Meadowbank North Cell TSF Expansion -Design of Internal Structures

March 11, 2016

AGNICO EAGLE

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948/2-01

March 2016

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Rev. #	Rev. Date	Author	Reviewer	PM Sign-off
00	16/01/2016	BD	MOK	BD
01	9/02/2016	PG	BD	BD
02	12/03/2016	PG	MOK	BD

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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. Mine commissioning and first gold production from the Portage open pit began in early 2010. The Meadowbank site is located in a region of continuous permafrost where the average daily temperature is about -12°C.

Based on potential additional tailings storage capacity required at Meadowbank, AEM evaluated options to optimize disposal of tailings in the North Cell TSF to accommodate additional tailings storage requirements for Whale Tail Pit within the current footprint of the approved Tailings Storage Facility. This report considers the addition of internal dike structures placed on the frozen beach tailings in the North Cell in support of an amendment to the approved North Cell Tailings Storage Facility. AEM contracted O'Kane Consultants Inc. (OKC) to design the internal structures based on the design parameters used for designing the North Cell TSF cover system and landform.

1.1 Project Objectives and Scope

The objectives of the project are to design internal dike structures to provide additional tailings storage capacity in the North Cell TSF using the design parameters developed for the North Cell cover system and landform design and ensuring that the designed final landform is still practicable (hillslope grades, channel grades, and outlet locations).

The scope of the project involved

- Review of existing design information of various existing tailings retaining structures;
- Review of basis for expansion and assess the structure dimensions;
- Conceptual design of internal structures;
- Numerical analysis to inform on designs, which included;
    - Slope stability,
    - Consolidation, and
    - Seepage;
- Final design of internal structures; and
- Compilation of final report, including design drawings.

Note that the design drawings are prepared with objective of allowing Agnico to develop costs for the expansion to the extent that approval can be evaluated. From a typical project flow perspective, the drawings are suitable for regulatory purposes and for concurrent feasibility studies.

1.2 Report Organization

For reference, this report has been sub-divided into the following sections:

- Section 1 - Introduction
- Section 2—Conceptual Design
- Section 3—Numerical Analyses
- Section 4—Final Design

2 CONCEPTUAL DESIGN

Based on current tailings production, AEM is looking at potential options to augment the capacity of the North Cell TSF (NC). After a review of several options, AEM decided to further explore the option of raising the North Cell to accommodate additional tailings. To accomplish this, dikes will be built along the North Cell perimeter road, which will form a perimeter for most of the North Cell TSF with the exception of above the Storm Water Dike (SWD). The dike will be placed as an offset on the tailings beach. The beach is expected to be frozen. Sufficient space will be available on the downstream side of the dike to allow for the construction of seepage water collection ditches. The seepage analysis conducted as part of this project estimates that seepage will be limited in volume and in time, as well as being manageable with minimal pumping required.

Based on the tailings production, including the Whale Tail Pit project, this report conservatively assumes 9000 tonnes per day will be deposited in the North Cell TSF over a 92 to 122-day operating season, from June to October. Deposition is planned to take place over three annual seasons from 2019 to 2021 for a total of over 3M tonnes of additional tailings deposited within the North Cell TSF. The remaining 5.3 M tonnes of storage required for the Whale Tail Pit operations will be placed in the approved South Cell Tailings Storage Facility (see Figure 2.1 - TSF site layout).

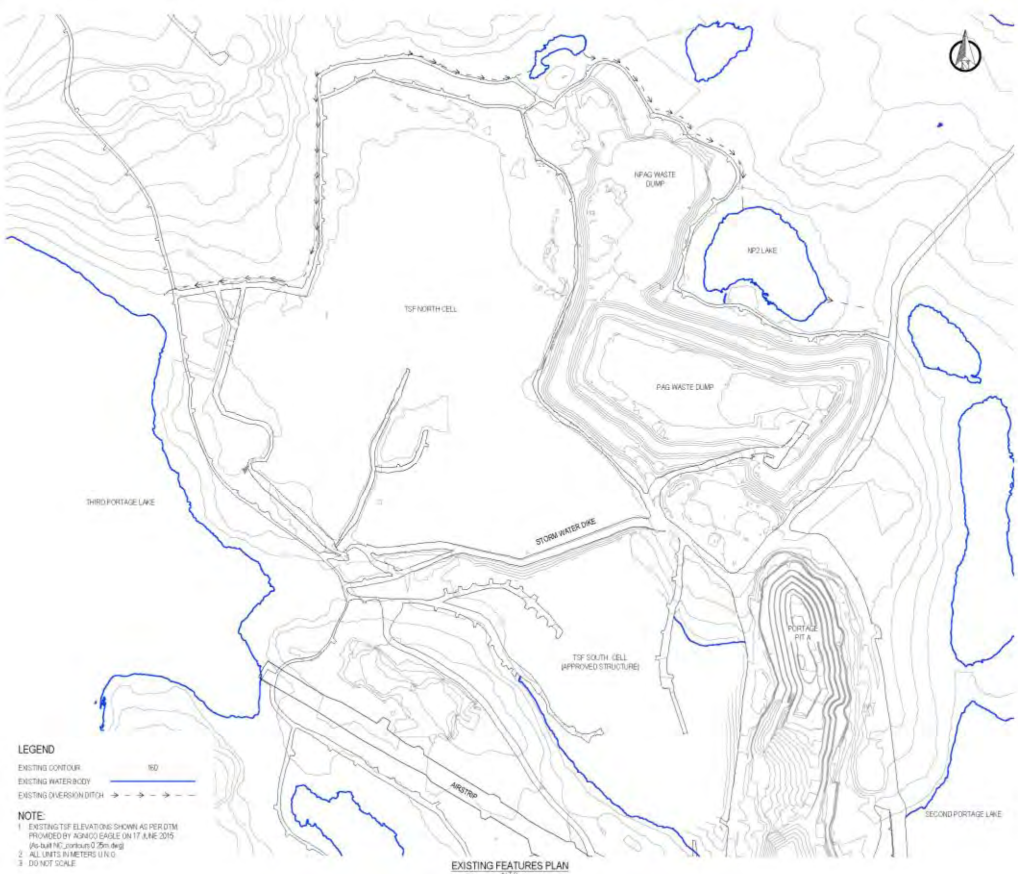


Figure 2.1: TSF Site Layout

Based on the additional space requirement in the North Cell, the present concept of the dike is one of an incline structure with minimal elevation to 152 m at its highest point along the northern portion of the TSF. It is intended to build the dike during the winter months over the frozen tailings and the previously placed 2015 capping in areas where this structure is present. The TSF closure cover system, consisting of a thermal layer of 2 to 4 m of non-acid generating (NAG) waste rock, will eventually be placed over the tailings to construct the final landform.

The rockfill dike will consist of non-potentially acid generating (NPAG) waste rock placed at angle of repose (upstream face) and at 3H:1V (downstream face) along the alignment presented in Technical Drawing 948-2-002. Note that the existing road embankment is built with a 1.3H:1V outer slope. The conceptual model assumes that this slope angle will not meet the long-term (closure) stability criteria, and therefore a reduction in this angle is required for the existing dike (to 3H:1V). On this basis, the slope for the new dike is proposed to also be set at 3H:1V.

The dike width at the crest is to be determined by construction equipment to be used. Technical drawings presented here show a 15m crest width, suitable for 2-way traffic with 50 t haul trucks. Numerical modelling of slope stability and seepage were done with a 30m wide dike. Sensitivity analysis of seepage showed no difference in seepage rates and total volumes between the 15 m and 30 m options. The height of the dike will vary between 2m and 4m, the higher portion located in the northern section of the TSF.

3 NUMERICAL ANALYSES

As part of the design process, it was necessary to ensure that the dikes would be safe and stable over the long-term as well as to account for seepage collection systems that may be required. Numerical analyses were completed to ensure that the dike design accounted for geotechnical slope stability and the quantity of potential seepage through the dike. Consolidation of tailings underneath the dike was also considered. Seven (7) typical cross-sections were developed for numerical modelling of slope stability and seepage. Each cross-section represents an area of the rockfill dike around the TSF, incorporating the specific infrastructure and foundation details (Figure 3.1).

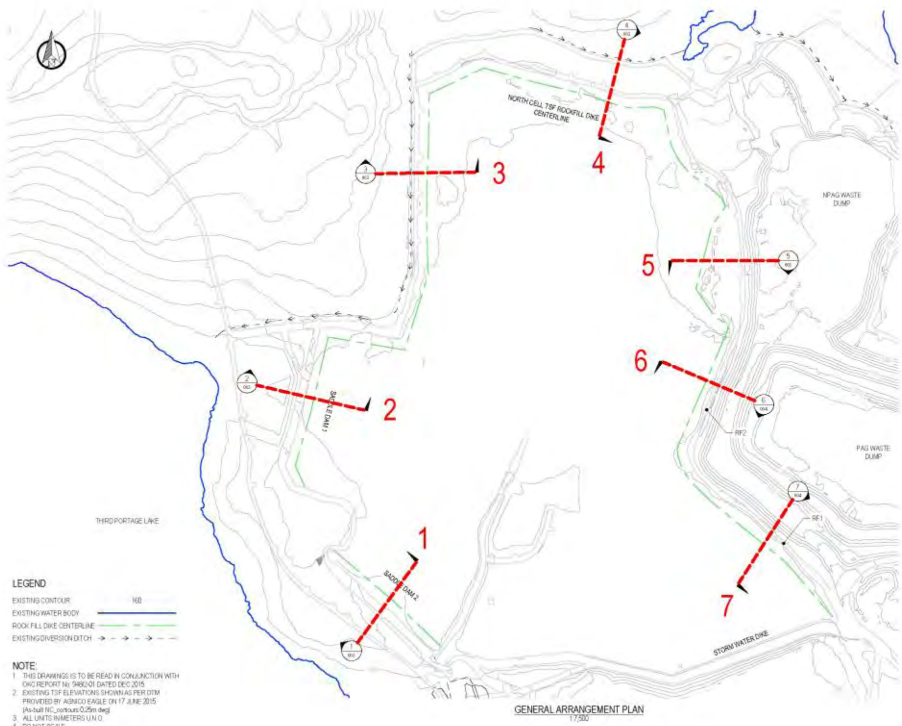


Figure 3.1: Plan view of Meadowbank North Cell TSF with slope stability and seepage analysis cross section locations.

3.1 Slope Stability Analyses

The purpose of this analysis is to evaluate the overall stability of the TSF, as well as the effects of dike location on TSF stability.

This section provides the design basis information, modelling methodology, summary of modelling scenarios, and summary of model results. Appendix B provides a summary of material properties, and all slip plane profiles.

3.1.1 Design Basis

The design basis set the following general criteria to be maintained.

- Meet or exceed required factors of safety (FS).
- Accommodate additional tailings.
- Feasibility of the construction approach (based on cost and effort).
- When the dike is used as a haul road, mine health and safety regulations, NWT/Nunavut will be followed.
- CDA 207 Dam Safety Guidelines will be followed.
- Maintain adequate setback to facilitate other works

Calculated FS values will then be compared to the minimum required values (i.e. the slope stability criteria). The minimum FS values are summarized in Table 3.1.

Table 3.1: Summary of minimum factor of safety values utilized for slope stability criteria

Condition	FS Value	Basis for FS Value
End of Construction	1.3	During or immediately after construction
Operations	1.5	Steady seepage with maximum tailings deposit
Closure	1.5	Long term seepage with the cover system
Pseudo static	1.0	Earthquake loading

3.1.2 Modelling Methodology

The commercial software SLOPE/W was used to conduct two-dimensional (2D) limit equilibrium analyses using the Morgenstern-Price method for static loading with a circular slip surface. In stability analyses, trial failure surfaces were defined with ‘entry and exit’ parameters, resulting in a range of possible locations within which the most critical potential failure surface may be found. The SLOPE/W program incorporates a search routine to locate those failure surfaces with the least factor of safety (FS) within the defined search limits. Calculated FS values were then compared to the minimum required values (slope stability criteria). Figure 3.2 presents a typical cross-section developed for the slope stability analysis. All cross-sections developed are available in Appendix B.

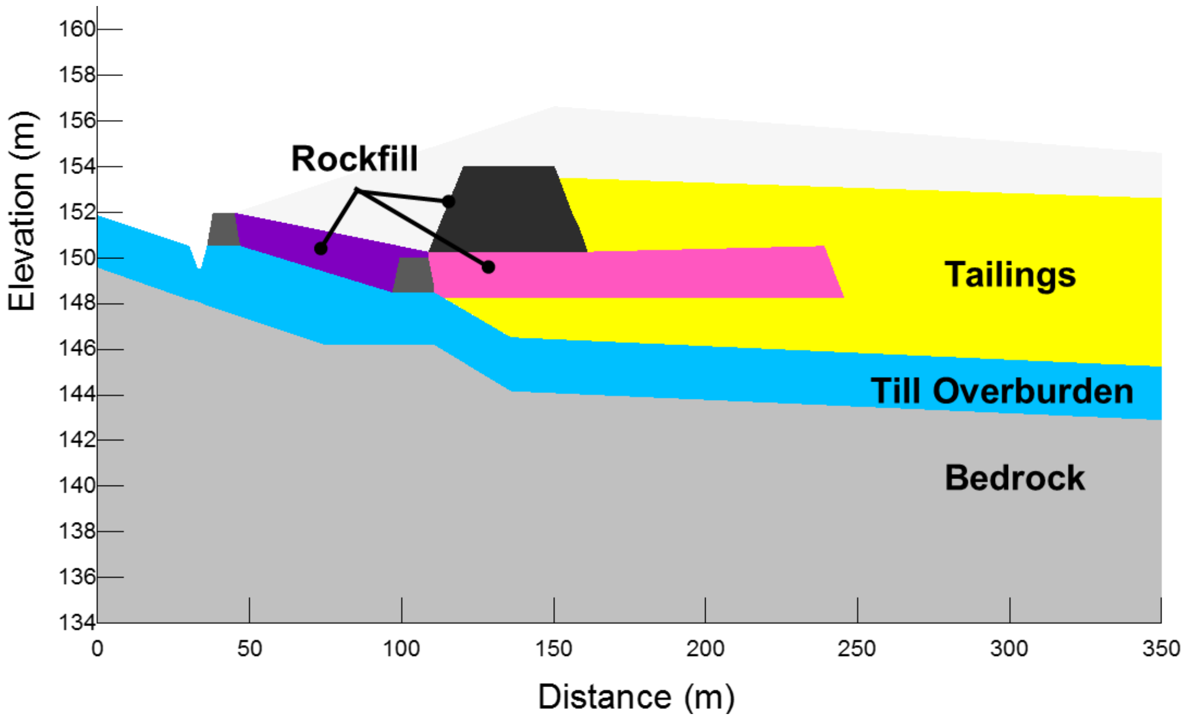


Figure 3.2: Typical cross section (Cross-Section 4) developed for slope stability analysis

3.1.3 Modelling Scenarios

Four scenarios were considered:

1) End of Construction – rockfill extension dike in place but tailings placement has yet to commence.
2) Operation – All tailings placed within the TSF.
3) Closure – Cover system placed over entire TSF.
4) Seismic Loading - a horizontal acceleration coefficient of 0.06 is applied to the scenario that has the lowest FS obtained from above three static case analyses.

For all scenarios, unfrozen materials were simulated as fully saturated with a maximum pore-water pressure of 20 kPa. Frozen materials were simulated with a -1 m pressure head. The rockfill extension dike in scenario 1 and any material within 2 m (the minimum TSF cover) of the surface were simulated as unfrozen.

3.1.4 Results

Table 3.2 provides a summary of the results for all four scenarios for each of the seven cross-sections.

Additional sensitivity analyses were completed using cross-sections 2 and 4 (Table 3.3). The angle of internal friction (phi) was reduced from 45° to 40° and 35°. Select models were also completed with the maximum pore-water pressure decreased to 10 kPa; results for these scenarios are in brackets in Table 3.3.

3.2 Seepage Analyses

Seepage analyses are required to address the potential for seepage through the rockfill extension dike. The main objective of the seepage modelling is to estimate seepage volumes through the rockfill dike, design appropriate seepage collection infrastructure as required, evaluate the need for a low permeability component on the internal slope of the rockfill extension dike, and evaluate if the width of the rockfill extension dike can be reduced.

Seepage modelling is completed assuming no permafrost formation within the rockfill as a “worst-case” scenario, defining the conservative seepage range through the extension dike. Thermal modelling undertaken as part of the North Cell TSF Cover System Design (OKC 948-01-02) shows that the permafrost active layer reaches 2 m depth for the warmest years of a 100-year climate database, taking into account climate change conditions. Assuming that the rockfill dike is constructed during the winter months and is 4 m thick where seepage is most important, the thawing front would not reach the base of the rockfill dike and the 2015 capping material will remain frozen. The conditions set out for the analysis where the rockfill dike is assumed unfrozen in its entirety, including a portion of the 2015 capping, are therefore considered conservative.

Table 3.2: Summary of slope stability analysis results.

Cross-Section	Scenario	FS	Slip Surface
1	End of Construction	1.6	Up-stream (U/S), along the rockfill dike slope
	Operation	1.6	Down-stream (D/S), along the rockfill dike slope
	Closure	3.1	Through the cover, rockfill dike, and saddle dam
	Seismic Loading	1.3	D/S, along the rockfill dike slope
2	End of Construction	1.5	U/S, through the rockfill dike and tailings
	Operation	2.0	D/S, through the rockfill dike and saddle dam
	Closure	2.1	Through the cover, rockfill dike, and saddle dam
	Seismic Loading	1.3	U/S, through the rockfill dike and tailings
3	End of Construction	2.4	D/S, through the rockfill dike, 2015 capping
	Operation	1.7	D/S, along the rockfill dike slope
	Closure	2.0	Through the cover, NC road, 2015 capping and overburden
	Seismic Loading	1.4	Along the rockfill dike slope
4	End of Construction	2.4	D/S, through the rockfill dike,2015 capping, and overburden
	Operation	1.9	D/S, along the rockfill dike slope
	Closure	2.5	Through the cover, 2016 capping and overburden
	Seismic Loading	1.5	D/S, along the rockfill dike slope
5	End of Construction	2.7	U/S, through the rockfill dike and 2015 capping
	Operation	1.7	D/S, along the rockfill dike slope
	Closure		Not analyzed*
	Seismic Loading	1.4	Along the rockfill dike slope
6	End of Construction	1.7	U/S, through rockfill dike and tailings
	Operation	1.7	Along the rockfill dike slope
	Closure		Not analyzed*
	Seismic Loading	1.6	U/S, through the rockfill dike and tailings
7	End of Construction	1.6	U/S, through the rockfill dike and tailings
	Operation	1.6	U/S, through the rockfill dike and tailings
	Closure		Not analyzed*
	Seismic Loading	1.2	U/S, through the rockfill dike and tailings

*Failure cannot occur due to rock storage facility sitting outside of the dike.

Table 3.3: Sensitivity analysis results

Cross-Section	Scenario	FS			Slip Surface
		Phi=35°	40°	45°	
2	End of Construction	1.4	1.4	1.5	U/S, through the rockfill dike and tailings
	Operation	1.5	1.7	2.0	D/S, through the rockfill dike and saddle dam
	Closure	1.5	1.8	2.1	Through the cover, rockfill dike, and saddle dam
	Seismic Loading	1.1	1.2	1.3	Through the rockfill dike and saddle dam
4	End of Construction	2.2	2.2	2.4	D/S, along the rockfill dike slope
	Operation	1.3	1,6	1.9	Through the cover, 2016 capping and overburden
	Closure	2.3	2.4	2.5	D/S, along the rockfill dike slope
	Seismic Loading	1.1	1.3	1.5	D/S, along the rockfill dike slope

Completing the seepage simulations required definition of the following model inputs:

- geometry for each typical cross-section;
- material properties;
- surface boundary condition;
- lower boundary condition;
- external edge boundary condition; and,
- internal edge boundary condition.

Each of these inputs are described in Appendix C with results summarized below. The cross section locations are shown in Figure 3.1. The geometry for all cross sections are provided in Appendix C. The geometry for cross section 4, which showed the maximum seepage rates, is provided in Figure 3.3.

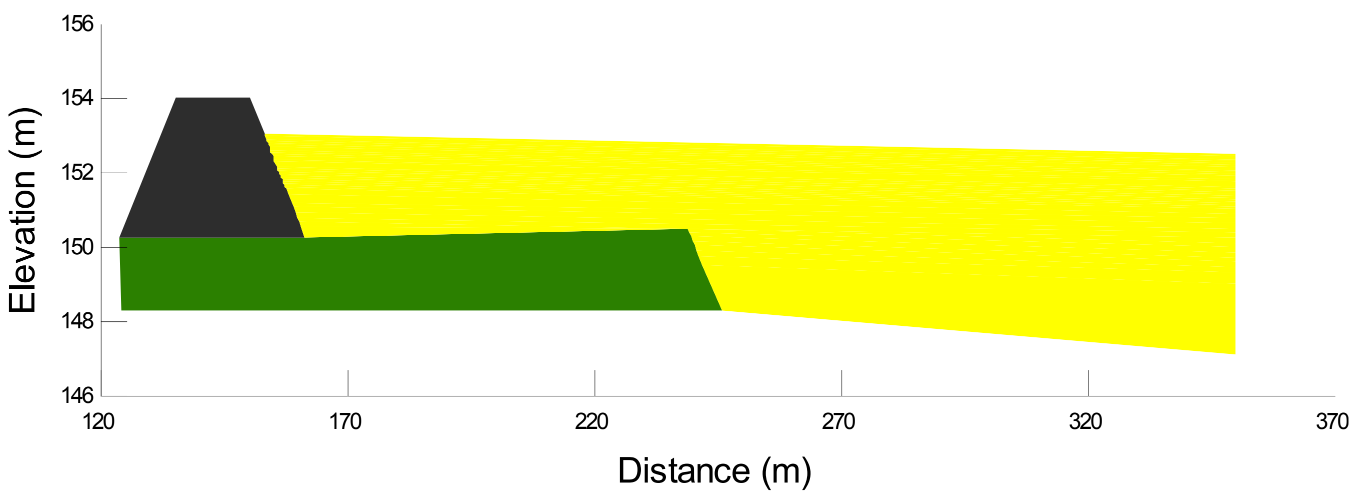


Figure 3.3: Cross-section 4 geometry at the end of deposition

3.2.1 Results

3.2.1.1 Transient Simulations

The results of the transient seepage analysis are summarized in Table 3.4. Cross-sections 1 and 7 resulted in negligible seepage; hence, no results are provided. Note that the "affected dike length" is estimated based on OKC's assumption that the rockfill dike will be built at the outer edge of the 2015 cover system placement. However, the annual tailings thickness were estimated assuming the extension dike is along the interior edge of the 2015 cover system as provided by AEM. This adds additional conservatism to the results as the dike length will either be shorter (if placed on the interior edge) or the tailings thickness will be reduced (if the dike is placed on the exterior edge of the 2015 cover system). The results are also conservative because the weekly amount of tailings are simulated as being placed, fully saturated, all at once rather than distributed throughout the week as in reality.

Table 3.4: Summary of transient seepage results for each deposition season.

Summer	Cross-Section	Maximum Seepage Velocity (m/s)	Maximum Seepage Rate (m^3/day/m)	Seepage per Length of Dike (m^3/m)	Affected Dike Length (m)	Maximum Daily Seepage Volume (m^3/day)	Total Season Seepage Volume (m^3)
2019	3	9.3E-07	0.03	1.7	724	22	1,227
	4	8.8E-06	0.5	12.3	681	341	8,358
	Total					*363*	*9,585*
2020	3	1.0E-05	0.07	2.5	724	51	1,779
	4	2.2E-05	0.15	3.3	681	102	2,266
	5	1.0E-06	0.01	0.6	559	6	312
	Total					*159*	*4,357*
2021	2	2.2E-06	0.03	2.4	851	26	2,070
	3	1.6E-05	0.03	2.5	724	22	1,811
	4	3.5E-05	0.24	6.4	681	163	4,339
	5	2.0E-06	0.09	6.8	559	50	3,776
	6	9.3E-07	0.01	0.1	480	5	39
	Total					*266*	*12,035*
2022 (no cover system in place)	2	3.8E-06	0.12	2	851	102	1,702
	3	2.3E-05	0.16	2.6	724	116	1,882
	4	2.6E-06	0.23	4	681	157	2,724
	5	1.1E-05	0.12	1.3	559	67	727
	6	5.8E-06	0.10	0.7	480	48	336
	Total					*490*	*7,371*

Transient simulations were completed with the dike width at its crest at 30 m as well as with the width reduced to 15 m. Both scenarios resulted in similar results; hence, overall dike width does not influence anticipated seepage rates, which is a function of the assumed conditions, as well as the properties of the materials modelled. 15 m was determined as the minimum width to accommodate 2-way traffic with 50-ton haul trucks.

Simulation of cross-section 4 was completed with a filter layer along the interior slope of the extension dike. This model showed that the presence of a filter layer does not influence seepage rates unless the k_{sat} of the filter layer is lower than the k_{sat} of the tailings.

3.2.1.2 Steady-State Simulations

A steady-state simulation was completed for the end of each deposition season for each cross-section using anticipated maximum seepage during that season to determine: the absolute maximum seepage rate and velocity; and, the maximum distance from the dike that tailings could still contribute to the seepage rate. The results are provided in Table 3.5. These values are highly conservative as the entire tailings mass, and the flow path through the extension dike, are assumed to be fully saturated and to remain so throughout the simulation. In reality, there would likely be some storage capacity available within the tailings and/or dike thus reducing the seepage rate. If the system was fully saturated as simulated, this condition would quickly dissipate.

Table 3.5: Summary of steady-state seepage results for the end of each deposition season.

Summer	Cross-Section	Maximum Seepage Velocity (m/s)	Maximum Seepage Rate (m^3/day/m)	Affected Dike Length (m)	Maximum Daily Seepage Volume (m^3/day)	Maximum Contributing Distance from Dike (m)
2019	3	1.3E-03	51	724	36,924	47
	4	1.8E-03	66	681	44,946	95
2019 (rockfill below tailings not included)	3	1.3E-03	9	724	6,516	3
	4	2.6E-03	18	681	12,258	3
2020	3	3.3E-03	45	724	32,580	8
	4	3.3E-03	50	681	34,050	8
	5	1.5E-03	22	559	12,298	74
2021	2	1.7E-03	73	851	62,123	8
	3	3.4E-03	76	724	55,024	25
	4	3.3E-03	109	681	74,229	10
	5	2.0E-03	49	559	27,391	80
	6	2.0E-03	16	480	7,680	50

Figures for all the cross-sections for each season are provided in Appendix C. Cross-section 4 (Figure 3.4 to Figure 3.7) is anticipated to have the highest seepage volume. The steady-state models show that the 2015 capping cover system rockfill layer under the tailings and dike provides a conduit for flow during the 2019 season, which allows for tailings pore-water much further away from the dike to influence seepage rates through the dike. Seepage rates and contributing distances are substantially reduced when the rockfill layer is not included in the simulation (Figure 3.5). In order to reduce seepage rates under the rockfill dike, the rockfill dike should be constructed during the winter months to ensure permafrost aggradation within the 2015 capping and the dike material. This is to ensure permafrost formation under and within the dike and to reduce the active layer to the dike itself during the deposition season, thus reducing the “conduit” effect in the rockfill material under the dike.

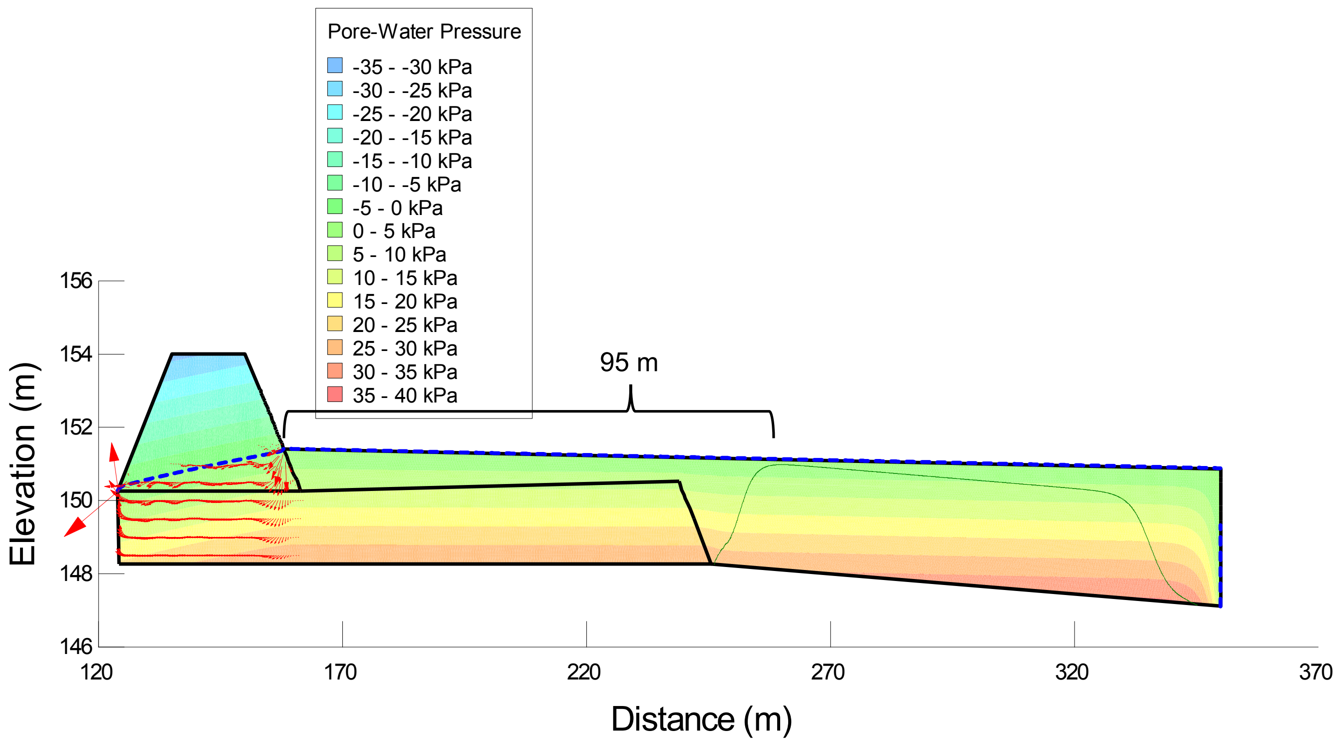


Figure 3.4: Steady-state pore-water pressure, flow paths and flow vectors for section 4 at end of 2019.

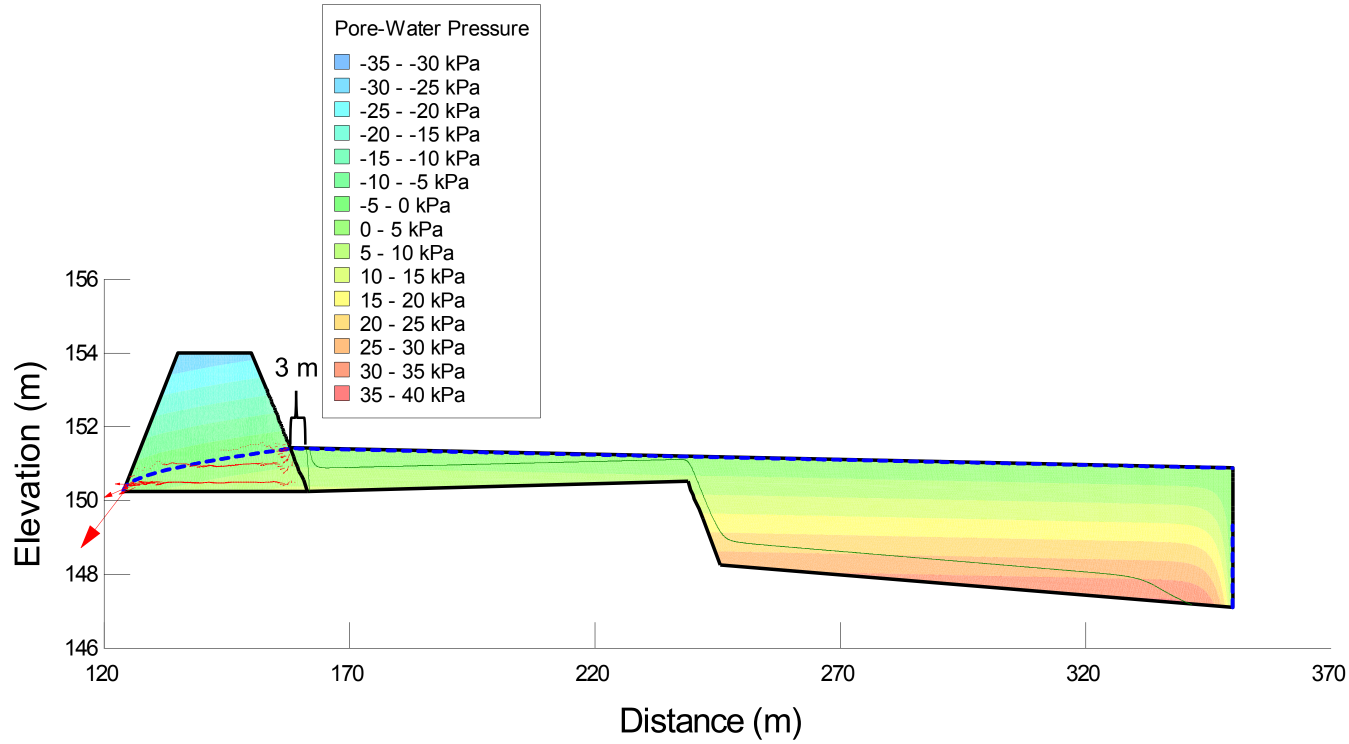


Figure 3.5: Steady-state pore-water pressure, flow paths and flow vectors for section 4 at end of 2019 when rockfill layer below tailings and dike not included.

