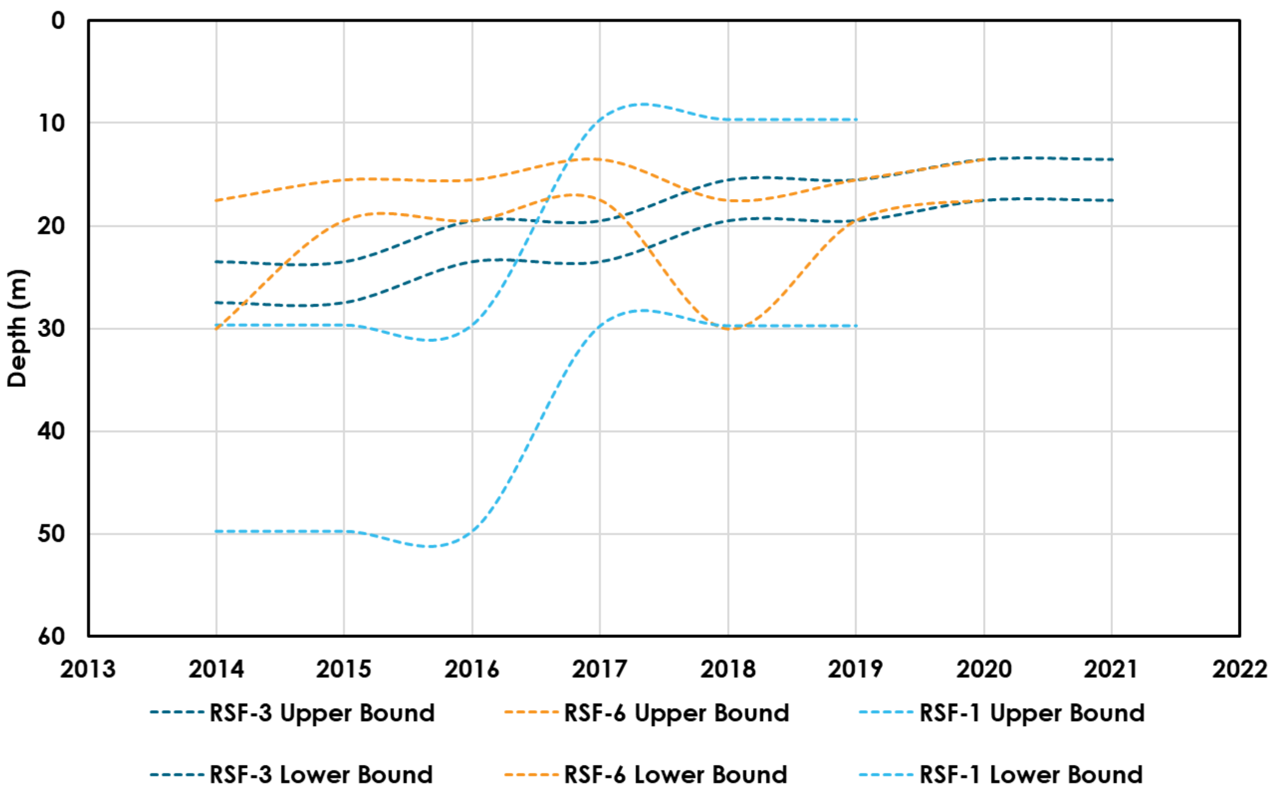

Figure 3.2: Depth to zero amplitude range for spatially consecutive thermistors beads bounding the zero amplitude point in the Portage RSF.

Table 3.1: RSF Permafrost Aggradation Adaptive Monitoring Strategy

Adaptive Monitoring Level	Threshold	Management Strategy
Level 0 (Normal Operating Condition)	-	• Monitor temperature at depth within RSF. • Monitor temperature in base of RSF. • Report rate of permafrost aggradation from monitoring data in the Annual Report.
Level 1 (Situation of Concern)	Average zero amplitude point moves downwards	• Continue Level 0 management strategy. • Complete review of climate data to place RSF permafrost aggradation rate in context of long-term climate conditions. • Complete data review of site, regional ground thermal data and RSF thermal data in context of regional permafrost conditions. • Report results for data review in the Annual Report.
Level 2 (Situation of Concern)	Average zero amplitude point moves downwards for two years	• Continue Level 1 management strategy. • Modification of instrumentation program based on interpretation of existing data and understanding of mechanism (could include installation of thermistors and downhole monitoring instruments). • Complete review of physical and geochemical properties of RSF materials including: o Geochemical testing of drill cuttings and/or grab samples obtained from additional monitoring program (noted above). • Report results of additional testing / monitoring in the Annual Report.
Level 3 (Situation of Concern)	Average zero amplitude point moves downwards for three years AND Geotechnical and geochemical properties of waste rock from Level 2 review are outside the bounds of those used in modelling	• Continue Level 1 management strategy, including the review of additional data collected in Level 2 management strategy. • Update modelling of permafrost aggradation predictions based on calibrated material properties and in situ conditions as well as updated climate model predictions available. • Update RSF water balance and water quality model based on results of updated thermal model to understand impact on performance of the structure. • Report updated performance targets for permafrost aggradation based on updated modelling in the Annual Report.
Level 4 (High Risk Situation)	Updated performance predicted by modelling does not fit within overall project closure objective as detailed in the ICRP (SNC, 2020)	• Evaluate and implement applicable construction measures to mitigate risk to the receiving environment. This will be situation specific based on result of previous level but could include: o Construction of passive ground freezing systems; o Construction of active ground freezing systems; o Relocation / reconfiguration of RSF; o Construction of new or expanded interception structures for water (ponds, sump, ditch, other conveyance systems) to redirect RSF contact water in the flooded pits.

3.3 Active Layer Development

Performance of the RSF is also defined by its ability to manage interaction between surface water (runoff) or near-surface water (interflow) with waste rock. Monitoring the expected active layer will provide a basis for identifying long-term warming trends within the RSF which would result in a greater amount of PAG/ML waste rock contributing to potential contaminant migration as the active layer depth will change annually based on seasonal variability, and potentially long term as the climate warms, temperature near the expected active zone depth and beyond will be monitored to ensure that frozen conditions are maintained. Additionally, monitoring the surface water balance at the NSMS stations will provide additional insight to the processes controlling potential contaminant migration and allow for the development of in situ physical properties of the cover materials.

Thermal data and cover material physical properties will be measured according to the RSF instrumentation plan (Okane, 2020). Table 3.2 summarizes a proposed adaptive monitoring plan and potential mitigation measures and associated management actions that can be taken if active layer development is not proceeding as predicted.

Table 3.2: Portage RSF active layer adaptive monitoring strategy

Adaptive Monitoring Level	Threshold	Management Strategy
Level 0 (Normal Operating Condition)	-	• Monitoring of near surface thermal / energy balance. • Monitoring of near surface water balance. • Report thermal condition within RSF below active layer in the Annual Report.
Level 1 (Situation of Concern)	Active layer extends beyond maximum depth (6 m) predicted by modelling	• Continue Level 0 management strategy. • Complete review of climate data to place RSF thermal data in context of annual climate conditions. • Complete data review of site, regional ground thermal data and RSF thermal data in context of regional permafrost conditions. • Report results of data review in annual report.
Level 2 (Situation of Concern)	Active layer extends beyond maximum depth (6 m) predicted by modelling for two years	• Continue Level 1 management strategy. • Complete review of physical and geochemical properties of cover system materials including: o Sampling program to confirm in situ properties and conditions; and o Comparison of in situ cover system conditions and properties to conditions observed during base case monitoring program and cover system construction QA/QC. • Complete review of cover system construction including: o Updated survey of RSF. • Report results of data review in annual report.
Level 3 (Situation of Concern)	Active layer extends beyond maximum depth (6 m) predicted by modelling for three years OR Physical and geochemical properties of cover system from Level 2 review are outside the bounds of those used in modelling	• Continue Level 2 management strategy. • If geochemical properties of cover system differ significantly from those used in modelling, complete review of cover system segregation procedures. • If construction review from the Level 2 management strategy does not identify the cause of non-target freeze-back, or if existing monitoring data does not support additional modelling, complete enhanced monitoring program to capture greater spatial distribution. • Complete updated RSF thermal modelling based on calibrated material properties and in situ conditions, as well as with available updated climate model predictions. • Review cover system freeze-back target based on updated model results and determine requirement to increase cover thickness to meet performance criteria. • Report updated cover system material segregation procedures (if required), additional monitoring data (if required), and updated freeze-back targets based on updated modelling (if required) in the Annual Report.
Level 4 (High Risk Situation)	Active layer extends beyond maximum depth (6 m) predicted by modelling for four years AND Updated performance predicted by modelling show that performance objective of the structure will not be met	• Continue Level 1 management strategy including additional data collected in Level 3 management strategy. • Evaluate and implement construction measures to mitigate risk to the receiving environment. This will be situation specific based on result of previous levels but could include: o Increasing the thickness of the cover locally with contingency NPAG material as per recommendations of Level 3 modelling; o Addition of finer-textured cover system material locally to the existing cover system based on recommendations of Level 3 modelling; o Addition of non-granular material amendments to the cover system (e.g., geosynthetic) based on recommendations of Level 3 modelling; or o Construction of new or expanded interception structures for water (ponds, sump, ditch) to protect the environment. • Report cover system construction measures completed and updated targets in the Annual Report.

3.4 Monitoring Plan

3.4.1 Thermal Monitoring

To observe the freezing conditions of the RSFs at the Meadowbank Mine Project, a series of subsurface thermistors have been installed at strategic locations. The purpose of the thermistors in the RSF is to monitor the RSF temperature as freezing progresses and provide a basis for any additional management actions required as described in the adaptive monitoring plan.

The thermistor data is reviewed periodically and as needed. This will continue throughout the operational period as well as during closure. The results collected are to be used to evaluate the predicted thermal response of the facilities with the actual thermal response. This will allow adjustments to the Waste Rock Management Plan and the Final Closure and Reclamation Plan.

Near surface monitoring instruments at the Portage RSF were installed in 2022 to support the landform design and further increase understanding of mechanisms that could impact the geochemical stability of the Portage RSF.

Additional thermistors and instrumentation are also planned to be installed within the Portage RSF at the end of operation or early closure.

3.4.2 Surface Water Monitoring

Surface water at the Meadowbank Mine is monitored as per the Water Quality and Flow Monitoring Plan (Agnico Eagle, 2016) prepared in accordance with the requirements of the Nunavut Water Board Type A water license 2AM-MEA0815 and updated as per the renewed Water License 2AM-MEA1530. The Plan is one component of the Aquatic Effects Management Program (AEMP) and is closely associated with the Water Management Report and Plan.

The current monitoring practices specifically for the Portage RSF are divided into two categories:

- Compliance monitoring; and
- Event monitoring.

Compliance monitoring requirements for the Portage RSF are defined by the stage of mine life as per the Water license 2AM-MEA1530, Schedule I. The Portage RSF sumps are monitored monthly during open water season in later operations. In Closure the Portage RSF moves to a bi-annual schedule during the open water season. During both time periods, the monitoring parameters are Group 1 (pH, turbidity, hardness, alkalinity, ammonia nitrogen, total metals (aluminum, arsenic, barium, cadmium, chloride, chromium, copper, fluoride, iron, lead, manganese, mercury, molybdenum, nickel, nitrite, nitrate, selenium, silver, thallium, zinc), sulphate, total dissolved solids (TDS), TSS, and total cyanide. If CN total is detected in an analysis result; further analysis of CN Free and CN WAD will be triggered.).

Compliance monitoring and sampling of the Portage RSF occurs at the following locations if water is observed:

- Portage RSF (ST-16); and
- Waste Extension Pool sumps (ST-30 and ST-31).

Event monitoring requirements for the Portage RSF are described in the 2021 Freshet Action Plan (Agnico Eagle, 2021).

4 DISCUSSION AND RECOMMENDATIONS

The Portage RSF closure cover system design consists of a 4 m NPAG cover system encapsuling PAG waste rock. The purpose of the cover system is to ensure geochemical stability of the Portage RSF by:

- Insulating the PAG waste rock from direct interaction with atmospheric forces; and
- Limiting oxidation by promoting frozen conditions within the PAG waste rock and limiting the mobility of water.

The level of confidence in the cover system to meet closure objectives has been advanced through analysis of the existing cover system data being collected, review of research completed to date, and updated thermal modelling of expected performance.

The reviews completed have also advanced the understanding of performance of the RSF cover system such that the methodology to achieving geochemical stability can be updated to reflect the updated thermal modelling and learnings from the Whale Tail Mine. Geochemical stability will instead be ensured by:

1) Limiting depth of yearly active layer to control impacts on water quality;
2) Promoting frozen conditions to limit acid generating reactions; and
3) Limiting ARD/ML migration of contaminants by promoting frozen conditions within the PAG material by limiting the mobility of water.

