TSF North Cell Closure Design Report Construction Plan

November 16, 2015

AGNICO EAGLE

O'Kane Consultants




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

TSF North Cell Closure Design Report
Construction Plan

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EXECUTIVE SUMMARY

Agnico Eagle Mines Limited (AEM) requires a detailed design and construction plan for reclamation of the North Cell Tailings Storage Facility (TSF) at the Meadowbank Mine. The ultimate goals for reclamation of the TSF are to mitigate long-term environmental effects to the aquatic receiving environment and to establish a landform similar to that of the natural surrounding area. Conceptual cover system designs previously modelled (Golder 2008) and presented in prior closure plans (Golder 2014) rely on aggradation of the tailings material into the surrounding permafrost to limit the production of Acid Mine Drainage (AMD) and the movement of contaminants through surface and groundwater. The construction of a cover system consisting of non-acid generating granular material (NPAG) over the tailings material ensures that the active layer (material going through freeze-thaw cycles, overlying permafrost) remains within the benign material. The objectives of the cover system is to maintain the tailings material below 0°C under most conditions and to maintain saturation above 85%.

To achieve the goals and criteria for the reclaimed TSF, the final design will consist of a landform that promotes water shedding from all surfaces covered by an engineered cover system. The final design for the engineered cover system is a layer of compacted NPAG waste rock (soapstone) of a minimal thickness of 2.0 m. The design was developed as a result of soil-plant-atmospheric (S-P-A) modelling, as well as thermal and seepage modelling. The nominal cover thickness over most of the landform is well over the minimum, up to 8.0 m in the thicker portions. This thickness variation is required to obtain the designed landform. Cover material is used to build up the landform because the tailings material displays a low angle of deposition and its frozen state makes it difficult to re-handle economically. Under the 2.0 m minimal cover, the tailings material remains frozen for all but the warmest years of the 100-year database, accounting for climate change. The unfrozen tailings are segregated in the upper 0.5 m of the TSF and remain above 85% saturation, thus reducing the risk of oxidation until the material freezes back into the permafrost over time.

The final landform consists of two watersheds with several catchments in each watershed creating positive drainage off all surfaces of the TSF. Design objectives were to minimize cover material volumes and tailings excavation by taking advantage of the tailings surface and balancing the required excavation and cover system material volumes. Several scenarios were prepared to compare tailings excavation volumes to cover material and the optimal option was selected based on site constraints. Facility minimum slope angle for the cover surface is 1%. Water is moved off the cover using a surface water management system consisting of grading the plateau areas towards engineered surface runoff drainage channels. The runoff drains have a minimum slope of 0.5%.

The surface water management plan for the reclaimed TSF is to minimize erosion, thus reducing suspended sediment loading to the receiving environment, and to safely convey runoff waters off the facility in the event of a storm event coupled with spring snowmelt. To achieve these, the surface water management system will be constructed using riprap-lined drainage channels and riprap-lined aprons

at the outlet of each catchment. The drainage channels convey surface runoff water off the TSF footprint through two surface runoff outlets located in the South and North-West portions of the TSF.

The proposed reclamation plan for the North Cell TSF is designed to be essentially maintenance free over the long term; however, AEM is committed to monitor, repair, and maintain the final reclaimed landform as required.

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1 INTRODUCTION

Agnico Eagle Mines Ltd. (AEM) owns and operates the Meadowbank Mine located in the Kivalliq region of Nunavut, about 110 kilometres by road north of Baker Lake. Meadowbank was AEM's largest gold producer in 2014. Mine commissioning and first gold production from the Portage open pit began in early 2010. The mine is expected to produce 430,000 ounces of gold in 2014, and an average of 380,000 ounces of gold per year from 2015 through 2016, with a mine life through 2017. The Meadowbank site is located in a region of continuous permafrost where the average daily temperature is about -12°C.

AEM contracted O'Kane Consultants Inc. (OKC) to design a cover system for the North Cell of the tailings storage facility (TSF). As part of closure and reclamation of the Meadowbank Mine site, the TSF requires a cover to limit the potential of acid rock drainage and metal leaching (ARD/ML). The selected closure option for the TSF to control ARD/ML formation involves permafrost encapsulation, including freezing of tailings and applying a rock fill cover for insulation and erosion control.

The TSF will be closed progressively during the mine life as the tailings deposition reaches its ultimate elevation. Conceptual design for the TSF closure includes the placement of a minimum 2 m thick layer of NPAG ultramafic waste rock over the tailings. The surface of the final cover system will be graded to blend into the existing topography, and to provide drainage to shed water from the surface of the North Cell to two surface runoff outlets via internal drainage channels. The outlets direct runoff to the TSF South Cell and to the western diversion ditch.

1.1 Project Objectives and Scope

The overall objective of this project is to design a landform and cover system for the North Cell of the TSF at Meadowbank Mine. The specific objectives of the closure plan are:

1) Detailed design of a cover system that will meet TSF closure objectives and design criteria;

2) Detailed design of a closure landform for the TSF that will visually blend with the surrounding landscape, support the intended functions of the cover system design, and manage incident surface runoff waters over the long term;

3) Prepare a cover / landform design report and construction package including technical specifications, engineering drawings, and construction Quality Control / Quality Assurance (QA/QC) program;

4) Update the cover design and construction package based on 2015 construction activities; and

5) Develop a performance monitoring program and remedial action plan(s) for the TSF closure landform to address potential defects in the cover system following performance assessment.

1.2 Report Organization

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

- Section 1 – Introduction;
- Section 2 – Site Background;
- Section 3 – Cover System Design;
- Section 4 – Final Landform Design;
- Section 5 – Surface Water Management;
- Section 6 – Failure Modes and Effects Analysis;
- Section 7 – Performance Monitoring Program.
- Section 8 – Construction Plan
- Section 9 – Post-Construction Maintenance.

Appendix A contains the construction drawings showing the proposed cover system design and landform for closure of the North Cell TSF. Appendices B to I contain memorandums and letter reports previously submitted to AEM through the course of the Project, in support to this main report.

2 BACKGROUND

To control ARD/ML production, many mining operations located in arctic climates use the existing continuous permafrost to keep their tailings frozen and reduce their reactivity (Meldrum, Jamieson, & Dyke, 2001 and Elberling, 2005). The method used consists of building a cover of non-reactive material thicker than the active zone of the local permafrost. Tailings located under the active zone are therefore kept permanently frozen thus reducing sulfide oxidation and the potential movement of contaminated water.

2.1 Integration of Tailings into Permafrost

Permafrost is defined as soil or ground, regardless of composition, that permanently remains under 0°C (Dobinski, 2011). It may be continuous over a region or be found in small scattered islands ranging in surface from a few square metres to several hectares. In Canada, over 50% of the land mass is under permafrost conditions.

Precipitation, temperature, and other meteorological factors influence tailings reactivity, the efficiency of reclamation concepts and ultimately, the scale of potential contamination. This holds especially true for mining operations located in arctic regions. Low temperatures slow down most chemical and biological reactions regulating the acid generation process while the frozen ground reduces the migration potential of contaminants. Integration into permafrost is often used as a control method for mine tailings oxidation and ARD/ML production. The goal of this approach is to keep the tailings frozen or to maintain their temperature close to the freezing point for most of the year (Kyhn & Elberling, 2001, and Elberling, 2005). However, acid mine drainage and heavy metal leaching were observed in some sites where this approach was taken. Several researchers have attempted to determine more accurately the cold conditions at which potentially acid generating mine wastes will not generate contamination. These studies show that the presence of contamination in permafrost region may in part be attributed to the active zone (soil layer at surface subjected to seasonal thaw) which allows the production of contamination, metal leaching and contaminant transport (Kyhn & Elberling, 2001). The thickness of the active zone depends mainly on the soil's thermal and hydrogeological properties and meteorological conditions. To take this into account, reclamation concepts involving permafrost are usually done by way of cover construction over the tailings material with a non-reactive material which will act as the active layer (Figure 2.1) going through freeze-thaw cycles as the underlying tailings material remain frozen.

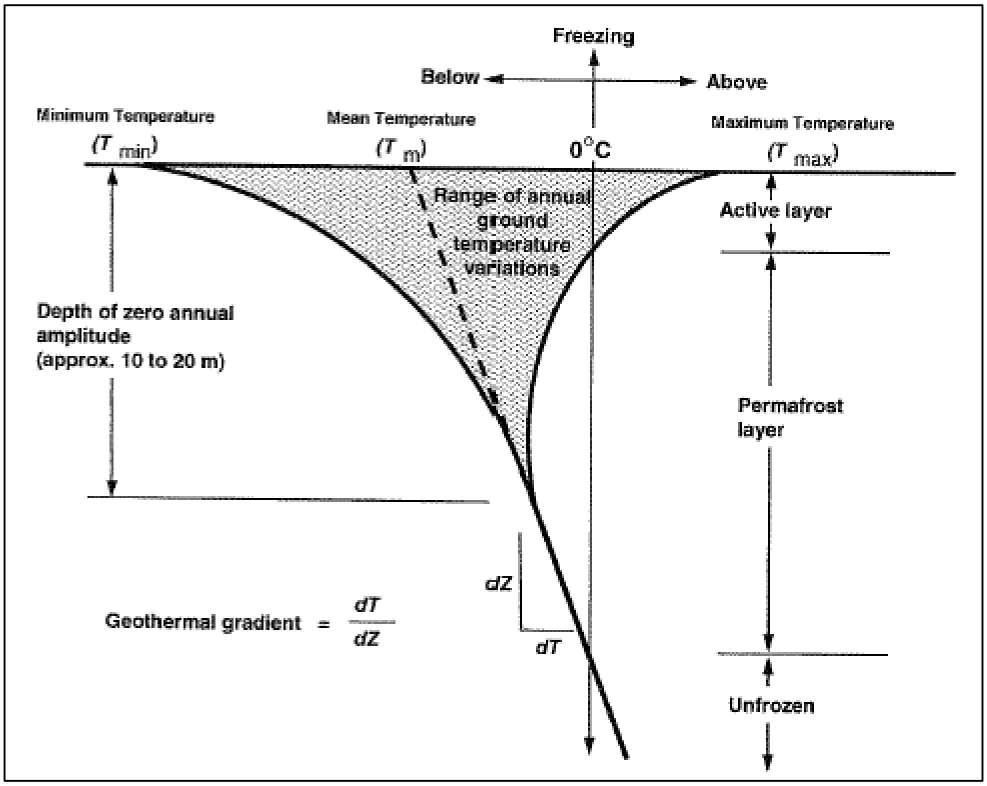

Figure 2.1: Permafrost temperature profile (MEND, 2009)

2.2 Effect of Climate Change

In addition to considering the climatic characteristics of each site to ensure proper management of tailings, it is becoming increasingly relevant to consider the impact of climate change, particularly in northern conditions where the environment is fragile and the effects of climate change magnified (MEND, 2006; Bussière and Hayley, 2010). Predictions indicate that the Arctic could be the most affected region of the planet from global warming (Pachauri and Reisinger, 2007). Over the past few decades, temperatures in the Arctic have risen at nearly twice the rate as in the rest of the world. Average winter temperatures in the western Canadian Arctic have increased by up to 4°C (Arctic Climate Impact Assessment, 2004).

The current climate change issue brings uncertainty on the perpetuity of the tailings cover concept in the eventuality of a future temperature increase that may cause an increase in the depth of the active layer. In such a case, tailings would no longer be permanently frozen, which could lead to ARD/ML production. In the context of potential climatic changes, it is important to know the capacity of the proposed cover to prevent oxidation in the underlying tailings material. This is important to ensure that the TSF is chemically stable in the long term and will not produce AMD in the future.

2.3 Previous TSF Closure Design

Documentation and previous reports relevant to the closure of the Meadowbank Tailings Storage Facility were made available by AEM and reviewed by OKC. Prior work on the tailings storage facility closure strategy includes conceptual design of the cover system and numerical modelling of the thermal regime. The Interim Closure and Reclamation Plan (ICRP) prepared by Golder Associates (Golder 2014) is the most recent conceptual design for the TSF cover system. The ICRP suggests a 4 m cover of inert (non-acid generating, NPAG) waste rock be placed over the tailings surface to provide thermal insulation and insure that tailings material remains frozen through the seasons.

Numerical modelling of the thermal regime, potential seepage, and contaminant transport was undertaken in 2008 (Golder 2008). The modelling exercise confirmed the validity of using permafrost associated with a thermal insulation cover to effectively manage potential ARD/ML from the TSF following closure.

Previous work on the landform design of the TSF appears to be limited. This is an important aspect for the closure of any mine waste storage facility.

OKC used prior design work as a starting point for the development of the detailed closure design for the TSF North Cell, including both the cover system and the landform of the facility.

3 COVER SYSTEM DESIGN

Design of an engineered cover system for the North Cell TSF is detailed in this section. Design objectives and criteria are outlined first, followed by key findings from analyses of soil-atmosphere, airflow, thermal, and seepage conditions within the TSF such that permafrost aggradation can be enhanced and promoted, and finally, details of the proposed engineered cover system design.

3.1 Design Objectives and Criteria

The primary purpose of placing a cover system on the North Cell TSF is to mitigate long-term environmental effects due to runoff, seepage, erosion, or direct contact with the waste. Closure objectives and design criteria for the TSF were presented in a memorandum found in Appendix B. Closure objectives specific to the cover system of the Meadowbank tailings storage facility are:

- Minimize catastrophic and/or chronic release of the tailings or contaminated water to the environment;
- Minimize wind migration of tailings dust; and
- Minimize the threat that the impoundment becomes a source of contamination.

From the determined closure objectives and from discussions with AEM personnel, design criteria for the closure of the North Cell of the TSF were developed. Design criteria specific to the cover system design include:

- Tailings Material Temperature
    - The tailings material placed within the North Cell should be entirely frozen after a period of 10 years following closure (frozen defined as tailings temperature <0°C).
    - The freezing front should continue at depth into the lake bed sediments and the bedrock underlying the North Cell, thus eliminating the talik currently in place. The time required for this phenomenon to take place will be determined from modelling and is to be corroborated by monitoring of ground temperatures following closure.
    - The tailings are to remain frozen for a period of over 150 years following closure, taking into account the agreed-upon climate change scenario. This will be based on modelling and monitoring of ground temperatures following closure of the facility.
    - Ground temperature monitoring should be conducted for a minimum of ten years following closure of the TSF and data compared to the modelled scenario. Model parameters are to be adjusted based on monitoring data and future ground temperature predictions refined.
    - For 90% of the TSF surface area, the active layer shall remain within the constructed NPAG cover system and the underlying tailings material shall remain frozen for a warm

year event with a return period of 1 in 100 years, accounting for the agreed climate change scenario.

- In areas where the active layer extends into the tailings material, the thawed layer should be limited to the upper 30 cm of the tailings mass and saturation of the tailings should remain above 85% to limit oxidation.

- Tailings Material Saturation
  - As an additional method to reduce tailings reactivity, the degree of saturation within the tailings mass should remain above 85%. This will reduce the tailings reactivity should part of the upper region of the tailings mass thaw during a warm year event.
- Dust Contamination
  - Following closure of the facility and completion of the cover construction, dust emissions from the TSF will be under applicable standards.

The main objectives of numerical modelling are to estimate the seepage within the deposit and heat transfer within the system. One-dimensional (1D) soil-plant-atmosphere (SPA) modelling was completed primarily to determine surface temperatures for use in the thermal/seepage model.

3.2 Modelling Philosophy

Thermal, seepage, and airflow modelling were completed to assess the effects of various methods of heat transport on permafrost aggradation in the Agnico-Eagle Mines (AEM) Meadowbank tailings storage facility (TSF). Thermal transport modelling takes into consideration three main processes:

- Thermal conductive heat transport;
- Water seepage; and
- Airflow.

Thermal conductive heat transport is the basic heat transfer mechanism, and occurs directly between two materials touching. Water seepage in the system is predominantly a function of hydraulic gradients and external influencing factors; however, seepage water can act as either a heat source or sink, and may affect the freeze-back of the stored tailings. Airflow within the system is a function of both seepage and thermal conduction, and can affect the temperatures of large areas as a result of rapid mass movements of air.

Seepage rates and air flow rates are highly influenced by waste rock texture and structure. Coarser textured waste rock material has high hydraulic conductivity and little surface runoff due to high infiltration rates. This material also shows the highest air permeability rates and thus, highest air infiltration. The opposite is true for finer textured material, in that this material has lower net percolation rates, higher surface runoff rates, and is also found to have lower air infiltration rates.

3.3 Climate Change Scenarios

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). The two middle class scenarios: RCP4.5 and RCP6 scenarios were chosen as the most appropriate climate change scenarios for the site. RCP6 represents non-climate policy scenarios. The RCP6 scenario is more equivalent to most predictions of emissions by 2100 in the case that no climate action is taken (van Vuuren et al. 2011). Full details of the climate change scenarios can be found in Appendix C.

The first of the two proposed scenarios, RCP4.5, is comparable to many scenarios that include some form of climate policy. This scenario still allows for increases in emissions while also implementing a climate policy. The policy most followed by the world's countries is outlined by the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC has the goal of stabilizing GHG emissions to a level that would prevent serious human-caused climate change. In addition to the UNFCCC, the Kyoto Protocol is the main international agreement that limits countries GHG emissions with the aim of an overall decrease. The Kyoto Protocol came into effect in 2005 and expired at the end of 2012. While several large polluters (USA and Canada included) did not sign or ratify the treaty, or did and later withdrew, others, like the European Union, are on track to achieve their reduction targets (EEA 2010). In 2013, an agreement was reached that all states of the UNFCCC would work to reduce their emissions as soon as possible. A new climate framework is to be negotiated in 2015, indicating a willingness to work toward a policy of reduced emissions.

The second proposed scenario, RCP6 is a stabilization scenario where total radiative forcing stabilizes after 2100 at 6 W/m2. This scenario would still require implementation of a range of technologies and strategies to reduce GHG emissions.

3.4 Soil-Plant-Atmosphere Modelling

Initial soil-plant-atmosphere (SPA) modelling was completed to obtain estimates of the cover surface temperature and infiltration through the cover system. These estimates were used as upper boundary conditions in the subsequent two-dimensional (2D) coupled seepage and thermal modelling. Complete details of the SPA modelling are found in Appendix D.

A total of four, one-dimensional (1D) SPA models were completed representing the combinations of two climate change scenarios (RCP4.5 and RCP6) and two cover system thicknesses (2 m and 4 m). As expected, temperatures at the surface of the cover system closely matched air temperatures through the timeline modelled under each scenario (air temperatures are detailed in the "Climate" section of Appendix D). Net infiltration estimated from modelling was effectively nil, due to the high potential evaporation compared to precipitation, as well as the barrier created by frozen tailings.

It was initially anticipated that limited runoff would occur over the cover system surface due to the coarseness of the NPAG cover material. However, it was noted during the site visit that the soapstone is fairly friable and will be expected to break down during placement and from weathering, resulting in reduced permeability at the cover system surface. It was also noted that an ice layer tends to form at the surface of the cover system from wind-packed snow filling voids at surface. The combination of a compacted weathered surface with a surficial ice layer is expected to lead to increased runoff during the early stages of spring thaw.

The SPA modelling produced an estimated annual water balance for each modelling scenario. No significant difference was found for the water balance between the 2 m and 4 m cover systems. Figure 3.1 shows the estimated water balances from the SPA models for the RCP4.5 and RCP6 climate scenarios. Although the precipitation patterns differ between RCP4.5 and RCP6, their overall annual water balances are similar since the annual total precipitation estimates are similar. The additional systemic energy available in the RCP6 scenario as potential evaporation (PE) does not influence the overall water balance since the system doesn't have any additional water available for removal by evaporation.

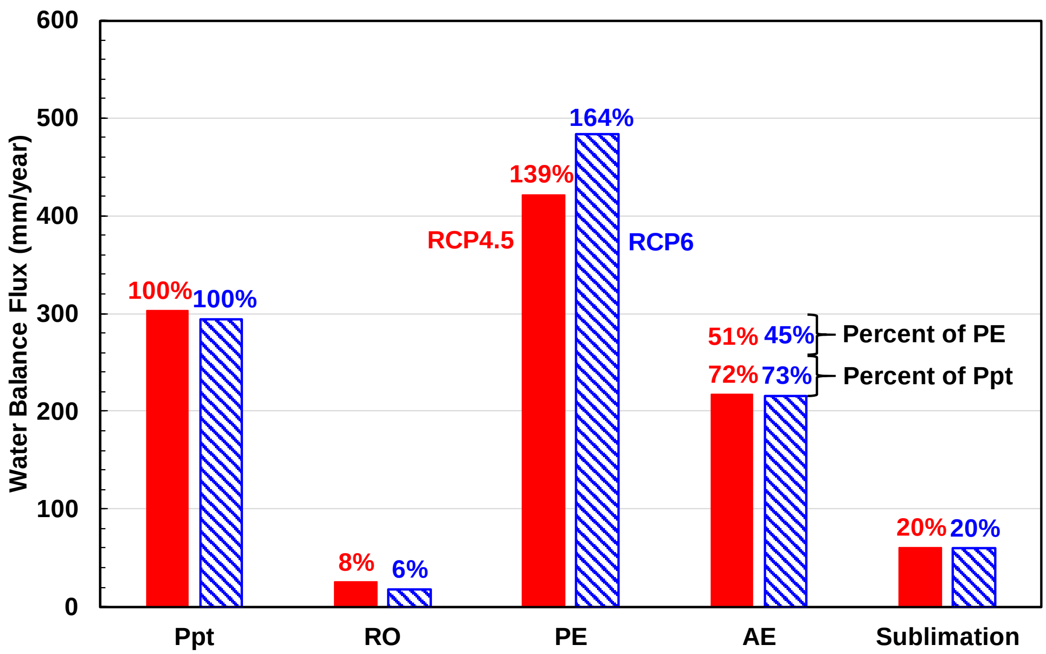

Figure 3.1: Water balance results from 1D SPA simulations with RCP4.5 and RCP6 climate scenarios. Percentages shown indicate percentage of precipitation unless otherwise marked.

Although the overall water balance does not show any net infiltration, the cover system displays large seasonal water fluxes. Figure 3.2 shows a typical cumulative infiltration for a year, with water being added to the cover system during September and October when precipitation rates are higher than potential evaporation. This added water is then stored as ice within the cover system through the winter months and ultimately removed via evaporation during the drier months following spring melt. The initial estimate for the cover system water balance assumed increased surface infiltration rates during the spring thaw period due to snow melt infiltration. Modelling disproved this assumption, historical data showing limited winter precipitation and modelling showing most of the winter precipitation removed from the cover system by sublimation and spring runoff. Historically, there is more precipitation during September and October than from November to April, inclusive.

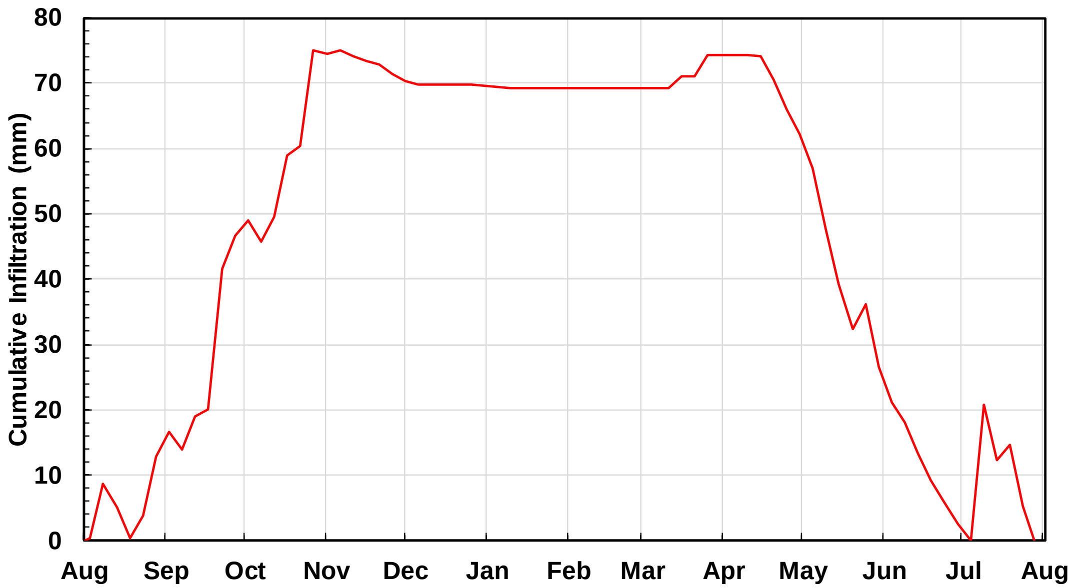

Figure 3.2: Cumulative infiltration for a typical year (Year 78 of 150 for the RCP4.5 scenario)

Although the SPA modelling software selected for this project (VADOSE/W) is capable of estimating material temperature conditions, the more sophisticated sister program TEMP/W was used to estimate permafrost formation as it is more appropriate for thermal modelling. Additionally, a SPA model would bring unwanted complexity to the two-dimensional seepage analysis. Hence, 2D models for seepage and permafrost formation were completed by coupling SEEP/W and TEMP/W simulations while using the initial VADOSE/W results to inform on the boundary and initial conditions.

3.5 Thermal and Seepage Modelling

Coupled thermal and seepage numerical modelling was carried out to estimate the performance of the permafrost encapsulation cover system design. Numerical models were carried out in both one and two-dimensions. The 2D numerical model utilized a cross section profile of the entire North and South TSF, as well as the eventual pit lake, in order to accurately estimate the subsurface thermal and flow regimes. To develop reasonable lower boundary conditions for the 2D models, deep 1D models were completed first. Complete details of the numerical models are provided in Appendix D.

3.5.1 1D Modelling

One key result available from the numerical modelling work is the predicted temperature of the subsurface zone through the timeline modelled. Although the temperature of a given area is provided by the numerical model; uncertainty exists in the assessment of what the temperature values mean with regards to the phase of pore water. Since both the tailings' pore water and the brackish groundwater display elevated salinity content, freezing point depression is likely in the subsurface. Taking this phenomena into account and to provide a factor of safety, any temperature between 0°C and -2°C was considered as a potentially unfrozen zone. However, the agreed cover design objectives were such that the cover system is considered to meet performance objectives if the degree of saturation of the tailings material remains above 85% when the tailings temperature is above the freezing point. The state of saturation is sufficient to effectively minimize oxygen ingress. The cover design objectives were presented in OKC External Memorandum – Design Basis, Closure Objectives and Design Criteria for TSF North Cell Cover Design (2014) found in Appendix B. The design objectives stated that the cover should maintain the tailings at either a temperature <0°C or a degree of saturation >85%.

Figure 3.3 shows the temperature of the tailings material in proximity to the cover system – tailings interface for the 2 m cover system under the RCP6 climate scenario. The data shows that the tailings just below the cover system interface are seasonally above 0°C for some of the modelled years and always seasonally above -2°C. However, the temperature remains below 0°C 20 cm below the interface and beyond. Investigating the degree of saturation of the material at the cover system – tailings interface, it is shown to remain over 85% for all but the initial 5-10 years of the simulation period (Figure 3.4).

The landform design presented in Section 4 shows that most of the TSF's surface area is expected to have a cover system thicker than 2 m. It is anticipated that, although minor thawing will occur for the upper portion of the tailings mass within the limited regions of the TSF surface with a cover thickness of 2 m, the cover system will still effectively minimize oxygen ingress due to the high saturation of the tailings. The cover system is therefore expected to effectively limit oxidation of the tailings under those conditions.

Figure 3.5 shows the temperature at the cover system – tailings interface under a 4 m cover system. Temperatures at the interface are usually below -2°C, and always below 0°C, for the entire 150-year simulation period, even under the climate conditions of the RCP6 scenario. The landform presented in Section 4 shows a cover thickness above 4 m for over 50% of the TSF surface area, increasing the confidence in the capacity of the designed cover system to limit oxidation and contaminant release.

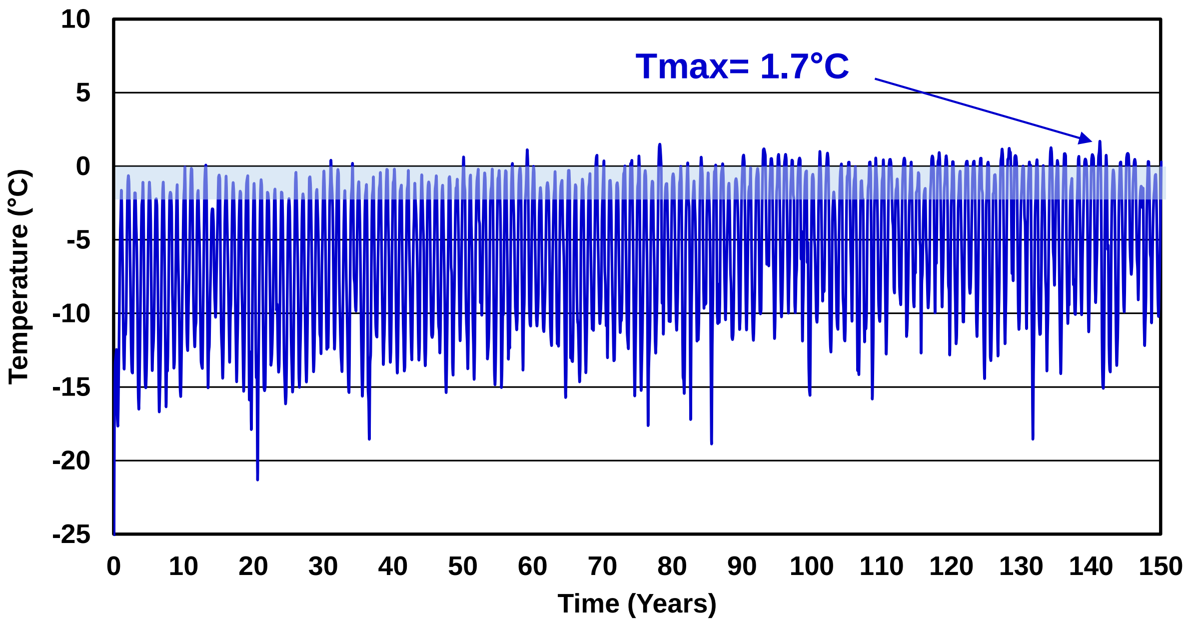

Figure 3.3: North Cell TSF tailings temperature at cover system – tailings interface, 2 m cover system, for RCP6 climate change scenario.

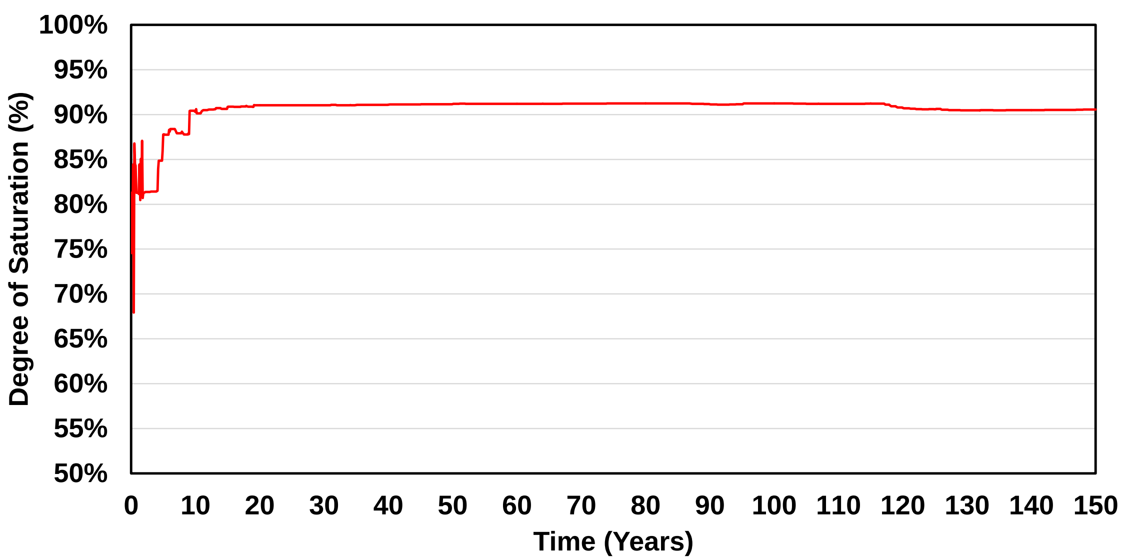

Figure 3.4: North Cell TSF tailings degree of saturation at cover system – tailings interface, 2 m cover system, RCP6.

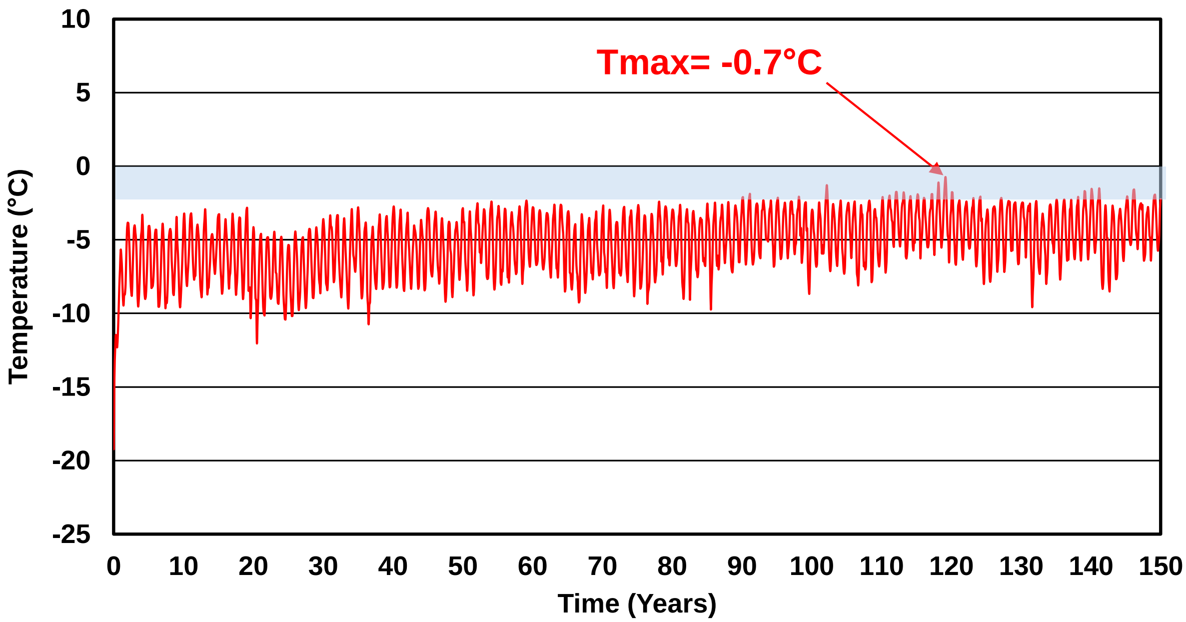

Figure 3.5: North Cell TSF tailings temperature at cover system – tailings interface, 4 m cover system, RCP6.

3.5.2 2D modelling

In order to provide a realistic cross-section profile for the development of the two-dimensional seepage and temperature model, it was assumed that a NPAG cover would be placed on the South Cell of the TSF, as per the base case TSF closure design. Any change to either the geometry or the cover system placed on the South Cell TSF would impact the freezing depth under the North Cell TSF as predicted by the numerical model results presented in this report. In particular, should a water cover be placed on the South Cell instead of a NPAG cover, this layer would be expected to behave as an energy source, and delay or prevent the long-term freeze-back of the talik underlying both the North Cell and South Cell TSF. The inclusion of the South Cell TSF to the 2D model also allowed the incorporation of the pit lake, providing a substantial source of energy to the system.

Figure 3.6 shows the initial temperature profile in the modelled 2D cross-section for the coupled thermal-seepage numerical model for the 4 m cover under climate scenario RCP4.5. Initial conditions were similar for the other 3 scenarios modelled.

Figure 3.7 shows the temperature profile for the final year of the 150-year simulation for the 2 m cover under climate scenario RCP6, i.e. the “worst case“ modelled.

There are several differences in the modelling results between the 2D coupled temperature/seepage models and the 1D models, the main difference being the reduced freezing depth at the end of the 150-year simulation period for the 2D model. While the 1D model results show a freezing depth (at

-2°C) of 75 m in the 1D model, it is reduced to 50 m in the 2D model. This is a direct result of the inclusion of the pit lake thermal boundary condition in the 2D model cross-section profile. The pit lake represents a continuous source of energy not accounted for in the 1D model. This energy source maintains a temperature condition above the freezing point in the subsurface, allowing water to continue seeping through the talik at this location, delivering energy to further points in the profile. This heat will radiate outwards until equilibrium is met.

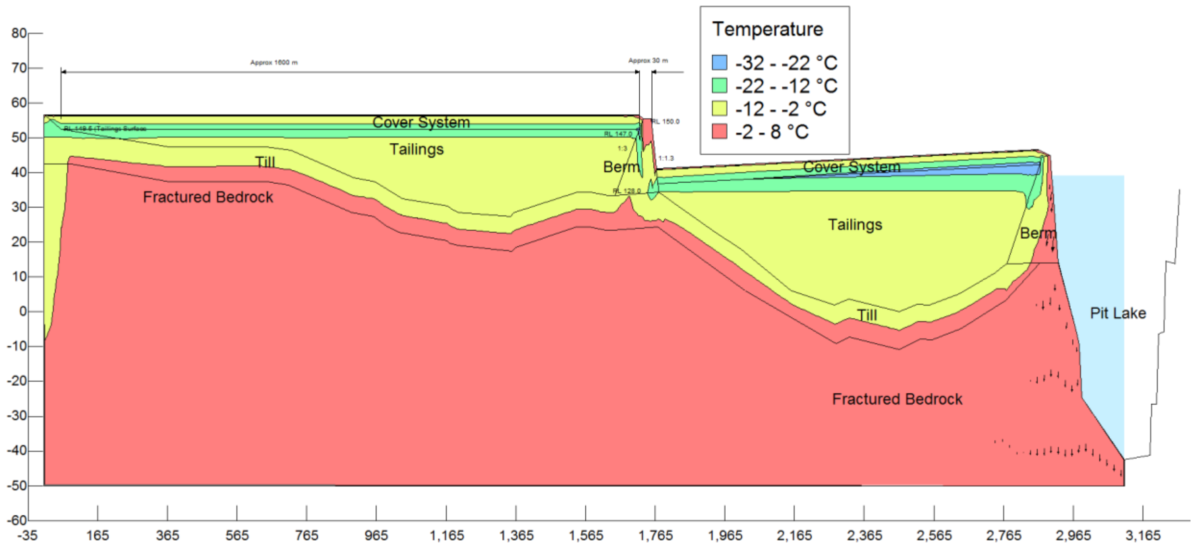

Figure 3.6: Temperature profile in TSF at beginning of model time, RCP4.5, for a 4 m cover system.

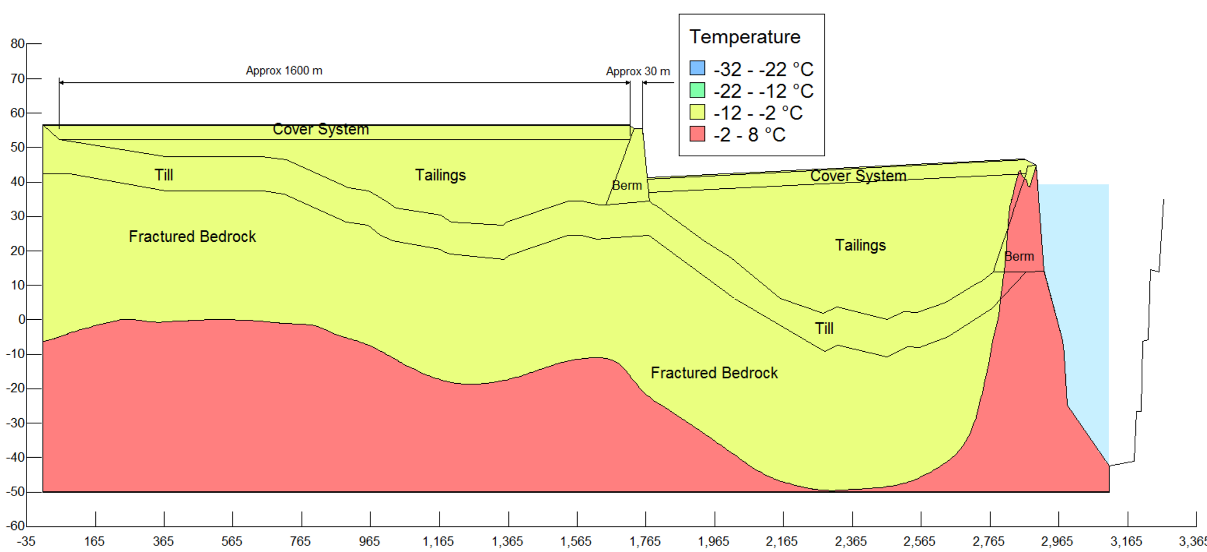

Figure 3.7: Temperature profile in TSF at end of model time for 2 m cover system (150 years), RCP6.0

Although the 2D modelling results for the coupled seepage – temperature models differs from the 1D model for the temperature profiles at depth, temperatures at the tailings – cover interface are similar for both approaches. The tailings – cover system interface results showed increased occurrences of temperatures rising above -2°C for the RCP6 and 2 m cover when compared to the model run under the RCP4.5 database with a 4 m cover. However, the conclusion from the 2D modelling approach remains the same as from the 1D approach, that the 2 m cover system is appropriate in meeting the performance criteria for the cover design.

3.6 Convective Airflow Numerical Model

The convective airflow model using modified geometry was run for a period of 150 years using the RCP4.5 climate database. Assuming the same initial temperature conditions as modelled in the thermal/seepage modelling, the airflow rates through the cover system and resultant temperatures within the buried tailings were calculated.

Due to the presence of a layer of crushed soapstone resulting from construction at the surface, airflow rates through the cover system were minimal. The peak airflow rate was calculated to be approximately 0.01 m/day on a unit basis. This equates to 0.01 m^3/m^2/day. This airflow rate is not substantial enough to result in temperature changes of the tailings at the cover system – tailings interface, as shown by the temperature profiles as a function of time in Figure 3.8 and Figure 3.9. Figure 3.8 shows the temperature profile of the interface with the presence of convective airflow, while Figure 3.9 shows the temperature of the interface without any airflow in the system.

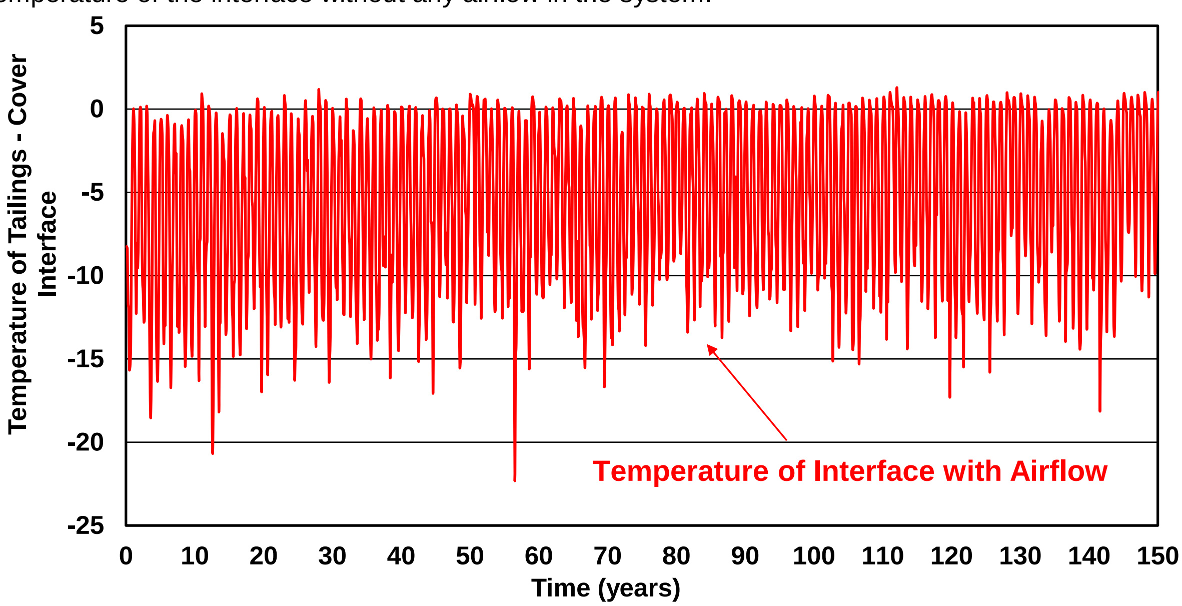

Figure 3.8: Time dependant temperature of cover system-tailings interface using RCP4.5 climate change scenario with airflow occurring in system for 4 m cover system.

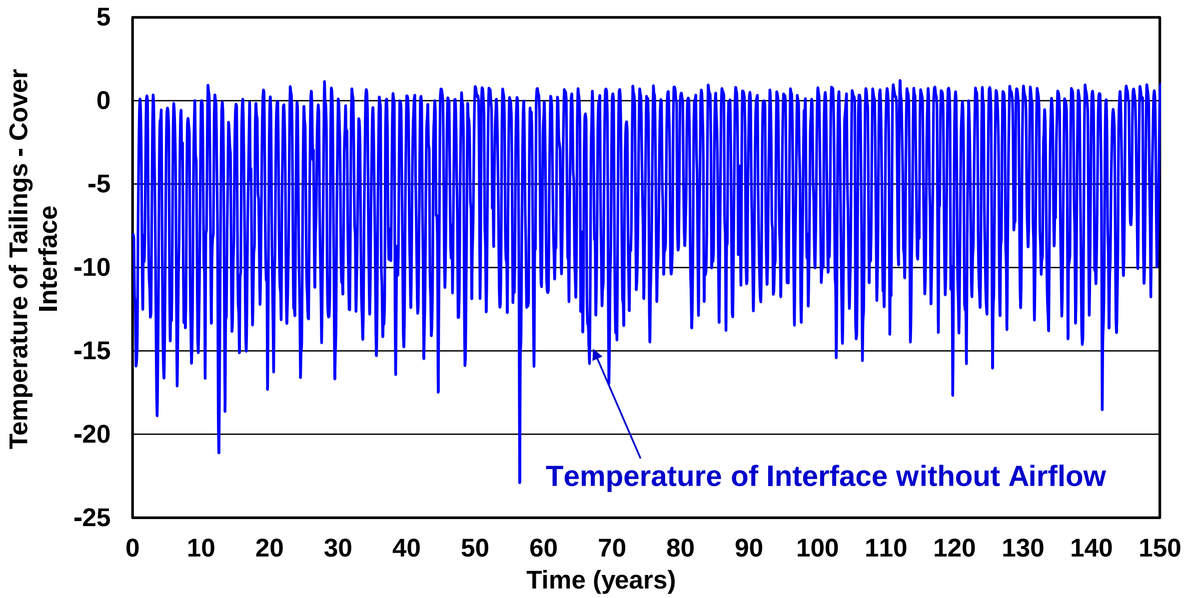

Figure 3.9: Time dependant temperature of cover system-tailings interface using RCP4.5 climate change scenario with zero airflow occurring in system for 4 m cover system.

Comparing Figure 3.8 and Figure 3.9 shows that the temperature profiles are almost identical, indicating that the small airflow rates determined by the numerical model in this idealized geometry were not substantial enough to cause changes in the tailings temperature. The effect of airflow through the cover system would be even more reduced in the presence of frozen water occupying the voids of the cover system, and thus preventing airflow.

Based on the results of this idealized model, it is predicted that airflow rates through the cover system on a large scale in the field will not be substantial enough to affect cover performance. This conclusion was drawn from the fact that the numerical modelling carried out herein used a geometry that was ideal for convective airflow to occur, and even under these conditions, there was no observable result on internal TSF temperatures.

4 FINAL LANDFORM DESIGN

This section provides details on the design of a final landform for the North Cell TSF as presented in the construction drawings provided in Appendix A. Design objectives and criteria are outlined first, followed by the conceptual landform, earthworks design, tailings deposition, consolidation analysis of the tailings material, and the proposed final landform design.

4.1 Design Objectives and Criteria

The design objectives for re-contouring the North Cell TSF are to facilitate construction of the preferred cover system and ensure long-term slope stability from a geotechnical and soil erosion perspective. The primary purpose of placing a cover system on the North Cell TSF is to mitigate long-term environmental effects due to runoff, seepage, erosion, or direct contact with the waste. Closure objectives and design criteria for the TSF were presented in a memorandum found in Appendix B. Closure objectives specific to the landform design of the Meadowbank tailings storage facility are:

- Stabilize slopes surrounding the tailings impoundment or containment system for flooded and/or dewatered conditions;
- Minimize catastrophic and/or chronic release of the tailings or contaminated water to the environment;
- Minimize wind migration of tailings dust; and
- Minimize the threat that the impoundment becomes a source of contamination.

From the determined closure objectives and from discussions with AEM personnel, design criteria for the closure of the North Cell of the TSF were developed. The following design criteria were considered in developing a final grading plan for the North Cell TSF:

- Surface Water Management
    - Surface runoff from precipitation and spring freshet shall be shed off the TSF surface through specified runoff outlets.
    - The minimal slope of drainage channels should be 0.5%.
    - Surface water will be contained within the facility for quality testing before release to either the environment or an agreed-upon water management structure for further treatment as required.
- Water Quality
    - All surface water from the closed facility is to meet CCME water quality criteria (2007).

- Dust Contamination
  - Following closure of the facility and completion of the cover construction, dust emissions from the TSF will be under applicable standards.
- Traditional Uses
  - The closed TSF should not hinder caribou migration in the area.

4.2 Conceptual Landform

The climate at Meadowbank presents a mean annual air temperature (MAAT) that encourages the development of continuous permafrost, and as such, can be utilized in the cover system design. A cover system designed to promote surface water shedding and frost penetration will ensure that permafrost aggradation within the cover system is maximized.

To take advantage of the MAAT at Meadowbank, a coarse material consisting of NPAG waste rock should be used for the cover system. A coarse cover material will ensure cold air can penetrate into the stored tailings, while having a sufficiently high permeability to ensure free water can be shed from the TSF. Due to the large area covered by the TSF, two individual landforms will be incorporated into the overall landform design such that the TSF is divided into two smaller catchments with individual surface runoff outlets. This design allows for surface water to be shed over a shorter distance, thus minimizing contact time with the frozen layers of the stored tailings. This latter aspect is a key design philosophy as water that is allowed to pond at the surface stores heat, and thus, has the potential to degrade the subsurface permafrost. As such, it is essential that ponding at the surface of the cover system is minimized, and the free water is removed quickly from the system.

The surface landform design will direct overland flow around the TSF using already in-place diversion ditches (the western and northern diversion ditches) and the South Cell of the TSF. Any precipitation that lands on the TSF will be directed towards central channels in each catchment, and redirected off the TSF to areas as allowed by regulatory bodies and mine permits. Surface water will be free of contaminants as it is simply precipitation run-off and will not have contact with underlying tailings.

4.2.1 Design Parameters

The main design parameters considered while developing the landform design were:

- Tailings deposition in the North Cell up to a maximum elevation of 150 masl;
- Tailings deposition in the South Cell up to an elevation of 137.2 masl;
- Tailings deposition leads to a natural 0.5% slope of the tailings surface;
- Thermal cover consisting of NPAG rock placed over both the North and South Cells with a minimal thickness of 2.0 m;

- Minimal slope of 1% grade towards the runoff drains for the final surface;
- Minimal grade of 0.5% for the invert of the runoff drains; and
- Tailings deposition conducted according to the latest tailings deposition plan (As-built NC_contours 0.25m.dwg), taking into account the requirements of the cover construction and thus maximizing tailings deposition in areas with thicker cover requirements.

These design parameters were used as a starting point to develop the landform design for closure of the North Cell TSF.

4.2.2 Options Considered

Due to the large surface area of the TSF, developing a landform allowing for efficient shedding of precipitation presents some challenges. Several options were studied to develop a landform that would efficiently move meteoric water away from the landform while minimizing earthworks required to build the landform, both in terms of tailings material excavation and volume of cover material required. The different options varied mostly based on the number of surface runoff outlets and their location. Landforms with one, two, and three runoff outlets were considered with the two-outlet option being preferred. This option was chosen as it presents a balance between minimizing the total volume of cover material required and the volume of tailings removal required at the outlets to maintain the minimal cover thickness, based on the expected final tailings surface. The runoff outlet locations were selected based on the tailings surface, the presence of major infrastructure, and potential synergies with existing water management infrastructure. Although positioning a runoff outlet at the lowest portion of the current tailings surface would reduce the required tailings material excavation volumes, this would require building the outlet through the highest portion of the stormwater dike. Positioning an outlet in this portion of the engineered dike could pose a risk to the integrity of the dike, it was therefore decided to re-position the outlet further West, in a shallower portion of the structure; while also taking advantage of an existing ramp to minimize earthworks required.

4.3 Earthworks Design

AutoDesk's AutoCAD Civil 3D 2014 was used to develop a final landform design for the North Cell TSF. AutoCAD Civil 3D, which is widely used in earthworks design, uses survey data to create a digital terrain model (DTM) of an existing landform. This software allows the user to create new landform designs based on the existing DTM and specified design criteria and constraints. New landform DTM designs are then compared to the existing landform DTM for calculating cut and fill material volumes.

A plan view of the current tailings surface is provided in DRG 948-1-001. The tailings surface was provided by AEM and was collected using a scan of the surface and tailings deposition modelling for upcoming deposition in the facility. In order to maintain the minimum 2 m cover thickness and follow the design parameters presented in Section 4.2.1, excavation of tailings material will be required in specific areas of the facility, mainly close to the surface runoff outlets locations. DRG 948-1-003 presents the Tailings Material Excavation plan with the required depths of excavation. A total of 93,300 m^3 of tailings will need to be excavated, transported and deposited to areas of the TSF showing thicker required cover thickness. It is expected that tailings excavation will be performed by drill and blast methods during the winter months to allow equipment access. A digital terrain model (DTM) surface of the final tailings elevation prior to cover placement will be provided to AEM.

A plan view showing the final cover thickness for the entire North Cell TSF is provided in DRG 948-1-004. Cover thickness varies from 2 m for the thinner sections in proximity to the surface runoff outlets to 8 m in some sections at the top of the internal drainage system. The total volume of cover material required to complete the cover system and landform is 6,376,000 m^3. A digital terrain model (DTM) surface of the final cover elevation will be provided to AEM.

The final landform design was developed based on the design objectives and criteria outlined in Section 4.1. A large number of iterations of the landform design were required to balance the requirements for tailings excavation while aiming to minimize the overall volume of cover material required for landform construction.

4.4 Tailings Deposition

Future mine operations can be optimized such that tailings deposition can be used to assist in building of the final landform and assist surface water runoff, while minimizing the total volume of NPAG waste rock required to construct the cover system and landform. Observed sub-aerial tailings deposition leads to a 0.5% deposited tailings slope. Due to the large surface area, any minimal slope gained by tailings placement will have large effects on the overall NPAG material requirements. It is OKC's understanding that following AEM's review of the preliminary landform design, AEM proceeded to optimize tailings deposition planning in order to minimize the required tailings excavation as well as the required cover system material volume. OKC was provided with the latest tailings deposition plan for upcoming and final tailings deposition in the North Cell TSF. This final surface was used for all volume calculations and final landform design.

4.5 Consolidation Analysis

The tailings are deposited in the TSF in a saturated state. This initial tailings saturation condition presents a high probability for consolidation (expulsion of pore water) to occur over time. As the tailings consolidate due to gravity, there is potential for differential settlement to occur that may result in degradation of the landform cover system, eliminating the benefits of the water shedding capabilities incorporated into the landform design. However, this effect may be mitigated due to the presence of permafrost, as the tailings are likely to be completely frozen, resulting in a tailings mass which is less likely to suffer from differential settlement.

Based on the results of the thermal and seepage numerical modelling, if the tailings are initially in a frozen state at the point of deposition, it is likely that they will remain frozen based on the assumed geometry and boundary conditions implemented in the numerical model. However, since the numerical model was only implemented in a 2D cross section at the deepest point of the TSF, there are likely to be variations. These variations may occur at the edges of the TSF where the cover system profile may be thinner, or the subsurface conditions may differ. As such, a consolidation assessment was carried out by OKC to determine the potential impacts of differential settlement and freezing on the tailings and landform cover system.

4.5.1 Key Consolidation Material Properties

Table 4.1 lists the material properties used for the tailings settlement and consolidation rate calculations while Table 4.2 lists key parameters. A tailings thickness of 4 m and cover thickness of 4 m was considered for worst case scenario taken at the proposed highest setting of the TSF, where the thickest cover is required for surface water management. Material properties were derived from previous work completed on the tailings and cover materials by Golder Associates Ltd. (2008). It was assumed that both material were fully saturated.