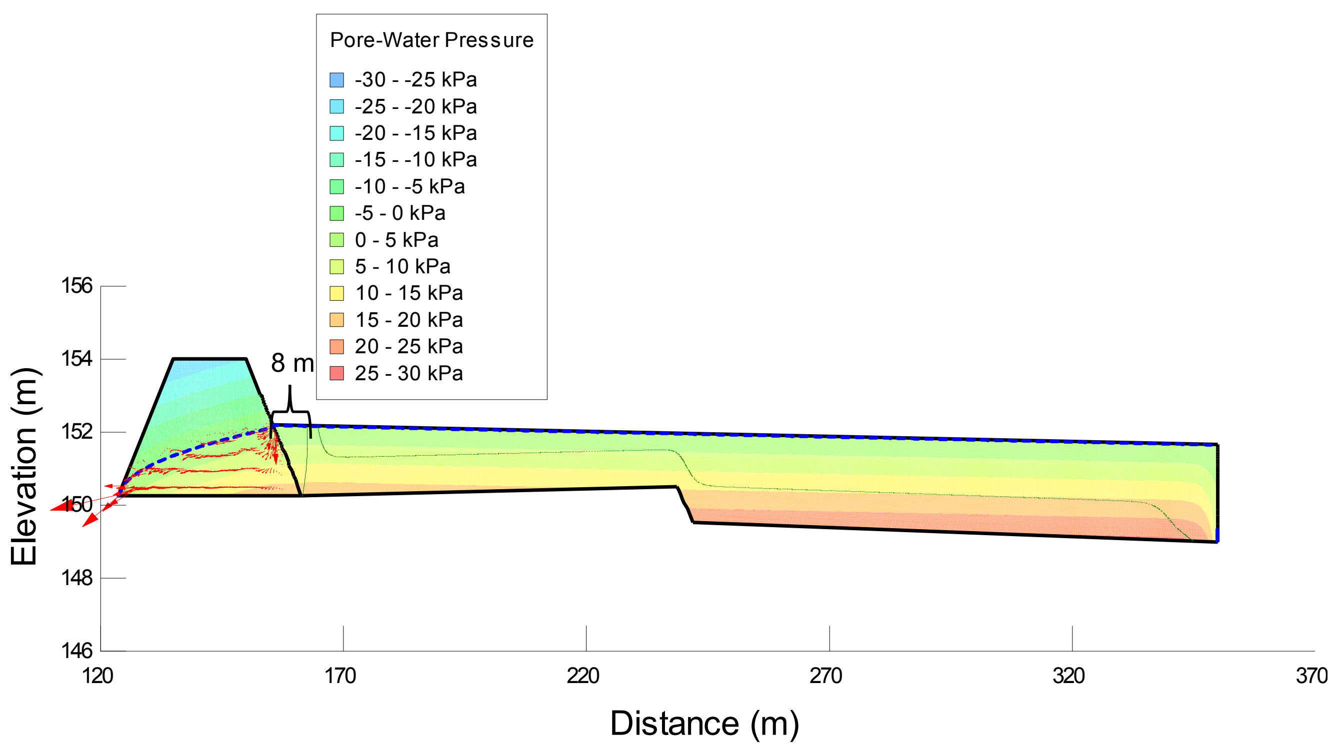


Figure 3.6: Steady-state pore-water pressure, flow paths and flow vectors for section 4 at end of 2020

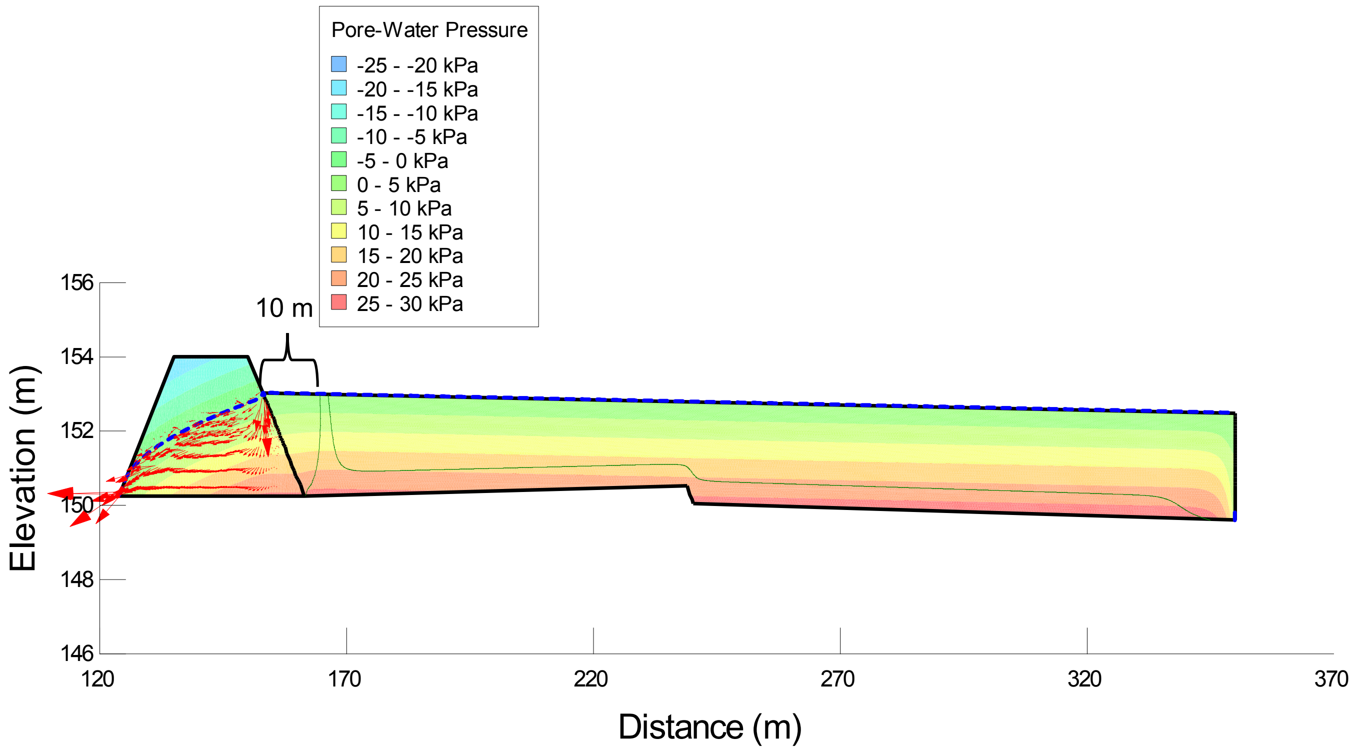


Figure 3.7: Steady-state pore-water pressure, flow paths and flow vectors for section 4 at end of 2021

It can be argued that a potential concern is fines within the tailings migrating into the extension dike via the seepage flow. It is the opinion of OKC that this "washing" of fines from the tailings will be minimal and will not influence performance of the extension dikes for the following reasons.

- The maximum seepage velocities provided in this report are very conservative, and, in the case of the maximum seepage velocities presented in Table 3.5, represent the absolute maximum seepage velocities if the full volume of annual tailings was placed, saturated and without permafrost, against the extension walls at one time. Although not as extreme as the steady-state simulations, the transient maximum seepage rates are also highly conservative as the weekly material placement is simulated as placed all at once and not distributed throughout the week as in reality.

- The maximum seepage velocities will quickly dissipate as the tailings drain; quickly losing its ability to keep particles in suspension.

- Preferential flow paths will change year-to-year due to the development of permafrost within the tailings and extension dike.

- Any initial movement of sediments will clog flow paths within the extension dike, quickly limiting flow and reducing the washing of fines from the tailings.

3.3 Climate Change Considerations

As part of the North Cell TSF Cover System Design (OKC 948-01-02), OKC considered climate change scenarios for the thermal analysis of the proposed cover system. Results from the thermal analysis were then used as inputs for the seepage analysis discussed in the previous 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). 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).

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/m^2. This scenario would still require implementation of a range of technologies and strategies to reduce GHG emissions.

3.4 Consolidation Analyses

A one-dimensional (1-D) consolidation analysis was conducted to assess the potential for overall tailings settlement due to the additional loading from the placement of the rockfill dike. The specific purpose of this analysis was to estimate settlement of the tailings mass that would be caused by permafrost degradation due to seepage beneath the dike during operations. The analysis looked to evaluate whether the predicted long-term settlement could affect the overall integrity of the rockfill dike. It is assumed that the internal structure will remain frozen or partially frozen once operations have ceased and the tailings are capped.

Essential criteria for ensuring long-term stability due to dike construction are:

1) Absolute magnitude of potential settlement;
2) Time dependent consolidation rates; and
3) Magnitude of secondary settlement to ensure long-term stability.

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 the same assumptions used for the consolidation analysis provided for the cover and landform design (OKC Report 948/1-02), 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 2 m was used in the analysis, which is consistent with the thawed depth of tailings used in other analyses; not taking into account cover system placement in order to develop a conservative case.

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 dike material placement is a key factor leading to tailings consolidation settlement.

The results indicate that a 2 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 0.29 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. However, it is anticipated that the tailings beneath the rockfill dike will re-freeze and therefore long-term consolidation is unlikely to occur.

The consolidation analysis is considered to be highly conservative. The conservatism in this analysis is due to:

- The assumption of 2 m of thawed tailings beneath the rockfill dike;
- The assumption that the 2 m of thawed tailings would also be at a saturation of 100%; and
- The assumption that 2 m of thawed tailings would exist instantaneously and allow primary consolidation to occur all at once.

The predicted consolidation is therefore considered to be somewhere between the minimum value of <1cm for the secondary consolidation rate (and frozen tailings) and the 0.29 m maximum value (for the 2 m of thawed tailings). If thawing due to seepage beneath the rockfill dike does occur, it is most likely to occur within the rockfill itself, rather than through the tailings. Therefore, both the thaw depth, and the fully saturated condition make this assessment highly conservative. Seepage will occur within the year of tailings placement or shortly after, so any thaw consolidation that might occur would occur over short timeframes, to enable modification to the dike elevation, if required.

4 FINAL DESIGN

The rockfill dike design was developed from the conceptual design along with completed numerical modelling to ensure the adequacy of the design meets the design and operational objectives of the infrastructure. Technical drawings were developed showing the main elements of the rockfill dike as well as its position within the North Cell TSF. Drawings are presented in Appendix A and are listed in below.

Table 4.1: Technical drawings list and description.

Drawing Number	Drawing Title	Description
948/2-001	Existing Feature Plans	Plan view of the greater area surrounding the North Cell TSF
948/2-002	Rockfill Dike Alignment Layout Plan	Plan view of the North Cell TSF, showing the alignment of the rockfill dike and set out data
948/2-003	Rockfill Dike, Sections 1-5	Typical cross-sections of the rockfill dike for Sections 1 &2, 3&4, and 5.
948/2-004	Rockfill Dike, Sections 6-7	Typical cross-section of the rockfill dike for Sections 6 & 7, and details of the filter layer

4.1 Rockfill Dike Cross-Section

The rockfill dike is constructed of NPAG material placed by haul truck and dozer. It is not designed to be a water retaining structure and numerical modelling shows that seepage reporting to the downstream side of the dike is manageable as part of regular operations. The height of the dike is limited to 4 m for its highest portions (cross-sections 3, 4 and 5 on DRG 948-2-002) and to 2 m for the remaining sections. It is suggested to limit lift height to 1m during construction to avoid particle segregation during placement and promote traffic compaction. This will further limit potential seepage during operational tailings deposition,

The rockfill dike is designed with 15 m crest width to allow for 2-way traffic with 50-ton haul trucks. If larger construction equipment was to be used, the rockfill dike may be built wider to accommodate the equipment. Seepage modelling was done on both the 15 m and 30 m dike width for cross-section 4, showing that overall width had little to no influence on the seepage rates reporting on the downstream side of the dike.

4.1.1 Filter Layer

Drawing 948-2-004 shows preliminary detail of the filter layer to be placed on the upstream side of the rockfill dike prior to tailings deposition. The overall width of this filter layer is in addition to the rockfill dike crest width. The filter layer consists of 0-6” granular fill against the NPAG rockfill dike, with 0-3/4” granular fill on either side of a non-woven geotextile. The purpose of the 0-3/4” granular material and geotextile is to prevent tailings material from migrating through the coarser rockfill of the dike. The

0-6" material is a transition material to prevent the finer granular material from migrating towards the rockfill. Should the stated layer widths prove challenging to implement, these can be increased as required. Anchoring of the geotextile layer will be dependent on the chosen manufacturer specifications for installation.

4.2 Rockfill Dike Alignment

The alignment presented in DRG 948-2-002 is based on a set offset from known infrastructure on the perimeter of the North Cell TSF. The offset is based on the edge of the roadway to the centre line of a 15 m wide rockfill dike. If AEM was to choose to build a wider dike to accommodate construction equipment, this additional width should be expanded on the upstream side in order to maintain the offset.

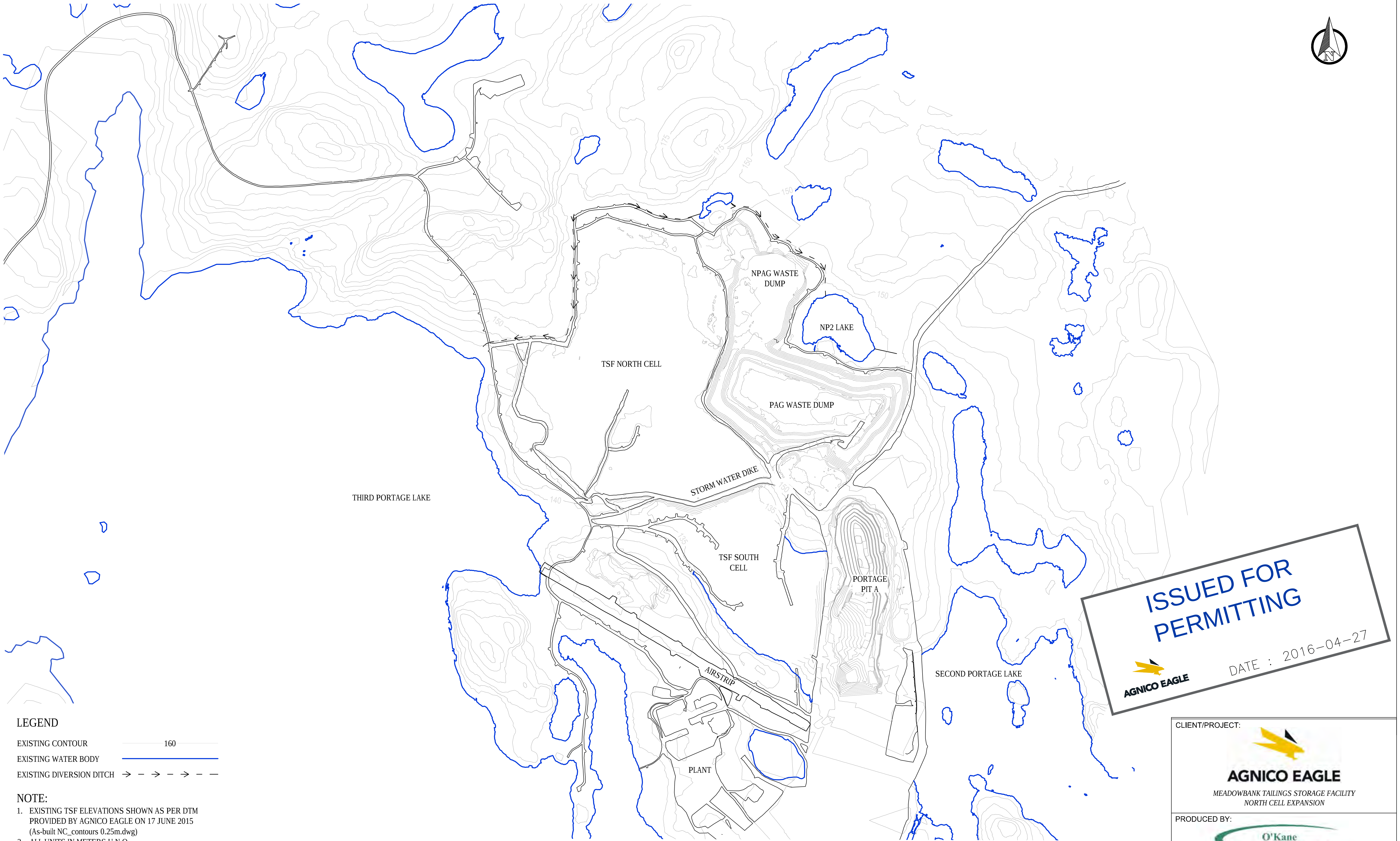
Some sections of the rockfill dike are to be built directly over the tailings beach (cross-sections 1, 2, 6 and 7) while the remainder will be built over the previously placed capping material; refer to DRG 948-2-003 and 948-2-004 for typical cross-sections.

4.2.1 Seepage Management Infrastructure

Numerical modelling developed for the project shows that seepage from the rockfill dike are limited both in volume and time. Conservative modelling suggests that most seepage occurs early following deposition and tails off when deposition stops. As deemed necessary, AEM will construct a collection ditch on the downstream side of the rockfill dike, 5 m from the toe of the dike. As survey data is conflicting for the areas close to the perimeter of the TSF, it is suggested that low-points along the collection ditch be identified during construction and collection sump positioned in these areas. The maximum daily seepage rate expected for the rockfill dike is 341 m^3 for the portion of the dike relating to cross-section 4 (dike length of 681 m). As such, pumping capacity of 15 m^3/hr (70 gpm, 250 L/min) is sufficient to manage seepage volumes for that section of dike. As deposition of tailings will take place over a limited section of the dike at any one time, seepage is expected to be limited in extent.

Appendix A

Drawings



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.
3. DO NOT SCALE.

EXISTING FEATURES PLAN

1:20,000

200 100 0 200 400 600 800 1000m

SCALE 1:20000

CLIENT/PROJECT:

AGNICO EAGLE

MEADOWBANK TAILINGS STORAGE FACILITY
NORTH CELL EXPANSION

PRODUCED BY:

O'Kane Consultants Inc.

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

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B	ISSUED FOR PERMITTING.	HSC	04.27.16

REVD. BY:	P. GARNEAU	DATE:	01.15.16
APPD. BY:	M. O'KANE	DATE:	01.15.16
SCALE:	AS SHOWN	REPORT NUM:	948/2-01

EXISTING FEATURES PLAN

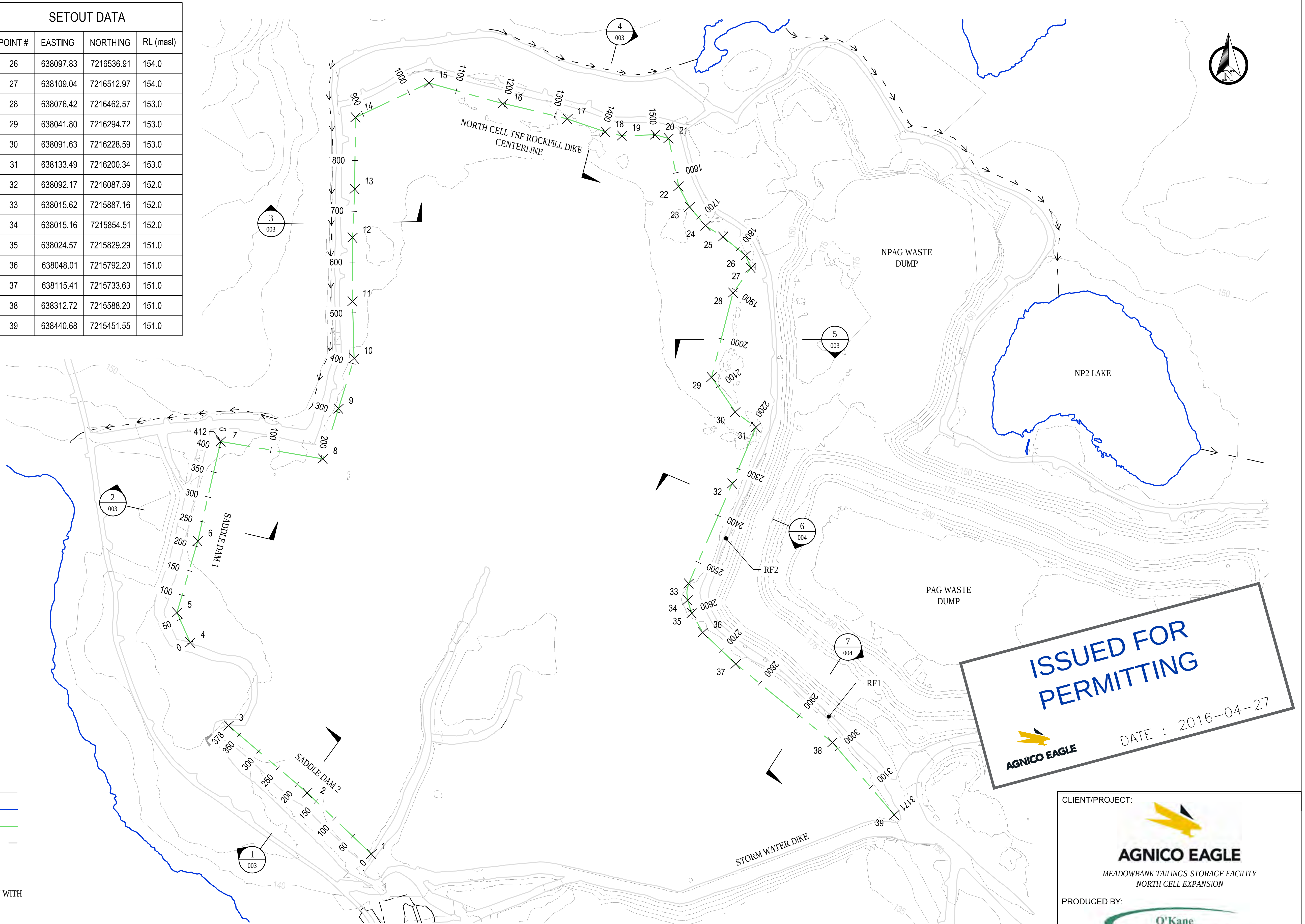
DRG NUM: 948/2-001 Rev: B

SETOUT DATA

POINT #	EASTING	NORTHING	RL (masl)
1	637416.88	7215327.07	152.0
2	637285.24	7215441.23	152.0
3	637124.73	7215566.12	152.0
4	637041.67	7215725.89	152.0
5	637013.09	7215783.62	152.0
6	637047.26	7215925.78	152.0
7	637083.42	7216123.70	154.0
8	637285.47	7216098.99	154.0
9	637311.70	7216199.01	154.0
10	637337.93	7216299.03	154.0
11	637329.40	7216411.02	154.0
12	637323.60	7216536.35	154.0
13	637323.60	7216631.99	154.0
14	637318.58	7216772.60	154.0
15	637459.53	7216847.10	154.0
16	637606.79	7216813.15	154.0
17	637735.01	7216789.14	154.0
18	637810.73	7216767.03	154.0
19	637843.73	7216760.82	154.0
20	637908.97	7216765.86	154.0
21	637935.76	7216760.04	154.0
22	637959.84	7216666.92	154.0
23	637983.08	7216627.25	154.0
24	638016.31	7216591.73	154.0
25	638051.47	7216571.66	154.0

SETOUT DATA

POINT #	EASTING	NORTHING	RL (masl)
26	638097.83	7216536.91	154.0
27	638109.04	7216512.97	154.0
28	638076.42	7216462.57	153.0
29	638041.80	7216294.72	153.0
30	638091.63	7216228.59	153.0
31	638133.49	7216200.34	153.0
32	638092.17	7216087.59	152.0
33	638015.62	7215887.16	152.0
34	638015.16	7215854.51	152.0
35	638024.57	7215829.29	151.0
36	638048.01	7215792.20	151.0
37	638115.41	7215733.63	151.0
38	638312.72	7215588.20	151.0
39	638440.68	7215451.55	151.0



GENERAL ARRANGEMENT PLAN
1:7,500

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

LEGEND

- EXISTING CONTOUR — 160
- EXISTING WATER BODY
- ROCK FILL DIKE CENTERLINE
- EXISTING DIVERSION DITCH
- SETOUT POINT LOCATION

NOTE:

1. THIS DRAWINGS IS TO BE READ IN CONJUNCTION WITH OKC REPORT No. 948/2-01 DATED DEC 2015.
2. EXISTING TSF ELEVATIONS SHOWN AS PER DTM PROVIDED BY AGNICO EAGLE ON 17 JUNE 2015 (As-built NC_contours 0.25m.dwg)
3. ALL UNITS IN METERS U.N.O.
4. DO NOT SCALE.

CLIENT/PROJECT:

AGNICO EAGLE

MEADOWBANK TAILINGS STORAGE FACILITY NORTH CELL EXPANSION

PRODUCED BY:

O'Kane Consultants Inc.

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

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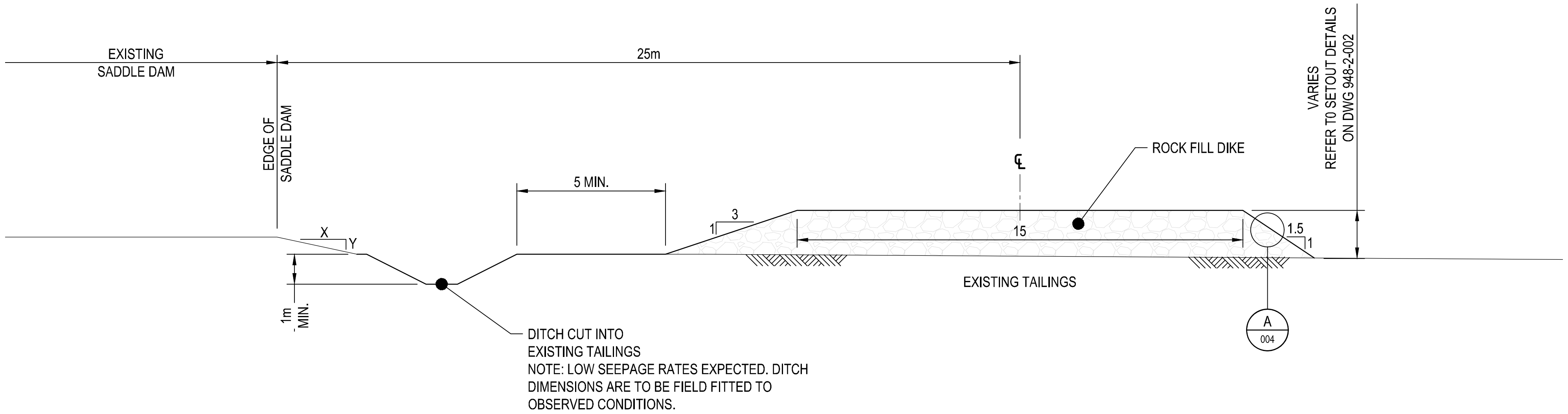
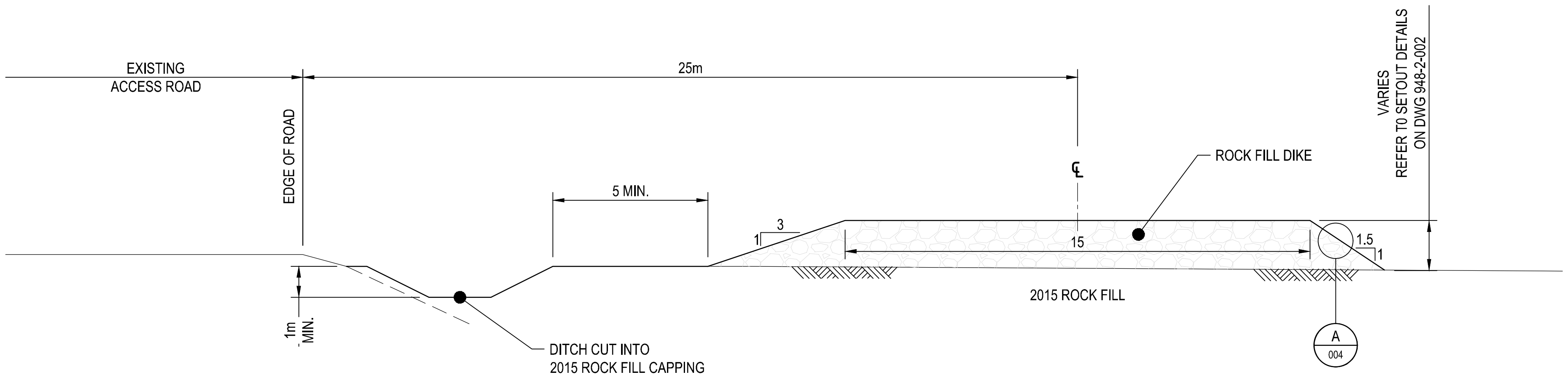
APPD. BY:	M. O'KANE	DATE:	01.15.16
SCALE:	AS SHOWN	REPORT NUM:	948/2-01

ROCKFILL DIKE ALIGNMENT LAYOUT PLAN

DRG NUM: 948/2-002 Rev: B



SECTION 1 & 2
1:200



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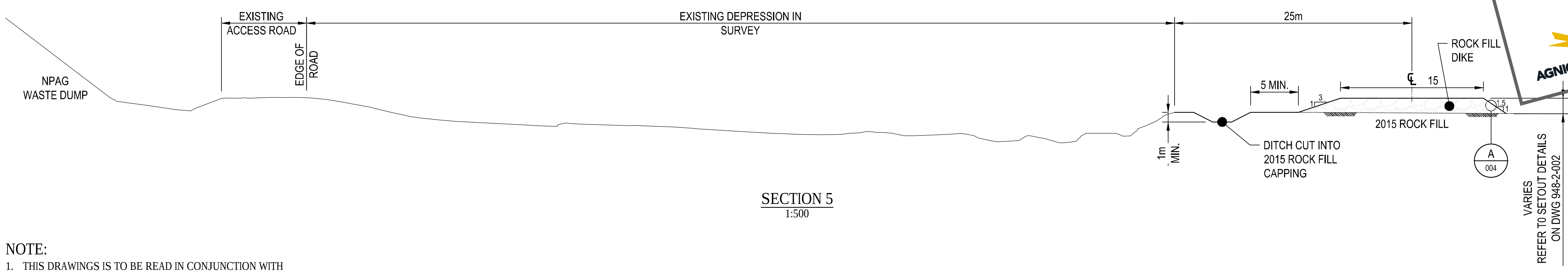

SECTION 5
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NOTE:
1. THIS DRAWINGS IS TO BE READ IN CONJUNCTION WITH OKC REPORT No. 948/2-01 DATED DEC 2015.
2. ALL UNITS IN METERS U.N.O.
3. DO NOT SCALE.

