Appendix A

Ground Thermal Assessment Report

SNC-LAVALIN	TECHNICAL NOTE Assessment of Ground Thermal Regime at IVR D-1 Dike	Prepared by: M. Durand-Jézéquel Reviewed by: G. Haile / N. Quan		
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Client: **AGNICO EAGLE MINES LIMITED, MEADOWBANK DIVISION**

Project: **Detailed Engineering of Water Management and Geotechnical Infrastructure Phase 2 Whale Tail Expansion**

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NOTICE TO READER

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1.0 Introduction

1.1 Context

Agnico Eagle Mines Limited, Meadowbank Division (AEM) is developing the Whale Tail Project, a satellite deposit located on the Amaruq property (Kivalliq Region of Nunavut, Canada). The Whale Tail Project construction is ongoing and commercial production has started in the third quarter of 2019. To continue mining and milling, AEM is proposing to expand the Whale Tail Project by expanding the Whale Tail pit, developing another open pit called the IVR pit and including underground mining operations. As part of the expansion project, new water management and geotechnical infrastructures are required for surface water management.

One of the proposed structures is the IVR Attenuation Pond, which will be located within the former Lake A53. The objective of the IVR Attenuation Pond is to store surface contact water which will be transferred by pumping to the treatment plant prior to discharge to the environment through approved diffusers. IVR D-1 Dike is proposed to increase the storage capacity of the IVR Attenuation Pond. The IVR Attenuation Pond and the dike location are shown on Figure 1-1.

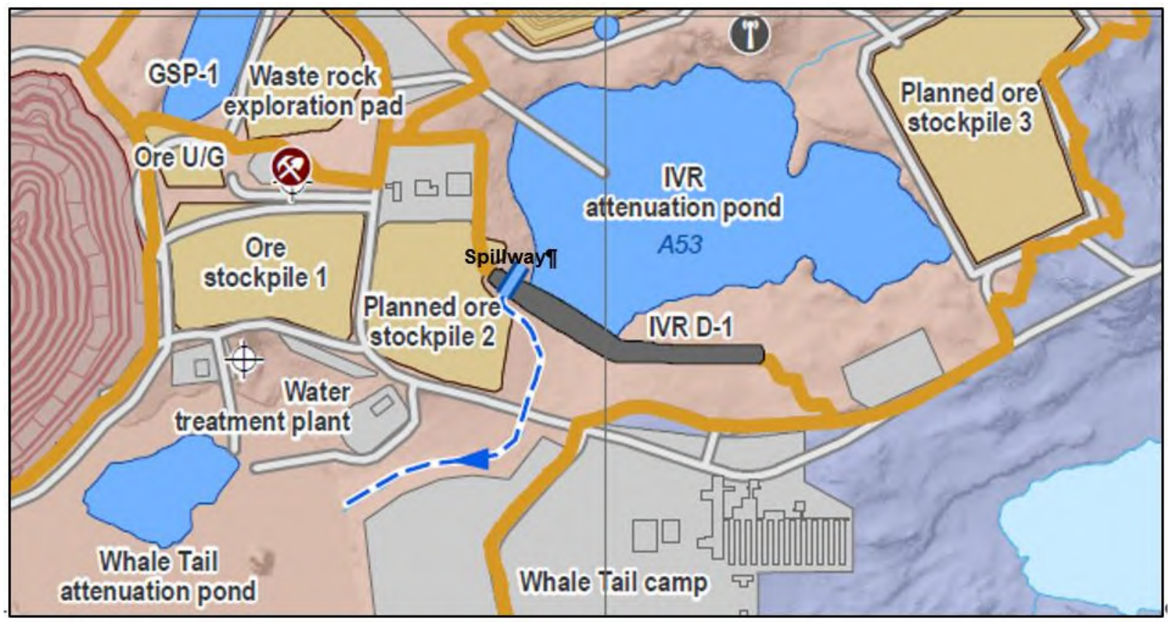


Figure 1-1: IVR Attenuation Pond and IVR D-1 Dike

1.2 Mandate

Since 2015, SNC-Lavalin Inc. (SNC-Lavalin) has been retained by AEM to develop the engineering of the water management infrastructure of the Whale Tail Project at a prefeasibility study level. Following the prefeasibility studies, SNC-Lavalin was retained in September 2017 to develop the detailed engineering of the water management infrastructure of Phase 1 of Whale Tail Project. During the 2018-2019 construction season, three water retention dikes (North East Dike, WRSF Dike and Mammoth Dike) as well as a main dewatering dike (Whale Tail Dike) were constructed. The commissioning of the Whale Tail Dike on March 5, 2019 enabled the dewatering of the Whale Tail North Basin and operations continuity of the Whale Tail Pit.

In September 2019, AEM mandated SNC-Lavalin for the detailed engineering design of surface water management and geotechnical infrastructure for the Whale Tail Project expansion. The scope of work includes the detailed design of the following:

> IVR Attenuation Pond Dike (IVR D-1 Dike) Design and its associated spillway;
> IVR Diversion;
> Development of operational concept and infrastructure for water management of Whale Tail and IVR WRSF;
> Pumping and Piping infrastructure for management of surface water.

As part of the IVR Attenuation Pond Dike (IVR D-1 Dike) design, this document focuses on the thermal analysis conducted at the IVR D-1 Dike. This study follows previous thermal analyses carried out as part of the design of the ancillary structures associated with Whale Tail Pit as listed in Table 1-1.

Table 1-1: Previous thermal analyses conducted as part of the Whale Tail Project

Date	Title	Reference
March 20, 2017	Thermal Analysis at Whale Tail Dike†	(SNC-Lavalin, 2017a)
June 6, 2018	Thermal Analysis at Whale Tail Dike	(SNC-Lavalin, 2018a)
August 13, 2018	Thermal Analyses at the WRSF Dike	(SNC-Lavalin, 2018b)
October 15, 2018	Thermal Analyses at Mammoth Dike	(SNC-Lavalin, 2018c)

†A first thermal analysis was conducted at the Whale Tail Dike as part of the prefeasibility phase.

This study is the fourth thermal analysis conducted as part of the detailed engineering of the Whale Tail Project. The current mandate includes the following scope of work:

> Review all the available geotechnical and thermistor data at the IVR D-1 Dike location;
> Carry out the post-calibration of the previous thermal analyses, when applicable, to validate the assumptions made in the previous phase;
> Determine the representative geothermal properties based on the available geotechnical data and past experience;
> Carry out a thermal analysis on a representative cross section of the IVR D-1 Dike.

1.3 Objective of the present study

Thermal analyses are an important aspect of the design of geotechnical infrastructures constructed on permafrost as they affect the local thermal regime of the foundation. The IVR attenuation pond to be located upstream of the IVR D-1 Dike will change the local thermal regime due to the heat transfer from the water to the ground, thus degrading the permafrost in the attenuation pond area. Understanding the thermal effect of water ponding against the water management infrastructure is required to account in the design for potential differential settlements of the dike and seepage through its foundation during operation.

The main objective of these thermal analyses is to assess the thermal regime of IVR D-1 Dike and its foundation over the lifespan of the structure, which is estimated to last fifteen (15) years.

2.0 Methodology

The thermal analyses were carried out using TEMP/W, a finite element computer program, a component of Geostudio software suite (version 8.16.2.14053, GEO-SLOPE 2016). This software can be used to model thermal changes in the ground by analyzing both simple and highly complex problems (GEO-SLOPE International Ltd., 2014).

The analyses were conducted in two dimensions (2D) and only heat transfers by conduction are considered. This simplification on the modelling process is justified by the little seepage expected given the frozen condition of the cut-off trench. This should limit heat transfers by convection due to water migrating within the dike materials and foundation; however, if seepage is initiated due to a defect in the foundation on the upstream side or through the hydraulic barrier or if the downstream side is flooded, the conclusions drawn from these analyses may not apply due to the inherent limitations of the thermal modelling.