Table 4.1: Key Inputs for Tailings Consolidation Analysis

Property	Materials	
	Cover System	**Tailings**
Dry Density (t/m^3)	2.15	1.31
Specific Gravity	3.2	3
Unit Weight (kN/m^3)	24.3	18.4
Void Ratio	0.49	1.29
Porosity (%)	33	56
Saturation	1	1
Hydraulic Conductivity (cm/s)	1.00	5.00E-05
Thickness (m)	4	4

Appendix E

Table 4.2: Key Parameters for the Tailings Consolidation Analysis

Parameters	
Compression Index (Cc)	0.277
Secondary Compression Index (Ca)	0.00160
Coefficient of volume compressibility (mv)	0.00175
Coefficient of consolidation (Cv)	1.55E-05
Time factor for 90% degree of consolidation (Tv)	0.85

Appendix E

4.5.2 Key Results of Consolidation Analysis

The modelled relationship showed that a primary consolidation of approximately 0.4 m is achieved following construction of a 4 m thick cover system. Figure 4.1 presents the relationship between the primary consolidation and cover thickness.

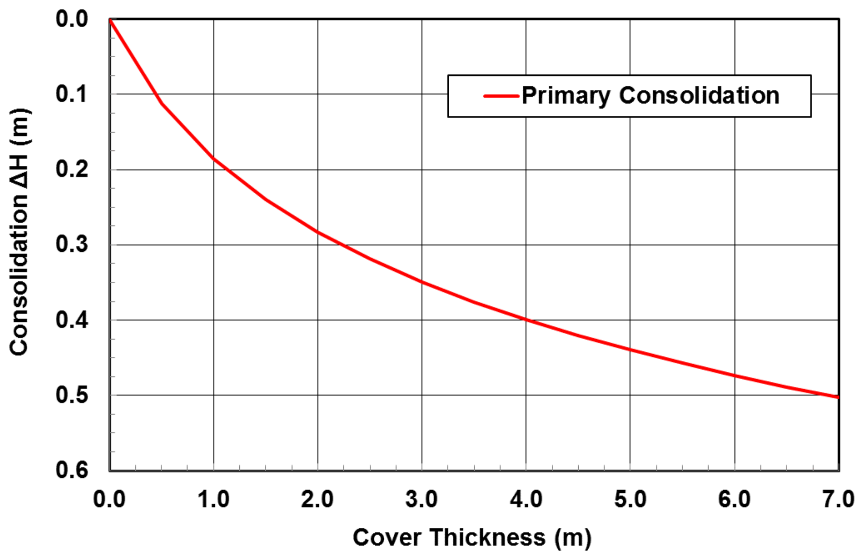

Figure 4.1: Primary Consolidation vs. Cover Thickness

The results indicate that a 4 m thick mass of tailings would consolidate to a 90% degree of consolidation in approximately 10 days. During this time, primary consolidation of the tailings would be approaching completion with a final change in height of approximately 0.4 m. Long-term consolidation, also known as creep, then commences. A secondary settlement of approximately 1 cm was calculated over a period of 100 years following completion of primary consolidation. Figure 4.2 presents the time-dependent long-term consolidation which occurred over a long period of time in response to the placement of the cover system.

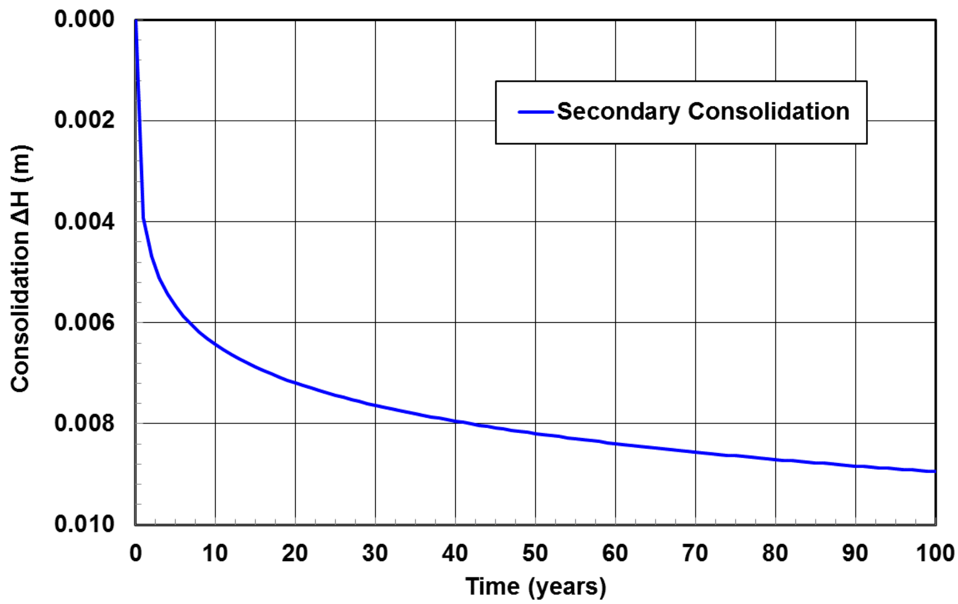

Figure 4.2: Secondary Consolidation (settlement rate for 100 years)

As the primary consolidation would occur over a short time period of 10 days, and only within the thawed portion of the tailings, and that long-term secondary consolidation is minor, consolidation of the tailings mass is not expected to cause long-term issues for the integrity of the landform. Any short term settlement can be addressed as part of regular monitoring and maintenance of the facilities during and shortly after construction.

4.6 Final Design Details

This section refers to Drawings found in Appendix A of this document. DRG 948-1-001 presents the existing features and tailings surface of the TSF North Cell. DRG 948-1-002 shows the general arrangement plan of the final landform and contains references to further detailed drawings found in Appendix A. The main features of the landform include:

- Minimum cover of 2 m of NPAG material over the tailings material;
- Minimum cover slope of 1% towards the runoff drains;
- Minimum slope of 0.5% of the runoff drains towards the runoff outlets;
- Two runoff outlets, Outlet #1 and Outlet #2;
- Excavation of 93,000 m^3 of tailings required; and
- Total volume of cover system material required is 6,376,000 m^3.

The minimum cover thickness was determined from completed numerical modelling (presented in Section 3 of this report). The minimum grades for the side slopes and the runoff drains were selected to ensure gravitational flow of surface runoff towards the outlets to avoid ponding.

The runoff drain system comprising of several linear surface channels was developed to minimize the volume of cover material required. Runoff drains 1a, 1b, and 1c report to Outlet#1, while runoff drains 2a, 2b, 2c, 2d, and 2e report to Outlet #2. All runoff drains located within the landform have similar profiles (see Section 5 of this report for details). DRG 948-1-010 to -017 and 948-1-020 show the elevation profile of the drains as well as their cross-section.

The outlets are positioned in areas where tailings are at a lower elevation to take advantage of gravitational flow. Outlet #1 (see DRG 948-1-002, Appendix A) is positioned over the stormwater dike and surface runoff will be directed towards the South Cell of the TSF. Outlet #2 is positioned on the north-west portion of the TSF and surface runoff will be directed towards the existing Western Diversion ditch, within the collection sump in that area. Surface runoff outlets were also positioned to minimize the required tailings excavation. In order to maintain the selected slope and runoff drains' grades, while keeping the volume of cover material within reason, different scenarios were evaluated with regards to the elevation of the final surface, which impacts both the volume of tailings excavation required and the volume of cover material required for construction.

Drawings DRG 948-1-010 to DRG 948-1-017 show the plans for all individual drains, including plan and elevation views as well as typical cross sections of the drain detail.

5 SURFACE WATER MANAGEMENT SYSTEM

The surface water management system has been developed for the North Cell TSF landform considering the effects of spring snowmelt and rainfall event runoff waters on the North Cell TSF. The primary components of the TSF final landform surface water management system include plateau drainage channels on the TSF as well as outlet channels to convey runoff waters to temporary sedimentation ponds and perimeter diversion ditches.

The design of an engineered surface water management system for the reclaimed TSF is detailed in this section. Design objectives and criteria are outlined first followed by design work details for a surface water management system design. More information on the design work for the surface water management system is found in Appendix F.

Drawings DRG 948-1-010 to 948-1-017 present the plan for each drain section. Drawings DRG 948-1-020 and 948-1-021 present typical cross sections of the drains and outlets as well as details of the drain connections.

5.1 Design Objectives and Criteria

The design objectives of the surface water management plan for the reclaimed TSF are twofold: to minimize erosion to reduce the suspended sediment loading to the receiving environment, and to safely convey runoff waters off the facility for the design storm event.

The following design criteria were proposed for development of a surface water management system for the reclaimed TSF:

- Use the 1 in 100 year design storm event to calculate peak design flows; and
- Incorporate robustness / conservatism into the design to account for increased precipitation due to potential effects of climate change.

5.1.1 Intensity-Duration-Frequency Storm Data

Precipitation data are used by Environment Canada to develop intensity-duration-frequency (IDF) tables. Information contained in an IDF table is generated from an extreme value statistical analysis of at least 10 years of rate-of-rainfall observations. IDF data can be used for sizing and design of hydraulic structures such as drainage channels and culverts.

Environment Canada developed IDF curves for the Baker Lake A meteorological station based on data measured between 1987 and 2006. These curves are assumed to be representative of short-duration precipitation conditions at Meadowbank. The 24-hour, 1 in 100 year design storm event has an intensity of about 3.1 mm/hr, which equates to 74.7 mm over a 24-hour period. To be conservative, it should be assumed that the design storm event occurs during the snowpack melt period, which means adding an additional volume of water to the design rainfall event to account for snowmelt runoff waters. The 24-hour snowmelt corresponding to the average year spring-melt is 126 mm over 30 days for Meadowbank (Golder, 2012). Therefore, a total accumulation of 78.9 mm was calculated for the 24-hour, 1 in 100 year design storm event.

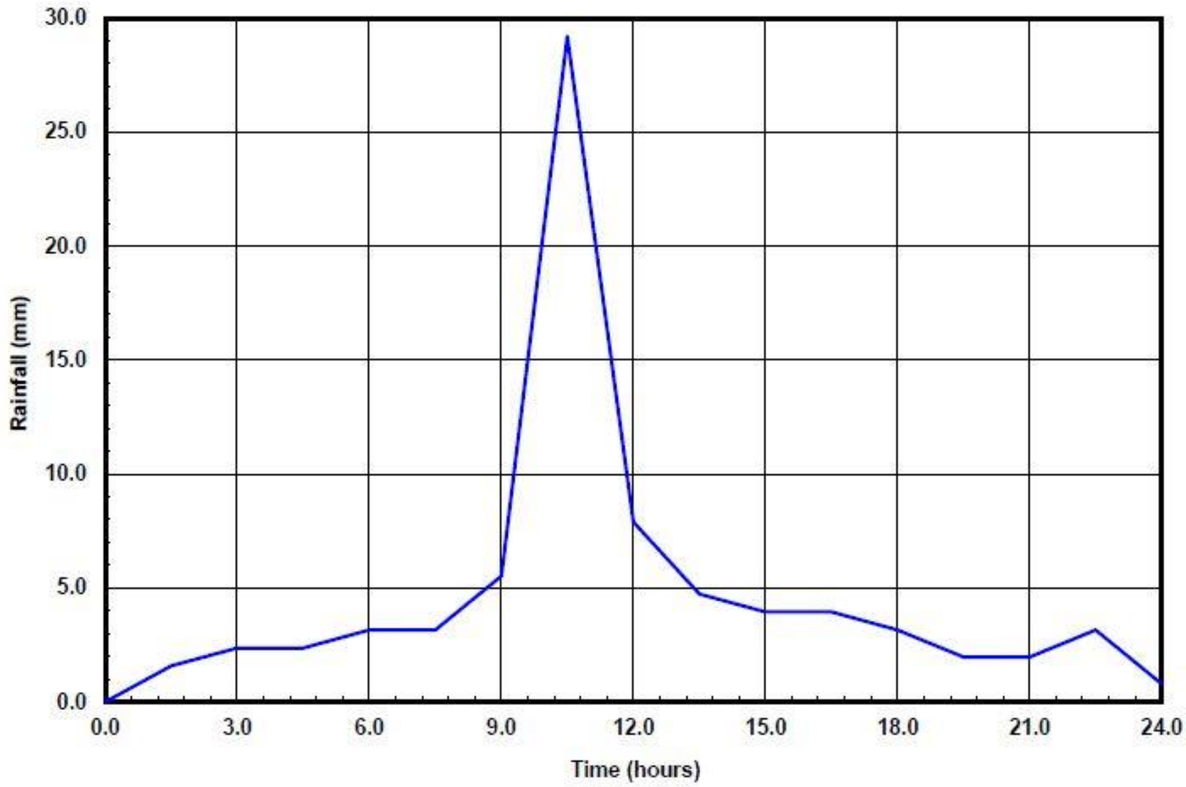

Figure 5.1: Distribution for the 24-hour 100-year design storm event (SCS Type I).

5.2 Design Work

5.2.1 Design Storm Peak Flow Calculation

The Soil Conservation Services (SCS) method was selected for calculating the peak flow from the design storm event for appropriately sizing and lining drainage channels planned for the reclaimed TSF.

Technical Release 55 (TR-55), a model based on the SCS method was used for calculating the design storm peak flow for the proposed catchments on the reclaimed TSF. Catchment areas are shown on drawing DRG 948-1-040. The TR-55 model begins with a rainfall amount uniformly imposed on the watershed with a specified time distribution. Mass of rainfall is converted to mass of runoff by using a runoff curve number (CN). A Type I temporal distribution was selected for calculation of catchment peak flows for the design event.

Each catchment proposed for the reclaimed waste pile was simulated in the TR-55 model. The geometries of the catchments input to the model are based on the proposed final grading design shown in DRG 948-1-002. The peak flow calculated for the outlet of each catchment was used as the design basis for sizing and lining each drainage channel.

Design storm peak flows were calculated assuming a frozen ground condition. A CN value of 93, which corresponds to a runoff/rainfall ratio of 70%, was selected to reasonably represent a frozen rock cover. Table 5.1 shows the design storm peak flows calculated by the TR-55 model for each catchment of the reclaimed TSF, while Table 5.2 presents peak flows for the various plateau and outlet channels.

Table 5.1: Design storm event peak flows for the TSF closure landform catchments.

Drainage Area (DRG 948-1-040)	**Area (ha)**	**Peak Flows (m^3/s) (CN=93, Type I storm)**
1a	9.42	1.04
1b	40.65	3.93
1c	24.45	2.72
2a	13.55	1.67
2b	18.65	1.94
2c	15.36	1.76
2d	12.63	1.44
2e	10.08	1.10
3	7.60	0.95
4	5.07	0.64
5	1.25	0.16

Table 5.2: Design storm event peak flows for the TSF plateau and outlet drainage channels.

Drainage Channel (DRG 948-1-002)	Contributing Areas (DRG 948-1-040)	Peak Flow (m^3/s)	Gradient (Flat <5% < Steep)
1a	1A, 1b, 1c, 3, 4	9.28	Flat
1b	1b, 4	4.57	Flat
1c	1c, 3	3.67	Flat
2a	2a	1.67	Flat
2b	2b, 2c, 2d, 2e	6.24	Flat
2c	2c	1.76	Flat
2d	2d	1.44	Flat
2e	2e, 5	1.26	Flat
Outlet #1	1a, 1b, 1c, 3, 4	9.28	Steep
Outlet #2	2a, 2b, 2c, 2d, 2e, 5	8.07	Flat

Appendix F

5.2.2 Drainage Channel Design Calculations

Drainage channels proposed for the TSF final landform were designed based on the tractive force method as documented in Smith (1995). In principle, the method is used to evaluate the adequacy of a designed channel from comparison of the shear stress generated by the flow to the shear resistance of the channel lining material. That is, the shear resistance of the lining material (grass, gravel, riprap, etc.) must be greater than the shear stress generated by the flow to produce a stable channel. In the case of a steep channel, it is necessary to modify the basic tractive force theory concept to also include the destabilizing influence of gravity on the stone material. Inclusion of the effect of gravity on stone stability was addressed using a procedure for the design of steep channels as outlined in Smith (1995). Spreadsheets were developed by OKC that allow the user to calculate the maximum allowable flow in a channel based on Manning’s equation for various channel geometries and linings, and evaluates the hydraulic condition (i.e. stability) of the channel flow based on the Froude number.

Table 5.3 presents the minimum dimensions and linings for the various drainage channels to safely convey the design storm peak flow for each catchment. An effort was made to minimize the number of different channel widths and riprap sizes for ease of construction. Two different sizes of riprap are needed to adequately protect the plateau and outlet drainage channels during the design storm event. A median stone diameter (D50) of 75 mm (Stone Type A) is adequate to line all of the plateau drainage channels. A much larger size riprap is required to adequately armour the outlet drainage channels given the relatively high flow rates and steeper slopes. It should be noted that only Outlet #1 requires the larger Stone Type B riprap. Outlet #2 is relatively flat and the peak flow remains within the limits to use Stone Type A as riprap within the confines of the TSF. The channel downstream of Outlet #2, from its steeper profile and increased catchment area, may require armouring. It is OKC’s understanding following communications with AEM that this channel was blasted through bedrock. All channel flows within the TSF footprint are hydraulically stable based on the calculated Froude number.

Filter layers are typically required beneath coarser riprap materials to prevent foundation material from being washed out or sucked through voids in the riprap layer. A natural granular material or a nonwoven, needle-punched geotextile can be used for this application. Given the planned waste rock cover for the TSF, it is presumed that a filter layer will not be required for plateau drainage channels. A filter layer will be required for beneath the riprap layer of the outlet drainage channels (DRG 948-1-021, Section 13). This filter layer will consist of bedding sand or other suitable material underlying a needle-punched geotextile, with a layer of Stone Type A material acting as protection under the Stone Type B material on the surface.

Outlet #1 flows into the South Cell TSF where runoff water quality will be monitored until quality standards are met and surface runoff can be discharged to the effluent. Outlet #2 flows into a collection sump within the Western Diversion ditch. Water quality will be monitored within this sump before discharge to the effluent. Should water quality not meet regulatory standards, it is to be pumped from the collection sump back to either the South Cell TSF or to the North Cell TSF if cover construction is not completed.

Table 5.3: Minimum drainage channel dimensions and linings for the proposed TSF final landform to safely convey the design storm peak flow

Parameter	**Plateau Drainage Channels**			**Outlet Drainage Channels**
	Q_p<1.8 m^3/s	Q_p<4.6 m^3/s	Q_p<9.3 m^3/s	Q_p=9.3 m^3/s
Slope of channel floor (min)	0.5%	0.5%	0.5%	20%
Width of channel bottom (m)	3.0	3.0	3.0	10
Slope of side channels (_H:1V)	3	3	3	3
Flow depth (mm)	430	700	980	240
Lining of channel	Stone	Stone	Stone	Stone
Median stone size (mm)	75	75	75	500
Channel discharge capacity (m^3/s)	1.93	4.87	9.54	9.7
Design peak flow (m^3/s)	1.8	4.6	9.3	9.3
Froude number (<0.8 or >1.2)	0.58	0.62	0.79	2.54

Appendix F

5.2.3 Estimate of Material Volumes and Gradation Specification

Based on the channel design, assuming a 20% slope grade for Outlet #1, the required total volume of Stone Type A material (D50: 75 mm) is 5,000 m^3 and 900 m^3 for Stone Type B material (D50: 500 mm). It should be noted that, from available PSD, the cover system NPAG material is suitable as riprap for the runoff drains. Therefore, cover material in place can be substituted for Stone Type A. However, Outlet #1 will require armouring with Stone Type B due to the slope grade.

A graded riprap material is preferred over a uniform material of the same median diameter as a result of greater interlocking effect between particles (giving increased shear strength) and decreased porosity (giving a better filter effect between flowing waters and base material under the stone) (Smith, 1995). Table 5.4 includes gradation limits for Stone Type A and B materials based on guidelines included in Brown and Clyde (1989), assuming that a D50 of 500 mm would be adequate for armouring the outlet drainage channels.

Table 5.4: Gradation limits for Stone Type A and B riprap materials for TSF drainage channels

Percent Finer Than	**Stone Type A**		**Stone Type B**	
	FL (mm)	CL (mm)	FL (mm)	CL (mm)
100	120	130	750	850
85	90	110	600	700
50	75	90	500	580
15	30	50	200	300

6 FAILURE MODES AND EFFECTS ANALYSIS

6.1 Purpose and Approach

A failure modes and effects analysis (FMEA) was completed by OKC on the preferred North Cell reclamation design. A FMEA is a top-down / expert-system approach to risk identification and quantification, and mitigation-measure identification and prioritization. Its value and effectiveness depends on having experts with the appropriate knowledge and experience participate in the evaluation during which failure modes are identified, risks estimated, and appropriate mitigation measures proposed. The goal is to provide a useful analysis technique that can be used to assess the potential for, or likelihood of, failure of the proposed design and effects of such failures on human health and the surrounding ecosystem. Robertson and Shaw (2006) describe the FMEA approach in greater detail.

An assessment period of 150 years was chosen for the FMEA. This matches the timeframe used in the Canadian climate change models.

The following people were involved in completion of the FMEA (referred to as the FMEA group):

- *Brian Ayres, M.Sc., P.Eng*. – Senior Geotechnical Engineer at OKC with nearly 20 years' experience in mine waste cover system and landform design;
- *Bonnie Dobchuk, M.Sc., P.Eng*. – Senior Geo-Environmental Engineer at OKC with over 12 years' experience in mine waste cover system design, monitoring, and performance evaluation (project manager and is familiar with the site);
- *Philippe Garneau, M.Sc., P.Eng*. – Senior Engineer at OKC with over 10 years' experience in mine waste cover system design, monitoring, and performance evaluation;
- *Denise Chapman, M.Sc., P.Eng*. – Senior Geo-Environmental Engineer at OKC with over 10 years' experience in mine waste cover system design, monitoring, and performance evaluation;
- *Rob Shurniak, M.Sc., P.Eng.* – Geotechnical Engineer and Lead Modeller
- *Dave Christensen, M.Sc., P.Eng.* – Senior Geotechnical Engineer
- *Todd Thompson, P.Eng.* – Geological Engineer

A total of 11 failure modes were developed for the FMEA as detailed in Appendix I. The potential failure modes encompass the key physical, chemical, and biological processes that are relevant to the site and could potentially influence the long-term integrity or performance of the North Cell TSF. Several of the failure modes include more than one effect and pathway. The FMEA group assessed the risk for each combination of failure mode and effects / pathways (21 combinations in total).

Table 6.1 shows the risk matrix used for the FMEA. The term 'risk' encompasses the concepts of both the likelihood of failure (expected frequency of failures) and the severity of the expected consequences, if such events were to occur (Robertson and Shaw, 2006). If the likelihood and consequences for a given failure mode and effect(s) results in a low risk rating, then the potential risk is broadly acceptable. If the risk rating is moderate or moderately high, then appropriate mitigation measures should be developed, which may include slight modifications to the design, post-closure monitoring, and/or post-closure maintenance. Once mitigation measures are implemented, the residual risk is considered to be 'as low as reasonably practicable' (ALARP). If the risk rating is high or critical, then the potential failure mode and effects are deemed to be intolerable, and a design modification is recommended.

Table 6.1: Risk matrix used for the FMEA

		Consequence Severity				
		Low (L)	*Minor (Mi)*	*Moderate (Mo)*	*Major (M)*	*Critical (C)*
Likelihood	*Expected (E)*	Moderate	Moderately High	High	Critical	Critical
	High (H)	Moderate	Moderate	Moderately High	High	Critical
	Moderate (M)	Low	Moderate	Moderately High	High	High
	Low (L)	Low	Low	Moderate	Moderately High	Moderately High
	Not Likely (NL)	Low	Low	Low	Moderate	Moderately High

Intolerable Region

ALARP Region

Broadly Acceptable Region

6.2 Results of Analysis

Detailed results of the FMEA completed for this study are provided in Appendix I, with a synopsis provided herein. Of the 11 combined failure modes and effects / pathways, 3 were assigned a high or critical risk rating, 6 were assigned moderately high risk rating, 9 were assigned a moderate risk rating, and 1 was assigned a low risk rating. Table 6.2 shows the failure modes and effects / pathways with those identified to have a risk rating of high or critical as well as pertinent comments and proposed mitigation measures. Provided the proposed mitigation measures or alternative measures are implemented to address the potential risks, OKC expects the proposed reclamation design for the North Cell TSF will be geotechnically stable and minimize effects on the receiving environment to acceptable levels over the long term.

Table 6.2**:** Potential failure modes identified in the FMEA requiring some form of mitigation.

Failure Mode ID	***Failure Mode Description***	***Effects and Pathways***	***Likelihood***	***Level of Confidence***	***Highest Risk Rating***	***Mitigation / Comments***
2b	Insufficient volume of NPAG material	Final design grades for TSF reclaimed landform unable to be constructed resulting in depressions / ponding leading to unfrozen layer of tailings.	M	L	H	The likelihood of occurrence of this failure mode is dependent on AEM's confidence in their site material balancing.
7	Differential settlement in cover system material	Undulations in surface resulting in ponding of w ater at surface leading to unfrozen layer of tailings.	M	H	H	During construction, a maximum lift thickness of 2 m w ill help to mitigate this. Additionally, the final landform grades allow for some slight variation from settlement.
11	Water ponding in South TSF Cell	Water ponding against SWD, resulting in subsurface thermal regime influences and detrimental effects on freezeback of tailngs and talik.	NL	L	H	Depends on likleihood of w ater cover on the South Cell.

7 PERFORMANCE MONITORING PROGRAM

Direct measurement of field performance is the state-of-the-art methodology for measuring performance of a cover system for a reclaimed TSF (MEND, 2004). This is the best method for demonstrating to all stakeholders that the cover system will perform as designed. A monitoring program should be designed to measure the various components that influence the performance of a cover system. For a full-scale cover system adequate monitoring should be implemented to capture spatial variability in thermal and moisture responses. Monitoring should also include an assessment of vegetation success and erosion (MEND, 2004). The objectives of the North Cell TSF cover performance monitoring program are provided first, followed by an overview of the various elements proposed for the monitoring program.

7.1 Monitoring Program Objectives

The objectives of the TSF North Cell cover system and landform are to (1) ensure long-term landform stability, (2) encourage TSF freeze-back into the surrounding permafrost, and (3) maintain either sub-zero temperature or high degree of saturation (>85%) in the tailings at all times. The purpose of the performance monitoring system is to ensure that these objectives are met. The objectives of the TSF North Cell cover system performance monitoring program are:

1) to monitor the temperature profile through both the tailings and the cover system to verify that the tailings beneath the cover system remain below freezing for most of the year and to verify that the tailings and talik are freezing into the surrounding permafrost;
2) to monitor the water content of the tailings below the cover system and understand the basic water content response at the base of the cover; and
3) to monitor settlement, consolidation, sediment loss and progression of erosion features on the landform.

7.2 Monitoring Program Details

Table 7.1 summarizes the proposed North Cell TSF post-closure monitoring program. OKC recommends that monitoring of thermal and moisture responses as proposed in the monitoring program are maintained for a minimum of five (5) years beyond reclamation of the North Cell TSF. Landform stability / erosion should be monitored for a minimum of ten (10) years. The proposed monitoring system is automated to the extent possible to avoid missing the collection of field response data during key times of the year (e.g. during spring snowmelt and storm events). In addition, the use of automated systems for data collection greatly reduces the need for human intervention and in particular, the demands placed on AEM personnel. Section 9.1 provides additional details for monitoring erosion and settlement.

Table 7.1: Summary of the proposed reclaimed North Cell TSF performance monitoring system.

Monitoring Component	Parameters	Sensors / Methods	Comments
Meteorology			• Use existing weather station on site for meteorology data • AEM personnel to conduct snow surveys at representative locations prior to spring melt
Monitoring Station #1 (Station 1)	• *In situ* temperature	• Geokon thermistor string (20 beads)	• Sensors controlled by a Data Acquisition System (DAS) consisting of a CR800 logger c/w 12V battery/solar panel • Thermistor string to measure temperature profile with depth through cover, tailings and into talik
Monitoring Station #2 (Station 2)	• *In situ* water content • *In situ* temperature • Water level	• CS655-L TDR sensor (x3) • PLS-L15M OTT Pressure Level Sensor (x1) • Geokon thermistor string (12 beads)	• Sensors controlled by a Data Acquisition System (DAS) consisting of a CR800 logger c/w 12V battery/solar panel • Thermistor string to measure temperature profile with depth through cover, tailings and till • CS655 to measure water content in tailings just below interface • PLS probe to measure water level (positive pore water pressures) in active zone
Monitoring Station #3 (Station 3)	• *In situ* water content • *In situ* temperature	• CS655-L TDR sensor (x3) • Geokon thermistor string (12 beads)	• Sensors controlled by a Data Acquisition System (DAS) consisting of a CR800 logger c/w 12V battery/solar panel • Thermistor string to measure temperature profile with depth through cover, tailings and till • CS655 to measure water content in tailings just below interface
Erosion and Settlement	• Erosional features and elevation change	• Erosion survey (visual/photographic) • Topographic survey	• AEM qualified personnel to conduct surveys of landform on an annual basis • Monitoring program

Appendix H

Cover system performance will vary spatially across the TSF due to differences in cover material texture and thickness, elevation of the underlying tailings surface, presence of talik and temperature of basal material. To accommodate for the variety in thermal and moisture dynamics, three (3) “monitoring stations” were strategically positioned across the TSF to develop a thorough understanding for the cover system regimes on a temporal and spatial basis.

Locations of each of the various monitoring components are shown on DWG 948-1-002. The plan is to install Station 1 in a similar location to the existing (non-functioning) thermistor string near the SWD where tailings depth is at its greatest and a talik is present. Station 2 and Station 3 will be situated near Outlet 1 and 2, respectively, to capture the behaviour of the cover system in areas where the cover is thin and may gain heat energy from the flow of runoff from landform surface drainage. DWG 948-1-050 provides the profile of the monitoring stations and depth of sensors in the soil profile.

7.3 Installation of Monitoring Instrumentation

OKC recommends that the performance monitoring system be installed in stages based on accessibility and cover placement. Thermistor strings and water level sensors are installed within bore holes established through the profile. This assumes that AEM will have access to a drilling rig capable of penetrating the cover material and underlying tailings, till, and bedrock layers. The annulus around the sensor leads will be backfilled with a minus No. 4 sieve size sand. Installation of the thermistor strings may occur in different calendar years given that construction of the cover system will progress over a five year period. OKC recommends that instrumentation would be installed within one year of cover material placement to final elevation to capture the as-constructed conditions.

Station 2 and 3 water content sensors will be installed into the near surface tailings prior to placement of the cover material. A hydraulic excavator or backhoe will be used to excavate into the shallow tailings and the sensors will be installed in the excavation. Mounds of cover material will then be constructed above the sensor nest on the tailings to facilitate the installation of a water content sensor in the cover material immediately above the tailings. The sensor leads will daylight at the final cover system elevation at the top of the mound. The landform cover system will merge with the constructed mounds.

8 CONSTRUCTION PLAN

This section describes the proposed construction plan for reclamation of the North Cell TSF, including:

- Methods suggested for construction of the various reclamation elements;
- Safety, health, and environmental protection measures required during construction;
- Proposed sources and estimated quantities of materials required for construction;
- Quality assurance / quality control (QA/QC) measures recommended for construction of the various reclamation elements; and
- Proposed schedule for construction.

8.1 Construction Methods

The construction methods outlined below for the various North Cell TSF reclamation activities are based on past experience with reclamation of TSFs at other mine sites in Canada. AEM personnel and equipment and/or a reputable contractor will carry out the necessary earthwork activities to construct the preferred final landform for the North Cell TSF. Qualified personnel should be on-site to provide engineering supervision for the duration of the project.

8.1.1 TSF Landform Earthworks Prior to Cover Placement

Re-shaping the tailings surface of the North Cell TSF into its final configuration will involve excavation of tailings material up to a depth of 4 m. Drawing 948-1-003 shows the area to be excavated. The total disturbance area covers 10.58 ha with most of that surface (6.94 ha) requiring less than 1 m of tailings removal. Tailings excavation is concentrated in the two areas around the surface runoff outlets, as they are the low points of the final landform to promote gravitational flow. A total of 93,000 m^3 of tailings will require excavation and transport to either other areas of the North Cell with higher final design elevation, or to the South Cell TSF.

The areas requiring excavation will require drill and blast due to the frozen state of the tailings material. Material can then be excavated by tracked excavator and hauled using 50 t capacity trucks (to be determined by operations). For the areas with shallower tailings excavation, AEM should determine if excavation of the thawed surface layer at the end of summer and/or early fall (when the thawed layer is deepest) is a feasible alternative to a drill and blast campaign.

8.1.2 Cover System Construction

Cover system construction will be completed by placing cover material in 2.0 m lifts over the tailings surface. The lifts will be created by paddock dumping from haulage truck, followed by placement of the surface to the nominal elevation by tracked dozer. The limited lift height is intended to promote compaction of the cover material from dozer and truck traffic and to minimize future settlement of the material. Increased compaction reduces permeability of the material close to the lift surface, where compaction is greater. This in turn will reduce percolation through the cover and increase surface runoff. Placement of the cover system using short lifts also limits material segregation during placement, which results from end-dumping from higher lifts.

Cover system material will be hauled from the NPAG waste rock dump located to the north-east of the North Cell TSF. Loading of the haul trucks will require an excavator on the WRD. Trucks are to paddock dump NPAG material over the final tailings surface or the previous cover material lift. Although a dozer is not required at all times during load-haul-dump operations, AEM should avoid leaving piles in place for extended periods as freezing of the piles could hinder dozer operations.

Care should be taken to remove any snow accumulation on the surface prior to placing cover material. This is to minimize the creation of potential ice pockets within the cover which could thaw and create depressions later on. Similarly, grading of the cover material piles should be done shortly after deposition to avoid snow accumulation between the piles prior to dozing of the material.

Following paddock dumping of the NPAG material over a given area, a dozer is to be used to work the surface and create the 2 m lift. Survey control will be required to ensure that each lift is of a maximum of 2 m height. The final lift will require adequate survey control to ensure that the surface is built as per the design to avoid creating low points within the landform where water accumulation could take place. Rigorous survey will be of particular importance in areas where the final lift will be thinner than 1 m. Each lift should create a smooth surface to allow for truck traffic for deposition of cover material forming the subsequent lift. Haulage truck movements across the area will aid in compaction of each lift. As such, as far as possible without hindering operations, creation of internal haul roads within the confines of the TSF should be avoided to promote traffic over the entire area and ensure adequate compaction across the surface.

8.1.3 Surface Water Management System

Conventional construction equipment can be used to construct the various components of the surface water management system for the North Cell TSF final landform. The drainage channels should be constructed shortly after final grading of the cover system has been completed. The bucket on a hydraulic excavator can be used to place material to the required grade and compact cover system materials that comprise the subgrade of all drainage channels. As the cover system material is appropriate as riprap scour protection for most of the channels (Stone Material A), it may be possible to build the channels as the cover system is being constructed, avoiding rehandling of cover material. This will require accurate survey taking place while cover construction is ongoing. The channel sections should be compacted using the excavator bucket as a tamping tool or a smooth-drum vibratory roller where channel width allows.

For sections requiring geotextile (Outlet #1), panels can be transported to the installation location using a front-end loader with forks or a spreader bar, and deployed using labourers. Riprap material at outlet #1 (Stone Material B) should be placed from the bottom of the outlet upwards to provide better interlocking of the riprap materials.

8.2 Safety, Health, and Environmental Protection during Construction

AEM Worker Health & Safety and Environment departments will be responsible for ensuring construction activities are conducted in a manner that meets safety, health, and environmental standards applicable to AEM. Some additional protection measures are recommended during the various reclamation activities as noted below.

8.2.1 TSF Landform Earthworks Prior to Cover Placement

Due care should be taken during drill and blast operations, as per AEM current practice. As work has to be undertaken over frozen tailings material, integrity of the surface and its capability to support heavy equipment should be tested before allowing personnel and equipment on the surface. A spotter standing on firm ground should be used during tailings excavation operations. Wherever possible, excavation and truck loading should be done from firm ground. Working from the tailings surface should be avoided while the upper layer of tailings is thawed. Surveying should only be done over frozen tailings and with a spotter present.

8.2.2 Cover System Construction

Dust will be generated during hauling and spreading of cover materials. Traffic management should be implemented to reduce risks associated with two-way traffic in poor visibility conditions, as per AEM standard practice. In addition, closed-cab equipment with positive ventilation is recommended for use in the cover system construction activities. Monitoring and surveying of the created surface prior to allowing truck traffic for deposition of the subsequent lift will be required.

8.3 Material Sources and Quantities

The estimated quantities of materials required to construct various elements of the North Cell TSF landform are shown in Table 8.1. All riprap materials will be produced by screening and blending suitable materials from available stockpiles. Riprap Type A quantity is shown as non-applicable due to the NPAG cover material meeting the required specification. Source for Riprap Type B will be boulders selected from an appropriate stockpile. Estimated quantities for the geotextile product include an additional 10% for seam overlap. The acceptability envelope for NPAG cover material particle size distribution is shown in Figure 8.1.

Table 8.1: Material sources and quantities for construction of the North Cell TSF landform.

Material	Source	Units	Quantity
NPAG Cover Material	NPAG Dump, Current Operations	m^3	6,376,000
Riprap Type A (D_{50} = 75 mm)	NPAG Dump, Current Operations	m^3	NA
Riprap Type B (D_{50} = 500 mm)	Vault Pit NPAG	m^3	900
Bedding Sand or approved material	Stockpile	m^3	120
Geotextile (500 g/m^2, non-woven, needle-punched)	Supplier	m^2	1350

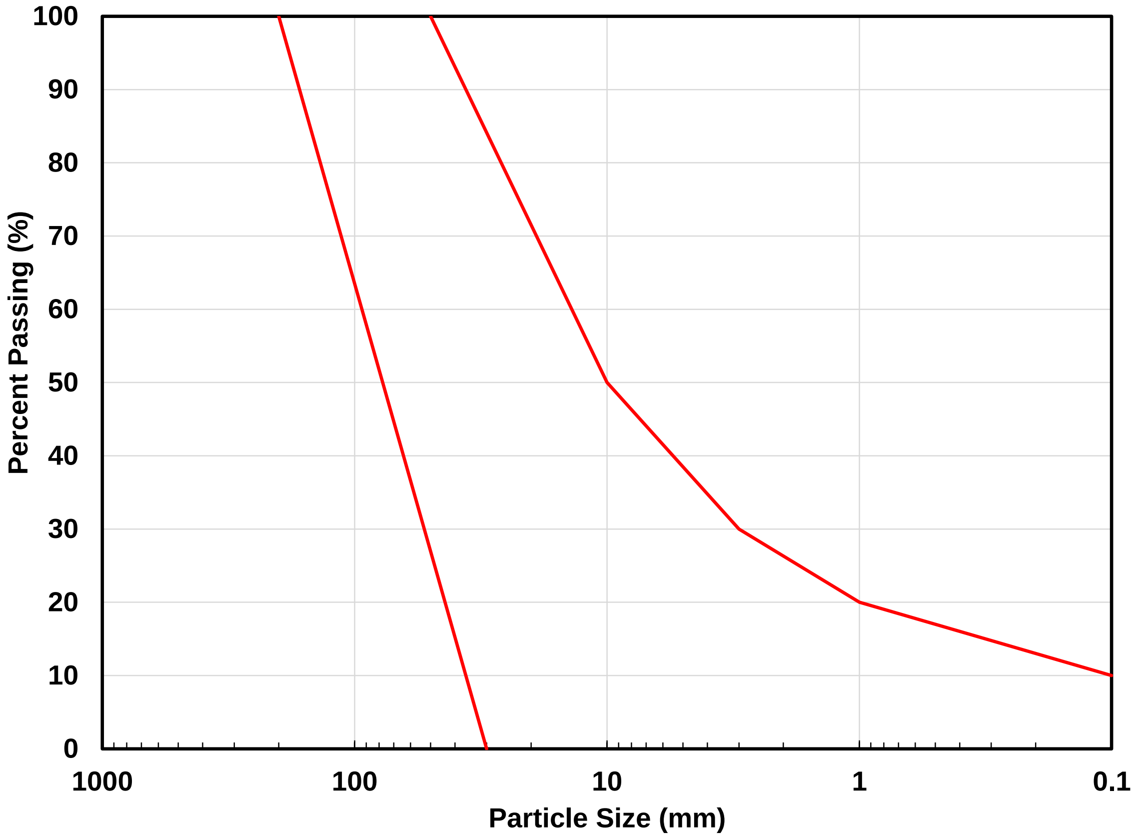

Figure 8.1: NPAG Cover Material PSD Acceptability Envelope

8.4 Quality Assurance and Control Plan

Quality assurance / quality control (QA/QC) measures must be implemented during reclamation of the North Cell TSF to ensure all components are constructed in accordance with the design and technical specifications. All construction work must be carried out under the supervision of the Engineer, which collectively refers to a Professional Engineer, registered in the Province of Nunavut, and a support team comprised of technologists and surveyors. Quality assurance and control includes cover material testing and surveying of various surfaces prior to, during, and after construction of the various work items. Table 8.2 outlines the proposed QA/QC program for the various reclamation activities planned at the North Cell TSF.

8.4.1 Cover Material Sampling and Testing

The Engineer will take samples of materials used for and in construction, and perform various tests on the samples to ascertain that the materials being placed or already placed meet the specified requirements. The results of the tests carried out by the Engineer will be final and conclusive in determining compliance with the technical specifications. Table 8.2 presents the anticipated schedule of quality assurance testing; however, the Engineer may modify the testing and rates of testing during the work.

8.4.2 Survey Control

AEM or the Engineer will be responsible for setting out the initial lines and grades for each work item. The Contractor or AEM, depending which entity is undertaking the rehabilitation work, will be responsible for all interim survey control necessary to complete the work. The work must be completed to the lines and grades shown on the Drawings (Appendix A) unless otherwise specified by the Engineer, and any specified tolerances for each work item will be adhered to. As-built surveys will be required for each interim and final lift of the cover system construction as well as for the water management structures.

Prior to the commencement, and following completion of each portion of work to be paid for on a unit quantity basis, a survey will be conducted by AEM or the Engineer to enable the measurement for payment to be made. This survey may also be used for the purpose of documenting the as-built configuration of the work. Check surveys may be carried out by the Contractor to confirm the accuracy of the Engineer's survey, or alternatively, the Contractor may elect to participate in the Engineer's survey.

Table 8.2: Overview of the proposed QA/QC program for various North Cell TSF reclamation activities.

Item	Requirement	Method	Frequency
Tailings Excavation	±0.1 m of design elevation	Survey	Daily or as required for excavation activities
Cover Material Quality and Layer Thickness	Gradation as specified Free from deleterious materials (e.g. hydrocarbons, trees)	Sieve Visual	As required by construction engineer Continuous
Cover Material Thickness	-0.2 m and +0.3 m of design	Survey	Daily or as required as lifts are placed and final topography is constructed
Drainage Channel Invert Grade	±0.15 m of design section ±0.50% of design grade Firm, unyielding	Survey Survey Visual	Daily Daily Continuous
Geotextile Quality and Installation	Product meets specifications Adjoining panels overlapped as specified Installed panels free of defects	Visual Visual Visual	Continuous Continuous Continuous
Riprap Material Quality and Layer Thickness	Hard, durable stone (for Type B) Gradation as specified Thickness as specified	Visual Visual/Photo analysis Survey / Tape	Continuous 1 per 300 m^3 Continuous

8.5 Construction Schedule

A preliminary construction schedule for carrying out the various activities required for reclamation of the North Cell TSF is proposed in Table 8.3. The plan is to complete the TSF reclamation work over a 5-year period beginning in the first quarter of 2015 with the placement of a 2 m lift of NPAG cover material in the northern portion of the North Cell TSF. The specific order and timing of work may vary based on interaction with operations, priorities on site and updates to the Life-of-Mine. All cover construction work will be carried out during the winter months to ensure trafficability of the tailings surface and a sub-zero°C temperature in the newly placed layer, thus favouring permafrost aggradation within the cover.

Cover construction is to be conducted in two main phases, corresponding to the catchment areas reporting to Outlet #2 (NW area) and to Outlet #1 (SE area). Construction activities in the NW portion of the TSF are to be prioritized in the early stages of construction. This will allow building the cover system from the higher points and allow for integration of a potential optimization options for tailings deposition. Figure 8.2 shows the volumes of cover placement per quarter as well as cumulatively for completion of the landform.

Table 8.3: Preliminary Construction Schedule

Activity	Construction Season (winter)				
	2015	2015-2016	2016-2017	2017-2018	2018-2019
Tailings Excavation (Outlet #2)		X			
Cover Material Placement NW (,000 m^3)	400	180	552	1,332	
Cover Material Placement SE (,000 m^3)					3,912
Construct Runoff Drains to Outlet #2			X	X	
Construct Outlet #2				X	
Tailings Excavation (Outlet #1)				X	
Construct Runoff Drains to Outlet #1					X
Construct Outlet #1					X

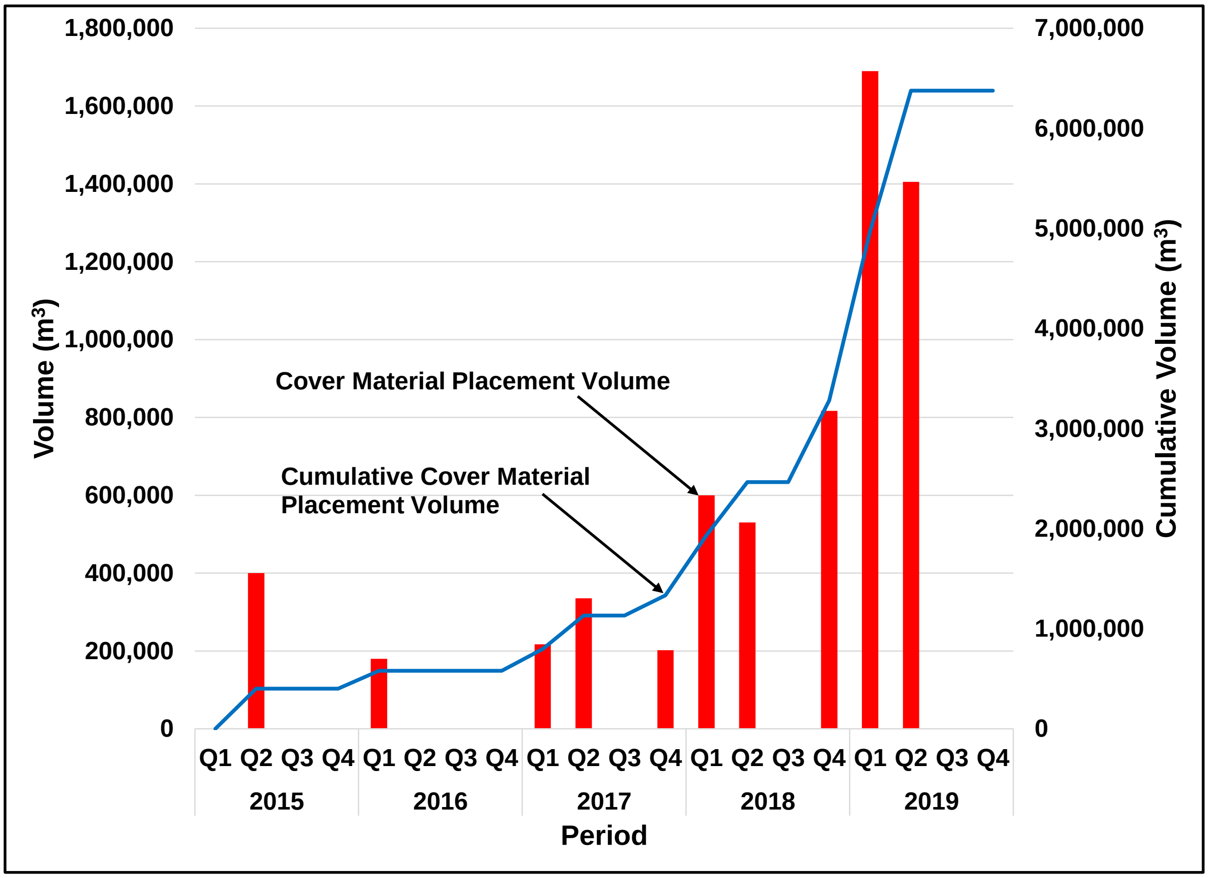

Figure 8.2: Cover Material Placement Schedule

9 POST CONSTRUCTION MAINTENANCE

The proposed reclamation plan for the North Cell TSF is designed to be maintenance free over the long term. However, some maintenance work may be required in the short term for the reclaimed landform as described below.

9.1 Repair of Erosional Features

The cover surface may be susceptible to rill or gully erosion. AEM or their representatives should inspect the entire North Cell TSF cover system at least twice per year for areas affected by erosion and differential settlement. Inspections should occur immediately after the snowmelt period and prior to the first snowfall in the fall (i.e. September 1st), and after significant rainfall events. Erosion maintenance work would likely consist of infilling of deep rills and gullies with granular fill. Areas showing signs of settlement will require filling with granular material with the same specifications as the original cover material. Some settlement is expected shortly after placement and will need to be addressed. Long term consolidation is not expected and any signs of greater scale settlement (over 1 m depression) will need to be investigated.

9.2 Performance Monitoring Equipment

AEM personnel should visit the reclaimed North Cell TSF at least once per month to collect data from and conduct maintenance of the various components of the performance monitoring system. Data should be reduced on a monthly basis to avoid data loss over long periods. If field data are not reduced and analyzed regularly, the potential exists that a malfunctioning sensor (or sensors) will not be discovered. The potential result is that key field data may be lost, even though a significant financial commitment has been made to obtain the field data. A monthly data collection and reduction schedule will ensure high data capture rates, which can significantly increase stakeholder confidence with respect to performance.

It is recommended that qualified personnel visit the North Cell TSF site on an annual basis in the second and third year post-reclamation to inspect the performance monitoring stations and make recommendations for improvements as necessary.

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11 CLOSURE

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We trust the above satisfies your requirements at this time.

Yours sincerely,

O'KANE CONSULTANTS INC.

per:

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Senior Engineer	Senior Geoenvironmental Engineer

Appendix A

Technical Drawings

AGNICO EAGLE LIMITED

MEADOWBANK MINE

NORTH CELL TSF CLOSURE DESIGN

DRAWING INDEX

DRAWING #	DESCRIPTION
948-1-000	COVER SHEET, DRAWING INDEX & LOCALITY PLAN
948-1-001	EXISTING FEATURES PLAN
948-1-002	GENERAL ARRANGEMENT PLAN
948-1-003	TAILINGS MATERIAL EXCAVATION PLAN
948-1-004	TSF COVER PLACEMENT DEPTH PLAN
948-1-010	RUNOFF DRAIN 1a LONGITUDINAL SECTION AND SETOUT DETAILS
948-1-011	RUNOFF DRAIN 1b LONGITUDINAL SECTION AND SETOUT DETAILS
948-1-012	RUNOFF DRAIN 1c LONGITUDINAL SECTION AND SETOUT DETAILS
948-1-013	RUNOFF DRAIN 2a LONGITUDINAL SECTION AND SETOUT DETAILS
948-1-014	RUNOFF DRAIN 2b LONGITUDINAL SECTION AND SETOUT DETAILS
948-1-015	RUNOFF DRAIN 2c LONGITUDINAL SECTION AND SETOUT DETAILS
948-1-016	RUNOFF DRAIN 2d LONGITUDINAL SECTION AND SETOUT DETAILS
948-1-017	RUNOFF DRAIN 2e LONGITUDINAL SECTION AND SETOUT DETAILS
948-1-020	DRAINAGE SECTIONS AND DETAILS - SHEET 1 OF 2
948-1-021	DRAINAGE SECTIONS AND DETAILS - SHEET 2 OF 2
948-1-030	LANDFORM SETOUT PLAN
948-1-040	CATCHMENT PLAN
948-1-050	PERFORMANCE MONITORING DETAILS

LOCALITY PLAN:

AERIAL IMAGERY: GOOGLE EARTH 2014
NOT TO SCALE

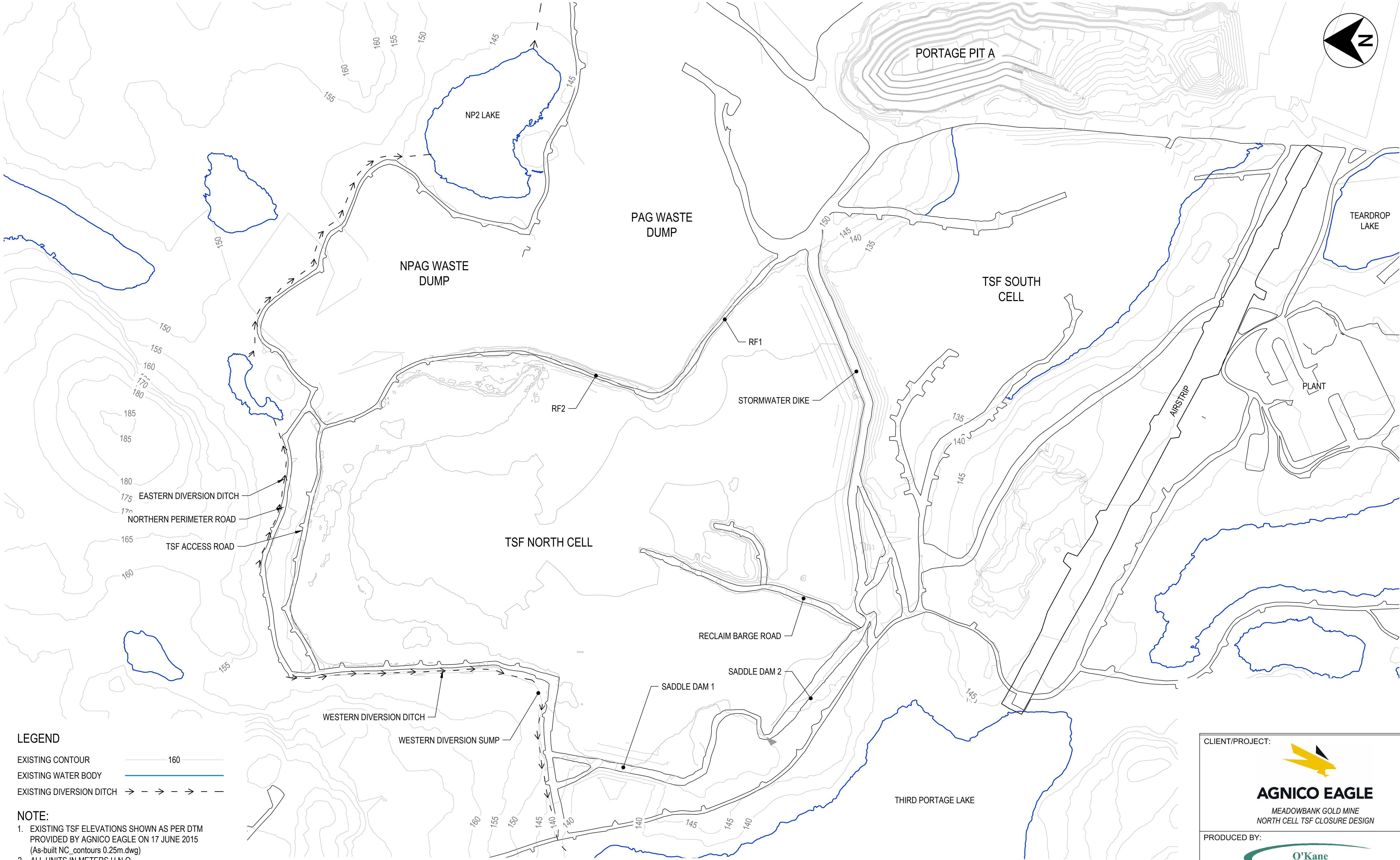
PREPARED BY:

O'Kane Consultants Pty Ltd.

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

PROVIDED FOR:

AGNICO EAGLE



LEGEND

- EXISTING CONTOUR — 160
- EXISTING WATER BODY
- EXISTING DIVERSION DITCH

NOTE:

1. EXISTING TSF ELEVATIONS SHOWN AS PER DTM PROVIDED BY AGNICO EAGLE ON 17 JUNE 2015 (As-built NC_contours 0.25m.dwg)
2. ALL UNITS IN METERS U.N.O.