While thaw below the cover system is expected as per the updated thermal modelling, the likelihood of a 4.0 m cover system thickness being insufficient, leading to unacceptable water quality in the receiver is expected to remain low. This is due to several factors, including:

- Low volumetric water content in the thawed waste rock, resulting in low likelihood of mobilization of seepage from waste rock;
- Lower pyrite oxidation rates within the thawed waste rock compared to the cover system material (as a result of consistent near-freezing temperatures within the waste rock) resulting in low to moderate likelihood of production of metal leaching and acid rock drainage (ML/ARD/) products;
- Limited volume of PAG/ML waste rock in the estimated thawed waste rock zone, resulting in low likelihood of production of ML/ARD products; and
- Limited interaction between infiltrating water and PAG/ML waste rock due to the development of ice lenses in the upper profile of the RSF and frozen conditions at the base of the RSF.

Updated thermal modelling of the Portage RSF indicates that a 4.0 m thermal cover of NPAG/NML material will reduce the risk to water quality in the receiving environment, associated with ML/ARD generated from the PAG/ML waste rock, by promoting frozen conditions within the RSF.

In addition, an Adaptive Monitoring Plan has been developed for the Portage RSF. The primary objective of the Adaptive Monitoring Plan is to identify a pathway for managing uncertainty and risk within the design of the Portage RSF cover system. The Portage RSF Adaptive Monitoring Plan addresses risks and uncertainties as they relate to:

- Permafrost aggradation; and
- Active layer development.

In order to progress the design of the Portage RSF closure cover system to detailed engineering design, the following must be completed:

- Continued monitoring of thermal and hydraulic conditions within the Portage RSF; and
- Update of the Adaptive Monitoring Plan to integrate learnings and criteria/thresholds developed through continued monitoring of thermal and hydraulic conditions;
- Installation of additional instrumentation in support of adaptive monitoring as required.

Agnico Eagle has committed to installing additional instrumentation prior to closure of the Portage RSF to increase the degree of confidence in the closure cover system. This additional instrumentation includes:

- Installation of vertical thermistors on the plateau (on top of the cover system at closure) of the RSF to increase spatial coverage;
- Installation of meteorological instrumentation to understand energy balance at the Portage RSF, and snowpack depth monitoring.

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Appendix A

Portage Rock Storage Facility Thermistor Data

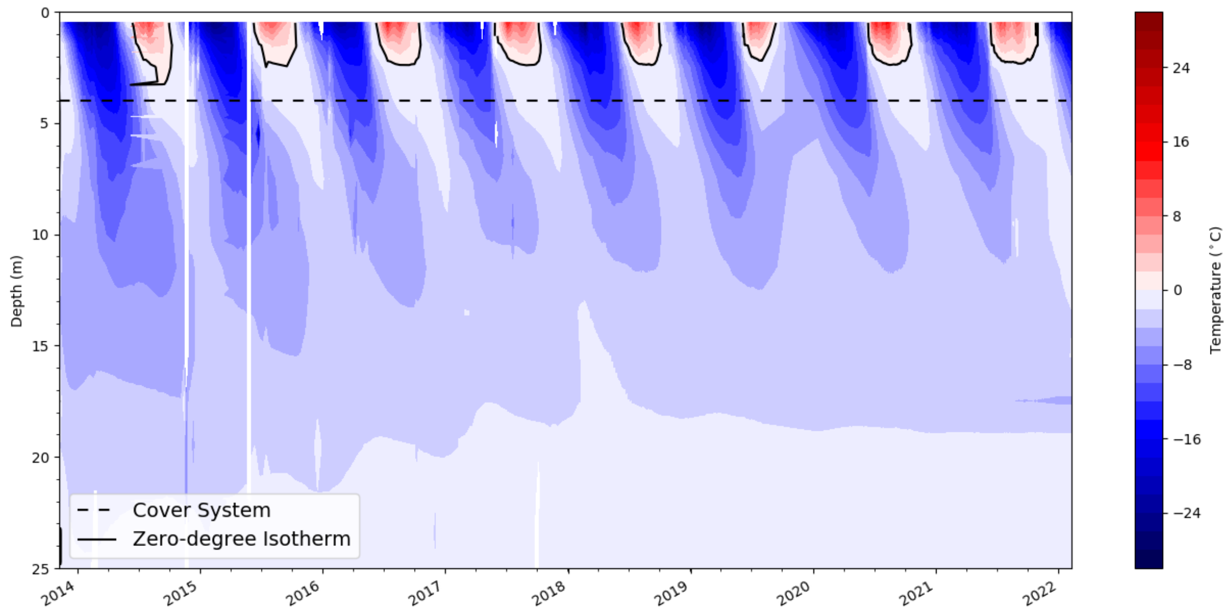

Figure A.1: RSF-3 Thermistor String data between 2014 and 2022

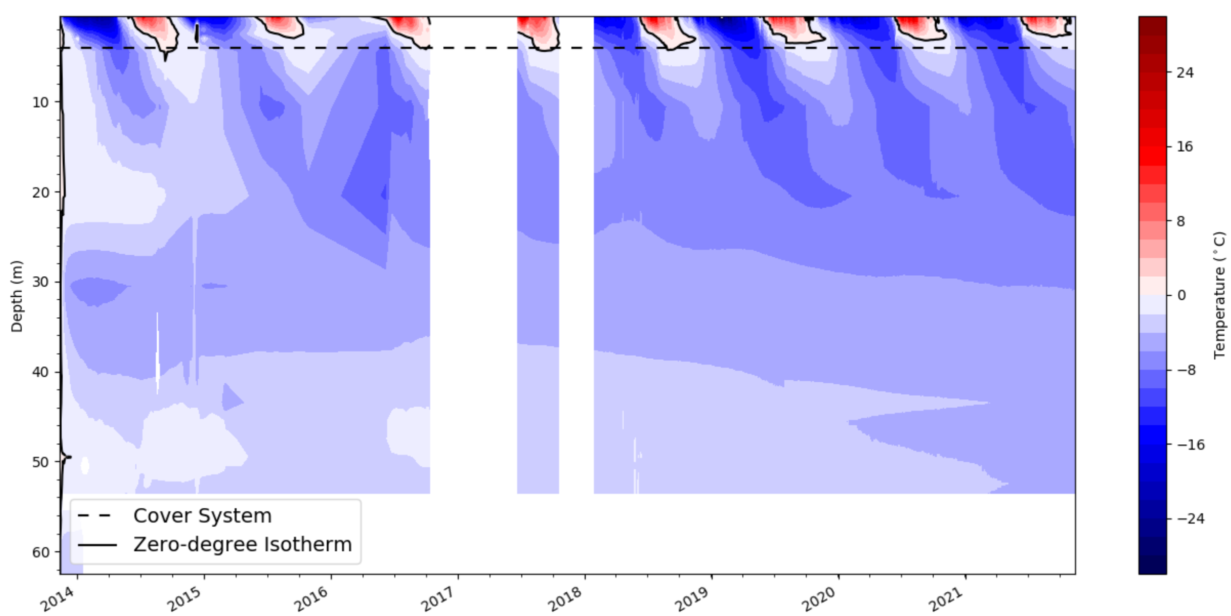

Figure A.2: RSF-5 Thermistor String data between 2014 and 2022

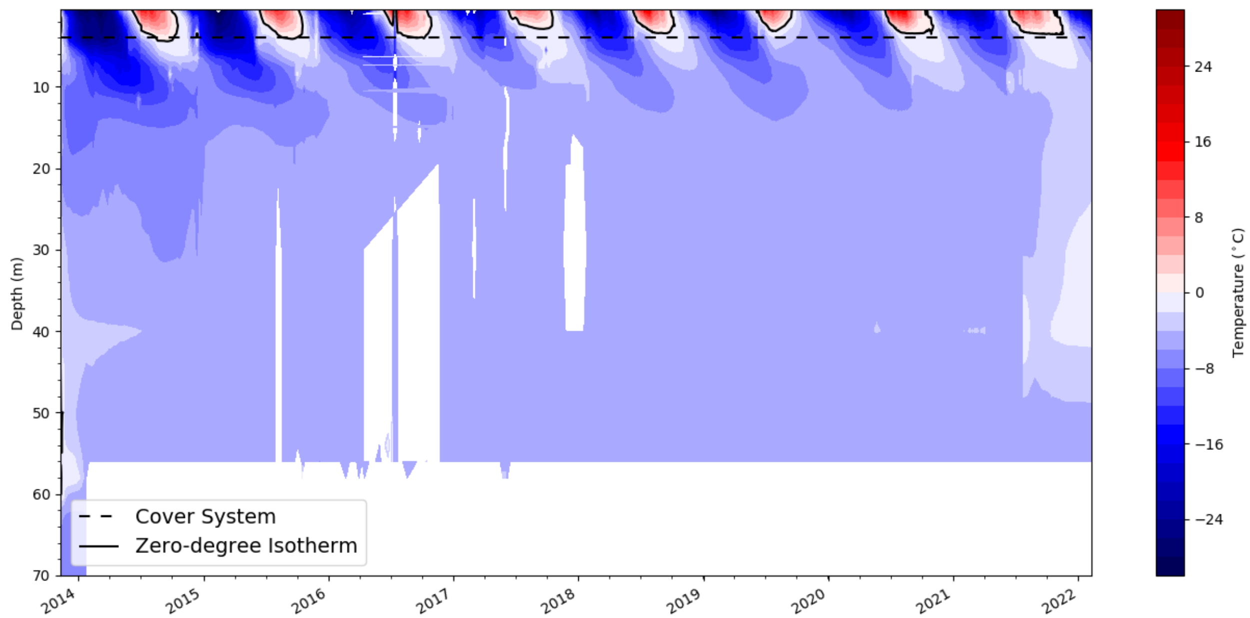

Figure A.3: RSF-6 Thermistor String data between 2014 to 2022

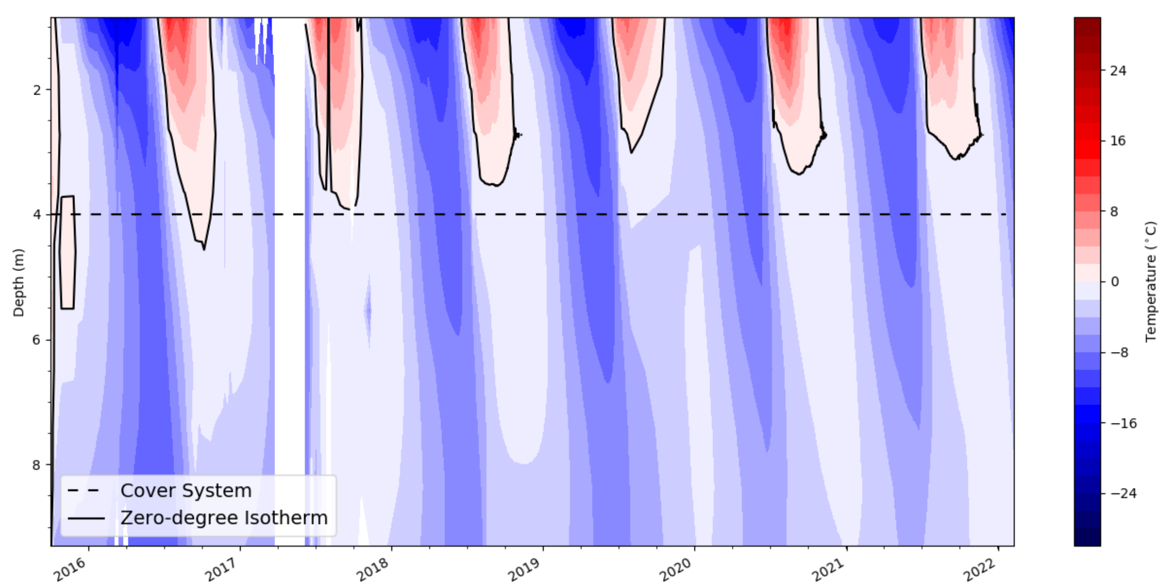

Figure A.4: RSF-8 Thermistor String between 2016 and 2022

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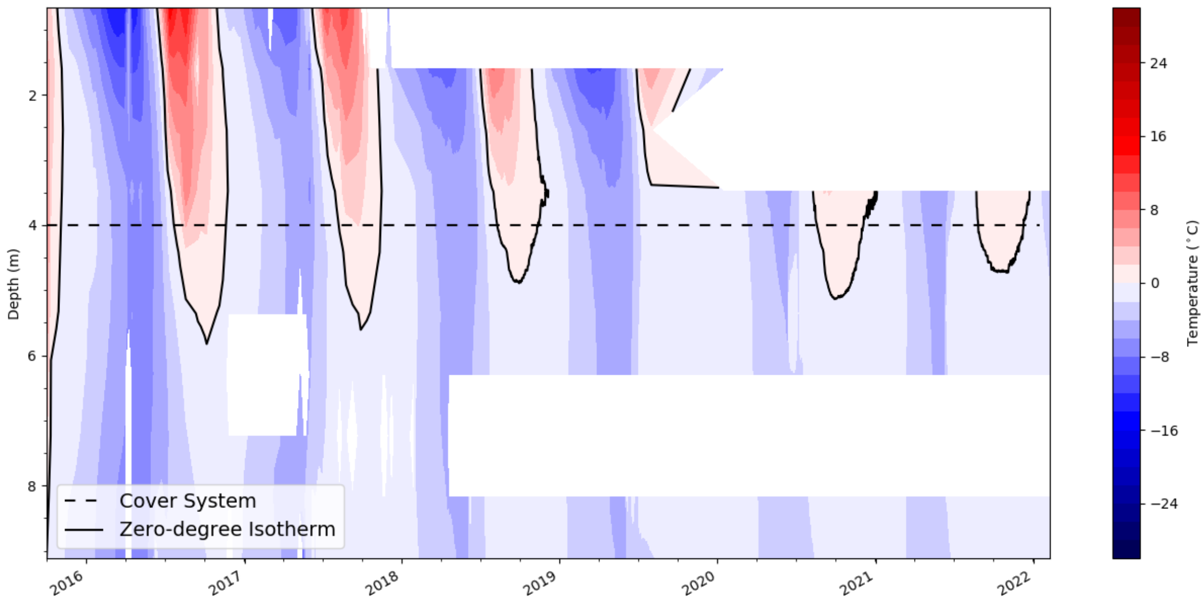