2.1 Sections analyzed

A typical cross section located at the lowest natural ground elevation was used for the base case thermal analysis of the IVR D-1 Dike as shown on Figure 2-1. This cross section corresponds to the preliminary design concept developed at the early stage of the design at the deepest section of the dike (Section B-B). At this location, the natural ground elevation is about 162 metres above sea level (masl) and the bedrock elevation is about 156 masl.

Two other sections (D-D and F-F) were also studied to assess the ground thermal regime at the IVR D-1 Dike locations other than the deepest area. Section D-D located at station 0+360 was studied, where the ground elevation reaches approximately 164 masl. This section was selected to assess the difference in thermal regime when the ground elevation is higher than the operational water level of the IVR Attenuation Pond (163.2 masl). Section F-F studied was the longitudinal profile along the centreline at the west abutment. The intent of this analysis was to design the abutment in such a way that the cut-off trench remains frozen on a yearly basis even when it reaches natural ground elevation.

For simplicity during the modelling process, the esker silt/sand/gravel were considered having the same geothermal properties as the fine filter material (0-19 mm). The 0-150 mm material is referred to as coarse filter based on past thermal analyses and design. Finally, the geomembrane and geotextile thermal effects were considered negligible and are not modelled.

2.2 Existing thermistor strings

Four (4) thermistor strings were installed in the ground close to the proposed location of IVR D-1 Dike. The locations of the installed thermistors are shown in Figure 2-2. Thermistor strings are 12-m long and are composed of 13 beads uniformly spaced by 1 m, with the first bead being placed at the ground's surface. The as built installation information is summarized in Table 2-1.

Table 2-1: IVR D-1 Dike Borehole and Thermistor strings as-built information

Borehole ID	BH-T2	BH-2	BH-4	BH-T9
Overburden thickness (m)	2.4	4.0	2.5	3.2
Sound bedrock depth (m)	2.8	4.5	3.5	4.0
Upper bead elevation (masl)	164.30	162.16	163.98	162.08
Lower bead elevation (masl)	152.30	150.16	151.98	150.08

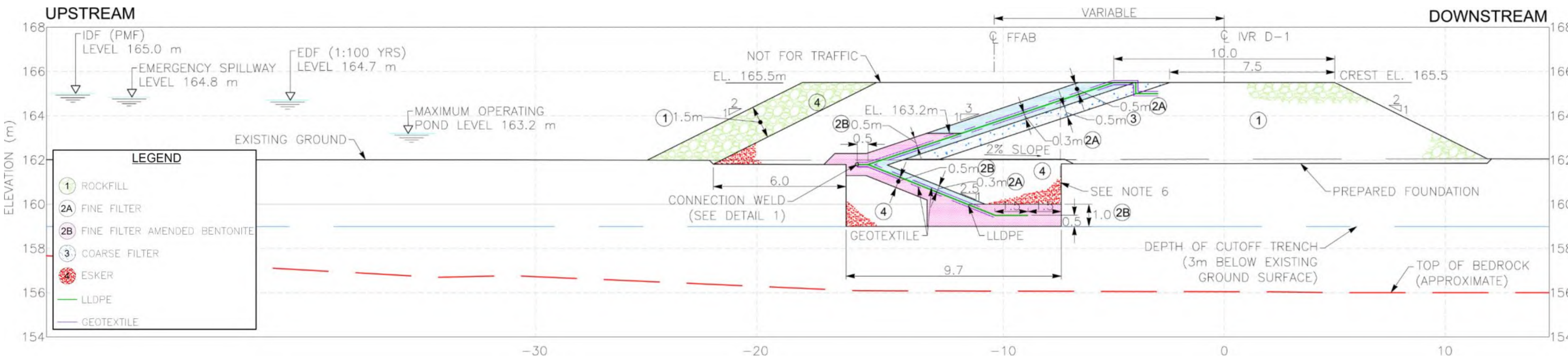


Figure 2-1: Base case cross section used for the thermal analysis

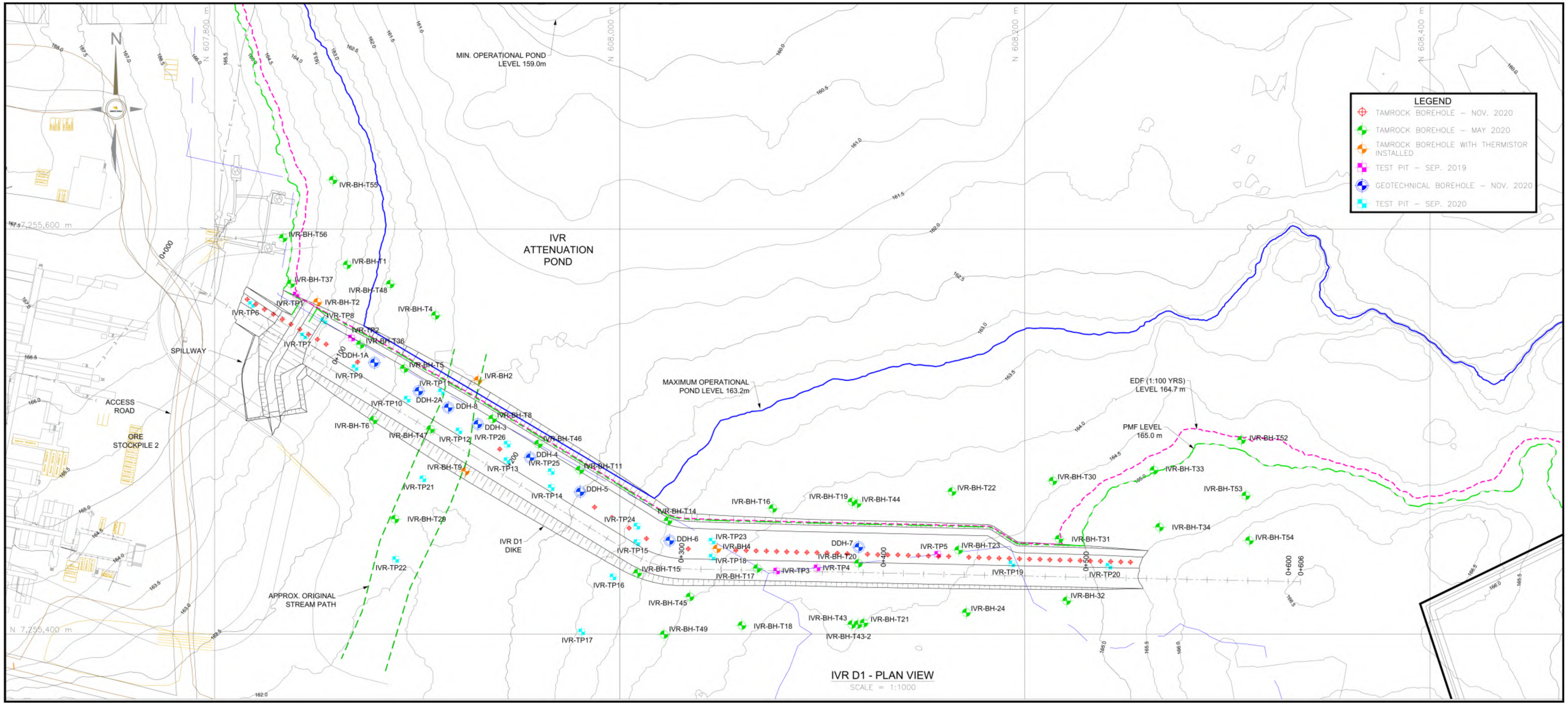


Figure 2-2: Thermistor Locations

The thermistors were installed in December 2019 and the available data cover up to December 2020. The temperature profile of each thermistor for that period is presented on Figure 2-3.