EXISTING FEATURES PLAN
1:10,000

100 50 0 100 200 300 400 500m
SCALE 1:10000

CLIENT/PROJECT:

AGNICO EAGLE
MEADOWBANK GOLD MINE
NORTH CELL TSF CLOSURE DESIGN

PRODUCED BY:

O'Kane Consultants Inc.
Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

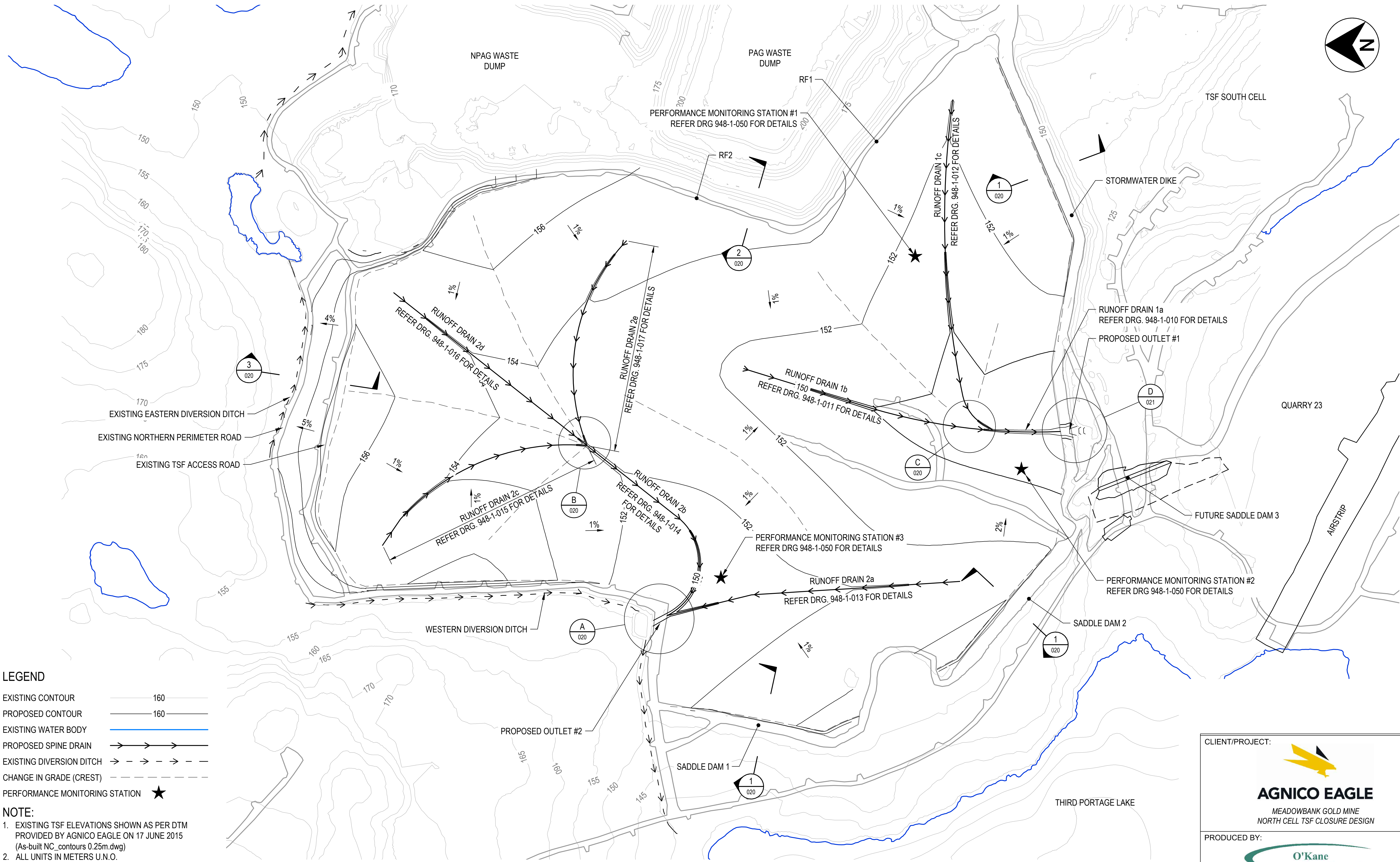
REFERENCE DWG. NO.	DESCRIPTION

REVISIONS NO.	DESCRIPTION	DRN. BY:	DATE
0	ISSUED TO CLIENT FOR REVIEW	SMW	14.08.15
1	FINAL DESIGN ISSUE	SMW	17.11.15

REVD. BY:	BA & PG	DATE:	14.08.15
APPD. BY:	P. GARNEAU	DATE:	17.11.15
SCALE:	AS SHOWN	REPORT NUM:	948/1-02

EXISTING FEATURES PLAN
2015 TAILINGS SURFACE

DRG NUM: 948-1-001 Rev: 1



LEGEND

- EXISTING CONTOUR — 160
- PROPOSED CONTOUR — 160
- EXISTING WATER BODY
- PROPOSED SPINE DRAIN
- EXISTING DIVERSION DITCH
- CHANGE IN GRADE (CREST)
- PERFORMANCE MONITORING STATION ★

NOTE:

1. EXISTING TSF ELEVATIONS SHOWN AS PER DTM PROVIDED BY AGNICO EAGLE ON 17 JUNE 2015 (As-built NC_contours 0.25m.dwg)
2. ALL UNITS IN METERS U.N.O.

GENERAL ARRANGEMENT PLAN
1:7,500

SCALE 1:7500 (0 75 150 225 300 375 450 525 600m)

CLIENT/PROJECT: AGNICO EAGLE
MEADOWBANK GOLD MINE
NORTH CELL TSF CLOSURE DESIGN

PRODUCED BY: O'Kane Consultants Inc.
Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

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APPD. BY:	P. GARNEAU	DATE:	17.11.15
SCALE:	AS SHOWN	REPORT NUM:	948/1-02

GENERAL ARRANGEMENT PLAN

DRG NUM: 948-1-002 Rev: 1

EXCAVATION SETOUT DATA			
POINT #	EASTING	NORTHING	R.L.
200	637464.47	7215320.39	148.57
201	637511.62	7215456.27	148.39
202	637569.62	7215540.26	147.96
203	637642.23	7215558.19	146.30
204	637675.71	7215577.06	147.68
205	637682.78	7215552.52	147.68
206	637832.48	7215535.05	147.01
207	637734.41	7215469.46	147.90
208	637797.12	7215328.39	148.07
209	637758.72	7215328.39	147.49
210	637625.75	7215311.88	145.87
211	637543.82	7215298.14	147.30
212	637625.31	7215388.90	145.60
213	637628.72	7215449.69	146.60
214	637632.73	7215494.34	145.98
215	637651.93	7215483.49	145.87
216	637756.70	7215523.58	146.60

EXCAVATION SETOUT DATA			
POINT #	EASTING	NORTHING	R.L.
217	637392.49	7215329.27	149.81
218	637436.38	7215500.35	149.45
219	637496.20	7215644.35	149.17
220	637138.16	7216143.51	148.82
221	637141.97	7216039.35	149.50
222	637242.53	7216130.30	146.86
223	637274.74	7216091.68	148.14
224	637252.46	7216084.93	149.08
225	637283.52	7215965.37	147.52
226	637295.67	7215776.90	148.30
227	637368.57	7216061.29	148.64
228	637481.98	7216151.80	148.97
229	637332.12	7216125.97	148.64
230	637304.24	7216194.69	148.94
231	637270.93	7216129.37	148.16

VOLUMES	
TAILINGS TO BE CUT (m³)	TAILING REMOVAL DISTURBANCE AREA (HA)
~ 93,300	~ 10.58

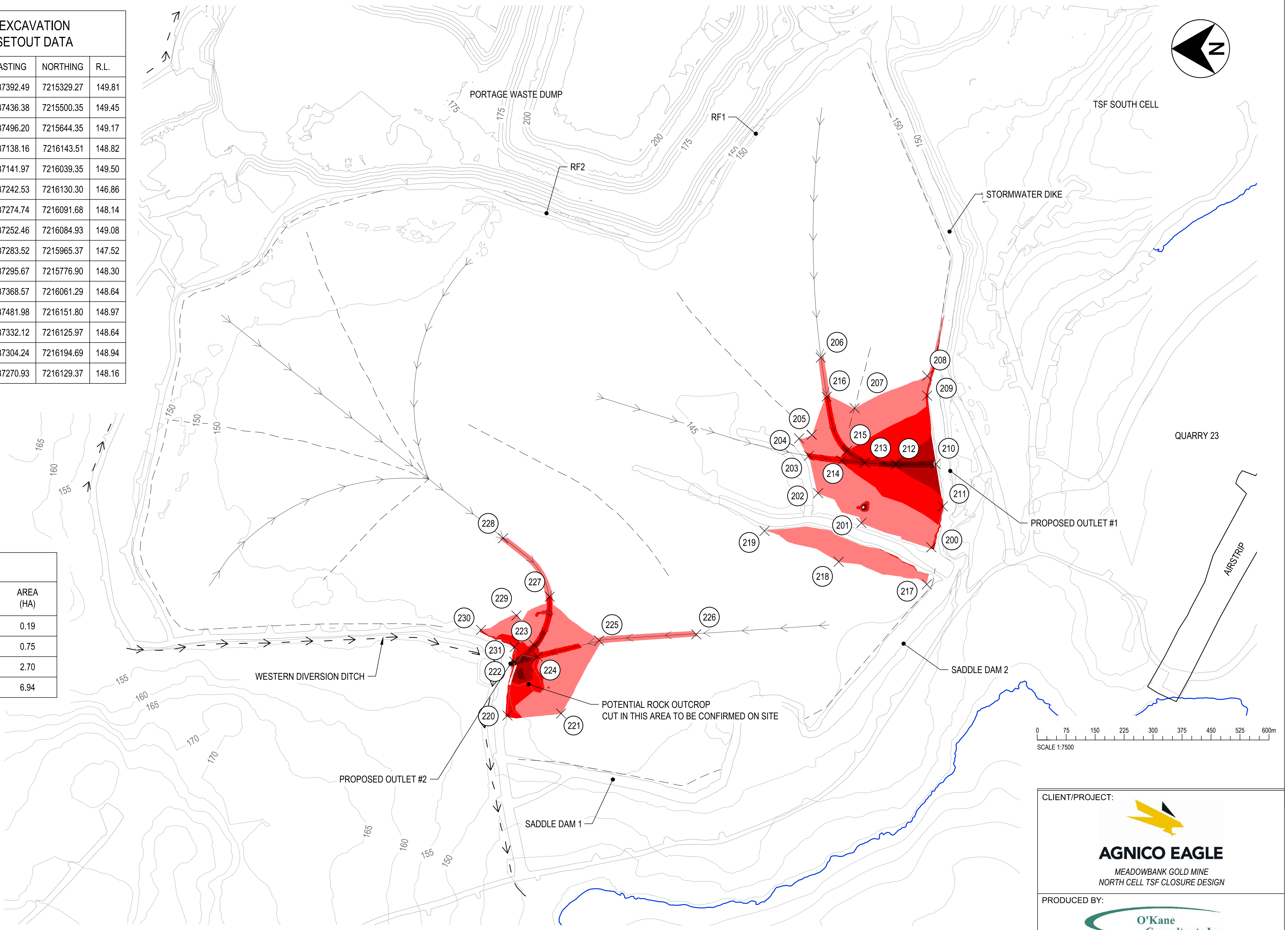
TAILINGS CUT DEPTHS				
NUMBER	COLOR	MIN. ELEVATION (m)	MAX. ELEVATION (m)	AREA (HA)
1	(dark red)	-4.2	-3.0	0.19
2	(red-brown)	-3.0	-2.0	0.75
3	(red)	-2.0	-1.0	2.70
4	(pink)	-1.0	0.0	6.94

LEGEND

- EXISTING CONTOUR — 160
- PROPOSED CONTOUR — 160
- EXISTING WATER BODY
- PROPOSED SPINE DRAIN
- EXISTING DIVERSION DRAIN
- CHANGE IN GRADE

NOTE:

1. EXISTING TSF ELEVATIONS SHOWN AS PER DTM PROVIDED BY AGNICO EAGLE ON 17 JUNE 2015 (As-built NC_contours 0.25m.dwg)
2. ALL UNITS IN METERS U.N.O.



TSF EXCAVATION PLAN

1:7,500

CLIENT/PROJECT:

AGNICO EAGLE

MEADOWBANK GOLD MINE
NORTH CELL TSF CLOSURE DESIGN

PRODUCED BY:

O'Kane Consultants Inc.

Integrated Mine Waste Management and Closure Services
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REFERENCE	DWG. NO.	DESCRIPTION

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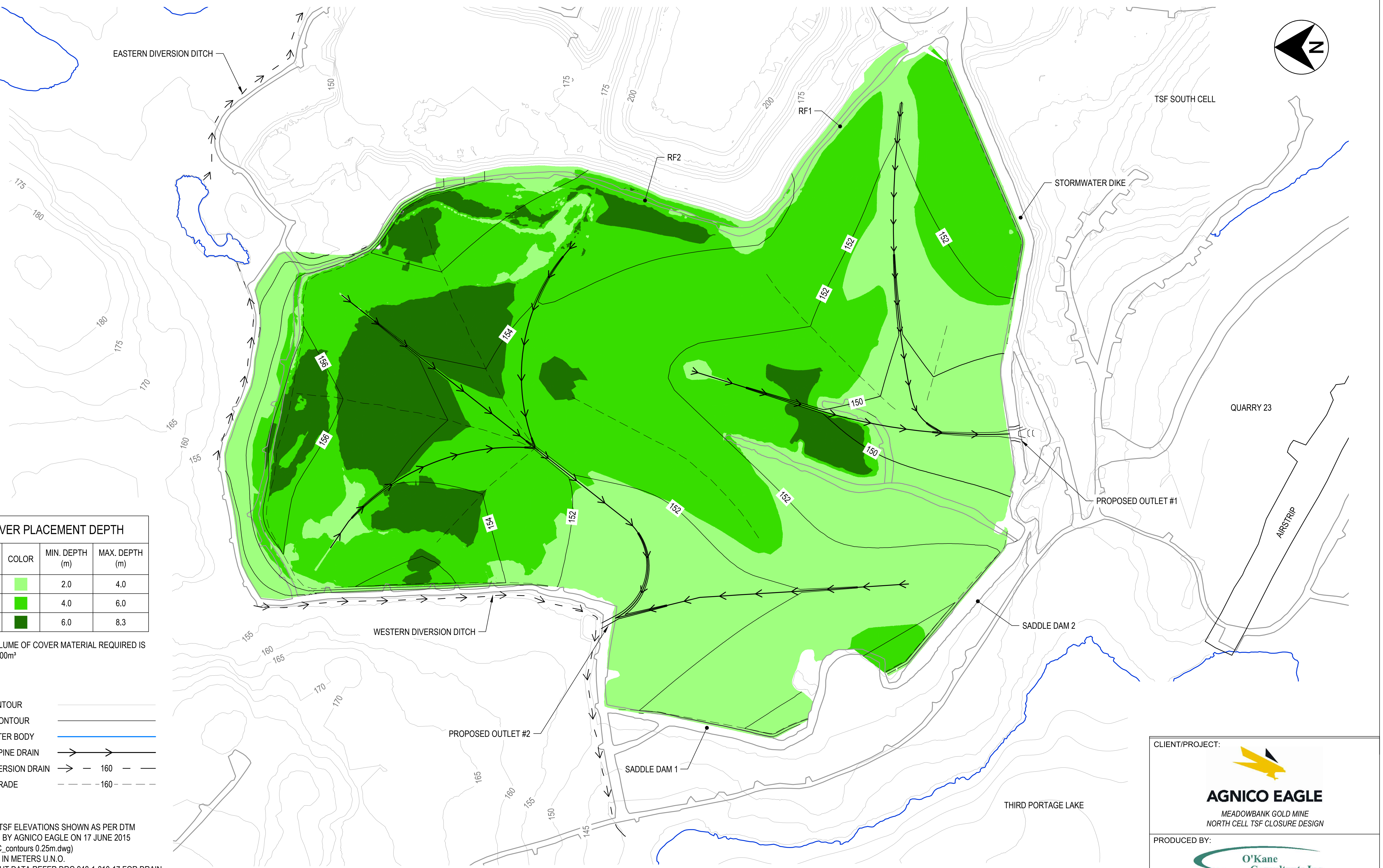
SCALE:	AS SHOWN	REPORT NUM:	948/1-02

TAILINGS MATERIAL EXCAVATION PLAN

DRG NUM: 948-1-003 Rev: 1



COVER PLACEMENT DEPTH

NUMBER	COLOR	MIN. DEPTH (m)	MAX. DEPTH (m)
1	light green	2.0	4.0
2	green	4.0	6.0
3	dark green	6.0	8.3

* TOTAL VOLUME OF COVER MATERIAL REQUIRED IS 6,376,000m³

LEGEND

- EXISTING CONTOUR
- PROPOSED CONTOUR
- EXISTING WATER BODY
- PROPOSED SPINE DRAIN
- EXISTING DIVERSION DRAIN — 160 —
- CHANGE IN GRADE — 160 —

NOTE:

1. EXISTING TSF ELEVATIONS SHOWN AS PER DTM PROVIDED BY AGNICO EAGLE ON 17 JUNE 2015 (As-built NC_contours 0.25m.dwg)
2. ALL UNITS IN METERS U.N.O.
3. FOR SETOUT DATA REFER DRG 948-1-010-17 FOR DRAIN DETAILS AND 948-1-030 FOR CRITICAL CHANGES IN GRADE (CREST) DETAILS.

TSF COVER FILL PLAN
1:7,500

0 75 150 225 300 375 450 525 600m
SCALE 1:7500

CLIENT/PROJECT:
AGNICO EAGLE
MEADOWBANK GOLD MINE
NORTH CELL TSF CLOSURE DESIGN

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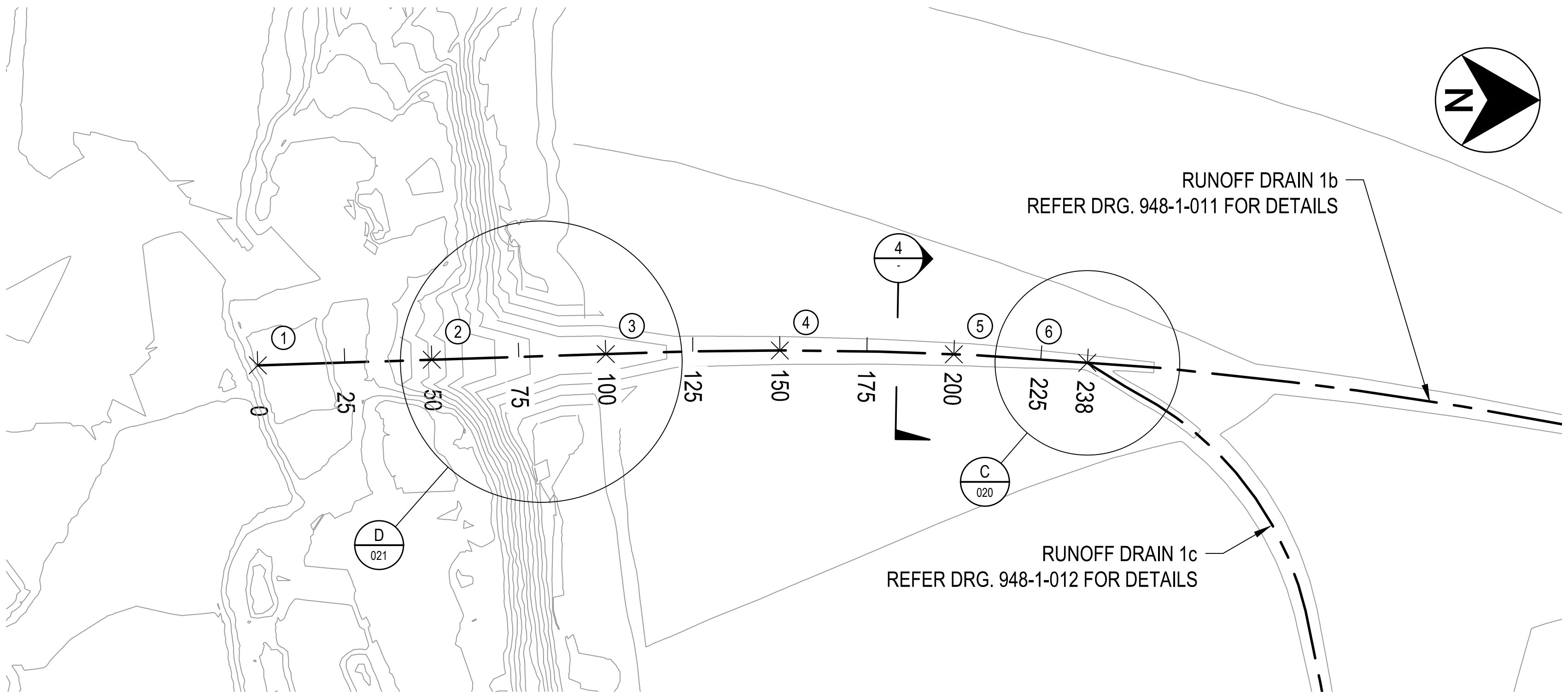
SCALE:	AS SHOWN	REPORT NUM:	948/1-02

TSF COVER PLACEMENT DEPTH

DRG NUM: 948-1-004 Rev: 1



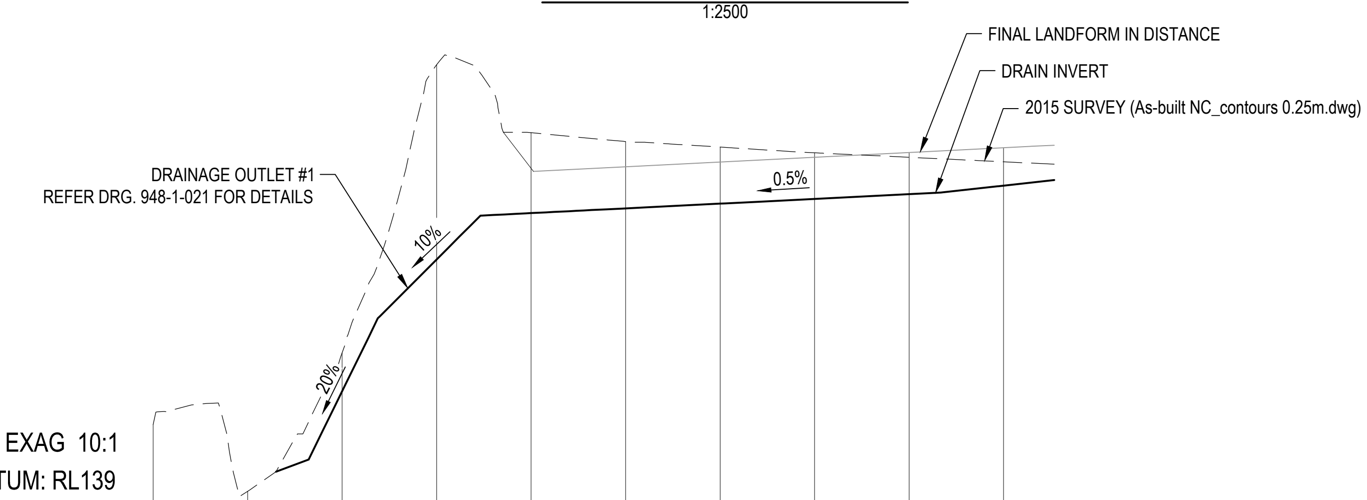
RUNNOFF DRAIN 1a SETOUT PLAN
1:2500

GRADATION LIMITS FOR TYPE 'A' AND TYPE 'B' RIP RAP MATERIALS				
PERCENT FINER THAN	TYPE 'A'		TYPE 'B'	
	FL (mm)	CL (mm)	FL (mm)	CL (mm)
100	120	130	750	850
85	90	110	600	700
50	75	90	500	580
15	30	50	200	300

SETOUT DATA			
POINT #	EASTING	NORTHING	RL
1	637629.50	7215211.18	141.32
2	637627.88	7215261.16	142.20
3	637626.26	7215311.13	146.91
4	637625.22	7215361.12	147.16
5	637626.32	7215411.10	147.41
6	637628.77	7215449.41	147.79

NOTES

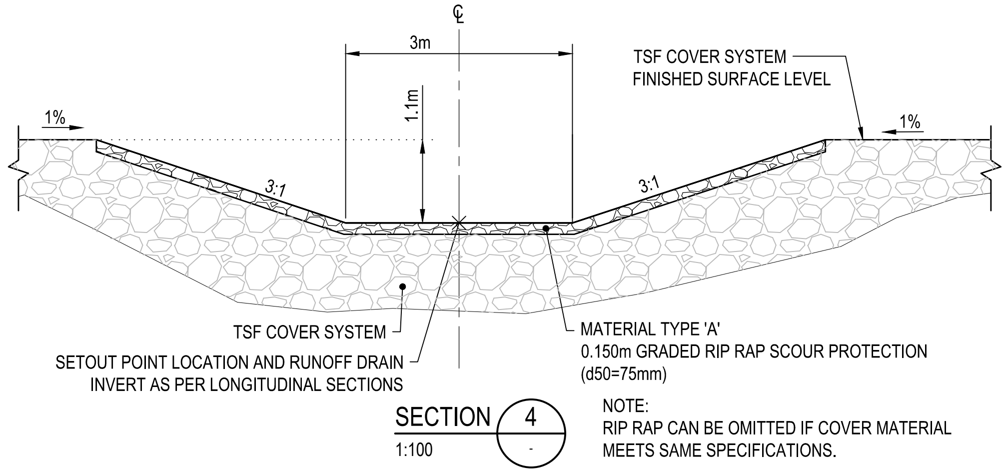
1. EXISTING TSF ELEVATIONS SHOWN AS PER DTM PROVIDED BY AGNICO EAGLE ON 17 JUNE 2015 (As-built NC_contours 0.25m.dwg)
2. SETOUT ELEVATIONS REPRESENT INVERT OF RUNOFF DRAIN. REFER LONGITUDINAL SECTION FOR FURTHER DETAIL.
3. RIP RAP MATERIAL AS SPECIFIED IN GRADATION LIMITS TABLE TO BE DETERMINED BY SUPERVISING ENGINEER



VERT EXAG 10:1
DATUM: RL139

DESIGN LEVEL (INVERT)			142.20	145.69	146.91	147.04	147.16	147.29	147.41	147.64	147.79		
EXISTING LEVEL	141.32	139.56	143.22	150.84	149.04	148.80	148.66	148.51	148.39	148.27	148.20		
ELEVATION DIFFERENCE			-1.01	-5.15	-2.12	-1.77	-1.49	-1.22	-0.98	-0.63	-0.42		
CHAINAGE		25	50	75	100	125	150	175	200	225	238	250	275

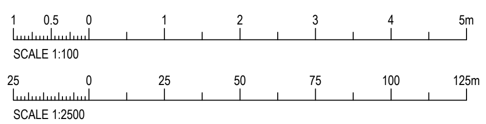
RUNOFF DRAIN 1a LONGITUDINAL SECTION
1:2500



SECTION 4 / -
1:100

NOTE:
RIP RAP CAN BE OMITTED IF COVER MATERIAL MEETS SAME SPECIFICATIONS.

TSF RUNOFF DRAIN DETAIL



CLIENT/PROJECT:

AGNICO EAGLE

MEADOWBANK GOLD MINE
NORTH CELL TSF CLOSURE DESIGN

PRODUCED BY:

O'Kane Consultants Inc.

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Specialists in Geochemistry and Unsaturated Zone Hydrology

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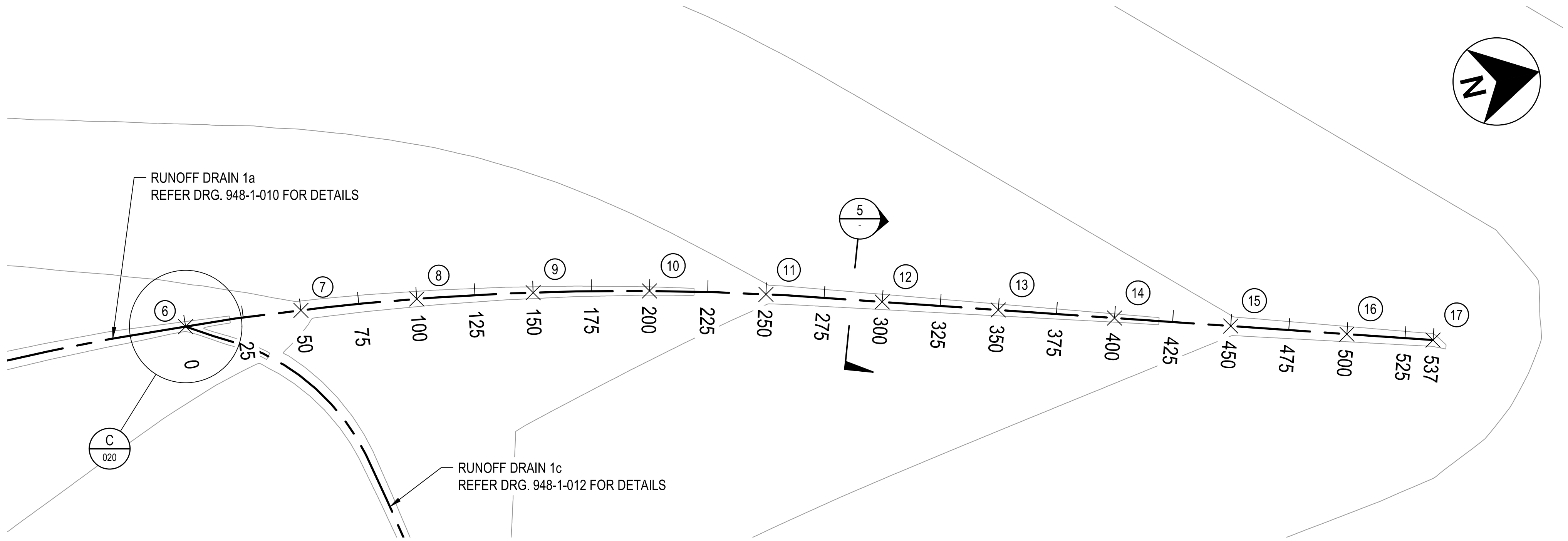
SCALE:	AS SHOWN	REPORT NUM:	948/1-02

RUNOFF DRAIN 1a LONGITUDINAL SECTION AND SETOUT DETAILS

DRG NUM: 948-1-010 Rev: 0



RUNOFF DRAIN 1b SETOUT PLAN

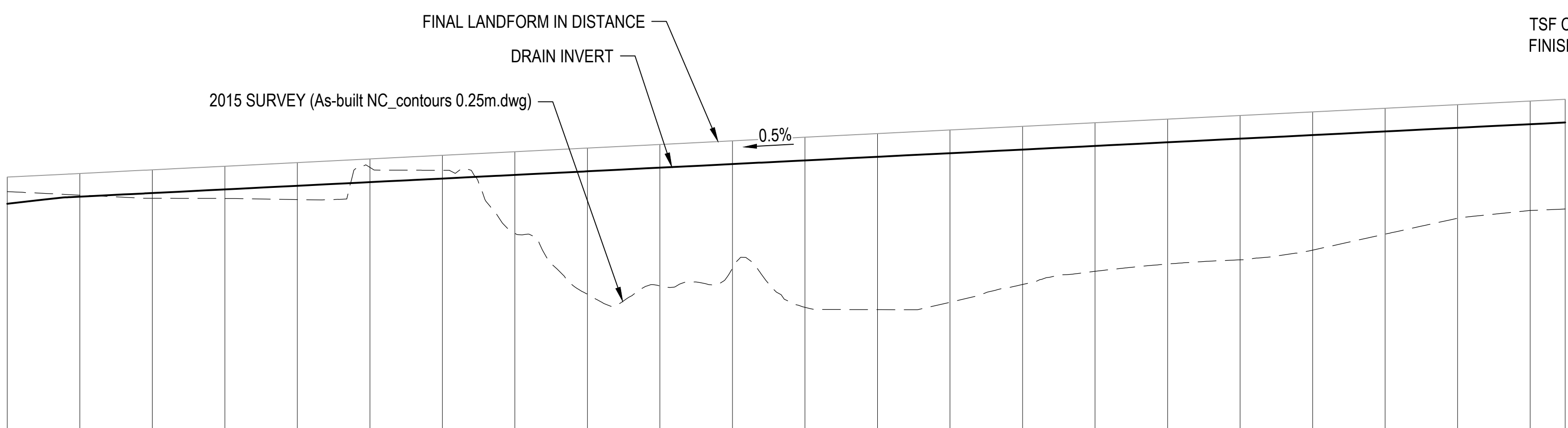
1:2500

GRADATION LIMITS FOR TYPE 'A' AND TYPE 'B' RIP RAP MATERIALS				
PERCENT FINER THAN	TYPE 'A'		TYPE 'B'	
	FL (mm)	CL (mm)	FL (mm)	CL (mm)
100	120	130	750	850
85	90	110	600	700
50	75	90	500	580
15	30	50	200	300

SETOUT DATA			
POINT #	EASTING	NORTHING	RL
6	637628.77	7215449.41	147.79
7	637633.38	7215499.19	148.16
8	637640.04	7215548.73	148.40
9	637648.88	7215597.94	148.65
10	637659.65	7215646.76	148.90
11	637672.58	7215695.06	149.15
12	637687.18	7215742.87	149.40
13	637702.00	7215790.63	149.65
14	637716.83	7215838.38	149.90
15	637731.66	7215886.13	150.15
16	637746.48	7215933.88	150.40
17	637757.46	7215969.30	150.59

NOTES

1. EXISTING TSF ELEVATIONS SHOWN AS PER DTM PROVIDED BY AGNICO EAGLE ON 17 JUNE 2015 (As-built NC_contours 0.25m.dwg)
2. SETOUT ELEVATIONS REPRESENT INVERT OF RUNOFF DRAIN. REFER LONGITUDINAL SECTION FOR FURTHER DETAIL.
3. RIP RAP MATERIAL AS SPECIFIED IN GRADATION LIMITS TABLE TO BE DETERMINED BY SUPERVISING ENGINEER

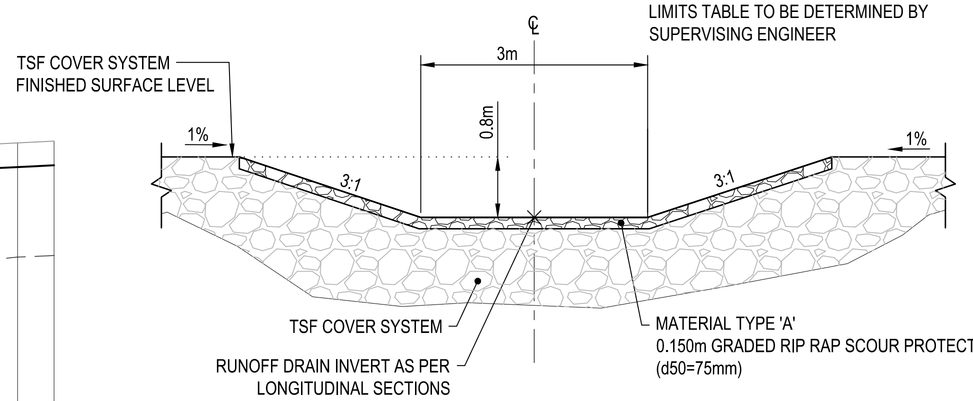


VERT EXAG 10:1
DATUM: RL140

DESIGN LEVEL (INVERT)	148.03	148.16	148.28	148.40	148.53	148.65	148.78	148.90	149.03	149.15	149.28	149.40	149.53	149.65	149.78	149.90	150.03	150.15	150.28	150.40	150.53	150.59
EXISTING LEVEL	148.08	147.98	147.97	147.93	149.04	148.94	146.76	144.66	144.94	145.56	144.21	144.13	144.39	145.00	145.45	145.71	145.85	146.19	146.74	147.29	147.55	147.61
ELEVATION DIFFERENCE	-0.05	0.18	0.31	0.47	-0.51	-0.28	2.02	4.24	4.09	3.60	5.07	5.27	5.14	4.66	4.33	4.20	4.18	3.97	3.54	3.12	2.98	2.98
CHAINAGE	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	537

RUNOFF DRAIN 1b LONGITUDINAL SECTION

1:2500



SECTION 5
1:100

NOTE:
RIP RAP CAN BE OMITTED IF COVER MATERIAL MEETS SAME SPECIFICATIONS.

TSF RUNOFF DRAIN DETAIL

SCALE 1:100 (1, 0.5, 0, 1, 2, 3, 4, 5m)
SCALE 1:2500 (25, 0, 25, 50, 75, 100, 125m)

CLIENT/PROJECT:

AGNICO EAGLE

MEADOWBANK GOLD MINE
NORTH CELL TSF CLOSURE DESIGN

PRODUCED BY:

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

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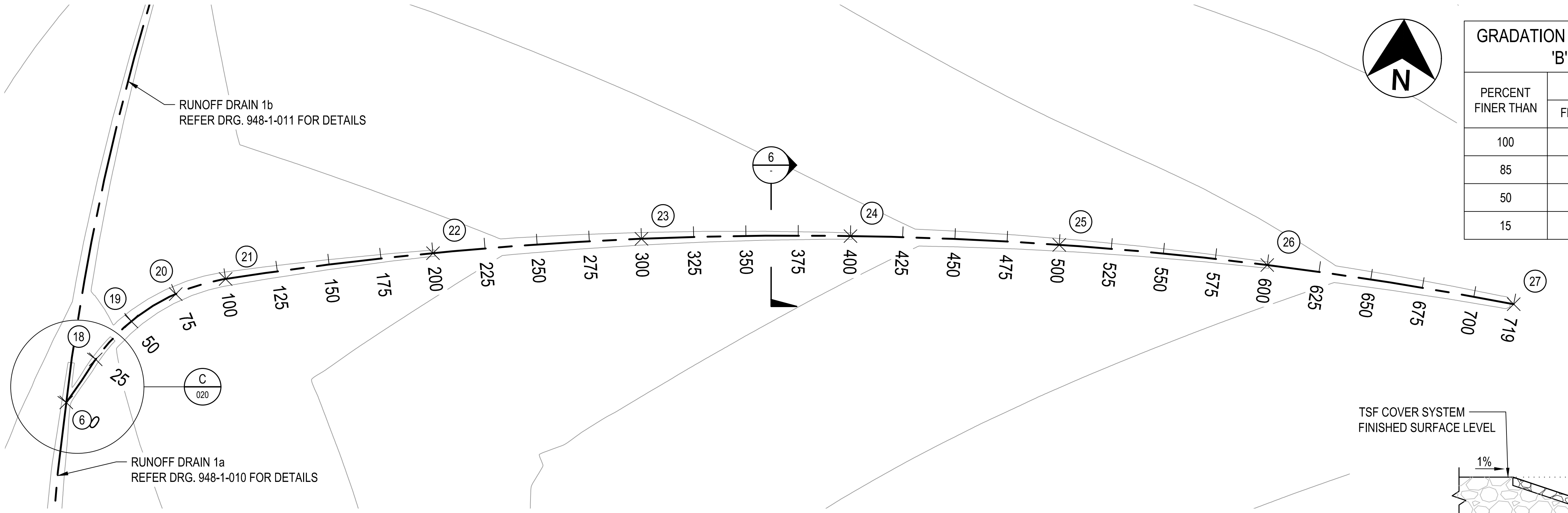
SCALE:	AS SHOWN	REPORT NUM:	948/1-02

RUNOFF DRAIN 1b LONGITUDINAL SECTION AND SETOUT DETAILS

DRG NUM: 948-1-011 Rev: 0



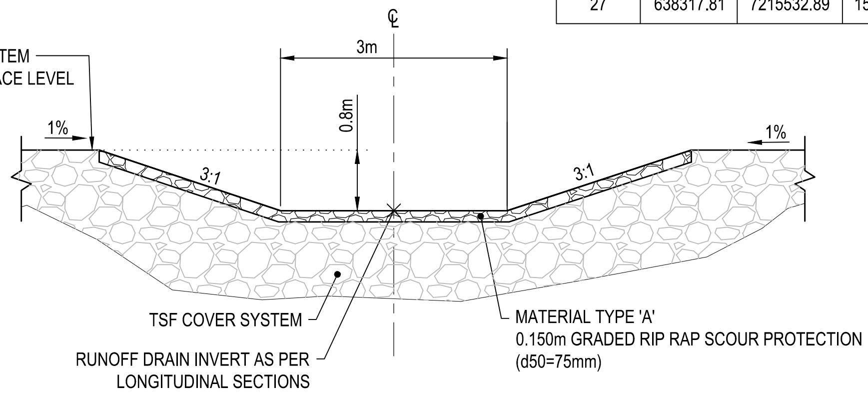
RUNNOFF DRAIN 1c SETOUT PLAN
1:2500

GRADATION LIMITS FOR TYPE 'A' AND TYPE 'B' RIP RAP MATERIALS

PERCENT FINER THAN	TYPE 'A'		TYPE 'B'	
	FL (mm)	CL (mm)	FL (mm)	CL (mm)
100	120	130	750	850
85	90	110	600	700
50	75	90	500	580
15	30	50	200	300

SETOUT DATA

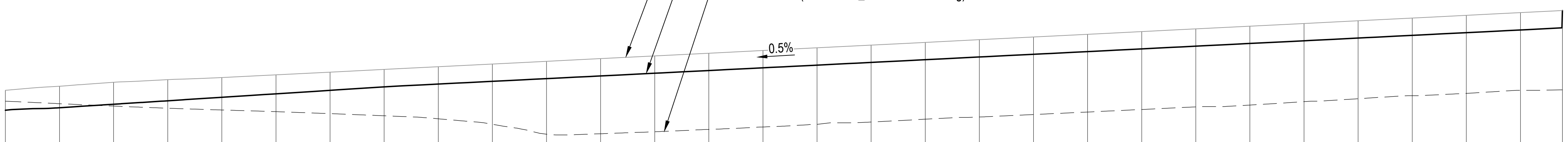
POINT #	EASTING	NORTHING	RL
6	637628.77	7215449.41	147.79
18	637641.73	7215470.78	147.92
19	637657.84	7215489.79	148.08
20	637678.33	7215503.96	148.23
21	637701.76	7215512.44	148.39
22	637800.19	7215530.00	149.00
23	637899.43	7215542.14	149.50
24	637999.21	7215548.70	150.00
25	638099.19	7215549.78	150.50
26	638199.07	7215545.39	151.00
27	638317.81	7215532.89	152.39



SECTION 6
1:100

NOTE:
RIP RAP CAN BE OMITTED IF COVER MATERIAL MEETS SAME SPECIFICATIONS.

TSF RUNOFF DRAIN DETAIL



VERT EXAG 10:1
DATUM: RL145

DESIGN LEVEL (INVERT)	147.90	148.06	148.22	148.38	148.54	148.70	148.86	149.00	149.12	149.25	149.37	149.50	149.62	149.75	149.87
EXISTING LEVEL	148.09	147.98	147.88	147.80	147.72	147.63	147.53	147.39	147.14	146.68	146.70	146.79	146.90	147.01	147.13
ELEVATION DIFFERENCE	-0.19	0.09	0.34	0.59	0.82	1.08	1.34	1.61	1.98	2.57	2.67	2.70	2.72	2.73	2.74
CHAINAGE	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375

DESIGN LEVEL (INVERT)	150.00	150.12	150.25	150.37	150.50	150.62	150.75	150.87	151.00	151.12	151.25	151.37	151.50	152.39
EXISTING LEVEL	147.24	147.37	147.47	147.59	147.70	147.82	147.94	148.03	148.18	148.32	148.46	148.57	148.71	148.73
ELEVATION DIFFERENCE	2.76	2.75	2.77	2.78	2.79	2.80	2.80	2.84	2.81	2.80	2.79	2.80	2.79	3.66
CHAINAGE	400	425	450	475	500	525	550	575	600	625	650	675	700	719

RUNOFF DRAIN 1c LONGITUDINAL SECTION
1:2500

SCALE 1:100
SCALE 1:2500

NOTES
1. EXISTING TSF ELEVATIONS SHOWN AS PER DTM PROVIDED BY AGNICO EAGLE ON 17 JUNE 2015 (As-built NC_contours 0.25m.dwg)
2. SETOUT ELEVATIONS REPRESENT INVERT OF RUNOFF DRAIN. REFER LONGITUDINAL SECTION FOR FURTHER DETAIL.
3. RIP RAP MATERIAL AS SPECIFIED IN GRADATION LIMITS TABLE TO BE DETERMINED BY SUPERVISING ENGINEER.

CLIENT/PROJECT:
AGNICO EAGLE
MEADOWBANK GOLD MINE
NORTH CELL TSF CLOSURE DESIGN

PRODUCED BY:
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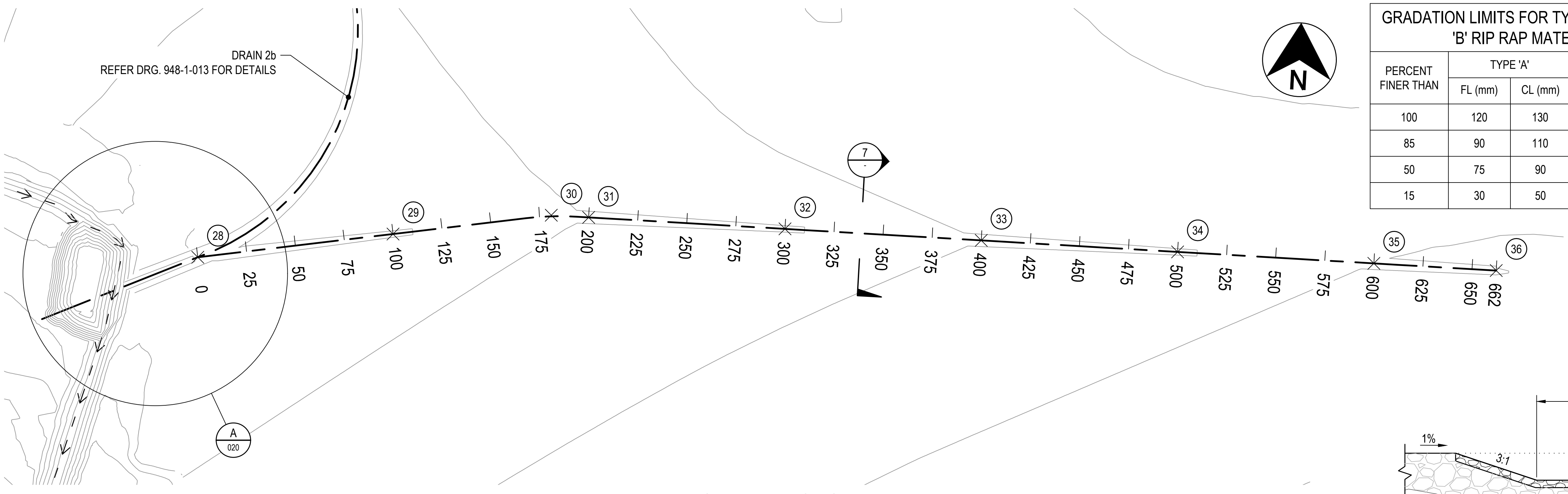
RUNOFF DRAIN 1c LONGITUDINAL SECTION AND SETOUT DETAILS

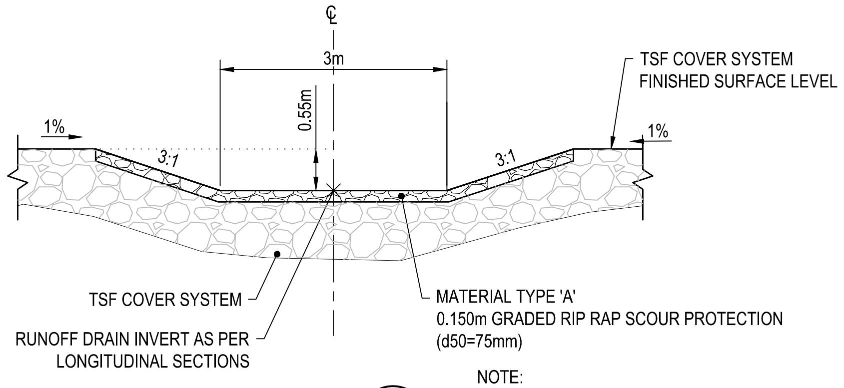
DRG NUM: 948-1-012 Rev: 0



RUNOFF DRAIN 2a SETOUT PLAN
1:2500

GRADATION LIMITS FOR TYPE 'A' AND TYPE 'B' RIP RAP MATERIALS				
PERCENT FINER THAN	TYPE 'A'		TYPE 'B'	
	FL (mm)	CL (mm)	FL (mm)	CL (mm)
100	120	130	750	850
85	90	110	600	700
50	75	90	500	580
15	30	50	200	300

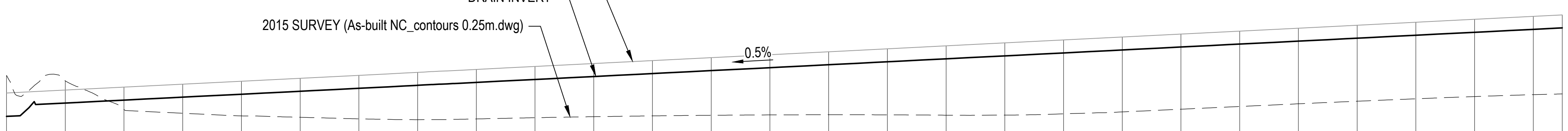
SETOUT DATA			
POINT #	EASTING	NORTHING	RL
28	637242.50	7216129.06	149.01
29	637266.37	7216031.95	149.95
30	637285.71	7215953.25	150.36
31	637286.92	7215934.26	150.45
32	637293.31	7215834.47	150.95
33	637299.70	7215734.67	151.45
34	637306.09	7215634.88	151.95
35	637312.48	7215535.08	152.45
36	637316.46	7215472.91	152.76



NOTE:
RIP RAP CAN BE OMITTED IF COVER MATERIAL MEETS SAME SPECIFICATIONS.

SECTION 7
1:100

TSF RUNOFF DRAIN DETAIL



VERT EXAG 10:1
DATUM: RL145

DESIGN LEVEL (INVERT)	149.57	149.70	149.82	149.95	150.07	150.20	150.33	150.45	150.58	150.70	150.83	150.95	151.08	151.20	151.33	151.45	151.58	151.70	151.83	151.95	152.08	152.20	152.33	152.45	152.58	152.70	152.76
EXISTING LEVEL	150.52	149.30	149.14	149.03	148.97	148.90	148.87	148.90	148.95	149.00	149.03	149.06	149.07	149.08	149.08	149.06	149.06	149.12	149.20	149.31	149.43	149.54	149.65	149.76	149.85	149.93	149.96
ELEVATION DIFFERENCE	-0.94	0.40	0.68	0.92	1.10	1.30	1.46	1.55	1.62	1.70	1.79	1.89	2.00	2.12	2.25	2.39	2.51	2.58	2.63	2.64	2.65	2.66	2.67	2.69	2.72	2.77	2.80
CHAINAGE	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	662

RUNOFF DRAIN 2a LONGITUDINAL SECTION
1:2500

NOTES

1. EXISTING TSF ELEVATIONS SHOWN AS PER DTM PROVIDED BY AGNICO EAGLE ON 17 JUNE 2015 (As-built NC_contours 0.25m.dwg)
2. SETOUT ELEVATIONS REPRESENT INVERT OF RUNOFF DRAIN. REFER LONGITUDINAL SECTION FOR FURTHER DETAIL.
3. RIP RAP MATERIAL AS SPECIFIED IN GRADATION LIMITS TABLE TO BE DETERMINED BY SUPERVISING ENGINEER.

1 0.5 0 1 2 3 4 5m
SCALE 1:100
25 0 25 50 75 100 125m
SCALE 1:2500

CLIENT/PROJECT:
AGNICO EAGLE
MEADOWBANK GOLD MINE
NORTH CELL TSF CLOSURE DESIGN

PRODUCED BY:
O'Kane Consultants Inc.
Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

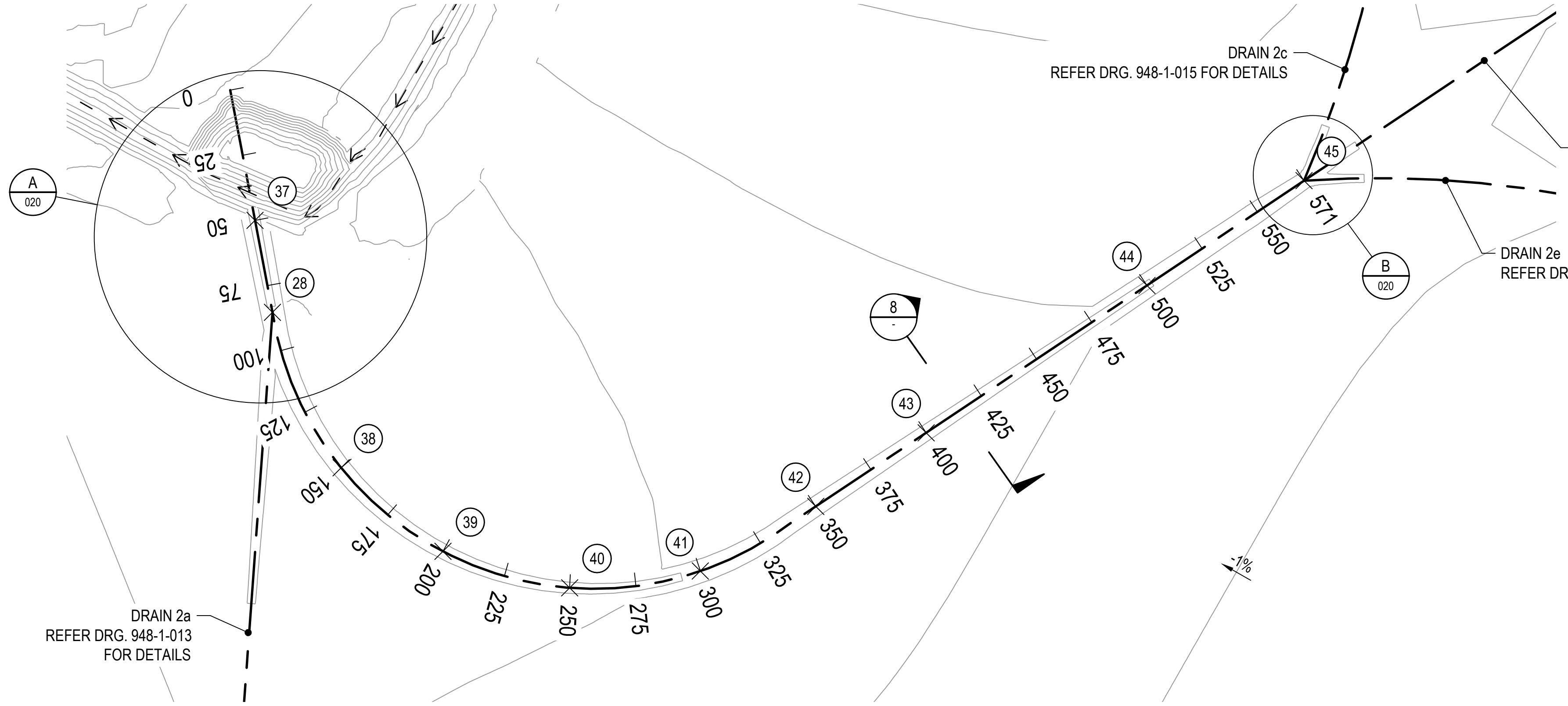
REFERENCE DWG. NO.	DESCRIPTION

REVISIONS NO.	DESCRIPTION	DRN. BY:	DATE
0	ISSUED TO CLIENT FOR REVIEW/INFORMATION	SMW	14.08.15
1	FINAL DESIGN ISSUE	SMW	17.11.15

REVD. BY:	BA & PG	DATE:	14.08.15
APPD. BY:	P. GARNEAU	DATE:	17.11.15
SCALE:	AS SHOWN	REPORT NUM:	948/1-02

RUNOFF DRAIN 2a LONGITUDINAL SECTION AND SETOUT DETAILS

DRG NUM: 736-4-002 Rev: 0

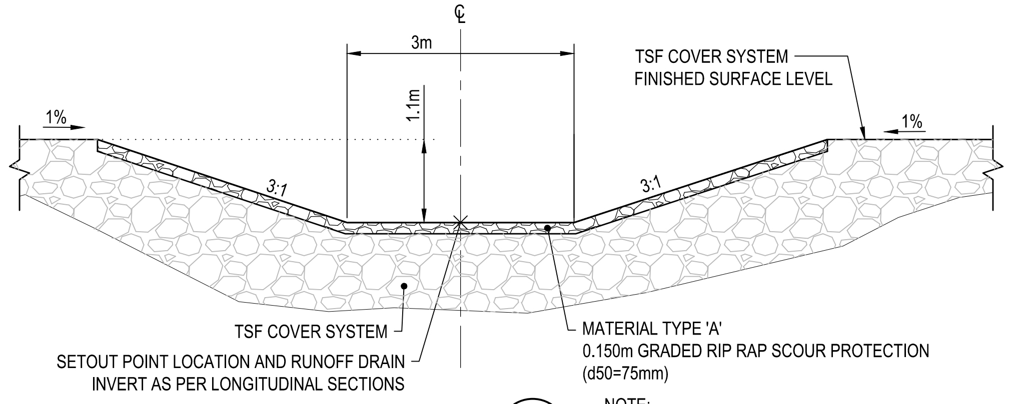


RUNOFF DRAIN 2b SETOUT PLAN

1:2500

GRADATION LIMITS FOR TYPE 'A' AND TYPE 'B' RIP RAP MATERIALS				
PERCENT FINER THAN	TYPE 'A'		TYPE 'B'	
	FL (mm)	CL (mm)	FL (mm)	CL (mm)
100	120	130	750	850
85	90	110	600	700
50	75	90	500	580
15	30	50	200	300

SETOUT DATA			
POINT #	EASTING	NORTHING	RL
28	637242.50	7216129.06	149.01
37	637225.58	7216159.98	148.84
38	637285.16	7216081.32	149.32
40	637381.01	7216064.87	149.80
41	637425.89	7216086.07	150.04
42	637459.73	7216122.61	150.27
43	637490.74	7216161.84	150.51
44	637552.75	7216240.28	150.99
45	637596.84	7216296.12	151.59



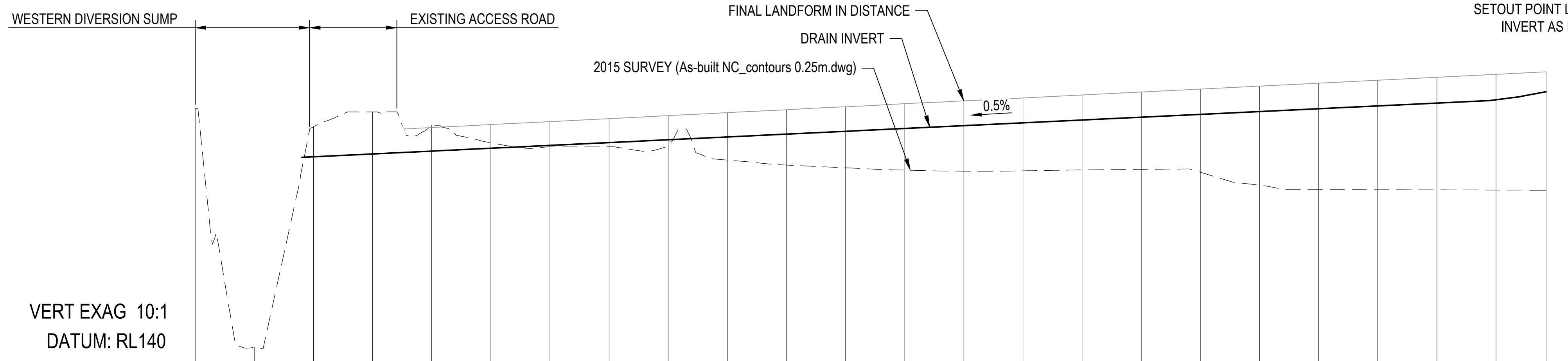
SECTION 8
1:100

NOTE:
RIP RAP CAN BE OMITTED IF COVER MATERIAL MEETS SAME SPECIFICATIONS.