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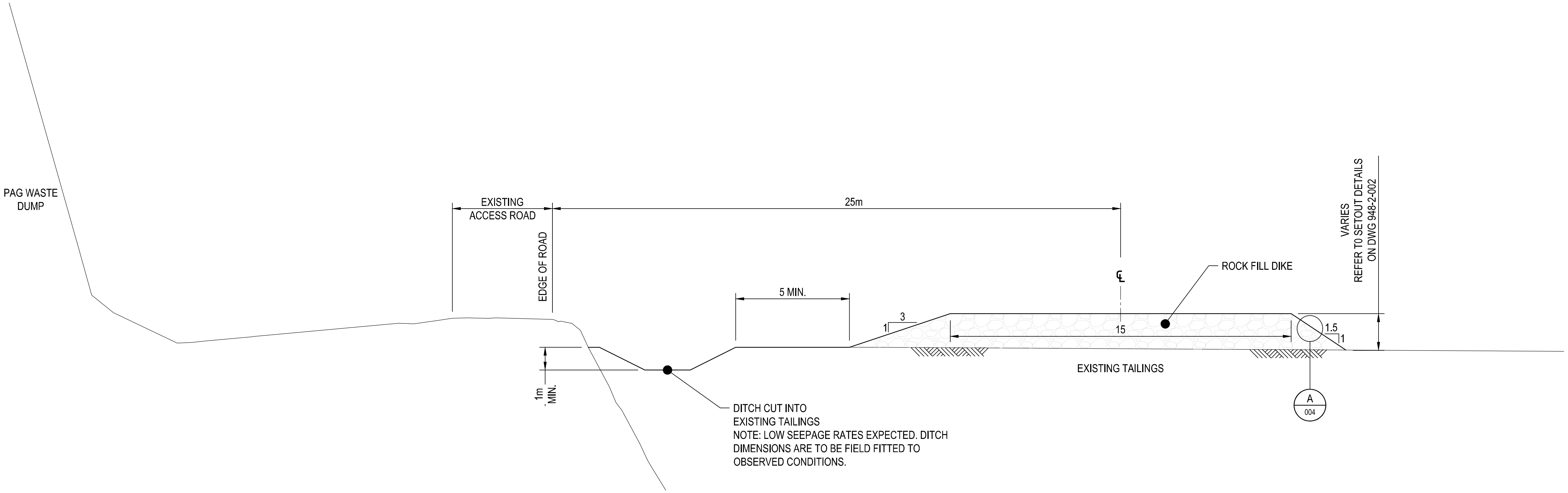
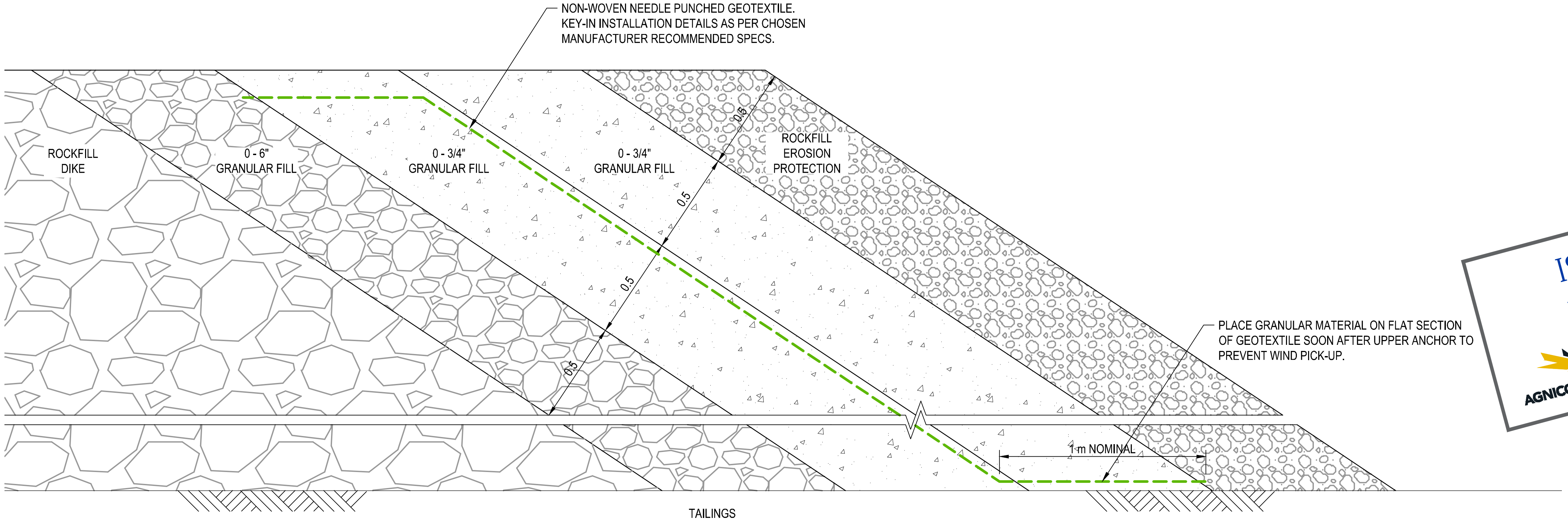
APPD. BY:	M. O'KANE	DATE:	01.15.16
SCALE:	AS SHOWN	REPORT NUM:	948/2-01

ROCKFILL DIKE
SECTIONS 1-5

DRG NUM: 948/2-003 Rev: B



SECTION 6 & 7
1:200



DETAIL A
1:20

ISSUED FOR PERMITTING
AGNICO EAGLE
DATE : 2016-04-27

NOTE:
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2. ALL UNITS IN METERS U.N.O.
3. DO NOT SCALE.

CLIENT/PROJECT:
AGNICO EAGLE
MEADOWBANK TAILINGS STORAGE FACILITY
NORTH CELL EXPANSION

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APPD. BY:	M. O'KANE	DATE:	01.15.16
SCALE:	AS SHOWN	REPORT NUM:	948/2-01

ROCKFILL DIKE
SECTIONS 6-7 & DETAIL A

DRG NUM: 948/2-004 Rev: B

Appendix B

Slope Stability Modelling-Detailed Results

O'Kane Consultants
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Interoffice Memorandum

To: Bonnie Dobchuk – Senior Geoenvironmental Engineer, O'Kane Consultants

From: Jason Song, Geoscientist P.Eng.

Cc: Philippe Garneau

Our ref: 948/2

Date: January 15, 2016

Re: **Meadowbank North TSF Extension - Results for Slope Stability Analysis**

O'Kane Consultants Inc. (OKC) was retained by Agnico Eagle Mines Ltd. (AEM) for design work to support evaluation and optimization of the current Meadowbank Tailings Storage Facility (TSF). A key component of this work is slope stability analysis of the rockfill extension dike, which will form a perimeter for most of the TSF North Cell with the exception of above the Storm Water Dike (SWD). The purpose of this analysis is to check the overall stability of the TSF as well as the effects of dyke location on the TSF stability. The body of this document provides the modelling methodology, summary of material properties, modelling cross-sections and scenarios, slope stability criteria, and summary of model results. The appendix provides all slip plane profiles.

Modelling Methodology

The commercial software SLOPE/W[1] was used to conduct two-dimensional (2D) limit equilibrium analyses using the Morgenstern-Price method for static loading with a circular slip surface. In stability analyses, trial failure surfaces were defined with 'entry and exit' parameters, resulting in a range of possible locations within which the most critical potential failure surface may be found. The SLOPE/W program incorporates a search routine to locate those failure surfaces with the least factor of safety (FS) within the defined search limits.

Summary of Material Properties

Table 1 provides a summary of the material properties used to simulate each component within each of the seven cross-sections.

[1] GEO-SLOPE International Ltd., 2014. Stability Modelling with VADOSE/W. June 2015 Edition. Calgary, Alberta, Canada.

Table 1: Summary of Material Properties

Name in Cross-Section	Material	Unit Weight (kN/m^3)	Friction Angle	Cohesion (kPa)	Notes	Colour in Profiles
Cover System	Cover Material	21.0	32°	0	Estimated	
Tailings	Tailings	18.0	27°	0	Golder	
Rockfill Dike	Rockfill	22.2	45°	0	Golder	
Road / NC Road	Rockfill	22.2	45°	0	Golder	
Compacted Till	Compacted Till	21.0	32°	0	Estimated	
Overburden	Overburden	18.0	22°	0	Estimated	
Saddle Dam	Rockfill	22.2	45°	0	Estimated	
LLDPE	Geomembrane	9.0	27°	0	Estimated	
Fine Filter	Rockfill	22.2	45°	0	Golder	
Coarse Filter	Rockfill	22.2	45°	0	Golder	
Rockfill Storage Facility	Rockfill	22.2	45°	0	Estimated	
2015 Capping	Rockfill	22.2	45°	0	Estimated	
2016 Capping	Rockfill	22.2	45°	0	Estimated	
Bedrock	Bedrock	N/A	N/A	N/A	Impenetrable	

In addition, the internal friction angle of the rockfill was reduced from 45° to 40° and 35° to analyze dike's slope stability sensitivity. The friction angles of other material did not change in the sensitivity analyses.

Modelling Cross-Sections

Seven cross-sections were modelled with slope stability (Figure 1). These sections were chosen along the dike perimeter and were considered representatives of all various dike segments.

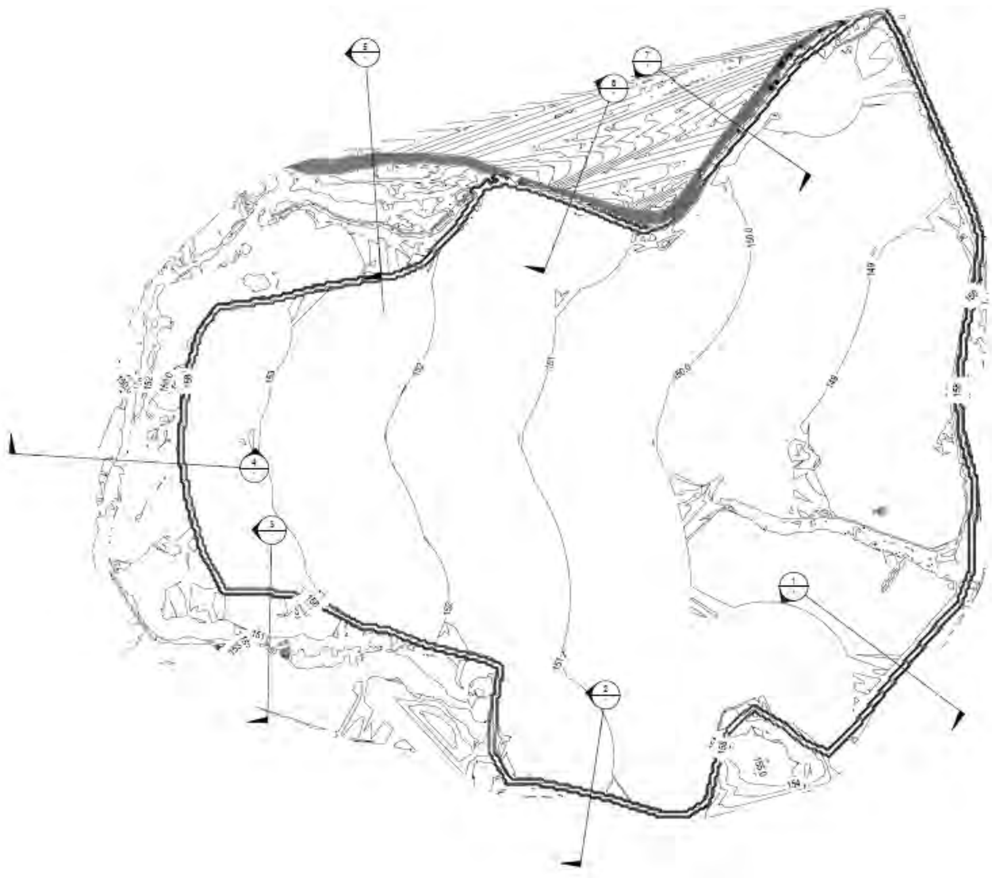

Figure 1 Locations of cross-sections for slope stability analyses for North Cell.

Dike's heights were variable, determined from the planned tailings maximum elevation that was supplied by AEM. A freeboard of approximately 0.5 m was added to the tailings maximum elevation. The maximum dike's height was 4 m. During the slope stability modelling, the dike's width was set as 30 m and the dike's slope angle was set as 3H:1V.

Modelling Scenarios

Four scenarios were considered:

1) End of Construction – rockfill extension dike in place but tailings placement has yet to commence.
2) Operation – All tailings placed within the TSF.
3) Closure – Cover system placed over entire TSF.
4) Seismic Loading - a horizontal acceleration coefficient of 0.06 is applied to the scenario that has the lowest FS obtained from above three static case analyses.

For all scenarios, unfrozen materials were simulated as fully saturated with a maximum pore-water pressure of 20 kPa. Frozen materials were simulated with a -1 m pressure head. Material within 2 m of the surface were simulated as unfrozen. Figures 1 – 3 shows pore-water pressures simulated for scenarios 1) to 3), respectively. Here Section 1 is illustrated as an example. Similar pore-water pressures were applied to other sections. The seismic loading analysis has the same pore-water pressure profile as its corresponding static case analysis. The blue dotted lines indicate zero pore-water pressure.

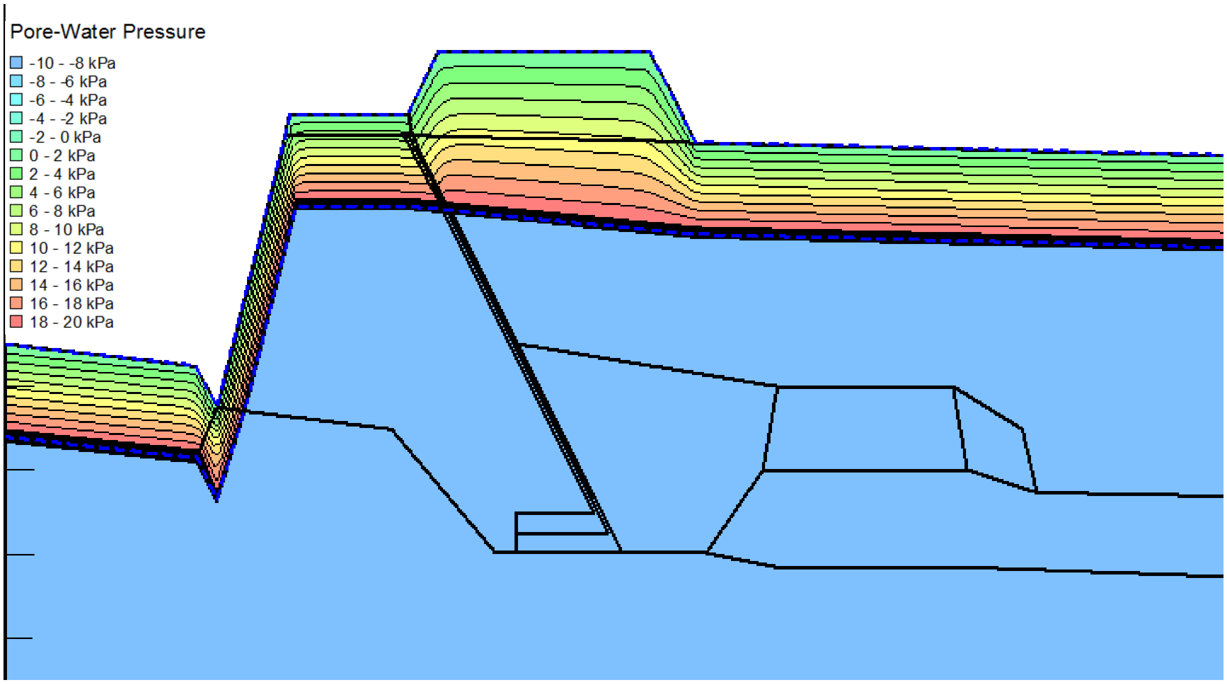

Figure 2 Pore-water pressure at the end of dike construction for Section 1.

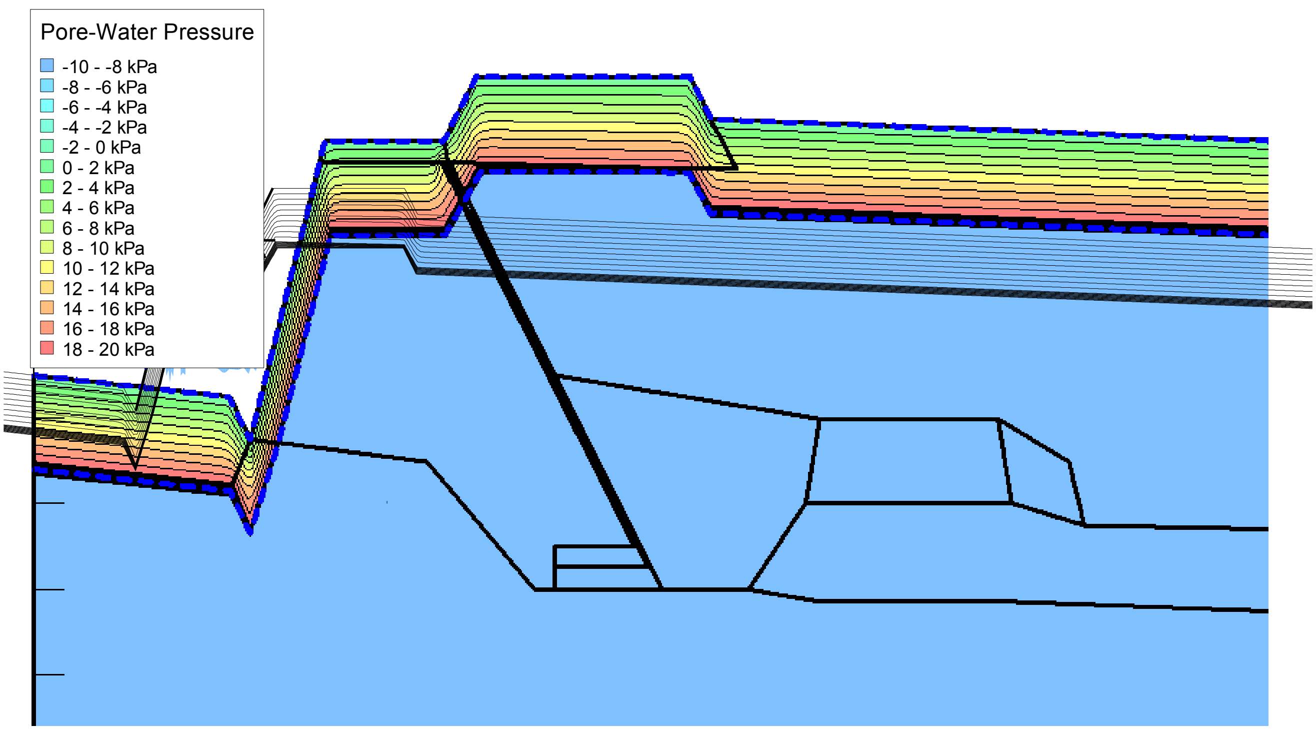

Figure 3 Pore-water pressure for the Operation scenario for Section 1.

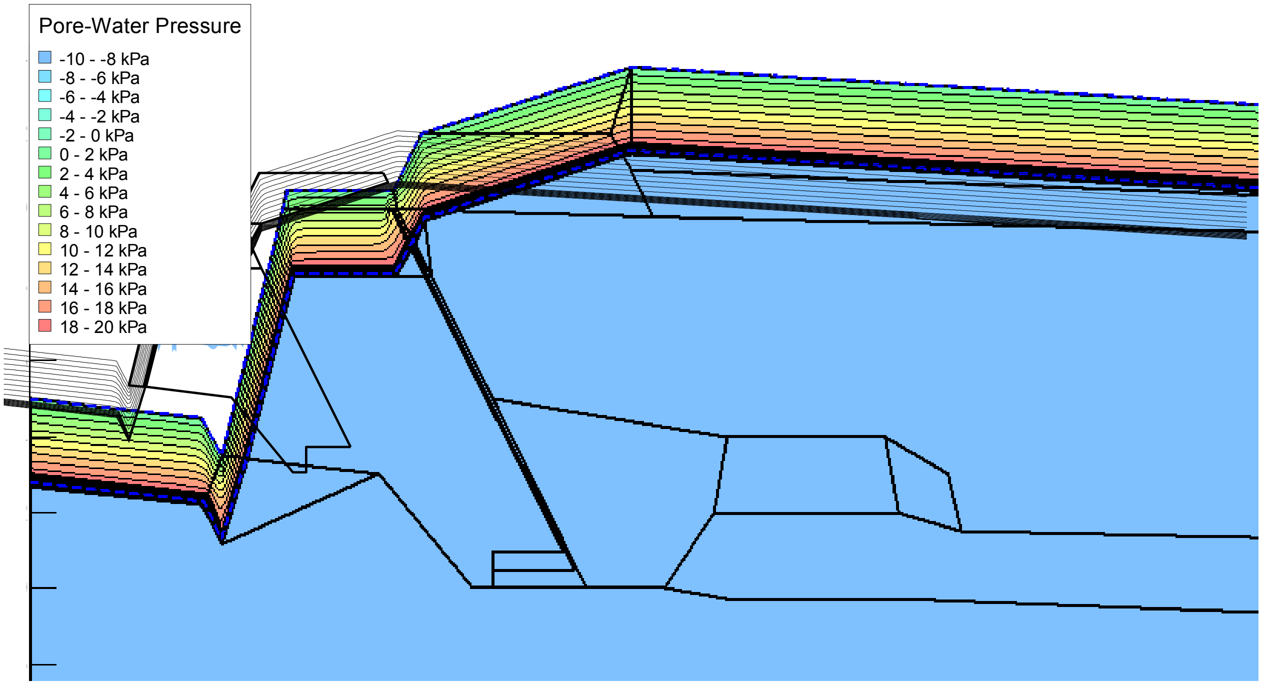

Figure 4 Pore-water pressure for the Closure scenario for Section 1.

Slope Stability Criteria

Calculated FS values from the SLOPE/W program will be compared to the minimum required values (i.e. the slope stability criteria). The minimum FS values are summarized in Table 2.

Table 2: Summary of minimum factor of safety values utilized for slope stability criteria

Condition	FS Value	Basis for FS Value
End of Construction	1.3	During or immediately after dike's construction
Operation	1.5	With maximum tailings deposition
Closure	1.5	After cover system placement
Pseudo static	1.0	Seismic loading

Results

Table 3 provides a summary of the results for all four scenarios for each of the seven cross-sections. The slip surfaces and factors of safety are presented in the appendix of this memorandum.

Table 3: Summary of slope stability analysis results

Cross-Section	Scenario	FS	Slip Surface
1	End of Construction	1.6	Up-stream (U/S), along the rockfill dike slope
	Operation	1.6	Down-stream (D/S), along the rockfill dike slope
	Closure	3.1	Through the cover, rockfill dike, and saddle dam
	Seismic Loading	1.3	D/S, along the rockfill dike slope
2	End of Construction	1.5	U/S, through the rockfill dike and tailings
	Operation	2.0	D/S, through the rockfill dike and saddle dam
	Closure	2.1	Through the cover, rockfill dike, and saddle dam
	Seismic Loading	1.3	U/S, through the rockfill dike and tailings
3	End of Construction	2.4	D/S, through the rockfill dike, 2015 capping
	Operation	1.7	D/S, along the rickfill dike slope
	Closure	2.0	Through the cover, NC road, 2015 capping and overburden
	Seismic Loading	1.4	Along the rockfill dike slope
4	End of Construction	2.4	D/S, through the rockfill dike,2015 capping, and overburden
	Operation	1.9	D/S, along the rockfill dike slope
	Closure	2.5	Through the cover, 2016 capping and overburden
	Seismic Loading	1.5	D/S, along the rockfill dike slope
5	End of Construction	2.7	U/S, through the rockfill dike and 2015 capping
	Operation	1.7	D/S, along the rockfill dike slope
	Closure		Not analyzed*
	Seismic Loading	1.4	Along the rockfill dike slope
6	End of Construction	1.7	U/S, through rockfill dike and tailings
	Operation	1.7	Along the rockfill dike slope
	Closure		Not analyzed*
	Seismic Loading	1.6	U/S, through the rockfill dike and tailings
7	End of Construction	1.6	U/S, through the rockfill dike and tailings
	Operation	1.6	U/S, through the rockfill dike and tailings
	Closure		Not analyzed*
	Seismic Loading	1.2	U/S, through the rockfill dike and tailings

*Failure cannot occur due to rock storage facility sitting outside of the dike.

The results presented in Table 3 indicate that modelled FS values satisfied the dike's slope stability criteria. It should be noted that the dike width (dike's crest width) was set as 30 m in these slope stability analyses. When the seepage modelling was completed in a later time, it was found that the dike's width can be reduced to 15 m and had no significant impact on seepage value. It is anticipated that the FS values will not change substantially when the dike width changes from 30 m to 15 m if the slope angle of the dike maintains. However, it is considered prudent to re-visit slope stability analysis when the dike's width and location is finalized.

Sensitivity analyses were completed using cross-sections 2 and 4. Results for these scenarios are in brackets in Table 4.

Table 4: Factor of safety values from sensitivity analysis

Cross-Section	Scenario	FS			Slip Surface
		Phi=35°	40°	45°	
2	End of Construction	1.4	1.4	1.5	U/S, through the rockfill dike and tailings
	Operation	1.5	1.7	2.0	D/S, through the rockfill dike and saddle dam
	Closure	1.5	1.8	2.1	Through the cover, rockfill dike, and saddle dam
	Seismic Loading	1.1	1.2	1.3	Through the rockfill dike and saddle dam
4	End of Construction	2.2	2.2	2.4	D/S, along the rockfill dike slope
	Operation	1.3	1.6	1.9	D/S, along the rockfill dike slope
	Closure	2.3	2.4	2.5	Through the cover, 2016 capping and overburden
	Seismic Loading	1.1	1.3	1.5	D/S, along the rockfill dike slope

Sensitivity analyses indicate that FS values can satisfy the slope stability criteria when the friction angle (phi) of the rockfill material was reduced to 35° except for a lightly lower FS (1.3) than the criterion (1.5) for Section 4 Operation scenario.

<u>Closure</u>

We trust information provided in this memorandum is satisfactory for your requirements. Please do not hesitate to contact me at (403) 215-3874 or jsong@okc-sk.com should you have any questions or comments.