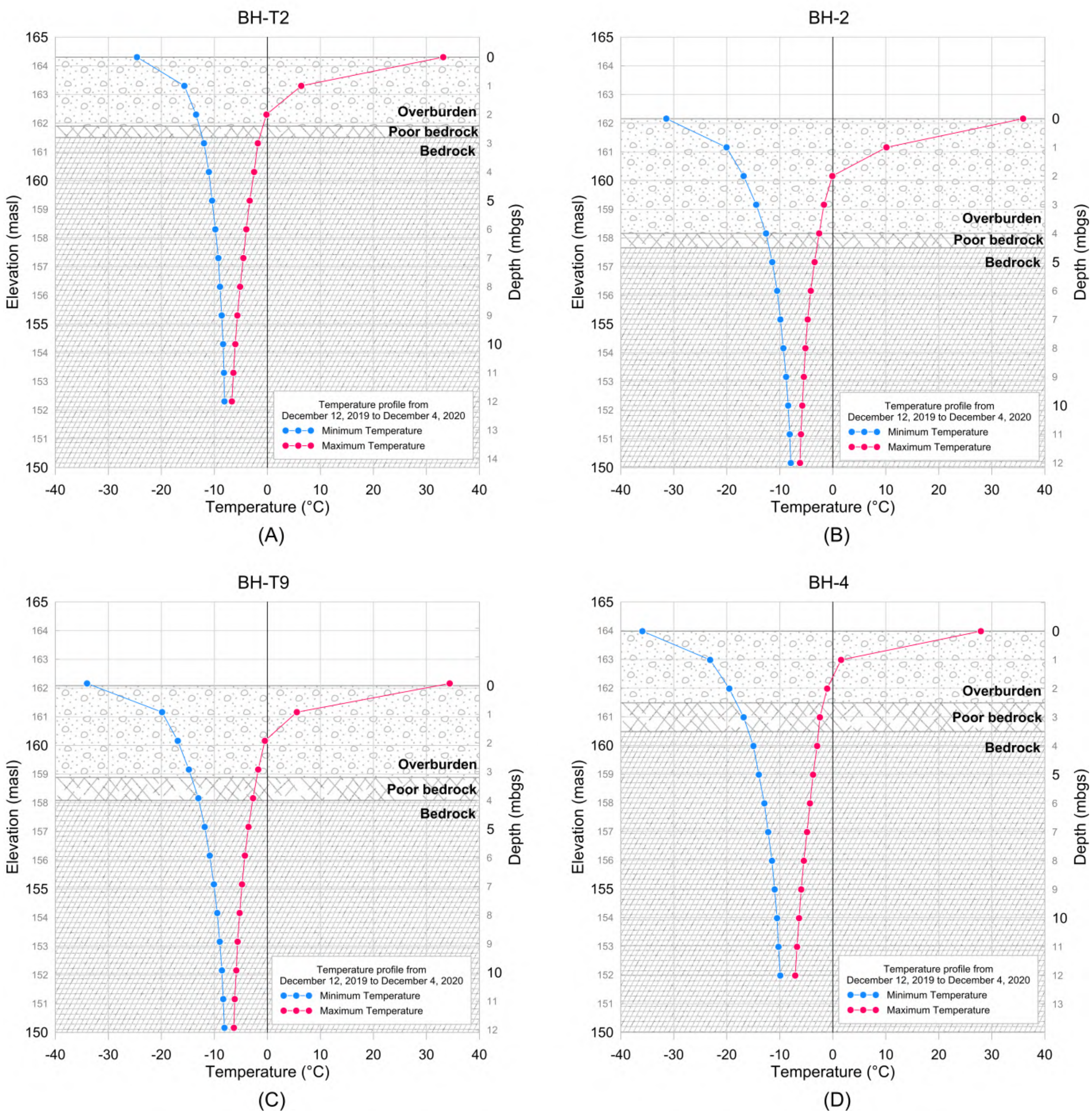


Figure 2-3: Temperature profile for thermistor (A) BH-T2, (B) BH-2, (C) BH-T9 and (D) BH-4

2.3 Modelling assumptions and boundary conditions

2.3.1 Air temperature

The average daily temperature data from the Amaruq weather station from January 1, 2019 to June 18, 2020 were used to develop the air temperature function as part of the calibration process. A similar approach to the one developed for the previous thermal analysis (SNC-Lavalin, 2017a) was used: in order to simplify the modelling process and reduce the temperature data set, the daily temperature readings from the Amaruq weather station were converted into a 28-day average air temperature cycle function on a 365-day basis. The first day of the air temperature function corresponds to the date of June 4, 2019 and ends after 365 days on June 3, 2020. This simplified 28-day air temperature function was hence repeated periodically for the duration of the calibration process. The recorded average air temperature at the Amaruq station and the 28-day air temperature function are shown on Figure 2-4.

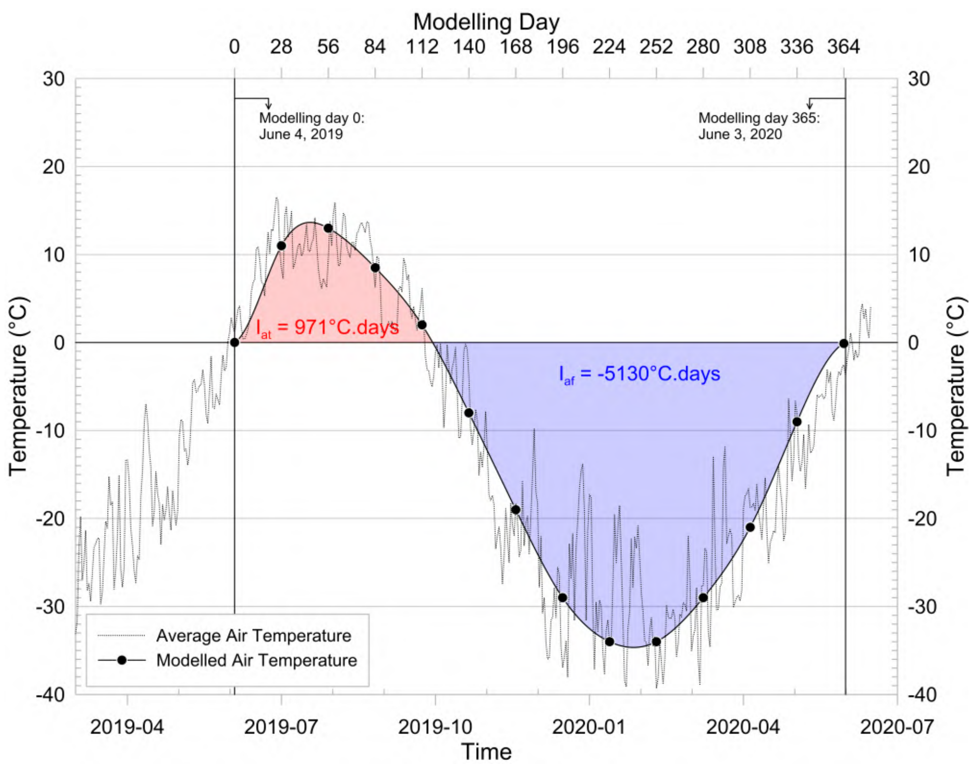


Figure 2-4: Air temperature function based on Amaruq Weather Station average air temperature

The synthetic 28-day average air temperature function was designed to fit the 2019-2020 air temperature data recorded at the Amaruq Weather Station. However, the climate is expected to vary throughout the years and warmer temperatures could affect the thermal regime of the dike and its foundation. To account for the potential warming trend due to climate change, another air temperature function based on the warmest year recorded at the Meadowbank Weather Station of the last decade, that is the 2016-2017 period, was developed for the ground thermal regime assessment during operation of the IVR D-1 Dike. The recorded average air temperature at the Meadowbank Weather Station during the 2016-2017 period and the associated 28-day air temperature function are shown on Figure 2-5.