TSF RUNOFF DRAIN DETAIL

NOTES

1. EXISTING TSF ELEVATIONS SHOWN AS PER DTM PROVIDED BY AGNICO EAGLE ON 17 JUNE 2015 (As-built NC_contours 0.25m.dwg)
2. SETOUT ELEVATIONS REPRESENT INVERT OF RUNOFF DRAIN. REFER LONGITUDINAL SECTION FOR FURTHER DETAIL.
3. RIP RAP MATERIAL AS SPECIFIED IN GRADATION LIMITS TABLE TO BE DETERMINED BY SUPERVISING ENGINEER.



DESIGN LEVEL (INVERT)			148.84	148.96	149.08	149.20	149.32	149.44	149.56	149.68	149.80	149.92	150.04	150.15	150.27	150.39	150.51	150.63	150.75	150.87	150.99	151.11	151.25	151.59
EXISTING LEVEL	150.90	140.81	150.11	150.74	150.16	149.43	149.26	149.26	149.34	148.70	148.49	148.37	148.28	148.23	148.25	148.28	148.31	148.19	147.64	147.46	147.45	147.44	147.43	147.43
ELEVATION DIFFERENCE			-1.26	-1.77	-1.08	-0.23	0.06	0.18	0.22	0.98	1.31	1.54	1.76	1.92	2.03	2.11	2.20	2.45	3.11	3.41	3.54	3.67	3.81	4.16
CHAINAGE		25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	571

RUNOFF DRAIN 2b LONGITUDINAL SECTION

1:2500

SCALE 1:100 (1 0.5 0 1 2 3 4 5m)

SCALE 1:2500 (25 0 25 50 75 100 125m)

CLIENT/PROJECT:

AGNICO EAGLE

MEADOWBANK GOLD MINE
NORTH CELL TSF CLOSURE DESIGN

PRODUCED BY:

O'Kane Consultants Inc.

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

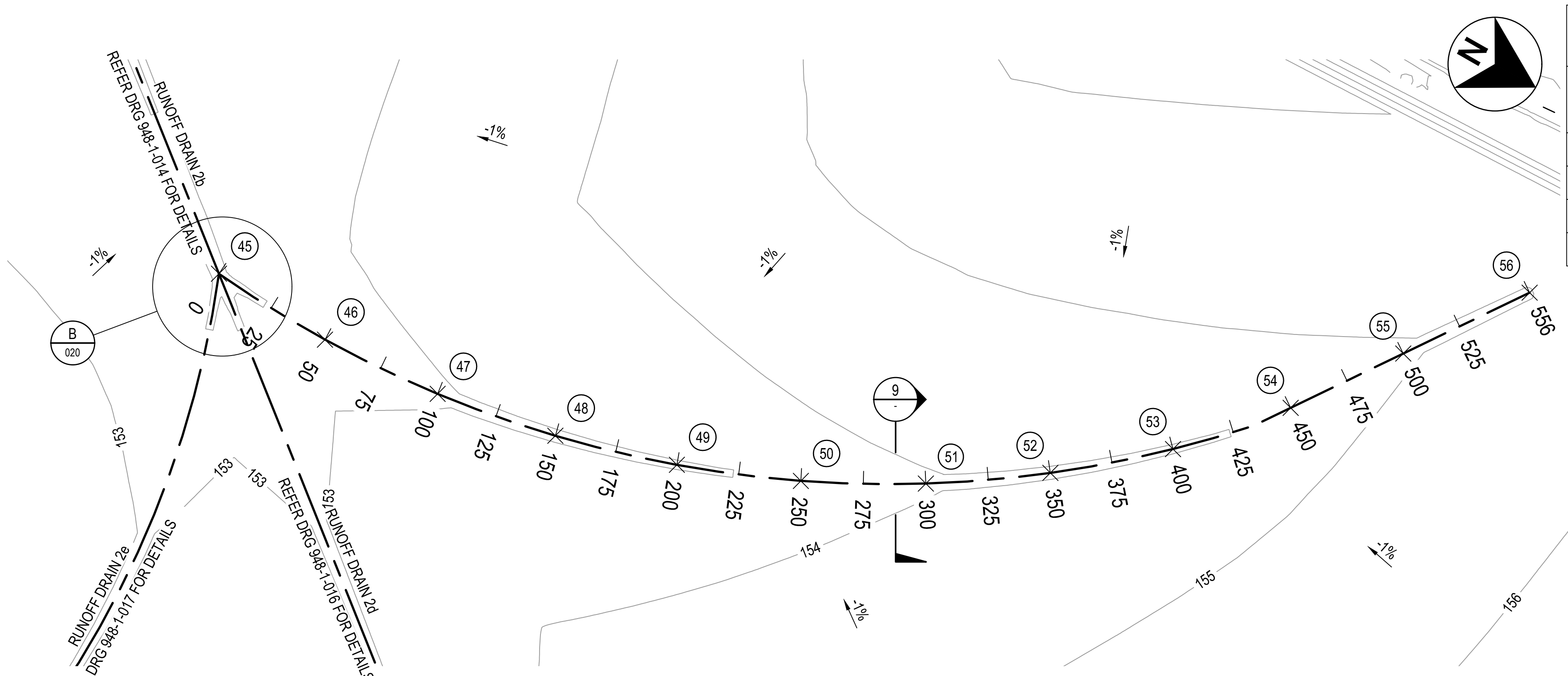
REFERENCE DWG. NO.	DESCRIPTION

REVISIONS NO.	DESCRIPTION	DRN. BY:	DATE
0	ISSUED TO CLIENT FOR REVIEW	SMW	14.08.15
1	FINAL DESIGN ISSUE	SMW	17.11.15

REVD. BY:	BA & PG	DATE:	14.08.15
APPD. BY:	P. GARNEAU	DATE:	17.11.15
SCALE:	AS SHOWN	REPORT NUM:	948/1-02

RUNOFF DRAIN 2a LONGITUDINAL SECTION AND SETOUT DETAILS

DRG NUM: 948-1-014 Rev: 0



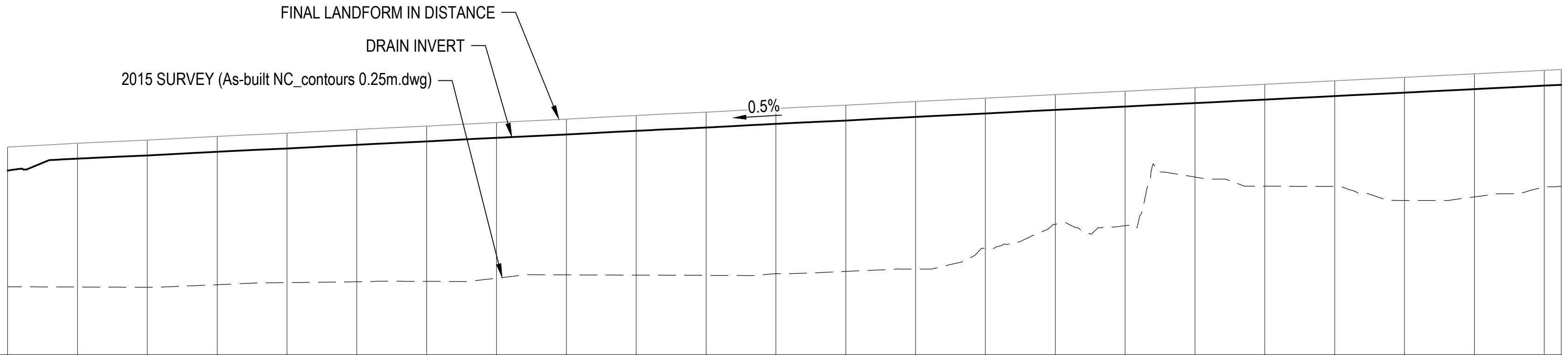
RUNOFF DRAIN 2c LAYOUT PLAN
1:2500

GRADATION LIMITS FOR TYPE 'A' AND TYPE 'B' RIP RAP MATERIALS

PERCENT FINER THAN	TYPE 'A' FL (mm)	TYPE 'A' CL (mm)	TYPE 'B' FL (mm)	TYPE 'B' CL (mm)
100	120	130	750	850
85	90	110	600	700
50	75	90	500	580
15	30	50	200	300

SETOUT DATA

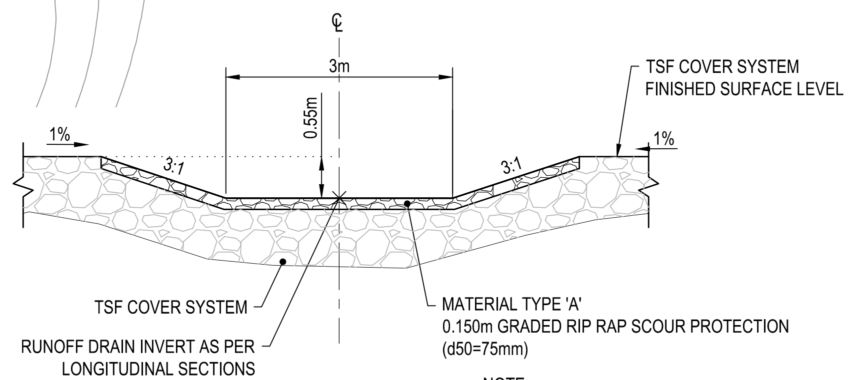
POINT #	EASTING	NORTHING	RL
45	637596.84	7216296.12	151.59
46	637598.64	7216346.05	152.13
47	637595.05	7216395.91	152.38
48	637586.18	7216445.09	152.63
49	637572.12	7216493.04	152.88
50	637553.03	7216539.25	153.13
51	637529.09	7216583.12	153.38
52	637500.62	7216624.20	153.63
53	637467.94	7216662.00	153.88
54	637430.24	7216694.62	154.13
55	637388.98	7216722.84	154.38
56	637342.69	7216754.57	154.66



CHAINAGE	25	50	75	100	125	150	175	200	225	250	275	300
DESIGN LEVEL (INVERT)	152.01	152.13	152.26	152.38	152.51	152.63	152.76	152.88	153.01	153.13	153.26	153.38
EXISTING LEVEL	147.42	147.41	147.50	147.57	147.61	147.62	147.73	147.85	147.84	147.84	147.90	147.98
ELEVATION DIFFERENCE	4.60	4.72	4.76	4.81	4.91	5.01	5.03	5.03	5.17	5.29	5.36	5.40

CHAINAGE	325	350	375	400	425	450	475	500	525	550	556
DESIGN LEVEL (INVERT)	153.51	153.63	153.76	153.88	154.01	154.13	154.25	154.38	154.50	154.63	154.66
EXISTING LEVEL	148.06	148.80	149.67	149.62	151.36	151.03	151.02	150.52	150.65	151.00	151.02
ELEVATION DIFFERENCE	5.45	4.83	4.09	4.26	2.65	3.10	3.23	3.86	3.86	3.63	3.64

RUNOFF DRAIN 2c LONGITUDINAL SECTION
1:2500

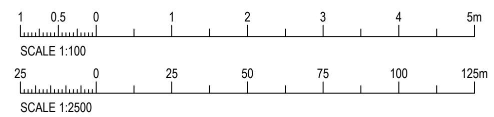


SECTION 9
1:100

NOTE:
RIP RAP CAN BE OMITTED IF COVER MATERIAL MEETS SAME SPECIFICATIONS.

TSF RUNOFF DRAIN DETAIL

NOTES
1. EXISTING TSF ELEVATIONS SHOWN AS PER DTM PROVIDED BY AGNICO EAGLE ON 17 JUNE 2015 (As-built NC_contours 0.25m.dwg)
2. SETOUT ELEVATIONS REPRESENT INVERT OF RUNOFF DRAIN. REFER LONGITUDINAL SECTION FOR FURTHER DETAIL.
3. RIP RAP MATERIAL AS SPECIFIED IN GRADATION LIMITS TABLE TO BE DETERMINED BY SUPERVISING ENGINEER.



CLIENT/PROJECT:
AGNICO EAGLE
MEADOWBANK GOLD MINE
NORTH CELL TSF CLOSURE DESIGN

PRODUCED BY:
O'Kane Consultants Inc.
Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

REFERENCE DWG. NO.	DESCRIPTION

REVISIONS NO.	DESCRIPTION	DRN. BY:	DATE
0	ISSUED TO CLIENT FOR REVIEW	SMW	14.08.15
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REVD. BY:	BA & PG	DATE:	14.08.15
APPD. BY:	P. GARNEAU	DATE:	17.11.15
SCALE:	AS SHOWN	REPORT NUM:	948/1-02

RUNOFF DRAIN 2c LONGITUDINAL SECTION & SETOUT DETAILS

DRG NUM: 948-1-015 Rev: 0

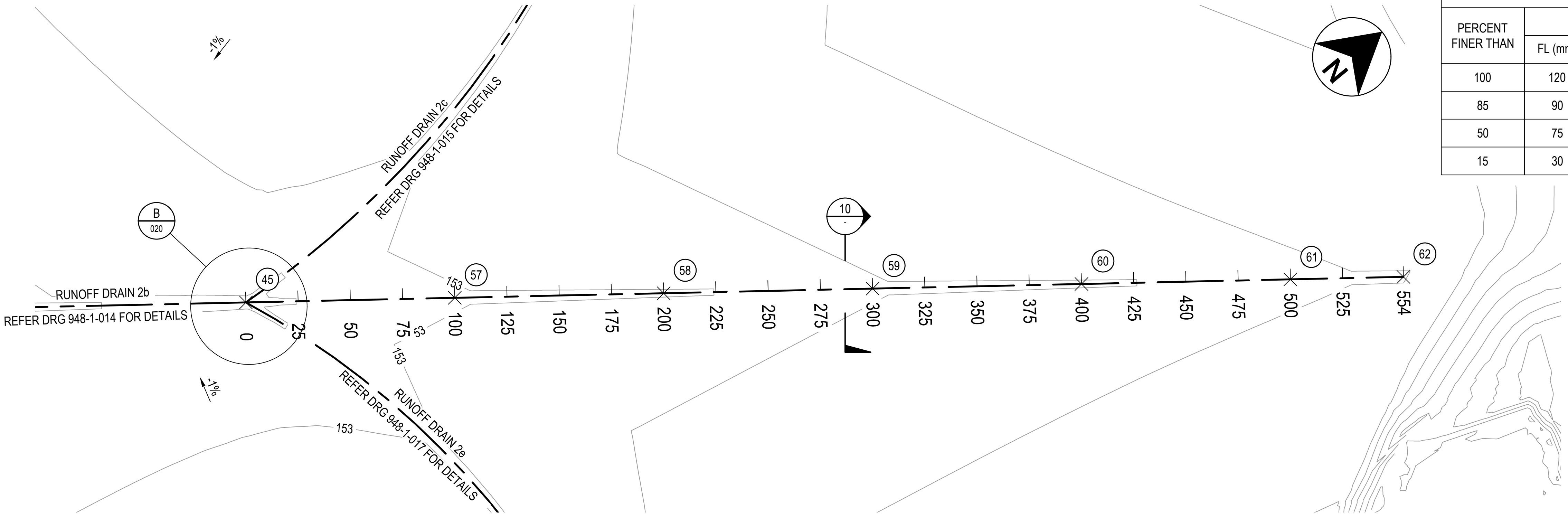
GRADATION LIMITS FOR TYPE 'A' AND TYPE 'B' RIP RAP MATERIALS				
PERCENT FINER THAN	TYPE 'A'		TYPE 'B'	
	FL (mm)	CL (mm)	FL (mm)	CL (mm)
100	120	130	750	850
85	90	110	600	700
50	75	90	500	580
15	30	50	200	300

SETOUT DATA

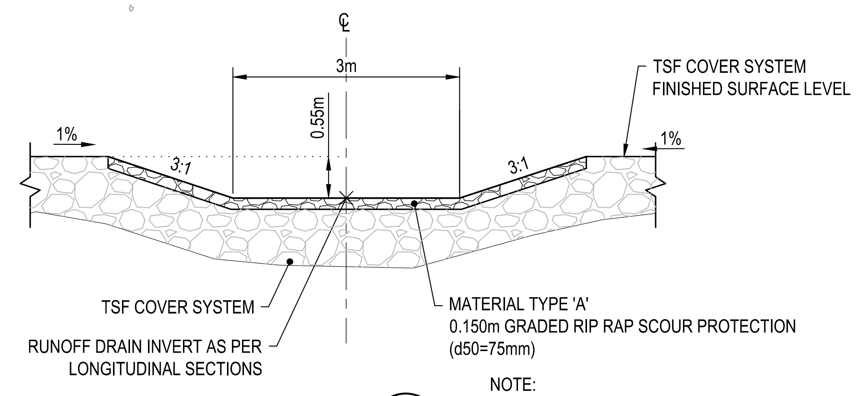
POINT #	EASTING	NORTHING	RL
47	637595.05	7216395.91	152.38
57	637658.87	7216374.56	152.38
58	637720.90	7216453.00	152.88
59	637782.89	7216531.46	153.38
60	637844.90	7216609.91	153.88
61	637906.93	7216688.34	154.29
62	637940.49	7216730.80	154.53

NOTES

1. EXISTING TSF ELEVATIONS SHOWN AS PER DTM PROVIDED BY AGNICO EAGLE ON 17 JUNE 2015 (As-built NC_contours 0.25m.dwg)
2. SETOUT ELEVATIONS REPRESENT INVERT OF RUNOFF DRAIN. REFER LONGITUDINAL SECTION FOR FURTHER DETAIL.
3. RIP RAP MATERIAL AS SPECIFIED IN GRADATION LIMITS TABLE TO BE DETERMINED BY SUPERVISING ENGINEER.



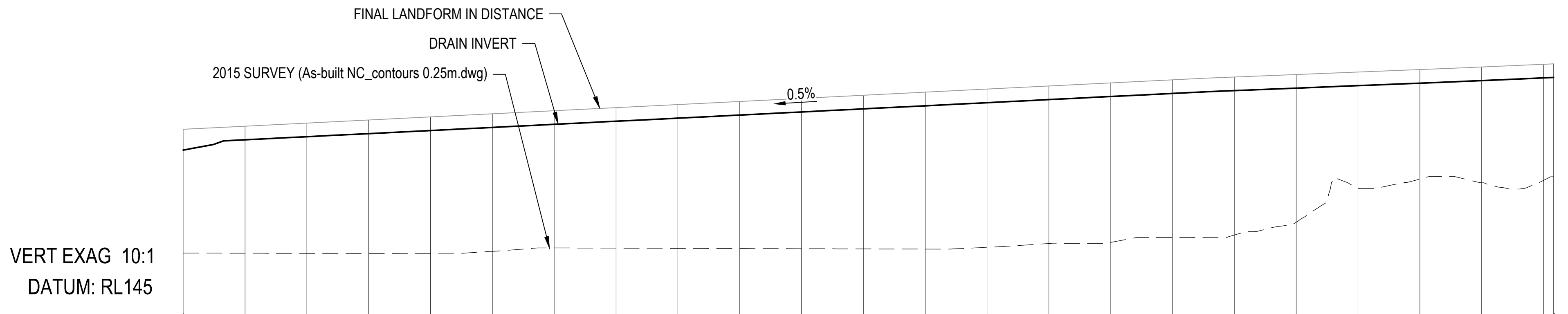
RUNOFF DRAIN 2d LAYOUT PLAN
1:2500



NOTE:
RIP RAP CAN BE OMITTED IF COVER MATERIAL MEETS SAME SPECIFICATIONS.

SECTION 10
1:100

TSF RUNOFF DRAIN DETAIL



DESIGN LEVEL (INVERT)	147.42	147.41	147.40	147.40	147.50	147.63	147.62	147.62	147.61	147.60	147.59	147.59	147.66	147.81	147.86	148.06	148.15	148.67	150.03	150.42	150.27	150.36	150.51
EXISTING LEVEL	147.42	147.41	147.40	147.40	147.50	147.63	147.62	147.62	147.61	147.60	147.59	147.59	147.66	147.81	147.86	148.06	148.15	148.67	150.03	150.42	150.27	150.36	150.51
ELEVATION DIFFERENCE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CHAINAGE	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	554

RUNOFF DRAIN 2d LONGITUDINAL SECTION
1:2500

SCALE 1:100
SCALE 1:2500

CLIENT/PROJECT:
AGNICO EAGLE
MEADOWBANK GOLD MINE
NORTH CELL TSF CLOSURE DESIGN

PRODUCED BY:
O'Kane Consultants Inc.
Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

REFERENCE DWG. NO.	DESCRIPTION

REVISIONS NO.	DESCRIPTION	DRN. BY:	DATE
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1	FINAL DESIGN ISSUE	SMW	17.11.15

REVD. BY:	BA & PG	DATE:	14.08.15
APPD. BY:	P. GARNEAU	DATE:	17.11.15
SCALE:	AS SHOWN	REPORT NUM:	948/1-02

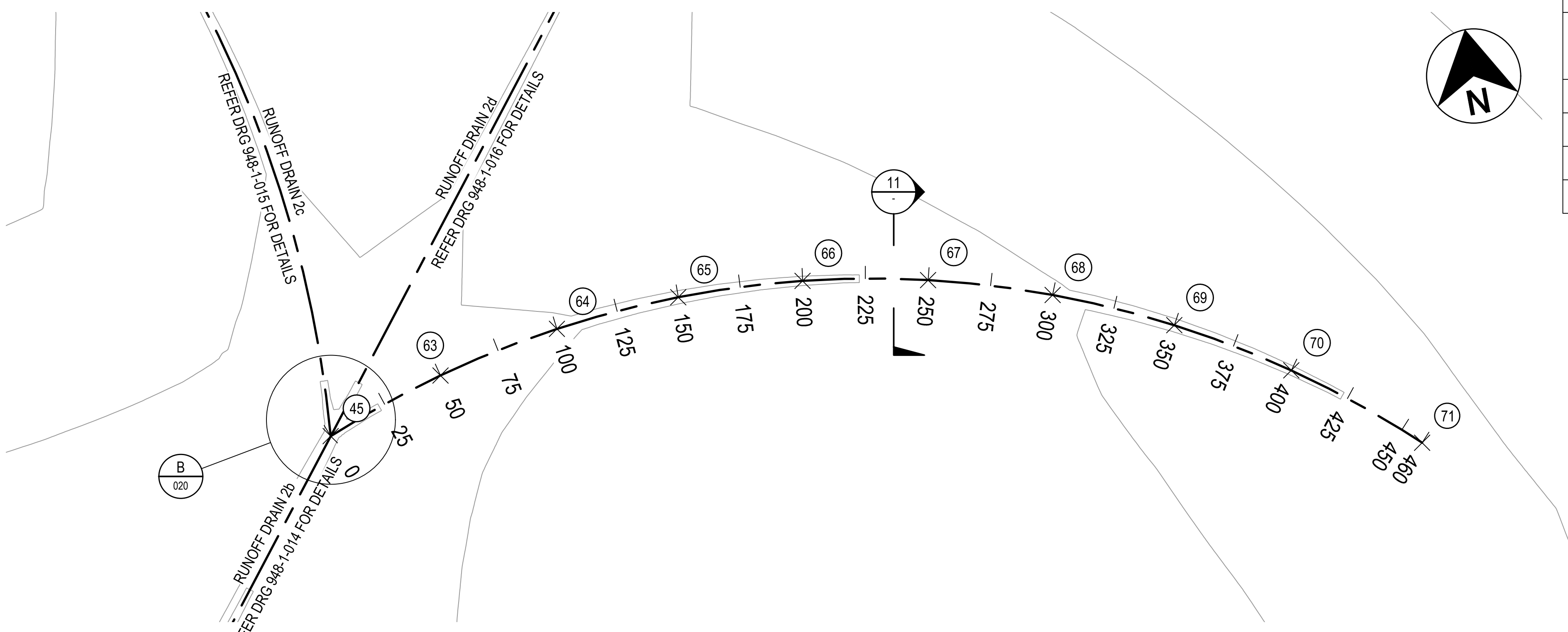
RUNOFF DRAIN 2d LONGITUDINAL SECTION & SETOUT DETAILS

DRG NUM: 948-1-016 Rev: 0

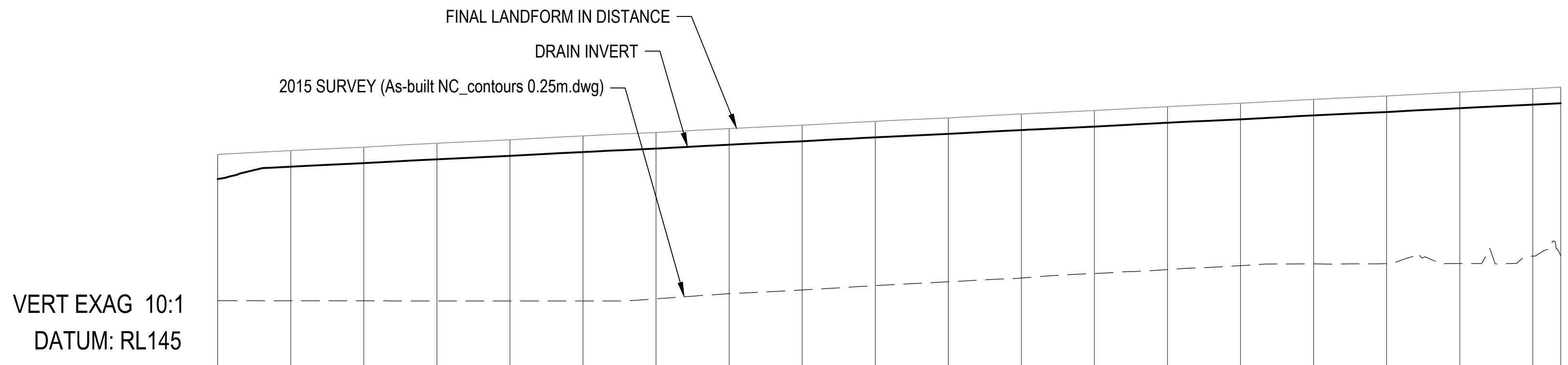
GRADATION LIMITS FOR TYPE 'A' AND TYPE 'B' RIP RAP MATERIALS				
PERCENT FINER THAN	TYPE 'A'		TYPE 'B'	
	FL (mm)	CL (mm)	FL (mm)	CL (mm)
100	120	130	750	850
85	90	110	600	700
50	75	90	500	580
15	30	50	200	300

SETOUT DATA

POINT #	EASTING	NORTHING	RL
45	637596.84	7216296.12	151.59
63	637644.29	7216311.84	152.13
64	637693.29	7216321.58	152.38
65	637743.14	7216325.11	152.63
66	637793.03	7216322.45	152.88
67	637842.21	7216313.57	153.13
68	637889.91	7216298.65	153.38
69	637935.36	7216277.96	153.63
70	637977.89	7216251.74	153.88
71	638023.87	7216213.85	154.18

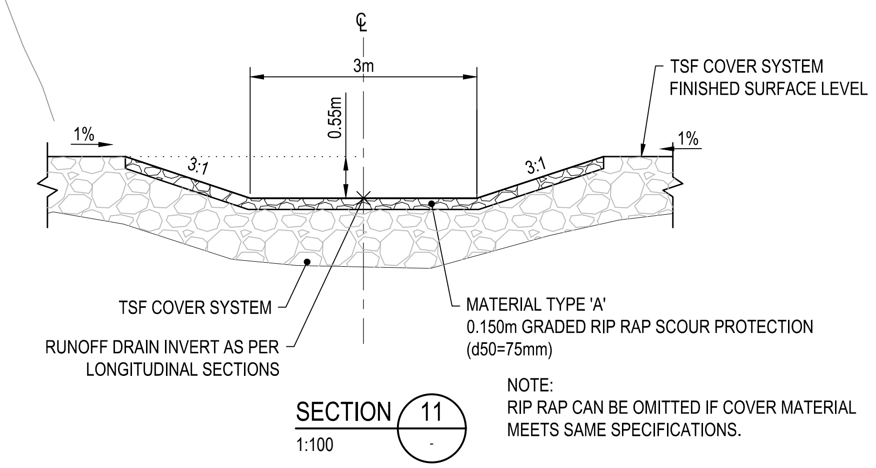


RUNOFF DRAIN 2e LAYOUT PLAN
1:2500



DESIGN LEVEL (INVERT)	152.01	152.13	152.26	152.38	152.51	152.63	152.76	152.88	153.01	153.13	153.26	153.38	153.51	153.63	153.76	153.88	154.01	154.13	154.18
EXISTING LEVEL	147.42	147.42	147.42	147.42	147.42	147.49	147.67	147.79	147.94	148.07	148.20	148.36	148.49	148.63	148.69	148.69	148.70	148.95	148.97
ELEVATION DIFFERENCE	4.59	4.71	4.84	4.96	5.10	5.14	5.10	5.09	5.07	5.06	5.06	5.02	5.02	5.00	5.08	5.19	5.32	5.18	5.20
CHAINAGE	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	460

RUNOFF DRAIN 2e LONGITUDINAL SECTION
1:2500



NOTE:
RIP RAP CAN BE OMITTED IF COVER MATERIAL MEETS SAME SPECIFICATIONS.

SECTION 11 -
1:100

TSF RUNOFF DRAIN DETAIL

NOTES

1. EXISTING TSF ELEVATIONS SHOWN AS PER DTM PROVIDED BY AGNICO EAGLE ON 17 JUNE 2015 (As-built NC_contours 0.25m.dwg)
2. SETOUT ELEVATIONS REPRESENT INVERT OF RUNOFF DRAIN. REFER LONGITUDINAL SECTION FOR FURTHER DETAIL.
3. RIP RAP MATERIAL AS SPECIFIED IN GRADATION LIMITS TABLE TO BE DETERMINED BY SUPERVISING ENGINEER.

SCALE 1:100 (1 0.5 0 1 2 3 4 5m)
SCALE 1:2500 (25 0 25 50 75 100 125m)

CLIENT/PROJECT:
AGNICO EAGLE
MEADOWBANK GOLD MINE
NORTH CELL TSF CLOSURE DESIGN

PRODUCED BY:
O'Kane Consultants Inc.
Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

REFERENCE DWG. NO.	DESCRIPTION

REVISIONS NO.	DESCRIPTION	DRN. BY:	DATE
0	ISSUED TO CLIENT FOR REVIEW	SMW	14.08.15
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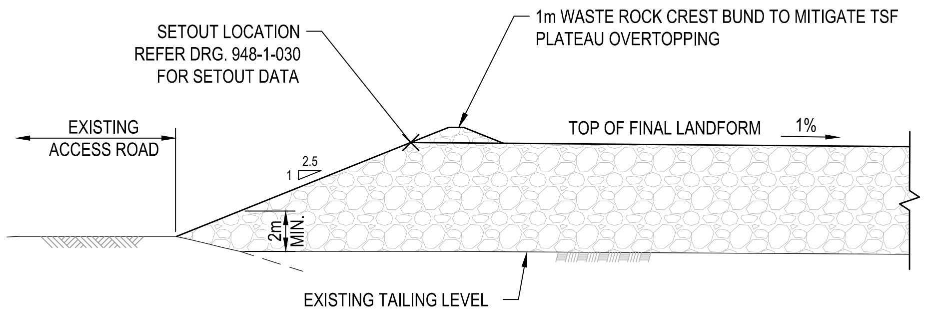
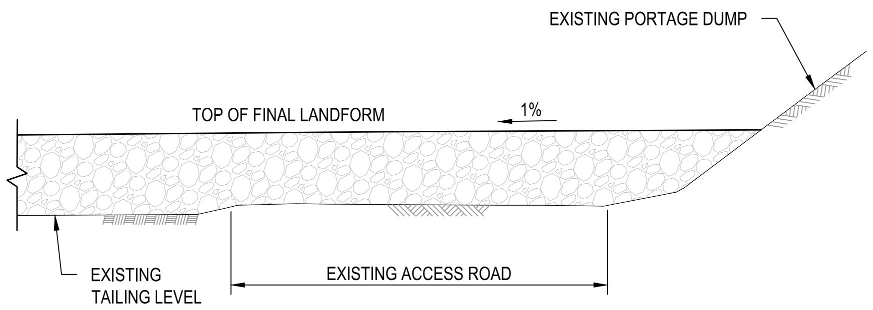
REVD. BY:	BA & PG	DATE:	14.08.15
APPD. BY:	P. GARNEAU	DATE:	17.11.15
SCALE:	AS SHOWN	REPORT NUM:	948/1-02

RUNOFF DRAIN 2e LONGITUDINAL SECTION & SETOUT DETAILS

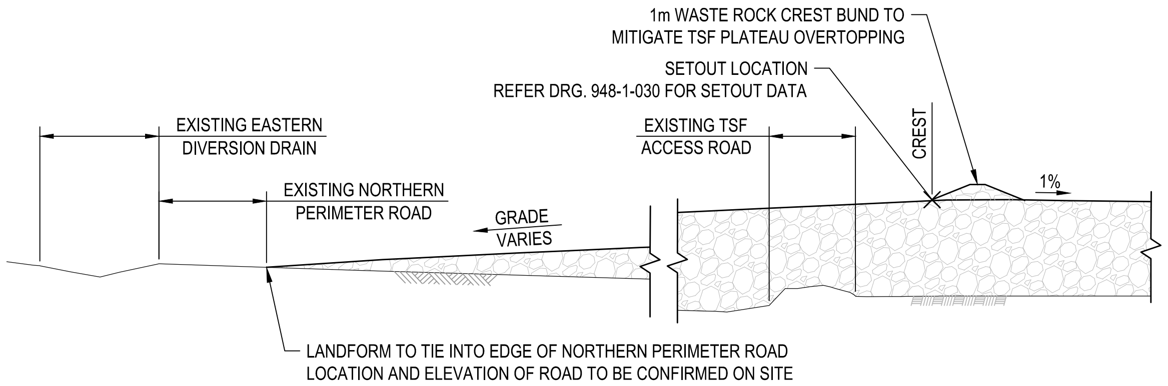
DRG NUM: 948-1-017 Rev: 1



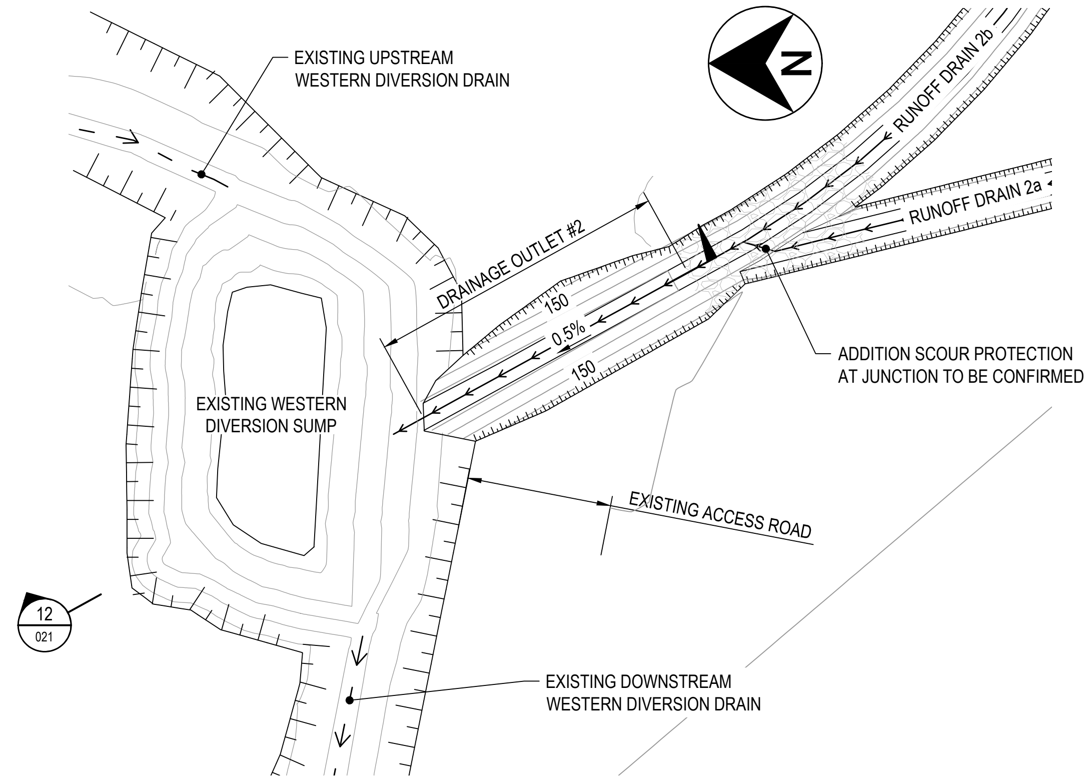
SECTION 1
1:500
002



SECTION 2
1:500
002

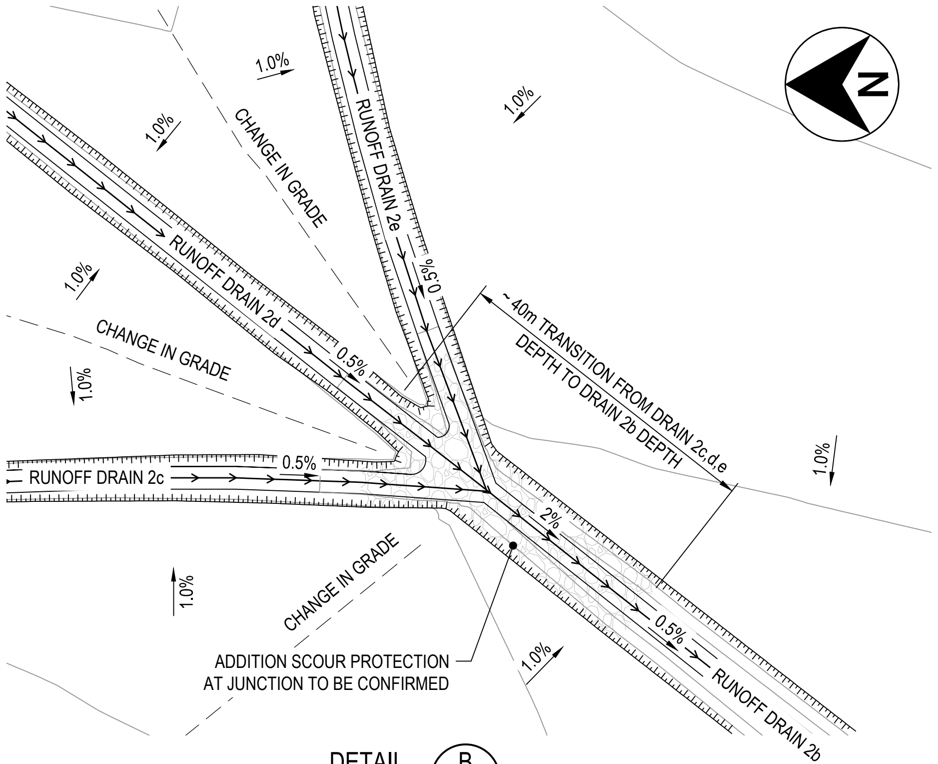


SECTION 3
1:500
002



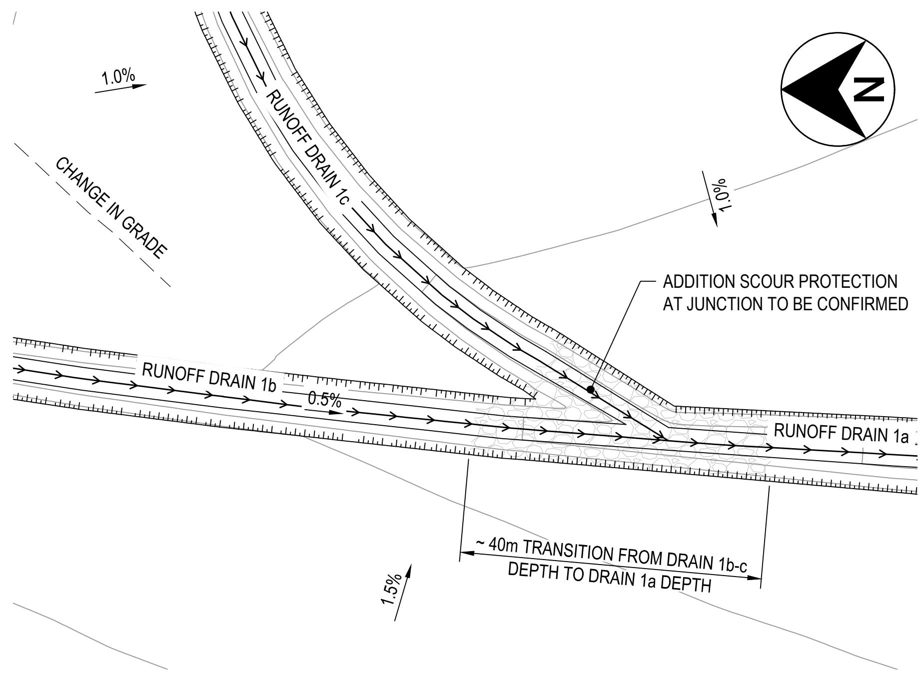
DETAIL A
1:1000
002

RUNOFF DRAIN JUNCTION 3 & LANDFORM DRAINAGE OUTLET #2



DETAIL B
1:1000
002

RUNOFF DRAIN JUNCTION 2



DETAIL C
1:1000
002

RUNOFF DRAIN JUNCTION 1

CLIENT/PROJECT:

AGNICO EAGLE

MEADOWBANK GOLD MINE
NORTH CELL TSF CLOSURE DESIGN

5 0 5 10 15 20 25
SCALE 1:500

10 5 0 10 20 30 40 50m
SCALE 1:1000

PRODUCED BY:

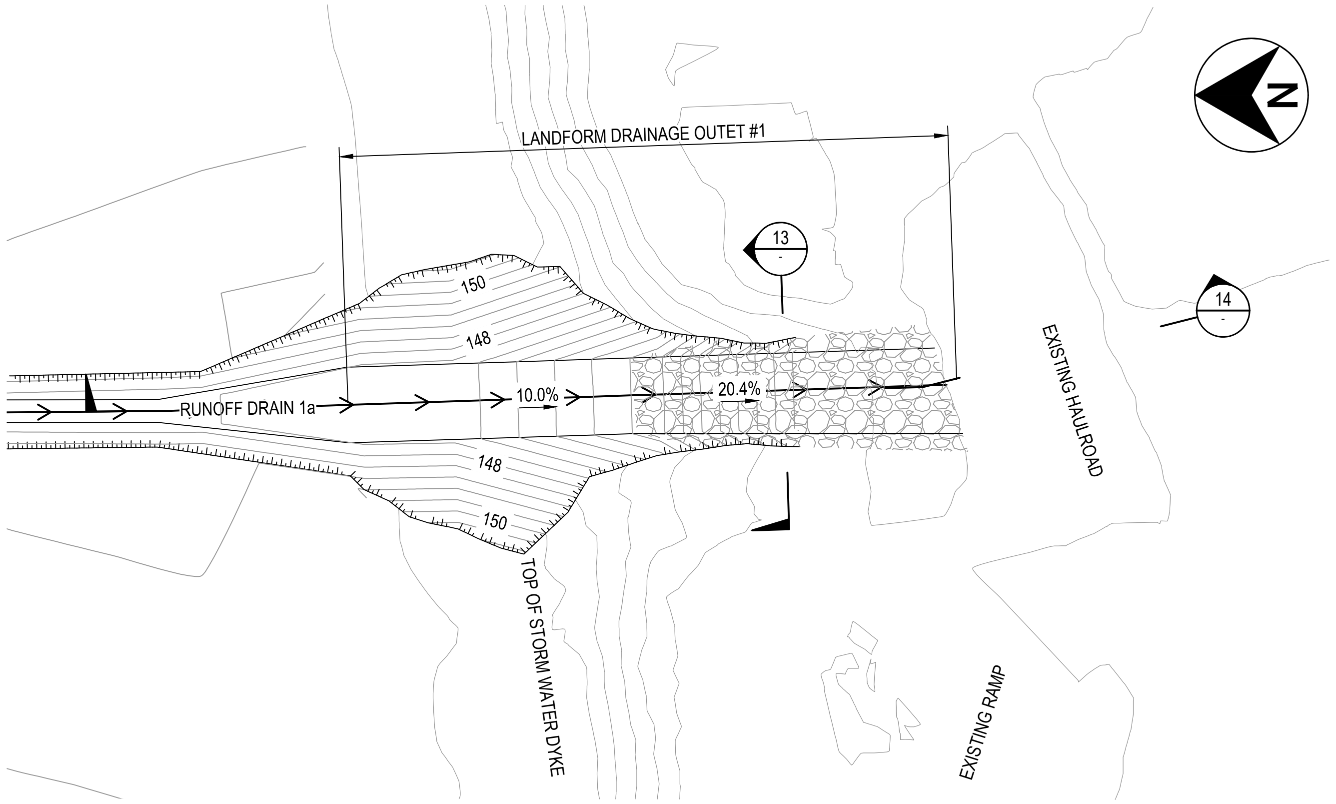
O'Kane Consultants Inc.
Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

REFERENCE DWG. NO.	DESCRIPTION	REVISIONS NO.	DESCRIPTION	DRN. BY:	DATE
		0	ISSUED TO CLIENT FOR REVIEW	SMW	14.08.15
		1	FINAL DESIGN ISSUE	SMW	17.11.15

REVD. BY:	BA & PG	DATE:	14.08.15
APPD. BY:	P. GARNEAU	DATE:	17.11.15
SCALE:	AS SHOWN	REPORT NUM:	948/1-02

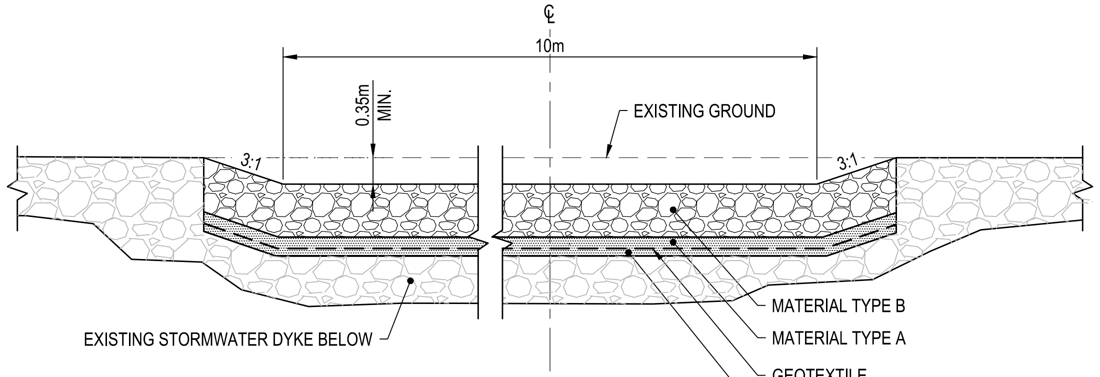
DRAINAGE SECTIONS AND DETAILS
SHEET 1 OF 2

DRG NUM: 948-1-020 Rev: 0



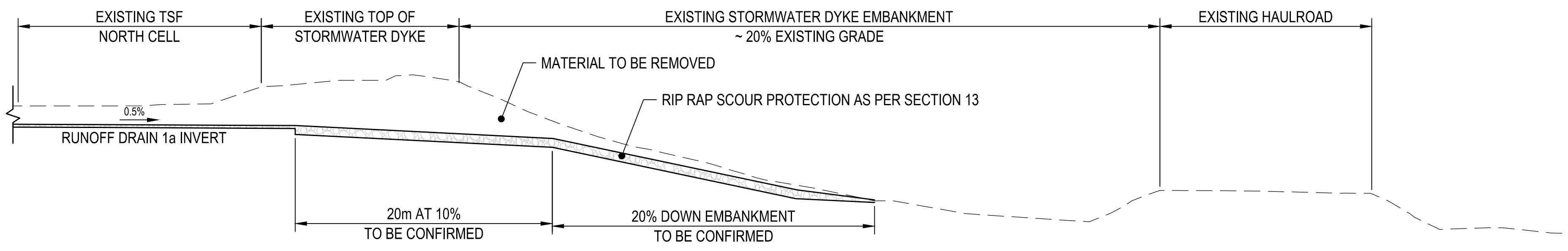
DETAIL D
1:1,000

LANDFORM DRAINAGE OUTLET #1

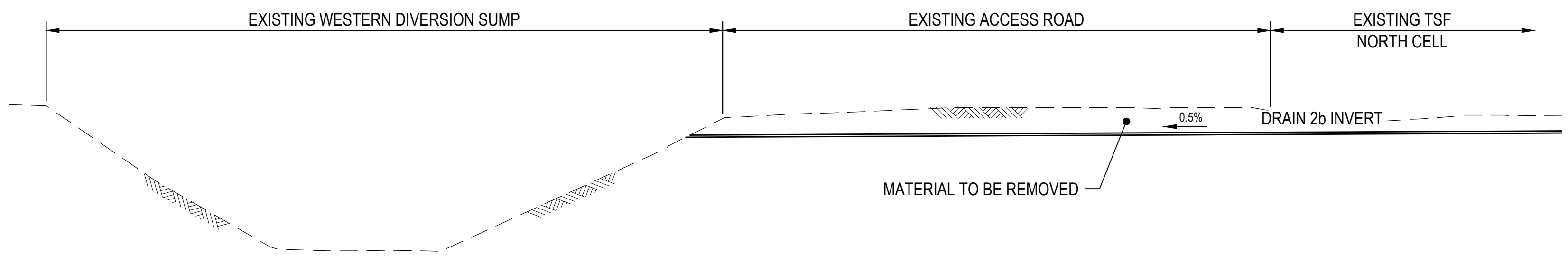


SECTION 13
1:100

DRAINAGE OUTLET #1 SCOUR PROTECTION	
MATERIAL TYPE B	0.75m GRADED RIP RAP SCOUR PROTECTION (d50=500mm)
MATERIAL TYPE A	0.15m BEDDING MATERIAL OVERLAYING LINER OR APPROVED MATERIAL (d50=75mm)
MATERIAL TYPE C	0.1m BEDDING SAND OR APPROVED MATERIAL
GEOTEXTILE	500 g/m², NON WOVEN, NEEDLE PUNCHED



SECTION 14
1:500



SECTION 12 020
1:500

SCALE 1:250 (2.5, 0, 2.5, 5, 7.5, 10, 12.5)
SCALE 1:500 (5, 0, 5, 10, 15, 20, 25)

CLIENT/PROJECT:
AGNICO EAGLE
MEADOWBANK GOLD MINE
NORTH CELL TSF CLOSURE DESIGN

PRODUCED BY:
O'Kane Consultants Inc.
Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

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DRAINAGE SECTIONS AND DETAILS SHEET 2 OF 2

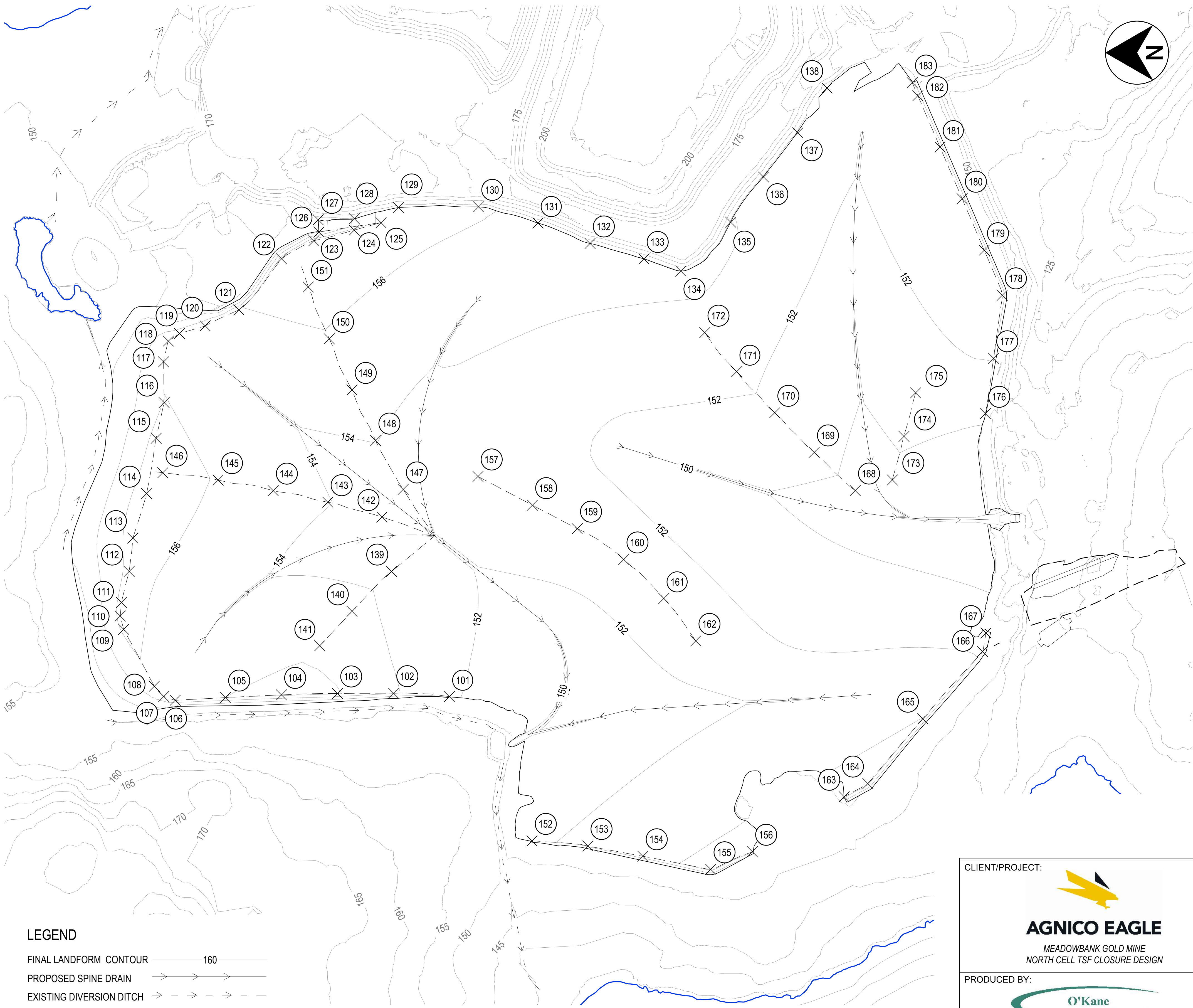
DRG NUM: 948-1-021 Rev: 1

SETOUT DATA			
POINT #	EASTING	NORTHING	R.L.
101	637310.01	7216269.84	152.41
102	637316.27	7216369.46	154.23
103	637315.80	7216469.46	156.14
104	637313.24	7216569.42	156.48
105	637308.36	7216669.30	156.00
106	637303.53	7216758.96	155.36
107	637310.39	7216779.27	155.44
108	637328.62	7216796.08	155.65
109	637430.19	7216850.88	156.41
110	637453.81	7216856.78	156.51
111	637477.93	7216854.86	156.53
112	637533.24	7216840.97	156.49
113	637592.84	7216834.45	156.82
114	637672.07	7216809.81	157.22
115	637770.60	7216792.91	156.55
116	637834.36	7216778.65	156.08
117	637907.02	7216779.67	155.72
118	637944.01	7216771.02	155.45
119	637957.40	7216751.15	155.21
120	637971.20	7216705.36	155.47
121	637999.71	7216645.22	155.94
122	638090.66	7216569.24	157.11
123	638123.15	7216511.46	157.32
124	638141.92	7216439.46	157.01
125	638155.10	7216391.73	156.85
126	638138.47	7216502.73	151.99
127	638160.29	7216503.76	151.53
128	638162.03	7216439.14	154.25
129	638182.16	7216360.96	156.84
130	638183.28	7216217.85	156.16
131	638154.50	7216111.83	155.42
132	638118.06	7216018.98	155.11
133	638090.55	7215922.88	154.70
134	638068.84	7215857.32	154.40
135	638156.25	7215768.40	154.07
136	638236.59	7215709.60	153.62
137	638315.49	7215648.30	153.32
138	638395.18	7215596.43	152.38
139	637533.13	7216373.18	153.49
140	637462.19	7216443.47	154.56
141	637400.75	7216501.21	155.44
142	637630.28	7216390.31	153.22
143	637656.74	7216486.59	154.07
144	637677.45	7216584.20	154.96

SETOUT DATA			
POINT #	EASTING	NORTHING	R.L.
145	637696.09	7216682.17	155.86
146	637709.32	7216781.02	156.78
147	637679.52	7216352.32	153.21
148	637766.61	7216401.29	154.05
149	637856.88	7216443.63	154.94
150	637947.99	7216483.99	155.84
151	638040.40	7216521.46	156.77
152	637052.90	7216122.44	151.63
153	637043.83	7216022.99	152.46
154	637025.45	7215924.71	153.33
155	637002.14	7215803.73	154.47
156	637033.49	7215729.38	154.60
157	637702.66	7216218.88	153.76
158	637651.52	7216121.76	153.43
159	637609.68	7216041.82	153.14
160	637554.73	7215958.90	152.94
161	637485.21	7215887.38	152.96
162	637409.43	7215830.51	153.14
163	637131.66	7215565.72	154.57
164	637155.14	7215523.51	154.59
165	637270.75	7215425.40	154.02
166	637390.41	7215319.06	151.66
167	637423.48	7215312.94	151.15
168	637677.48	7215546.10	149.59
169	637745.51	7215619.30	150.57
170	637816.22	7215689.82	151.54
171	637889.49	7215757.54	152.50
172	637959.14	7215814.35	153.34
173	637696.38	7215479.71	149.44
174	637774.04	7215459.07	150.26
175	637851.70	7215438.44	150.97
176	637814.48	7215313.82	150.37
177	637913.43	7215299.39	152.10
178	638025.60	7215284.07	153.54
179	638105.98	7215316.00	153.70
180	638197.89	7215355.40	153.76
181	638289.78	7215394.86	153.74
182	638381.62	7215434.43	153.66
183	638404.90	7215444.46	153.63

NOTE:

1. EXISTING TSF ELEVATIONS SHOWN AS PER DTM PROVIDED BY AGNICO EAGLE ON 17 JUNE 2015 (As-built NC_contours 0.25m.dwg)
2. ALL UNITS IN METERS U.N.O.
3. REFER DRG. 948-1-020, SECTIONS 1, 2 AND 3 FOR INDICATIVE SETOUT POINT LOCATIONS



LEGEND

FINAL LANDFORM CONTOUR — 160

PROPOSED SPINE DRAIN

EXISTING DIVERSION DITCH

CHANGE IN GRADE (CREST)

LANDFORM SETOUT PLAN

1:7,500

0 75 150 225 300 375 450 525 600m

SCALE 1:7500

CLIENT/PROJECT:

AGNICO EAGLE

MEADOWBANK GOLD MINE
NORTH CELL TSF CLOSURE DESIGN

PRODUCED BY:

O'Kane Consultants Inc.