Figure A.5: RSF-10 Thermistor String between 2016 and 2022

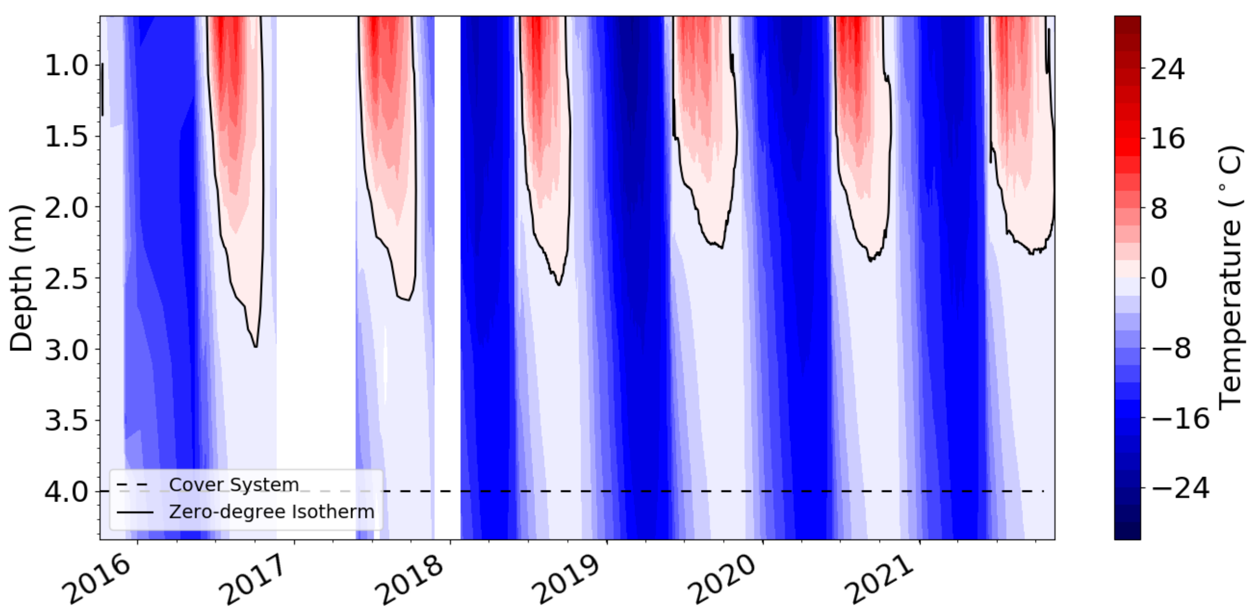

Figure A.6: RSF-11 Thermistor String between 2016 and 2022

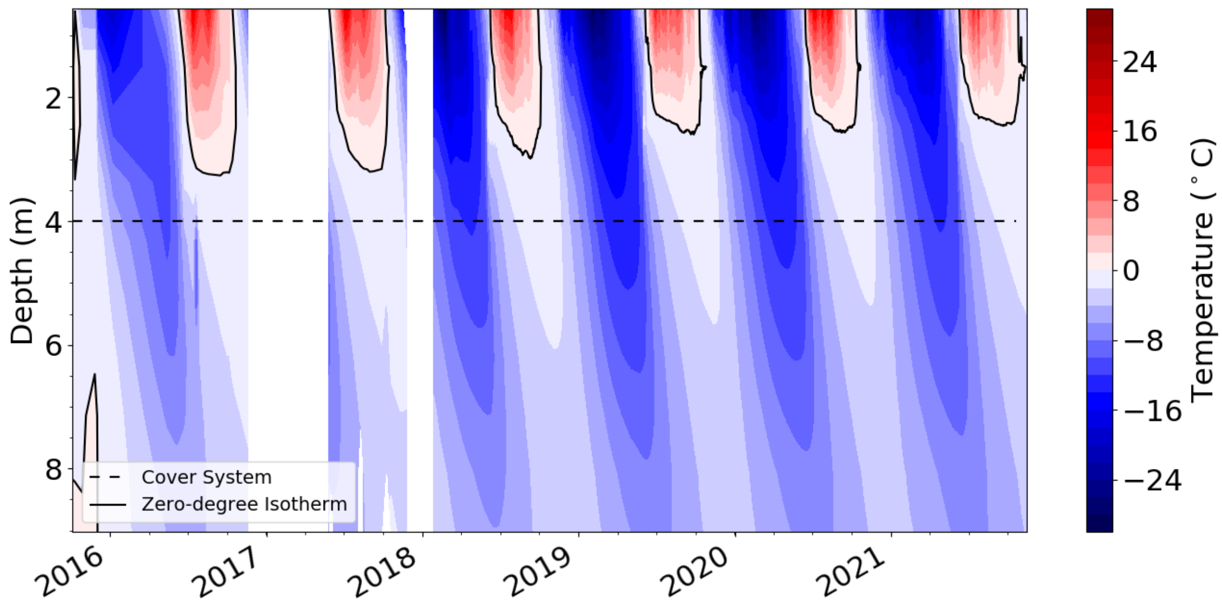

Figure A.7: RSF-12 Thermistor String between 2016 and 2022

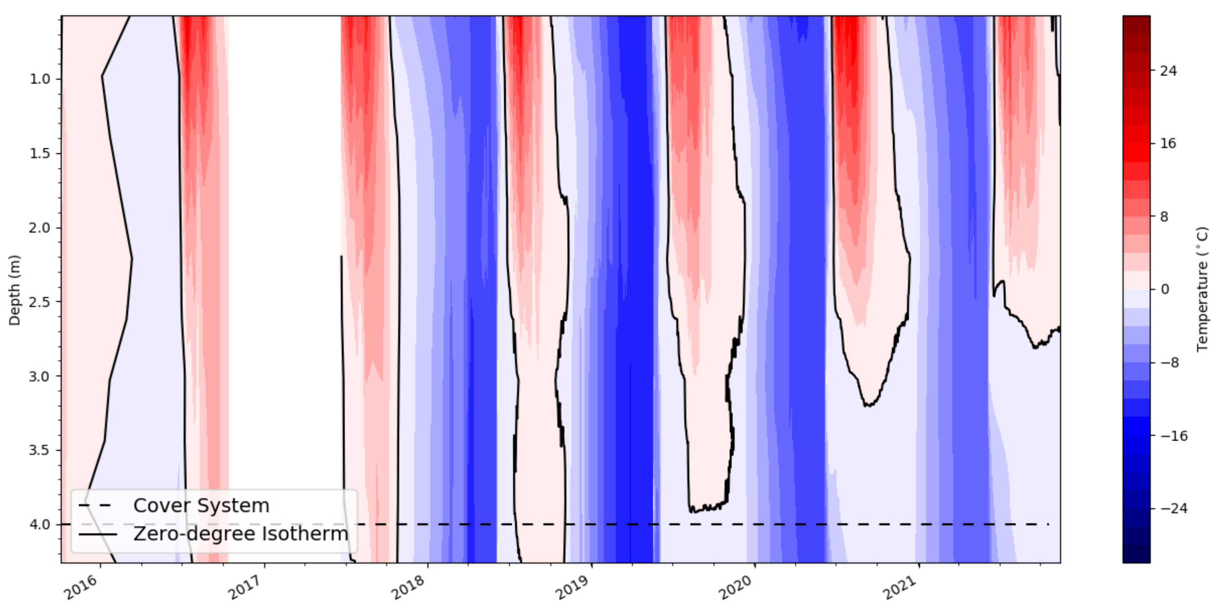

Figure A.8: RSF-15 Thermistor String between 2016 and 2022

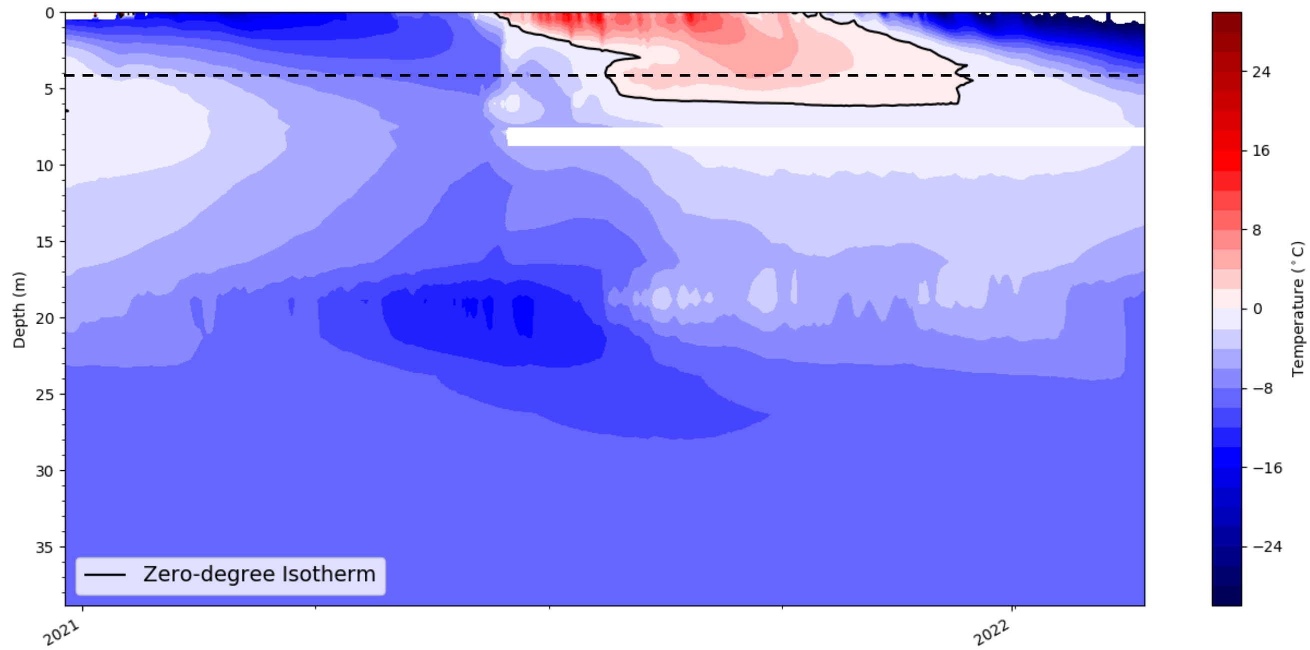

Figure A.9: RSF-17 Thermistor String between December 25, 2020 and February 22, 2022