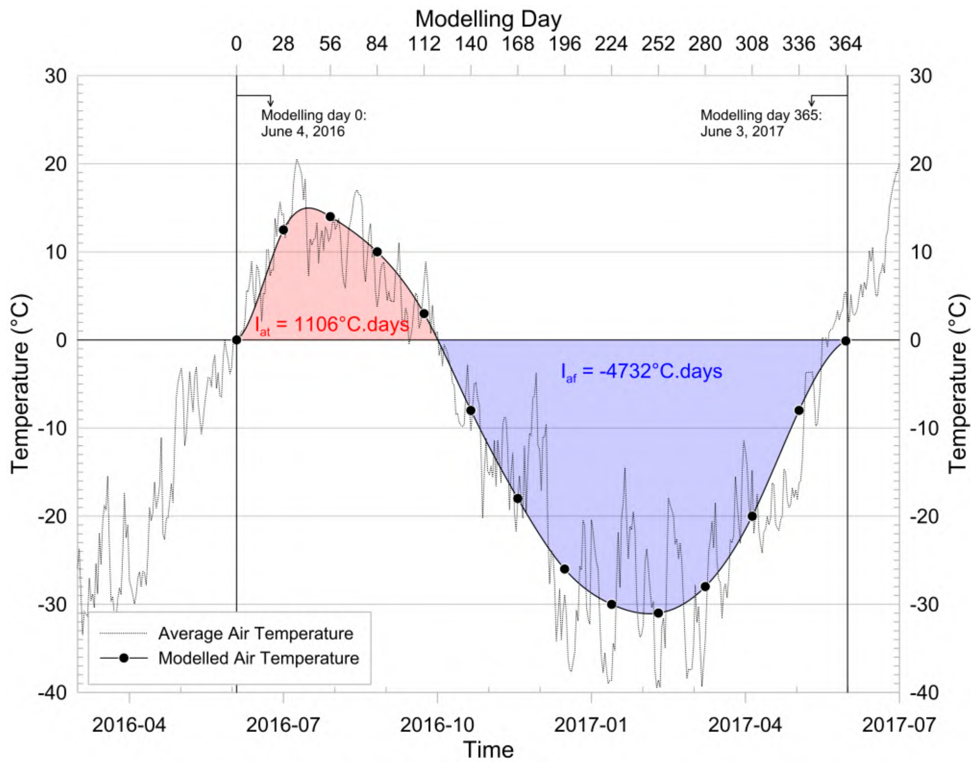


Figure 2-5: Air temperature function based on Meadowbank Weather Station average air temperature from the year 2016-2017

Since there are variations in the air temperature throughout the year, the Air Thawing Index (I_{at}) and Air Freezing Index (I_{af}) were used to develop of the air temperature functions. As a result, the air temperature indices are within 0.5% of the targeted value as shown in Table 2-2.

Table 2-2: Calibration of the modelled air temperature function using air temperature indices

Weather Station	Amaruq†		Meadowbank‡	
Air temperature index (°C.days)	I_{at}	I_{af}	I_{at}	I_{af}
Data from weather station	967	-5 151	1 105	-4 737
Modelled air temperature	971	-5 130	1 106	-4 732
Difference (%)	0.4	-0.4	-0.1	0.1

†The Amaruq air temperature indices were computed from June 4, 2019 to June 3, 2020
‡The Meadowbank air temperature indices were computed from June 4, 2016 to June 3, 2017.

The modelled air temperature functions allow a replication of the air temperature recorded either at the Amaruq mine site in the 2019-2020 period or at the Meadowbank mine site during the 2016-2017 period. The 2019-2020 Amaruq air temperature function is used only for the calibration of the surface n-factors (Section 2.3.6) and for calibration of the geothermal properties (Section 2.4). The 2016-2017 Meadowbank air temperature function is used for the thermal modelling of the IVR D-1 Dike and the assessment of ground thermal regime condition during operation.

2.3.2 Water temperature

The water temperature in the IVR Attenuation Pond can be estimated using the data available at the Whale Tail Lake South Basin as shown on Figure 2-6.

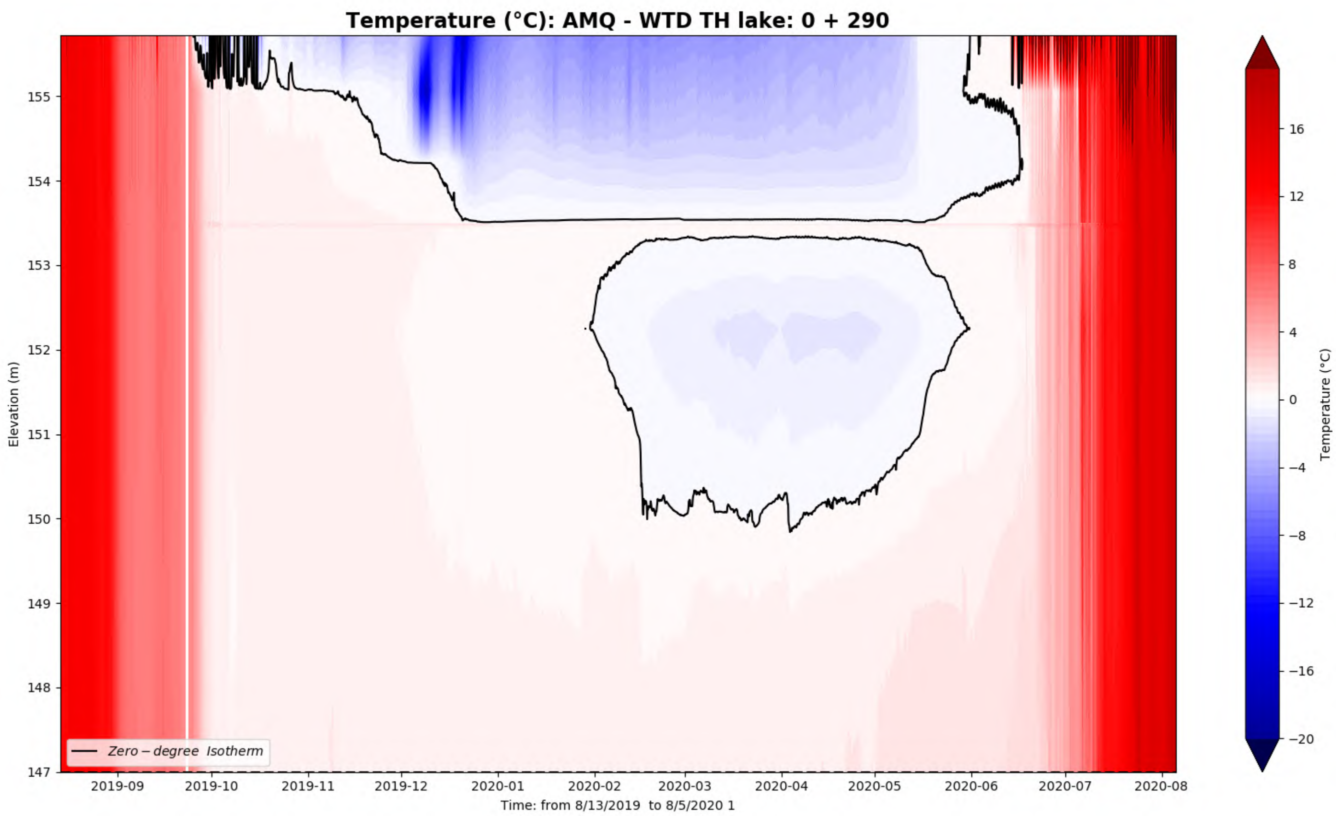


Figure 2-6: Whale Tail Lake South Basin temperature variation from August 2019 to August 2020

During summer, the whole water column can reach temperatures up to around 16°C, whereas the surficial water temperature can reach up to 18°C. During winter operations, it is considered that water at a constant temperature of 4°C will be pumped in the IVR Attenuation Pond based on field measurement from the East Dike seepage at Meadowbank site.