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

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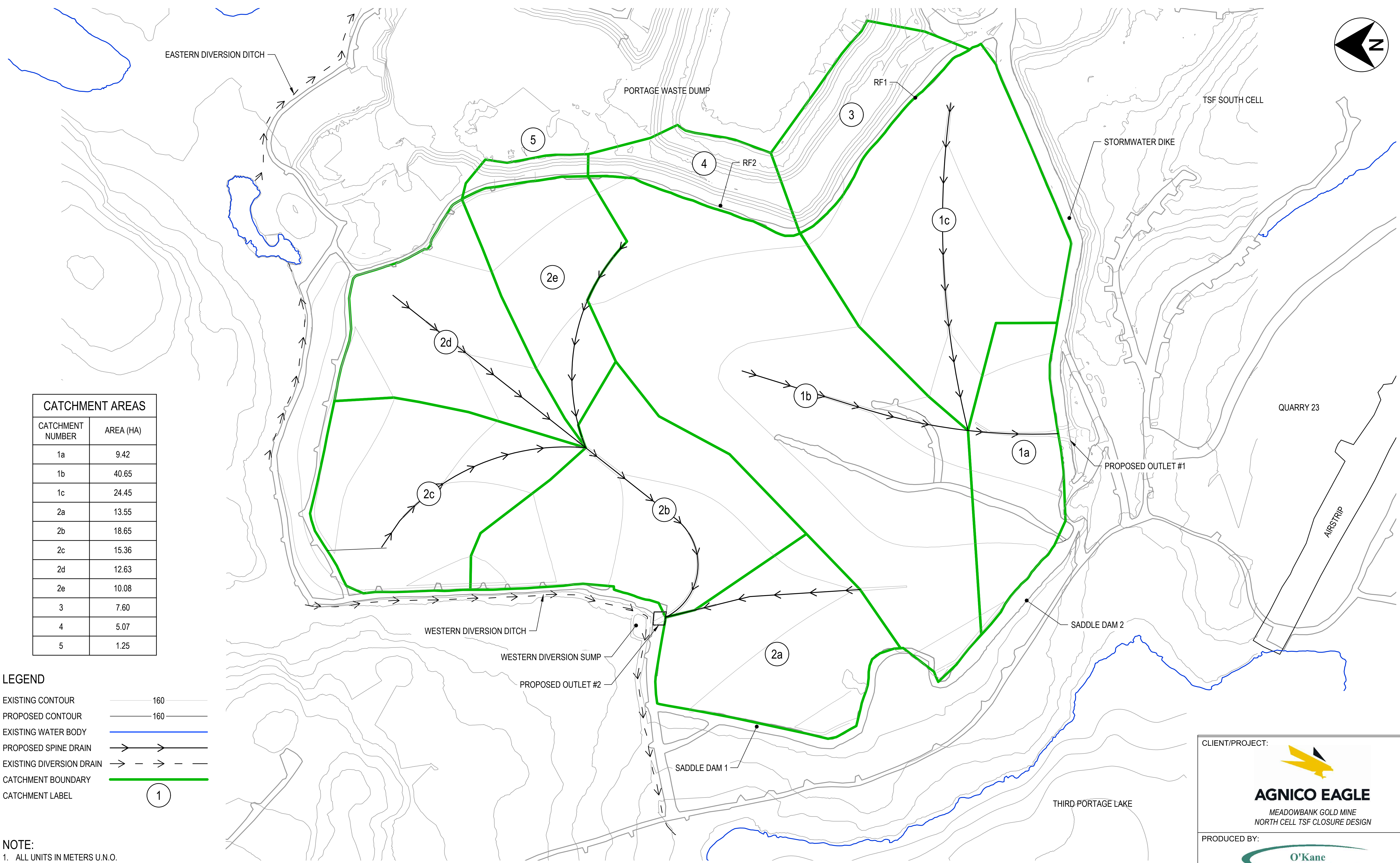
LANDFORM SETOUT PLAN

DRG NUM: 948-1-030 Rev: 1



CATCHMENT AREAS

CATCHMENT NUMBER	AREA (HA)
1a	9.42
1b	40.65
1c	24.45
2a	13.55
2b	18.65
2c	15.36
2d	12.63
2e	10.08
3	7.60
4	5.07
5	1.25

LEGEND

- EXISTING CONTOUR — 160
- PROPOSED CONTOUR — 160
- EXISTING WATER BODY
- PROPOSED SPINE DRAIN
- EXISTING DIVERSION DRAIN
- CATCHMENT BOUNDARY
- CATCHMENT LABEL — 1

NOTE:

1. ALL UNITS IN METERS U.N.O.
2. EXISTING TSF CONTOURS DEPICT NOVEMBER 2014 LEVELS AS PROVIDED BY AGNICO EAGLE.

CATCHMENT PLAN
1:7,500

REFERENCE DWG. NO.	DESCRIPTION

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CLIENT/PROJECT:
AGNICO EAGLE
MEADOWBANK GOLD MINE
NORTH CELL TSF CLOSURE DESIGN

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Integrated Mine Waste Management and Closure Services
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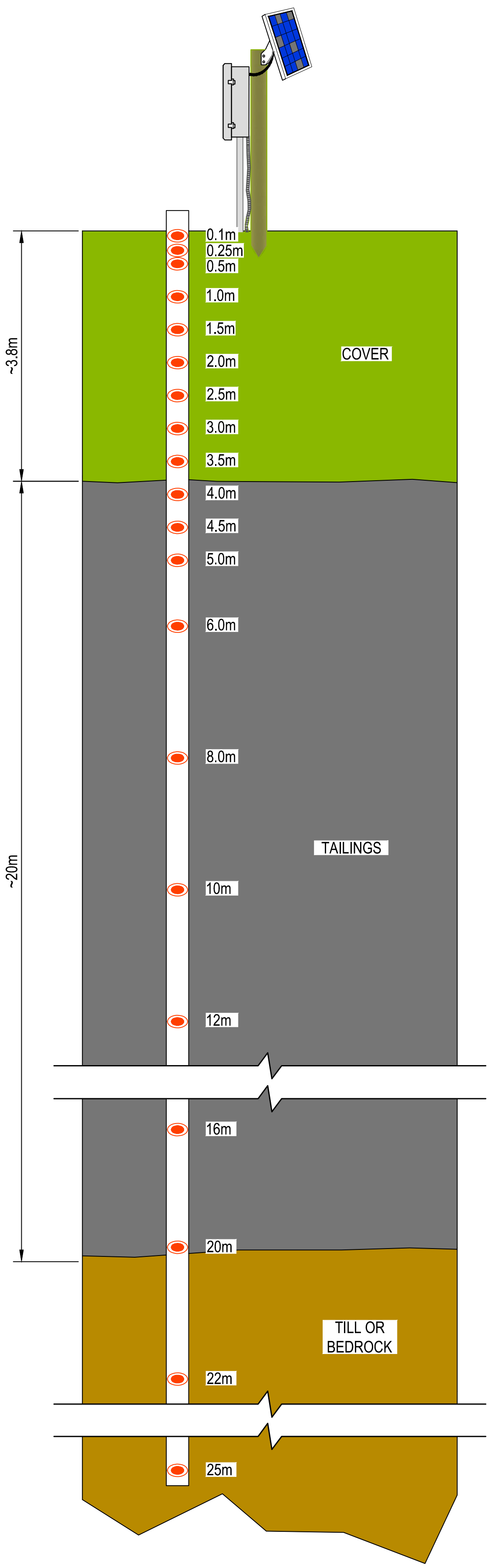
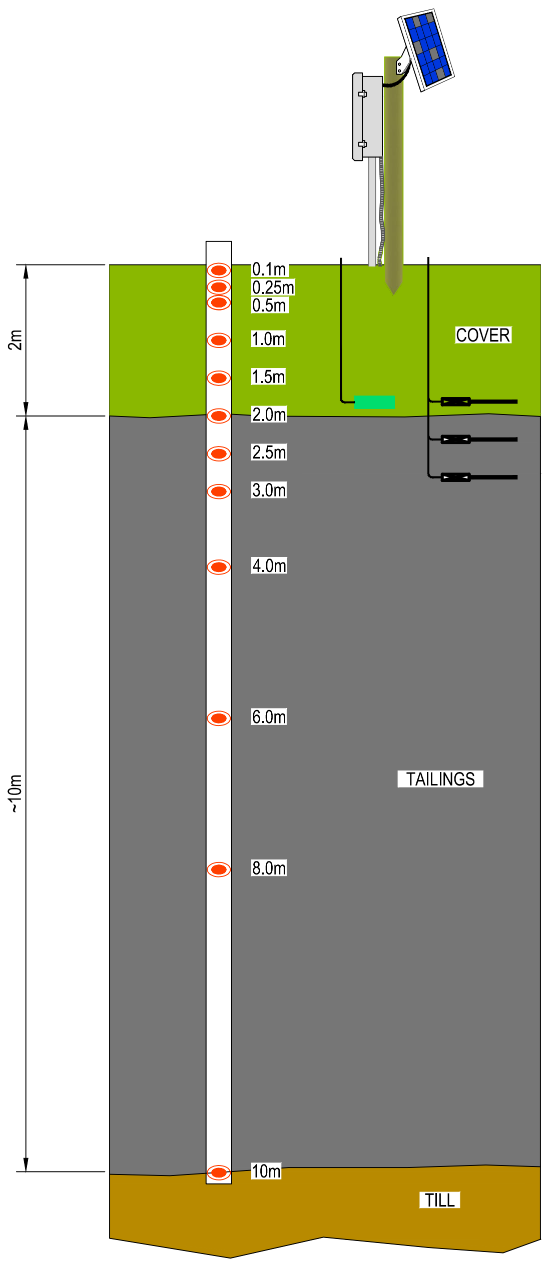
CATCHMENT PLAN

DRG NUM: 948-1-040 Rev: 1



STATION #1
1:200



STATION #2
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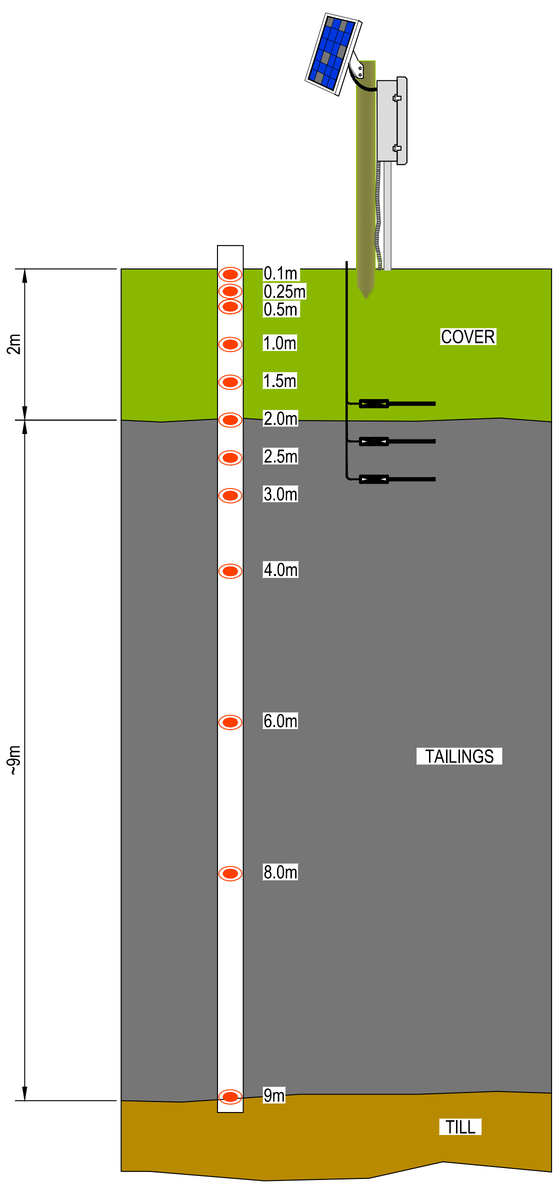

STATION #3
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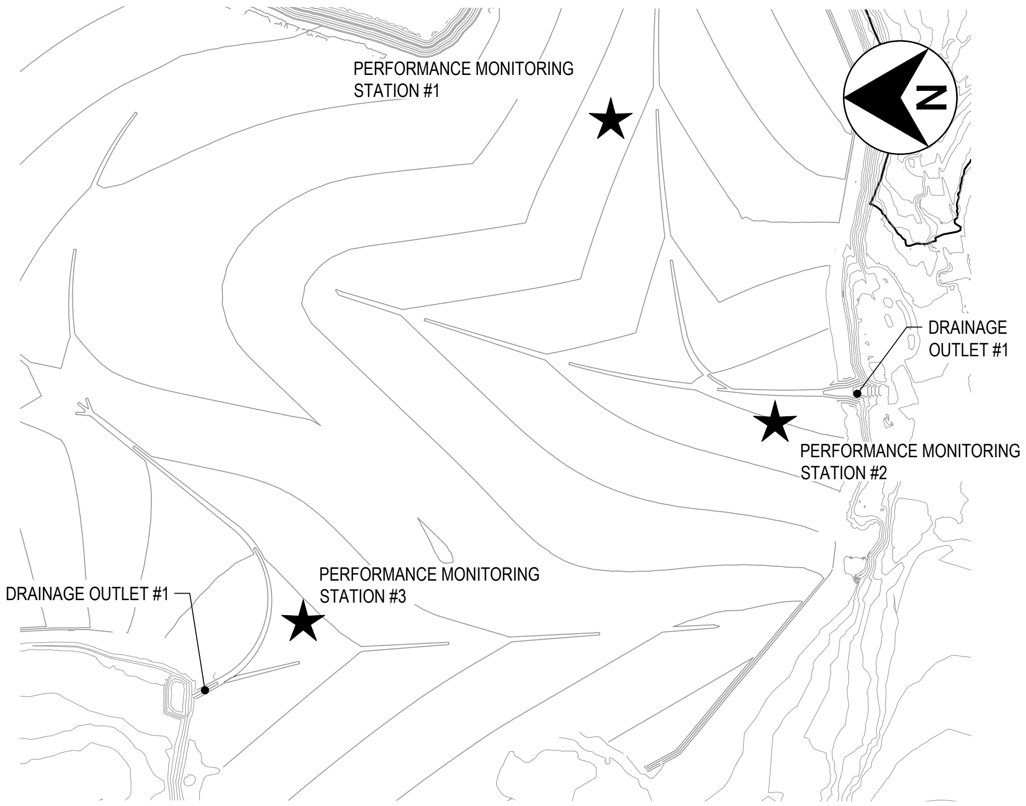


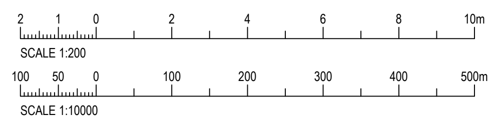
PERFORMANCE MONITORING LOCALITY PLAN
1:10,000

INSTRUMENTATION QUANTITIES			
INSTRUMENTATION	STATION #1	STATION #2	STATION #3
THERMISTOR	20	12	12
C665-L	-	3	3
PLS-L	-	1	-

LEGEND

- CONTOUR
- CHANGE IN GRADE (CREST)
- PERFORMANCE MONITORING STATION
- THERMISTOR
- CS655-L
- PLS-L

NOTE:
1. EXISTING TSF ELEVATIONS SHOWN AS PER DTM PROVIDED BY AGNICO EAGLE ON 17 JUNE 2015 (As-built NC_contours 0.25m.dwg)
2. TAILINGS DEPTHS ESTIMATED BASED ON OKC FINAL LANDFORM ELEVATIONS AND BATHYMETRY DATA PROVIDED BY AGNICO EAGLE. (Site Survey.dwg)
3. ALL UNITS IN METERS U.N.O.



CLIENT/PROJECT:
AGNICO EAGLE
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NORTH CELL TSF CLOSURE DESIGN

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PERFORMANCE MONITORING DETAILS

DRG NUM: 948-1-050 Rev: 1

Appendix B

Design Basis, Closure Objectives and Design Criteria for TSF North Cell Cover Design

O'Kane
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Specialists in Unsaturated Zone Hydrology

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S7N 3R3
Telephone: (306) 955-3250 Facsimile: (306) 955-1596

MEMORANDUM

To: Thomas Lépine (AEM), Patrice Gagnon (AEM), Dominic Tremblay (SNC)

From: Bonnie Dobchuk, Philippe Garneau (OKC)

Date: November 17, 2014

Re: **OKC External Memorandum – Design Basis, Closure Objectives and Design Criteria for TSF North Cell Cover Design**

This memorandum presents closure objectives and design criteria for the development of the Agnico Eagle Mines (AEM) Meadowbank Project (the Client) North Cell TSF cover system design. It builds on a review of available documentation and discussions with site personnel. The information contained herein should be considered preliminary. It will be reviewed and updated as the project progresses and new information becomes available and will allow for refinement of the design criteria based on results from the modelling tasks. The TSF design basis for the TSF infrastructure is presented and will be used as a starting point for developing the modelling approach and subsequent cover system design.

Background

Tailings deposition at the Meadowbank Gold mine has been taking place in the North Cell of the TSF since the start of production in 2010 (Figure 1). In November 2014, tailings deposition will move to the South Cell, which until then is being used as an attenuation pond. Progressive reclamation of the North Cell is to start in 2015 by placement of a cover system consisting of non-acid generating (NAG) waste rock from ongoing operations and reclaimed from the adjacent waste rock dump. Some tailings deposition in the North Cell will still take place in 2015 to finalize the tailings surface.

Figure 1. Meadowbank Mine Aerial View (AEM, 2013)

The current closure strategy for the North Cell is to use permafrost aggradation in the tailings mass to reduce oxidation of the tailings and potential contaminant transport.

Design Basis

As discussed with AEM personnel, OKC developed the closure objectives and design criteria presented here using a "base-case" closure approach as described in prior documents detailing the closure strategy for the North Cell TSF. The main elements of this base case are:

- Tailings deposition in the North Cell up to an elevation of 150 masl;
- Tailings deposition in the South Cell up to an elevation of 137.2 masl;
- Thermal cover consisting of NAG rock placed over both the North and South Cells with a minimal thickness of 2.0 m;
- Portage Pit final lake elevation at 133.6 masl following breach of the dewatering dikes;
- Presence of a talik underneath the portions of the TSF that were within the area of the former Second Portage Lake arm; and
- Tailings deposition conducted according to the tailings deposition plan up to November 2014.

This design basis will be used as a starting point to develop the required modelling for the Project. OKC recognizes that other options for TSF development and final closure are currently studied and will take these into account as the Project develops.

Closure Objectives

The Environmental Code of Practice for Metal Mines developed by Environment Canada (2009) presents the main objectives for mine closure:

- Ensure public and wildlife safety by preventing inadvertent access to mine openings and other infrastructure;
- Provide for the stable, long-term storage of waste rock and tailings;
- Ensure that the site is self-sustaining and prevent or minimize environmental impacts; and
- Rehabilitate disturbed areas for a specified land use.

Closure objectives for the overall site as well as specific to the TSF are mentioned in previously-developed closure plans including the latest Interim Closure and Reclamation Plan (ICRP) prepared by Golder Associates in January 2014. The closure objectives mentioned evolve from the Mine Site Reclamation Guidelines for the Northwest Territories, 2007, prepared by Indian and Northern Affairs Canada. Four specific overall closure objectives for the site were identified:

- Lands and waters affected by mining activities are to be physically and chemically stable; safe for human, wildlife and aquatic life;
- Lands and waters at the reclaimed Meadowbank sites should allow for traditional uses of the area;
- The final landscape should be guided by pre-development conditions and traditional knowledge from local populations; and
- Where appropriate, post-closure conditions should not require the continuous presence of project staff until walk-away condition is achieved (land relinquishment).

When developing closure objectives for individual components of the mine site, it is paramount to take into account specific considerations of each component. For the tailings storage facility, the following elements are considered for closure:

- Embankment stability;
- Changes in tailings geochemistry;
- Effects of seepage;
- Surface water management;
- Dust generation; and
- Access and security.

Water management facilities associated with the TSF are also considered as they relate to:

- Restoration and removal of dikes, settling ponds, sumps, pumps, pipelines and culverts not required post-closure;
- Site surface water drainage and discharge; and
- Maintenance of closure water management facilities.

Closure objectives specific to the Meadowbank tailings storage facility are (adapted from INAC 2007):

- Stabilize slopes surrounding the tailings impoundment or containment system for flooded and/or dewatered conditions;
- Minimize catastrophic and/or chronic release of the tailings or contaminated water to the environment;
- Minimize wind migration of tailings dust; and
- Minimize the threat that the impoundment becomes a source of contamination.

Design Criteria

From the above previously-determined closure objectives and from discussions with AEM personnel, design criteria for the closure of the North Cell of the TSF were developed. It is expected that some of these will be updated based on results from the modelling exercise currently ongoing for the Project.

Tailings Material Temperature

- The tailings material placed within the North Cell should be entirely frozen after a period of 10 years (to be confirmed by modelling) following closure (frozen defined as tailings temperature <0°C).
- The freezing front should continue at depth into the bedrock underlying the North Cell, thus eliminating the talik currently in place. The time required for this phenomenon to take place will be determined from modelling and is to be corroborated by monitoring of ground temperatures following closure.
- The tailings are to remain frozen for a period of over 150 years following closure, taking into account the agreed-upon climate change scenario. This will be based on modelling and monitoring of ground temperatures following closure of the facility.
- Ground temperature monitoring should be conducted for a minimum of ten years following closure and data compared to the modelled scenario. Model parameters are to be adjusted based on monitoring data and future ground temperature predictions refined.

- The active layer shall remain within the constructed NAG cover system and the underlying tailings material shall remain frozen for a warm year event with a return period of 1 in 100 years, accounting for the agreed climate change scenario.

Tailings Material Saturation

- As an additional method to reduce tailings reactivity, the degree of saturation within the tailings mass should remain above 85%. This will reduce the tailings reactivity should part of the upper region of the tailings mass thaw during a warm year event.

Surface Water Management

- Surface runoff from precipitation and spring freshet shall be shed off the TSF surface through specified runoff outlets.
- The minimal slope of drainage channels should be 0.5%.
- Surface water will be contained within the facility for quality testing before release to either the environment or an agreed water management structure for further treatment as required.

Water Quality

- All surface water from the closed facility is to meet CCME water quality criteria.

Dust Contamination

- Following closure of the facility and completion of the cover construction, dust emissions from the TSF will be under applicable standards.

Traditional Uses

- The closed TSF should not hinder caribou migration in the area.

Conclusion

The closure objectives and design criteria presented in this document are based on available documentation related to closure of the Meadowbank mine site. It is intended to generate discussions and to reach agreement with the Client on agreed objectives and design criteria. As such, the design criteria presented herein should be considered preliminary and will be updated as the project progresses and following further discussion with site personnel.

References

AEM (Agnico Eagle Mines Ltd). 2013. History and Overview of the General Closure Concept, TSF. PowerPoint Presentation. Prepared by Agnico Eagle Mines Ltd, Meadowbank Division, September.

CCME (Canadian Council of Ministers of the Environment). 2007. Canadian Water Quality Guidelines for the Protection of Aquatic Life: Summary Table. Updated December, 2007.

INAC (Indian and Northern Affairs Canada). 2007. Mine Site Reclamation Guidelines for the Northwest Territories. Yellowknife, January Version.

Golder (Golder Associates Ltd) 2014. Interim Closure and Reclamation Plan, Meadowbank Gold Project, Nunavut. Report No. 13-1151-0131, January.

Appendix C

Climate Change Scenarios for Meadowbank Mine

O'Kane
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Integrated Geotechnical Engineering Services
Specialists in Unsaturated Zone Hydrology

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Saskatoon, Saskatchewan, Canada
S7N 3R3
Telephone: (306) 955-3250 Facsimile: (306) 955-1596

MEMORANDUM

To: Thomas Lépine (AEM), Patrice Gagnon (AEM), Dominic Tremblay (SNC)

From: Bonnie Dobchuk, Philippe Garneau (OKC)

Date: February 4, 2015

Re: **OKC External Memorandum - Climate Change Scenarios for Meadowbank**

The following memorandum highlights the various climate change scenarios considered for the Agnico Eagle Meadowbank Gold project. IPCC's 5th Assessment Report presents Representative Concentration Pathways (RCP) for radiative forcing to be used as input for climate modelling. RCP4.5 and RCP6 scenarios were chosen as the most reasonable climate change scenarios for the Meadowbank site. Both scenarios anticipate temperatures to rise at about the same rate (approximately 0.05°C/year) for the next 60 years after which RCP4.5 estimates a much larger reduction in temperature increase than RCP6, with temperatures stabilizing in approximately 100 years, whereas RCP6 results in temperatures still increasing after 150 years. Both scenarios predict an increase in precipitation with time of approximately 0.6 mm/year for RCP4.5 and 0.7 mm/year for RCP6.

Background

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). The four adopted RCPs differ from the SRES in that they represent greenhouse gas concentration trajectories, not emissions trajectories. The four scenarios are named after the radiative target forcing level for 2100, which are based on the forcing of greenhouse gases and other agents (van Vuuren et al. 2011). These values are relative to pre-industrial levels.

The lowest scenario, RCP2.6, peaks at a radiative forcing of 3 W/m^2 (~490 ppm CO_2 equivalent) before declining to 2.6 W/m^2 by 2100. This scenario assumes annual greenhouse gas (GHG) emissions peak sometime between 2010 and 2020 and then decline. After 2070, RCP2.6 implies net negative emissions, reducing CO_2 equivalent to 360 ppm by 2300 (IPCC 2013). To achieve this scenario, stringent climate policies to limit emissions are required (van Vuuren et al. 2011).

The two middle scenarios reach a peak value and stabilize by 2150. RCP4.5 begins to stabilize between 2050 and 2060, reaching a stable value of 4.5 W/m^2 (~650 ppm CO_2 equivalent) by 2150. RCP6 continues to rise until beginning to stabilize at around 2125 (IPCC 2013). Stabilization occurs by 2150 at a value of 6 W/m^2 (~850 ppm CO_2 equivalent). The RCP6 scenario represents most non-climate policy scenarios, while RCP4.5 represents several climate policy scenarios (van Vuuren et al. 2011).

The final scenario, RCP8.5, continues the current trend of increasing annual GHG emissions, leading to 8.5 W/m^2 (~1370 ppm CO_2 equivalent) by 2100. This scenario assumes high emissions between 2100 and 2150, followed by a linear decrease to 2250, when concentrations stabilize at approximately 2000 ppm CO_2 equivalent or almost seven times the pre-industrial level (IPCC 2013). This scenario represents the high range of non-action climate policy scenarios.

The IPCC attached no probability or likelihood of occurrence to the four different scenarios. Using median temperature increases by 2100, the current RCP scenarios can be compared to the old SRES scenarios. The RCP2.6 scenario has no equivalent SRES scenario (Rogelj et al. 2012). The RCP4.5 scenario can be compared to the SRES B1 scenario, while RCP6 can be compared to the SRES B2 scenario. The RCP8.5 scenario can be compared to the SRES A1FI scenario.

Table 1. RCP Scenarios

RCP Scenario	Radiative Forcing	CO2 Concentration Equivalent	Climate Policy	SRES equivalent
RCP2.6	Peak at 3 W/m^2 before declining to 2.6 W/m^2 by 2100	~490 ppm	• Strict climate policy • GHG emissions peak by 2020	None
RCP4.5	Stabilization at 4.5 W/m^2 after 2100	~650 ppm	• Some climate policy	SRES B1
RCP6	Stabilization at 6 W/m^2 after 2100	~850 ppm	• No climate policy	SRES B2
RCP8.5	Rising pathway leading to 8.5 W/m^2 by 2100	~1370 ppm	• No climate policy	SRES A1F1

Previous Approaches

Climate change is taken into account in a variety of projects in Canada's north. Approaches to incorporate climate change into the design differ from site to site and are often limited in temporal length. It is not always clear how or why the temperature increases were chosen. Several projects and their application of climate change are explored below.

- SRK Consulting carried out previous climate change modelling for the Meadowbank site in 2007. This modelling included the climate change scenario of increasing the mean annual air temperature (MAAT) by 5.5 ºC over the next 100 years, but no increases after that, despite thermal simulations of 300 years being completed.
- The vulnerability of the NWT Highway 3 to climate change was tested using the IPCC SRES A2 scenario. Using 18 different global climate models (GCMs), the median change in MAAT by the

2020s was 2.1 ºC and 3.6 ºC by the 2050s. These values agreed with the median change from GCMs found by Prowse et al. (2009).

- The EKATI Diamond Mine in the Northwest Territories used thermal simulations up to 2025 for the design of a dam on site. An overall warming of 1.9 ºC by 2025, based on Environment Canada predictions, was incorporated into the simulations.
- The Nanisivik Mine in Nunavut used an overall increase of 5 ºC in MAAT by 2100 in the geothermal modelling done by BGC Engineering of a permafrost aggradation cover system for the site.
- The Doris North project in Nunavut looked at the effect of changing climate on two frozen core dams for tailings impoundment over 40 years. The thermal simulations included seasonal variability in temperature increases, while working toward an overall increase in MAAT of 6.5 ºC over the next 100 years. Daily temperatures were increased by a rate of 0.03 ºC per year for half of the year during the summer and increased at a rate of 0.1 ºC per year for the remaining portion of the year for the winter increases.
- The Kiggavik-Sissons sites used a set mean annual surface temperature of -7 ºC, which was increased at a constant rate of 0.05 or 0.10 ºC per year for the first 200 years to account for climate change. No further increases were applied, but the simulations were run for 1000 years.
- The Colomac Mine Project used two different climate change scenarios in the 200 years of thermal simulations of the dam. The first simulation was based on Environment Canada predictions of an increase of 2.7 ºC per 100 years. The second simulation used a more extreme scenario of an increase of 5.4 ºC for the first 100 years followed by a reduced increase of 2.7 ºC for the remaining 100 years.
- A vulnerability assessment of thermosyphon foundations under public buildings in the Northwest Territories calculated the average trend in MAAT since 1985 for 17 climate stations across the Canadian North to predict future warming (Holubec 2008). The linear regression was then used to extrapolate and calculate future MAAT and mean annual ground temperature (MAGT). Climate stations were sorted into groups based on location and the mean climate warming rate for each group was calculated. Mean warming rates varied from 7 ºC per 100 years in the Western Arctic up to 17 ºC per 100 years in the Eastern Arctic.

Meliadine FEIS Approach

Volume 5 of the the Meliadine Project FEIS addressed the issue of climate change. Three SRES scenarios developed by the IPCC were selected for the impact assessment: Scenarios A1B, A2 and B1. Three periods covered by the IPCC were selected for analysis: the 2020s, 2050s and 2080s. Longer term effects of climate change, beyond 2100, were not considered for the impact assessment.

Selected Approach

RCP4.5 and RCP6 scenarios were chosen as the most appropriate climate change scenarios for the site. RCP2.6 was not considered as it was realized that in order to achieve the concentrations of the RCP2.6 scenario and the peak of GHG emissions within the next 5 years, strict intergovernmental environmental policies and controls would need to be enacted. Of the four RCPs, RCP2.6 shows the least global climate warming. The two upper climate scenarios, RCP6 and RCP8.5, both represent non-climate policy scenarios, with RCP8.5 being the ‘worst case’ scenario for global climate change. The RCP6 scenario is more equivalent to most predictions of emissions by 2100 in the case that no climate action is taken (van Vuuren et al. 2011).

The first of the two proposed scenarios, RCP4.5, is comparable to many scenarios that include some form of climate policy, including the SRES B1 scenario. This scenario still allows for increases in emissions while also implementing a climate policy. The policy most followed by the world's countries is outlined by the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC has the goal of stabilizing GHG emissions to a level that would prevent serious human-caused climate change. In addition to the UNFCCC, the Kyoto Protocol is the main international agreement that limits countries GHG emissions with the aim of an overall decrease. The Kyoto Protocol came into effect in 2005 and expired at the end of 2012. While several large polluters (USA and Canada included) did not sign or ratify the treaty, or did and later withdrew, others, like the European Union, are on track to achieve their reduction targets (EEA 2010). In 2013, an agreement was reached that all states of the UNFCCC would work to reduce their emissions as soon as possible. A new climate framework is to be negotiated in 2015, indicating a willingness to work toward a policy of reduced emissions.

The second proposed scenario, RCP6, is comparable to the SRES B2 scenario. It is a stabilization scenario where total radiative forcing stabilizes after 2100 at $6 W/m^2$. This scenario would still require implementation of a range of technologies and strategies to reduce GHG emissions.

OKC used the GeoStudio 2012 program suite for numerical modelling completed for the Meadowbank modelling, specifically TEMP/W, VADOSE/W, SEEP/W and AIR/W (Geo-Slope International Ltd, 2014a-d). Together, these numerical modelling programs required daily values of: maximum and minimum, and surface air temperature; maximum and minimum relative humidity (RH); average wind speed; and precipitation (amount and duration). Historic values for all these parameters except net radiation are available from Environment Canada (2014) for Baker Lake, approximately 80 km south of Meadowbank. Environment Canada has hourly records for Baker Lake from 1964 to present, of which the period August 1964 to July 2014 (excluding 1993) was used to create an historic 50-year database for this project. Measurements from Baker Lake during 1993 were not included due to poor data quality that year, as previously noted by SNC-Lavalin (2013). After comparing the climate data measured at Meadowbank from January 2012 to September 2014 to measurements taken at Baker Lake for the same period it was concluded that the Baker Lake data did not need to be adjusted to represent the Meadowbank site. Any missing data in the Baker Lake climate record were filled with average measurements for a given day.

A "synthetic average" climate year was defined by averaging daily climate conditions from the 50-year climate database (e.g. averaging the maximum temperature on January 1st for all 50 years). However, rainfall was not applied just considering 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 1 provides a summary of the average monthly conditions in the 50-year historic database developed for this project.

Table 1
Summary of average climate parameters for the 50-year Meadowbank historic climate database.

Month	**Temperature** (ºC)		**Relative Humidity** (%)		**Wind** (m/s)	**Rainfall**	
	Maximum	Minimum	Maximum	Minimum		(mm)	(days)
January	-28.2	-35.2	71.5	60.0	6.4	8	27
February	-27.8	-35.0	70.7	59.7	6.3	7	24
March	-22.8	-31.3	72.9	60.7	5.9	10	24
April	-12.5	-21.9	81.2	67.7	5.8	15	19
May	-2.6	-9.8	89.5	75.2	5.4	15	20
June	8.9	0.5	89.6	61.9	4.8	22	15
July	16.8	6.1	88.6	52.5	4.7	38	14
August	14.3	5.4	91.7	58.6	4.9	42	17
September	6.1	-0.4	93.0	68.2	5.5	43	21
October	-3.6	-9.8	91.1	77.3	6.0	31	26
November	-15.8	-23.2	80.9	67.7	6.1	18	24
December	-23.6	-30.8	74.2	62.0	6.1	10	25
Annual	***-7.5***	***-15.4***	***82.9***	***64.3***	***5.7***	***259***	***256***

Monthly results from two general circulation models (GCM) were used to provide estimates of climate conditions for Meadowbank over the next 150 years. The CanESM2/CGCM4 model developed by the Canadian Centre for Climate Modelling and Analysis (CCCma) was used to develop inputs for the RCP4.5 climate database (CCCma, 2014). A second GCM needed to be selected as the CCCma has not publicly released its results for the RCP6 scenario. Hence, the CESM1-CAM5 model, develop by the National Center for Atmospheric Research (NCAR), was selected to provide monthly estimates of climate conditions for the RCP6 climate database (NCAR, 2014).

The output of both GCMs are gridded datasets. Hence, historic estimates between August 1964 and July 2014 (excluding 1993) from the nearest point in the gridded dataset to Meadowbank were compared to the 50-year climate database developed for the site to determine monthly adjustment factors for each required parameter so that the GCM predictions were more representative of site conditions. Once the monthly GCM data were adjust, the GCM monthly conditions were used to adapt the daily data in the historic database to represent the GCM predictions. To do this, the 50-year historic database was repeated three times (to create a 150-year database) and adjustment factors were developed for each parameter for each month of each year so that the databases have the same monthly predictions as the adjusted GCMs. Figures 1 and 2 show the annual temperature and precipitation, respectively, estimated for the RCP4.5 and RCP6 150-year climate databases developed for Meadowbank. Both models anticipate temperatures to rise at about the same rate (approximately 0.05°C/year) for the next 60 years after which RCP4.5 estimates a much larger reduction in temperature increase than RCP6, with temperatures stabilizing in approximately 100 years, whereas RCP6 results in temperatures still increasing after 150 years. Both scenarios predict an increase in precipitation with time of approximately 0.6 mm/year for RCP4.5 and 0.7 mm/year for RCP6.

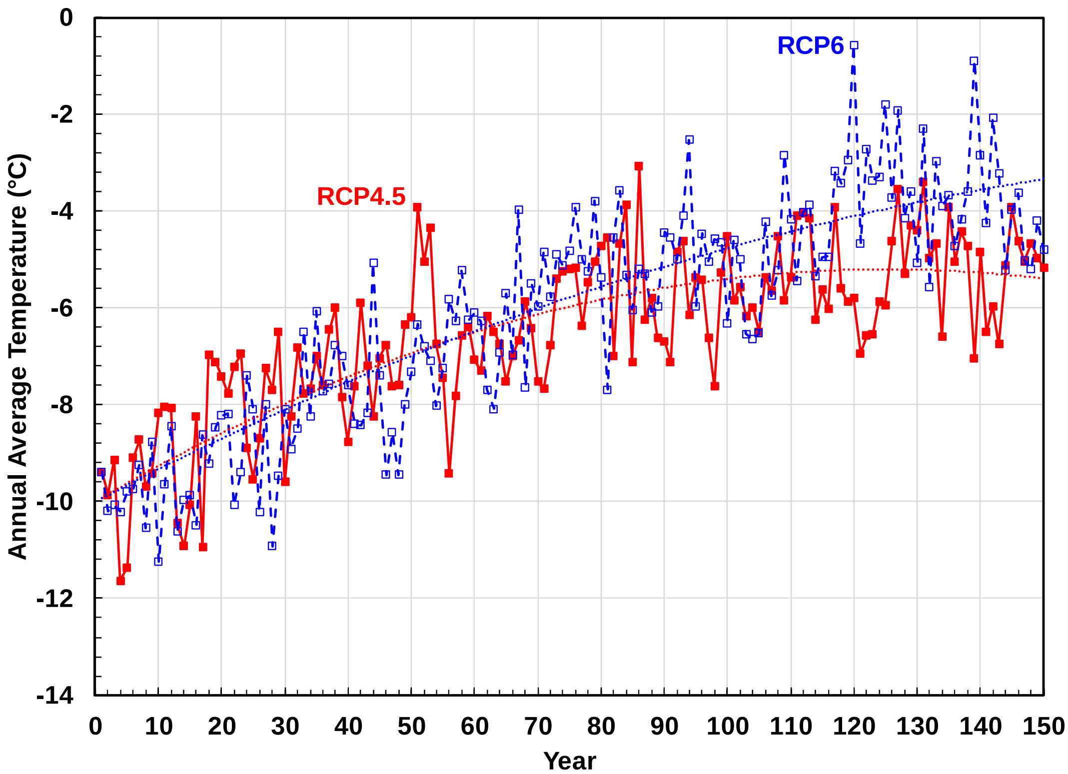

Figure 1 Annual average temperature estimated for the RCP4.5 and RCP6 databases

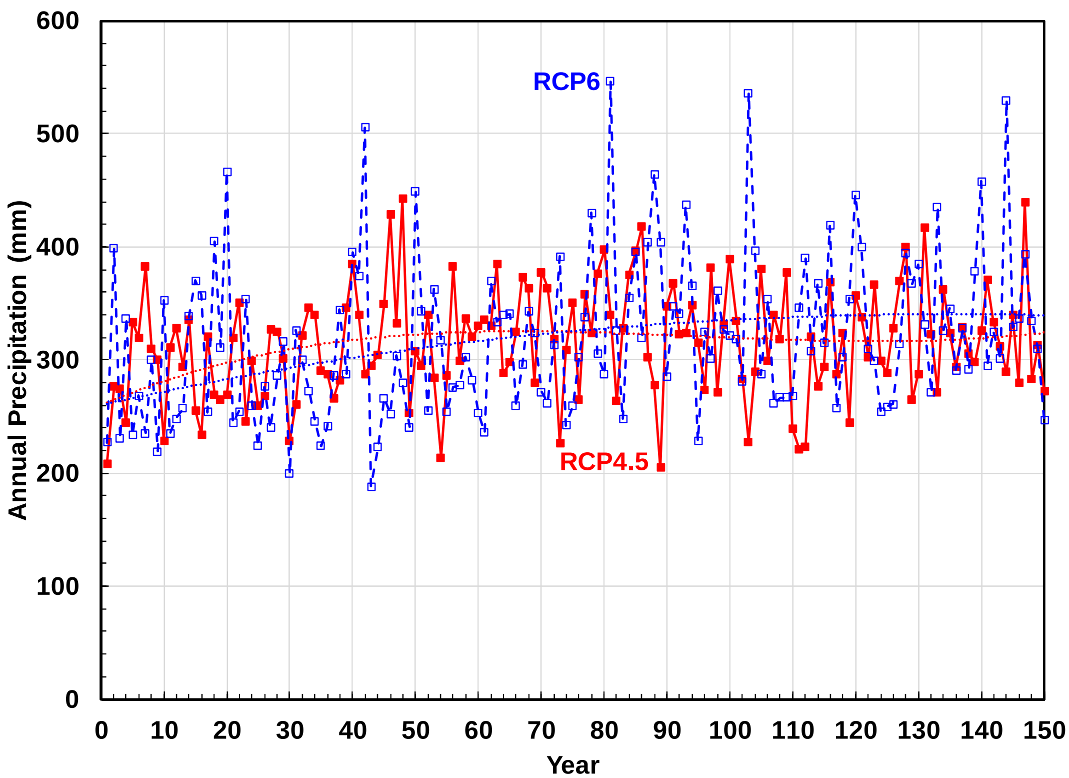

Figure 2 Annual precipitation estimated for the RCP4.5 and RCP6 databases

Conclusions

After reviewing the four representative concentration pathways set forth by the IPCC, RCP4.5 and RCP6 scenarios were chosen as the most appropriate climate change scenarios. The CanESM2/CGCM4 model developed by the Canadian Centre for Climate Modelling and Analysis (CCCma) was used to develop inputs for the RCP4.5 climate database (CCCma, 2014). A second GCM needed to be selected as the CCCma has not publicly released its results for the RCP6 scenario. Hence, the CESM1-CAM5 model, develop by the National Center for Atmospheric Research (NCAR), was selected to provide monthly estimates of climate conditions for the RCP6 climate database (NCAR, 2014). Both models anticipate temperatures to rise at about the same rate (approximately 0.05°C/year) for the next 60 years after which RCP4.5 estimates a much larger reduction in temperature increase than RCP6, with temperatures stabilizing in approximately 100 years, whereas RCP6 results in temperatures still increasing after 150 years. Both scenarios predict an increase in precipitation with time of approximately 0.6 mm/year for RCP4.5 and 0.7 mm/year for RCP6.

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Appendix D

Modelling Letter Report

O'Kane
Consultants Inc.
Integrated Geotechnical Engineering Services
Specialists in Unsaturated Zone Hydrology

December 20, 2014

Thomas Lépine & Patrice Gagnon
Agnico Eagle Mines - Meadowbank Division

Re: Agnico Eagle Mines - Meadowbank Project – Summary of Modelling of Potential Cover Systems for the North Cell Tailings Storage Facility

Agnico Eagle Mines (AEM) retained O'Kane Consultants Ltd. (OKC) to design a cover system and develop the cover system construction methodology for the Meadowbank North Cell Tailings Storage Facility (TSF). A major component of the cover system design is the assessment of soil-atmosphere, airflow, thermal, and seepage conditions within the TSF such that permafrost aggradation can be enhanced and promoted. In order to assess the requirements for permafrost aggradation within the TSF, numerical modelling was employed by OKC, which will be used to assist in determining final TSF cover system designs.

The main objectives of numerical modelling are to estimate the seepage within the deposit and heat transfer within the system. One-dimensional (1D) soil-plant-atmosphere (SPA) modelling was completed primarily to determine surface temperatures for use in the thermal/seepage model. The following letter report starts with a summary of the conceptual model and key model results from the modelling programs followed by additional details of the SPA, airflow, and thermal/seepage modelling completed for this project.

CONCEPTUAL MODELS

SPA Model

The conceptual water balance for the SPA model consists of very low net percolation through the tailings deposit due to frozen, predominantly saturated conditions. Hence, all precipitation must either be stored within the cover system, runoff, evaporate, or (in the case of snowpack) sublimate. Storage within the cover system is a finite and short-term (e.g. seasonal) component of the water balance, and, therefore, does not affect the long-term water balance.

Thermal and Seepage Numerical Model

The ideal design objective of the TSF at Meadowbank is for the entire tailings deposit to remain frozen (i.e. permafrost). In order to assess tailings freezeback and overall permafrost aggradation in the deposit under a variable cover system, two separate 1D models were carried out to give a preliminary estimate of tailings freezing depth. In addition, the 1D models can be used to determine the thermal flux rates from the unfrozen talik at the base of the profile, to be used in a 2D full cross-section numerical model. These models utilized a forecasted climate at the surface based on the RCP4.5 and RCP6.0 climate change scenarios, as described in the 'Climate" section later in this report. The two cover system configurations were simulated with thicknesses of 2 m and 4 m.

A 2D coupled thermal/seepage numerical model was also assessed. The 2D profile was derived from site drawings, and represents the longest section of the north cell tailings pond. It includes thermal effects from the south cell tailings pond and pit lake. It is anticipated that the pit lake, a component of the final closure strategy, will have thermal effects on the deposit, and as such was included in the 2D cross section geometry.

When TEMP/W and SEEP/W are coupled within the same modelling environment, it allows the system to be assessed based on variable moisture contents in the soil profile. This is an important consideration as a higher water content system will prevent cooling of the tailings since water typically has a lower thermal conductivity than the native materials at site. In addition, moving water in the system will prevent freezeback as the moving water will cause heat migration from one location to the next.

Convective Airflow Numerical Model

Air flow in natural soils has many implications to engineering problems, and in the case of waste rock dumps and mine waste in cold regions, substantial occurrence of convective airflow in a system may affect the permafrost aggradation rates in the subsurface. Depending on the thermal conditions in the deposit and moisture transfer in the system, the airflow may either encourage or prevent permafrost aggradation.

Density dependent convective airflow is a well-documented process, and has been observed in coarser textured waste rock piles (Lu, 2001). Convective airflow is initiated when a temperature induced density gradient exists between air within mine waste storage facilities (WSF) and ambient conditions. The basic principle guiding convective airflow analyses is that higher density, cooler air will replace lower density, warmer air. In the case of a naturally heated WSF, warmer, lower density air will rise out the surface of the WSF, while cooler, higher density air will be drawn in through the base of the WSF, which is subsequently heated and the process continues, hence creating the convective cycle.

The presence of a convective cycle is heavily influenced by the following parameters (Ball and Schjønning, 2002):

- *In situ* moisture conditions;
- Air temperature within the matrix of stored waste material;
- Ambient air temperature; and,
- Material characteristics (texture and structure).

In situ moisture conditions and material characteristics heavily influence the air permeability that governs the rate of air movement through the WSF. A material that is at a higher saturation condition will result in reduced airflow rates as the voids between particles are blocked by water, whereas material at a lower saturation condition will result in higher airflow rates as the air-filled voids of the material provide flow paths for air through the system.

At AEM Meadowbank, the main area of concern that may be affected by the convective airflow process is the cover system, as it is a coarse-textured material. It is anticipated that the tailings are fine enough such that the air conductivity is sufficiently low and the water content will be sufficiently high, that the airflow through the tailings will be negligible. In environments such as Meadowbank (cold temperatures and low precipitation), convective airflow in a coarse cover system overlying the tailings may assist in permafrost aggradation by creating a thermal boundary layer in warmer seasons. This is outlined by Figure 1 below, which shows the cover system profile in the summer. Due to the fact that the density of the air at the cover system – tailings interface is higher, this air will naturally remain at the bottom of the profile. Whereas the air at the surface of the cover system is lower in density, it will have a tendency to sit higher in the profile. This results in a stable system in which little to no advective airflow occurs, and the coldest air always resides on the tailings surface. In such a way, thawing of tailings in the summer is minimized.

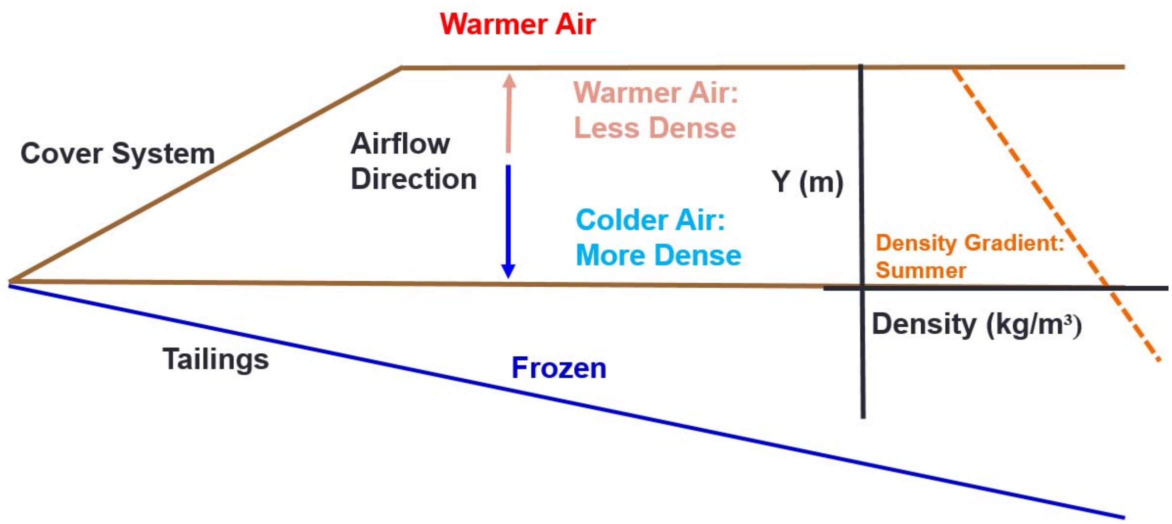

Figure 1 Convective airflow conceptual model in summer.

Alternatively, in the winter the opposite is true (Figure 2). Due to the tailings being a reservoir of heat, in the winter the air at the base of the cover is typically lower in density than the surrounding air. This results in the air at the cover system-tailings interface rising, while the ambient air sinks. Therefore, the coldest air always resides on the tailings surface, while the warm air is removed. In such a way, the maximum freezing of tailings is ensured in the winter.

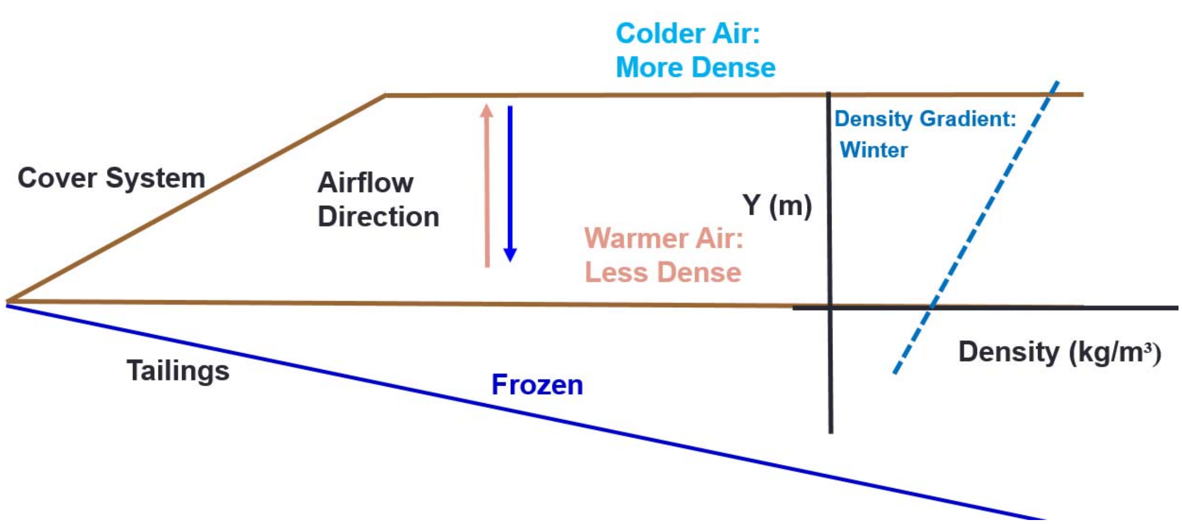

Figure 2 Convective airflow conceptual model in winter.