Appendix

Slip Plane Profiles

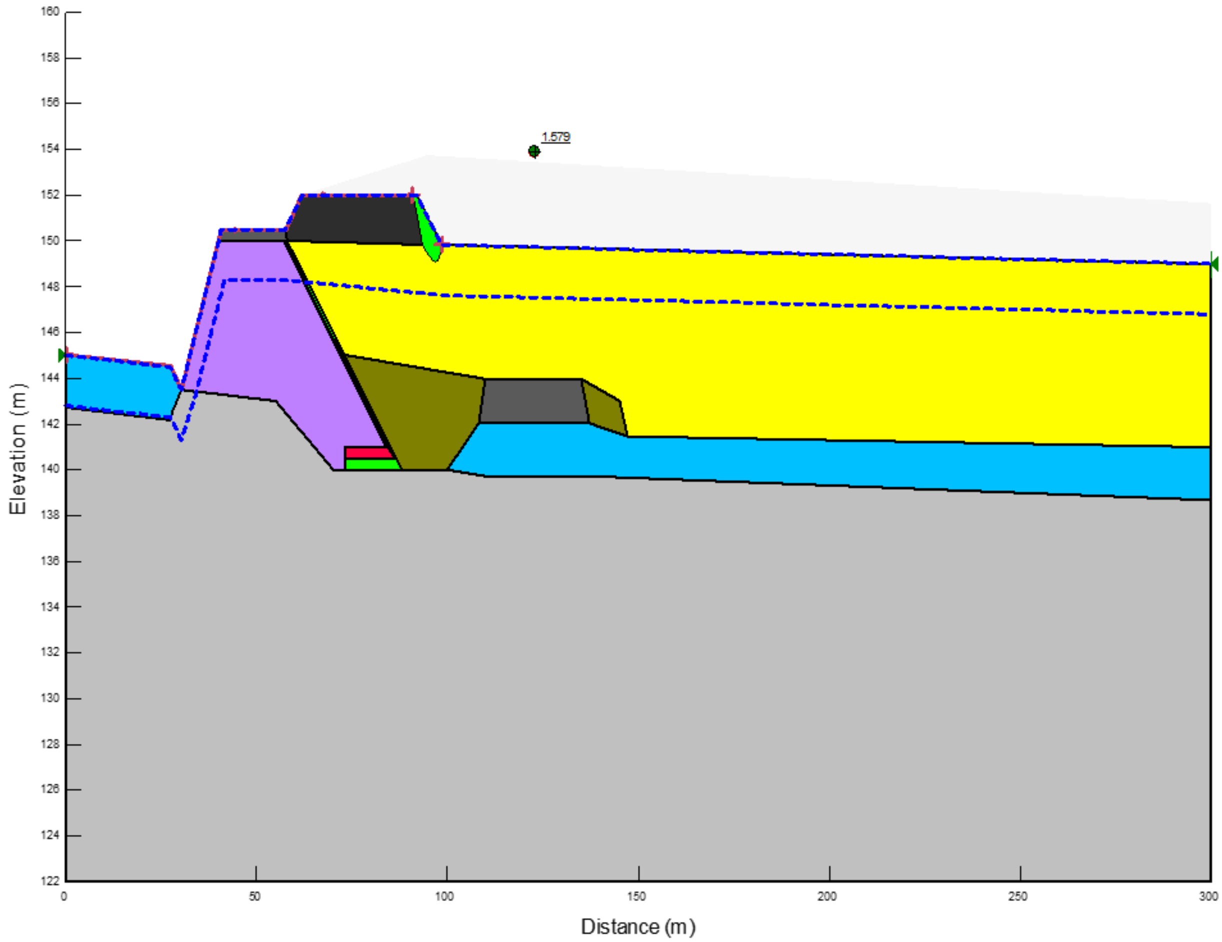

Figure 5: Cross-Section 1 – End of Construction

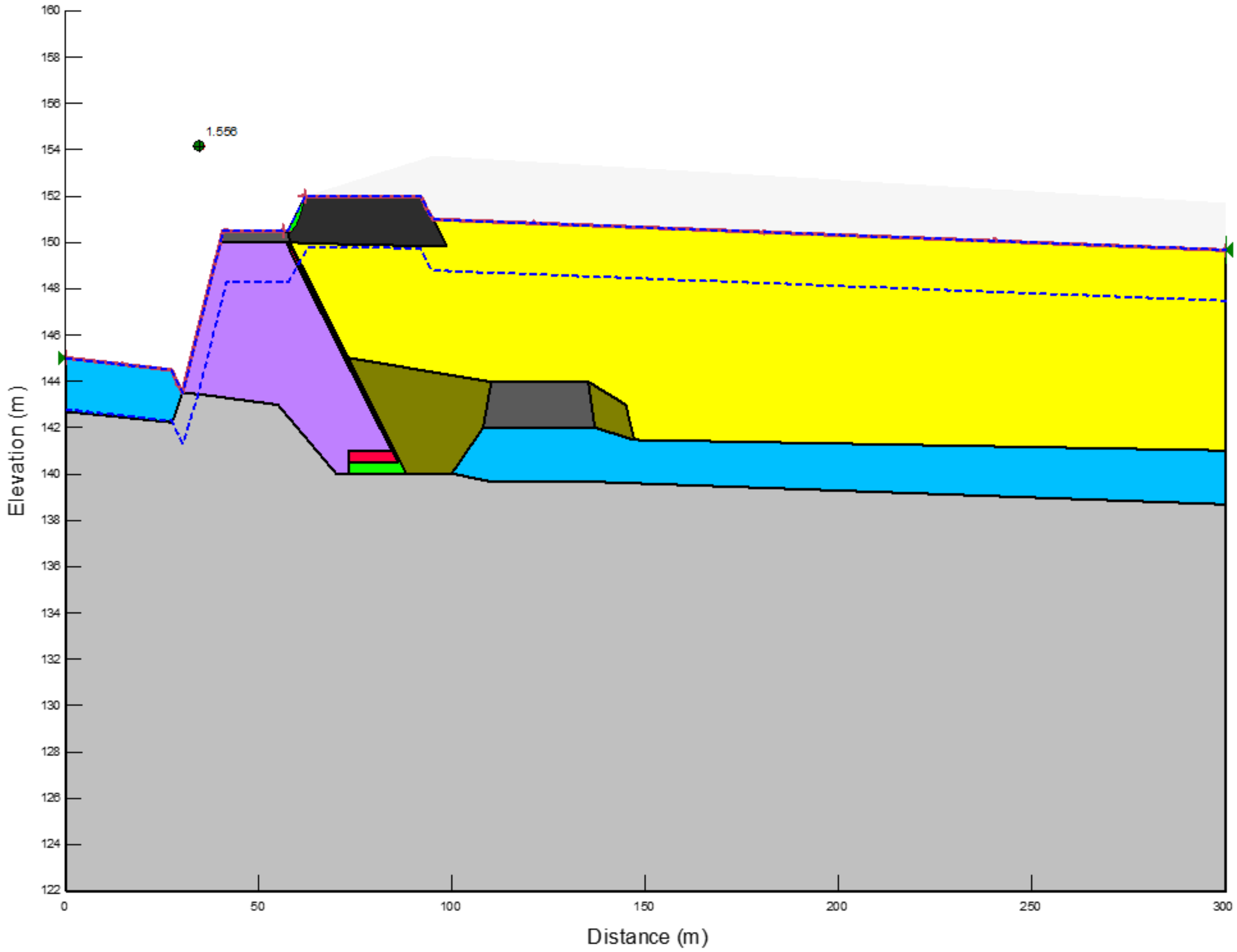

Figure 6: Cross-Section 1 – Operation

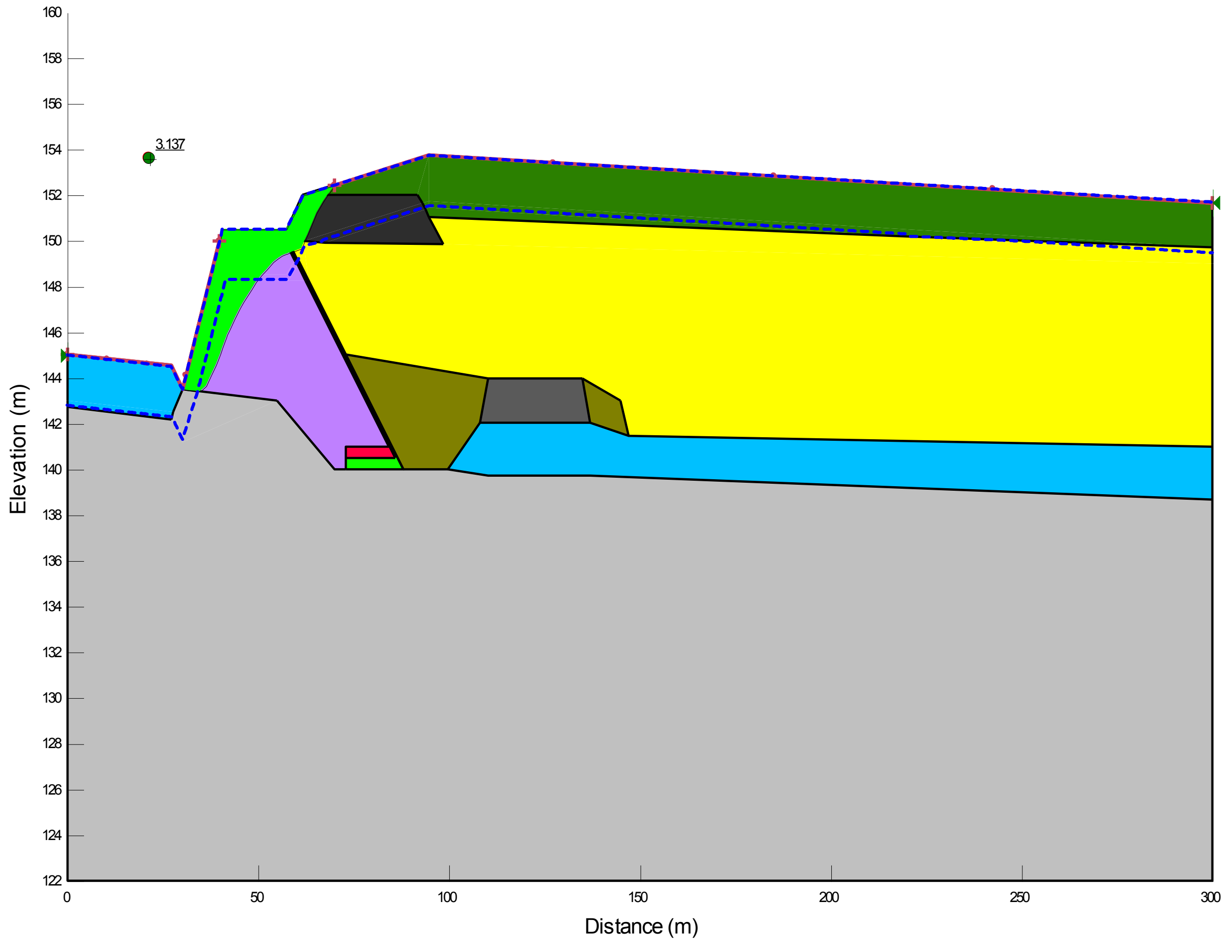

Figure 7: Cross-Section 1 - Closure

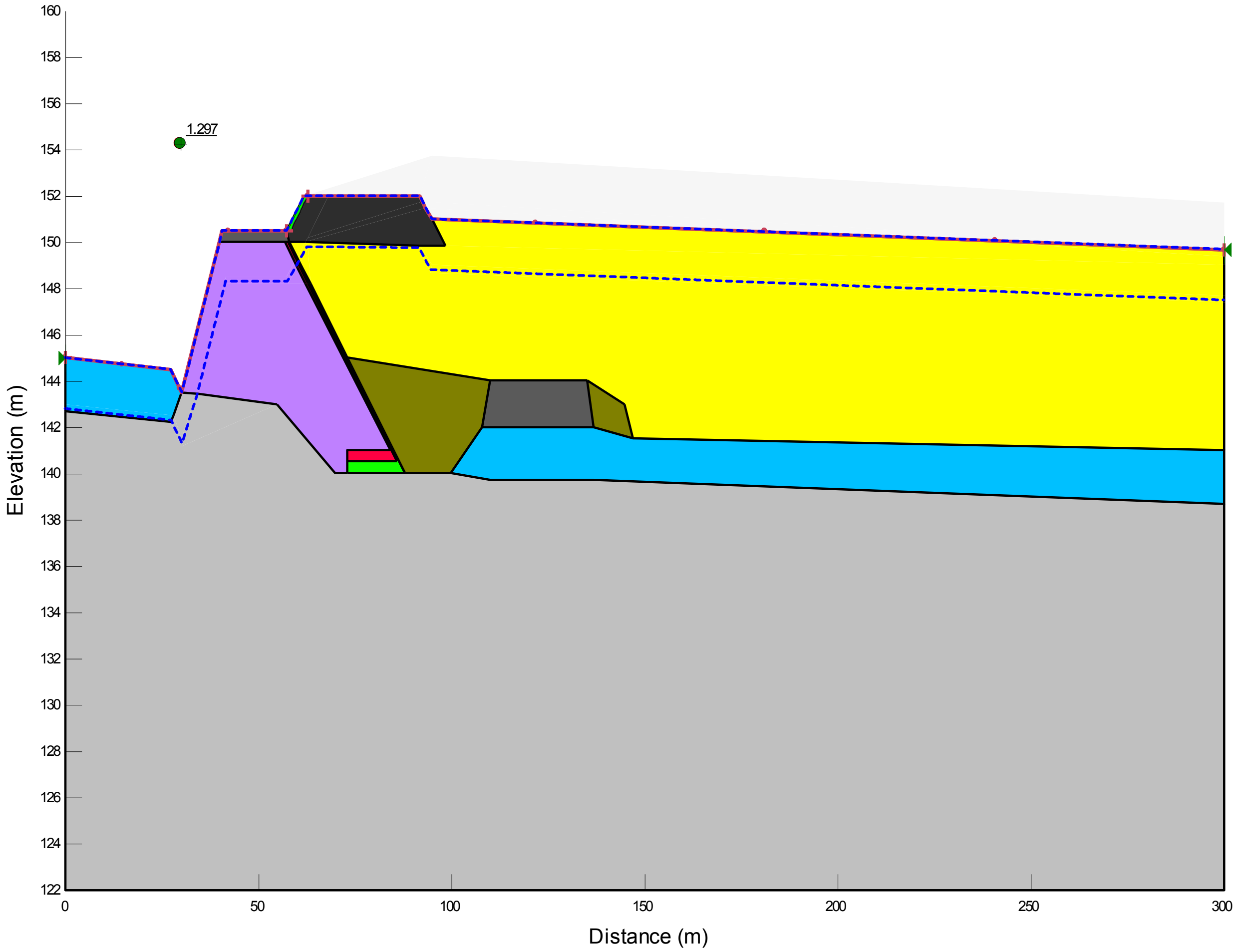

Figure 8: Section 1 – Seismic loading applied to "End of Construction" scenario

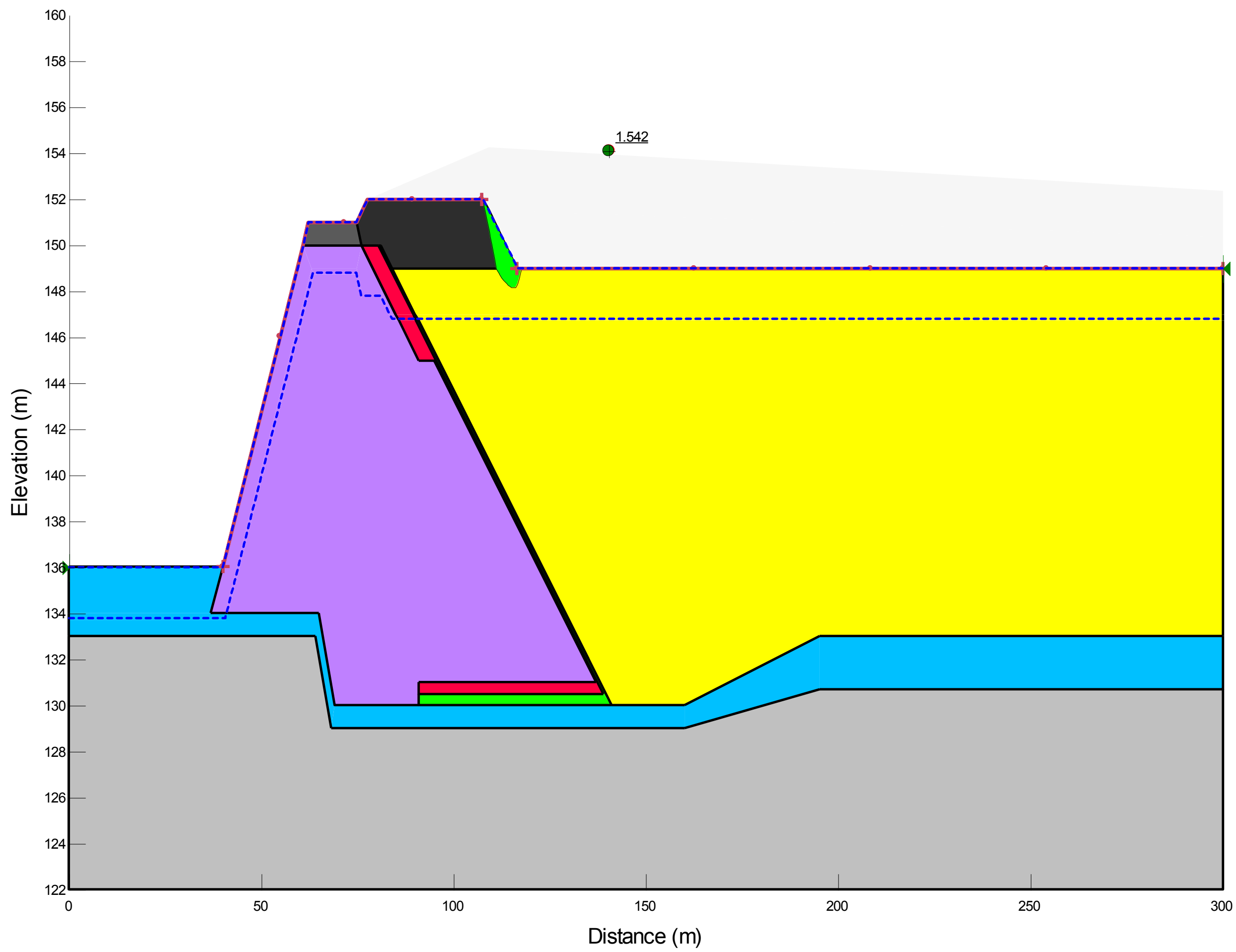

Figure 9: Cross-Section 2 – End of Construction

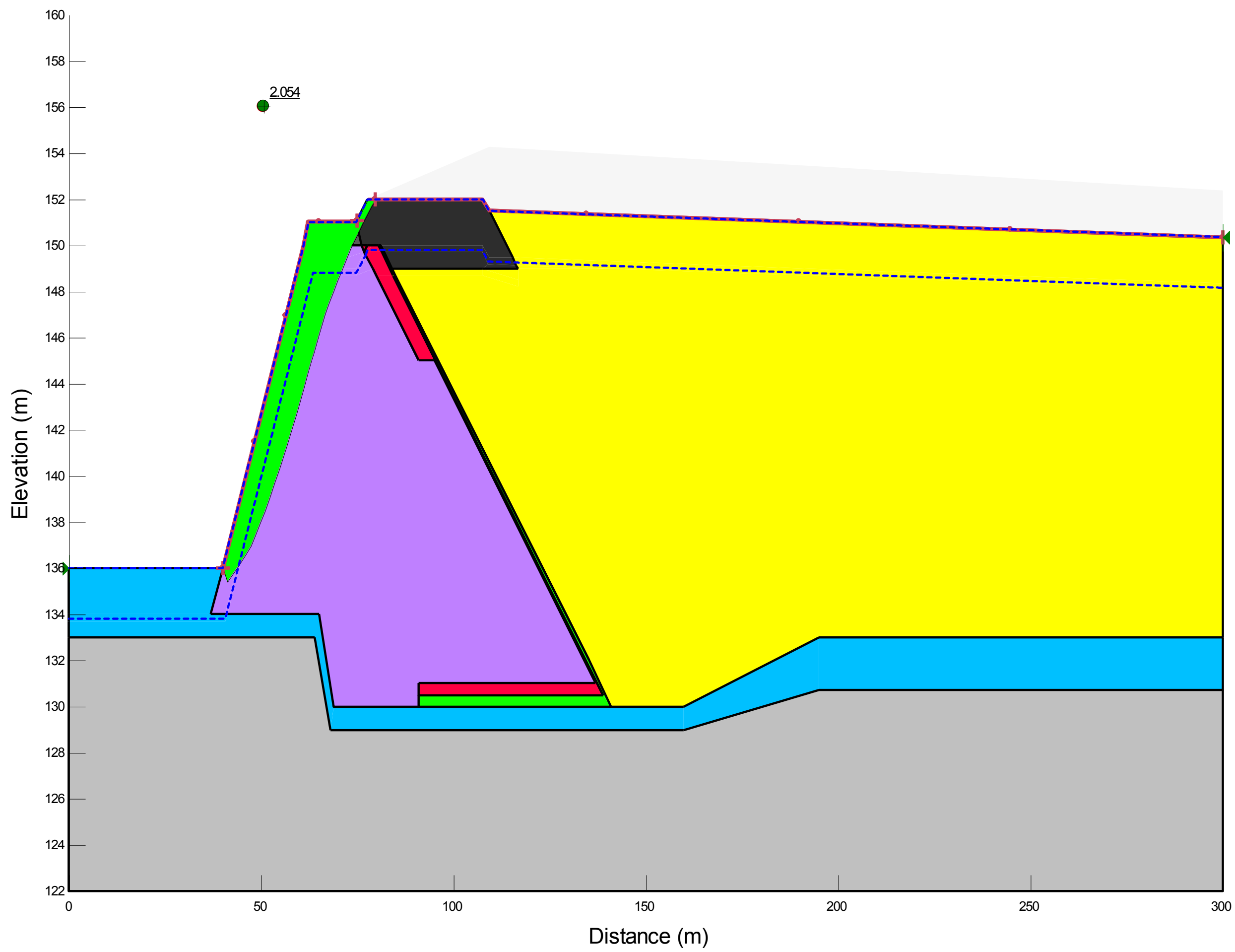

Figure 10: Cross-Section 2 – Operation

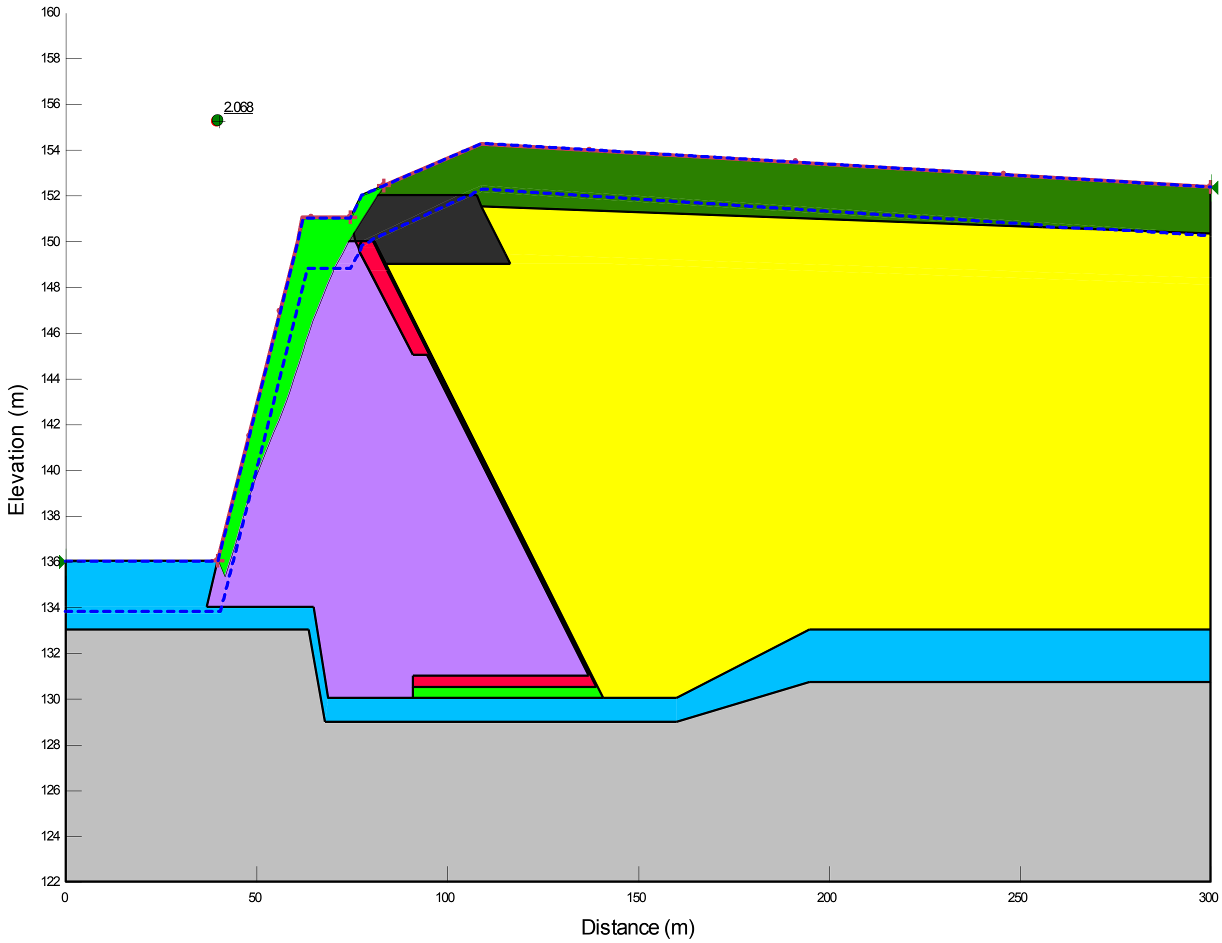

Figure 11: Cross-Section 2 – Closure

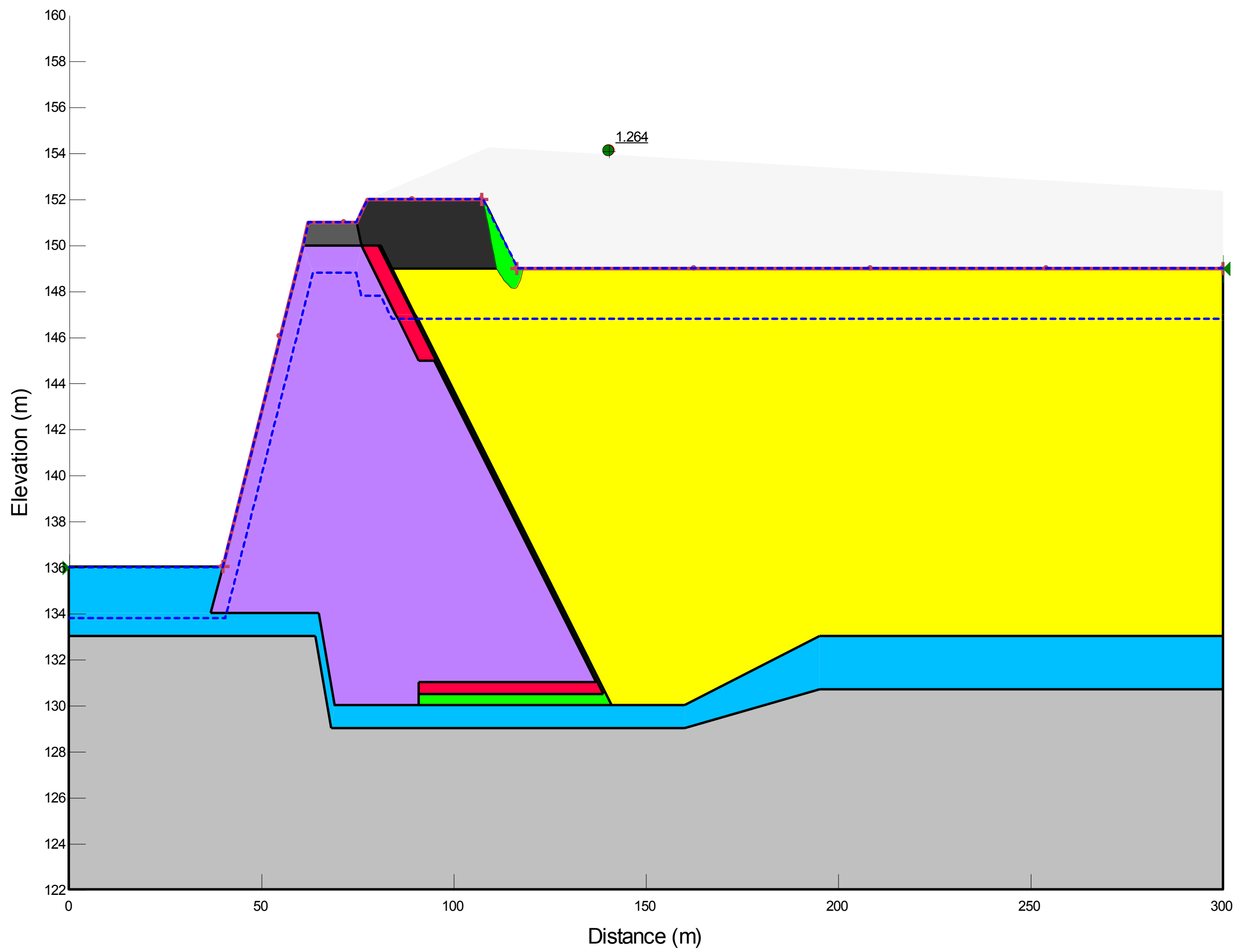

Figure 12: Cross-Section 2 – Seismic loading applied to “End of Construction” scenario