2.3.3 Precipitations

It has been assumed that there is no significant snow accumulation during winter or rain precipitation during summer that could affect the thermal regime of the thermal model.

2.3.4 Material properties

The availability of field data and geotechnical testing is limited and assumptions were made regarding the geothermal properties of the foundation. For simplicity, the material layers were assumed to be homogeneous with regards to their properties for the purpose of the thermal analysis.

For the construction materials, the as-built data of the dikes during the first phase of the Whale Tail Project such as gradation curves, water content and dry density were used when available.

Since the geothermal parameters used in the finite element model are one of the main driving factors in such thermal modelling, a sensitivity analysis was carried out on the geotechnical properties of the foundation and construction materials, which reflect in the different thermal properties. The geotechnical and geothermal properties described in Sections 2.3.4.1 and 2.3.4.2 are the main properties used in the simulations. Another simulation using materials in a looser state, which decrease the thermal conductivity as an effect, was carried out on Section B-B of the thermal analysis (refer to Figure 2-1).

2.3.4.1 Geotechnical properties

The results from field investigations carried out in the IVR D-1 Dike area together with typical values retrieved from the literature were used to generate the geotechnical properties of the foundation. These geotechnical properties are required to estimate geothermal properties for the modelling. The geotechnical properties assumed in this study are presented further in Table 2-3.

Bedrock: Exploration boreholes in the IVR Attenuation Pond area (AMQ16-901, AMQ17-1384) identified the bedrock as greywacke. The geothermal properties of sandstone from the published literature were used for this study. The porosity was estimated at 1.6 %, which is a typical value for bedrock. The other geotechnical properties are based on this value, assuming fully saturated bedrock.

Till: Five (5) test pit samples collected during the September 2019 geotechnical investigation campaign (Agnico Eagle Mines, 2020) and 21 test pit samples collected during the September 2020 geotechnical campaign were tested for gradation and water content. Moreover, a diamond drilling campaign comprising eight (8) boreholes was carried out in October 2020, of which 23 samples were collected and tested for gradation (and 19 for water content). The samples collected in 2020 (from both test pits and diamond drilling boreholes) were also tested for ice content, which is defined by the gravimetric melt water content collected from the thawed sample when stored at room temperature. The thawed samples from test pits were collected at a depth from 0.5 to 2.1 m while the average sample depth from diamond drilling boreholes varied from 0.8 to 7.0 m. In general, the overburden depth is around five (5) metres and can reach seven (7) to eight (8) metres in some locations. The sample locations are shown on Figure 2-2.

In general, the top 1.5 m of the overburden within the footprint of IVR D-1 Dike can be described as a silty and sandy gravel classified GM with a surficial organic layer of 0.14 m. The gravimetric water content of the thawed samples collected at the bottom of the test pits varied from 1.1% to 26.7% with an average of 8.1%. Thus, the laboratory data of the unfrozen samples suggest an ice-poor till material (when frozen) for the top 1.5 m of overburden.

For thermal modelling purposes, the overburden will be considered as a homogeneous layer of saturated ice-poor till with typical geotechnical parameters (dry density, porosity, etc.) assumed given the absence of measured values. However, sporadic higher water/ice content were noted at some locations along the IVR D-1 Dike, where the excess ice content can reach more than 50% in one instance. It should also be noted that samples collected within the current footprint of the Whale Tail Camp located approximately 300 m South of the IVR D-1 Dike indicated the presence of an ice-rich till layer between depths of 1.5 m to 4 m below ground surface (SNC-Lavalin, 2017b; 2018a). Moreover, ice-rich till and buried ice lenses were observed during the excavation of the east abutment of Whale Tail Dike located approximately 700 m from the IVR D-1 Dike.

Fine filter / esker: The as-built data gathered from the construction of the phase 1 dikes was used to assess the geotechnical properties of the fine filter material (SNC-Lavalin, 2020a; 2019). The gravimetric water content and fines content of the 116 fine filter samples averaged 2.3% and 7.7%, respectively.

Moreover, the *in situ* dry density of the fine filter material was estimated using the standard Proctor test result on fine filter material (2265 kg/m³) and the average *in situ* dry density of the fine filter amended with bentonite (FFAB) from the 30 nuclear densometer tests (averaging about 94.9% of Standard Proctor Maximum Dry Density). These results allowed estimation of the dry density of the compacted fine filter material to be about 2149 kg/m³. The other geotechnical properties were calculated using a specific gravity of soil solids G_s = 2.8.

Coarse filter: Similar to the fine filter material, the as-built data gathered from the construction of the Phase 1 dikes was used to assess the geotechnical properties of the coarse filter material (SNC-Lavalin, 2020a; 2019). The gravimetric water content and fines content of the 20 coarse filter samples averaged 2.3% and 3.7%, respectively. However, in the absence of dry density values measured on the field, a typical void ratio e = 0.25 was considered for the calculation of the other geotechnical properties.

Rockfill: The geotechnical properties of the rockfill material are considered similar to those of the coarse filter material since they are both made from crushed rocks. The void ratio e = 0.25 is typical for rockfill material used in dam construction (Kermani, Konrad, & Smith, 2018). However, the unsaturated water content is lower due in the rockfill material to a lower fines content.

FFAB: The fine filter amended with bentonite (FFAB) geotechnical properties are based on the as-built data gathered from the construction of the Phase 1 dikes (SNC-Lavalin, 2019). The fines content of FFAB and its *in situ* dry density averaged 13.3% and 2047 kg/m³, respectively. The other geotechnical properties were computed using a specific gravity of soil solids G_s = 2.7 which is lower than the value for fine filter material to account for the presence of bentonite. An arbitrary specific surface area of 40 m²/g measured out of a Fairbanks silt (Anderson, Tice, & McKim, 1973) was selected to take into account the presence of unfrozen water within the frozen FFAB due to the presence of bentonite.

2.3.4.2 Geothermal properties

The basic input data for the modelling software are the volumetric water content, thermal conductivity and volumetric heat capacity. Advanced functions such as thermal conductivity and unfrozen water content vs temperature relationships can be implemented into the software as well.

The generalized thermal conductivity model described by Côté & Konrad (2005) was used for calculating thermal properties of the soils. The empirical method developed by Kersten (1949), yet simple, was not suitable for this study because of the wide range of water contents and degrees of saturation in the soils. The model used in this study integrates the effects of porosity, degree of saturation, mineral content, grain-size distribution and particle shape on the thermal conductivity of unfrozen and frozen soils (Côté & Konrad, 2005). The thermal conductivity is calculated as

$$k = \left(k_{\text{sat}} - k_{\text{dry}}\right)k_{\text{r}} + k_{\text{dry}}$$

where k_{sat} and k_{dry} are the thermal conductivity of the saturated and dry soils, respectively, and k_{r} is the relative thermal conductivity, which is a function of the degree of saturation of the soil, its physical state (frozen or unfrozen) and the type of soil. The parameter k_{sat} is a geometric mean of the soil components (solid particles, ice and water) and k_{dry} depends on the porosity and the type of particles. The thermal conductivity takes into account the amount of unfrozen water in the soil in both unfrozen and frozen states, which were calculated using the relationship developed by Anderson & Tice (1972), which is

$$\ln(w_{\text{u}}) = 0.2618 + 0.5519\ln(S_{\text{s}}) - 1.449\ln(-T)S_{\text{s}}^{-0.264}$$

where w_u is the unfrozen water content (% by weight), S_s is the specific surface area (m^2/g) and T is the temperature (°C). Typical values for the specific surface area were taken in the literature for bedrock, ice-poor till and FFAB (Anderson & Tice, 1972; Smith & Tice, 1988; Anderson, Tice, & McKim, 1973; Andersland & Ladanyi, 2004). The unfrozen water content in coarse filter and rockfill is assumed to be negligible. Hivon & Sego (1995) showed that for a sand similar to the esker material, the unfrozen water content remains zero for a range of temperatures between -12 and -1 °C, hence the unfrozen water content is negligible for the esker material and fine filter as well. The normalized water content, defined as the ratio of unfrozen water content θ_u to total water content θ_w, is shown in Figure 2-7. The relationships for the materials used in the sensitivity analysis (S. A.) are included in dashed lines.