It is anticipated that airflow rates through the AEM cover materials will be low due to the finer textured soapstone material “blocking” the path through which air must travel to complete convective cycles, both due to the overall lower permeability of the material in an unsaturated condition, but also due to the higher moisture retention properties of the material.

KEY RESULTS

The key results confirmed by the numerical modelling are the predicted temperatures in the subsurface. Temperature is easily extracted from the numerical model; however, uncertainty exists in the assessment of what the temperature values mean. Due to a high salinity concentration in both the tailings and the brackish groundwater, there exists the possibility of freezing point depression in the subsurface. As such, in order to provide a factor of safety, any temperature between 0°C and -2°C is considered as a potentially unfrozen zone, and represents a reduction in performance of the assessed cover systems (based on reaction rate) for the scenarios assessed by the numerical model. However, even when the tailings reach temperatures exceeding 0°C the cover system will meet performance objectives as long as the tailings remain sufficiently saturated to effectively minimize oxygen ingress. The cover design objectives were presented in OKC External Memorandum – Design Basis, Closure Objectives and Design Criteria for TSF North Cell Cover Design (2014). The design objectives stated that the cover should maintain the tailings at either a temperature <0°C or a degree of saturation >85%.

Figure 3 shows that the tailings just below the cover system interface is seasonally above 0°C when a 2 m cover system is placed above the tailings and assuming the RCP6 climate change scenario. However, the temperatures remain below 0°C less than 20 cm below the interface. Additionally, the degree of saturation at the cover system – tailings interface remains above 85% for all but the initial 5-10 years of the simulation period (Figure 4). Hence, it is anticipated that, although minor thawing may occur in the small regions of the TSF surface with a cover thickness of 2 m, the cover system will still effectively minimize oxygen ingress due to the high saturation of the tailings.

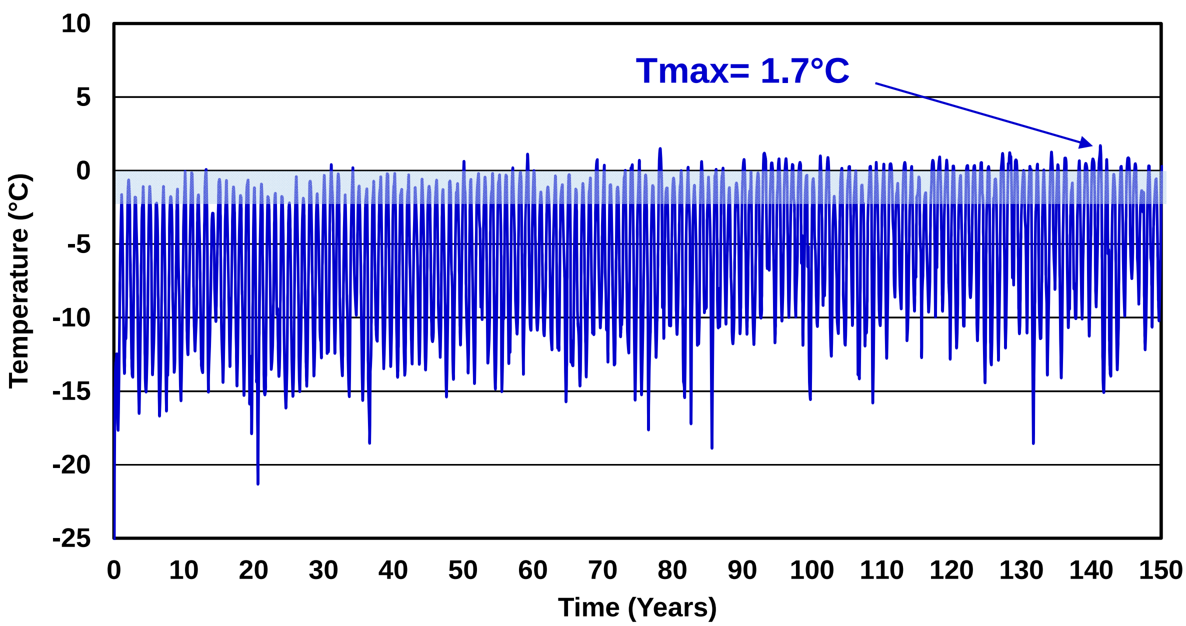

Figure 3 North Cell TSF tailings temperature at cover system – tailings interface, 2 m cover system, for RCP6 climate change scenario.

As shown in Figure 5, areas with a 4 m cover system are anticipated to keep the temperatures at the cover system – tailings interface usually below -2°C and always below 0°C for the entire 150-year simulation period, even for the more warming climate scenario (RCP6).

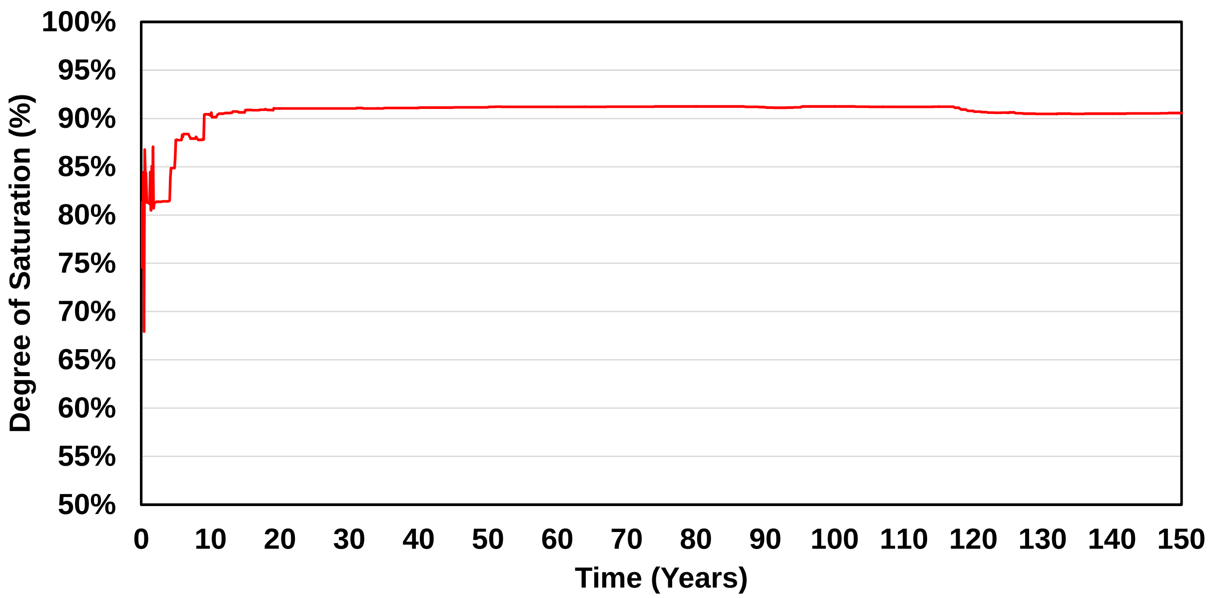

Figure 4 North Cell TSF tailings degree of saturation at cover system – tailings interface, 2 m cover system, RCP6.

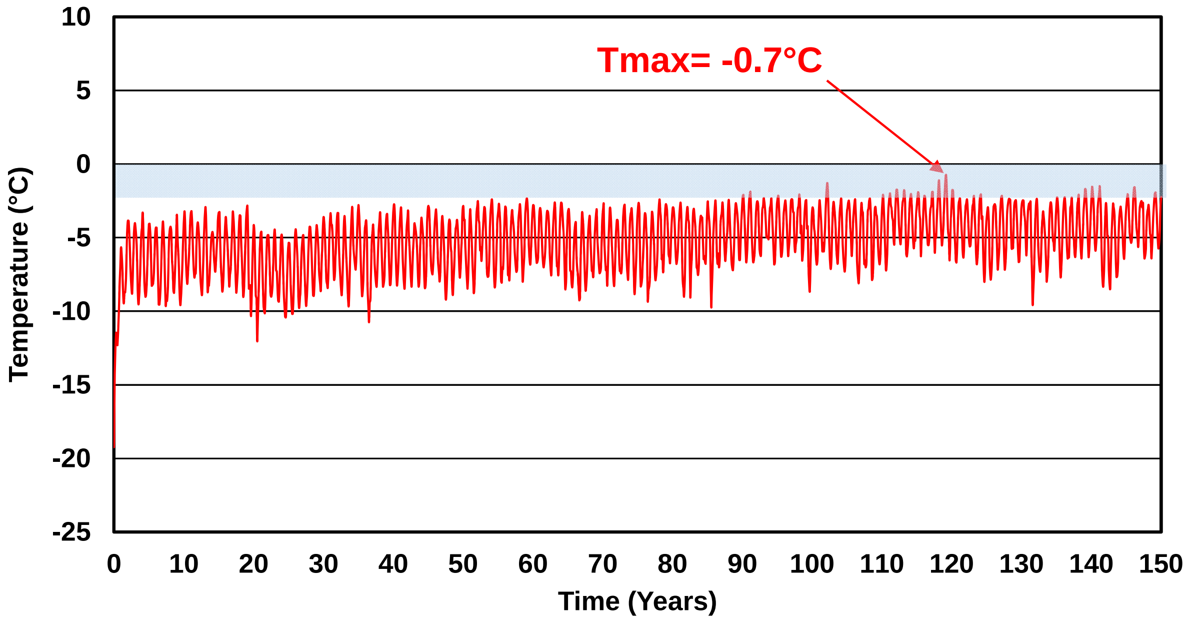

Figure 5 North Cell TSF tailings temperature at cover system – tailings interface, 4 m cover system, RCP6.

ADDITIONAL RESULTS

1D SPA Models

Four, 1D SPA models were completed: two climate change scenarios (RCP4.5 and RCP6) were simulated with two cover system thicknesses (2 m and 4 m). These models were completed to obtain surface temperature and infiltration estimates for the subsequent two-dimensional (2D) coupled seepage and temperature modelling. As expected, the surface temperatures followed the same patterns as the air temperatures (detailed in the following “Climate” section of this memorandum). However, net infiltration is effectively zero due to the high potential evaporation when compared to precipitation and the barrier created by the frozen tailings. Prior to the site visit it was anticipated that little runoff would occur onsite due to the coarseness of the NAG cover material. The site visit showed that RO should be anticipated due to the friable nature of the surface soapstone; breaking down during placement and weathering, and forming a less permeable surface layer. Additionally, an ice layer forms at the surface due to wind-packed snow that fills the voids. This frozen layer also leads to high runoff rates from the initial thawing of any snowpack.

Figure 6 provides the estimated water balances for the SPA models for the RCP4.5 and RCP6 databases. There was no significant difference in water balance performance between the 2m and 4 m cover system thicknesses. Although the precipitation patterns differ for RCP4.5 and RCP6, their overall water balances are similar because the overall precipitation amounts are similar which means the additional energy (i.e. potential evaporation, PE) available in the RCP6 scenario does not have any additional water available to remove.

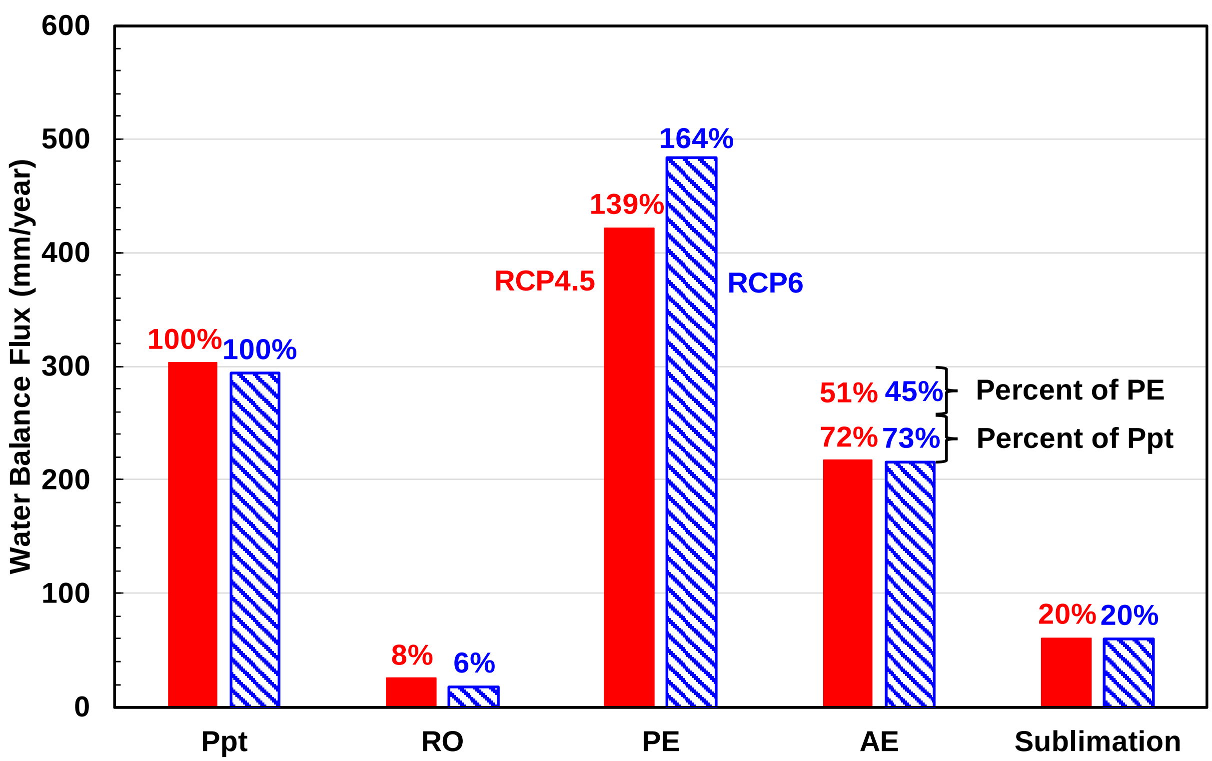

Figure 6 Water balance results from 1D SPA simulations with RCP4.5 and RCP6 climate scenarios. Percentages shown indicate percentage of precipitation unless otherwise marked.

Although the overall water balance results in no net infiltration, there are large seasonal water fluxes into and out of the cover system. Figure 7 shows a typical cumulative infiltration for a year, with water being added to the cover system during September and October when precipitation rates are higher than potential evaporation, and water being removed during the drier months following spring melt. The initial conceptual cover system performance estimated by OKC assumed more infiltration during the spring melt, but this does not happen because there is little winter precipitation (e.g. historically, there is more precipitation during September and October than from November to April, inclusive) and most of this winter precipitation is removed by sublimation and spring runoff.

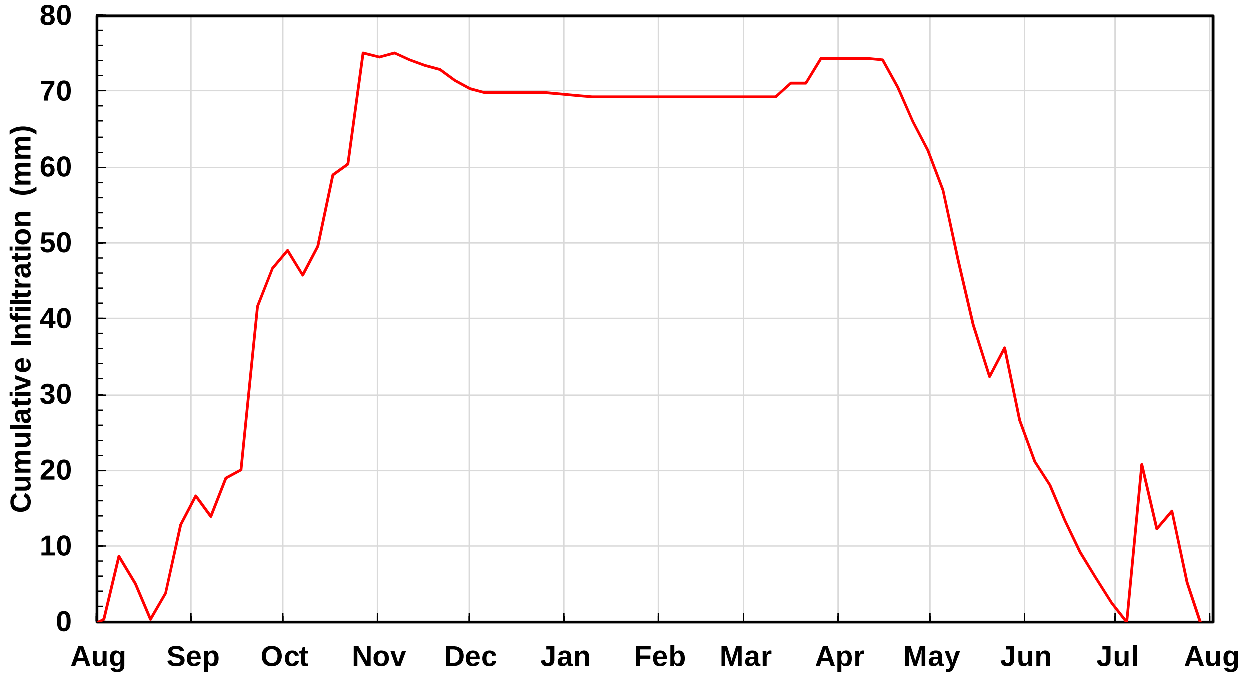

Figure 7 Cumulative infiltration for a typical year (Year 78 of 150 for the RCP4.5 scenario)

Although the SPA model chosen for this project (VADOSE/W) is capable of estimating material temperature conditions, it was not used to estimate permafrost formation as it is not as sophisticated as its sister program TEMP/W for estimating temperature. Additionally, a SPA model would add too much complexity to a 2D seepage analysis. Hence, 2D models of seepage and permafrost formation were completed by coupling SEEP/W and TEMP/W simulations, using the VADOSE/W results to inform on the boundary and initial conditions.

1D Thermal/Seepage Model

Thermal and seepage numerical modelling carried out in 1D for the Meadowbank TSF found that in all cases, when assuming either the RCP4.5 or RCP6 for both the 4 m and 2 m cover system, permafrost aggradation could be expected. This is illustrated by the temperature profiles of the deposit in Figure 8 for the RCP4.5 climate change scenario, and by Figure 9 for the RCP6 climate change scenario. Although the deposits were modelled to a depth of 500 m, only the upper 250 m of the deposit are shown for illustration purposes. The blue box outlines the potentially unfrozen zone (-2 to 0°C).

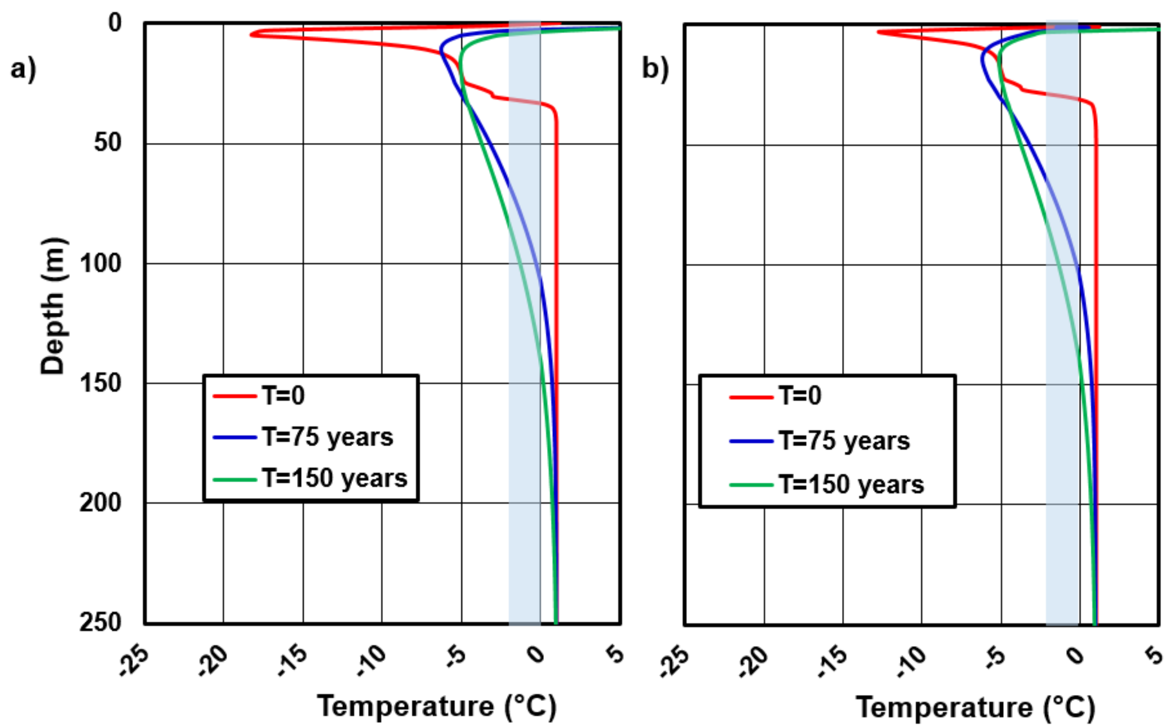

Figure 8 Temperature profile through TSF and into underlying material using 4 m cover system (a) and 2 m cover system (b) for RCP4.5 climate change scenario.

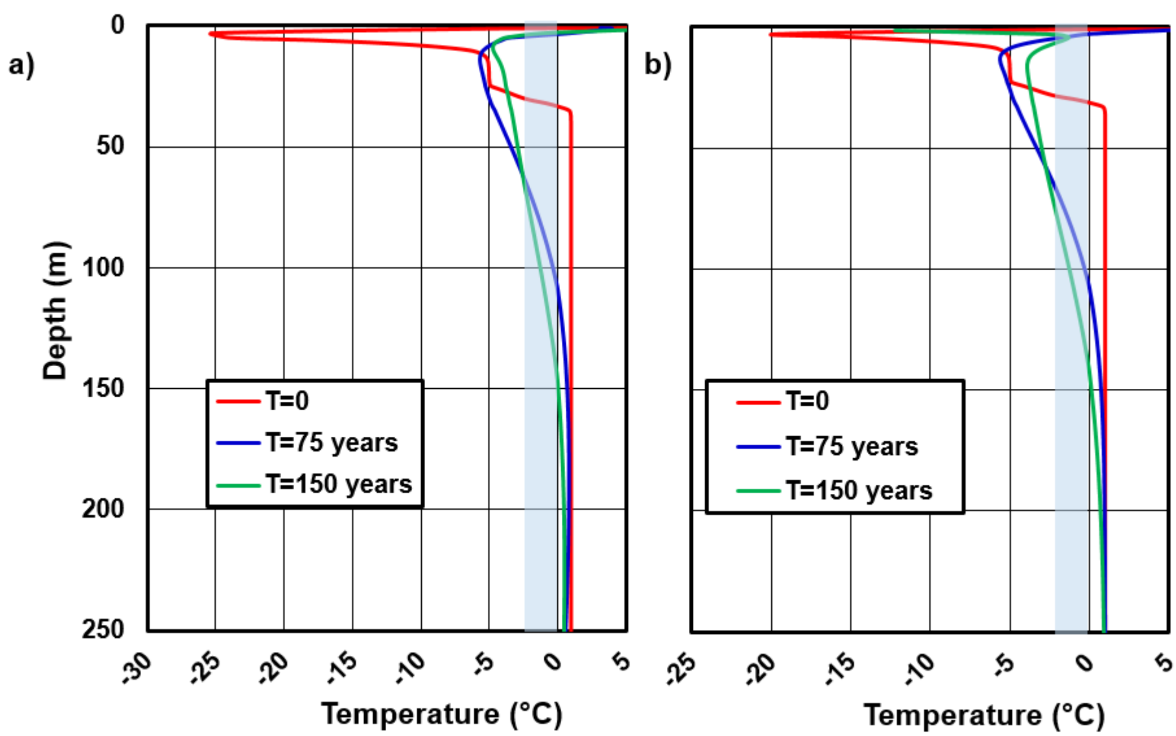

Figure 9 Temperature profile through TSF and into underlying material using 4 m cover system (a) and 2 m cover system (b) for RCP6 climate change scenario.

It can be seen by Figures 8 and 9 that the permafrost aggradation (to -2°C) occurs to a depth of approximately 75 m with the 4 m and 2 m cover systems under the RCP 4.5 scenario. Under the RCP6 scenario, the freezing depth reaches approximately 60 m and approximately 75 m with the 4 m and the 2 m cover system, respectively, showing the 2 m cover system to be more effective at promoting freezing at depth under this climate change scenario. At greater depths, the temperature profile enters the potentially frozen zone (0 to -2°C). In Figure 8 it can be seen that the freezing at the surface of the system covered by a 2 m deposit is less apparent than the 4 m cover system counterpart. This is a result of the fact that there is a shallower insulating layer, allowing warmer temperatures in the summer to penetrate deeper into the deposit. A similar result is seen between the two cover systems modelled for RCP6.

In both the RCP4.5 and RCP6.0 climate change scenarios, permafrost aggradation seemed to decrease near the surface when comparing the midway point at 75 years to the final modelled year at 150 years. This is illustrated by a decrease in temperature at a depth of approximately 20-30 m from the surface. This is likely a result of the increase in air temperature for each model from the effects of climate change, thus increasing the temperature of the TSF. However, it should be noted that for both the climate change scenarios, no thawing of the tailings was calculated by the numerical model at any point in time for the 4 m cover system (Figures 10 and 11). The 2 m cover system saw some thawing of the shallow tailings in both climate change scenarios (Figures 12 and 13).

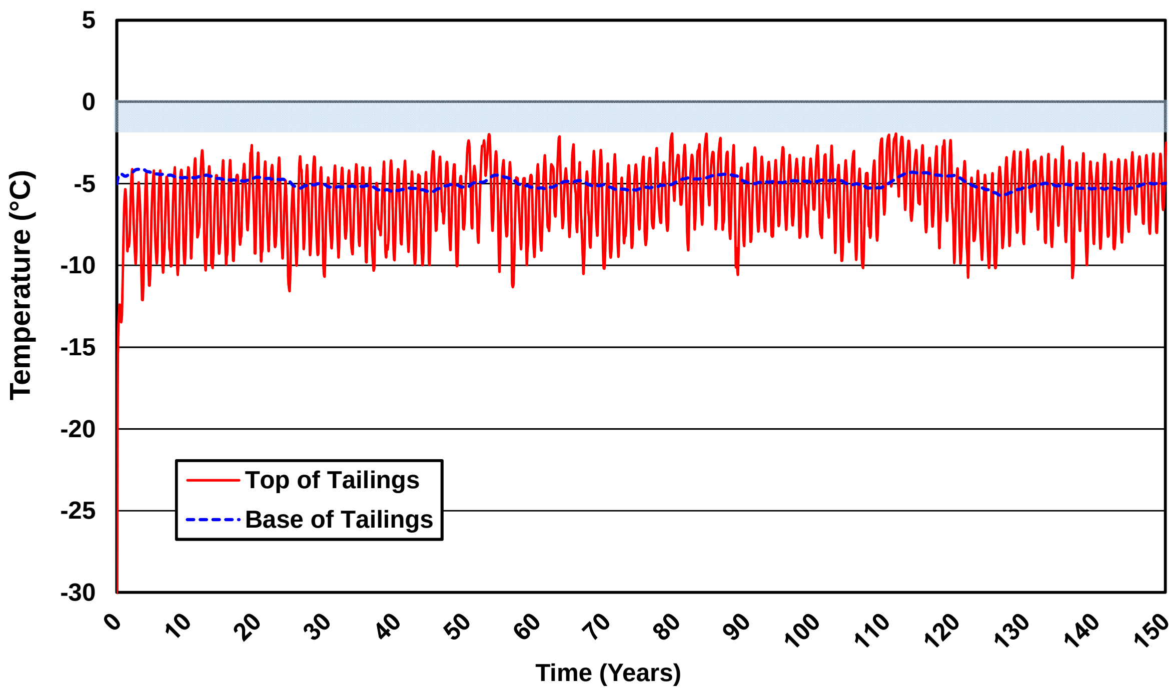

Figure 10 Temperature of tailings with 4 m cover system for RCP4.5 climate change scenario.

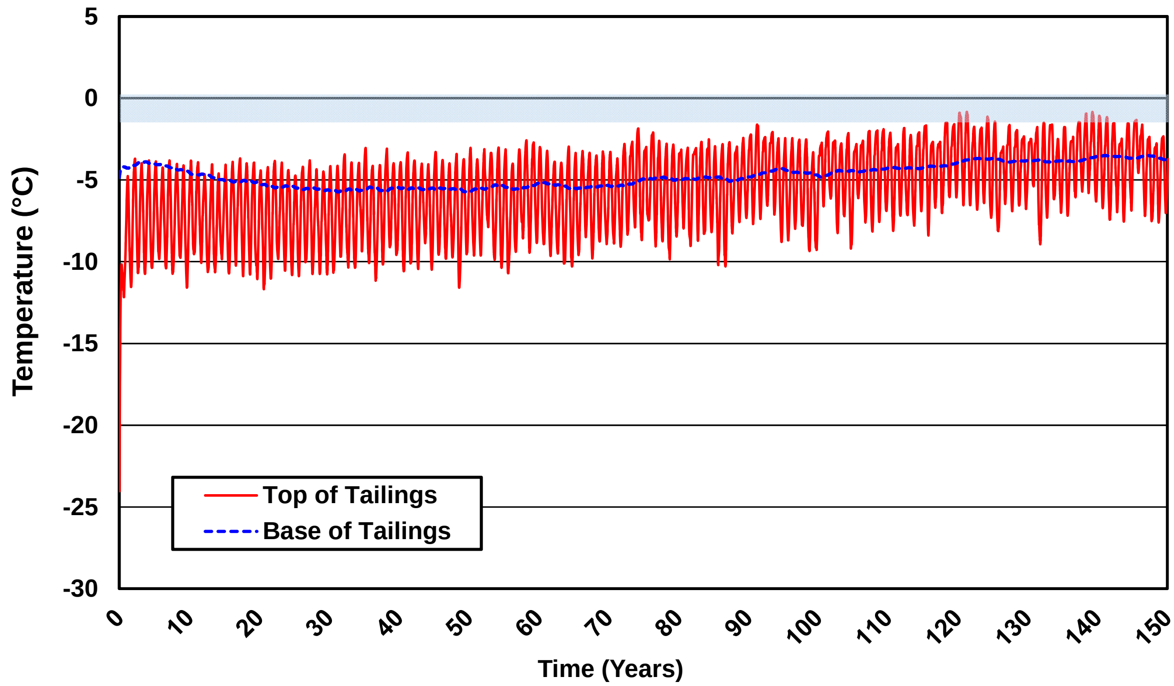

Figure 11 Temperature of tailings with 4 m cover system for RCP6.0 climate change scenario.

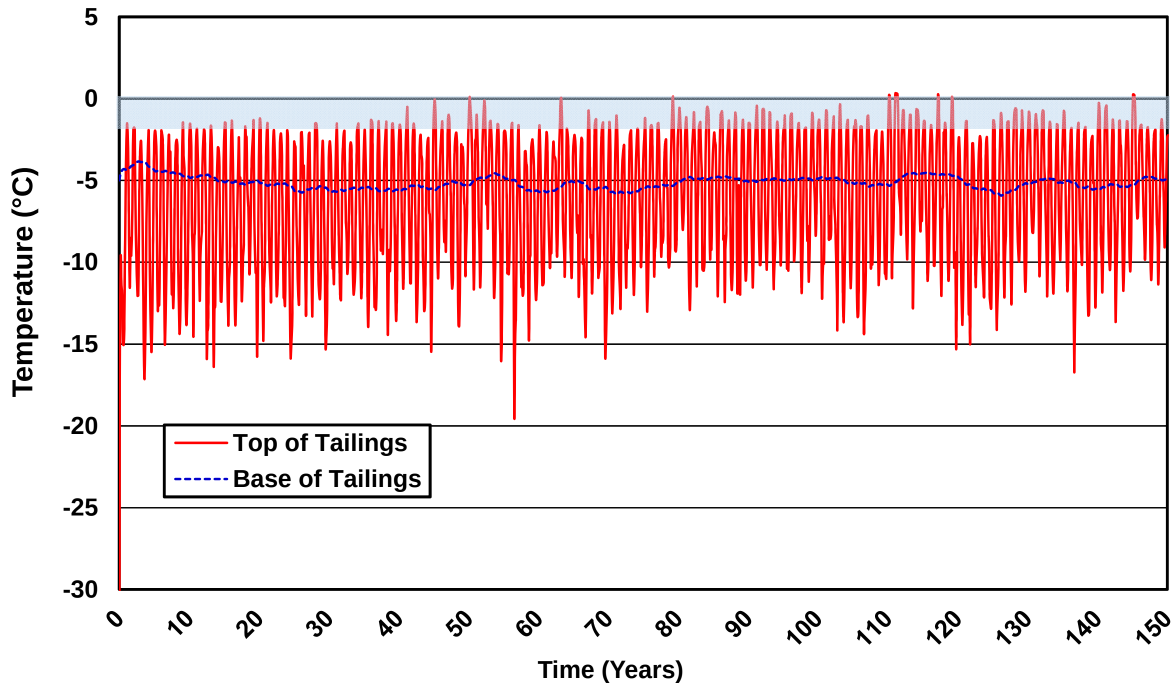

Figure 12 Temperature of tailings with 2 m cover system for RCP4.5 climate change scenario.

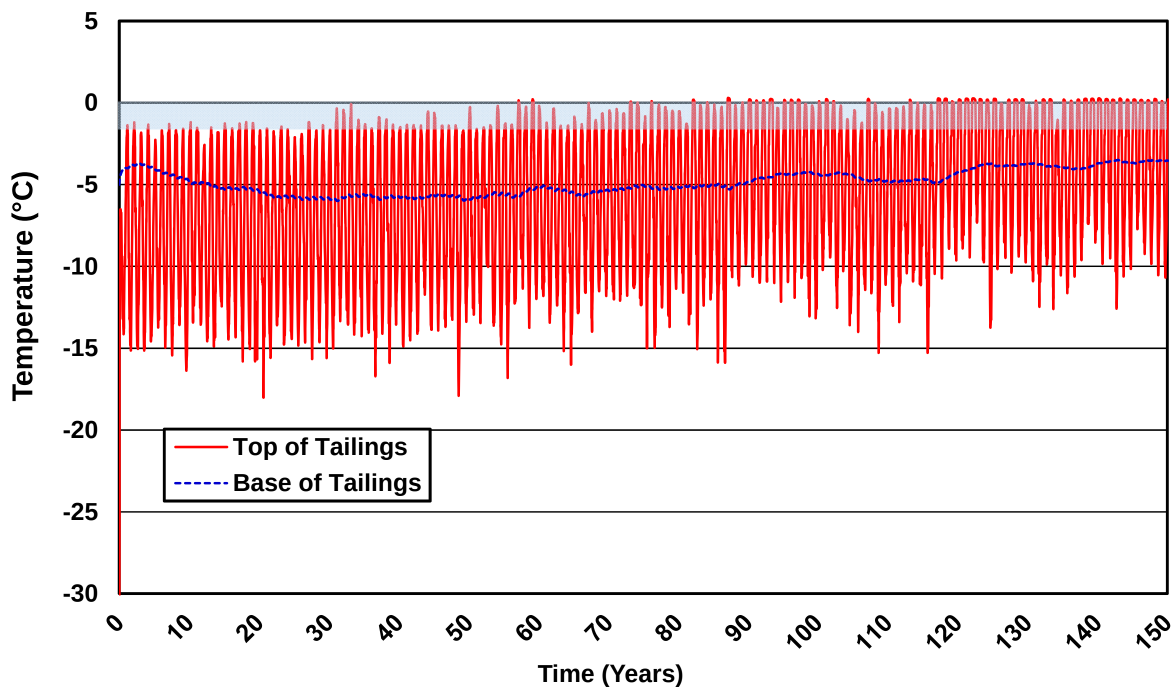

Figure 13 Temperature of tailings with 2 m cover system for RCP6.0 climate change scenario.

2D TEMP/SEEP Model

In the 2D coupled temperature/seepage model, several key differences are noted in the results when compared to the 1D models. The main difference is the fact that the freezing depth at the end of the 150-year period in the profile was substantially reduced. What was previously calculated to be a 75 m freezing depth (-2°C) in the 1D model was reduced to a freezing depth of approximately 50 m. This is a result of the inclusion of the pit lake thermal boundary condition. This pit lake represents a large continuous source of heat which was not accounted for in the 1D model. This source of heat maintains a temperature condition in the subsurface that is above the freezing point, and as such, water can continue to seep through the talik in this location, delivering the heat to further points in the profile. This heat will radiate outwards until an equilibrium is met. The temperature profile at the beginning and end of the 2D thermal model under the RCP4.5 climate change scenario can be found in Figure 14 and Figure 15, respectively.

Note that a NAG cover was modelled on the surface of the South Cell, as per the base case TSF closure design. A significant change to either the geometry or the cover on the South Cell would change the freezing depth under the TSF compared to what was predicted in the modelling shown. For example, if a water cover was placed on the South Cell instead of a NAG cover, there is the potential for this layer to behave as an energy source and delay or prevent the long-term freeze-back of the talik underlying the TSF.

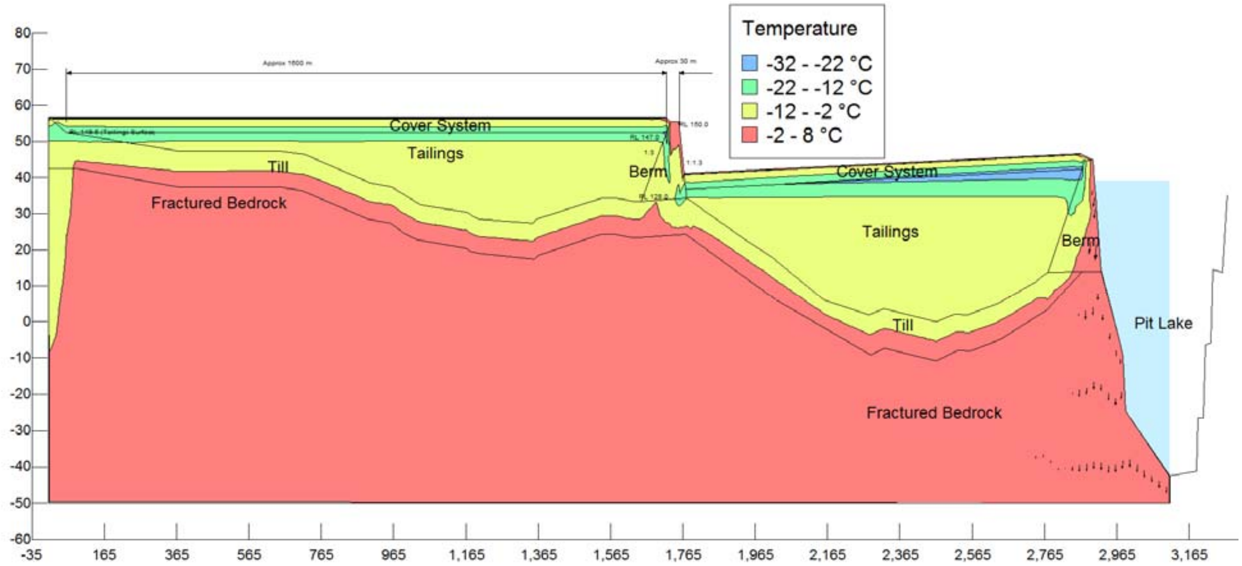

Figure 14 Temperature profile in TSF at beginning of model time, RCP4.5 for a 4 m cover system.

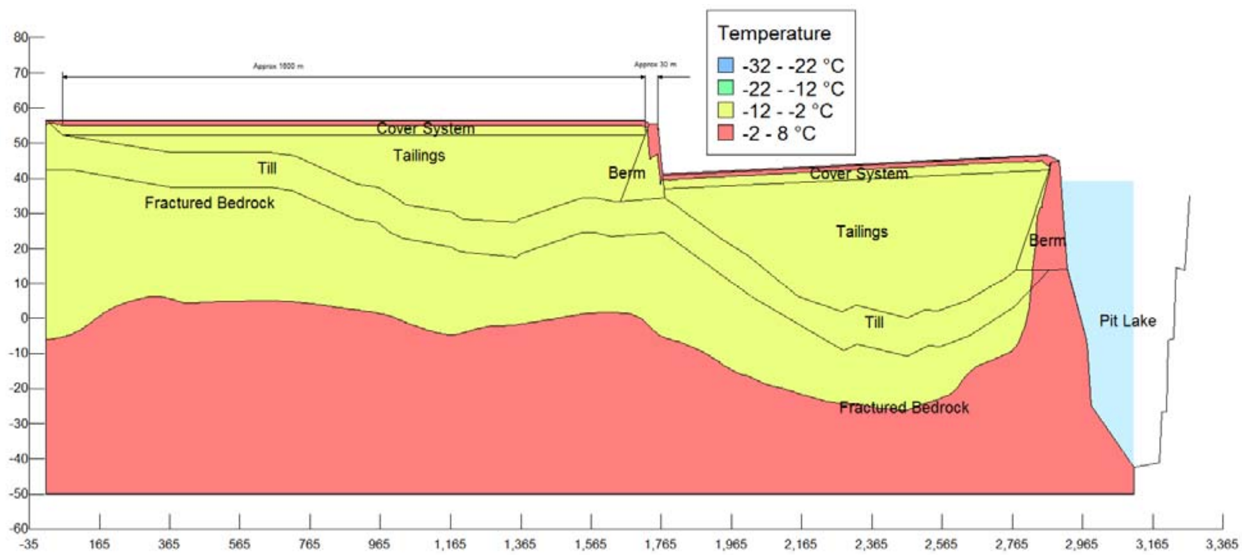

Figure 15 Temperature profile in TSF at end of model time (150 years), RCP4.5, for a 4 m cover system

In the case of the RCP4.5 climate change model, with a 4 m cover, the tailings stored within the TSF were shown to not exceed 0°C. The north cell of the TSF showed several instances of the temperature at the surface of the tailings (tailings-cover system interface) exceeding the -2°C criteria. In the north cell, the peak calculated temperature was -1.8°C occurring at approximately 140 years into the model runtime. The temperature profiles in the north cell using a 4 m cover system can be found in Figure 16.

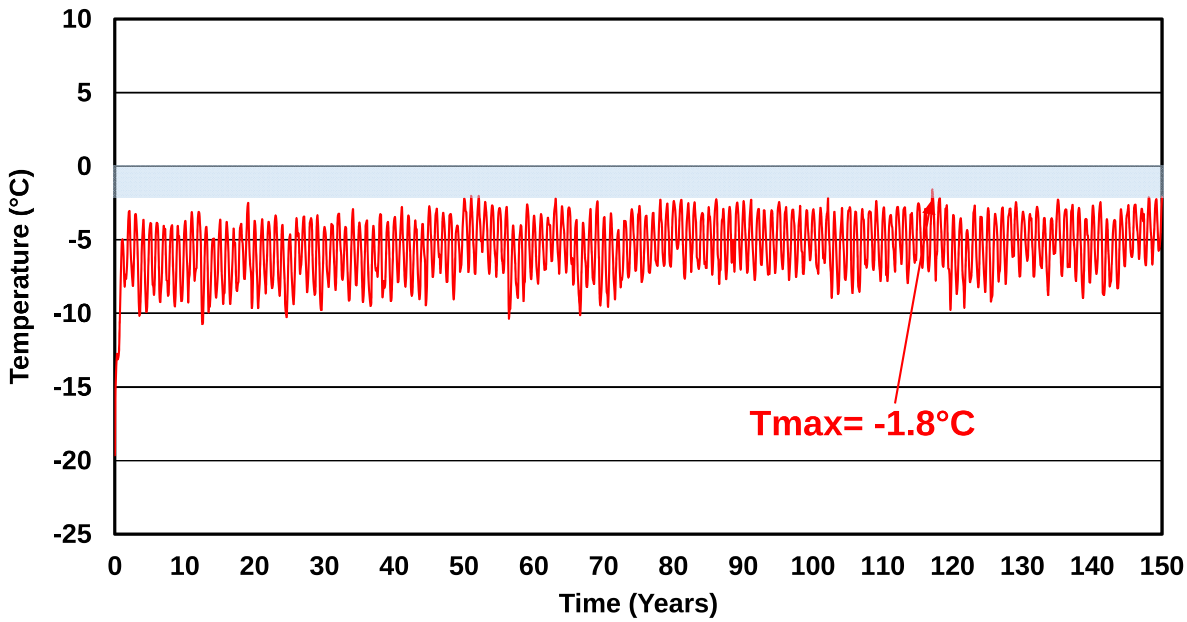

Figure 16 North Cell TSF tailings temperature at cover system – tailings interface, 4 m cover system, RCP4.5.

When using a 2 m cover system with the RCP4.5 climate change scenario, the results show the temperature of the shallow tailings exceeds -2°C, and in many instances, exceeds 0°C (Figure 17). In addition, due to the fact that the cover system is much thinner, the temperature of the tailings is more erratic, as it experiences thermal fluctuations from the ambient atmosphere more intensely. The peak calculated temperature from the numerical model with the 2 m cover system was approximately 1.5°C.

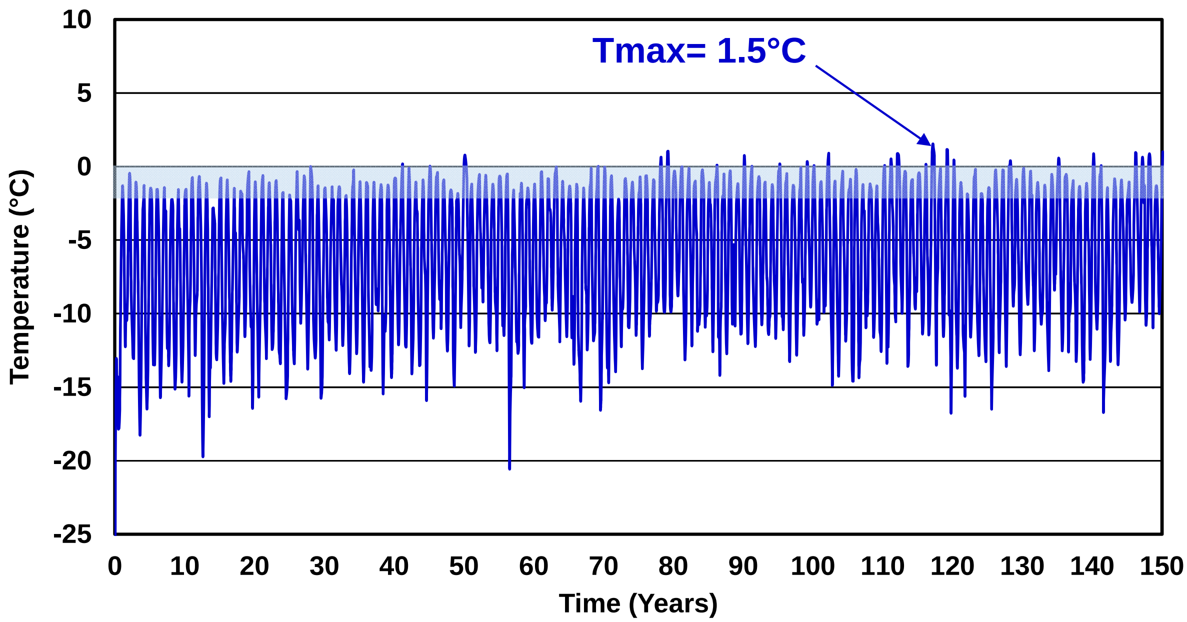

Figure 17 TSF tailings temperature at cover system – tailings interface, 2 m cover system, RCP4.5.

The numerical model, when simulated for 150 years using the RCP6 climate data set showed very different results when compared to the model run under the RCP4.5 dataset for a 4 m cover system. The key differences noted were the depth of freezing, where the model using the RCP6 dataset showed the greatest freezing depth (Figure 18). This is despite the fact that the RCP6 database is considered a worse scenario than the RCP4.5 database. It is estimated that the reason for the greater freezing depth is due to the RCP6 scenario having a lower concentration of forcing agents in the atmosphere (and therefore lower predicted air temperatures) than RCP4.5 during, approximately, the first 50 years of the simulations. However, it should be noted that although this climate dataset showed deeper frost penetration, it also showed more thawing of the tailings at the tailings – cover system interface beyond a modelled period of 90 years. This is due to the fact that the RCP6 dataset shows much warmer temperatures later in the estimation period when compared to the RCP4.5 dataset.

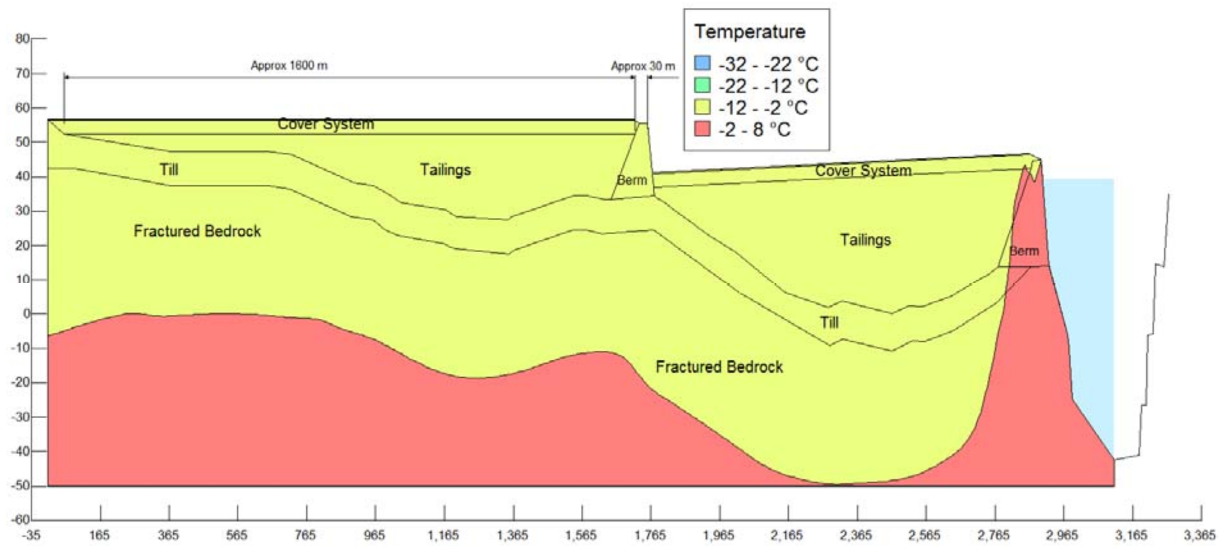

Figure 18 Temperature profile in TSF at end of model time (150 years), RCP6.0

As previously mentioned, the tailings – cover system interface saw increased occurrences of temperatures rising into the potentially unfrozen region of -2°C when compared to the model run under the RCP6 database. This is seen in the north cell in Figure 5, where a peak temperature of -0.7°C was calculated by the model. This effect of the RCP6 climate change scenario is even more pronounced when using a cover system of 2 m thickness. This is shown by the peak temperature modelled of 1.7°C at the cover system-tailings interface (Figure 3), as well as the fact that the temperature at this interface remains predominantly in the potentially unfrozen zone for the duration of the simulation.

2D Convective Airflow Model

The convective airflow model using modified geometry (see 'Geometry' section later in this report) was run for a period of 150 years using the RCP4.5 climate database. Assuming the same initial temperature conditions as modelled in the thermal/seepage modelling, the airflow rates through the cover system and resultant temperatures within the buried tailings were calculated.

Due to the presence of a layer of crushed soapstone resulting from construction at the surface, airflow rates through the cover system were minimal. The peak airflow rate was calculated to be approximately

0.01 m/day on a unit basis. This equates to 0.01 m^3/m^2/day. This airflow rate is not substantial enough to result in temperature changes of the tailings at the cover system – tailings interface, as shown by the temperature profiles as a function of time in Figure 19 and Figure 20. Figure 19 shows the temperature profile of the interface with the presence of convective airflow, while Figure 20 shows the temperature of the interface without any airflow in the system.

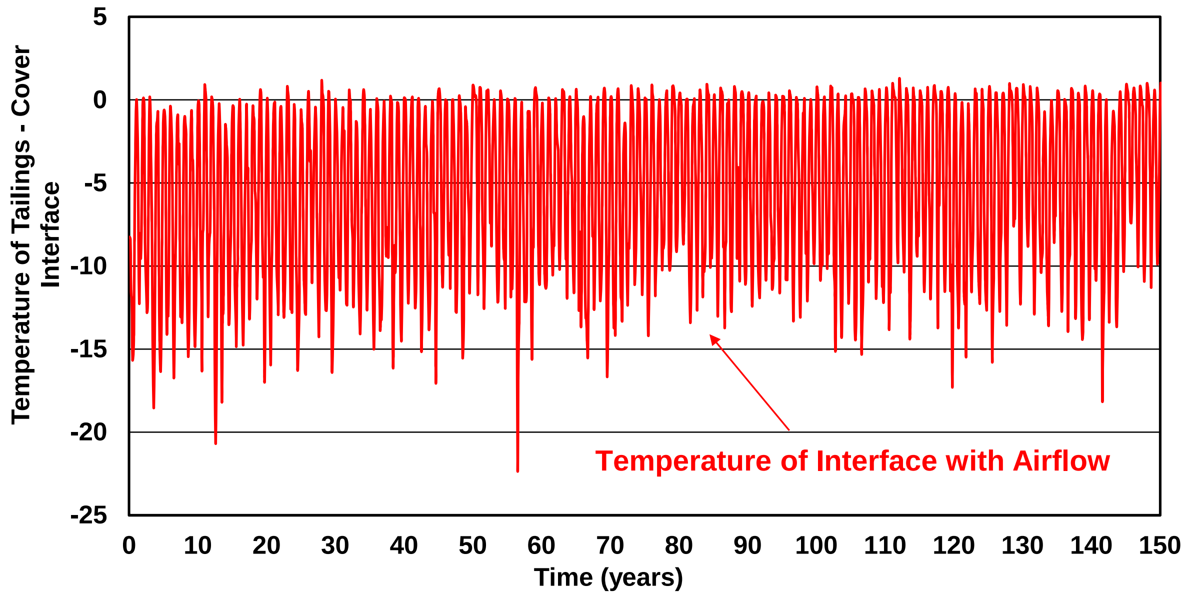

Figure 19 Time dependant temperature of cover system-tailings interface using RCP4.5 climate change scenario with airflow occurring in system for 4 m cover system.

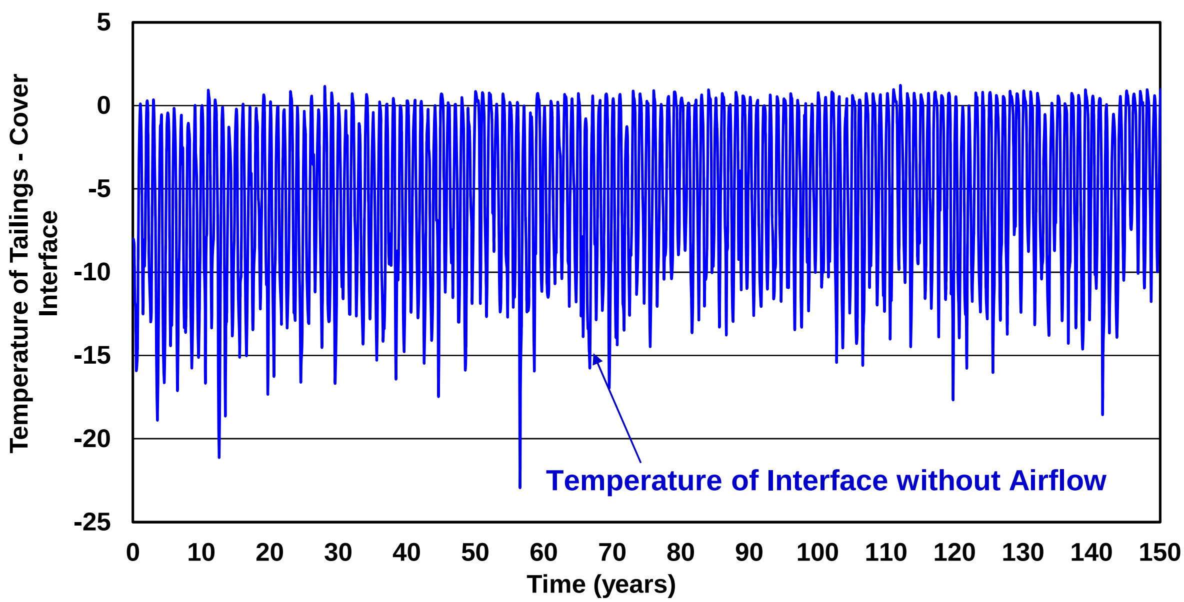

Figure 21 Time dependant temperature of cover system-tailings interface using RCP4.5 climate change scenario with zero airflow occurring in system for 4 m cover system.