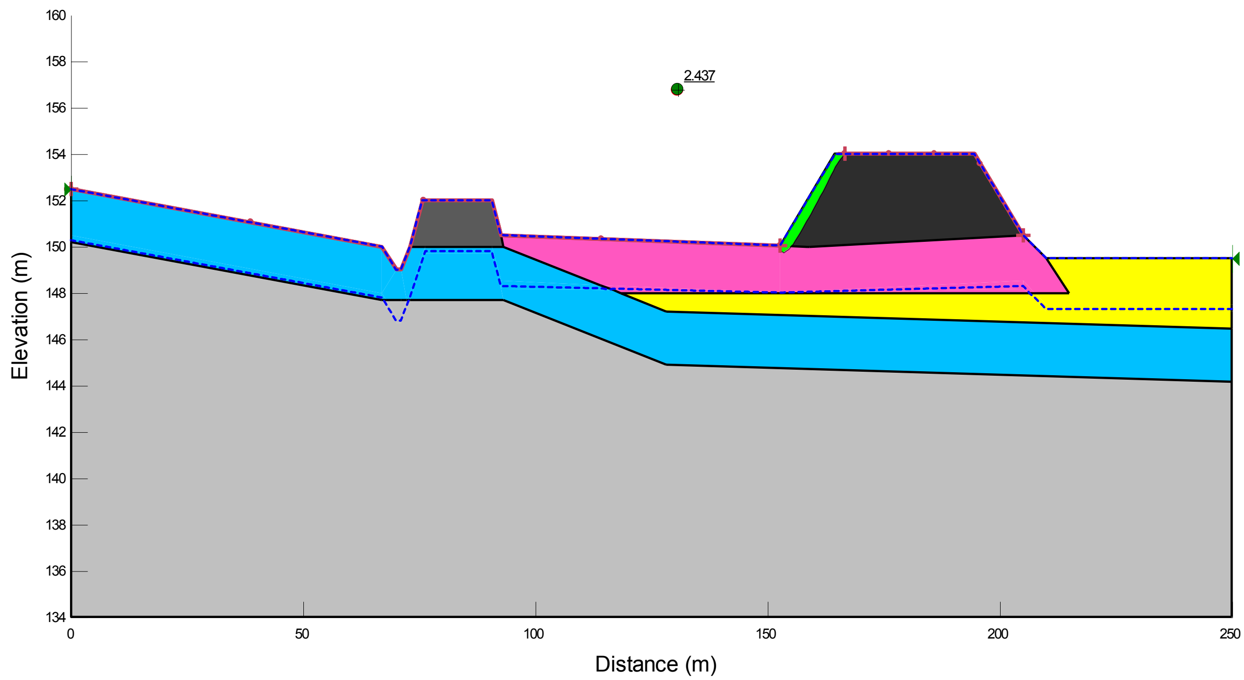

Figure 13: Cross-Section 3 – End of Construction

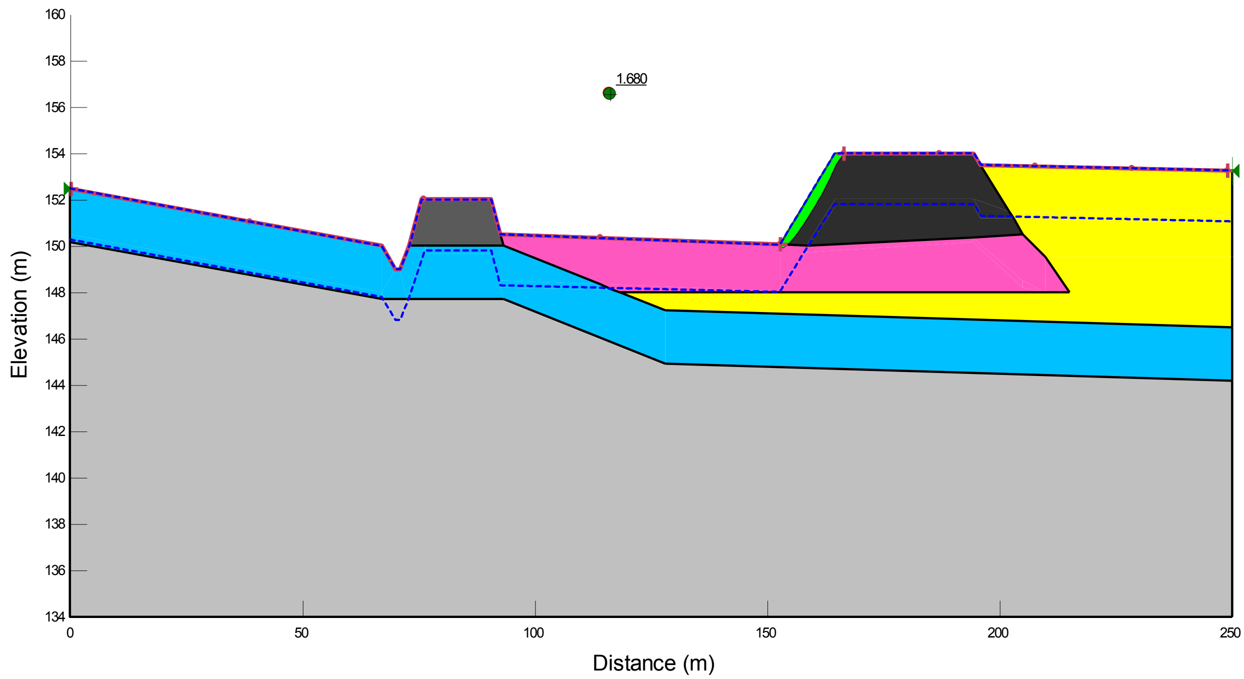

Figure 14: Cross-Section 3 - Operation

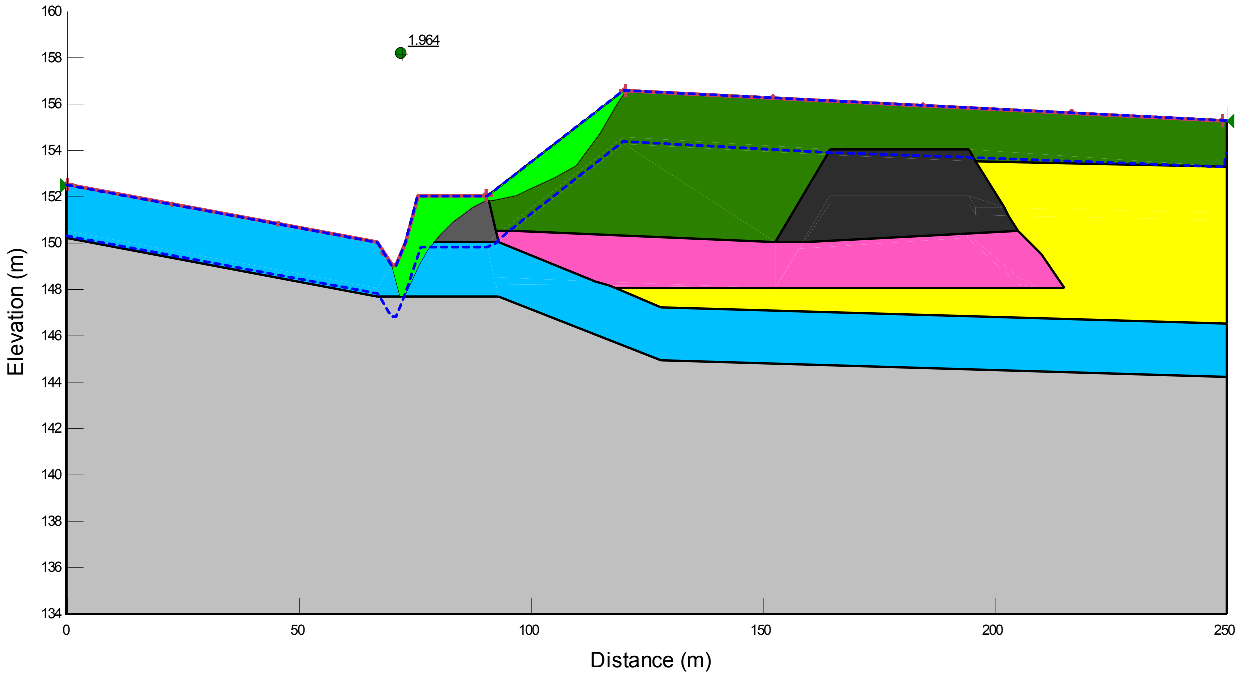

Figure 15: Cross-Section 3 – Closure

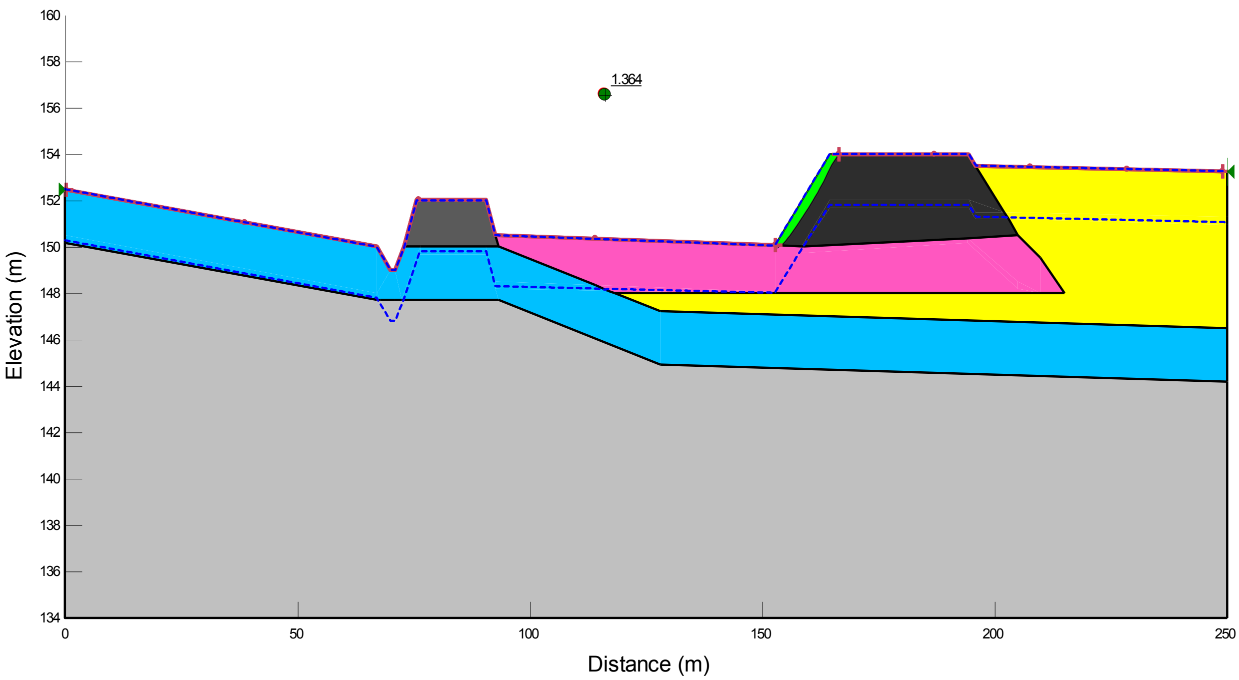

Figure 16: Cross-Section 3 – Seismic loading applied to “Operation” scenario

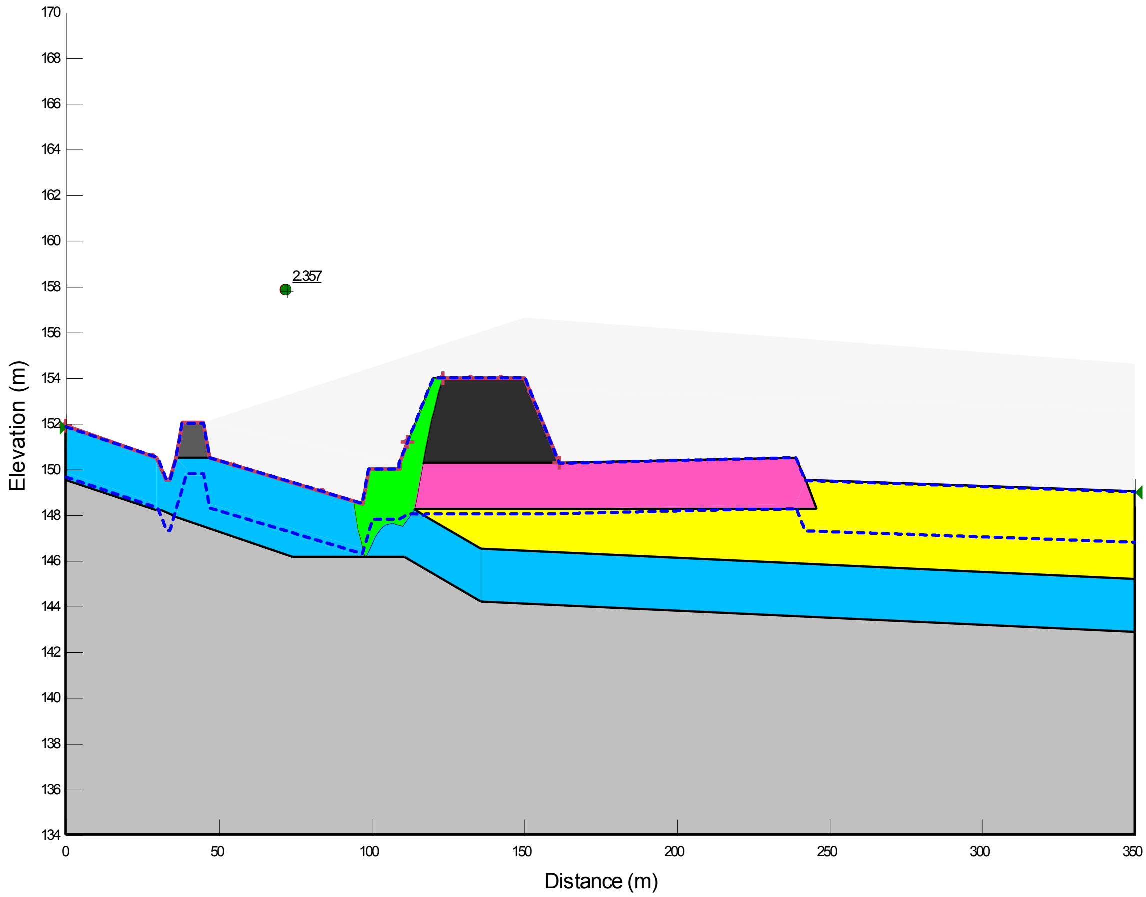

Figure 17: Cross-Section 4 – End of Construction

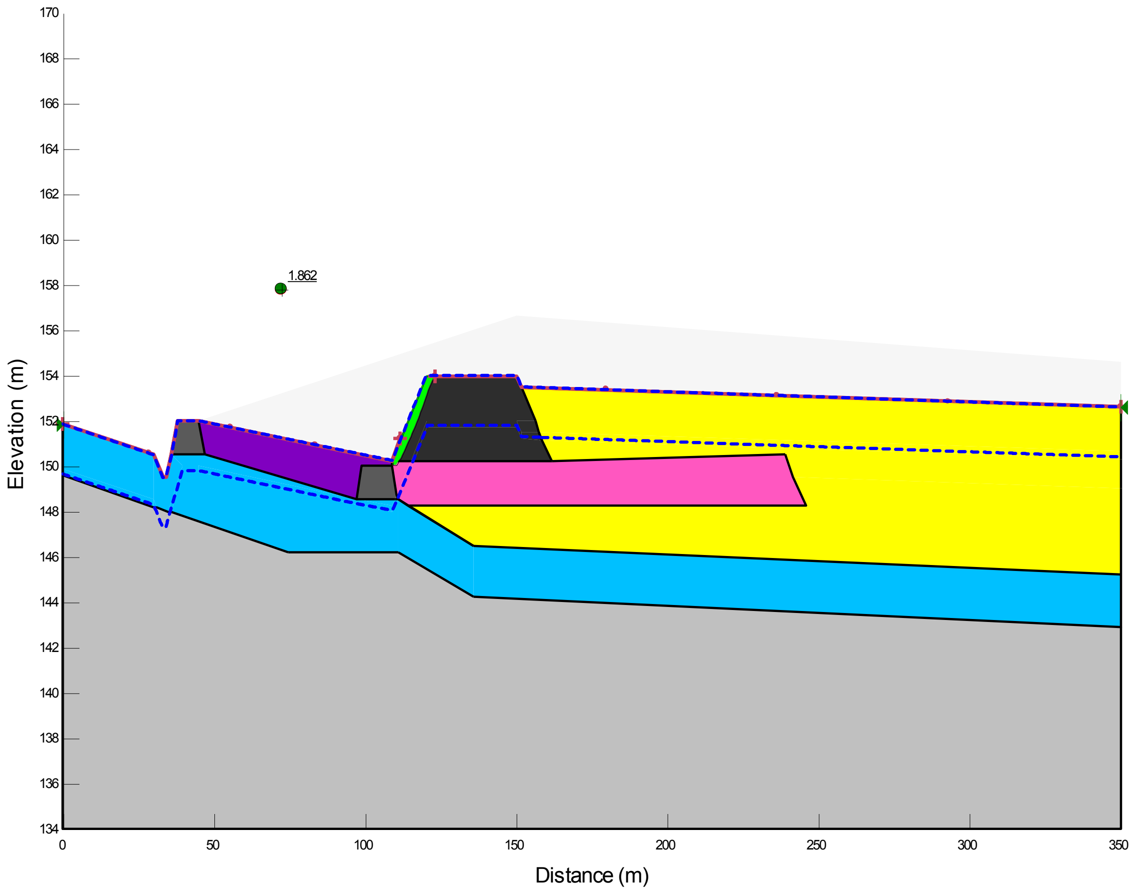

Figure 18: Cross-Section 4 – Operation

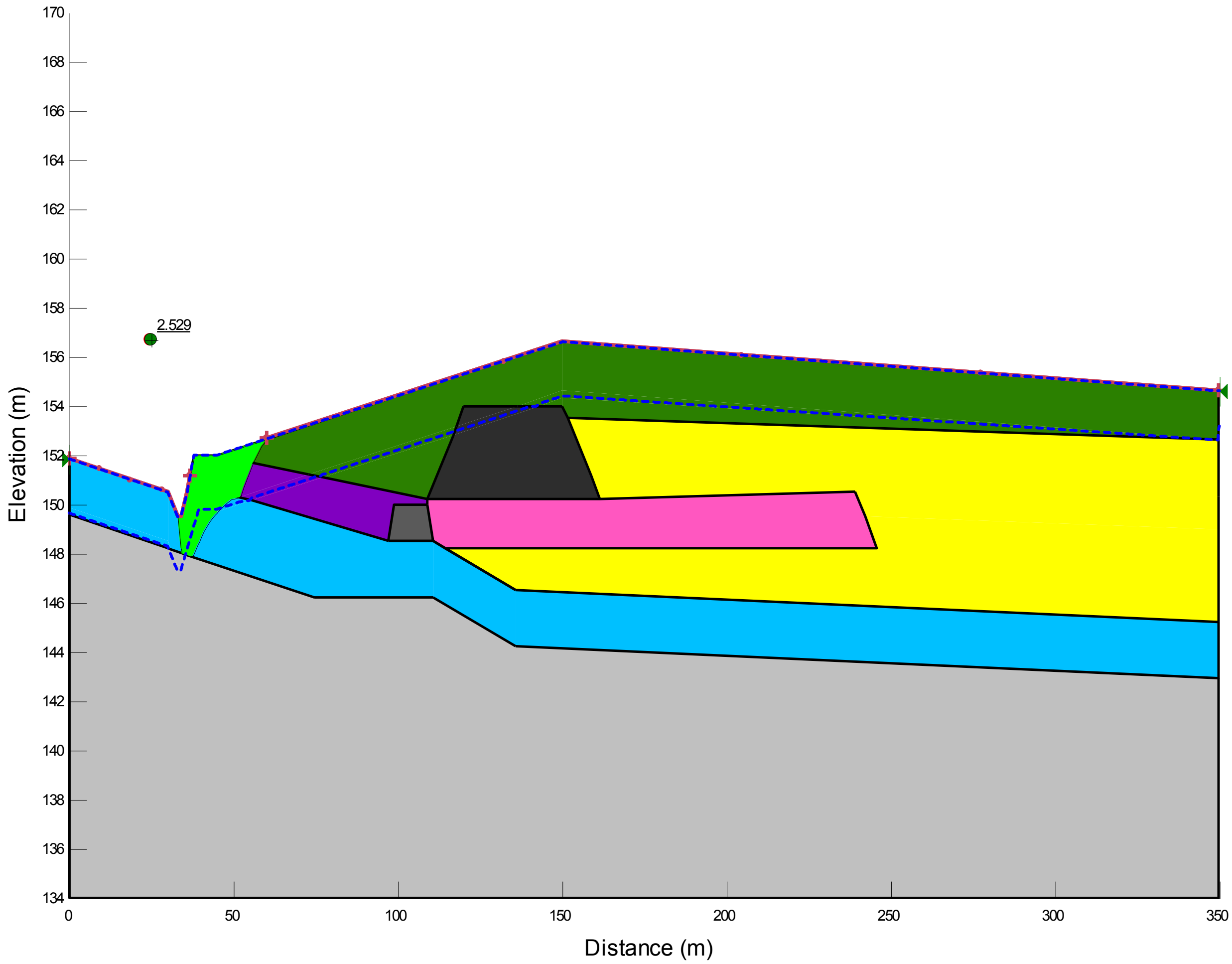

Figure 19: Cross-Section 4 – Closure

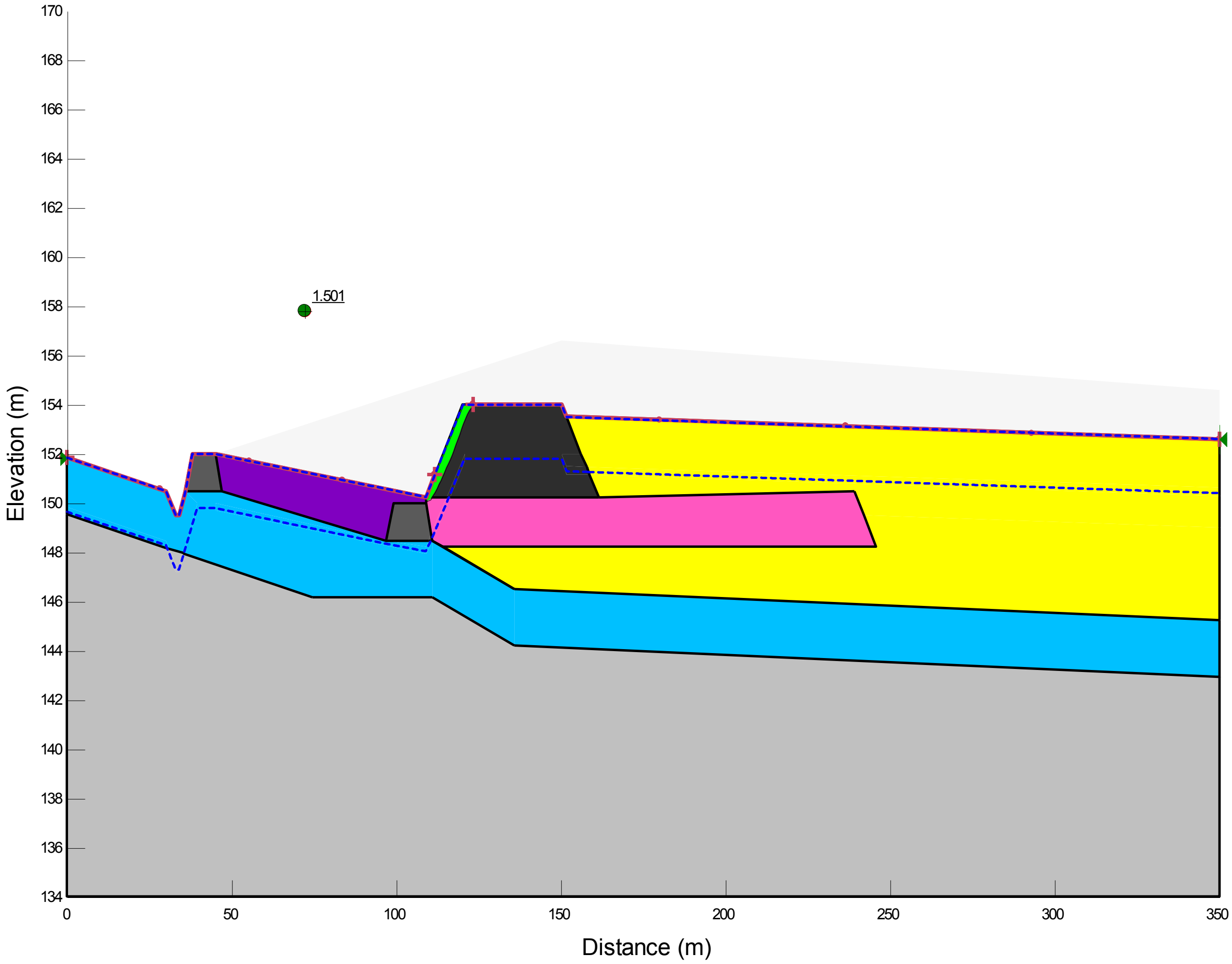

Figure 20: Cross-Section 4 – Seismic loading applied to “Operation” scenario

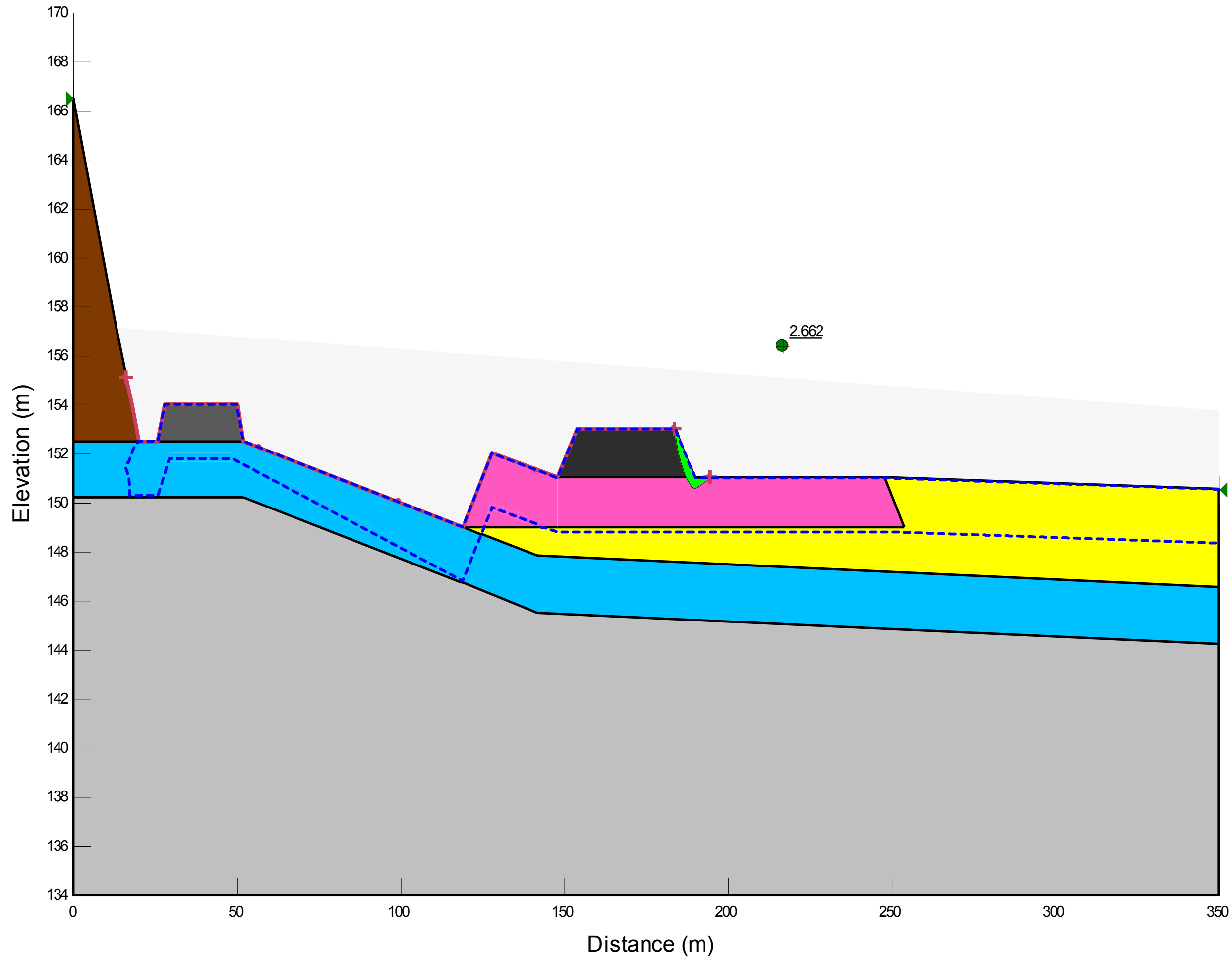

Figure 21: Cross-Section 5 – End of Construction

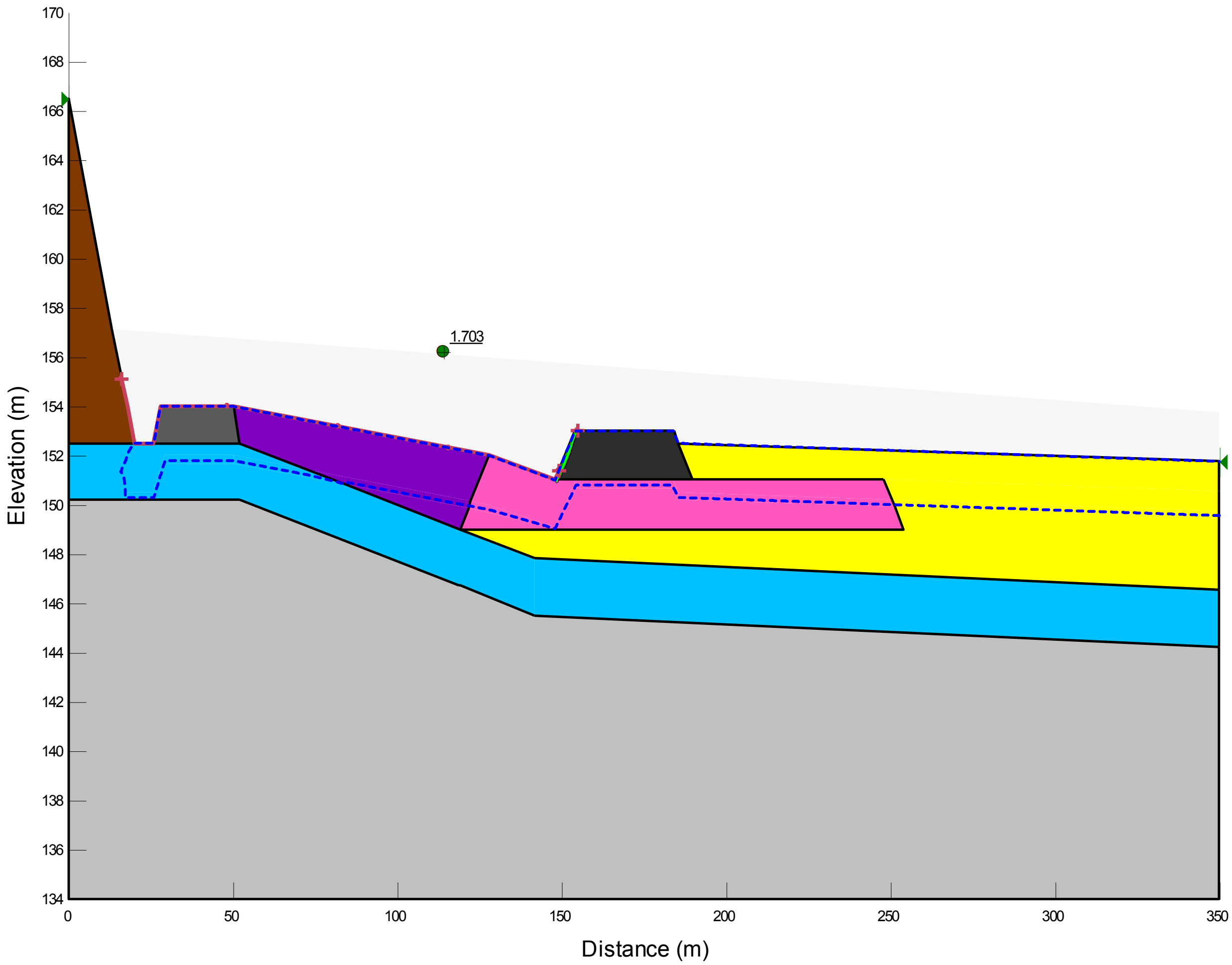

Figure 22: Cross-Section 5 – Operation

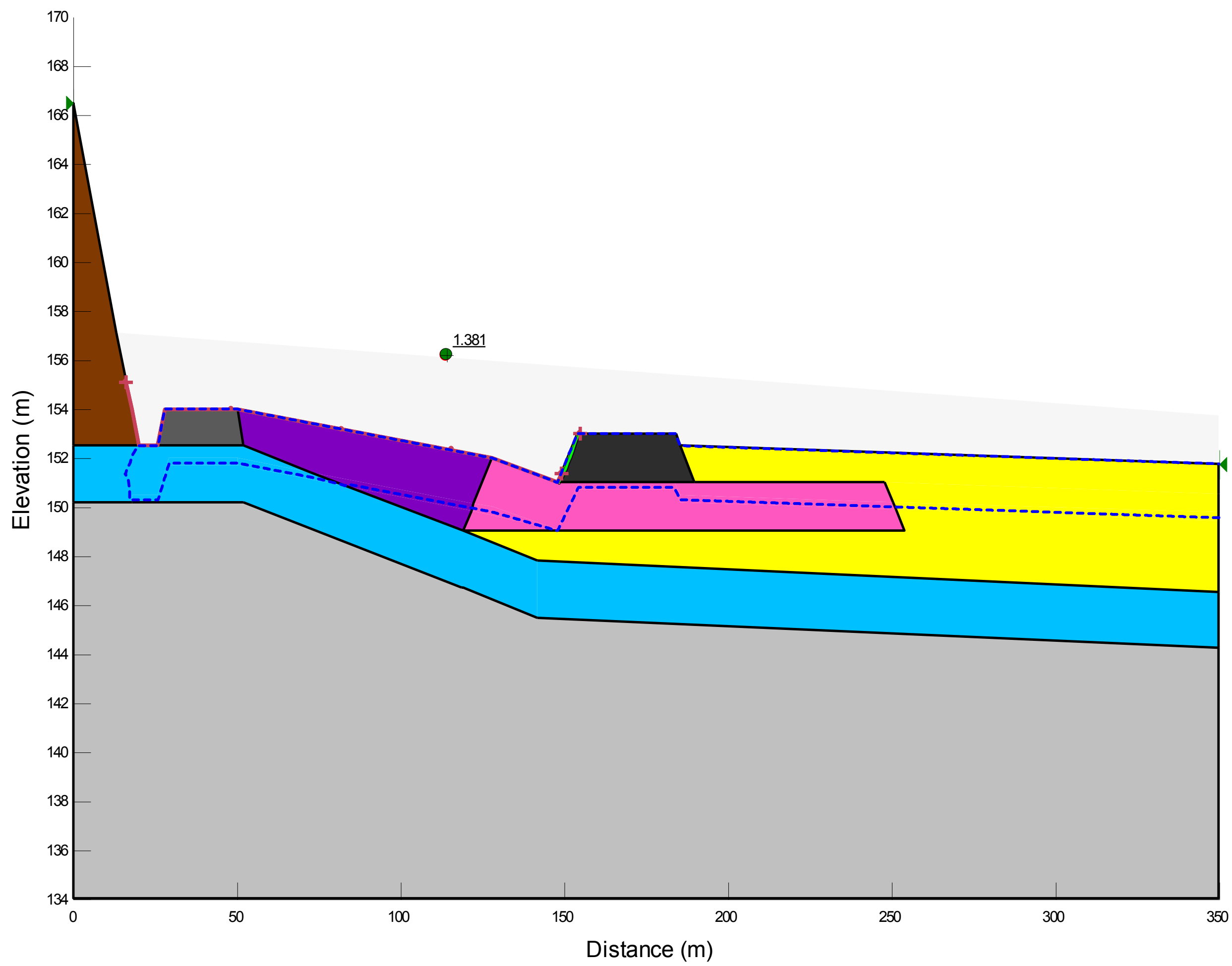

Figure 23: Cross-Section 5 – Seismic loading applied to “Operation” scenario

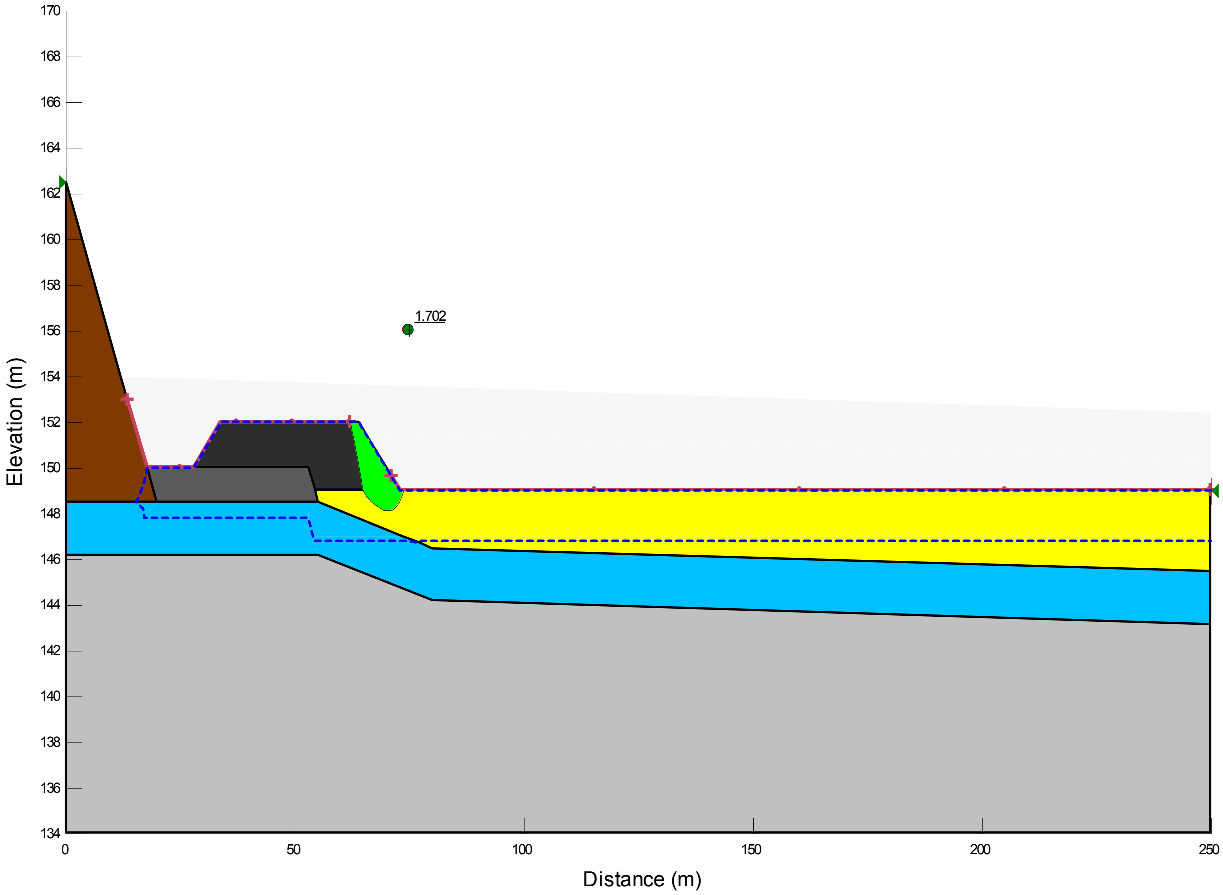

Figure 24: Cross-Section 6 – End of Construction

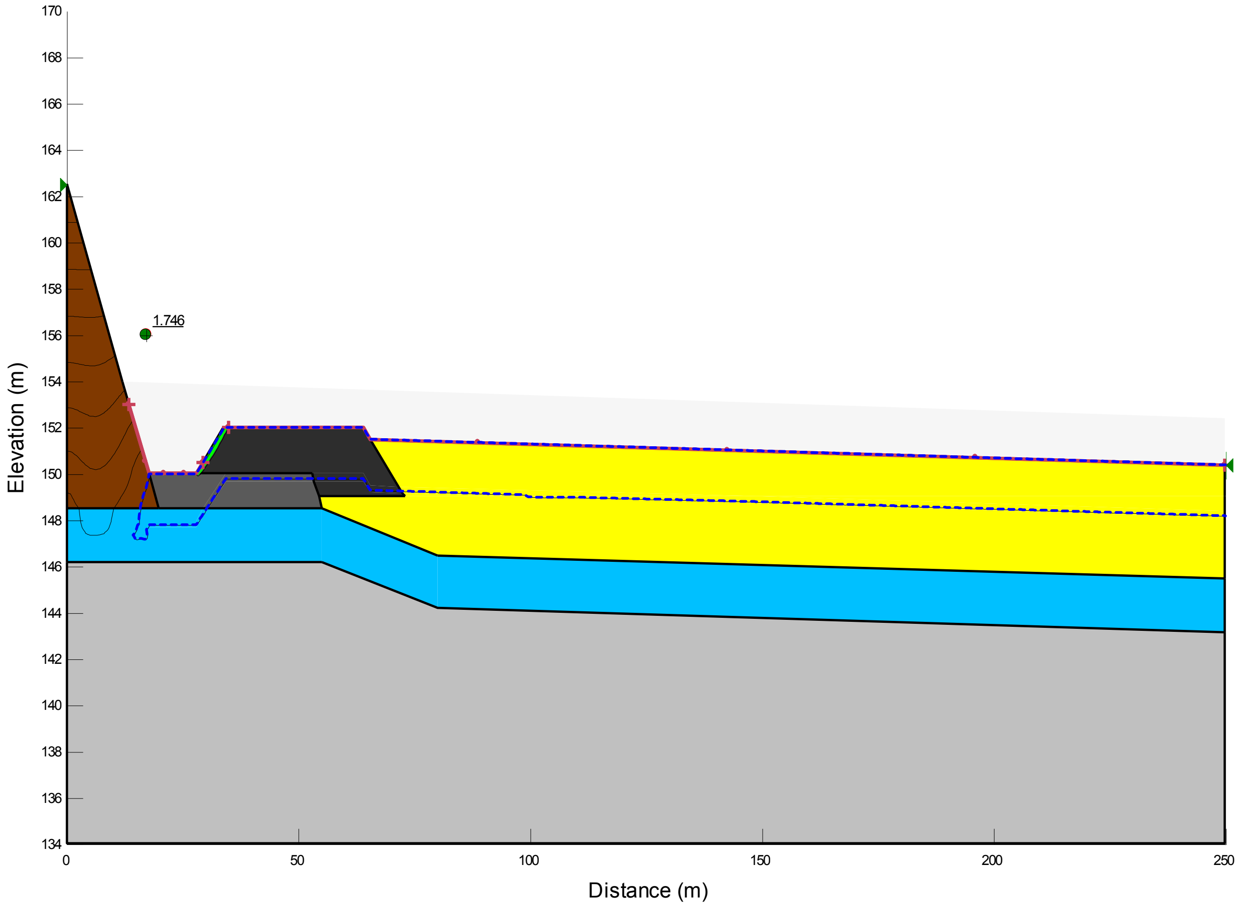

Figure 25: Cross-Section 6 – Operation

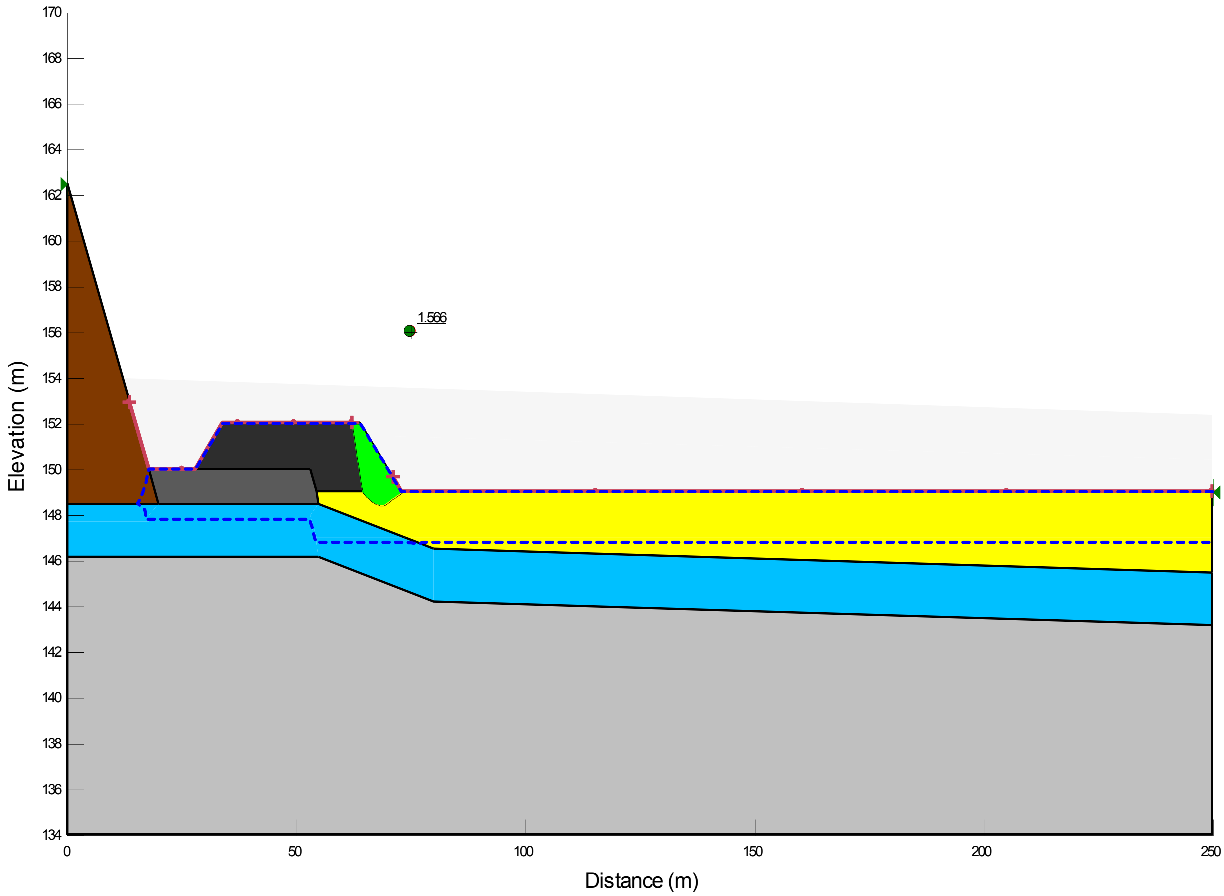

Figure 26: Cross-Section 6 – Seismic loading applied to “End of Construction” scenario