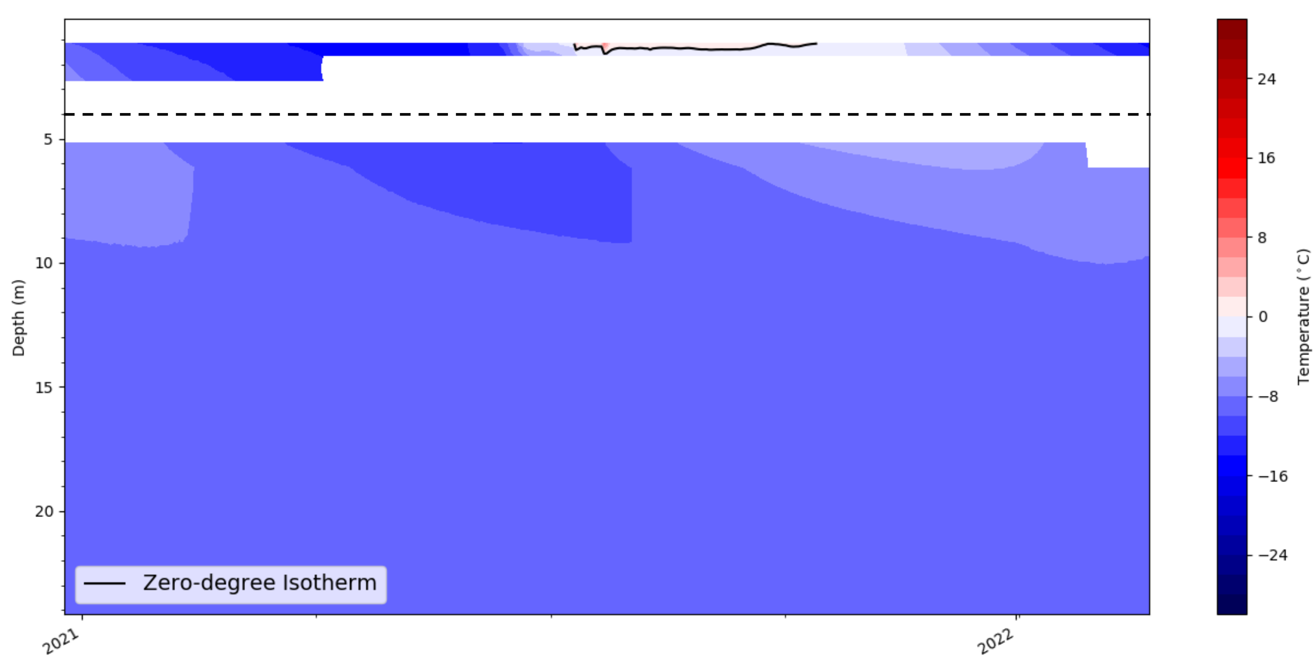

Figure A.10: RSF-18 Thermistor String between December 25, 2020 and February 22, 2022

Appendix B

Thermal Modelling of the Portage Rock Storage Facility Closure Landform Design

Model Inputs

Model inputs for the Portage RSF can be divided into five types:

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

The following sections describe the inputs proposed for the Portage RSF thermal modelling update.

Climate

TEMP/W requires daily surface temperature data whereas SEEP/W and AIR/W require daily values of maximum and minimum air temperature; maximum and minimum relative humidity (RH); average wind speed; daily net radiation; and precipitation (amount and duration).

A historical climate database for the Whale Tail and Meadowbank sites was developed by Okane. Historical values for the required parameters discussed above, with the exception of net radiation, are available from Environment Canada (2022) for Baker Lake, approximately 70 km south of the Meadowbank site and 150 km south of the Whale Tail Mine. Solar radiation for Baker Lake is estimated by Environment Canada (2022) in the Canadian Weather Energy and Engineering Datasets (CWEEDS) using the MAC3 model. This data was used to estimate net radiation on a daily basis. Environment Canada has hourly records for Baker Lake from 1963 to present, of which the period August 1963 to December 2021 was used to create a historical 59-year database for the Whale Tail project. After comparing the climate data measured at Meadowbank and Whale Tail to measurements taken at Baker Lake it was previously concluded that the Baker Lake data did not need to be adjusted to represent the Meadowbank or Whale Tail site. Any missing data in the Baker Lake climate record were filled with average measurements for a given day.

ECCC also provides precipitation data that have been adjusted for gauge undercatch and evaporation due to wind effect, which was incorporated into the Whale Tail climate database (ECCC, 2017). The adjusted precipitation data is available until 2013, after which the methodology was reproduced by Tetra Tech (2021) and applied to subsequent years.

A "synthetic average" climate year was defined by averaging daily climate conditions from the 59-year climate database (e.g., averaging the maximum temperature on January 1st for all 59 years). However, rainfall was not applied considering solely the daily average amount, but also the average number of rainfall events per month. Hence, rainfall was applied for the average number of rainfall days per month and on days with the highest chance of rainfall. The daily rainfall amounts for days with lower chances of rainfall were added to the next high-chance event in the month so that the synthetic average climate year had the average amount of rainfall.

Table B.5.1 provides a summary of the average monthly conditions in the 59-year historical database developed for the Meadowbank and Whale Tail site.

Table B.5.1: Summary of average climate parameters for 59-year Meadowbank and Whale Tail historical climate database (1963-2021).

Month	Temperature (°C)		Relative Humidity (%)		Wind (m/s)	Precipitation	
	Maximum	Minimum	Maximum	Minimum		(mm)	(days)
January	-27.8	-34.8	71.7	60.7	6.3	15	7
February	-27.9	-35.0	70.5	60.0	6.3	14	7
March	-22.5	-31.1	73.3	61.3	6.0	19	8
April	-12.7	-22.1	81.4	68.0	5.8	25	9
May	-2.7	-9.8	90.1	76.0	5.6	22	9
June	9.1	0.6	90.0	61.6	4.7	27	13
July	16.8	6.3	88.9	52.5	4.6	43	14
August	14.3	5.5	92.0	58.8	5.0	47	17
September	6.1	-0.3	93.2	68.3	5.5	51	17
October	-3.6	-9.8	91.4	77.8	6.1	44	16
November	-15.7	-23.2	81.2	68.4	6.1	32	11
December	-23.5	-30.6	74.5	62.9	6.1	20	9
Annual	**-7.4**	**-15.2**	**83.3**	**64.7**	**5.7**	**359**	**137**

Climate Change

The 59-year historical database presented above was adapted to account for climate change predictions over the next 150 years (to 2170). This process is explained in the remainder of this section.

As part of the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (AR5), the IPCC adopted new representative concentration pathways (RCPs) to replace the previous emission scenarios of the Special Report on Emission Scenarios (SRES) (IPCC, 2013). The four adopted RCPs differ from the SRES in that they represent greenhouse gas concentration trajectories, not emissions trajectories. The four scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) are named after the radiative target forcing level for 2100, which are based on the forcing of greenhouse gases and other agents and are relative to pre-industrial levels (van Vuuren et al., 2011). RCP2.6 represents a very low RCP with a peak of radiative forcing at around 3.1 W/m^2 mid-century, followed by a decline to 2.6 W/m^2 by 2100.

RCP4.5 represents a medium RCP with stabilization of radiative forcing around 2100. RCP6.0 represents a medium-high RCP with stabilization of radiative forcing shortly after 2100, while RCP8.5 represents a high RCP with increasing emissions that do no stabilize until after 2200. Climate at the Meadowbank and Whale Tail site is expected to remain within the subarctic (Dfc) climate category, described above, under the A1FI (former SRES emission scenarios) climate change scenario, which is similar to RCP8.5 (Rubel and Kottek, 2010). Figure B.1 provides the concentration of all forcing agents (in parts per million (ppm) of CO_2-equivalence) for the four RCP scenarios.

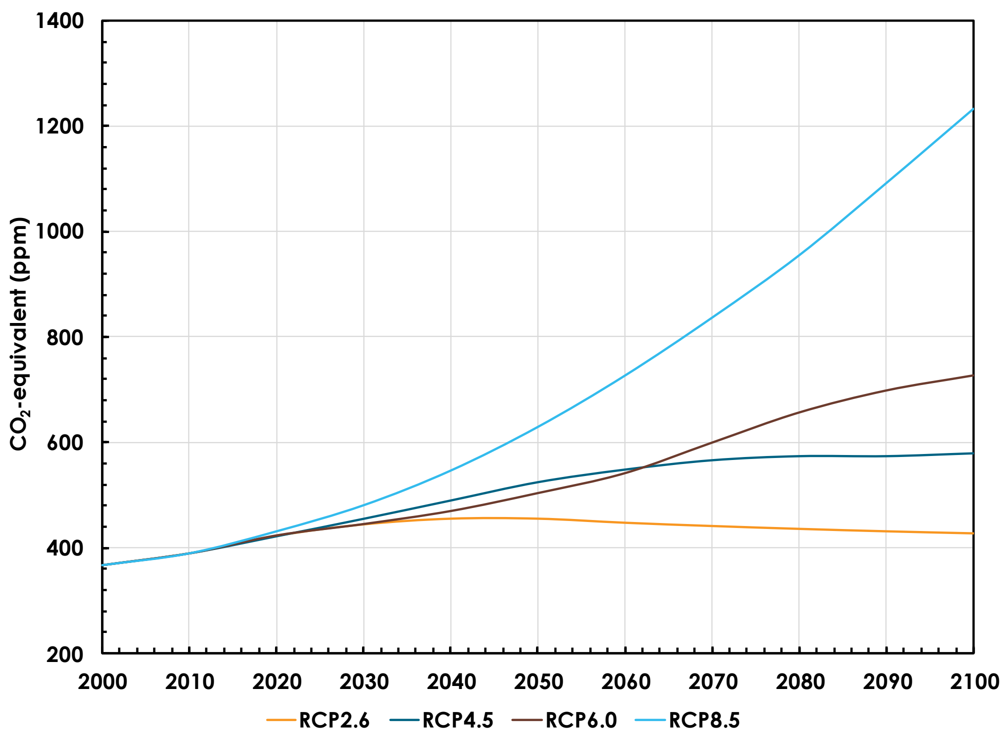

Figure B.1: All forcing agents' atmospheric CO_2-equivalent concentrations according to the four RCP scenarios.

The climate change database for Meadowbank and Whale Tail was developed following the recommendations outlined on the Canadian Climate Data and Scenarios (CCDS) website, which is wholly supported by ECCC (CCDS, 2018). The website recommends the use of statistical downscaling to "downscale" a general circulation model's (GCM's) predictions to a specific location based on historical observations. Statistical downscaling is a two-step process consisting of i) development of statistical relationships between local climate variables (e.g., surface air temperature and precipitation) and large-scale predictors (e.g., pressure fields), and ii) application of such relationships to the output of GCM experiments to simulate local climate characteristics in the future. The Pacific Climate Impact Consortium (PCIC) at the University of Victoria provides statistically downscaled daily temperature and precipitation under the RCP2.6, RCP4.5 and RCP8.5 scenarios for all of Canada at a resolution of approximately 10 km (PCIC, 2018). For this project, the second-generation Canadian Earth System Model (CanESM2), developed by the Canadian Centre for Climate Modelling and Analysis (CCCma), was used as the predictor GCM to downscale and make climate change databases representative of Meadowbank. Temperature and precipitation were derived from the PCIC output, while the other climate variables required for SEEP/W and TEMP/W (i.e., relative humidity and net radiation) were downscaled using the Statistical Downscaling Model (SDSM) (Wilby et al., 2002; 2013; 2014), with the exception of wind speed due to the lack of climate change predictors.

Statistical downscaling is limited by the availability of large-scale predictors. Current CCCma CanESM2 model runs are limited temporally to 2100. In order to predict beyond 2100, the radiative forcing trend was applied to the temperature. RCP4.5 and RCP6.0 are expected to stabilize shortly after 2100, while RCP8.5 is expected to continue along the same trend until after 2200 (Meinshausen et al., 2011).

The CCCma does not provide GCM output for RCP6.0. In order to develop annual averages for RCP6.0, a weighted average function of RCP4.5 and RCP8.5 was developed based on the predicted climate change trends in Northern Canada using the Community Climate System Model, version 4 (CCSM4) (Peacock, 2012). Figure B.2 and Figure B.3 show the annual temperature and precipitation, respectively, estimated for the RCP4.5 and RCP6.0 100-year climate databases developed for Whale Tail and Meadowbank. Temperatures are anticipated to rise at about the same rate (approximately 0.06°C/year) for RCP4.5 and RCP6.0 until approximately 2070, after which RCP4.5 estimates a reduction in the temperature increase rate. RCP4.5 predicts an average annual temperature of approximately -4.6°C over the last 30 years of the climate change database (2090-2120), while RCP6.0 predicts an average annual temperature of -3.2°C over the same time period. Both scenarios predict an increase in precipitation with time. An increase of approximately 13 mm over 100 years or 0.013 mm/year is predicted for RCP4.5, while an increase of approximately 18 mm over 100 years or 0.018 mm/year is predicted to RCP6.0. RCP4.5 was selected as the scenario for the Base Case simulations, with RCP6.0 completed as a Climate Sensitivity.