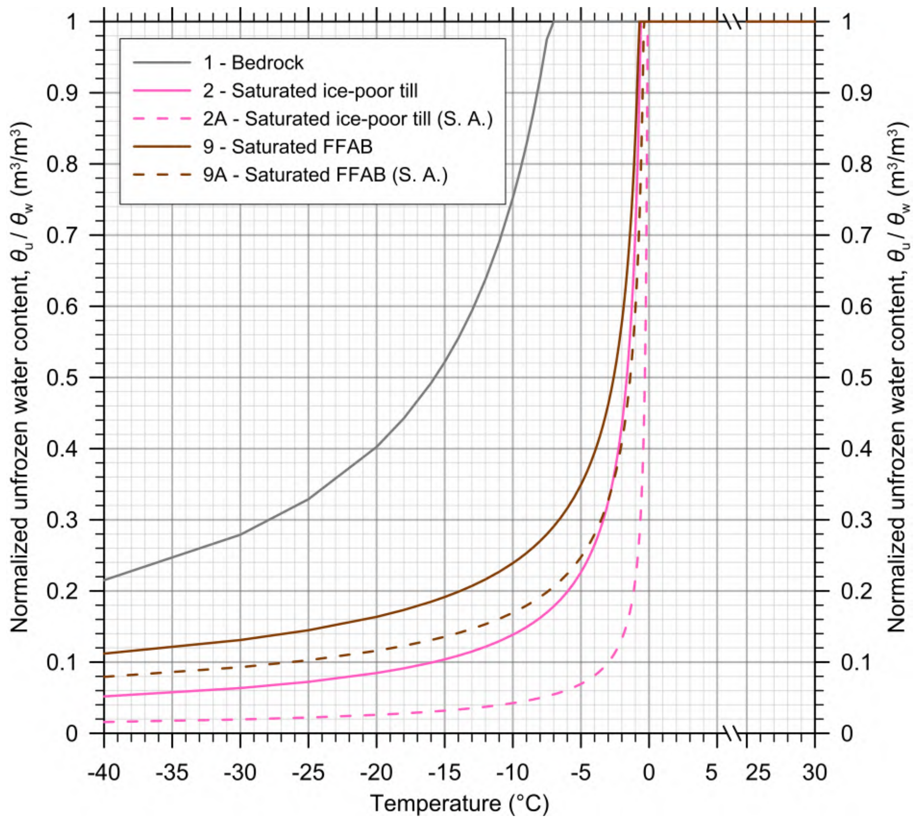


Figure 2-7: Normalized water content as a function of temperature for three materials

The unfrozen water content has an impact on the thermal conductivity of frozen soils. Because the thermal conductivity of water is lower than that of ice, soils in the frozen state have a higher thermal conductivity. The presence of unfrozen water in frozen soils can decrease their thermal conductivity, hence the importance of taking that aspect into account. The thermal conductivity against temperature curves of the materials affected by the presence of unfrozen water below 0 °C are plotted in Figure 2-8. Once again, the relationships for the materials used in the sensitivity analysis (S. A.) are included in dashed lines.

The difference between the frozen and unfrozen thermal conductivities can be attributed to the water content of the soils. Because the saturated ice-poor till material has a higher water content, its thermal conductivity in the unfrozen state is lower because the thermal conductivity of water is lower than that of mineral particles. Bedrock, at the opposite side, has a very low water content, therefore the rise of the thermal conductivity in the frozen state is marginal.

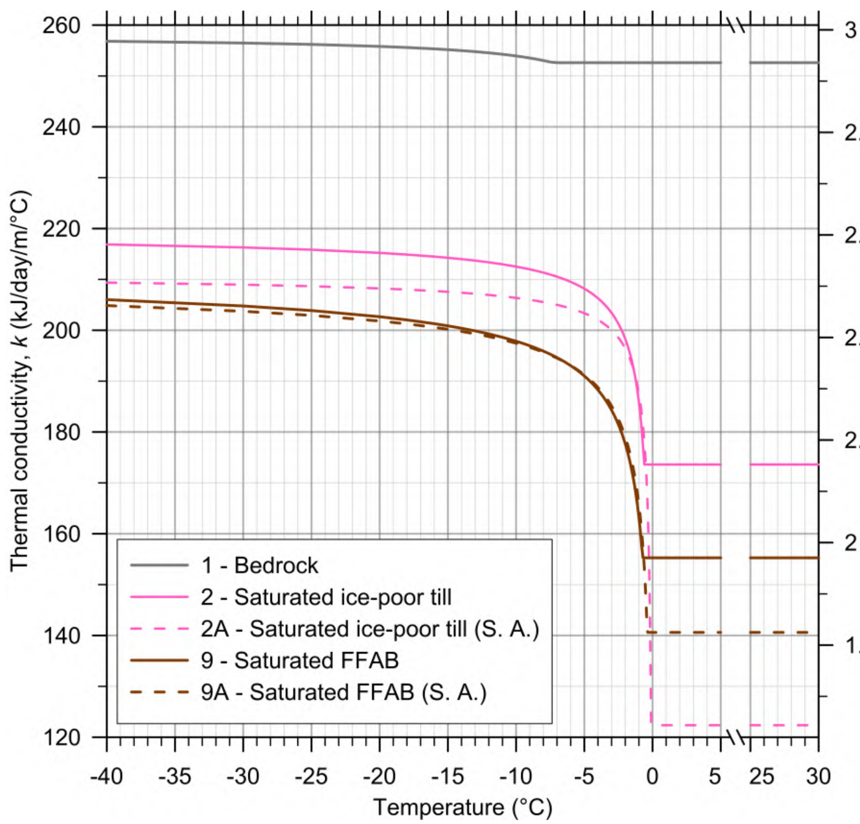


Figure 2-8: Thermal conductivity as a function of temperature for three materials

The volumetric thermal capacities of the soils were calculated using Dysli's approach (1991). The unfrozen heat capacity C_u is calculated as

$$C_\mathrm{u} = (1-n)C_\mathrm{s} + (S_\mathrm{r} n)C_\mathrm{w}$$

where n is the porosity, S_r is the degree of saturation, and C_s and C_w are the volumetric heat capacity of soil particles and water, respectively. On the other hand, the frozen volumetric heat capacity C_f is calculated as

$$C_\mathrm{f} = (1-n)C_\mathrm{s} + (S_\mathrm{r} n - \theta_\mathrm{u})C_\mathrm{i} + \theta_\mathrm{u} C_\mathrm{w}$$

where C_i denotes the volumetric heat capacity of ice and θ_u denotes the volumetric unfrozen water content. For granular soils, a typical value of C_s = 2000 kJ/m^3/°C was assumed for mineral particles. The volumetric heat capacity of water and ice are C_w = 4190 kJ/m^3/°C (Weast, Astle, & Beyer, 1984) and C_i = 1900 kJ/m^3/°C (Alter, 1969). Since the values of C_u and C_f are fixed in the modelling software, it is assumed that θ_u = 0 in the calculation of the frozen heat capacity.