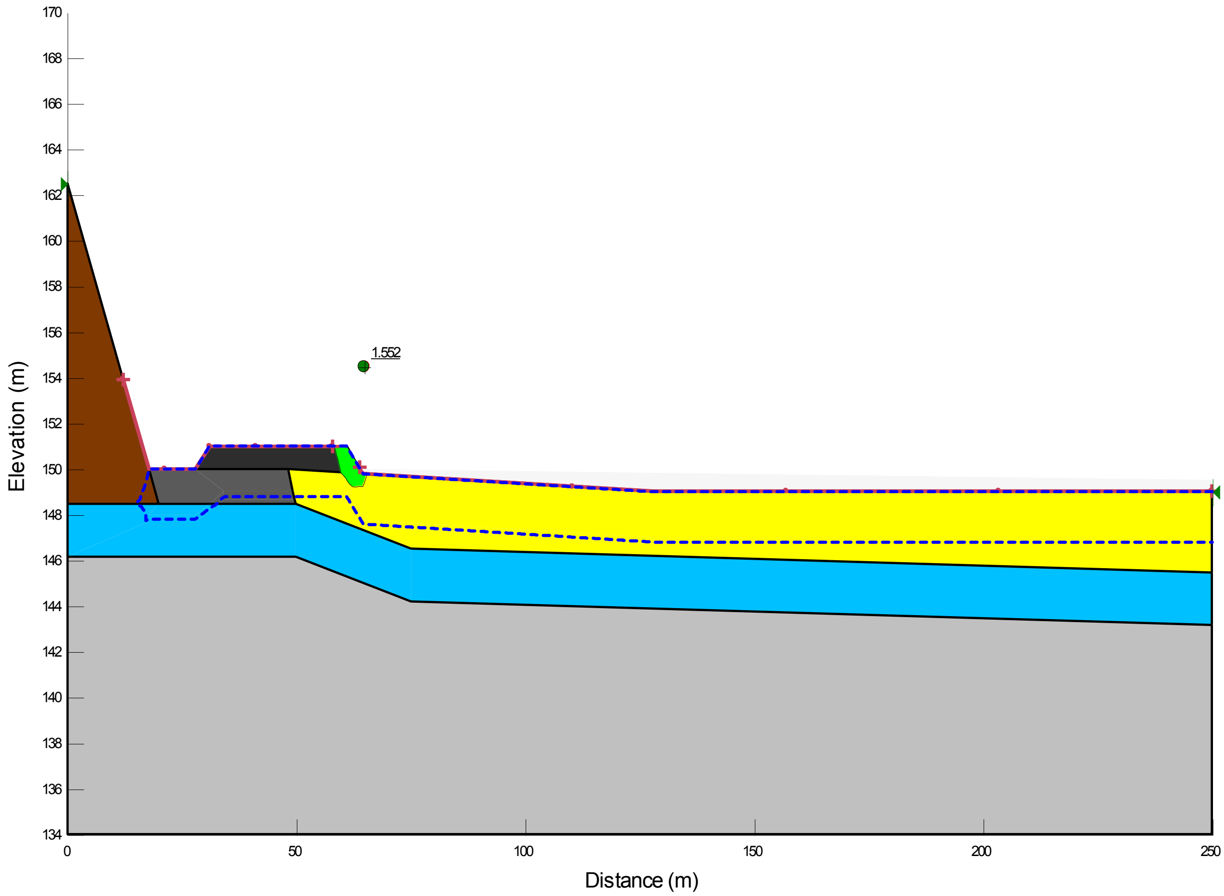

Figure 27: Cross-Section 7 – End of Construction

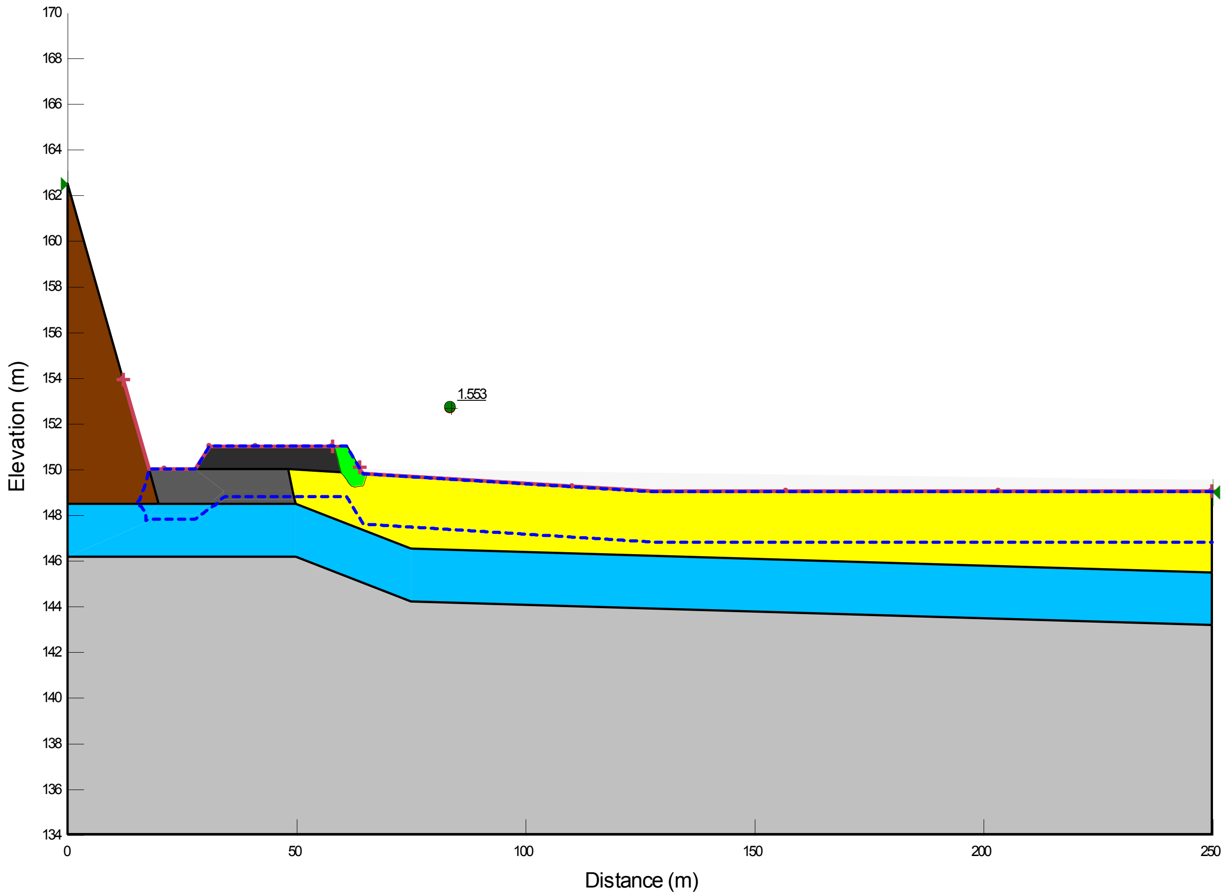

Figure 28: Cross-Section 7 – Operation

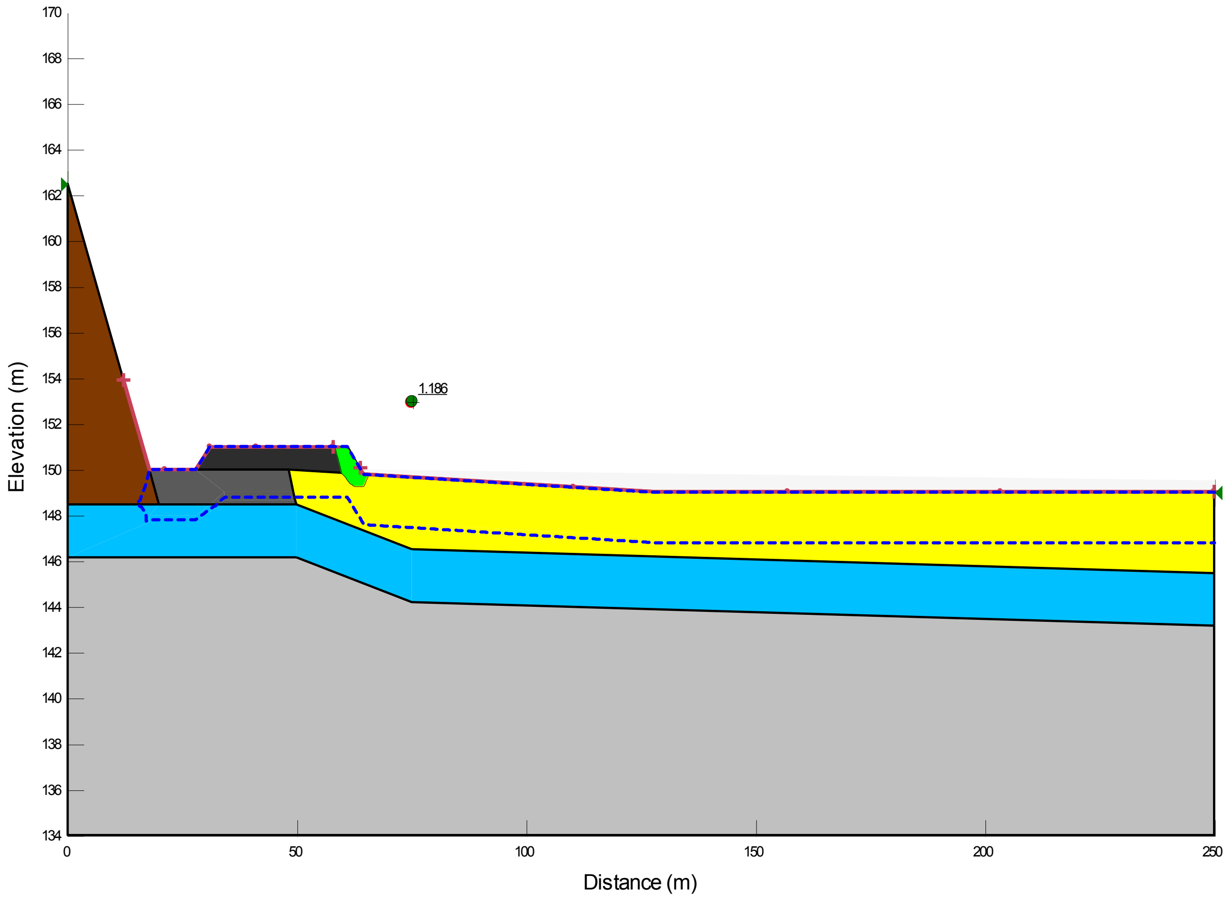

Figure 29: Cross-Section 7 – Seismic loading applied to “End of Construction” scenario

Appendix C

Seepage Modelling-Detailed Results

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

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T: (306) 955 0702 F: (306) 955 1596
www.okc-sk.com

Interoffice Memorandum

To:	Bonnie Dobchuk – Senior Geoenvironmental Engineer, O'Kane Consultants
From:	Robert Shurniak, Geotechnical Engineer
Cc:	Philippe Garneau – O'Kane Consultants
Our ref:	948/2
Date:	March 17, 2016
Re:	**Meadowbank North TSF Extension - Results for Seepage Analysis**

O'Kane Consultants Inc. (OKC) was retained by Agnico Eagle Mines Ltd. (AEM) for design work to support evaluation and optimization of the current Meadowbank Tailings Storage Facility (TSF). During the design process it was recommended that numerical analysis be completed to address the potential for seepage through the rockfill extension dike, which will form a perimeter for most of the North Cell TSF with the exception of above the Storm Water Dike (SWD). The main objective of this seepage modelling is to estimate seepage volumes through the rockfill dike, design appropriate seepage collection infrastructure as required, evaluate the need for a low permeability component on the internal slope of the rockfill extension dike, and evaluate if the width of the rockfill extension dike can be reduced. Up to this point, OKC had assumed that the permafrost would not degrade within the dike so that no seepage would flow through the rockfill extension dike. For the current exercise, seepage modelling will be completed assuming no permafrost formation within the rockfill as a "worst-case" scenario, defining the other "end-member" of the seepage range through the extension dike. As this modelling is completed, the results are provided to AEM for review to determine if information is sufficient to determine the requirement for seepage collection infrastructure or a HDPE liner; or if additional simulations of conditions between the two end-members are required.

Completing the simulations required definition of the following model inputs:

- geometry for each typical cross-section;
- material properties;
- surface boundary condition;
- lower boundary condition;
- external edge boundary condition; and,
- internal edge boundary condition.

Each of these inputs and the seepage results are described in the following sections.

Inputs

Geometry

Seven cross-sections of the rockfill extension dike were developed for the slope stability numerical analysis portion of this project (Figure 1). The locations of these cross-sections are shown in Figure 1. All seven cross-sections were simulated as part of the seepage analysis. The slope stability cross-sections were adapted for the seepage models in two ways:

1) The bedrock, till overburden and frozen tailings layers were not simulated as seepage into these regions is assumed to be negligible. Also, having no downward seepage aligns with the "worst-case" scenario by promoting seepage through the rockfill extension dike.
2) Additional internal regions were added so that the tailings placement could be staggered, simulating actual placement throughout the summer. This was achieved by estimating the lift thickness placed weekly during the three summer deposition periods.

All the cross-sections are provided in the appendix of this report.

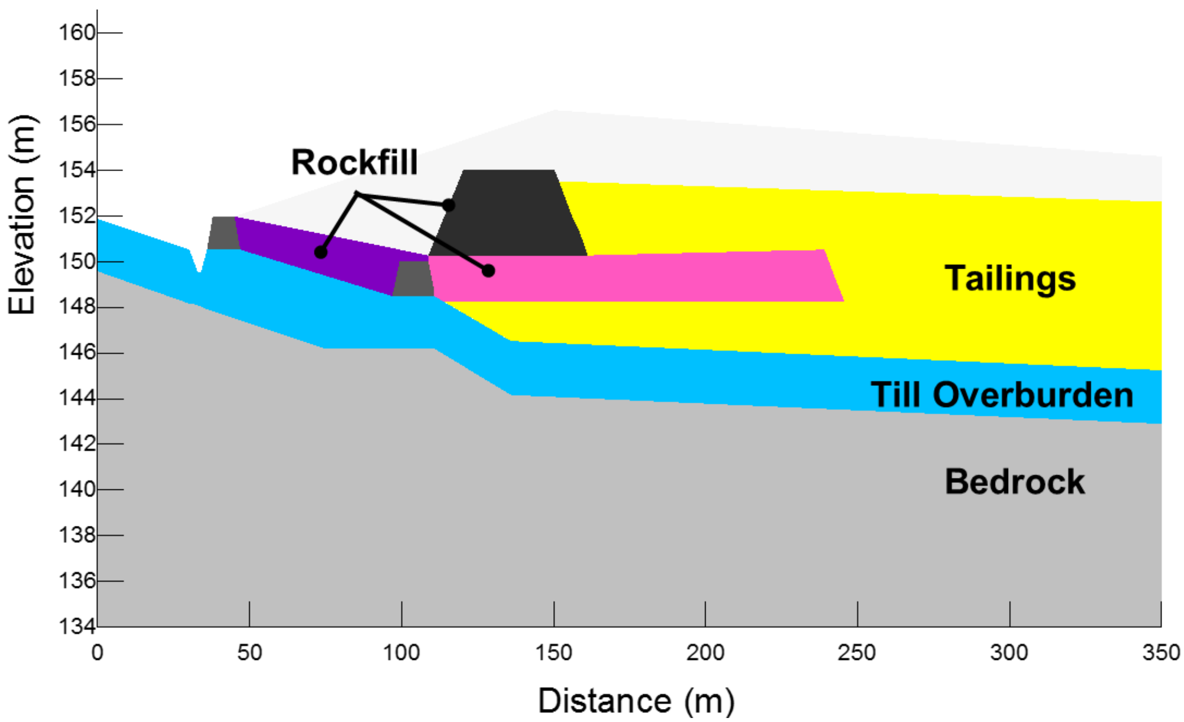

Figure 1: Typical cross section (Cross-Section 4) developed for slope stability analysis

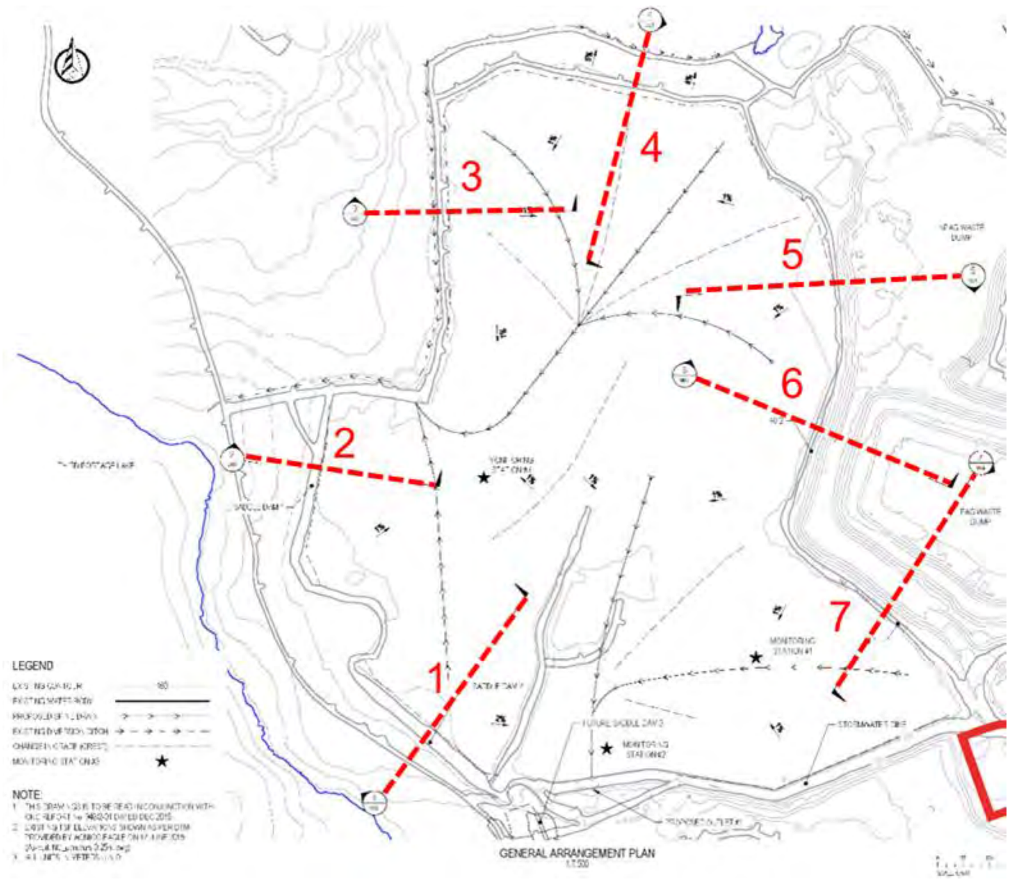

Figure 2: Plan view of Meadowbank TSF with slope stability and seepage analysis cross section locations.

Material Properties

Seepage modelling requires definition of a water retention curve (WRC) and hydraulic conductivity function (k-function) for each material simulated. For examining seepage through the rockfill extension dike, two materials need to be defined: tailings; and rockfill. It is assumed that the bedrock and till overburden layers are within the permafrost zone, and therefore essentially impermeable.

Figures 3 and 4 provide the WRCs and k-functions estimated to represent the two materials. These estimates were used for the cover system design modelling previously completed by OKC for AEM, and are based on previous work completed by Golder Associates Ltd. Particle size distribution (PSD) data is compared to material in the SoilVision database with similar PSDs and known material properties. The ‘rockfill’ estimates are based on previous estimates made for NPAG material for the cover system.

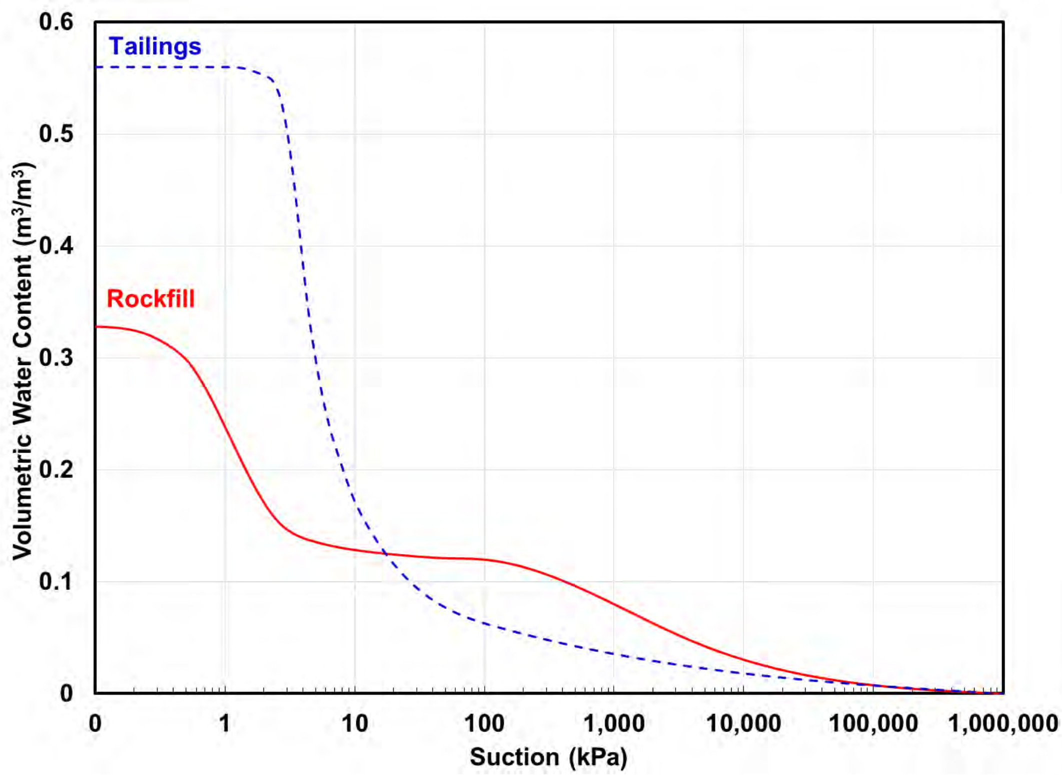

Figure 3: Water retention curves proposed to simulate Meadowbank materials.

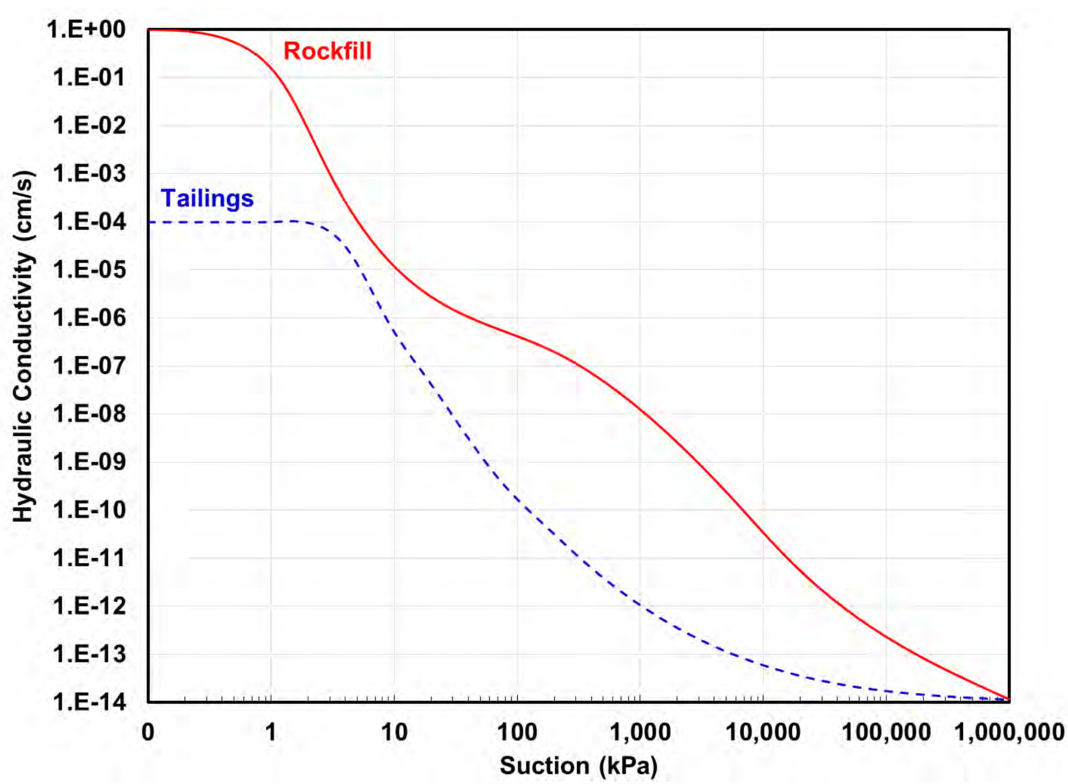

Figure 4: Hydraulic conductivity functions proposed to simulate Meadowbank materials.

Surface Boundary Condition

The surface boundary condition is mainly governed by climate; specifically, precipitation and evaporative energy. There is the potential for rainfall during tailings deposition to negate the benefits of evaporation. Hence, the worst-case from a seepage point of view is to not include a surface flux attributable to climate. This means water is only added in the model by the deposition of tailings and removed either by lateral seepage downslope towards the pond or through the rockfill extension dike.

Lower Boundary Condition

The lower boundary is assumed to be a no flow boundary due to the presence of permafrost. If seepage was allowed from the lower boundary it would reduce the potential for seepage through the rockfill extension dike. Therefore, the current concept does not necessitate simulating a permeable lower boundary.

The lower boundary is moved upward at the end of each season to maintain the estimated maximum 2 m active layer.

External Edge Boundary Condition

The external edge of the rockfill extension dike (i.e. the edge exposed to the atmosphere) is simulated as a potential seepage face to allow water to drain though the dike.

Internal Edge Boundary Condition

The internal edge of the simulated cross-section(s) (i.e. the edge within the TSF) was simulated as a potential seepage face placed far enough away from the extension dike so as to not influence seepage through the dike.

Results

Transient Simulations

The results of the transient seepage analysis are summarized in Table 1. Cross-sections 1 and 7 resulted in negligible seepage; hence, no results are provided. Note that the "affected dike length" is estimated based on OKC's assumption that the rockfill dike will be built at the outer edge of the 2015 cover system placement. However, the annual tailings thickness were estimated assuming the extension dike is along the interior edge of the 2015 cover system as provided by AEM. This adds additional conservatism to the results as the dike length will either be shorter (if placed on the interior edge) or the tailings thickness will be reduced (if the dike is placed on the exterior edge of the 2015 cover system).

Table 1: Summary of transient seepage results for each deposition season

Summer	Cross-Section	Maximum Seepage Velocity (m/s)	Maximum Seepage Rate (m^3/day/m)	Seepage per Length of Dike (m^3/m)	Affected Dike Length (m)	Maximum Daily Seepage Volume (m^3/day)	Total Season Seepage Volume (m^3)
2019	3	9.3E-07	0.03	1.7	724	22	1,227
	4	8.8E-06	0.5	12.3	681	341	8,358
	Total					*363*	*9,585*
2020	3	1.0E-05	0.07	2.5	724	51	1,779
	4	2.2E-05	0.15	3.3	681	102	2,266
	5	1.0E-06	0.01	0.6	559	6	312
	Total					*159*	*4,357*
2021	2	2.2E-06	0.03	2.4	851	26	2,070
	3	1.6E-05	0.03	2.5	724	22	1,811
	4	3.5E-05	0.24	6.4	681	163	4,339
	5	2.0E-06	0.09	6.8	559	50	3,776
	6	9.3E-07	0.01	0.1	480	5	39
	Total					*266*	*12,035*
2022 (no cover system in place)	2	3.8E-06	0.12	2	851	102	1,702
	3	2.3E-05	0.16	2.6	724	116	1,882
	4	2.6E-06	0.23	4	681	157	2,724
	5	1.1E-05	0.12	1.3	559	67	727
	6	5.8E-06	0.10	0.7	480	48	336
	Total					*490*	*7,371*

Transient simulations were completed with the dike width at its crest at 30 m as well as with the width reduced to 15 m. Both scenarios resulted in similar results; hence, overall dike width does not influence anticipated seepage rates. 15 m was determined as the minimum width to accommodate 2-way traffic with 50-ton haul trucks.

Simulation of cross-section 4 was completed with a filter layer along the interior slope of the extension dike. This model showed that the presence of a filter layer does not influence seepage rates unless the k_{sat} of the filter layer is lower than the k_{sat} of the tailings.

Steady-State Simulations

A steady-state simulation was completed for the end of each deposition season for each cross-section using anticipated maximum seepage during that season to determine: the absolute maximum seepage rate and velocity; and, the maximum distance from the dike that tailings could still contribute to the seepage rate. The results are provided in Table 2. These values are highly conservative as the entire tailings mass, and the flow path through the extension dike, are assumed to be fully saturated and to remain so throughout the simulation. In reality, there would likely be some storage capacity available within the tailings and/or dike thus reducing the seepage rate. If the system was fully saturated as simulated, this condition would quickly dissipate.

Table 2: Summary of steady-state seepage results for the end each deposition season

Summer	Cross-Section	Maximum Seepage Velocity (m/s)	Maximum Seepage Rate (m^3/day/m)	Affected Dike Length (m)	Maximum Daily Seepage Volume (m3/day)	Maximum Contributing Distance from Dike (m)
2019	3	1.3E-03	51	724	36,924	47
	4	1.8E-03	66	681	44,946	95
2019 (rockfill below tailings not included)	3	1.3E-03	9	724	6,516	3
	4	2.6E-03	18	681	12,258	3
2020	3	3.3E-03	45	724	32,580	8
	4	3.3E-03	50	681	34,050	8
	5	1.5E-03	22	559	12,298	74
2021	2	1.7E-03	73	851	62,123	8
	3	3.4E-03	76	724	55,024	25
	4	3.3E-03	109	681	74,229	10
	5	2.0E-03	49	559	27,391	80
	6	2.0E-03	16	480	7,680	50

Figures for all the cross-sections for each season are provided in the appendix. Cross-section 4 (Figures 15 to 18) is anticipated to have the highest seepage volume. The steady-state models show that the 2015 cover system rockfill layer under the tailings and dike provides a conduit for flow during the 2019 season, which allows for tailings water much further away from the dike to influence seepage rates through the dike. Seepage rates and contributing distances are substantially reduced when the rockfill layer is not included in the simulation (Figure 16). In order to reduce seepage rates under the rockfill dike, a winter season should pass between construction of the dike and tailings deposition in that area. This is to ensure permafrost formation under and within the dike and to reduce the active layer to the dike itself during the deposition season, thus reducing the “conduit” effect in the rockfill material under the dike.