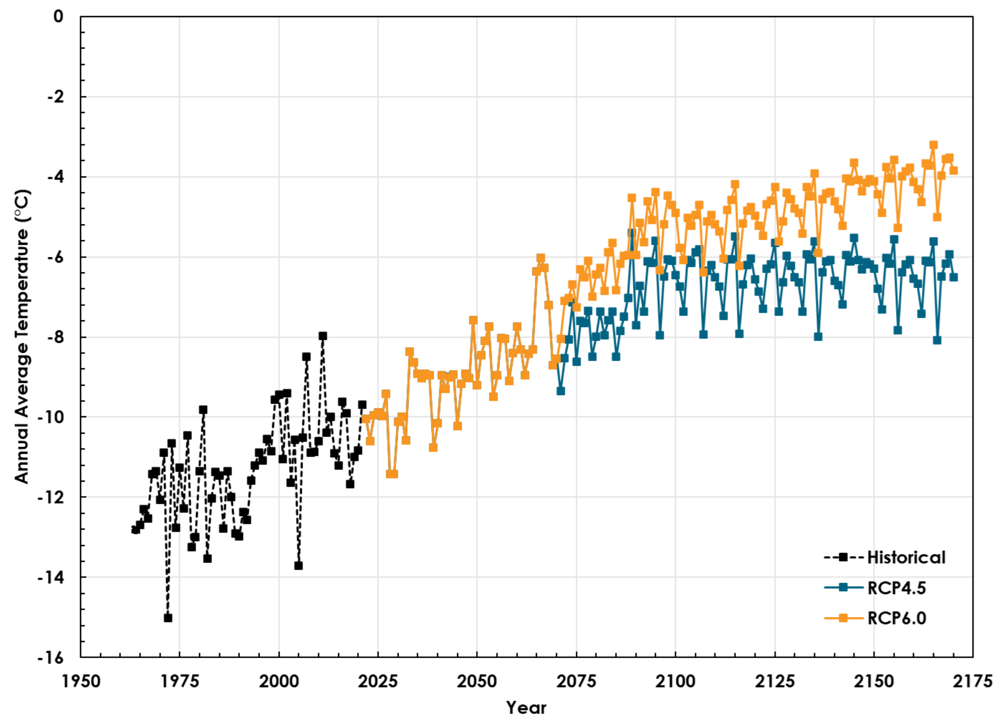

Figure B.2: Annual average temperature estimated for the RCP4.5 and RCP6.0 climate change scenarios. Historical temperature at Baker Lake is also shown.

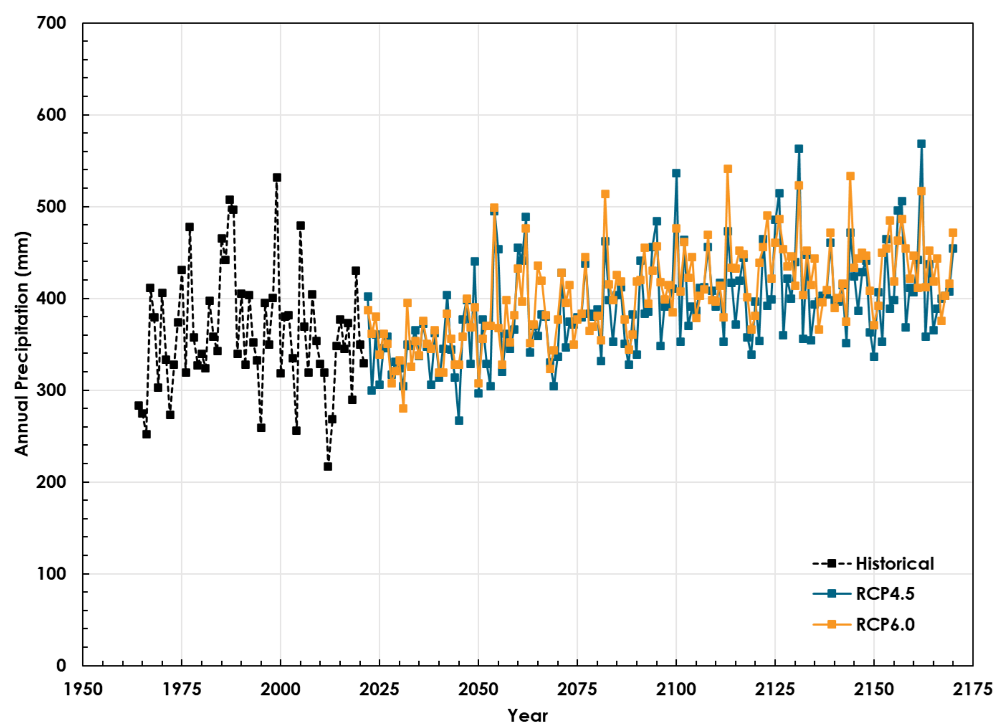

Figure B.3: Annual precipitation estimated for the RCP4.5 and RCP6.0 climate change scenarios. Historical precipitation at Baker Lake is also shown.

To account for the creation of micro-climates on the embankments of the Portage RSF, calibrations to the base 150-year climate database were done to the net radiation and wind speed parameters. Net radiation was adjusted for north facing and south facing slopes according to the method proposed by Swift (1976) and Weeks and Wilson (2006). Wind direction and speed were also be adjusted for the modelled cross sections by creating a specific wind speed data set for N and S directions according to the wind roses shown in Figure B.4 prepared from hourly wind speed and direction data from the Meadowbank site between December 2012 and December 2018. The effects of surrounding landforms (such as the North Cell TSF) were assumed not to affect wind speed and direction. As the Portage RSF is the dominant landform in the adjacent landscape, this is a reasonable assumption.

The impact of wind on the thermal regime (forced convection/advection) is likely limited to the edges of the RSF in the predominant wind direction, as the permeabilities of the materials are not sufficient to allow high enough air velocities within the centre of the RSF to drive advection (Pham et al., 2015).

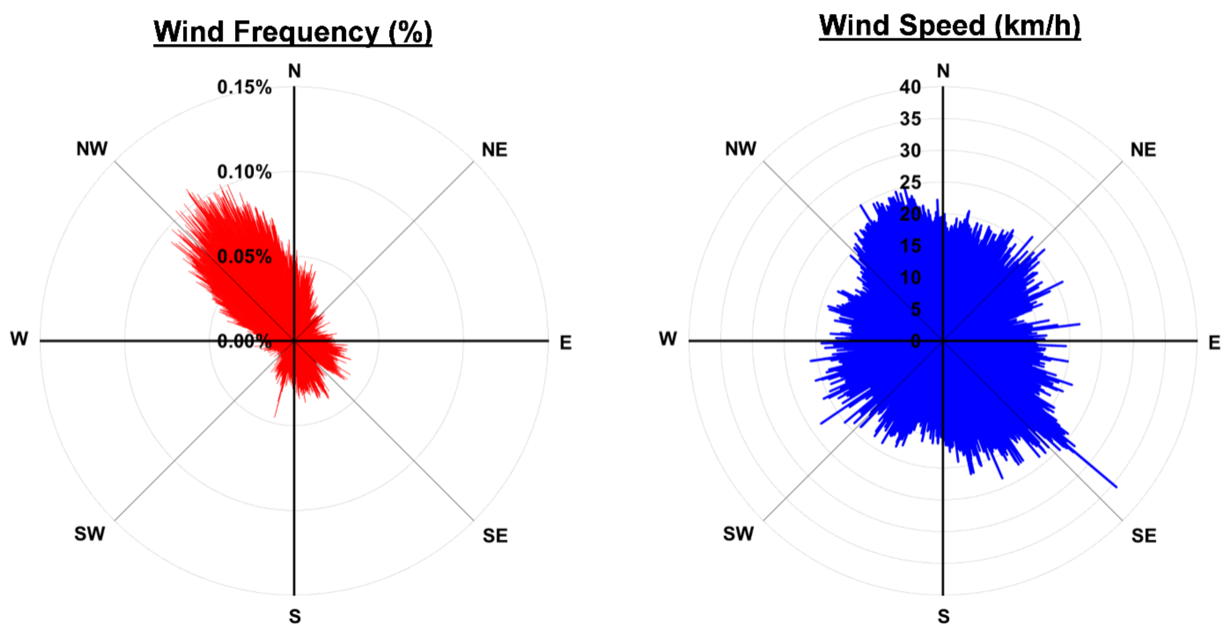

Figure B.4: Windrose for Meadowbank climate station.

Materials

The material properties or functions developed for each material based on available geochemical and geotechnical testing (e.g. particle size distributions) are as follows:

- water retention curves (WRC – suction versus volumetric water content);
- hydraulic conductivity function (k-function – suction versus hydraulic conductivity);
- air conductivity function;

- thermal conductivity function (volumetric water content versus thermal conductivity);
- volumetric specific heat function (volumetric water content versus volumetric specific heat capacity);
- unfrozen water content function (unfrozen water content versus temperature); and
- geochemical reactivity.

A set of material properties were previously estimated for the Portage RSF for the following four materials: crushed (from vehicular traffic) soapstone (NPAG); run-of-mine (ROM) soapstone; till; and bedrock. All material properties were estimated based on previous work completed by Golder Associates Ltd. (2008) and, for the crushed soapstone, ROM soapstone, comparisons of particle size distribution (PSD) data to materials in the SoilVision database with similar PSDs and known material properties.

The NPAG and PAG materials are initially to be simulated with the same material properties (i.e., soapstone). Refinement of the NPAG and PAG material properties will be made by calibrating the initial models to current conditions using thermistor strings data.

Hydraulic Material Properties

The initial estimates for hydraulic material properties are to be unchanged from 2014 modelling inputs. The estimated WRC (Figure B.5) and k-function (Figure B.6) as well as the calibrated value for each simulated material are shown below.

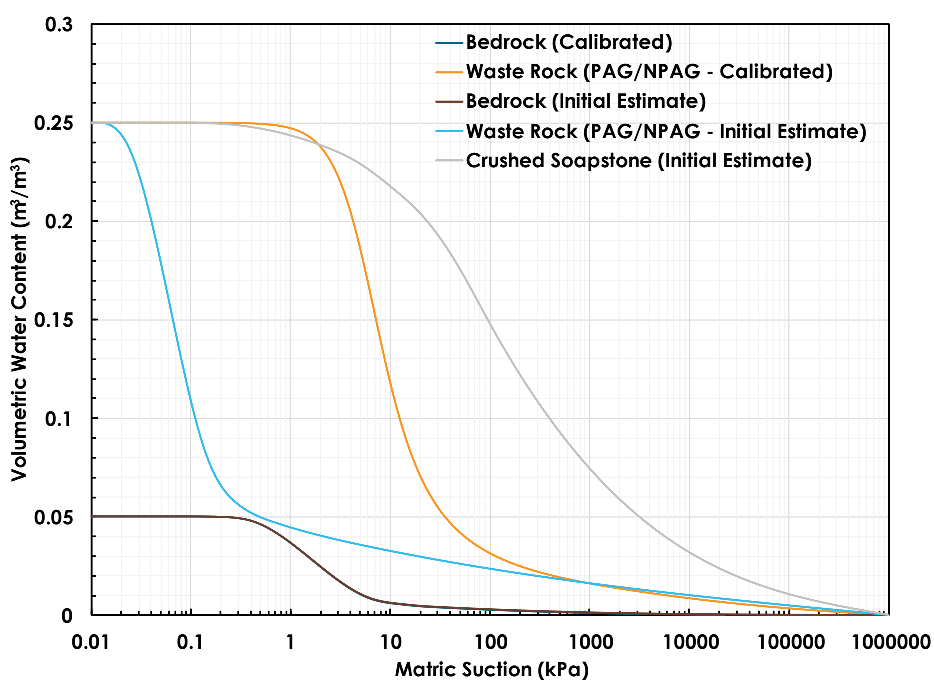

Figure B.5: Water retention curves proposed to initially simulate Meadowbank materials.

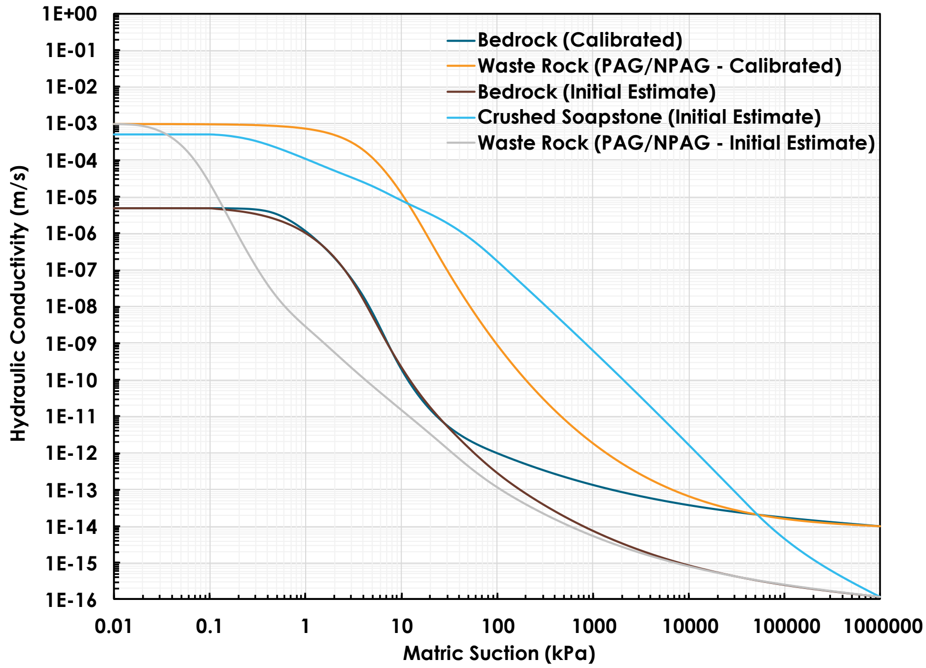

Figure B.6: Hydraulic conductivity functions proposed to initially simulate Meadowbank materials.