Table 2-3 presents the geotechnical and thermal properties deemed the most representative of the site and assumed for all but the sensitivity analysis. The geothermal parameters used in the sensitivity analysis are presented in **Appendix A**.

Table 2-3: Geotechnical and geothermal properties of the materials used in the thermal model

Layer	1 - Bedrock	2 - Saturated ice-poor till	3 - Saturated fine filter	4 - Unsaturated fine filter	5 - Saturated coarse filter	6 - Unsaturated coarse filter	7 - Saturated rockfill	8 - Unsaturated rockfill	9 - Saturated FFAB	10 - Unsaturated FFAB
Description	Greywacke / sandstone	Silty and sandy gravel (GM)	Poorly graded sand (SP)	Poorly graded sand (SP)	Crushed rock / poorly graded gravel with no fines	Crushed rock / poorly graded gravel with no fines	Crushed rock	Crushed rock	Poorly graded sand (SP) amended with 6% bentonite	Poorly graded sand (SP) amended with 6% bentonite
Geotechnical Parameter										
Dry density, ρ_d (kg/m³)	2 755	2 178	2 149	2 149	2 240	2 240	2 240	2 240	2 047	2 047
Density of soil solids, ρ_s (kg/m³)	2 800	2 650	2 800	2 800	2 800	2 800	2 800	2 800	2 700	2 700
Bulk density, ρ (kg/m³)	2 771	2 356	2 381	2 199	2 440	2 291	2 440	2 262	2 289	2 095
Gravimetric water content, w	0.6%	8.2%	10.8%	2.3%	8.9%	2.3%	8.9%	1.0%	11.8%	2.3%
Volumetric water content, θ_w	1.6%	17.8%	23.3%	5.0%	20.0%	5.1%	20.0%	2.2%	24.2%	4.8%
Degree of saturation, S_r	100%	100%	100%	22%	100%	26%	100%	11%	100%	20%
Porosity, n	0.016	0.18	0.23	0.23	0.20	0.20	0.20	0.20	0.24	0.24
Void ratio, e	0.016	0.22	0.30	0.30	0.25	0.25	0.25	0.25	0.32	0.32
Specific surface area, S_s (m²/g)	6[(a)]	15[(b)]	40	0	0	0	0	0	40[(c)]	40[(c)]
Geothermal Parameters										
Unfrozen thermal conductivity, k_u (kJ/day/m/°C)	Refer to Figure 2-8	Refer to Figure 2-8	156	114	163	129	163	105	Refer to Figure 2-8	109
Frozen thermal conductivity, k_f (kJ/day/m/°C)			212	108	212	125	212	94		102
Unfrozen Heat capacity, C_u (kJ/m³/°C)	2 035	2 390	2 509	1 745	2 437	1 815	2 437	1 694	2 529	1 716
Frozen Heat capacity, C_f (kJ/m³/°C)	1 998	1 982	1 977	1 630	1 980	1 698	1 980	1 643	1 976	1 607

<u>References:</u>
(a) Basalt (Anderson & Tice, Predicting unfrozen water contents in frozen soils from surface area measurements, 1972)
(b) West Lebanon gravel (Smith & Tice, 1988)
(c) Fairbanks silt (Anderson, Tice, & McKim, 1973)

2.3.5 Phase change of water

Freezing point depression is associated with a specific temperature where free water starts to freeze. For pure water, the freezing point depression is equal to 0°C. It can be predominantly affected by the salinity (total dissolved solids in the solution) or by matric potential in fine-grained soils. Due to the lack of data, the assumption was made that the freezing point of water was 0 °C. This assumption was used for all thermal analyses presented in this study.

2.3.6 Surface n-factor

To simplify calculations in thermal modelling, the impact of solar radiation, snow cover, topography, etc. can be evaluated in the model with the use of surface n-factors. The freezing n-factor n_f corresponds to the ratio between the ground surface freezing index I_{sf} and the air freezing index I_{af}, whereas the thawing n-factor n_t corresponds to the ratio between the ground surface thawing index I_{st} and the air thawing index I_{at}. The freezing index is the sum of negative degree-days over a given period (thawing index is the sum of positive degree-days).

Because of the installation of the thermistors at the IVR D-1 Dike location took place in December 2019 and the thermal analysis was first conducted during summer 2020, the collected data only cover the first half year period (December 2019 to June 2020). Therefore, the surface freezing n-factor n_f was estimated using the partial dataset available during winter. For the four thermistor strings installed at the IVR D-1 Dike location, the n_f values computed from December 12, 2019 to June 3, 2020 averaged 0.8.

However, the thawing n-factor n_t could not be directly computed using the available data due to the absence of data recorded during summer at the time of the analysis. Trial and error simulations during the calibration process (refer to Section 2.4) gave an empirical value of n_t = 1.7.

Air temperature and ground surface temperature data at the WRSF Dike and Mammoth Dike are available since May 2019, which allowed computing the n-factors for the rockfill material for the 2019-2020 period. The n_f and n_t values from June 4, 2019 to June 3, 2020 averaged 0.7 and 1.0, respectively.

The n-factors empirically determined for the tundra at the IVR D-1 Dike location were used for the initial calibration of the model as well as for the upstream and downstream natural terrain (modelled as ice-poor till), whereas the rockfill n-factors computed at the WRSF Dike and Mammoth Dike were used for the dike crest, berm and slopes. The surface n-factors used in this study are summarized in Table 2-4.

Table 2-4: Surface n-factors used for the thermal modelling

Material	n_t	n_f
Tundra	1.7	0.8
Rockfill	1.0	0.7

It should be noted that the average air temperature data from the Amaruq Weather Station were used for computing the surface n-factors presented in Table 2-4.

2.3.7 Geothermal gradient

The previous thermal analyses (SNC-Lavalin, 2018a; 2018b; 2018c) used a geothermal gradient of 0.0217°C/m. The same value was used in the current study.

2.3.8 IVR Attenuation Pond water level

During the mining operations, the IVR Attenuation Pond water level is expected to vary throughout the year. According to the water balance, the minimum water level of 158.3 masl will be reached during summer (July to September) while the pond level will rise during winter operations up to approximately 163.2 masl. To simplify the modelling process and stay on the conservative side, the modelled IVR Attenuation Pond water level was fixed at the maximum operational water level of 163.2 masl except during the environmental design flood (EDF) event where the water level reaches 164.7 masl. The duration of the transient analysis represents 15 years of operation where the EDF event is repeated on a yearly basis as shown on Figure 2-9.