Consolidation Analysis

The tailings consolidation analysis aims at determining the consolidation process at the north cell of the TSF that may occur beneath the rockfill dyke. Settlement rates of fine tailings have to be distinguished between primary and secondary (long-term) consolidation portions. Essential criteria for both stabilization of tailings due to covering and ensuring long-term stability due to decommissioning are:

1) Absolute magnitude of settlement;
2) Time dependent consolidation rates; and
3) Magnitude of secondary settlement to ensure long-term stability of the rockfill dykes.

Objectives and Scope

A one-dimensional (1-D) consolidation analysis was conducted to assess the potential for overall tailings settlement due to the additional loading from the placement of the rockfill dyke. The specific purpose of this analysis was to estimate long-term settlement of the tailings mass, and evaluate whether the predicted long-term settlement could affect the overall integrity of the rockfill dykes.

An analytical approach was selected for the 1-D tailings consolidation analysis. Material properties (e.g. unit weight) of the tailings and dyke construction materials (NPAG waste rock) were estimated based on material characterization 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 2 m was used in the analysis, which represents the tailings thickness at the location where the rockfill dyke will be placed, or in the case of thicker tailings zone, the maximum potential depth the tailings may thaw.

Tailings consolidation for the purposes of this report is referred to as tailings volume change (settlement). External loading from rockfill dyke placement is a key factor leading to tailings consolidation settlement.

Methods of Analysis

Figure 5 illustrates the loading conditions. The scenario simulates tailings consolidation when a 4 m rockfill dyke is placed on top of the tailings mass.

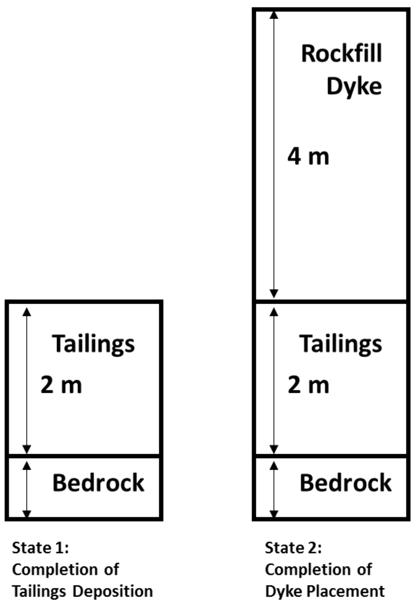

Figure 5: Tailings consolidation analysis scenario

Consolidation analyses are based on changes of effective stress in the tailings. Equation 1 and 3 were 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 dyke placement (Zardari 2010). The equation below was used to determine the primary consolidation of the tailings mass following placement of a 4 m rockfill dyke overlying the tailings mass (Table 3 and 4 summarize the inputs).

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

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).

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

Table 3: Key inputs for the tailings consolidation analysis

Property	Rockfill Dyke	Tailings
Dry Density (t/m^3)	2.15	1.31
Specific Gravity	3.2	3
Unit Weight (kN/m^3)	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	2

Table4: Key parameters for the tailings consolidation analysis

Parameter	Value
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 0.19 m is achieved following construction of a 4 m rockfill dyke. Figure 6 presents the relationship between the change in primary consolidation and cover thickness.

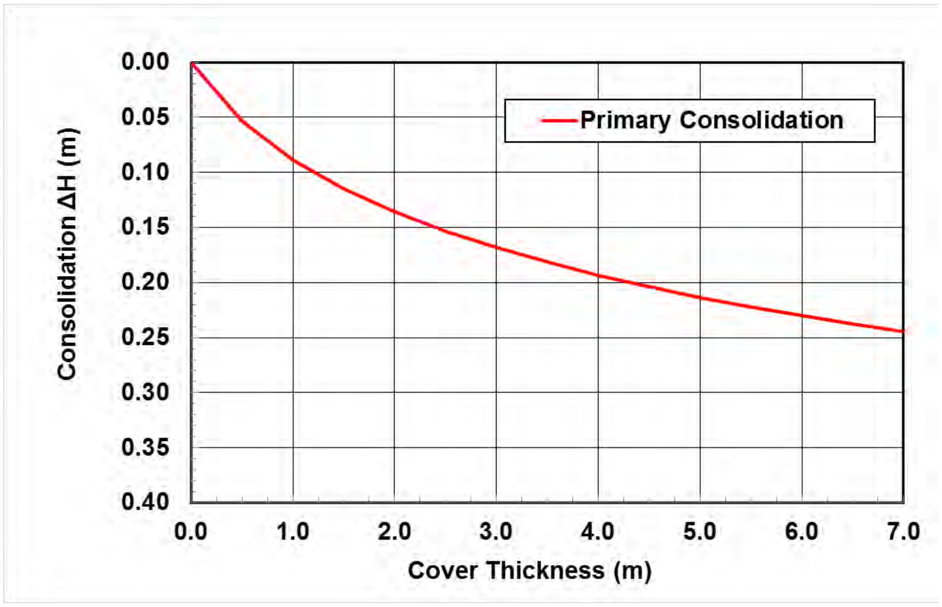

Figure 6: Primary consolidation vs. cover thickness

The results indicate that a 2 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 0.5 cm was calculated over a period of 100 years following completion of primary consolidation. Figure 7 presents the time-dependent long-term consolidation which occurred over a long period of time in response to the placement of the cover system.

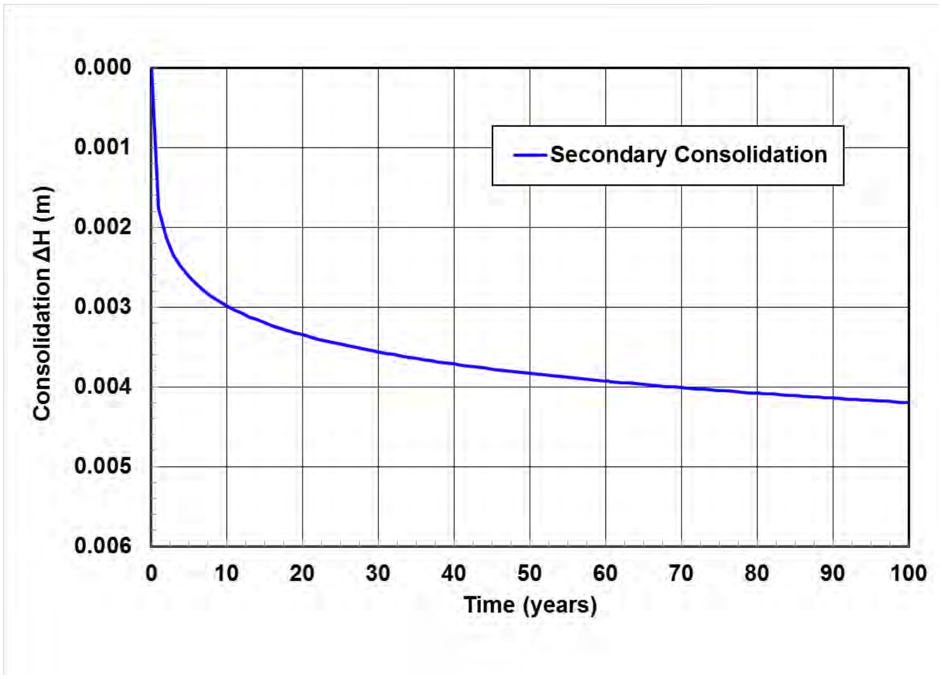

Figure 7: Tailings secondary consolidation model (settlement rate prediction for 100 years)

Key Findings

Key findings from the tailings consolidation analysis are as follows:

1) In general, the tailings ultimate settlement for the Northern Cell TSF tailings beneath the rockfill dykes is approximately 0.2 m.
2) It is considered highly unlikely that the tailings underlying the rockfill dyke will thaw, and if some thaw occurs it will be substantially less than 2 m into the underlying tailings.

Closure

We trust information provided in this memorandum is satisfactory for your requirements. Please do not hesitate to contact me at (250) 585-7328 or rshurniak@okc-sk.com should you have any questions or comments.

Appendix

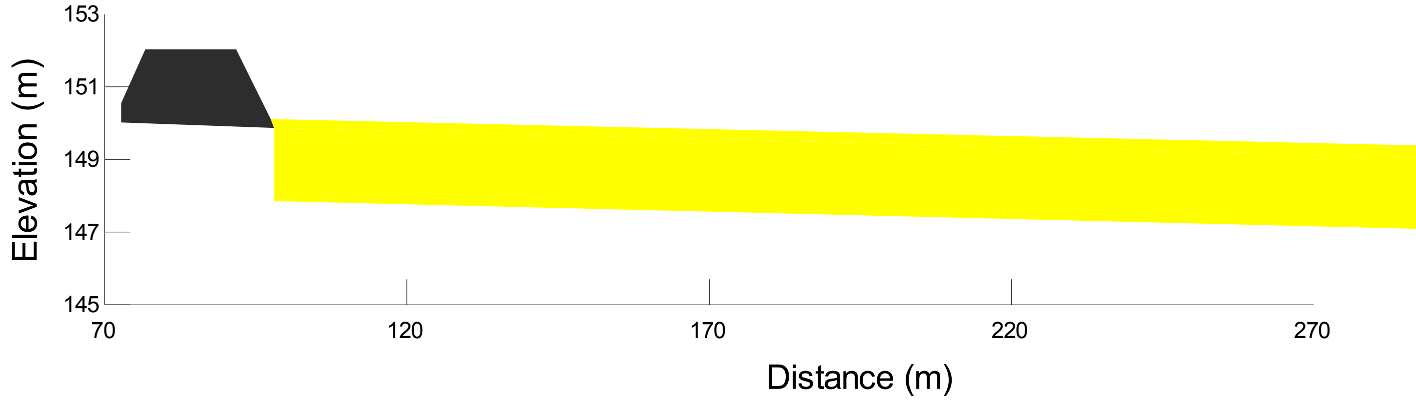

Figure 5: Cross-section 1 geometry at the end of deposition.

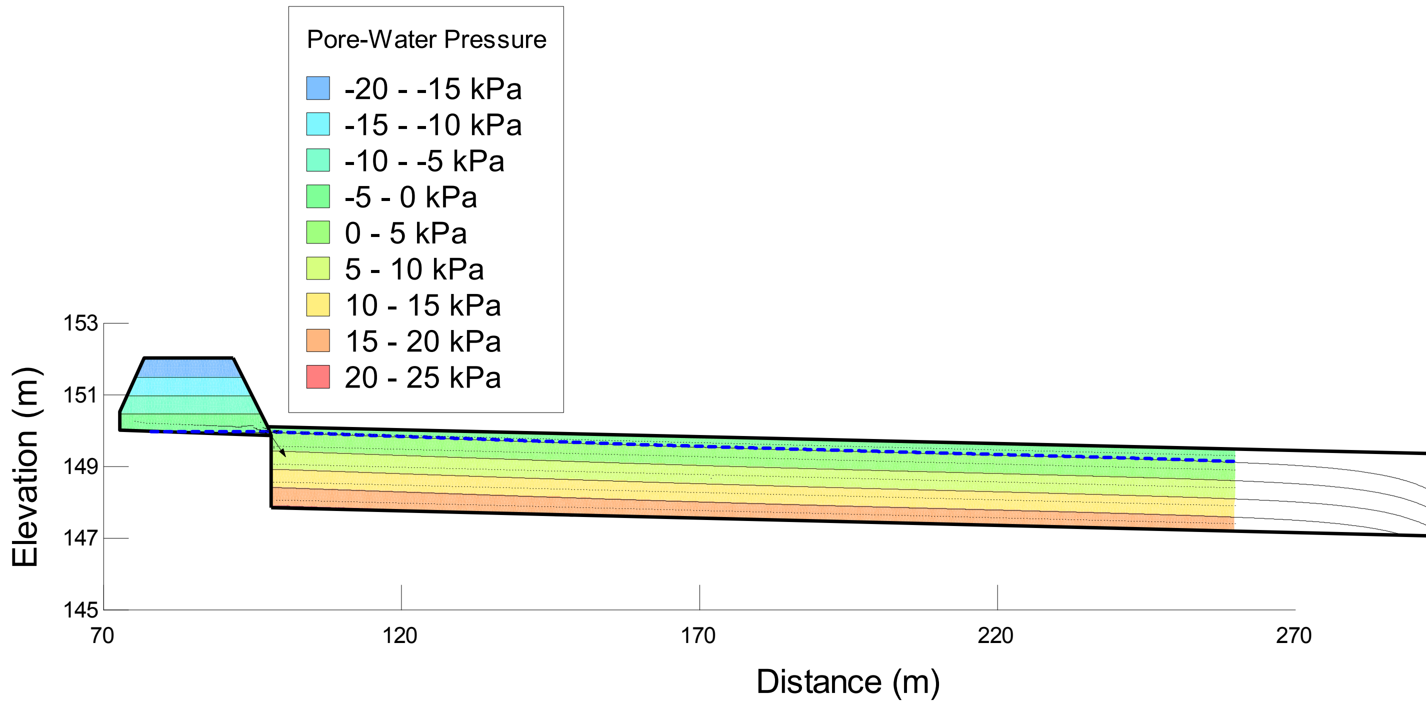

Figure 6: Cross-section 1 pore-water pressure, and flow vectors at end of 2021. No flow into the dike.

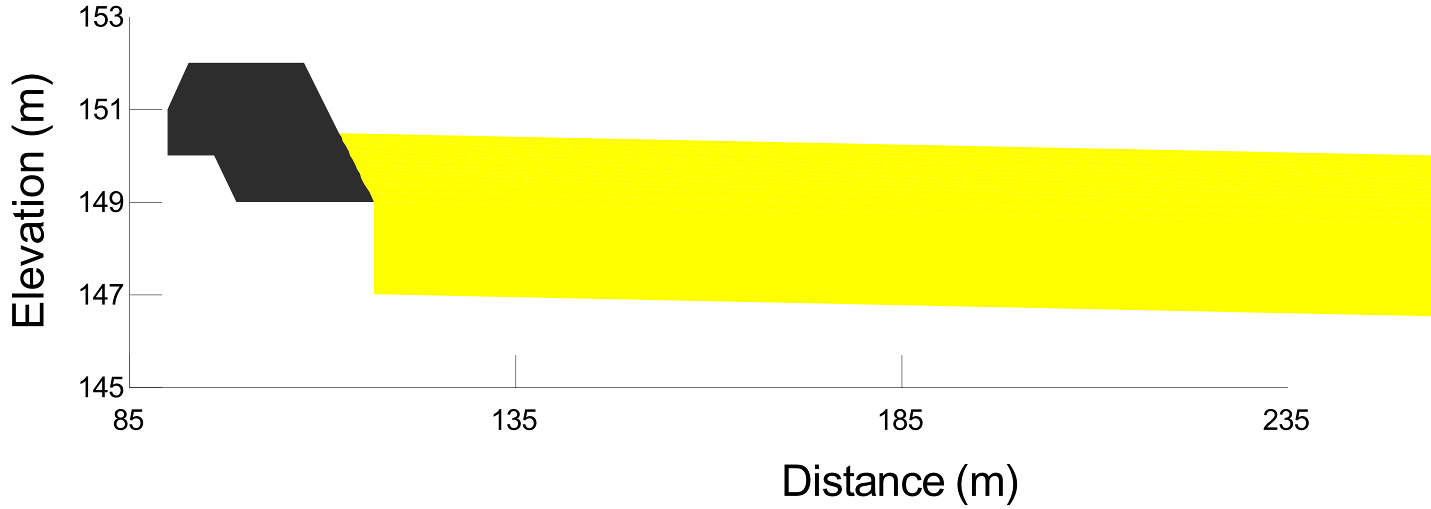

Figure 7: Cross-section 2 geometry at the end of deposition

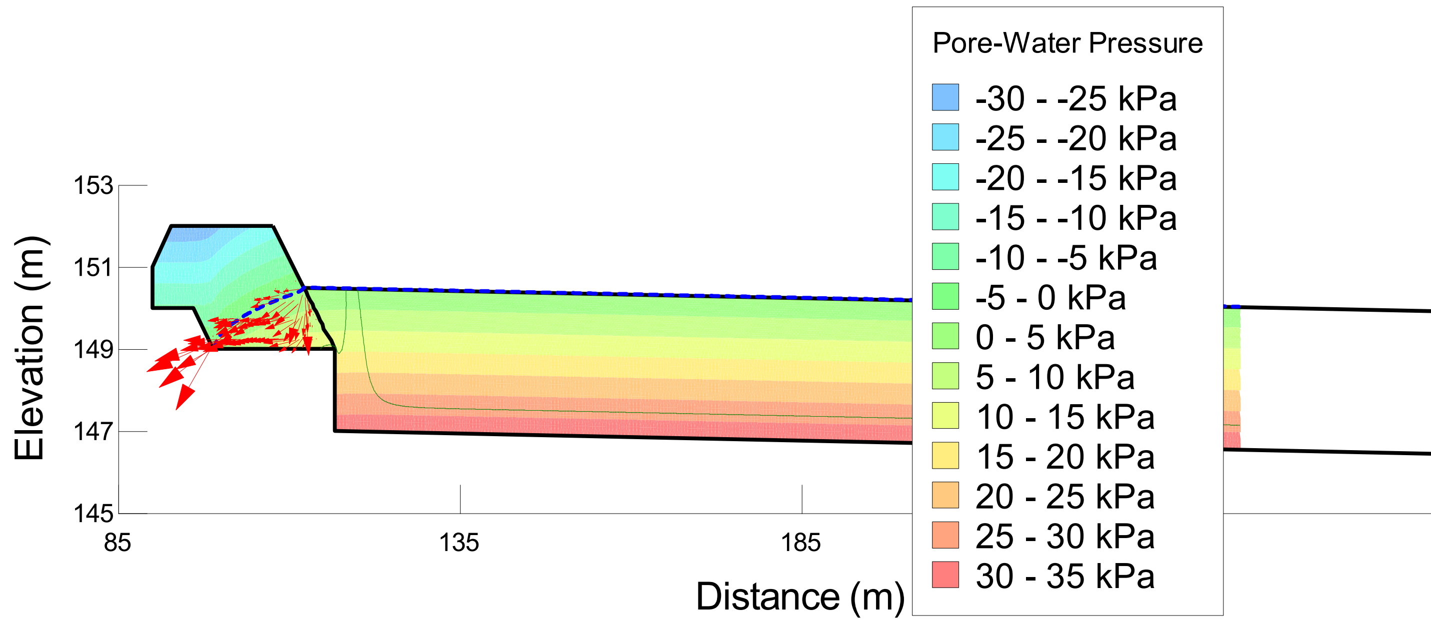

Figure 8: Steady-state pore-water pressure, flow paths and flow vectors for section 2 at end of 2021

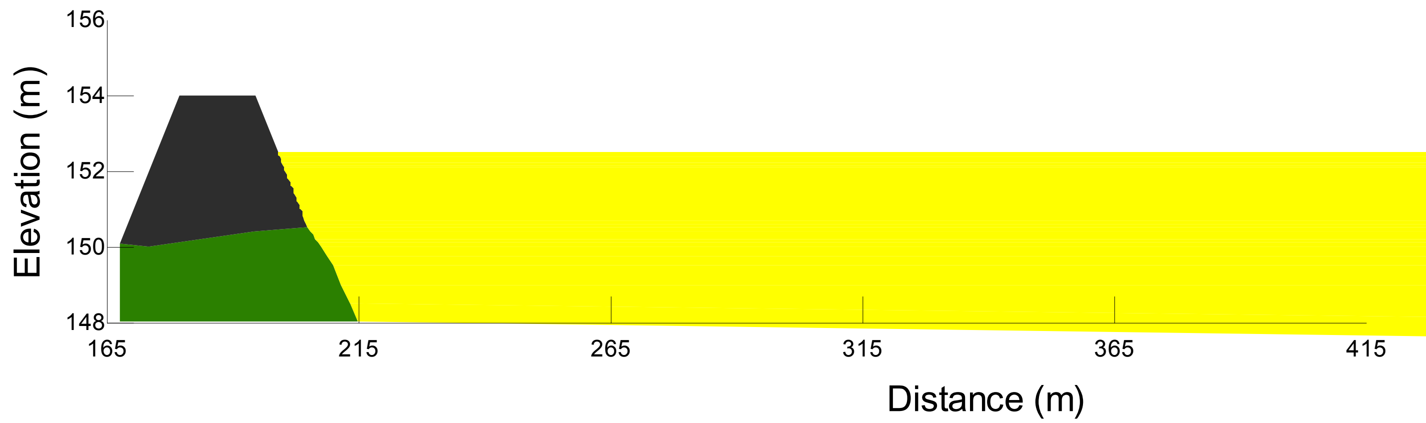

Figure 9: Cross-section 3 geometry at the end of deposition

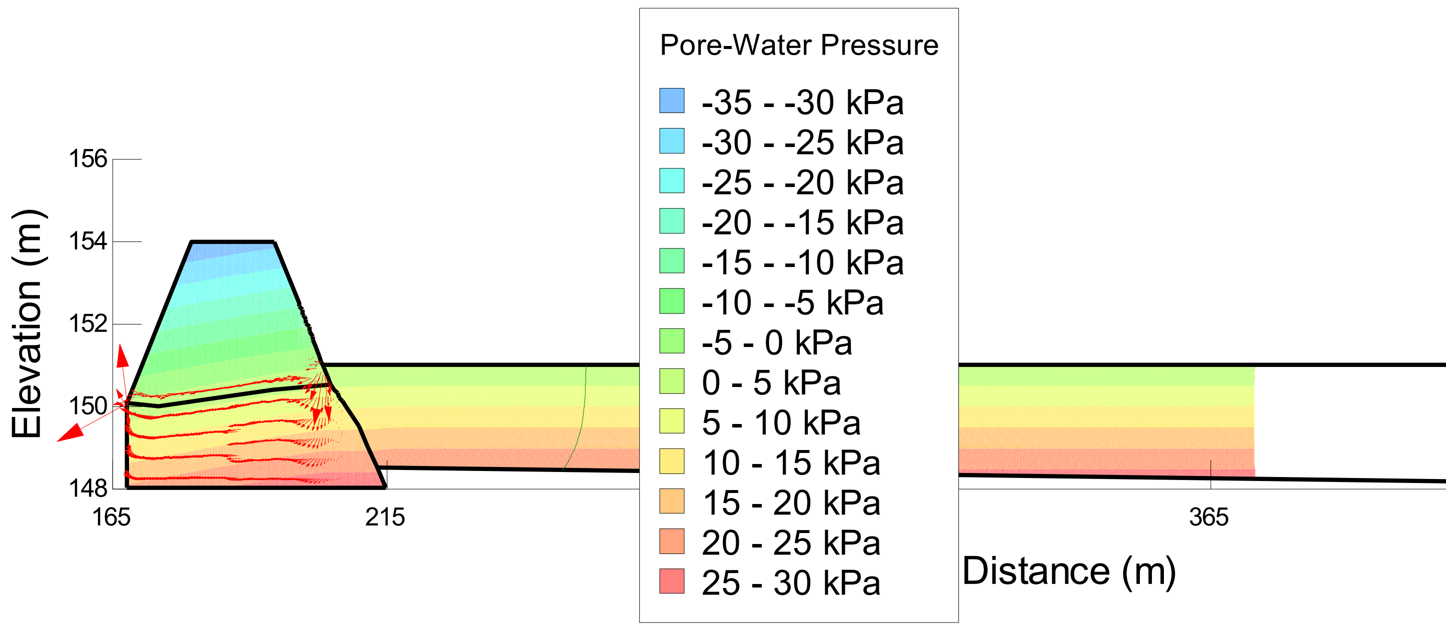

Figure 10: Steady-state pore-water pressure, flow paths and flow vectors for section 3 at end of 2019

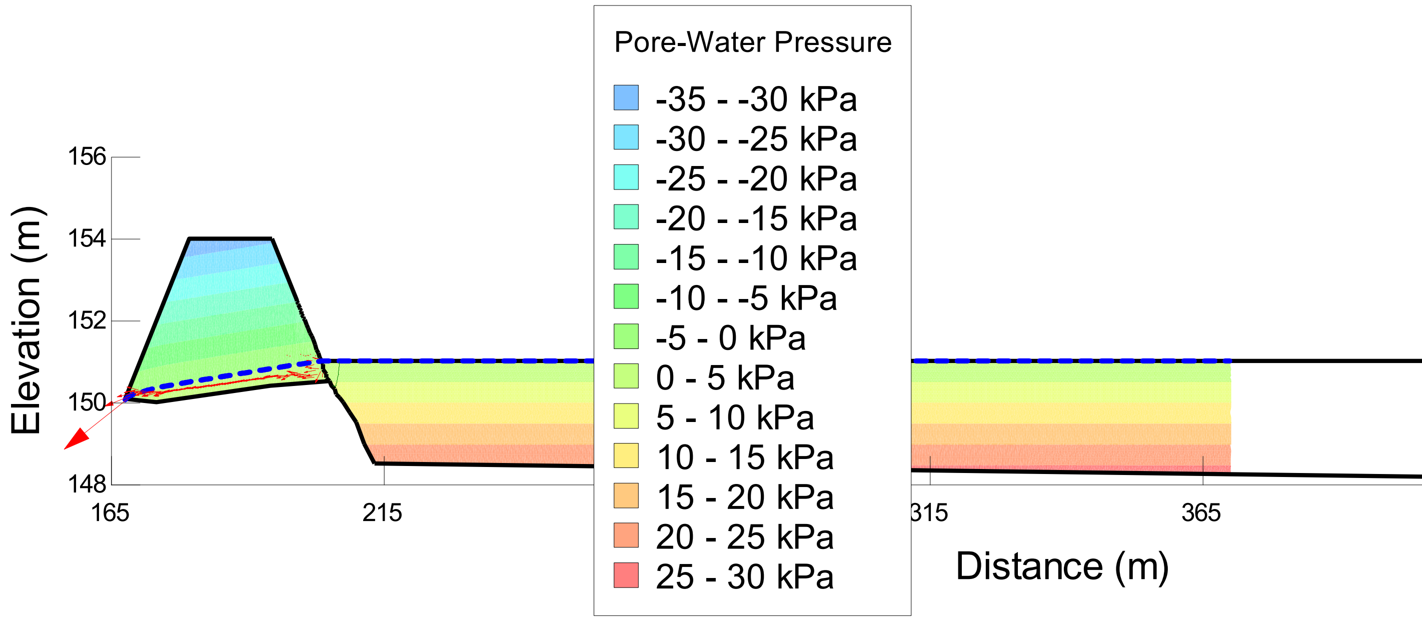

Figure 11: Steady-state pore-water pressure, flow paths and flow vectors for section 4 at end of 2019 when rockfill layer below tailings and dike not included

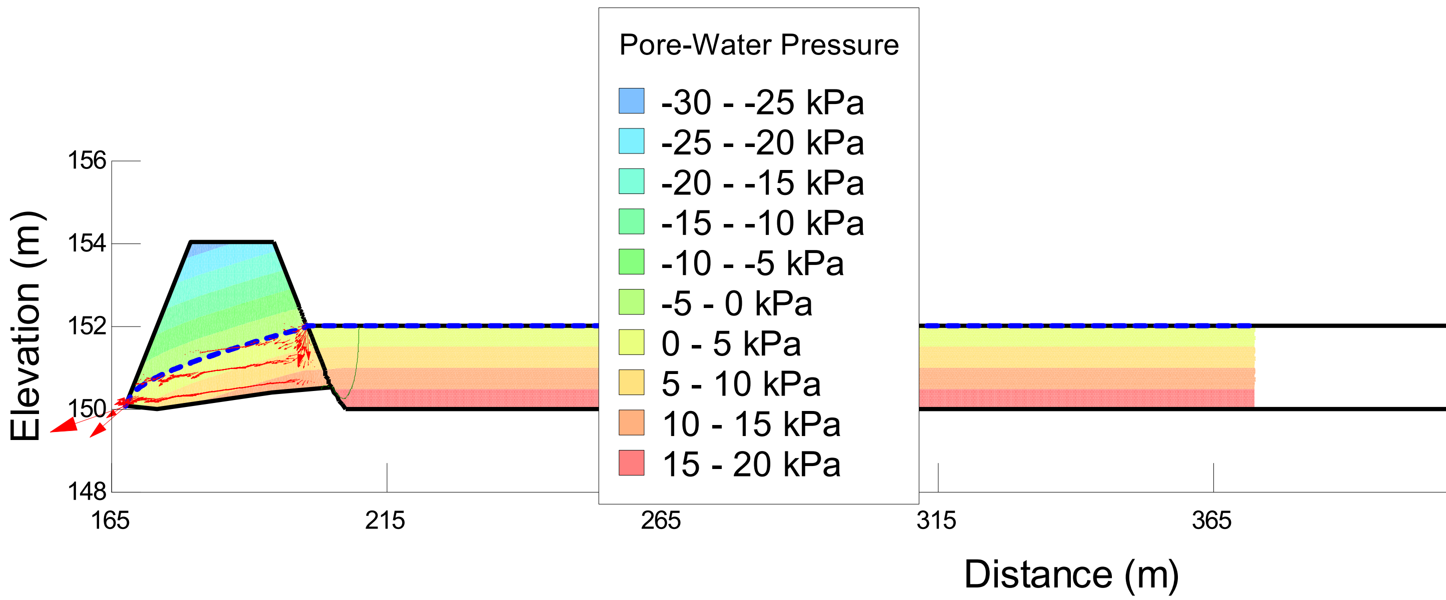

Figure 12: Steady-state pore-water pressure, flow paths and flow vectors for section 3 at end of 2020

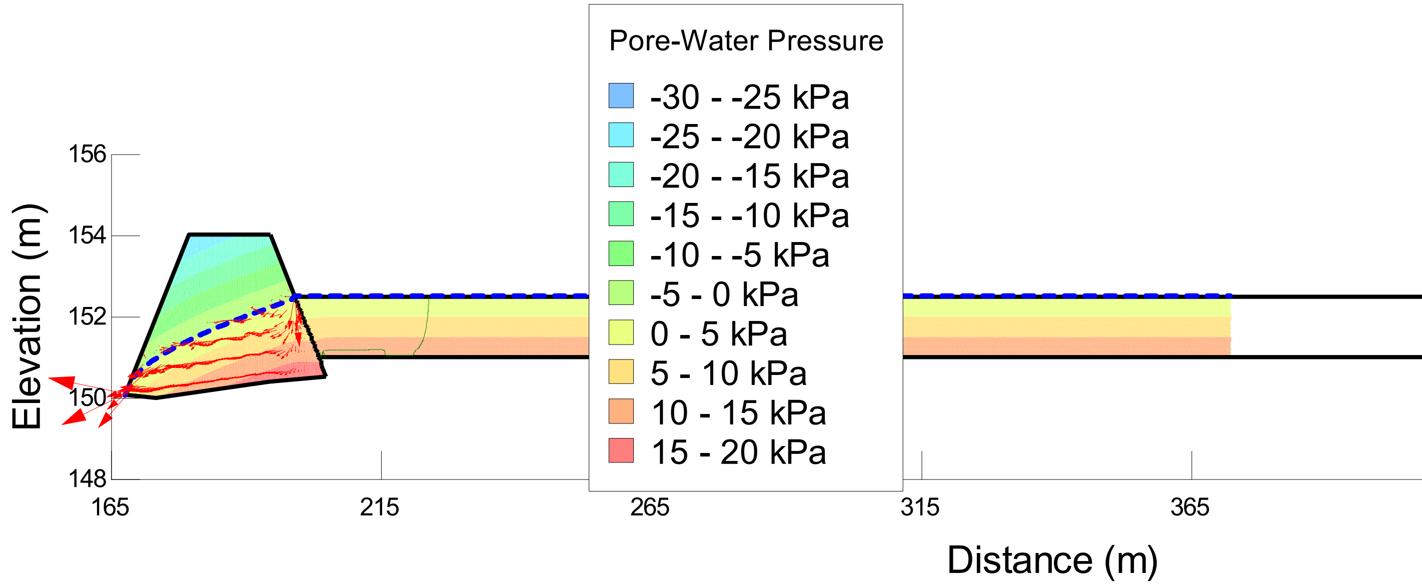

Figure 13: Steady-state pore-water pressure, flow paths and flow vectors for section 3 at end of 2021