Thermal Material Properties

The thermal functions were estimated using methods programmed into the VADOSE/W software. The same thermal properties were used for Portage and Whale Tail thermal modelling. Following a review and comparison of the Whale Tail field data, estimated thermal functions, and literature values from the Research Institute for Mining and Environment (RIME) (Figure B.7 and Figure B.8), it was concluded that the thermal properties should remain the same as the Okane estimated thermal properties.

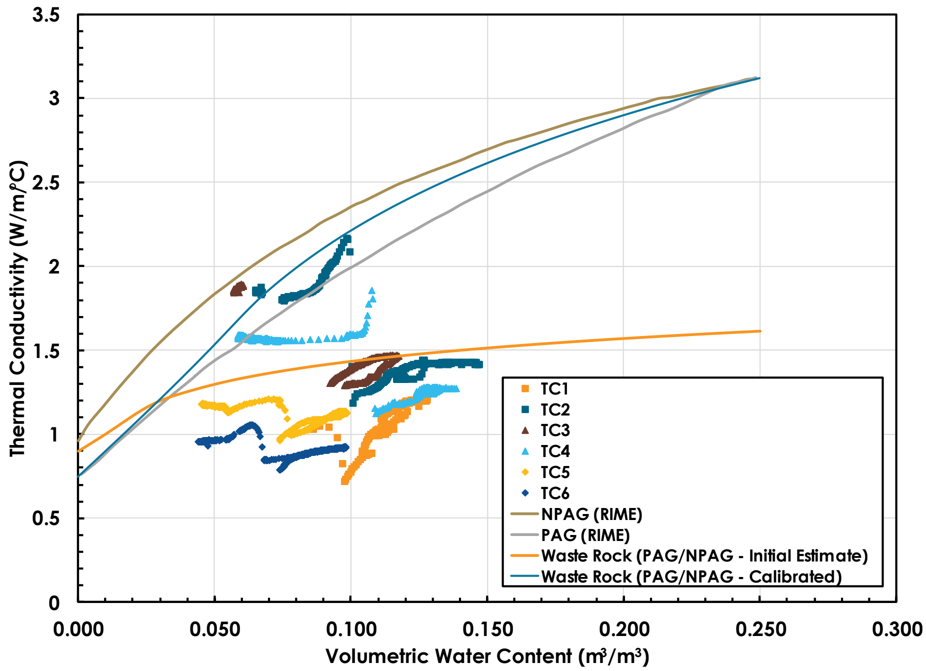

Figure B.7: Comparison of estimated, literature, and field measured thermal conductivity functions.

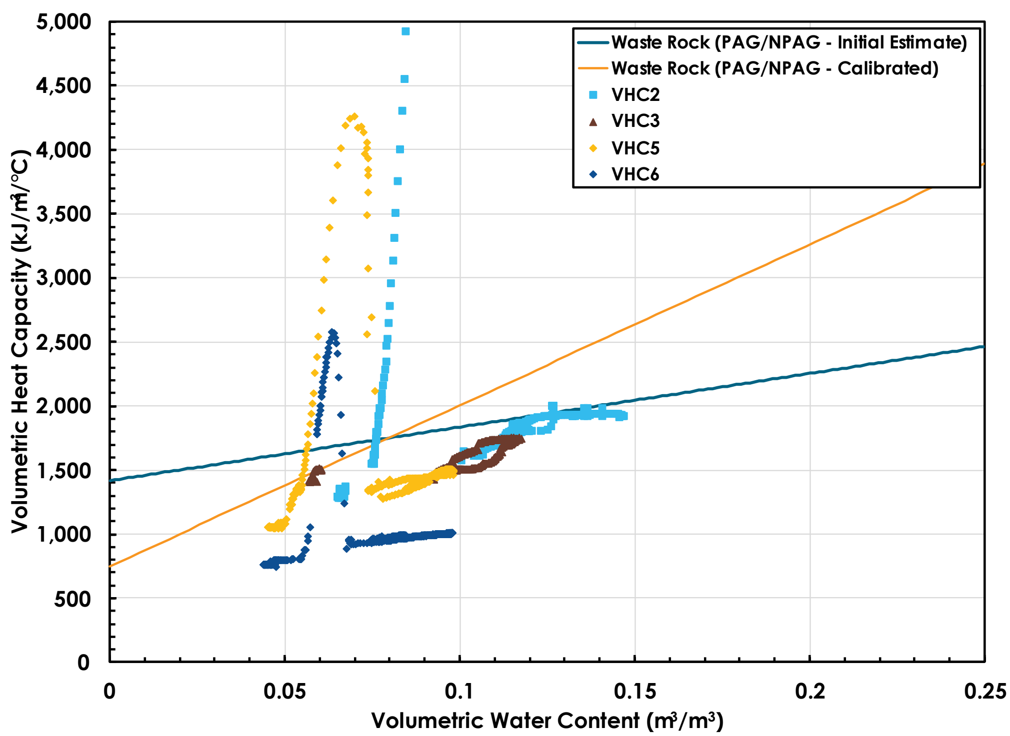

Figure B.8: Comparison of estimated, literature, and field measured volumetric heat capacity functions.

Air and Gas Material Properties

The air conductivity and oxygen diffusion functions from latest Meadowbank models will be utilized to initiate the modelling for this project (Figure B.9).

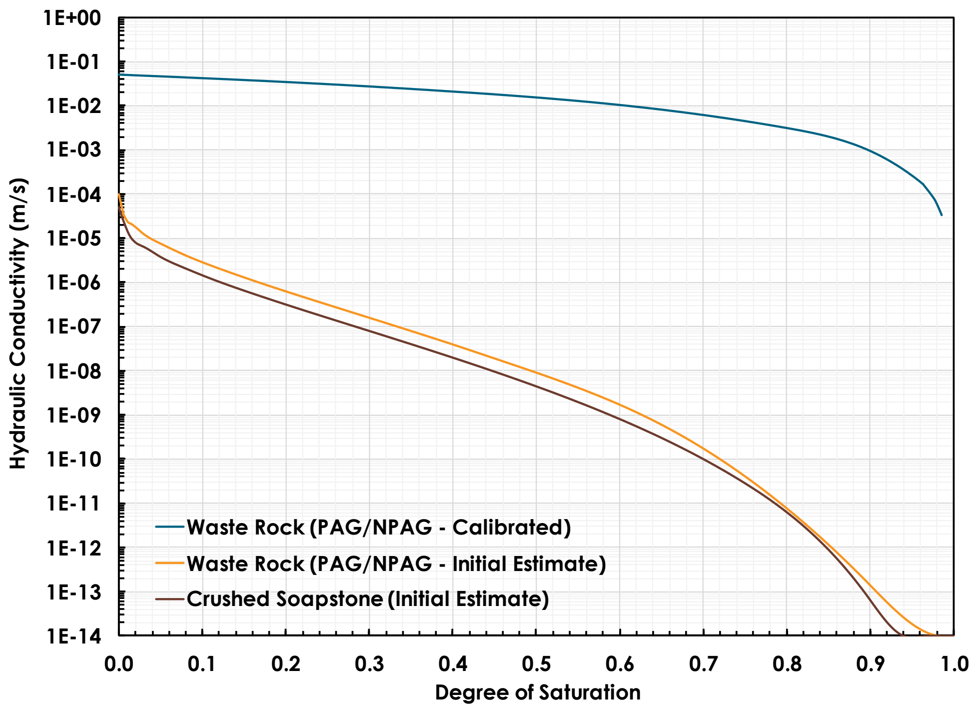

Figure B.9: Air conductivity functions proposed to initially simulate Meadowbank materials.

To simulate exothermic reactions from the oxidation of waste rock, the Gas Consumption and Exothermic Reaction boundary condition was applied to the waste rock material. This boundary condition couples the oxygen consumption due to mineral oxidation to heat generated by the associated exothermic reactions.

Optimal reaction rates were determined from humidity cell tests (Golder, 2018) as 0.052 kg O_2/t/year for the NAG/NML cover material and 0.062 kg O_2/t/year for the PAG waste rock. The waste rock within the RSF was assumed to be PAG rock, while the cover system material was assumed to be NAG/NML rock. 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.

It will be assumed that no oxidation will occur in the bedrock.

Geometry

Okane modelled the N-S cross-section used in 2014 (Figure B.10) as it includes RSF-3, which has the longest dataset of all the thermistor stings installed in the Portage RSF and was used for 1D calibration during 2014. The N-S cross section also captures the predominant wind direction (N) and the slope with the highest radiative forces (S).

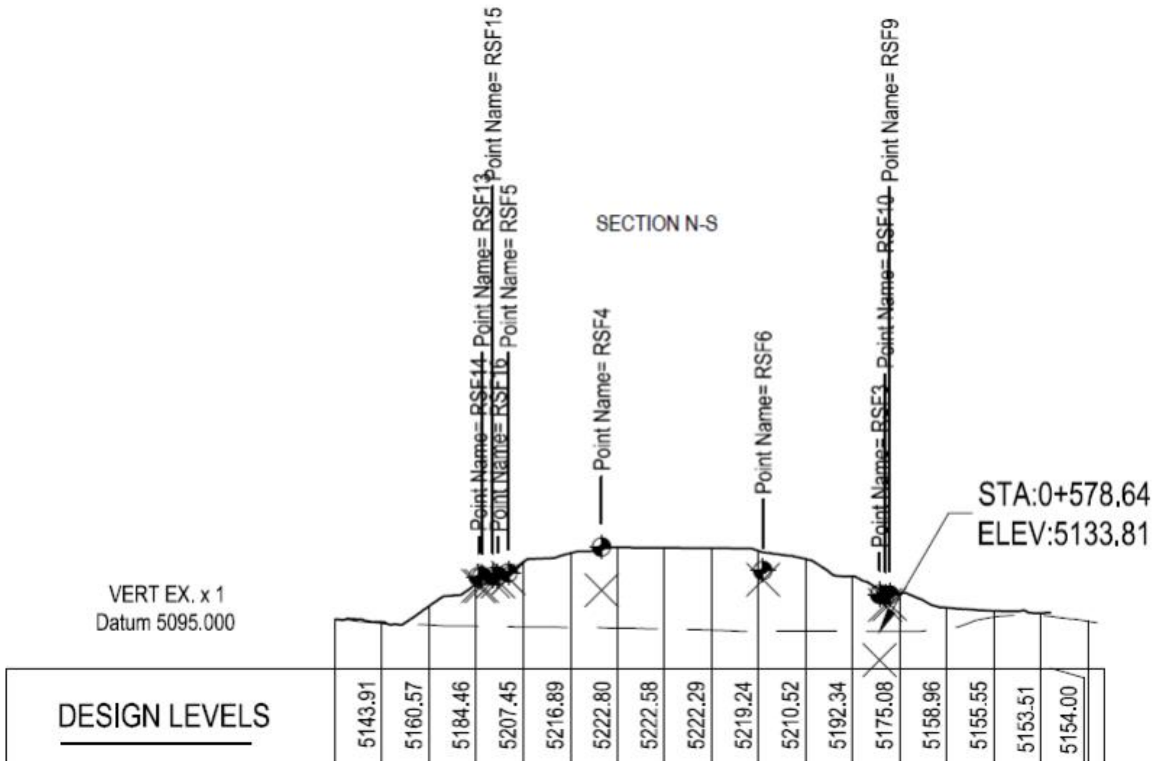

Figure B.10: Portage RSF N-S cross-section.

Initial Conditions

The initial conditions of the 2D long-term modelling were established during 1D calibration and surface boundary condition modelling. The initial conditions used for the 1D calibration and surface boundary condition modelling are detailed in Table B.5.2.

Table B.5.2: Summary of initial conditions for 1D modelling.