Comparing Figures 19 and 20 shows that the temperature profiles are almost identical, indicating that the small airflow rates determined by the numerical model in this idealized geometry were not substantial enough to cause changes in the tailings temperature. The effect of airflow through the cover system would be even more reduced in the presence of frozen water occupying the voids of the cover system, and thus preventing airflow.

Based on the results of this idealized model, it is predicted that airflow rates through the cover system on a large scale in the field will not be substantial enough to affect cover performance. This conclusion was drawn from the fact that the numerical modelling carried out here-in used a geometry which was ideal for convective airflow to occur, and even under these conditions, there was no observable result on internal TSF temperatures.

Sensitivity Analysis

In order to assess the impacts of the various initial conditions and boundary conditions that were assumed when constructing the model, it is necessary to carry out a sensitivity analysis. This sensitivity analysis varies these assumed conditions based on professional judgement and rationalization of various alternatives. The model is then allowed to recalculate values and compares the presented results in previous sections and the relative impacts, if any, on the design and overall functionality of the system in meeting the design goals.

The sensitivity analysis for the numerical model used in the design process varied the following parameters, with the numerical model profile in brackets (1D or 2D):

- Surface infiltration (1D); and
- Permafrost below TSF (2D).

Each of the above variations on the initial numerical model were performed for both the RCP4.5 and RCP6 climate change scenarios.

1D Variable Surface Infiltration

Based on the 1D SPA modelling, both the 1D and 2D thermal/seepage models assumed zero net percolation through the cover system as a result of permafrost layers developing within the cover system blocking infiltration. However, due to the high heat capacity of water, even if water does not infiltrate through the cover system, surface infiltration resulting in interflow and/or evaporation may still have an effect on the thermal regime in the cover system that may result in degradation of the frozen layers. The degradation of these frozen layers may open up channels for future infiltration and net percolation, resulting in further permafrost degradation within the system.

The results of the 1D numerical model with a 4 m cover system show several instances where the seepage rates affected the temperature of the tailings, as seen by the areas which exceed -2°C in Figure 21. When comparing these results to those in Figure 10, which showed no instances of temperatures exceeding -2°C, it can be said that seepage through the cover system does have some effect on the internal tailings temperature.

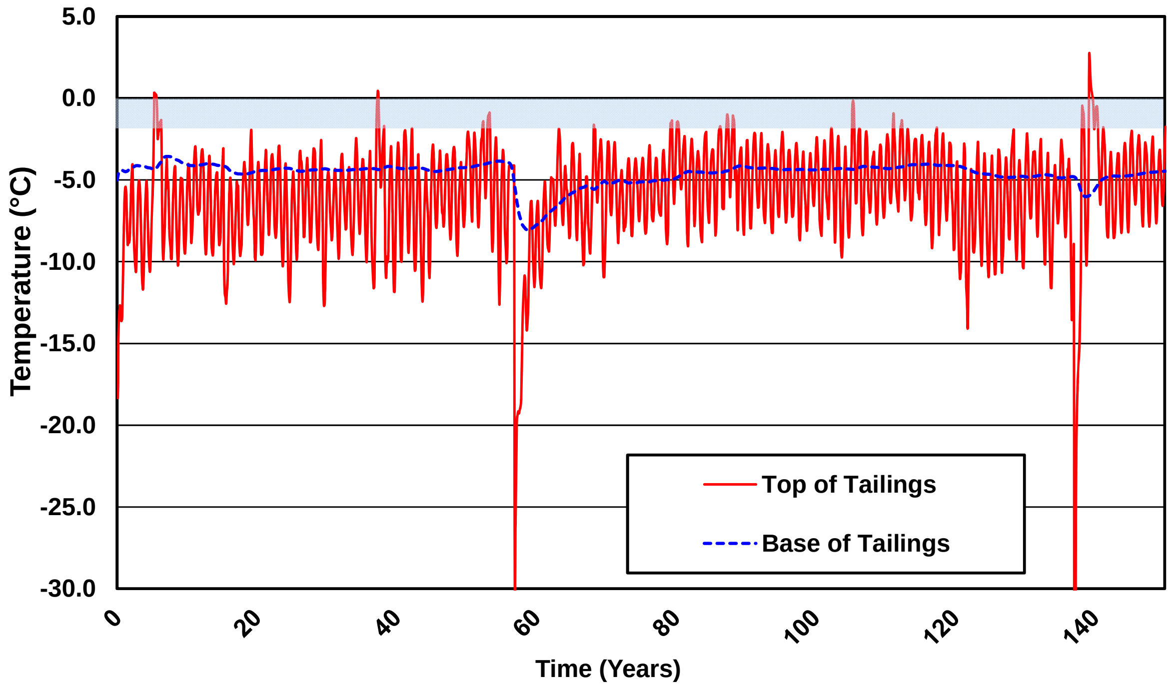

Figure 21 Temperature of tailings over time with consideration given to surface infiltration through 4 m cover system, RCP4.5.

The results in Figure 21 are further supported by those in Figure 22, which show the tailings temperatures in 1D using a 2 m cover system. In this case, the effects of seepage are more pronounced, as indicated by temperatures exceeding 0°C on several occasions. This contrasts to the results in Figure 11, which show no temperatures exceeding the 0°C mark.

Although the seepage rates indicate thermal movement into the tailings in both the 4 m and 2 m cover system scenarios, they only show substantial effects compared to the zero seepage scenarios initially modelled on several occasions. Therefore, it is concluded that if a proper surface water management system is designed as a component of the overall cover system design, then the thermal effects of infiltrating water can likely be minimized to a point where they are no longer a failure mechanism.

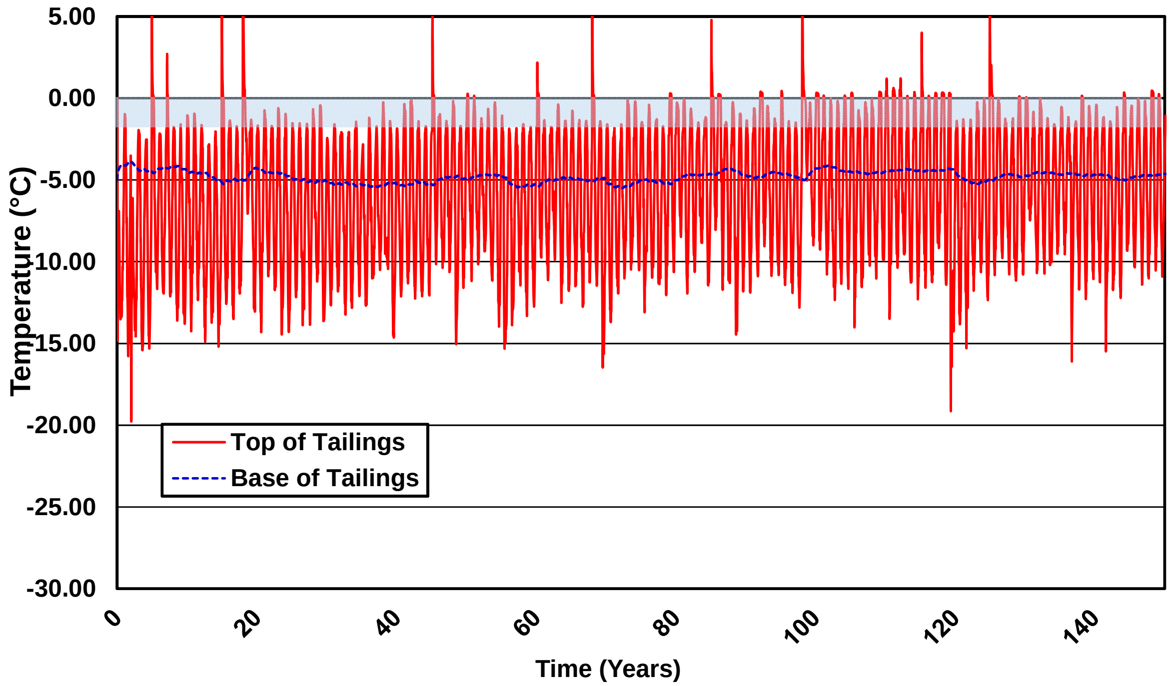

Figure 22 Temperature of tailings over time with consideration given to surface infiltration through 2 m cover system, RCP4.5

6.2 2D Variable Permafrost Depth

The true temperature of the original ground beneath the TSF is currently unknown. Hence, it was necessary to assess the permafrost aggradation under a variable permafrost condition beneath the TSF. The original model results above assumed the worst case scenario of a complete talik beneath the TSF (i.e. completely unfrozen) to assess the permafrost aggradation. However, field conditions also permit some existent permafrost beneath the TSF, and, as such, this condition needed to be assessed as well. The change in initial subsurface temperature can be seen in Figure 24, with the talik following the bathymetry of the TSF (previously Second Portage Lake).

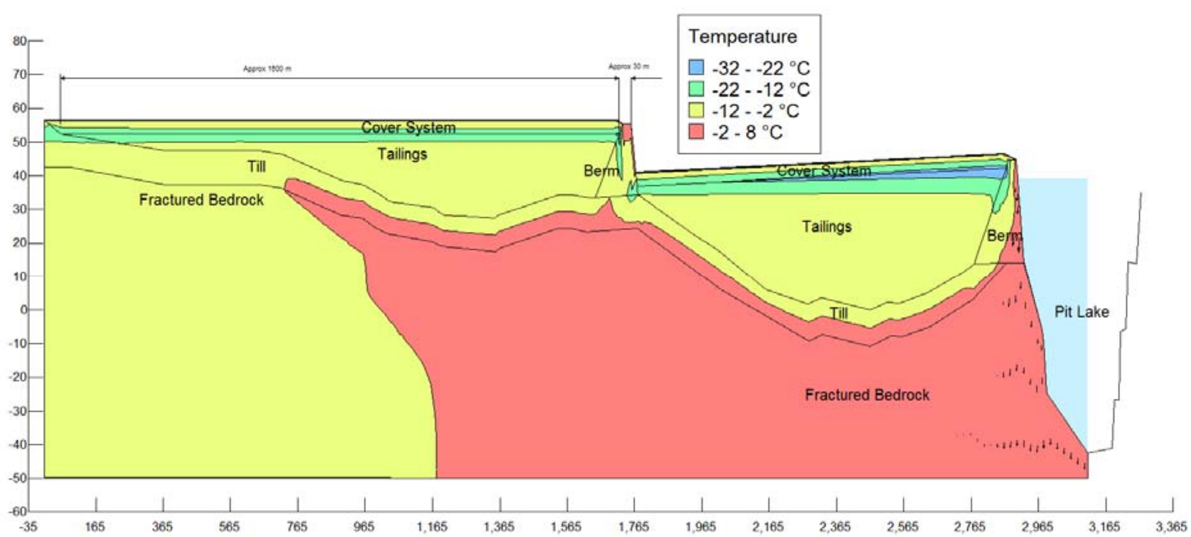

Figure 24 Initial permafrost condition used in thermal sensitivity analysis.

The existent permafrost extends from the boundary of the 2D profile and intersects the talik. The numerical model was then able to calculate the gradient between the permafrost and talik to create a smooth temperature transition between the two regions.

The modified permafrost conditions were tested using both climate databases. The results of the model run under the RCP4.5 climate database are shown in Figure 25, and show that there is some additional permafrost aggradation in the system based on the new initial conditions. However, this permafrost aggradation is only seen in the area surrounding where the new permafrost condition was applied. It fails to increase permafrost aggradation beneath the south cell, or near the pit lake. No effects on tailings temperature were seen using the new permafrost condition.

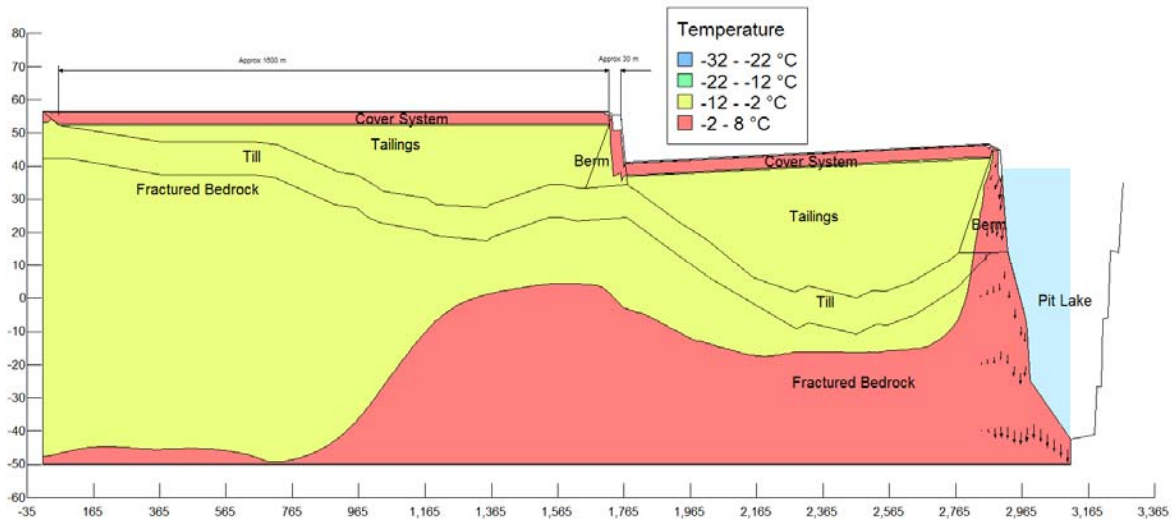

Figure 25 Final permafrost profile following 150 years of RCP4.5 for thermal sensitivity analysis

Similar results were seen for the new permafrost condition under the RCP6.0 climate change scenario (Figure 26). The permafrost extended deeper in the profile under this climate change scenario. This is similar to the results discussed previously due to the lower forcing agent concentrations estimated for the initial years of the RCP6 scenario when compared with RCP4.5. However, the same general trends were seen in the RCP6.0 scenario compared to the RCP4.5 scenario in that the majority of extra permafrost aggradation occurred in the area surrounding the initial permafrost. Little to no extra permafrost aggradation was seen in the area beneath the south cell TSF and next to the pit lake, when compared to the initial results in Figure 18.

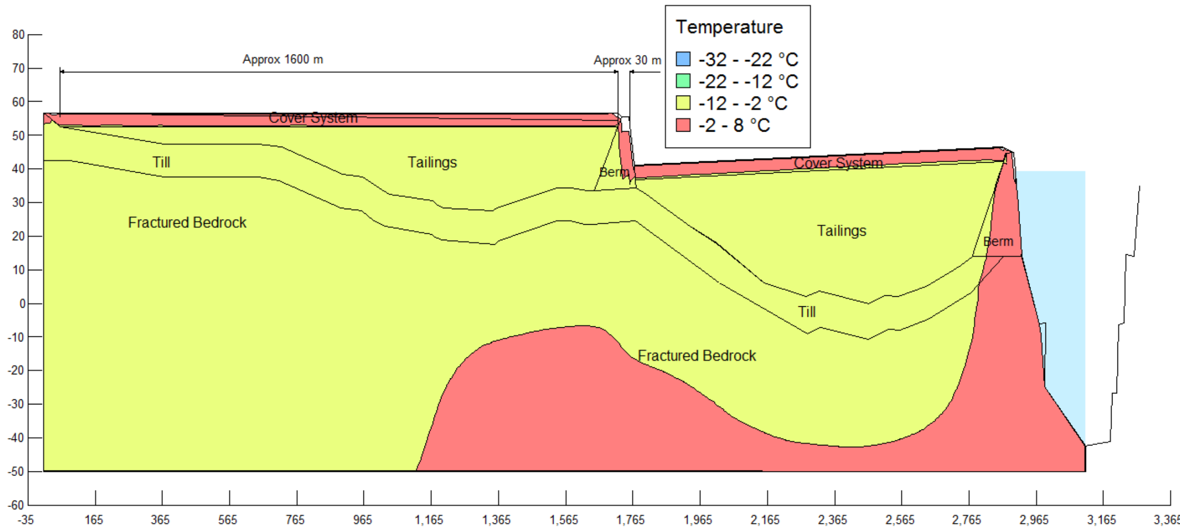

Figure 26 Final permafrost profile following 150 years of RCP6.0 for thermal sensitivity analysis.

Description of Numerical Model Programs

Four components of the GeoStudio suite of programs were used for this modelling project: VADOSE/W; SEEP/W; TEMP/W; and, AIR/W. GeoStudio 2012, Version 8.13.1.9253, was used to conduct the modelling completed for this project.

VADOSE/W (Geo-Slope International, 2014a) is a two-dimensional (2D) finite element model (which can also perform 1D simulations) that predicts pressure head (suction) and temperature profiles in the soil profile in response to climatic forcing (such as evaporation) and lower boundary conditions (such as a water table). A key feature of VADOSE/W is the ability of the model to predict actual evaporation and transpiration based on potential evaporation and predicted suction, as opposed to the user being required to input these surface flux boundary conditions. The actual evapotranspiration rate is generally well below the potential rate during prolonged dry periods because the suction in the material profile increases as the surface desiccates. In addition, VADOSE/W is a fully coupled (through the vapour pressure term) heat and mass transfer model, which is capable of predicting water vapour movement.

VADOSE/W is also capable of evaluating the impact of frozen conditions on moisture storage and transport for a given soil or rock material. The change of phase from liquid to solid (i.e. water to ice) is accounted for using the apparent specific heat capacity approach, which is standard in thermal modelling. A heat source or sink is added at each time step based on the amount of heat released when a set volume of water changes to ice. When the ground becomes frozen, the permeability must be reduced. In the physics of freezing, there is a phenomenon whereby even in a saturated material, a “suction” develops at the ice-water interface much like that at the air-water interface in an unsaturated soil. If the temperature below freezing is known, then the suction can be computed using the Clausius Clapeyron phase equilibrium equation (Black and Tice, 1989). VADOSE/W does not account for this suction at the microscopic level in the mass transfer equation, but does use the actual temperature to compute what the suction should be so that the program can look up a reduced permeability from the material’s hydraulic conductivity function (suction versus hydraulic conductivity). VADOSE/W simulations can be completed with or without this functionality.

Thermal modelling for the AEG TSF was done by using two models coupled together within the GeoStudio software suite:

- SEEP/W; and,
- TEMP/W

Typically in a TEMP/W simulation, it is assumed that moisture content remains the same. However, when water movement occurs in a system, substantial heat transfer can occur as a result of this movement of water. As such, by coupling the TEMP/W simulation with a SEEP/W simulation, a more accurate temperature condition in the subsurface can be estimated. In order to assess the effect of a deep talik (>500m) on tailings freezeback, an initial 1-dimensional model will be assessed to a depth of 500 m below the surface, inclusive of the cover system, tailings, till, and bedrock profiles. From the results of the 1D analysis, thermal flux rates determined by the numerical model at specific points in the profile will be applied to a larger scale, 2D thermal/seepage model to assess thermal and water flow rates across the entire profile of the TSF. This 2D model will take into account the effects of the flooded pit lake on the subsurface temperature.

SEEP/W (Geo-Slope International, 2014b) is a 1D/2D finite element model that can be used to model the saturated and unsaturated movement of moisture and pore-water pressure distribution within porous materials such as soil and rock (Geo-Slope International, 2014b).

TEMP/W (Geo-Slope International, 2014c) is a 1D/2D finite element model that can be used to model thermal changes in porous systems due to various changes in the environment, internal changes in temperature, or any other influencing condition that may result in a change of temperature in the subsurface. When coupled with SEEP/W, the effect on thermal regimes within the system as a result of flowing heated water can be calculated to determine relative temperature changes.

When investigating the potential for convective airflow in the cover system, three congruent models within the GeoStudio software suite were used:

- SEEP/W;
- TEMP/W; and,
- AIR/W

AIR/W (Geo-Slope International, 2014d) is a 2D finite element model that is executed within the SEEP/W model, which can be used to model air pressure and flow within a system in response to changes in pressure conditions at the boundary, or changes in water pressure. When coupled with TEMP/W, it can also calculate changes in air flow and pressure as a result of changes in air temperature.

Model Inputs

Before SPA modelling can be undertaken the model inputs must be clearly defined. These inputs can be placed into five categories: material properties; upper boundary conditions; geometry; lower and edge boundary conditions; and initial conditions. Vegetation, a sub-category of the upper boundary conditions, was assumed to be negligible and not included in the simulations. Descriptions of the five categories are presented in the following sections.

Material Properties

The material properties or functions required for each material are as follows:

- water retention curve (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); and,
- volumetric specific heat function (volumetric water content versus volumetric specific heat).

A set of material properties were estimated for the following five materials: crushed soapstone (from vehicular traffic); NPAG; tailings; till; and, bedrock. All material properties were estimated based on previous work completed by Golder Associates Ltd. (2008) and, for the crushed soapstone, NPAG and tailings, comparisons of particle size distribution (PSD) data to materials in the SoilVision database with similar PSDs and known material properties (SoilVision Systems Ltd., 2005). Figures 27, 28 and 29 show the estimated WRC, k-function, and air conductivity function for each simulated material. The thermal functions were estimated using methods programmed into the VADOSE/W software.

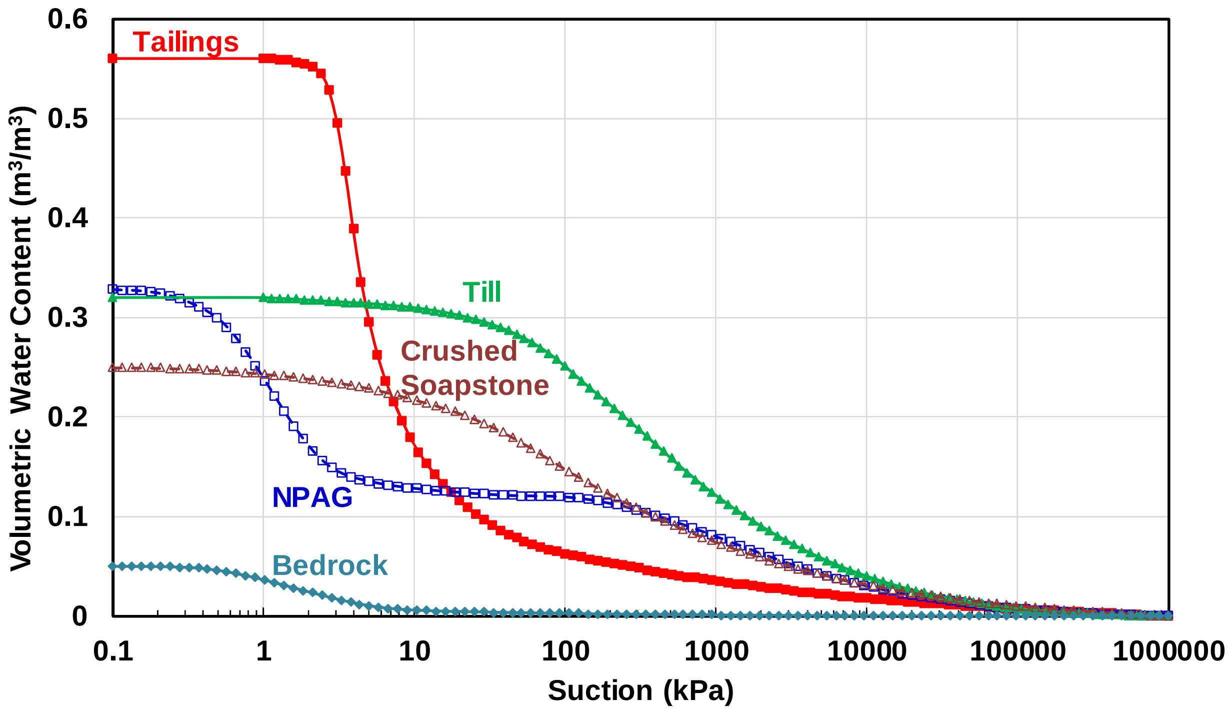

Figure 27 Water retention curves used to simulate Meadowbank materials

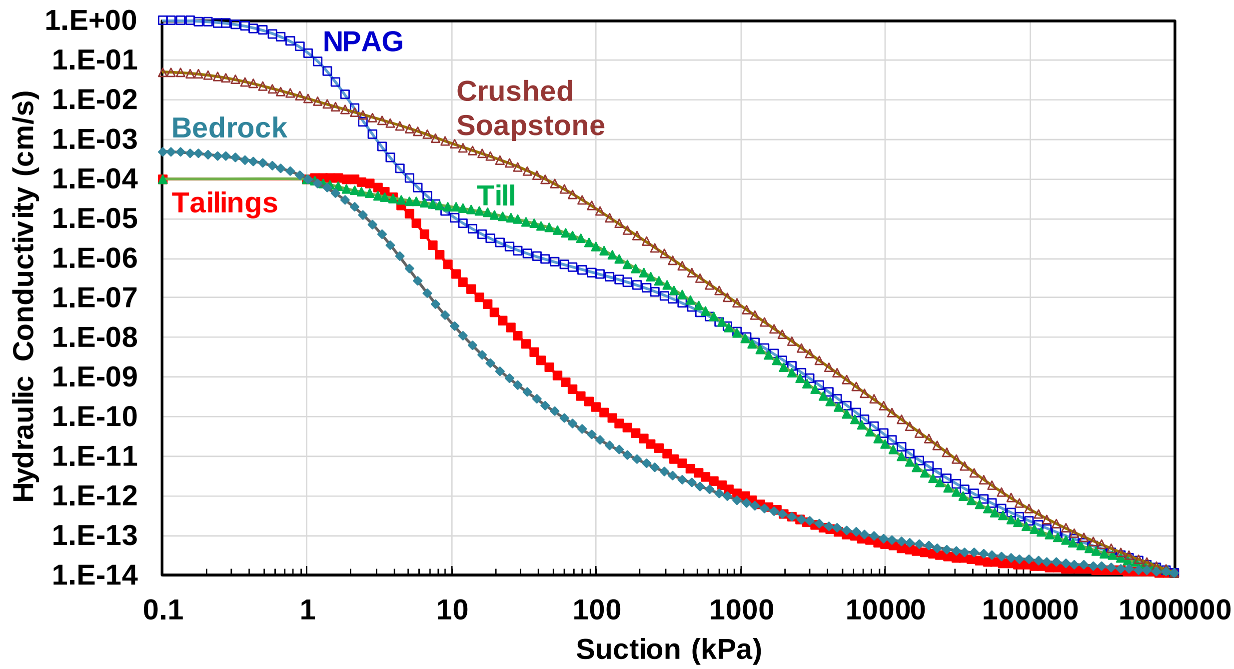

Figure 28 Hydraulic conductivity functions used to simulate Meadowbank materials

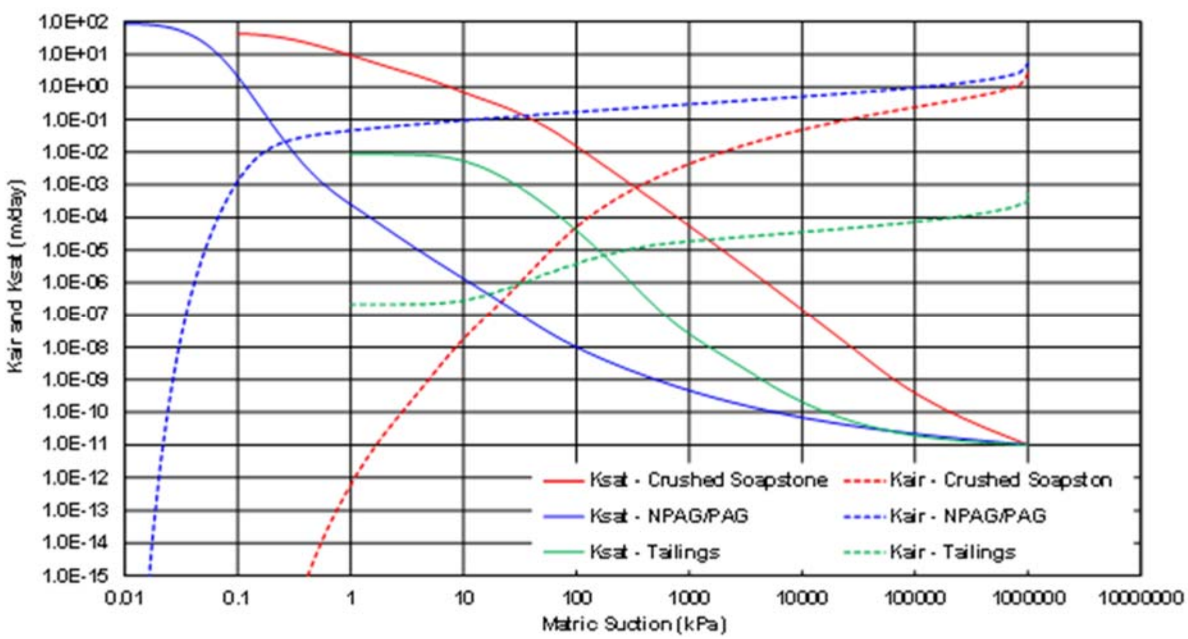

Figure 29 Air conductivity functions used to simulate Meadowbank materials

Upper Boundary Conditions

Based on the results of the 1D VADOSE modelling, it was determined that due to permanent freezing of the tailings, there would be no net percolation into the tailings mass, and as such, no surface flux was applied to the SEEP/W numerical models.

TEMP/W requires daily surface temperature data whereas VADOSE/W and AIR/W require daily values of: maximum and minimum air temperature; maximum and minimum relative humidity (RH); average wind speed; and precipitation (amount and duration). Historic values for all these parameters except net radiation are available from Environment Canada (2014) for Baker Lake, approximately 80 km south of Meadowbank. Environment Canada has hourly records for Baker Lake from 1964 to present, of which the period August 1964 to July 2014 (excluding 1993) was used to create an historic 50-year database for this project. Measurements from Baker Lake during 1993 were not included due to poor data quality that year, as previously noted by SNC-Lavalin (2013). After comparing the climate data measured at Meadowbank from January 2012 to September 2014 to measurements taken at Baker Lake for the same period it was concluded that the Baker Lake data did not need to be adjusted to represent the Meadowbank site. Any missing data in the Baker Lake climate record were filled with average measurements for a given day.

A "synthetic average" climate year was defined by averaging daily climate conditions from the 100-year climate database (e.g. averaging the maximum temperature on January 1st for all 100 years). However, rainfall was not applied just considering 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 1 provides a summary of the average monthly conditions in the 50-year historic database developed for this project.

Table 1
Summary of average climate parameters for the 50-year Meadowbank historic climate database.

Month	**Temperature** (ºC)		**Relative Humidity** (%)		**Wind** (m/s)	**Rainfall**	
	Maximum	Minimum	Maximum	Minimum		(mm)	(days)
January	-28.2	-35.2	71.5	60.0	6.4	8	27
February	-27.8	-35.0	70.7	59.7	6.3	7	24
March	-22.8	-31.3	72.9	60.7	5.9	10	24
April	-12.5	-21.9	81.2	67.7	5.8	15	19
May	-2.6	-9.8	89.5	75.2	5.4	15	20
June	8.9	0.5	89.6	61.9	4.8	22	15
July	16.8	6.1	88.6	52.5	4.7	38	14
August	14.3	5.4	91.7	58.6	4.9	42	17
September	6.1	-0.4	93.0	68.2	5.5	43	21
October	-3.6	-9.8	91.1	77.3	6.0	31	26
November	-15.8	-23.2	80.9	67.7	6.1	18	24
December	-23.6	-30.8	74.2	62.0	6.1	10	25
Annual	***-7.5***	***-15.4***	***82.9***	***64.3***	***5.7***	***259***	***256***

Climate change is an important factor in determining the long-term performance of cover systems. Hence, the historic database was adapted to account for climate change predictions over the next 150 years. How this was done 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 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 (van Vuuren et al. 2011). These values are relative to pre-industrial levels. RCP4.5 and RCP6 scenarios were chosen as the most reasonable climate change scenarios and used to create two, 150-year climate change databases for this project. Figure 30 provides the concentration of all forcing agents (in parts per million (ppm) of CO2-equivalence) for the four RCP scenarios.

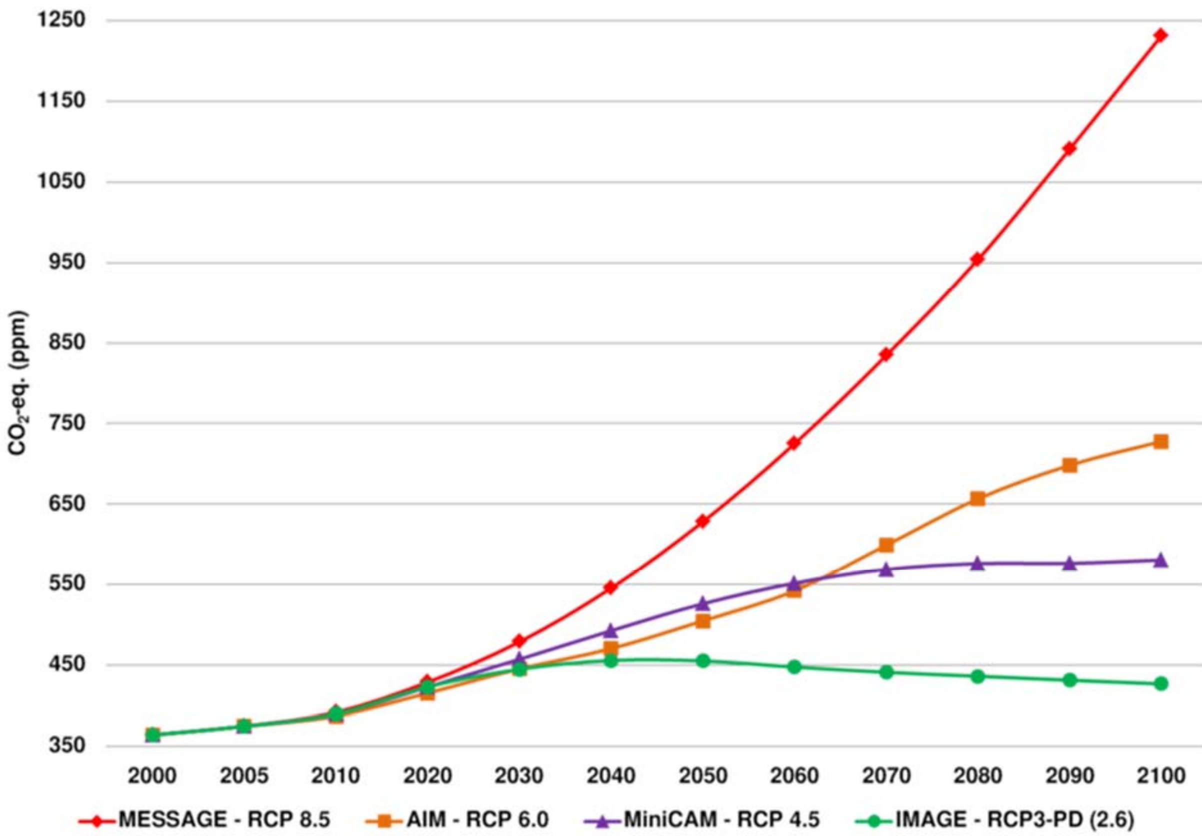

Figure 30 All forcing agents' atmospheric CO_2-equivalent concentrations according to four RCP scenarios

Monthly results from two general circulation models (GCM) were used to provide estimates of climate conditions for Meadowbank over the next 150 years. The CanESM2/CGCM4 model developed by the Canadian Centre for Climate Modelling and Analysis (CCCma) was used to develop inputs for the RCP4.5 climate database (CCCma, 2014). A second GCM needed to be selected as the CCCma has not publicly released its results for the RCP6 scenario. Hence, the CESM1-CAM5 model, develop by the National

Center for Atmospheric Research (NCAR), was selected to provide monthly estimates of climate conditions for the RCP6 climate database (NCAR, 2014).

The output of both GCMs are gridded datasets. Hence, historic estimates between August 1964 and July 2014 (excluding 1993) from the nearest point in the gridded dataset to Meadowbank were compared to the 50-year climate database developed for the site to determine monthly adjustment factors for each required parameter so that the GCM predictions were more representative of site conditions. Once the monthly GCM data were adjust, the GCM monthly conditions were used to adapt the daily data in the historic database to represent the GCM predictions. To do this, the 50-year historic database was repeated three times (to create a 150-year database) and adjustment factors were developed for each parameter for each month of each year so that the databases have the same monthly predictions as the adjusted GCMs. Figures 31 and 32 show the annual temperature and precipitation, respectively, estimated for the RCP4.5 and RCP6 150-year climate databases developed for Meadowbank. Both models anticipate temperatures to rise at about the same rate (approximately 0.05°C/year) for the next 60 years after which RCP4.5 estimates a much larger reduction in temperature increase than RCP6, with temperatures stabilizing in approximately 100 years, whereas RCP6 results in temperatures still increasing after 150 years. Both scenarios predict an increase in precipitation with time of approximately 0.6 mm/year for RCP4.5 and 0.7 mm/year for RCP6.

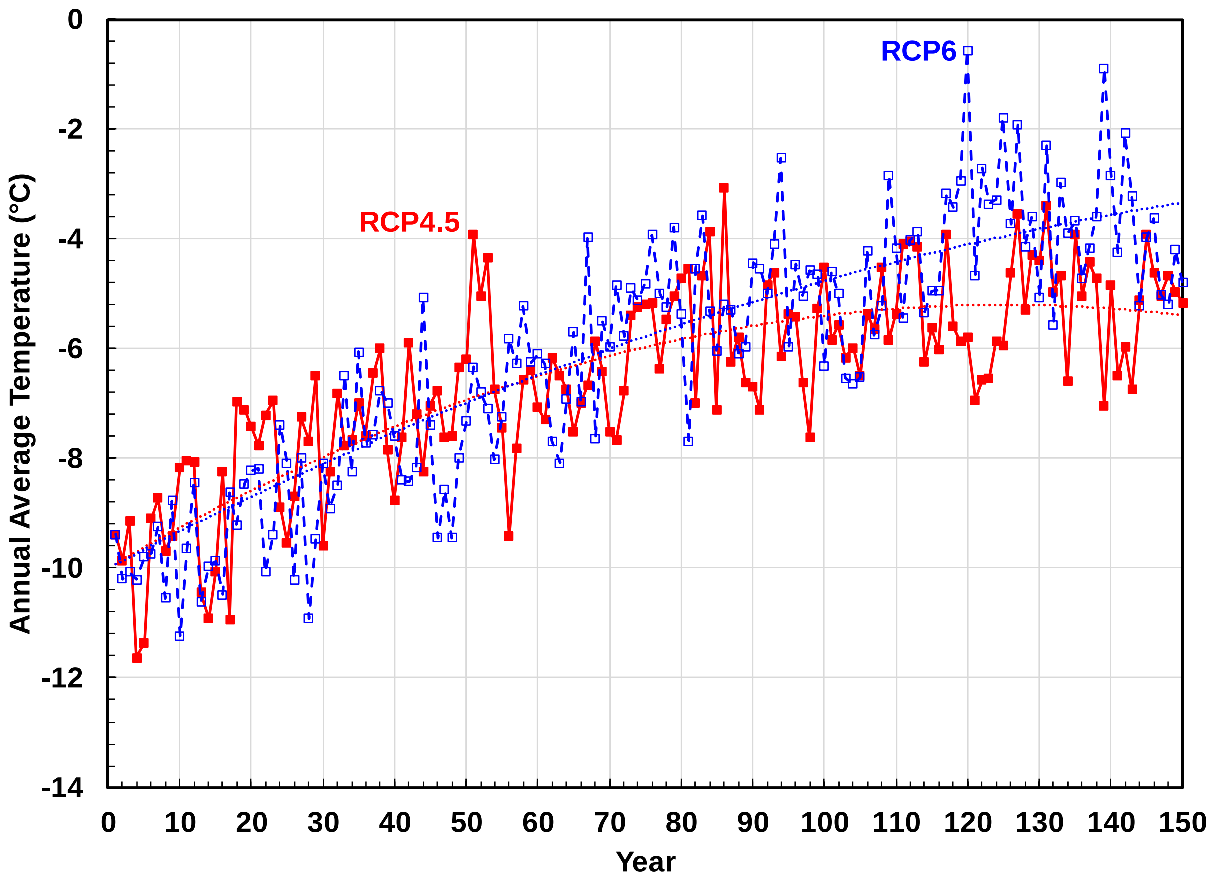

Figure 31 Annual average temperature estimated for the RCP4.5 and RCP6 databases

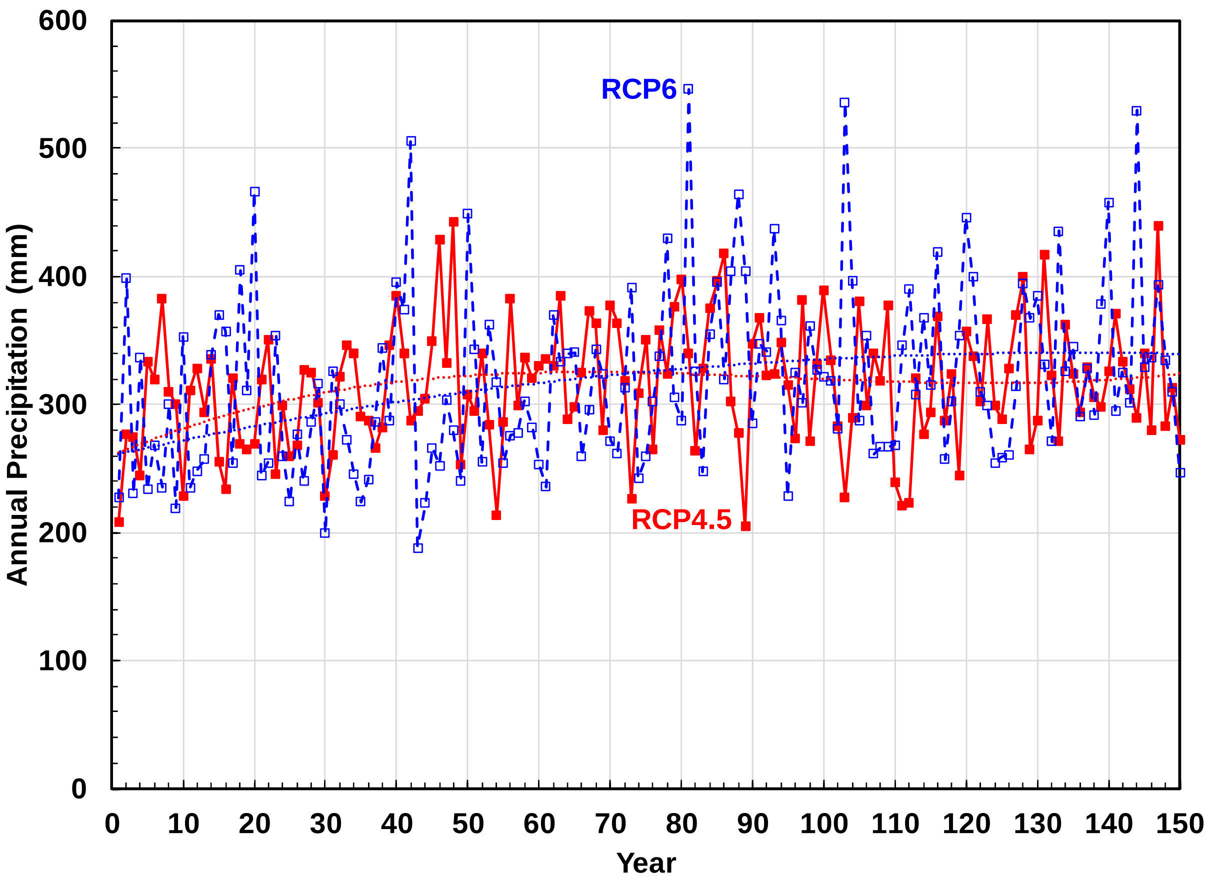

Figure 32 Annual precipitation estimated for the RCP4.5 and RCP6 databases

Geometry

<u>1D SPA Model</u>

All 1D SPA models consisted of (from surface to base):

- 0.25 m of crushed soapstone;
- 1.75 m (2m cover system) or 3.75 m (4 m cover system) of NPAG;
- 20 m of tailings;
- 10 m of till; and,
- 20 m of bedrock.

<u>1D Thermal and Seepage Model</u>

The 1-dimensional thermal and seepage model was assessed on a unit scale horizontally, and to a depth of 500 m vertically. Two different cover systems were assessed using the 1-dimensional model. The layout of the numerical model which assessed the 4 m cover system, from the surface downwards, is as follows:

- 0.25 m compacted soapstone;
- 3.75 m granular NPAG;
- 20 m tailings;
- 10 m till; and

- 466 m bedrock.

The key difference for the alternative 2 m cover system scenario is:
- 0.25 m compacted soapstone; and
- 1.75 m granular NPAG

2D Thermal/Seepage Model

The cross section for the 2D thermal/seepage numerical model was extrapolated from topographical drawings of the AEG TSF site and translated into a 2D profile. This profile can be seen in Figure 33, and extends to a depth of approximately 110 m below the surface of the tailings in Second Portage Lake.

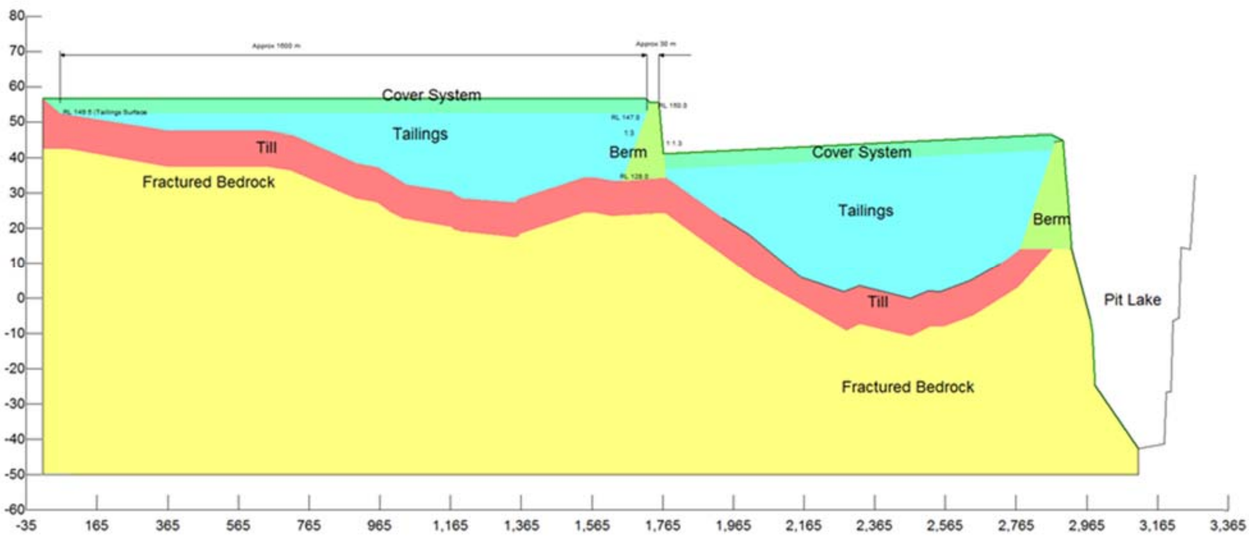

Figure 33 2D thermal/seepage model geometry and regions

2D Convective Airflow Model

It is anticipated that due to the high saturation and fine nature of the tailings material at the present time, and anticipated saturated condition into the future, the airflow rates through the buried materials will be negligible. However, since the cover system is coarser in nature, and will be placed in the unsaturated state, there is the potential for airflow to occur. In order to properly assess the effects of convective airflow occurring in the cover system, a simplified geometry was modelled which was set up in such a way that it would be the ideal geometry to allow convective airflow to occur. This includes a sloped surface of coarse material which eventually narrows as it approaches the edge. The edge was then left uncovered, while the remainder of the sloped surface was covered with the same crushed sandstone as used in the thermal modelling. The geometry profile used in the convective airflow model is shown in Figure 34.

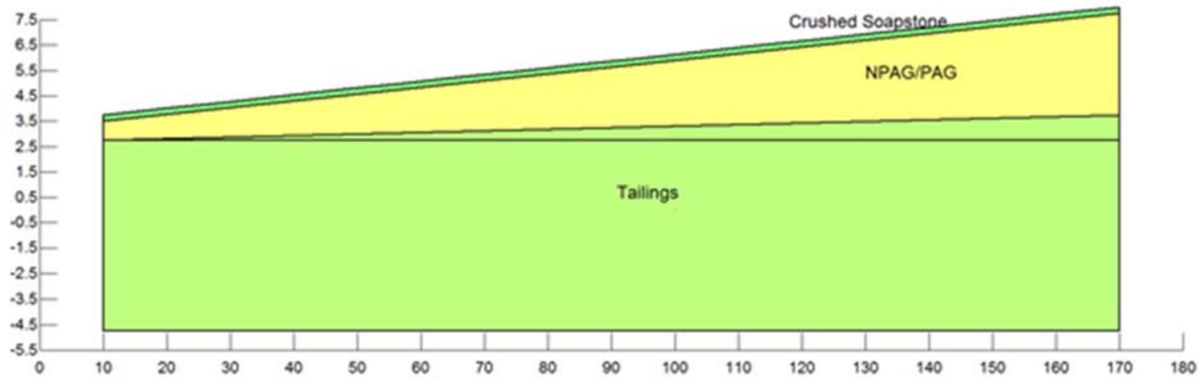

Figure 34 Geometry of 2D convective airflow model

This assessment was only carried out for the RCP4.5 scenario as it was anticipated that the airflow rates would not be substantial, and that the RCP4.5 scenario would provide proof of this lack of airflow in the system, and lack of relative effects on internal TSF temperature.

Lower and Edge Boundary Conditions

<u>1D SPA Model</u>

For the 1D SPA modelling, the lower boundary (i.e. the base of the bedrock) was estimated to be a no flow boundary at a constant temperature of -6°C. The edges were also assumed to be no flow boundaries.

<u>Seepage Models</u>

For the 1-D seepage model component, It was assumed that the base of the seepage model (500 m below the surface), was a free draining condition. This would allow any changes in head to be drained out the base of the system, representative of a talik in the field.

For the 2-D seepage model component, the same free draining condition was assumed for the base of the bedrock in the profile, however, the numerical model is set up in such a way that as permafrost aggradation occurs within the system, seepage no longer occurs due to freezing of the voids between material particles.

The flooded pit lake presents a constant head condition which will result in seepage into the underlying till and bedrock layers, and may potentially cause migration of a constant source of heat into the deposit. As such, the pit lake was modelled with a constant head boundary condition representative of the estimated final surface elevation of the pit lake.

<u>Thermal Models</u>

The TSF at Meadowbank was previously a large lake, known as Second Portage Lake. This lake was deemed to be large enough to result in an open talik extending through the permafrost beneath the lake. As such, since the area was only recently reassigned to a TSF, it was assumed that the Talik still exists in its entirety to date. Due to the fact that the Talik is unfrozen, it was assumed that the entirety of the bedrock beneath the TSF had an initial temperature of 1oC as an initial condition. During the transient analysis of the 1-D numerical model, it was assumed that the base of the system had a constant lower boundary condition of 1oC, while the remainder of the system was allowed to fluctuate its temperature with changes in thermal conditions of overlying layers.

From the 1-D numerical model assessment, the thermal flux as a function of time calculated from the results was extracted and applied as the lower boundary condition at the corresponding depth in the 2-D model. This allows the model to determine temperature migration relative to a deep talik condition, without undergoing the complex calculations of modelling the entire 500 m deep talik in 2-D. The thermal flux applied to the base of the bedrock in each numerical model for the variable climate change scenarios is shown in Figure 35.

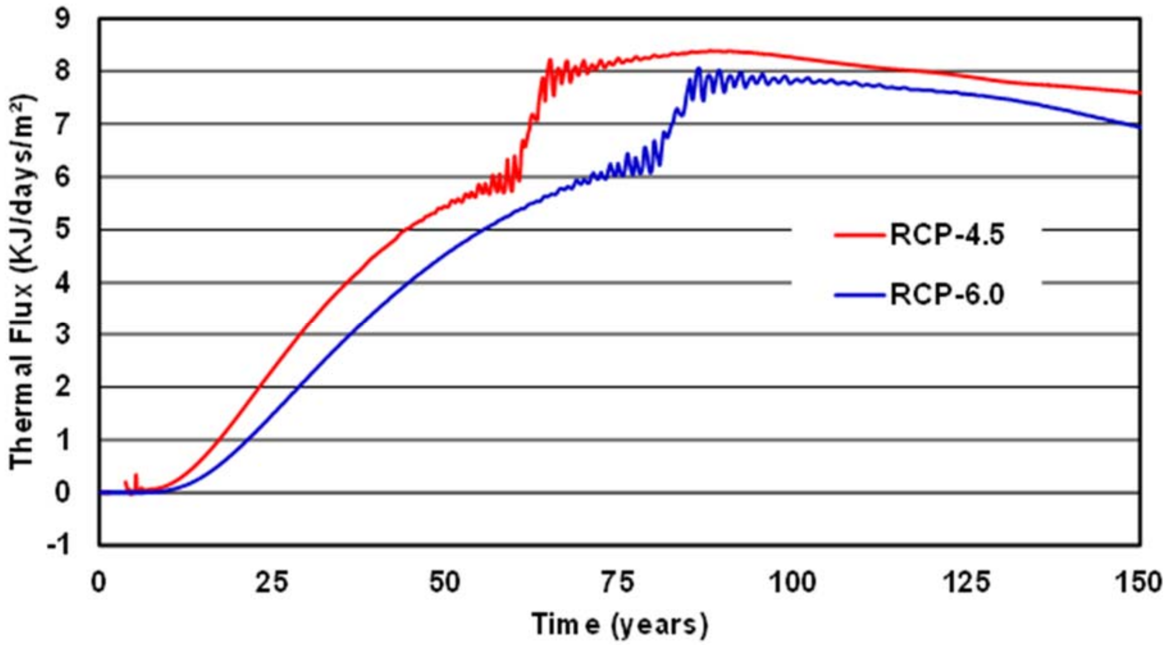

Figure 35 Thermal flux rates applied at base of model as function of time, as extracted from 1D numerical model results.

The flooded pit lake presents a large source for potential impacts to the thermal regime. As such, due to the depth of the lake exceeding the depth of the active layer, it was assumed that the edge boundary condition at the location of the lake would maintain a constant temperature of 2oC, or slightly above freezing.

<u>2D Airflow Model</u>

The lower and edge boundary conditions took into account a variable air pressure as a function of height, assuming atmospheric pressure at the surface of the North Cell. In such a way, any vertical point lower in elevation than the surface of the North Cell TSF would show a higher air pressure.

Initial Conditions

<u>1D SPA Model</u>

The synthetic average year was simulated for two consecutive years with the final conditions of the second year used as the initial conditions for the 150-year simulations.

Seepage Model

It was assumed that the tailings stored in the TSF in both the 1D and 2D models were completely saturated. In addition, it was assumed that the till and bedrock layers were also saturated, as they were previously a talik and as such, would remain in a saturated condition. It was assumed that the cover system material was placed in an unsaturated state.

Thermal Model

For both 1D and 2D numerical models, it was assumed that the cover system material was placed in February, and as such, maintained a temperature equivalent to the mean monthly temperature in February. The temperature of the tailings were determined from temperature profiles provided by AEM in previous tailings monitoring reports. The temperature of the tailings in the monitoring reports equilibrated at around -5°C. These temperature profiles did not extend past the tailings, and as such, no temperature data was available for materials below the base of the tailings ponds. As such, a temperature of 1°C was assumed for any material which was deemed as 'bedrock' in the profile. This assumption holds valid as the region in which the TSF is located was previously a lake which showed high potential for a talik which extended through the permafrost layer. In order to retain the fluid condition characteristic of a talik, the temperature would need to be greater than 0oC. The temperature of the till was determined by the modelling software as a gradient between the temperature of the tailings and the temperature of the bedrock. The full temperature profile based on material types is presented in Figure 36.