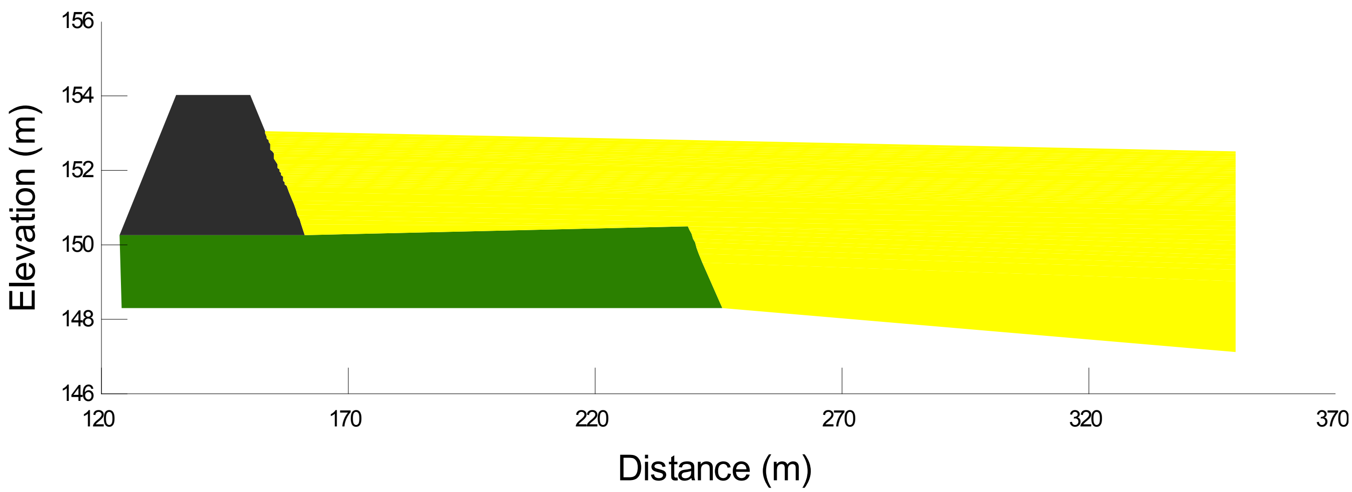

Figure 14: Cross-section 4 geometry at the end of deposition

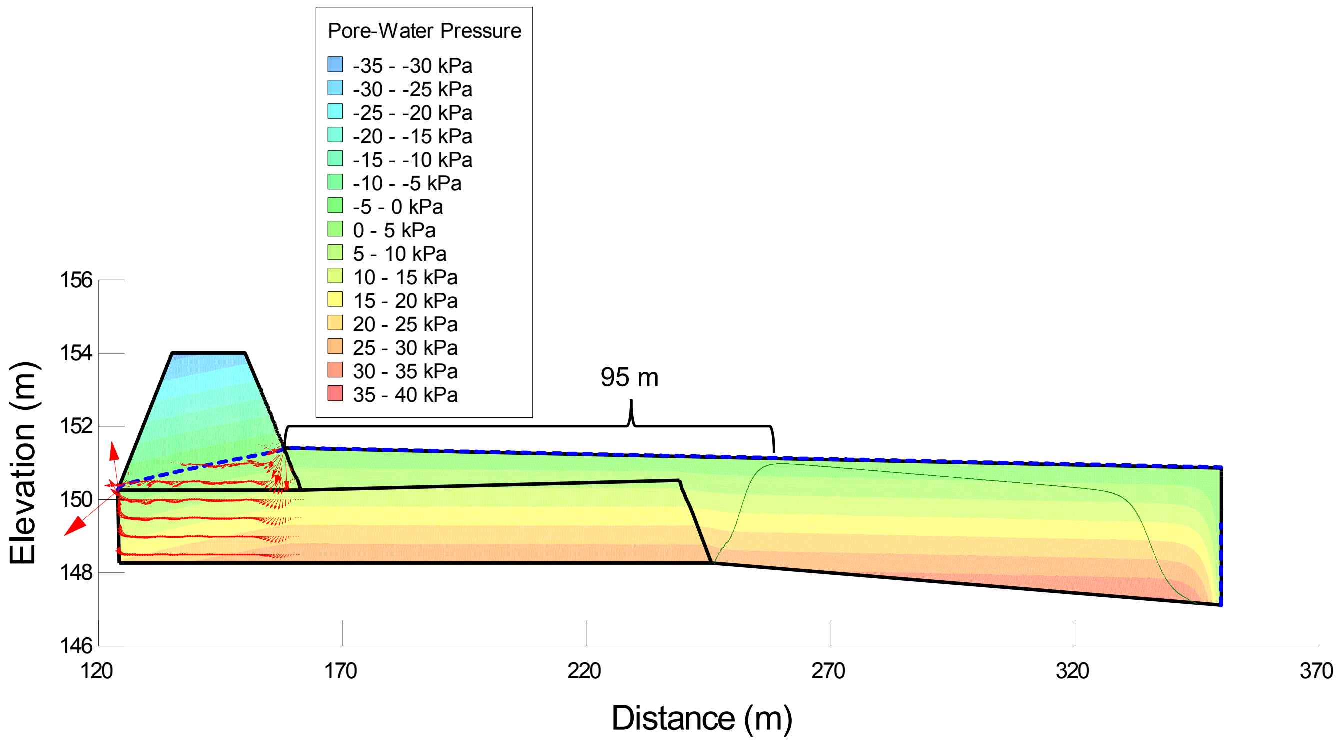

Figure 15: Steady-state pore-water pressure, flow paths and flow vectors for section 4 at end of 2019

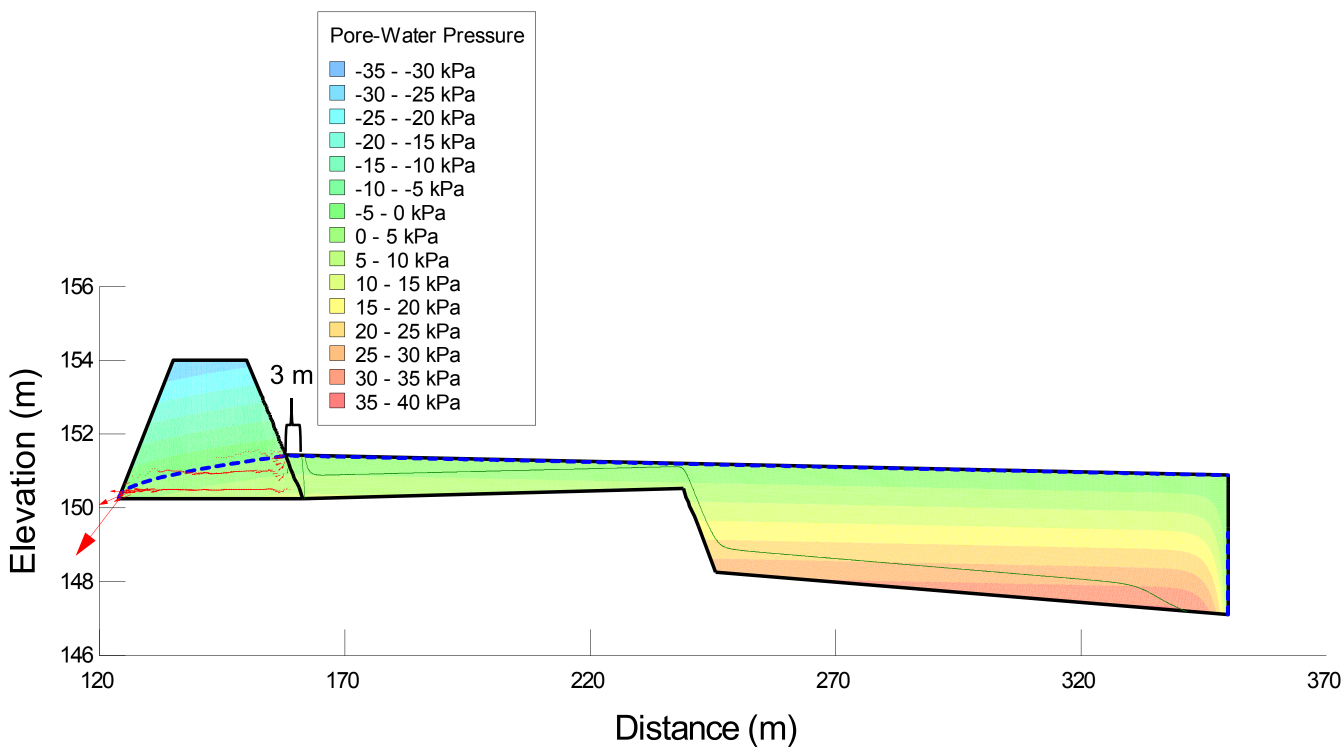

Figure 16: Steady-state pore-water pressure, flow paths and flow vectors for section 4 at end of 2019 when rockfill layer below tailings and dike not included.

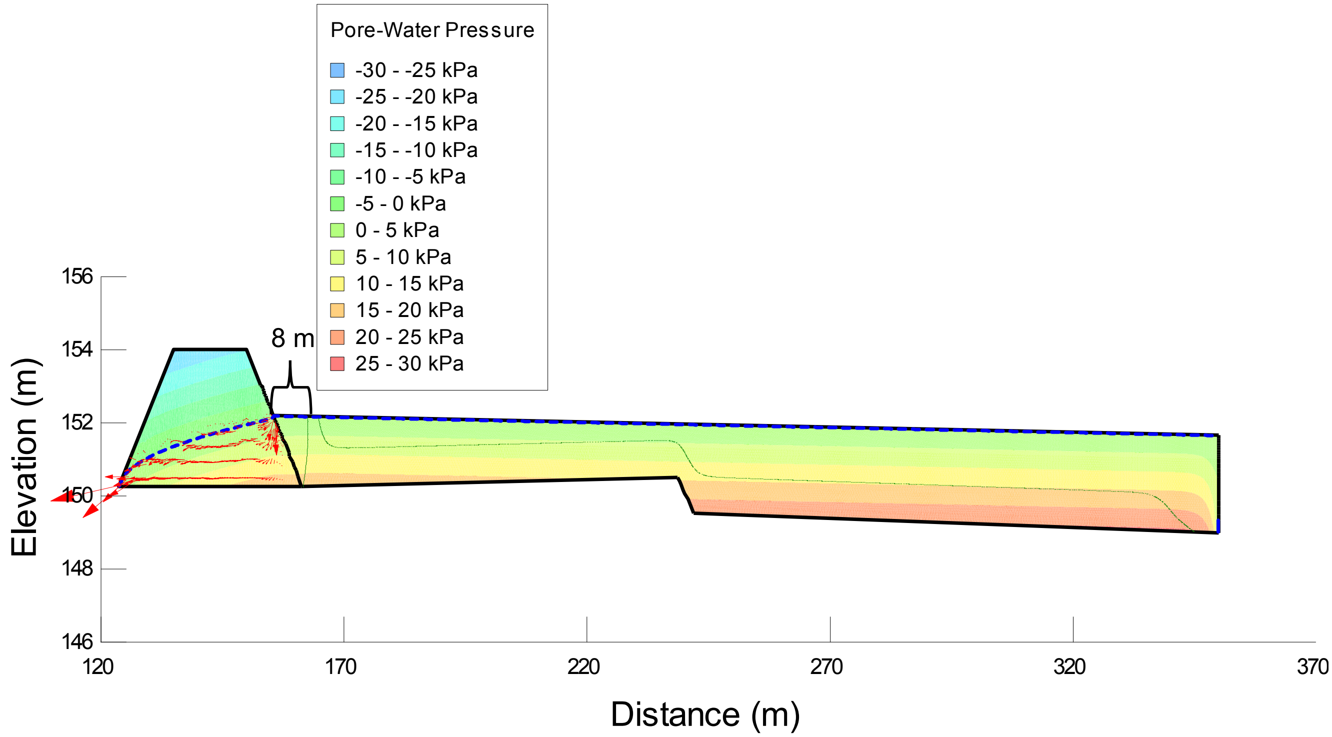

Figure 17: Steady-state pore-water pressure, flow paths and flow vectors for section 4 at end of 2020

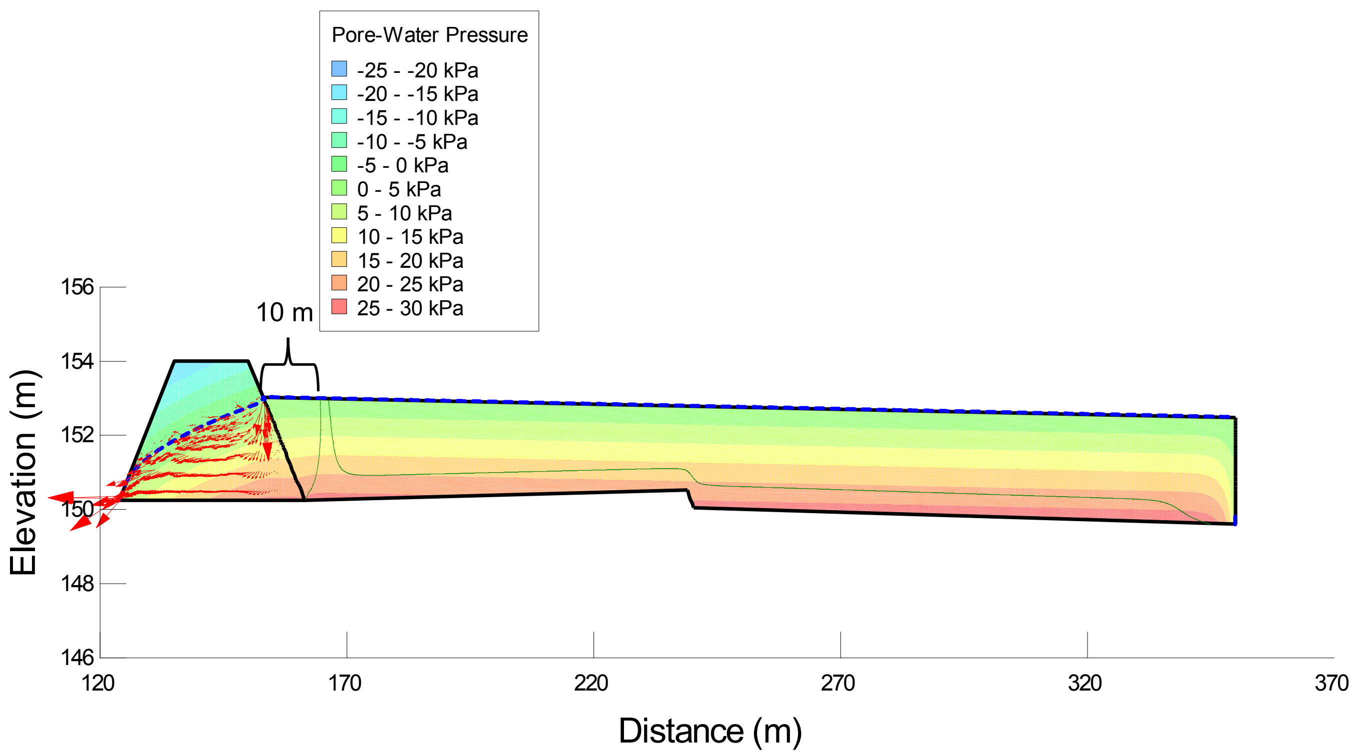

Figure 18: Steady-state pore-water pressure, flow paths and flow vectors for section 4 at end of 2021

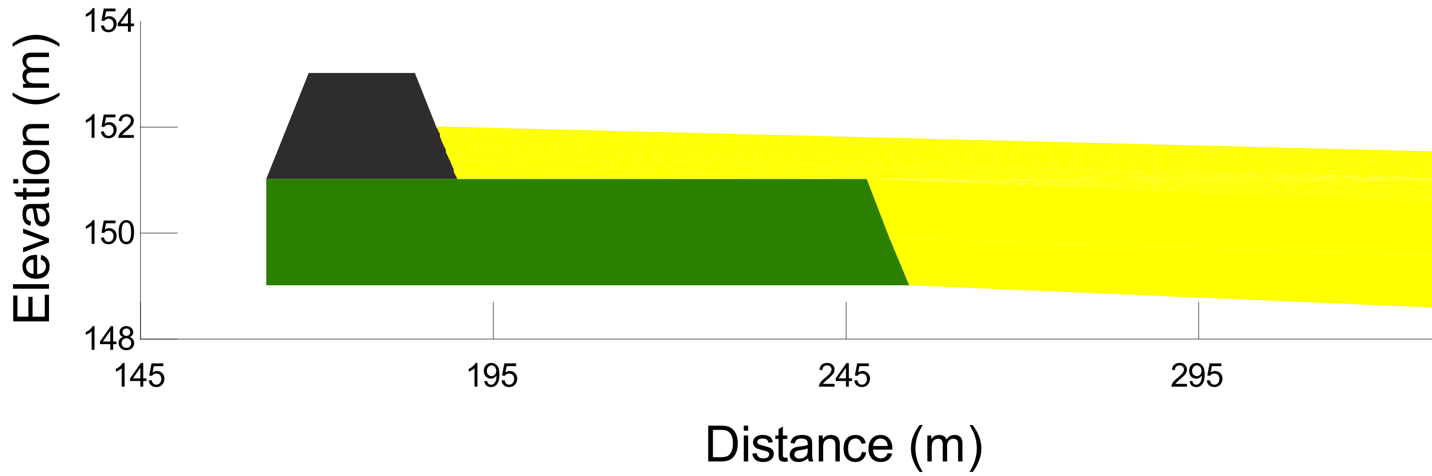

Figure 19: Cross-section 5 geometry at the end of deposition

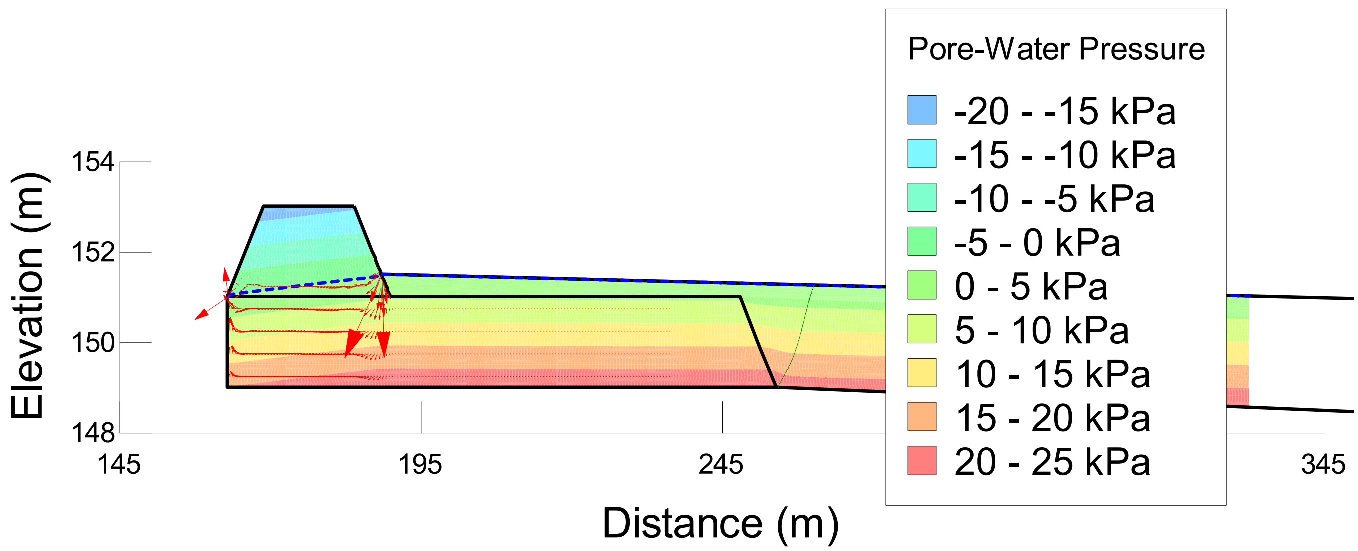

Figure 20: Steady-state pore-water pressure, flow paths and flow vectors for section 5 at end of 2020

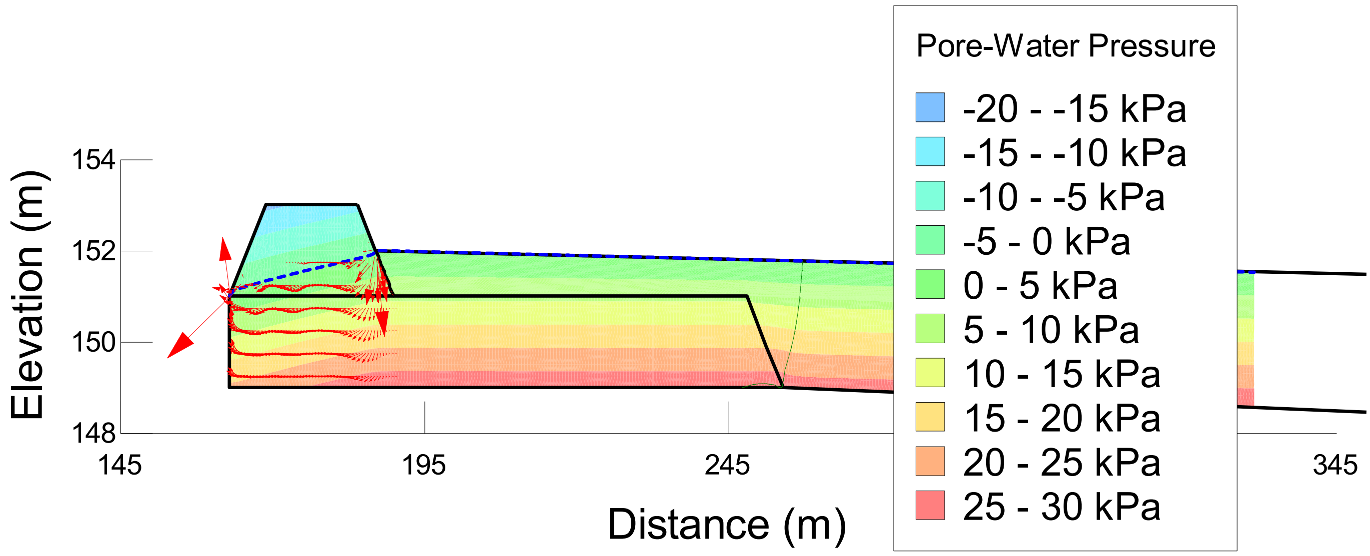

Figure 21: Steady-state pore-water pressure, flow paths and flow vectors for section 5 at end of 2021

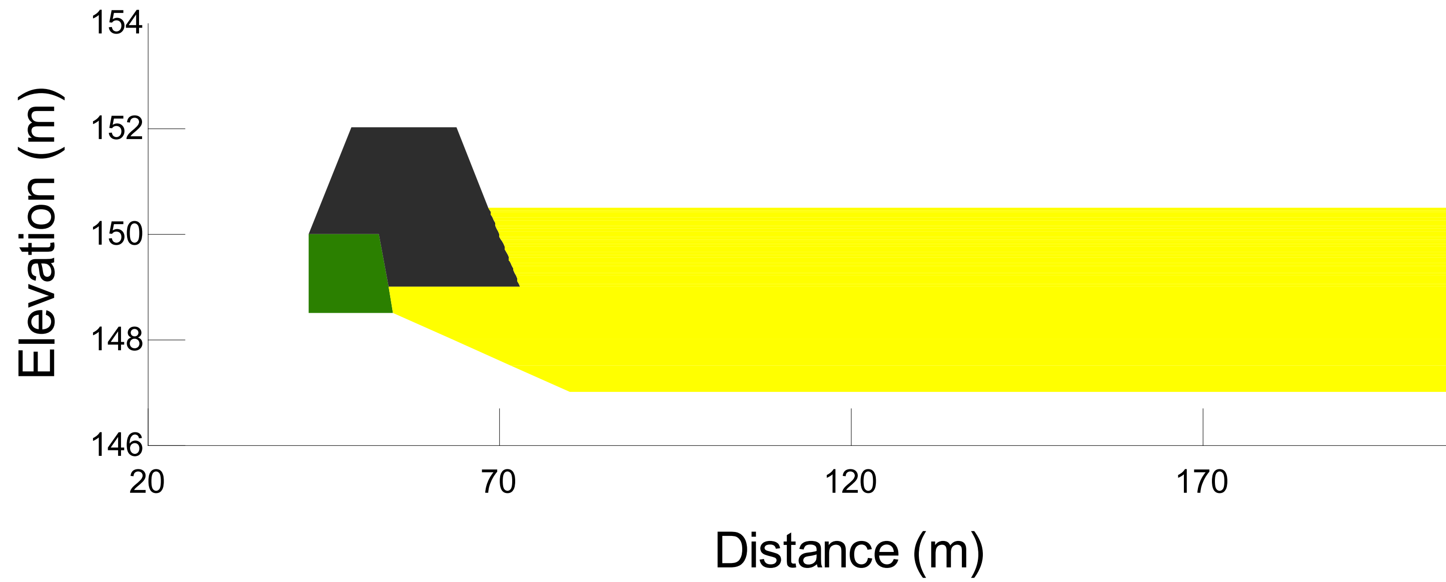

Figure 22: Cross-section 6 geometry at the end of deposition

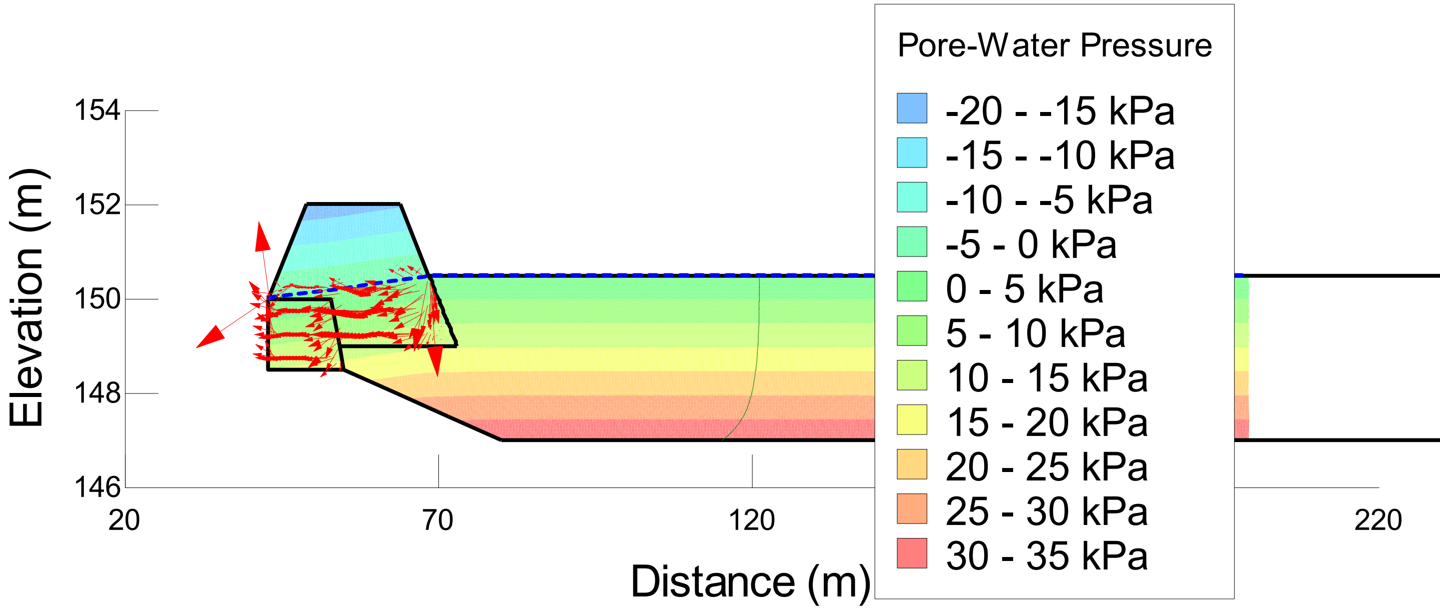

Figure 23: Steady-state pore-water pressure, flow paths and flow vectors for section 6 at end of 2021

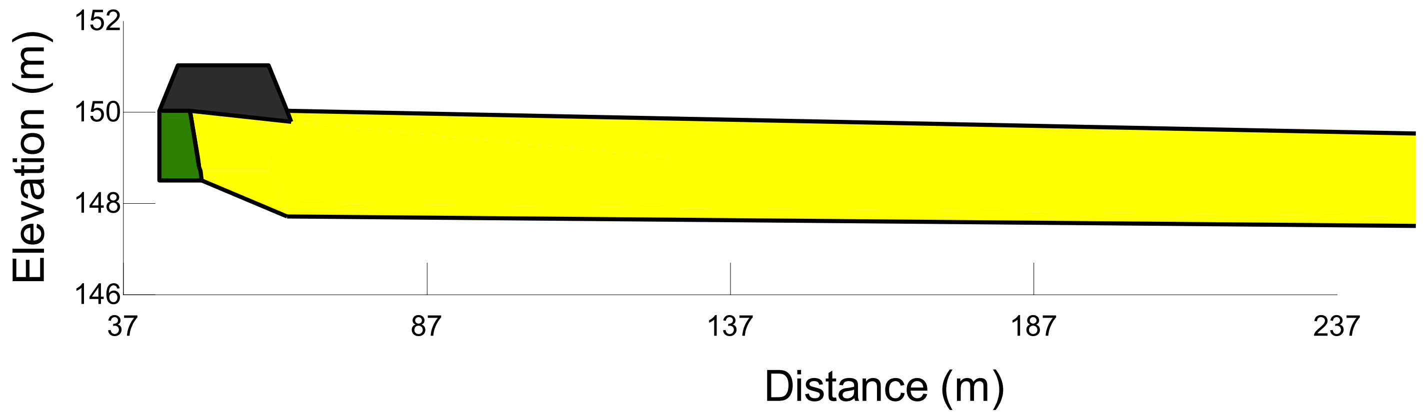

Figure 24: Cross-section 7 geometry at the end of deposition

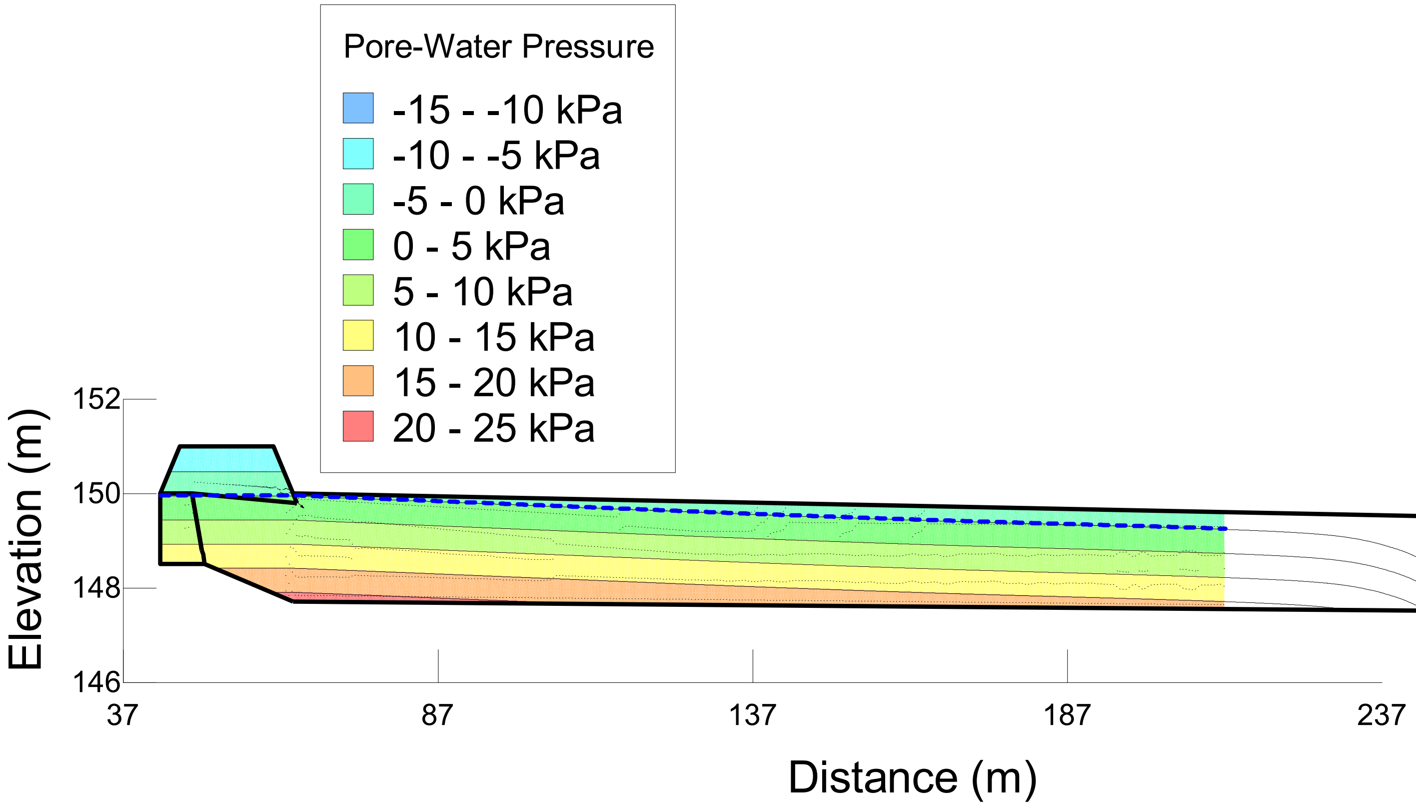

Figure 25: Cross-section 7 pore-water pressure, and flow vectors at end of 2021. No flow into the dike

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