Initial Condition	Parameter	Material	Value
Hydraulic	Porewater Pressure	Waste Rock	-10 kPa
		Cover System Material	
Air and Gas	Oxygen Concentration	Waste Rock	280 g/m^3
		Cover System Material	
	Air Pressure	Waste Rock	0 kPa
		Cover System Material	
Temperature	Temperature	Waste Rock	Measured by RSF-3 Thermistor
		Cover System Material	

Boundary Conditions

The boundary conditions of the 2D long-term modelling will be established during simulation of historical conditions. The boundary conditions used for the 1D modelling are summarized below in Table B.5.3.

Table B.5.3: Summary of boundary conditions for 1D modelling.

Boundary Condition	Parameter	Location	Value
Hydraulic	Land-Climate Interaction	Surface	Daily maximum and minimum temperature Daily maximum and minimum relative humidity Daily precipitation Daily wind speed Daily net radiation
	Snow Density	Surface	300 kg/m^3
	Snow Ablation	Plateaus/South Benches North Bench/Slopes South Slopes	0.725 0.500 0.450
	Unit Gradient	Base of bedrock	Unit Gradient
Air and Gas	Oxygen Concentration	Surface	280 g/m^3
	Barometric Air Pressure	Surface	Referenced to 160 masl
Temperature	Gas Consumption and Exothermic Reactions Add-in	Waste Rock	0.062 kg O_2/t/year
		Cover System	0.052 kg O_2/t/year
	Permafrost Temperature	Base of bedrock (~20 mbgl)	-5 °C
	Surface Energy Balance	Surface	Daily maximum and minimum temperature Daily wind speed Daily net radiation
	Snow Conductivity	Surface	5.00 x 10^{-5} W/m/°5.00x1000 x 10^{-5} W/m/°C

Model Results

Modelling of the RSF was completed in three major steps: historical calibration modelling, one-dimensional boundary condition modelling, and long-term two-dimensional climate modelling. Following completion of 1D calibration modelling on the idealized cross section, long term climate modelling was completed using the RCP4.5 and RCP6.0 climate database described previously. The range of long-term climate scenarios were included in long term modelling to generate the range of expected thermal and hydraulic performance of the RSF in closure and post-closure. Long term climate modelling was competed for the idealized cross-section.

1D Results

Preliminary Calibration to Portage Field Conditions

One dimensional SPA modelling was initially completed to calibrate and validate the model material properties to temperatures measured by thermistor RSF-3 within the Portage RSF, which have equilibrated.

RSF-3 was chosen for material calibration. The location of the thermistors in shown in Figure B.10. The 1D calibration model ran between December 1, 2013 and December 31, 2022 using site data as external boundary conditions. Once calibrated, the modelled temperature profile was shown to be a reasonable match to the measured temperature data over the entire profile of RSF-3 between December 2013 and December 2022. The modelled and measured temperature data is shown at different depths in Figure B.11 through Figure B.13.

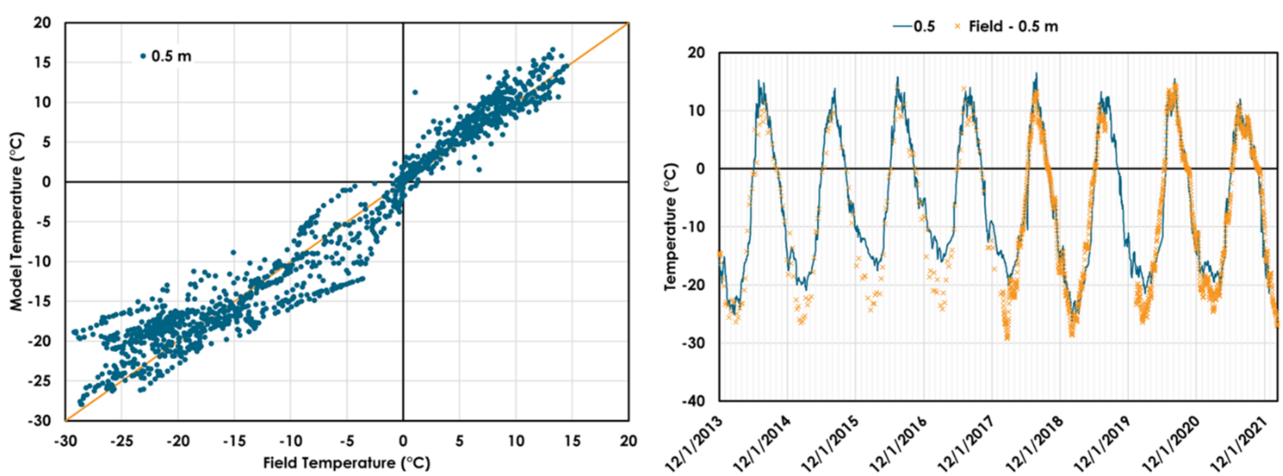

Figure B.11: Calibration results for the Portage RSF-3 at 0.5 m depth.

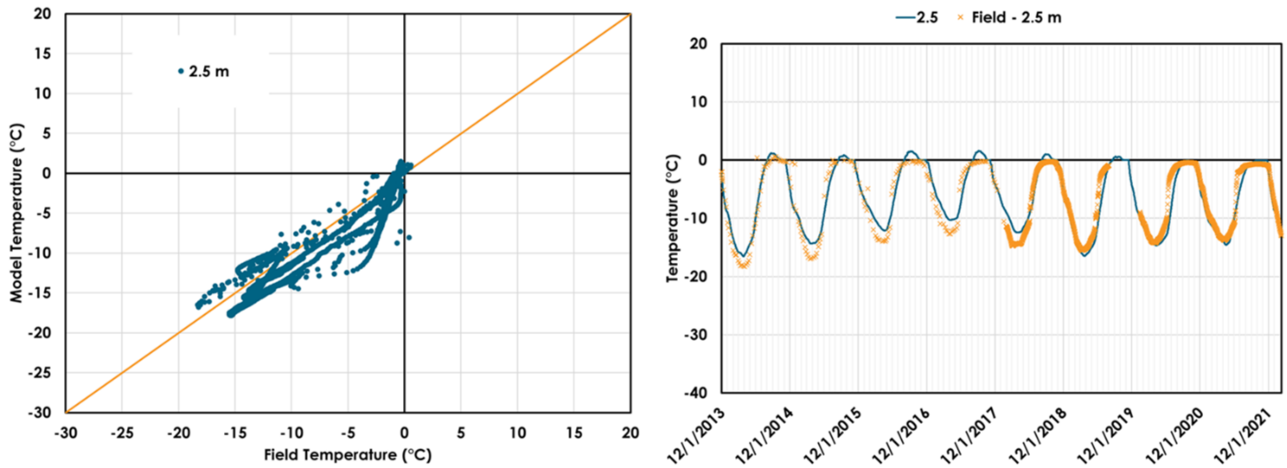

Figure B.12: Calibration results for the Portage RSF-3 at 2.5 m depth.

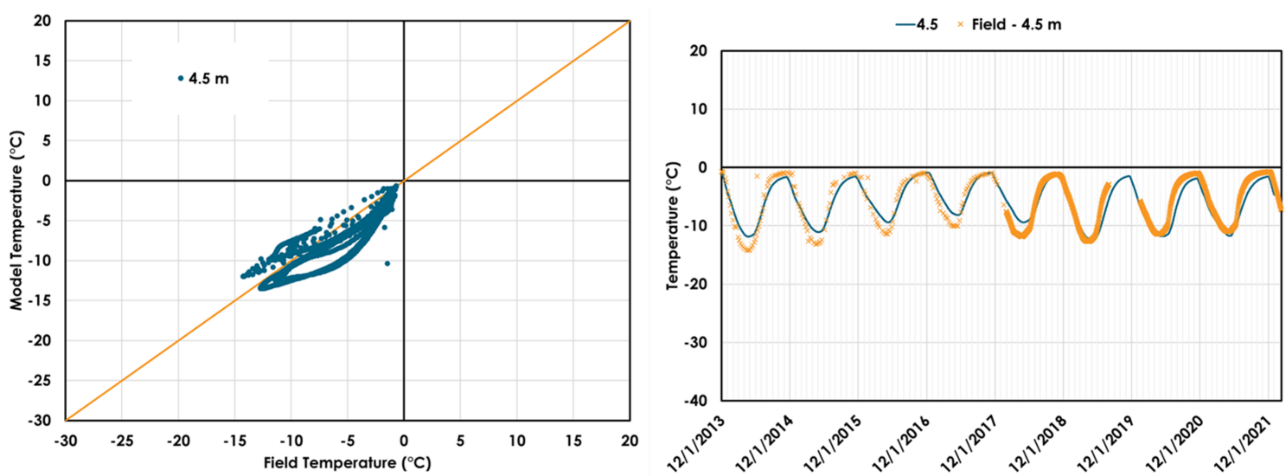

Figure B.13: Calibration results for the Portage RSF-3 at 4.5 m depth.

Development of Surface Boundary Conditions

One dimensional SPA modelling was completed to determine the surface water balance and surface temperature inputs for the 2D model. Models were completed for both the Base Case climate change scenario (RCP4.5) and for the Climate Sensitivity (RCP6.0). The full climate database was applied to the Land-Climate-Interaction and Surface Energy Balance boundary conditions to determine the surface water balance and the surface temperature. The surface infiltration and surface temperature were then applied to the two-dimensional model.

2D Results

Following completion of the calibration to the Portage field data and 1D boundary condition modelling, long-term 2D modelling 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 98-year period (2022-

2120) was modelled under the Base Case and Climate Sensitivity scenarios. The following sections summarize the results of the long-term 2D modelling.

Active Thermal Layer Depth

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 to 2120) indicates an active layer of approximately 6 m in the base case climate scenario (RCP4.5). The following figures (Figure B.15 and Figure B.16) illustrate annual average near-surface thermal conditions at several locations on the RSF (Figure B.14) between 2090 to 2120 under the Base Case and Climate Sensitivity scenarios, respectively.

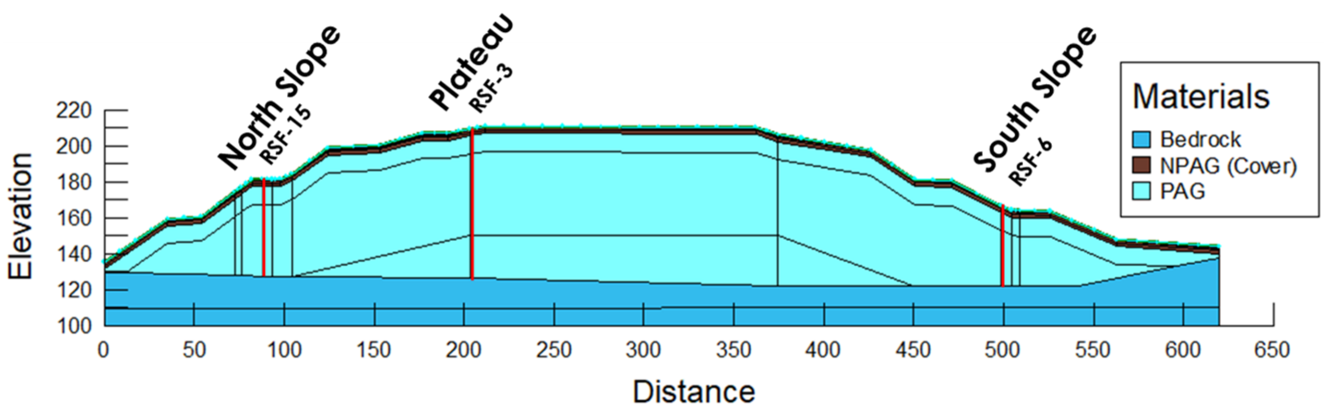

Figure B.14: Section view of N-S cross section and typical thermal locations rendered below.

Table B.5.4: Annual average active layer depths for the 30-year period 2090 to 2120.

Profile	Corresponding Thermistor	Base Case (RCP4.5)	Climate Sensitivity (RCP6.0)
North Slope	RSF-15	3.8 m	5.7 m
Plateau	RSF-3	5.7 m	6.5 m
South Slope	RSF-6	10.6 m*	8.3 m

***Note:** Highlights the difference in the shape/location of the active layer between climate change scenarios at the RSF-6. Not necessarily indicative of overall degree of thaw for the RSF.