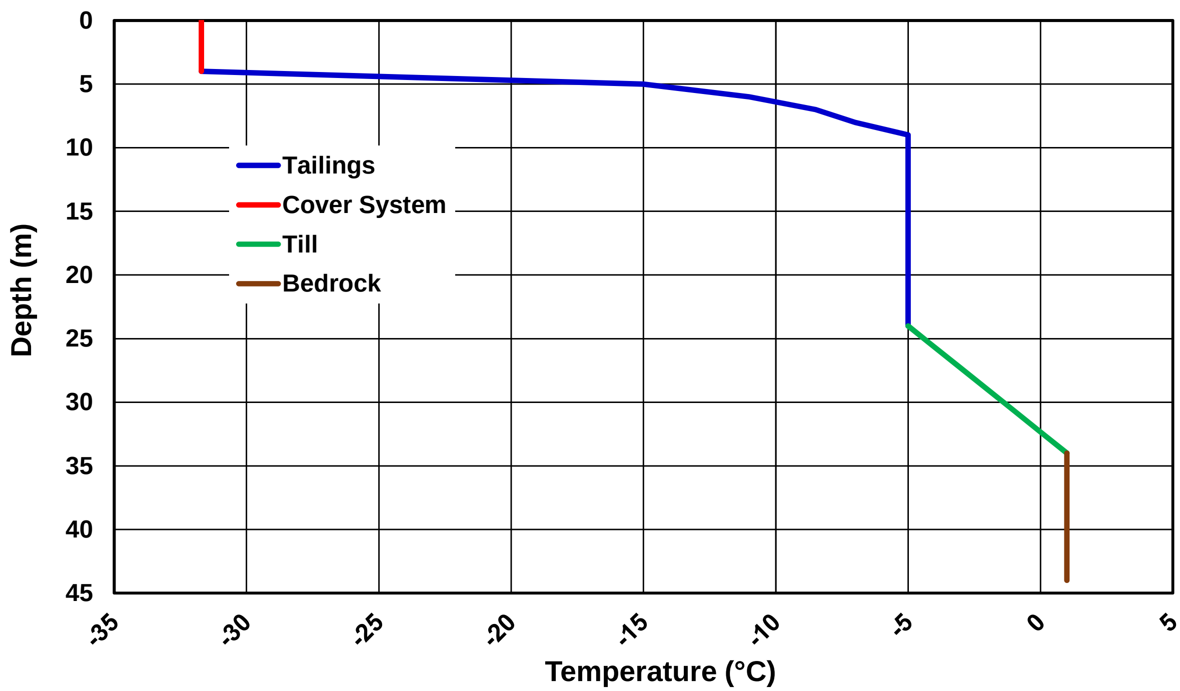

Figure 36 Initial temperature condition in numerical model profile.

2D Airflow Model

A similar temperature profile and moisture content profile were used as in the 2-D thermal model, save for the fact it was only assigned to the simplified cross section used in the convective airflow model.

Model Assumptions

The following assumptions were made to complete the modelling presented in this report:

- flow regime can be reasonably represented by a 2D model;
- cover system placed in winter and unsaturated;
- initial temperature profiles derived from single point measurements using thermistor strings are representative of temperature profile in entire TSF;
- uniform temperature profile throughout TSF;
- surface of cover system is assumed to be traffic compacted across entire TSF due to surface activities;
- permafrost conditions in bedrock are unknown, and as such, temperature profiles in the bedrock are assumed constant, and assessed using a sensitivity analysis;
- pit lake, tailings placement, and cover system placement is assumed to occur instantaneously rather than over the course of several years; and,
- air permeability of materials based on published values of Bear (1972).

Model Limitations

The thermal, airflow, and seepage models presented in this report are mathematical representation of moisture and heat transport within the cover system alternatives examined for the TSF. The models were constructed to develop an understanding of the thermal regime anticipated for the TSF and underlying bedrock. The complex hydrogeology of the TSF had to be simplified into a conceptual model that could be represented in a mathematical model. The numerical model is thus limited by the accuracy and detail of the conceptual model.

The following limitations should be noted when interpreting the results of the model predictions for the numerical modelling program.

- The conceptual model assumes that movement of air and water in the unsaturated zone can be represented as Darcian flow in a porous media. The model does not accurately account for any potential non-Darcian flow in macropores and/or cracks within the materials;
- The conceptual model assumes that the tailings can be represented by various material types with homogeneous material properties. The potential influence of local heterogeneity (within a given material type) was not investigated;
- The numerical model cannot account for freezing point depression, and resultant unfrozen lenses at temperature below 0°C. The presence of these unfrozen lenses in the permafrost may change seepage and thermal transport in a real world scenario;
- The thermal and seepage numerical models employed in this analysis cannot accommodate temperature influxes and residual heat storage due to ponded water at the surface. Should a situation exist in which ponding water is occurring on the surface of the TSF, there may be degradation of the frozen zone in the cover system and tailings near the ponded water; and
- The moisture, temperature, and air movement within the OSA is defined by the unsaturated hydraulic conductivity versus matric suction relationship. This relationship is extremely difficult to measure in situ and consequently is derived by a theoretical algorithm based on the value input for ksat. The theoretical relationship defines the hydraulic conductivity function over several orders of

magnitude, while a single or half order of magnitude change can greatly affect the predicted net percolation results from a simulation.

The key advantage to the numerical modelling results summarised herein is the ability to enhance judgment, rather than to lend predictive accuracy. Hence, instead of focusing on the absolute results predicted, it is recommended that the modelling results be viewed as a tool to understand key processes and characteristics that will influence performance of the potential TSF cover system designs, and develop engineering decisions based on this understanding

Closure

We thank AEM for the opportunity to work on the Meadowbank project. Please contact Philippe Garneau should you wish to discuss the work presented in this memorandum in greater detail.

Sincerely,

Bonnie Dobchuk, M.Sc., P.Eng.

Senior Geoenvironmental Engineer

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Appendix E

Tailings Consolidation Analysis

O'Kane Consultants
Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

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Australia
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Memorandum

To:	Patrice Gagnon – Geotechnical Supervisor, Agnico Eagle Mines Limited - Meadowbank Mine
From:	Kelly Albano, Civil Engineer
Cc:	Thomas Lepine – AEM; Bonnie Dobchuk, Philippe Garneau – OKC
Our ref:	948/1
Date:	31 March 2015
Re:	**Meadowbank North Cell TSF Closure Design - Consolidation Analysis**

Introduction

The tailings consolidation analysis aims at determining the consolidation process at the north cell of the TSF during the remediation phase. The results of the consolidation and settlement analyses are used to evaluate the stability of fine tailings contour, i.e. to ensure success for surface management plan following placement of the cover system during and post remediation. Settlement rates of fine tailings have to be distinguished between primary and secondary (long-term) consolidation portions. Essential criteria for both stabilisation of tailings due to covering and ensuring long-term stability due to decommissioning are:

1) Absolute magnitude of settlement in order to design a final cover and landform design
2) Time dependent consolidation rates to ensure a successful stabilisation progress
3) Magnitude of secondary settlement to ensure long-term stability of the final cover system and landform design.

Purpose and Approach

A one-dimensional (1-D) consolidation analysis was conducted to assess the potential for overall tailings settlement due to the additional loading from reclamation cover material placement. The specific purpose of this analysis was to estimate long-term settlement of the tailings mass following cessation of tailings deposition into the TSF, and evaluate whether the predicted long-term settlement could affect the overall integrity of the reclaimed landform.

An analytical approach was selected for the 1-D tailings consolidation analysis. Material properties (e.g. unit weight) of the tailings and reclamation cover materials were estimated based on material characterisation work completed from previous studies provided by AEM, and were used to calculate initial and final vertical effective stresses in the tailings mass. The tailings ultimate settlement due to consolidation was then determined based on the calculated vertical effective stresses. A tailings mass thickness of 4 m was used in the analysis, which is about 2 m thicker than the tailings thickness at the location where maximum cover material placement is anticipated for the Northern Cell TSF.

Tailings consolidation for the purposes of this report is referred to as tailings volume change (settlement) at the end of tailings deposition. External loading from reclamation cover placement is a key factor leading to tailings consolidation settlement.

Methods of Analysis

Figure 1 illustrates the reclamation cover loading conditions. The scenario simulates tailings consolidation when a 4 m reclamation soil cover (residual soil) is placed on top of the tailings mass.

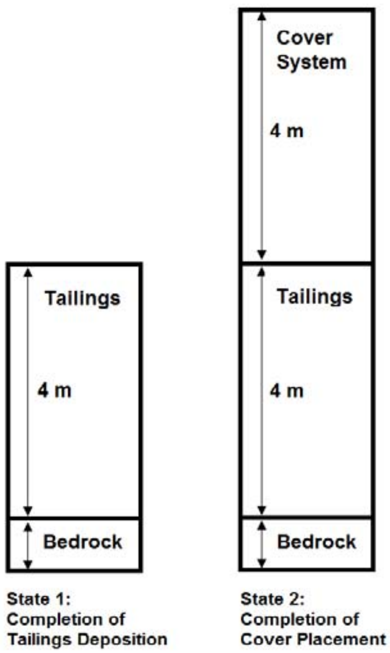

Figure 1: Tailings consolidation analysis scenario

Consolidation analyses are based on changes of effective stress in the tailings. Equation 1 and 3 was used to calculate the primary consolidation and secondary compression of the tailings mass, respectively. Initial and final effective stresses were calculated based on the tailings initial and final state.

Primary consolidation is the change in volume of tailings caused by the expulsion of water from the voids and the transfer of load from excess pore water pressure to the soil particles following cover placement (Zardari 2010). The equation below was used to determine the primary consolidation of the tailings mass following placement of a 4 m cover system overlying the tailings mass.

$$(\delta_c)_{Primary} = \frac{C_c}{1+e_0} H \log\left(\frac{\sigma'=f}{\sigma'=0}\right) \quad [1]$$

where:

(δ_c) = is the settlement due to consolidation

c_c = is the compression index,

e_o = is the initial void ratio,

H = is the thickness of tailings material (m),

σ_{zf}' = is the final vertical effective stress (kN), and

σ_{zo}' = is the initial vertical effective stress (kN).

It was assumed that the tailings were normally consolidated and the compressibility is defined by the compression index, Cc. The Rendon-Herrero (1983) method was applied to determine the compression index (Equation 2).

$$C_c = 0.141 G_s^{1.2} \left(\frac{1+e_0}{G_s}\right)^{2.38} \quad [2]$$

Table 1: Key inputs for the tailings consolidation analysis

Property	Materials	
	Cover System	Tailings
Dry Density (t/m3)	2.15	1.31
Specific Gravity	3.2	3
Unit Weight (kN/m3)	24.27	18.36
Void Ratio	0.49	1.29
Porosity	32.8	56.3
Saturation	1	1
Hydraulic Conductivity (cm/s)	NA	5.00E-07
Thickness (m)	4	4

Table 2: Key parameters for the tailings consolidation analysis

Parameters	
Compression Index (Cc)	0.2771
Secondary compression Index (Ca)	0.00160
Coefficient of volume compressibility (mv)	0.00175
Coefficient of consolidation (Cv)	1.55E-05
Time Factor for 90% degree of consolidation (Tv)	0.848

Analytical Results

The modelled relationship, Equation 1, showed that a primary consolidation of approximately 0.4 m is achieved following construction of a 4 m thick cover system. Figure 2 presents the relationship between the change in primary consolidation and cover thickness.

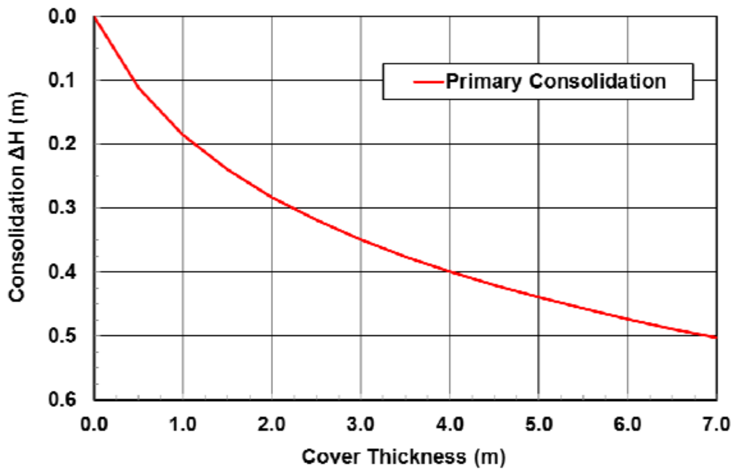

Figure 2: Primary consolidation vs. cover thickness

The results indicate that a 4 m thick mass of tailings would consolidate to a 90% degree of consolidation in approximately 10 days. During this time, primary consolidation of the tailings would be approaching completion with a final change in height of approximately 0.4 m. Long-term consolidation, also known as creep then commences. A secondary settlement of approximately 1 cm was calculated over a period of 100 years following completion of primary consolidation. Figure 3 presents the time-dependent long-term consolidation which occurred over a long period of time in response to the placement of the cover system.

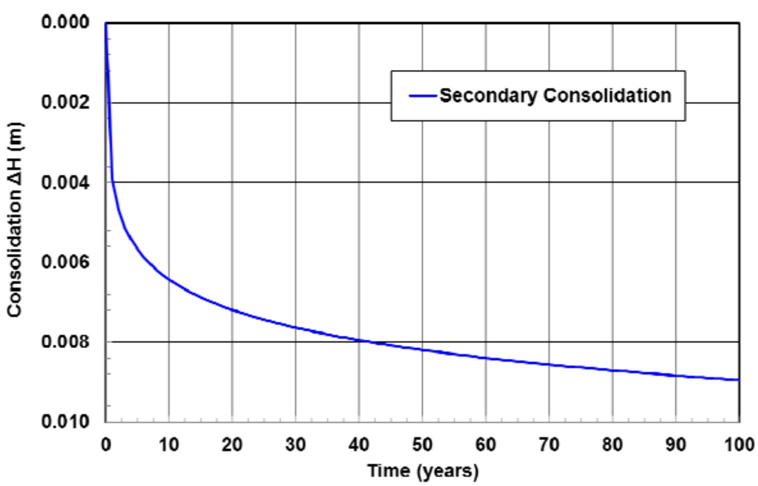

Figure 3: Tailings secondary consolidation model (settlement rate prediction for 100 years)

Key Findings from Tailings Consolidation Analysis

Key findings from the tailings consolidation analysis are as follows:

1) In general, the tailings ultimate settlement for the Northern Cell TSF tailings is approximately 0.4 m under a condition of 4 m. cover load.
2) The tailings settlement could affect integrity of the overlying cover system when the tailings ultimate settlement is substantial. Consolidation will need to be considered when designing the cover system and landform of the TSF

Tailings consolidation during the process of deposition was not analysed because of insufficient information regarding the history of tailings deposition for the Northern Cell TSF.

Closure

We trust information provided in this memorandum is satisfactory for your requirements. Please do not hesitate to contact me at +61 (7) 3367 8063 or kalbano@okc-sk.com should you have any questions or comments.

Appendix F

Closure Channel and Outlet Design

O'Kane Consultants Inc.
Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

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MEMORANDUM

To:	Thomas Lépine, Patrice Gagnon, Rebecca Cameron – Agnico Eagle Mines, Meadowbank Project
From:	Brian Ayres, P.Eng.
cc:	Phil Garneau and Bonnie Dobchuk – O'Kane Consultants Inc.
Date:	March 6, 2015
Re:	**Meadowbank TSF Closure Design Project – Preliminary Design Details for Plateau and Outlet Drainage Channels (UPDATED March 6, 2015)**

Agnico Eagle Mines (AEM) retained O'Kane Consultants Inc. (OKC) to develop a closure cover system and landform design for the North Cell TSF at the Meadowbank Project in Nunavut. A key element of this design is a surface water management system that can properly manage spring snowmelt and rainfall event runoff waters on the reclaimed TSF. The primary components of the TSF final landform surface water management system include plateau drainage channels on the TSF as well as outlet channels to convey runoff waters to temporary sedimentation ponds or perimeter diversion ditches.

The initial preliminary design of plateau and outlet drainage channels was summarized in a technical memorandum dated February 26, 2015. Upon receiving feedback from AEM as well as additional information, OKC proceeded with updating the preliminary drainage channel design, which is summarized in this memorandum. OKC would appreciate feedback on the updated preliminary channel design from AEM project personnel before proceeding with the final design.

Design Objectives and Criteria:

The design objectives of the surface water management plan for the reclaimed TSF are twofold: 1) minimize erosion to reduce the suspended sediment loading to the receiving environment, and 2) safely convey runoff waters off the facility for the design storm event.

The following design criteria are proposed for development of a surface water management system for the reclaimed TSF:

- Use the 1 in 100 year design storm event to calculate peak design flows; and
- Incorporate robustness / conservatism into the design to account for increased precipitation due to potential effects of climate change.

Precipitation data are used by Environment Canada to develop intensity-duration-frequency (IDF) tables or curves. Information contained in an IDF table is generated from an extreme value statistical analysis of at least 10 years of rate-of-rainfall observations. IDF data can be used for sizing and design of hydraulic structures such as drainage channels and culverts.

Environment Canada developed IDF curves for the Baker Lake A meteorological station based on data measured between 1987 and 2006. These curves, which are shown in Figure 3.1 of SNC (2013)[1], are assumed to be representative of short-duration precipitation conditions at Meadowbank. The 24-hour, 1 in 100 year design storm event has an intensity of about 3.1 mm/hr, which equates to 74.7 mm over a 24-hour period. To be conservative, it should be assumed that the design storm event occurs during the snowpack melt period, which means adding an additional volume of water to the design rainfall event to account for snowmelt runoff waters. The 24-hour snowmelt corresponding to the average year spring-melt is 126 mm over 30 days for Meadowbank (Golder, 2012)[2]. Therefore, a total accumulation of 78.9 mm was calculated for the 24-hour, 1 in 100 year design storm event.

Design Storm Peak Flow Calculation:

The Soil Conservation Services (SCS) method was selected for calculating the peak flow from the design storm event for the reclaimed TSF. The United States Department of Agriculture (USDA) developed a model based on the SCS method called Technical Release 55 (TR-55) (USDA, 1986)[3]. The MS-Windows version WinTR-55 v1.00.10, released in 2011, was used for calculating the design storm peak flow for the proposed catchments on the reclaimed TSF.

The TR-55 model begins with a rainfall amount uniformly imposed on the watershed with a specified time distribution. Mass of rainfall is converted to mass of runoff by using a runoff curve number (CN). CN is based on soil properties, plant cover, impervious area, interception by vegetation, and surface storage. Runoff is then transformed into a hydrograph by using unit hydrograph theory and routing procedures that depend on runoff travel time through segments of the watershed. The peak runoff rate is based on the selected distribution of the 24-hour design storm and the calculated time of concentration (tc), which is the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest within the watershed. A Type I temporal distribution was selected for calculation of peak flows for the design event (see Figure 1), which matches the type used by Golder (2012).

Each catchment proposed for the reclaimed TSF was simulated in the TR-55 model. The geometries of the catchments input to the model are based on the currently proposed final grading design as shown in the attached Dwg. No. 948-1-004. The peak flow calculated for the outlet of each catchment was used as the design basis for preliminary sizing and lining plateau and outlet drainage channels.

Design storm peak flows were calculated assuming a frozen ground condition. A CN value of 93, which corresponds to a rainfall/runoff ratio of 70%, was selected to reasonably represent a frozen rock cover; this matches the value used by Golder (2012) to design the perimeter diversion ditches. Table 1 shows the design storm peak flows calculated by the TR-55 model for each catchment of the reclaimed TSF, while Table 2 presents peak flows for the various plateau and outlet channels.

[1] SNC-Lavalin. 2013. Meadowbank Gold Project Water Management Plan 2012. Final technical note prepared for AEM, March.
[2] Golder (Golder Associates Ltd.). 2012. Design basis memorandum for the detailed design of surrace water dfiversions along the northern perimeter of the mine site – Meadowbank gold project, Nunuvat. Memo to AEM dated May 10.
[3] USDA (United States Department of Agriculture). 1986. Urban hydrology for small watersheds. Technical release 55 (TR-55), Natural Resources Conservation Service, June.

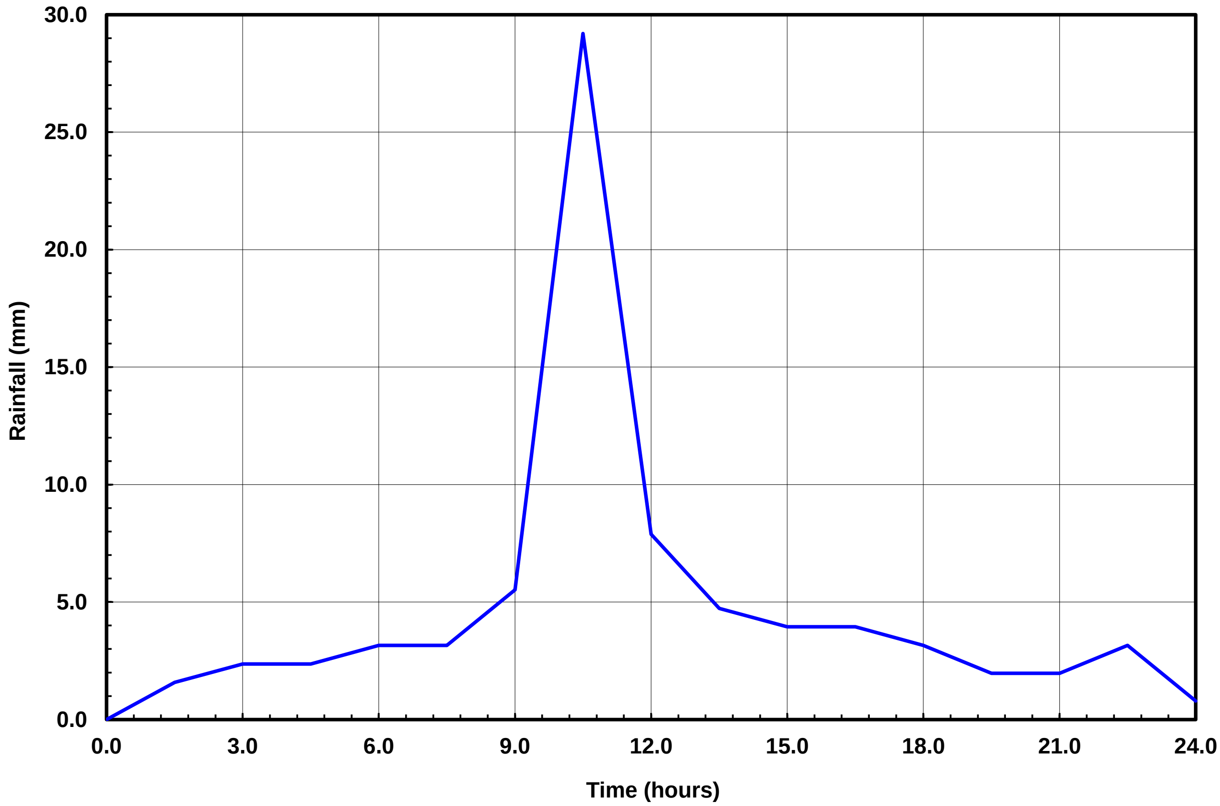


Figure 1 Distribution for the 24-hour 100-year design storm event (SCS Type I).

Table 1
Preliminary design storm event peak flows for the TSF closure landform catchments.

Drainage Area	Area (ha)	Peak Flows (m^3/s) (CN = 93, Type I storm)
A1	18.65	1.94
A1a	15.36	1.76
A1b	12.63	1.44
A1c	10.08	1.10
A2	13.55	1.67
A3	9.42	1.04
A3a	40.65	3.93
A3b	24.45	2.72
A4	7.60	0.95
A5	5.07	0.64
A6	1.25	0.16

Table 2
Preliminary design storm event peak flows for the TSF plateau and outlet drainage channels.

Drainage Channel	Contributing Areas	Peak Flow (m^3/s)	Flat (<5%) or Steep (>5%) Gradient
C1	A1, A1a, A1b, A1c	6.24	Flat
C1a	A1a	1.76	Flat
C1b	A1b	1.44	Flat
C1c	A1c, A6	1.26	Flat
C2	A2	1.67	Flat
C3	A3, A3a, A3b, A4, A5	9.28	Flat
C3a	A3a, A5	4.57	Flat
C3b	A3b, A4	3.67	Flat
Outlet #1	A3, A3a, A3b, A4, A5	9.28	Steep
Outlet #2	A1, A1a, A1b, A1c, A2, A6	8.07	Steep

Drainage Channel Design Calculations:

Drainage channels proposed for the TSF final landform were designed based on the tractive force method as documented in Smith (1995)[4]. In principle, the method is used to evaluate the adequacy of a designed channel from comparison of the shear stress generated by the flow to the shear resistance of the channel lining material. That is, the shear resistance of the lining material (grass, gravel, riprap, etc.) must be greater than the shear stress generated by the flow to produce a stable channel. In the case of a steep channel, it is necessary to modify the basic tractive force theory concept to also include the destabilizing influence of gravity on the stone material. Inclusion of the effect of gravity on stone stability was addressed using a procedure for the design of steep channels as outlined in Smith (1995). Spreadsheets were developed by OKC that allow the user to calculate the maximum allowable flow in a channel based on Manning's equation for various channel geometries and linings, and evaluates the hydraulic condition (i.e. stability) of the channel flow based on the Froude number.

Table 3 presents the minimum dimensions and linings for the various drainage channels to safely convey the design storm peak flow for each catchment. An effort was made to minimize the number of different channel widths and riprap sizes for ease of construction. Two different sizes of riprap are needed to adequately protect the plateau and outlet drainage channels during the design storm event. A median stone diameter (D_{50}) of 75 mm (Stone Type A) is adequate to line all of the plateau drainage channels. A much larger size riprap is required to adequately armour the two outlet drainage channels given the relatively high flow rates and steeper slopes. Three different outlet channel geometries and riprap linings are included in Table 3; at this time, the channel profile and termination point have not been determined, but it is presumed the outlet channels will have a slope angle between 2.5H:1V (40%) and 5H:1V (20%). All channel flows are hydraulically stable based on the calculated Froude number.

[4] Smith, C.D. 1995. Hydraulic Structures. University of Saskatchewan Printing Services, Saskatoon, SK.

Table 3

Preliminary minimum drainage channel dimensions and linings for the proposed TSF final landform to safely convey the design storm peak flow.

Parameter	Plateau Drainage Channels			Outlet Drainage Channels (Q_p = 9.3 m^3/s)		
	Q_p < 1.8 m^3/s	Q_p < 4.6 m^3/s	Q_p < 9.3 m^3/s	5H:1V Slope	3.3H:1V Slope	2.5H:1V Slope
Slope of channel floor (minimum)	0.5%	0.5%	0.5%	20%	30%	40%
Width of channel bottom (m)	3.0	3.0	3.0	10.0	10.0	14.0
Slope of channel sides (_H:1V)	3	3	3	3	3	3
Flow depth (mm)	430	700	980	240	220	170
Lining of channel	Stone	Stone	Stone	Stone	Stone	Stone
Median stone size (mm)	75	75	75	500	700	700
Channel discharge capacity (m^3/s)	1.93	4.87	9.54	9.70	9.70	10.11
Design peak flow (m^3/s)	1.80	4.60	9.30	9.30	9.30	9.30
Froude number (<0.8 or >1.2)	0.58	0.62	0.79	2.54	2.90	3.23

AEM requested during a tele-conference held on March 3, 2015 that OKC examine the effect on design of the plateau drainage channels if the D_{50} was increased from 75 to 150 mm. Doubling the median stone size of riprap for armouring the plateau drainage channels slightly reduces the Froude number, which creates a hydraulically more stable flow condition in the channel. However, the larger stone size results in increased surface roughness, which means the design flow depth needs to increase to convey the same flow rate (i.e. the wetted perimeter, and thus cross-sectional area of the channel, will increase slightly if the median stone size were doubled). Also, the thickness of a riprap layer should be a minimum 1.5 times the D_{50} but not less than 150 mm from a quality control and construction perspective (Smith, 1995); therefore, the riprap layer with a D_{50} of 150 mm should be at least 225 mm thick. Although this is somewhat counter-intuitive, increasing the D_{50} beyond the recommended minimum value of 75 mm will result in a greater volume of material to construct the plateau drainage channels (50% higher volume with a 150 mm D_{50}).

The following additional items will be taken into consideration during final design of the plateau and outlet drainage channels:

- Filter layers are typically required beneath coarser riprap materials to prevent foundation material from being washed out or sucked through voids in the riprap layer. A natural granular material or a non-woven, needle-punched geotextile can be used for this application. Given the planned waste rock cover for the TSF, it is presumed that a filter layer will not be required for plateau drainage channels. A filter layer will more than likely be required for beneath the riprap layer of the outlet drainage channels.
- The riprap stone must be hard, durable, and chemically stable (i.e. non-acid generating). Its particle density should not to be less than approximately 2,650 kg/m^3. The riprap stone material must be resistant to weathering, and be substantially free of overburden, spoil, shale, and organic material.
- The riprap stone material should be generally cubic in shape; if possible, angular or sub-angular material is preferred.

Preliminary Estimate of Material Volumes and Gradation Limit Specifications:

Table 4 includes an estimate of stone materials required for the preliminary TSF final landform surface water management system design. The quantities are neat or in-place quantities and are based on the following assumptions:

- The cross-sectional areas for riprap and filter layers are based on the channel wetted perimeter for the discharge capacity (i.e. a freeboard allowance has not been included in the channel depth calculation);
- The cross-sectional areas for the Stone Type A material is based on a thickness of 150 mm;
- The cross-sectional areas for the Stone Type B material is based on a thickness of 750 mm; and
- A length of 100 m was assumed for outlet channel #1 and 40 m for outlet channel #2.

Based on the preliminary channel design, assuming a 5H:1V slope for the outlet channels, the required total volume of Stone Type A material (75 mm D_{50}) is about 5,000 m^3 and about 1,300 m^3 for Stone Type B material (500 mm D_{50}).

Table 4
Approximate volume of stone materials required for the preliminary TSF final landform surface water management system design.

Design Element	Material	Channel Length (m)	X-sectional Area (m^2)	Quantity (m^3)
Plateau drainage channels, low flow - riprap	Stone Type A - 75 mm D50	1,886	1.02	1,930
Plateau drainage channels, med flow - riprap	Stone Type A - 75 mm D50	1,180	1.35	1,600
Plateau drainage channels, high flow - riprap	Stone Type A - 75 mm D50	675	1.85	1,250
Outlet drainage channels - filter layer	Stone Type A - 75 mm D50	140	1.80	260
Outlet drainage channels - riprap	Stone Type B - 500 mm D50	140	9.00	1,260

A graded riprap material is preferred over a uniform material of the same median diameter as a result of greater interlocking effect between particles (giving increased shear strength) and decreased porosity (giving a better filter effect between flowing waters and base material under the stone) (Smith, 1995). Table 5 includes *preliminary* gradation limits for Stone Type A and B materials based on guidelines included in Brown and Clyde (1989)[5], assuming that a D_{50} of 500 mm would be adequate for armouring the outlet drainage channels.

[5] Brown, S.A. and Clyde, E.S. 1989. Design of Riprap Revetment. Report no. FHWA-IP-89-016 HEC-11 prepared for US Federal Highway Administration, March.

Table 5

Preliminary gradation limits for Stone Type A and B riprap materials for TSF closure landform drainage channels.

Percent Finer Than	Stone Type A		Stone Type B	
	FL (mm)	CL (mm)	FL (mm)	CL (mm)
100	120	130	750	850
85	90	110	600	700
50	75	90	500	580
15	30	50	200	300

Options for TSF Outlet Channels:

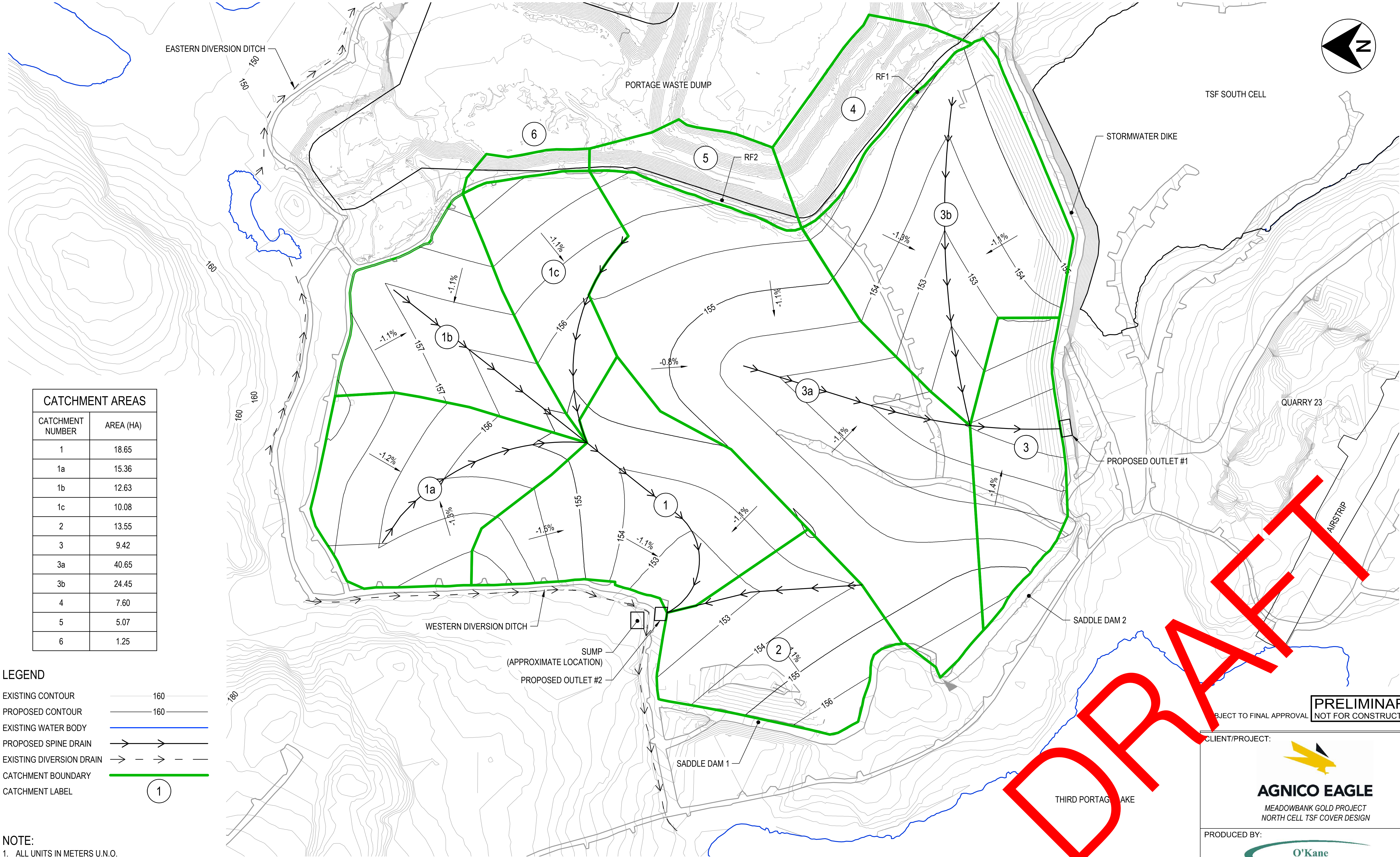
Although the 1:100 year design storm event is a reasonable return period for the TSF closure drainage channel design, the relatively large catchment sizes lead to large flow rates when ~70% runoff is assumed. Below are some options to reduce the required median stone size for armouring the outlet drainage channels:

- Reduce the design peak flows by increasing the number of drainage outlets (i.e. reduce the catchment areas feeding each of the outlets);
- Flatten the slope of the outlet drainage channels to the greatest extent possible; and
- Increase the width of the channel bottoms; however, this leads to a higher material volume needed for construction.

Closure:

A preliminary design of TSF closure landform plateau and outlet drainage channels has been updated. We look forward to AEM's feedback on the updated preliminary design. Please do not hesitate to contact me at 306-241-2263 or bayres@okc-sk.com should you have any questions or comments.

Attachment: Drawing No. 948-1-004



CATCHMENT AREAS	
CATCHMENT NUMBER	AREA (HA)
1	18.65
1a	15.36
1b	12.63
1c	10.08
2	13.55
3	9.42
3a	40.65
3b	24.45
4	7.60
5	5.07
6	1.25

LEGEND

- EXISTING CONTOUR — 160
- PROPOSED CONTOUR — 160
- EXISTING WATER BODY
- PROPOSED SPINE DRAIN
- EXISTING DIVERSION DRAIN
- CATCHMENT BOUNDARY
- CATCHMENT LABEL — 1

NOTE:

1. ALL UNITS IN METERS U.N.O.
2. EXISTING TSF CONTOURS DEPICT NOVEMBER 2014 LEVELS AS PROVIDED BY AGNICO EAGLE.

CATCHMENT PLAN
1:7,500

0 75 150 225 300 375 450 525 600m
SCALE 1:7500

SUBJECT TO FINAL APPROVAL | PRELIMINARY NOT FOR CONSTRUCTION

CLIENT/PROJECT:
AGNICO EAGLE
MEADOWBANK GOLD PROJECT
NORTH CELL TSF COVER DESIGN

PRODUCED BY:
O'Kane Consultants Inc.
Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

REFERENCE DWG. NO.	DESCRIPTION

REVISIONS NO.	DESCRIPTION	DRN. BY:	DATE
0	ISSUED TO CLIENT FOR INFORMATION	SMW	XX.XX.15

DRN. BY:	S. WALKER	DATE:	XX.XX.15
APPD. BY:		DATE:	XX.XX.15
SCALE:	AS SHOWN	REPORT NUM:	948/1

CATCHMENT PLAN

DRG NUM: 948-1-004 | Rev: 0

Appendix G

Quality Assurance and Quality Control Plan

O'Kane Consultants
Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

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www.okc-sk.com

Memorandum

To:	Patrice Gagnon / Thomas Lépine – Geotechnical Supervisors, Meadowbank
From:	Philippe Garneau, Senior Engineer
Our ref:	948/1
Date:	15 July 2015
Re:	**Agnico Eagle Meadowbank Mine - TSF North Cell Closure - QA/QC Plan**

Quality Assurance and Control Plan

Quality assurance / quality control (QA/QC) measures must be implemented during reclamation of the North Cell TSF to ensure all components are constructed in accordance with the design and technical specifications. All construction work must be carried out under the supervision of the Engineer, which collectively refers to a Professional Engineer, registered in the Province of Nunavut, and a support team comprised of technologists and surveyors. Quality assurance and control includes cover material testing and surveying of various surfaces prior to, during, and after construction of the various work items. Table 8.2 outlines the proposed QA/QC program for the various reclamation activities planned at the North Cell TSF.

Cover Material Sampling and Testing

The Engineer will take samples of materials used for and in construction, and perform various tests on the samples to ascertain that the materials being placed or already placed meet the specified requirements. The results of the tests carried out by the Engineer will be final and conclusive in determining compliance with the technical specifications.

Material control tests will be carried out on materials in borrow areas to determine the adequacy of the materials for use in the project. Record tests will be conducted on the materials in the completed portions of the work following placement or compaction to confirm the adequacy of the work, and to provide an as-built record of the workmanship achieved. Record tests may also be used to modify the construction procedures if necessary. Tests carried out by the Engineer must be performed in accordance with the principles and methods prescribed by the American Society for Testing and Materials (ASTM) and other such recognized authorities. These methods shall be modified to the extent necessary to take into account local conditions and the particle sizes of the materials specified.

Table 8.2 presents the anticipated schedule of quality assurance testing; however, the Engineer may modify the testing and rates of testing during the work.

Survey Control

AEM or the Engineer will be responsible for setting out the initial lines and grades for each work item. The Contractor or AEM, depending which entity is undertaking the rehabilitation work, will be responsible for all interim survey control necessary to complete the work. The work must be completed to the lines and grades shown on the Drawings (Appendix A) unless otherwise specified by the Engineer, and any specified tolerances for each work item will be adhered to. As-built surveys will be required for each interim and final lift of the cover system construction as well as for the water management structures.

Prior to the commencement, and following completion of each portion of work to be paid for on a unit quantity basis, a survey will be conducted by AEM or the Engineer to enable the measurement for payment to be made. This survey may also be used for the purpose of documenting the as-built configuration of the work. Check surveys may be carried out by the Contractor to confirm the accuracy of the Engineer's survey, or alternatively, the Contractor may elect to participate in the Engineer's survey.

Table 1: QA/QC Measures for Construction

Item	Requirement	Method	Frequency
Tailings Excavation	±0.1 m of design elevation	Survey	Daily or as required for excavation activities
Cover Material Quality and Layer Thickness	Gradation as specified Free from deleterious materials (e.g. hydrocarbons, trees)	Sieve Visual	As required by construction engineer Continuous
Cover Material Thickness	-0.2 m and +0.3 m of design	Survey	Daily or as required as lifts are placed and final topography is constructed
Drainage Channel Invert Grade	±0.15 m of design section ±0.50% of design grade Firm, unyielding	Survey Survey Visual	Daily Daily Continuous
Geotextile Quality and Installation	Product meets specifications Adjoining panels overlapped as specified Installed panels free of defects	Visual Visual Visual	Continuous Continuous Continuous
Riprap Material Quality and Layer Thickness	Hard, durable stone (for Type B) Gradation as specified Thickness as specified	Visual Visual/Photo analysis Survey / Tape	Continuous 1 per 300 m^3 Continuous

We trust information provided in this memorandum is satisfactory for your requirements. Please do not hesitate to contact me at +61 7 3367 8063 or pgarneau@okc-sk.com should you have any questions or comments.

Appendix H

Performance Monitoring System Memorandum

O'Kane Consultants Inc.
Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

112 – 112 Research Drive
Saskatoon, Saskatchewan, Canada
S7N 3R3
Telephone: (306) 955-0702 Facsimile: (306) 955-1596

MEMORANDUM

To: Thomas Lépine, Patrice Gagnon, Rebecca Cameron – Agnico Eagle Mines, Meadowbank Project

From: Bonnie Dobchuk, P.Eng.

cc: Phil Garneau and Brian Ayres O'Kane Consultants Inc.

Date: March 10, 2015

Re: **Meadowbank TSF Closure Design Project – Preliminary Design and Cost Estimate for Performance Monitoring System**

Agnico Eagle Mines (AEM) retained O'Kane Consultants Inc. (OKC) to develop a closure cover system and landform design for the North Cell TSF at the Meadowbank Project in Nunavut. As part of ensuring the long-term performance of the cover system, an element of this design project is the development of a performance monitoring system. Direct measurement of field performance is the best method for demonstrating to all stakeholders that the cover system will perform as designed. Recommendations provided for the proposed cover performance monitoring system are based on OKC's experience with sites in similar climates. This memorandum outlines preliminary design details and costs for the recommended performance monitoring system. OKC would appreciate feedback on the preliminary design from AEM project personnel before proceeding with the final design to ensure that the program aligns with their needs and requirements.

Design Objectives and Criteria:

The objectives of the TSF North Cell cover and landform are to (1) ensure long-term landform stability (2) encourage TSF freeze-back into the surrounding permafrost and (3) maintain either sub-zero temperature or high degree of saturation (>85%) in the tailings at all times. The purpose of the performance monitoring system is to ensure that these objectives are being met. The objectives of the TSF North Cell cover system performance monitoring program are:

1) to monitor the temperature profile through both the tailings and the cover system to verify that the tailings beneath the cover system remain below freezing for most of the year and to verify that the tailings and talik are freezing into the surrounding permafrost;

2) to monitor the water content of the tailings below the cover system and understand the basic water content response at the base of the cover; and

3) to track the evolution of the cover system in response to various site-specific physical, chemical, and biological processes.

Several factors need to be considered when designing a cover system performance monitoring program for a reclaimed TSF. Cover system performance will be different on plateaus compared to side-slopes and channels as a result of higher surface runoff and lateral diversion of subsurface waters on slopes. In addition, slope aspect will have an influence on cover system performance due to differences in incident solar radiation and resulting snowpack formation and melting period and evaporation. Performance will also vary depending on the thickness of cover material at a particular location.

Monitoring Program Details

Table 1 summarizes the proposed monitoring program. OKC recommends that the proposed monitoring program be maintained for a minimum of five years beyond reclamation of the TSF North Cell. The proposed monitoring system is automated to the extent possible to ensure data quality and it greatly reduces the need for human intervention and in particular, demands placed on AEM personnel.

Table 1
Summary of the proposed Meadowbank TSF North Cell performance monitoring system.

Monitoring Component	Parameters	Sensors / Methods	Comments
Meteorology			• Use existing weather station on site for full meteorology data. • AEM personnel to conduct snow surveys at representative locations prior to spring melt.
Monitoring Station #1 (Station 1)	• *In situ* water content • *In situ* temperature • Air temperature	• 41342VC-L RM YOUNG Temperature Probe • CS655-L TDR sensor (x3) • 107-L temperature probe (x8) • Geokon (or equiv) thermistor string (~13 beads)	• Sensors controlled by a Data Acquisition System (DAS) consisting of a CR1000 logger c/w 12v battery/solar panel. • Thermistor string to measure temperature profile with depth through tailings and into talik. • CS655 and 107 sensors to measure temperature and water content in cover system and in tailings just below interface. • Temperature probe to measure air temperature on TSF.
Monitoring Station #2 (Station 2)	• *In situ* water content • *In situ* temperature • Water level	• CS655-L TDR sensor (x3) • 107-L temperature probe (x8) • PLS PLS-L15M OTT Pressure Level Sensor	• Sensors controlled by a Data Acquisition System (DAS) consisting of a CR1000 logger c/w 12v battery/solar panel. • CS655 and 107 sensors to measure temperature and water content in cover system and in tailings just below interface. • PLS probe to measure water level (positive pore water pressures) at interface.
Monitoring Station #3 (Station 3)	• *In situ* water content • *In situ* temperature	• CS655-L TDR sensor (x3) • 107-L temperature probe (x8)	• Sensors controlled by a Data Acquisition System (DAS) consisting of a CR1000 logger c/w 12v battery/solar panel. • CS655 and 107 sensors to measure temperature and water content in cover and in tailings just below interface.
Erosion and Settlement	• Erosional features and elevation change	• Erosion survey (visual/photographic) • Topographic survey	• AEM qualified personnel to conduct surveys of landform on an annual basis.

Further details on each of the various monitoring components, including locations and detailed drawings, will be provided in the final construction document. The current plan is to install Station 1 in a similar location to the existing (non-functioning) thermistor string near SWD. Station 2 and Station 3 will be situated near Outlet 1 and 2, respectively, to capture the behaviour of the cover system in areas where the cover is thin and may be gaining heat energy from the flow of runoff.

Installation of Monitoring Instrumentation

Installation of the recommended performance monitoring system will need to occur in stages based on accessibility and cover placement.

The deep thermistor string must be installed prior to any cover material placement in the area and timing for this installation must be based on when a drill rig can safely access the required area on the TSF. The additional sensors for Station 1, depending on how thick the cover system winds up being in this area, may need to be installed in stages along with cover material placement. Details on this installation will be developed once the final cover landform has been designed and the exact location of the station has been defined. Stations 2 and 3 can be installed shortly after final grading of the cover system, before these layers freeze. A backhoe or excavator will be used to excavate into the cover material and the shallow tailings and the sensors will be installed in the excavation.

Cost Estimate

A preliminary cost estimate is provided.

Professional Fees and Travel (OKC)

Installation of Performance Monitoring System (includes site visit (4 days on-site), travel (time and cost) to Montreal, and preparation of as-built report)	**$30,200**
Annual Performance Monitoring (includes monthly data management, troubleshooting, and preparation of year-end memo outlining cover system performance)	**$12,000**

Instrumentation

Campbell Scientific Instrumentation	**$29,750**
Additional Field Equipment (posts, concrete, etc.)	**$500**
Shipping of Instrumentation to Meadowbank	**$2,000**
Thermistor String Instrumentation	**$10,000**
Thermistor String Installation (by AEM)	**$4,500**

Closure:

We look forward to AEM's feedback on the preliminary design and cost estimate. Please do not hesitate to contact me at 306-717-3371 or bdobchuk@okc-sk.com should you have any questions or comments.

Appendix I

Failure Modes and Effects Analysis

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences												Level of Confidence	Highest Risk Rating	Mitigation / Comments
				Environmental Impact		Special Considerations		Legal and Other Obligations		Consequence Costs		Community / Media / Reputation		Human Health and Safety				
1a	Poor execution of construction QA/QC program and/or inexperienced personnel supervising construction.	Thickness of NPAG waste rock cover system not built to minimum thickness as specified by the design leading to unfrozen layer of tailings.	L	Mi	L	n/a	n/a	Mo	Mo	Mo	Mo	Mi	L	L	L	H	Mo	Assumed that less than 5% of area is too thin. Assuming this is discovered shortly after construction and there would still be an access road and equipment on site. Given the anticipated level of resources available for construction the likelihood of this occurring is low. It is critical that people with adequate experience and QA/QC experience supervise. Survey quality pre-and post construction is also important.
1b		Cover material placed has substantial fines content resulting in increased short-term erosion and high TSS of runoff waters.	M	Mi	Mo	n/a	n/a	Mo	Mo-H	Mi	Mo	L	L	L	L	H	Mo-H	Assumed that this is short-term exceedance. Sedimentation ponds are still in place and monitored.and there would still be an access road and equipment on site. Given the use of run-of-mine materials, the likelihood of short term high TSS was considered moderate, even with sufficient QA/QC. The key mitigation measure for this will be frequent monitoring and maintenance of sedimentation ponds for the first few years post-construction.
1c		Final grades for TSF reclaimed landform exceed allowable tolerances resulting in depressions / ponding leading to unfrozen layer of tailings.	L	Mo	Mo	n/a	n/a	Mo	Mo	Ma	Mo-H	Mo	Mo	L	L	M	Mo-H	Assumed that thawing of tailings would require a substantial permanent pond as opposed to a transient ponding during an extreme storm event.
2a	Insufficient volume of NPAG material	Design specification thickness of cover system not able to be met, resulting in significant unfrozen layer of tailings.	M	Mo	Mo-H	n/a	n/a	Mo	Mo-H	C	H	Mo	Mo-H	L	L	L	H	It is assumed that >10% of the area of tailings are unfrozen and the tailings are desaturating and leading to solute loading in downstream receptors. The likelihood of occurrence of this failure mode is dependant on AEM's confidence in their site material balancing. OKC set the likelihood as moderate however, AEM should advise on this. Mitigation methods to be discussed.
2b		Final design grades for TSF reclaimed landform unable to be constructed resulting in depressions / ponding leading to unfrozen layer of tailings.	M	Mo	Mo-H	n/a	n/a	Mo	Mo-H	C	H	Mo	Mo-H	L	L	L	H	The likelihood of occurrence of this failure mode is dependant on AEM's confidence in their site material balancing. OKC set the likelihood as moderate however, AEM should advise on this. Mitigation methods to be discussed.
3a	Freeze / thaw cycling of the cover system and upper tailings profile	Differential frost heave resulting in depressions / ponding leading to unfrozen layer of tailings.	L	Mo	Mo	n/a	n/a	Mo	Mo	Mo	Mo	Mo	Mo	L	L	H	Mo	Assumed that less than 5% of area would be thawed.
3b		Frost boils result in tailings migration to surface, which in turn leads to contaminated surface runoff waters.	NL	Mi	L	n/a	n/a	Mo	L	Ma	Mo	Mo	L	L	L	H	Mo	Given thickness of cover layer, this is considered not likely.
4a	Sediment build-up in TSF drainage and perimeter diversion channels	Flow bypass in channels resulting in erosion of cover system material leading to unacceptable TSS levels in surface water receptors.	L	Mi	L	n/a	n/a	Mo	Mo	Mi	L	L	L	L	L	H	Mo	The likelihood of this occurring is considered low because it is assumed that post-construction maintenance and monitoring of the TSF drainage and perimenter drainage channels will occur during the time when the majority of the fines will wash out of the cover material. Due to the coarse-textured nature of the cover material, it is unlikely that even with a greater-than-expected event, substantial fines are not likely to enter surface water receptors. .
4b		Flow bypass in channels resulting in erosion of cover system profile to the point where tailings are exposed and contamination of surface waters.	NL	Mi	L	n/a	n/a	Ma	Mo	Mo	L	Mi	L	L	L	H	Mo	The likelihood of this occurring is considered low because it is assumed that post-construction maintenance and monitoring of the TSF drainage and perimenter drainage channels will occur. Due to the coarse-textured nature of the cover material, erosion of the channels may occur but sufficient erosion leading to a catastrophic event would be unlikely.
4c		Ponding that results in an unfrozen layer of tailings.	NL	Mi	L	n/a	n/a	Mo	L	Mo	L	L	L	L	L	H	L	Assumed that thawing of tailings would require a substantial permanent pond as opposed to a transient pond. As above, due to the coarse textured nature of the cover material, sufficient diversion leading to erosion/build-up to cause a permanent pond is considered unlikely.

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences: Environmental Impact		Special Considerations		Legal and Other Obligations		Consequence Costs		Community / Media / Reputation		Human Health and Safety		Level of Confidence	Highest Risk Rating	Mitigation / Comments
4d		Ponding causes retardation of talik freezeback and results in unacceptable loadings to receiving environment.	NL	Mo	L	n/a	n/a	Ma	Mo	Ma	Mo	Mo	L	L	L	M	Mo	Assumed that retardation of the talik freezeback would require a substantial permanent pond as opposed to a transient pond. Due to the coarse textured nature of the cover material, sufficient diversion leading to erosion/build-up to cause a permanent pond is considered unlikely.
5a	Higher than expected rainfall/snowmelt events due to climate change	Flow bypass in channels resulting in erosion of cover system material leading to unacceptable TSS levels in surface water receptors.	L	Mi	L	n/a	n/a	Mo	Mo	Mi	L	L	L	L	L	H	Mo	The likelihood of this occurring is considered low because it is assumed that post-construction maintenance and monitoring of the TSF drainage and perimenter drainage channels will occur during the period when the majority of the fines will wash out of the material. Due to the coarse-textured nature of the cover material, bypass of the channels leading to an erosion event leading to unacceptable TSS levels would be unlikely.
5b		Flow bypass in channels resulting in erosion of cover system profile to the point where tailings are exposed and contamination of surface waters.	NL	Mi	L	n/a	n/a	Ma	Mo	Mo	L	Mi	L	L	L	H	Mo	Due to the coarse-textured nature of the cover material, bypass of the channels leading to an erosion event leading tailings contamination of surface waters would be unlikely.
6	Differential settlement in tailings mass	Undulations in surface resulting in ponding of water at surface leading to unfrozen layer of tailings.	L	Mo	Mo	n/a	n/a	Mo	Mo	Ma	Mo-H	Mo	Mo	L	L	M	Mo-H	Assumed that thawing of tailings would require a substantial permanent pond. Undulations may occur however this has been mitigated by ensuring sufficient minimum grades on the final landform.
7	Differential settlement in cover system material	Undulations in surface resulting in ponding of water at surface leading to unfrozen layer of tailings.	M	Mo	Mo-H	n/a	n/a	Mo	Mo-H	Ma	H	Mo	Mo-H	L	L	H	H	During construction, a maximum lift thickness of 2 m will help to mitigate this. Additionally, the final landform minimum grades allow for some slight variation due to settlement.
8a	Climate change trends outside of predicted climate trends used in design considerations	Warmer climate resulting in changes to active layer depth leading to an unfrozen layer of tailings.	L	Mi	L	n/a	n/a	Ma	Mo-H	Ma	Mo-H	Mo	Mo	L	L	M	Mo-H	Include conservatism in the design where possible.
8b		Warmer climate resulting in change to thermal regime such that talik does not completely freezeback.	L	Ma	Mo-H	n/a	n/a	Mo	Mo	Ma	Mo-H	Mo	Mo	L	L	M	Mo-H	Include conservatism in the design where possible.
9a	Channel glaciation during the spring snowmelt period	Cover system erosion and ponding leads to thinning of cover profile and eventually unfrozen layer of tailings.	L	Mi	L	n/a	n/a	Mo	Mo	Mi	L	Mi	L	L	L	M	Mo	Due to the coarse-textured nature of the cover material, an erosion event leading to area with permanent ponding is considered unlikely.
9b		Cover system erosion exposes tailings and leads to discharge of tailings to environment.	L	Mi	L	n/a	n/a	Ma	Mo-H	Mo	Mo	Mi	L	L	L	H	Mo-H	Due to the coarse-textured nature of the cover material, an erosion event leading tailings contamination of surface waters would be unlikely.
10	Salt cryoconcentration in tailings during freezeback	Long-term existence of water lenses leading to differential settlement of tailings, which in turn leads to ponding and an unfrozen layer of tailings.	NL	Mo	L	n/a	n/a	Mo	L	Ma	Mo	Mo	L	L	L	M	Mo	Assumed that thawing of tailings would require a substantial permanent pond. Tthe final landform minimum grades allow for some slight variation due to settlement without leading to permanent ponding.
11	Water ponding in South TSF Cell	Water ponding against SWD, resulting in subsurface thermal regime influences and detrimental effects on freezeback of tailngs and talik.	M	Mo	Mo-H	n/a	n/a	Mo	Mo-H	Ma	H	Mo	Mo-H	L	L	L	H	Need AEM to comment on likelihood as this depends largely on the likelihood of a water cover on south cell.

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