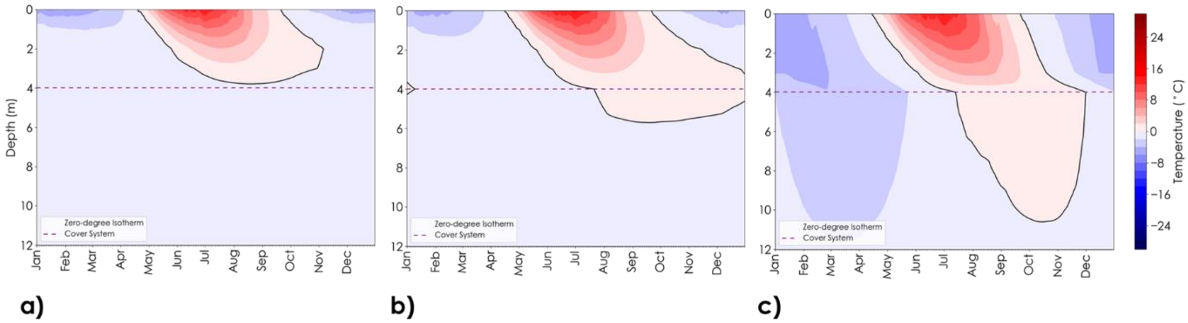

Figure B.15: Annual long term near surface temperature along the slope of the idealized cross section at the a) north slope, b) plateau, and c) south slope under the Base Case (RCP4.5) climate conditions.

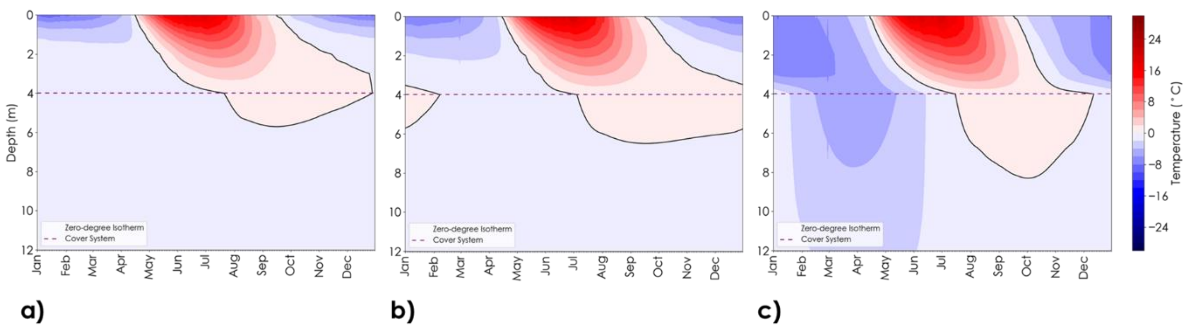

Figure B.16: Annual long term near surface temperature along the slope of the idealized cross section at the a) north slope, b) plateau, and c) south slope under Climate Sensitivity (RCP6.0) climate conditions.

In permafrost environments, thaw of the active layer occurs as a unidirectional process from the surface. During the summer months, when air temperatures are 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 and air flow can contribute to the heat transfer through 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 active layer reaches its maximum depth at this stage. 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 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. Thus, there is the possibility for movement of water, but such movement is likely limited. In addition, under zero-curtain conditions, oxidation, and thus the production of ML/ARD products, is likely reduced.

The primary mechanism responsible for thaw, conduction, is typically constrained to the cover system before colder air temperatures decrease the thermal gradient. This is relatively consistent with previous thermal modelling work ((Golder, 2018) and (Okane, 2021)) completed to date. The effect of conduction is loosely represented by the contours greater than 2 °C (contoured 'bulb' occurring between late April and September). The secondary thaw mechanism, heat re-distribution due to convection, results in thaw at near-zero conditions below the cover system. Freezing from the surface progresses rapidly, while freezing from the bottom is a slower process. Zero-curtain conditions are created, slowing the upper freezing front, until all pore water is frozen.

While the thermal regime is governed by two separate mechanisms, conduction and convection, the hydrologic regime must be accounted for to fully understand the effect of the depth of thaw on cover system performance. Figure 2.9 compares the unfrozen volumetric water content, or the portion of pore water available to be mobilized, compared to thaw depth at the same location. Figure B.17 illustrates that the warming beyond the cover system does not equate to the mobilization of water through the RSF. For very low volumetric water content (less than 0.04 m^3/m^3), the hydraulic conductivity of the waste rock material is less than 1 x 10^{-7} m/s. This very low hydraulic conductivity limits the movement of moisture in the thawed zone below to cover system to the range of <1 m/year.

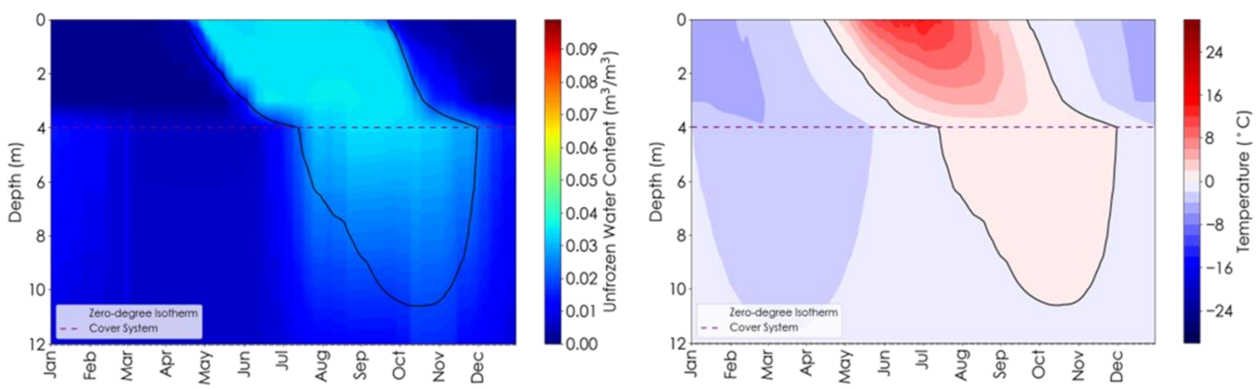

Figure B.17: Annual long term near surface unfrozen volumetric water content (left) and temperature (right) for the Base Case along the south slope of the cross section at RSF-6 with the cover system interface shown by the black dashed lines.

Landform Water Balance

A landform water balance was completed for the Portage RSF. This work included estimates of runoff, interflow, and basal seepage rates for the Base Case and Climate Sensitivity analyses of the Portage RSF (Table B.5.5) for the water year (October 1 to September 30).

Table B.5.5: Summary of average surface water balance for the Portage RSF under different climate scenarios (2022-2120).

Water Balance Parameter	Base Case (RCP4.5)	Climate Sensitivity (RCP6.0)
Total Precipitation (mm)	378 mm	389 mm
Rainfall (% of Total Precipitation)	45-50%	45-50%
Snow (% of Total Precipitation)	50-55%	50-55%
Actual Evaporation (% of Total Precipitation)	40-45%	40-45%
Runoff (% of Total Precipitation)	10-15%	5-10%
Surface Infiltration (% of Total Precipitation)	5-10%	10-15%
Sublimation (% of Total Precipitation)	35-40%	35-40%

Runoff

Runoff is an important component with respect to the site-wide water balance as it is considered to be contact water. 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. The runoff distribution by month for the Portage RSF in detailed in Table B.5.6.

Table B.5.6: Runoff distribution by month for the Portage RSF (2022-2120)

Month	Percent of Total Annual Runoff by Month	
	RCP4.5	RCP6.0
January	0%	0%
February	0%	0%
March	0%	0%
April	63%	77%
May	36%	22%
June	1%	0%
July	0%	0%
August	0%	1%
September	0%	0%
October	0%	0%
November	0%	0%
December	0%	0%

Basal Seepage

The high infiltration capacity of the waste rock material results in a preference for precipitation to result in surface infiltration, rather than runoff (Table B.5.5). As water infiltrates into the surficial materials, net percolation flows vertically through the RSF, eventually freezing back at depth. The base layer of the RSF is consistently frozen from the time of placement. As a result, basal seepage from the landform is negligible under the base case and sensitivity scenario.

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 RSF 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 (Figure B.18).

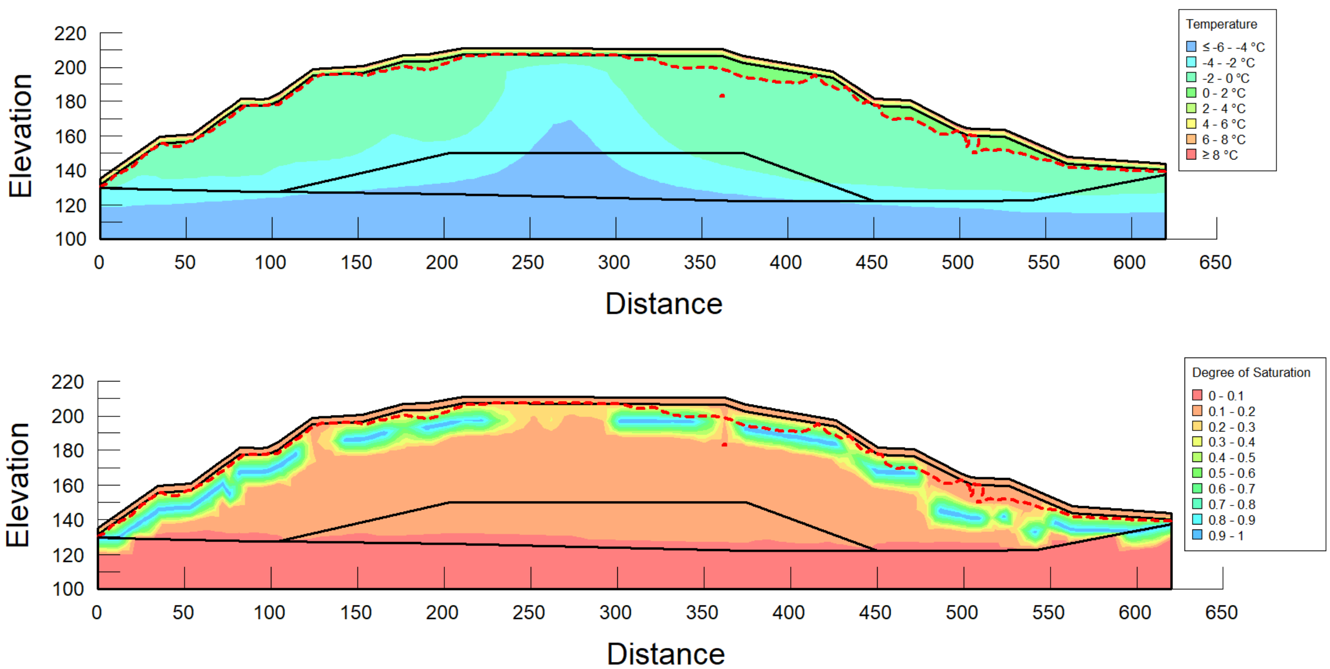

Figure B.18: Temperature and saturation profiles for the Base Case at 2120.

Table B.5.7 shows the estimated interflow as a percent of total precipitation for the Portage RSF. The monthly distribution of interflow is shown in Table B.5.8 for the Portage RSF.

Table B.5.7: Interflow for the Portage RSF cross section as a percent of total precipitation.

	RCP4.5	RCP6.0
Interflow (% of Total Precipitation)	1-5%	5-10%

Table B.5.8: Interflow distribution by month for the Portage RSF cross section as a percent of total interflow (2022-2120).

Month	Percent of Interflow Occurring by Month	
	RCP4.5	RCP6.0
January	0%	0%
February	0%	0%
March	0%	0%
April	0%	0%
May	2%	5%
June	12%	17%
July	26%	24%
August	32%	29%
September	19%	19%
October	7%	4%
November	1%	1%
December	0%	1%

CONCLUSIONS

Based on learnings from the Agnico Eagle Whale Tail Mine, the updated thermal modelling of the Portage RSF cover system described in this report, the performance of the Portage RSF cannot be measured alone by the depth of the active layer, it is the fulsome interaction of air and water in the intermittent non-frozen zones and the impacts (if any) that has on seepage and seepage water quality from the facility.

While thaw below the cover system is expected as per the updated thermal modelling, the likelihood of a 4.0 m cover system thickness being insufficient, leading to unacceptable water quality in the receiver is expected to remain low. This is due to several factors, including:

- Low volumetric water content in the thawed waste rock, resulting in low likelihood of mobilization of seepage from waste rock;
- Lower pyrite oxidation rates within the thawed waste rock compared to the cover system material (as a result of consistent near-freezing temperatures within the waste rock) resulting in low to moderate likelihood of production of metal leaching and acid rock drainage (ML/ARD/) products;
- Limited volume of PAG/ML waste rock in the estimated thawed waste rock zone, resulting in low likelihood of production of ML/ARD products; and

- Limited interaction between infiltrating water and PAG/ML waste rock due to the development of ice lenses in the upper profile of the RSF and frozen conditions at the base of the RSF.

Updated thermal modelling of the Portage RSF indicates that a 4.0 m thermal cover of NPAG/NML material will reduce the risk to water quality in the receiving environment, associated with ML/ARD generated from the PAG/ML waste rock, by promoting frozen conditions within the RSF.

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