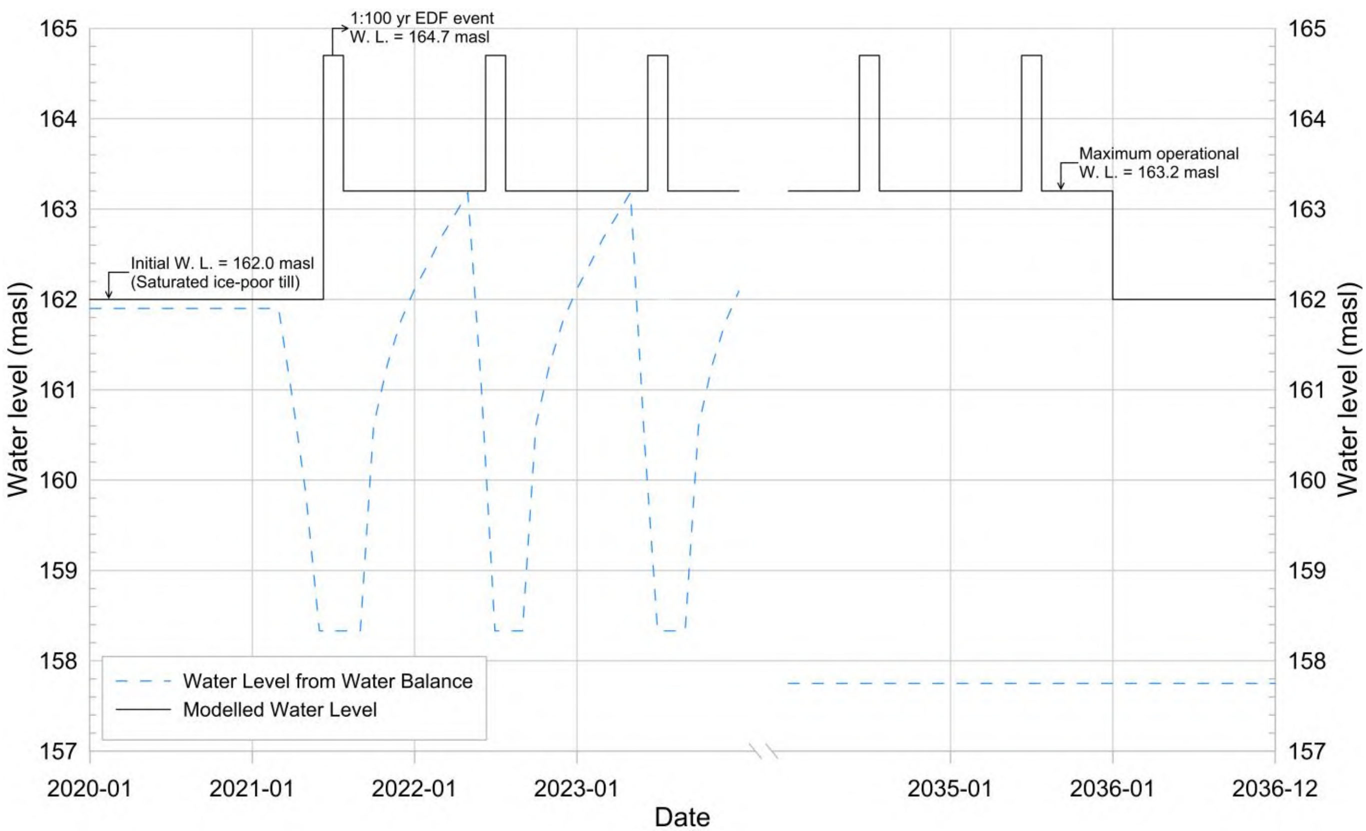


Figure 2-9: Modelled IVR Attenuation Pond water level

The initial conditions of the thermal model correspond to the thermal regime before 2021, where the ice-poor till is considered fully saturated. Fifteen (15) years of operations from 2021 to 2035 with a varying water level are then modelled. The final conditions are reached at the beginning of 2036 where the IVR Attenuation Pond will be kept at its minimum level.

In order to evaluate the thermal effect of an eventual 1:100 year spring flood event (SNC-Lavalin, 2020b), a constant temperature boundary condition of 18°C applied for 45 days up to elevation 164.7 masl as shown on Figure 2-10.

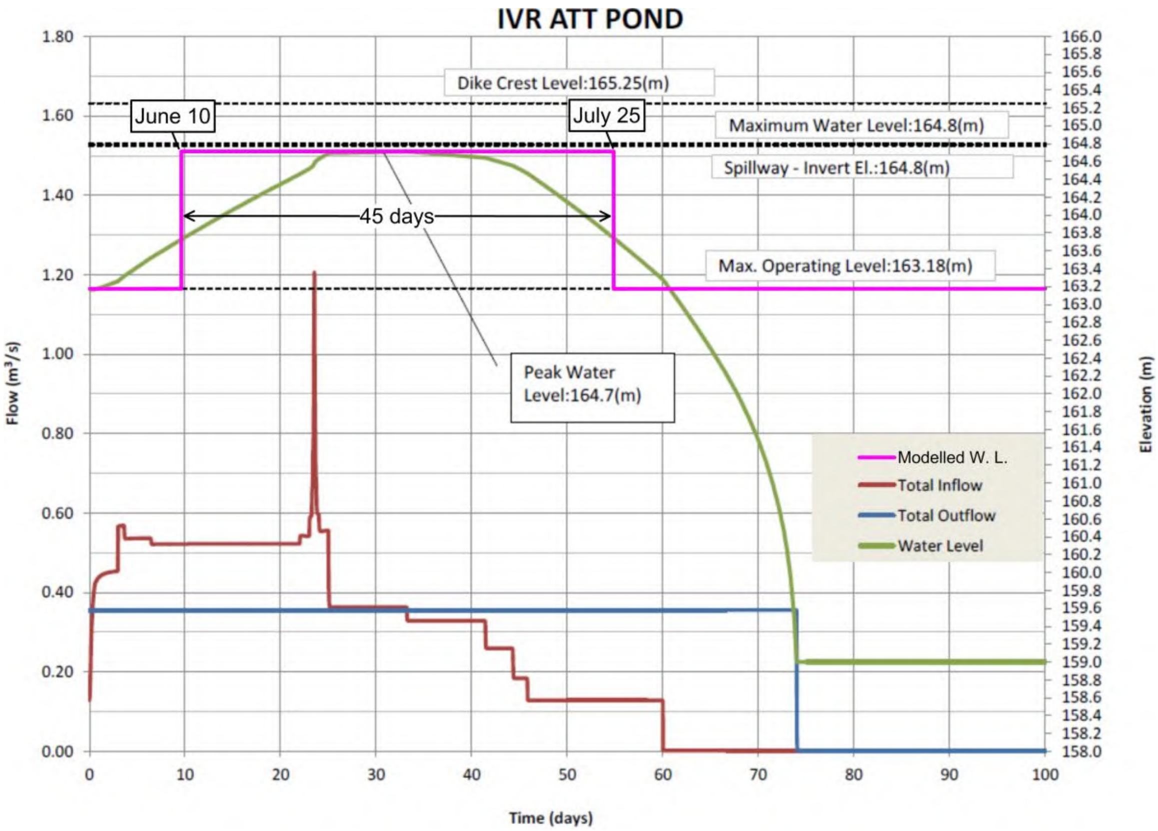


Figure 2-10: Modelled Attenuation Pond water level during a 1:100 year spring flood event (after SNC-Lavalin (2020b))

2.3.9 Boundary conditions

2.3.9.1 Ground surface

In the steady-state analysis, the upper surface boundary condition corresponds to the mean annual ground temperature (MAGT) at the ground surface. This value was calculated using the air temperature dataset and by multiplying the values over 0°C by n_t (1.7) and the values below 0°C by n_f (0.8). By correlating the air temperature with the corresponding n-factor, the MAGT can be estimated at -6.7°C for the Amaruq (AMQ) site and at -5.2°C for the Meadowbank (MB) site.

In the transient analyses, ground surface boundary conditions were correlated with the air temperature using a thermal modifier function (n-factors). As mentioned in Section 2.3.6, different n-factors were used depending on the ground surface: the natural ground surface (tundra) empirically determined n-factors differ from those computed at the WRSF Dike and Mammoth Dike for the rockfill material. These 365-day cycle temperature datasets are compared with the MB air temperature and AMQ air temperature functions on Figure 2-11.

As mentioned in Section 2.3.1, The AMQ air temperature function is used for computing n-factors and for the initial calibration of the model, whereas the MB air temperature function is used for the thermal modelling of the IVR D-1 Dike.

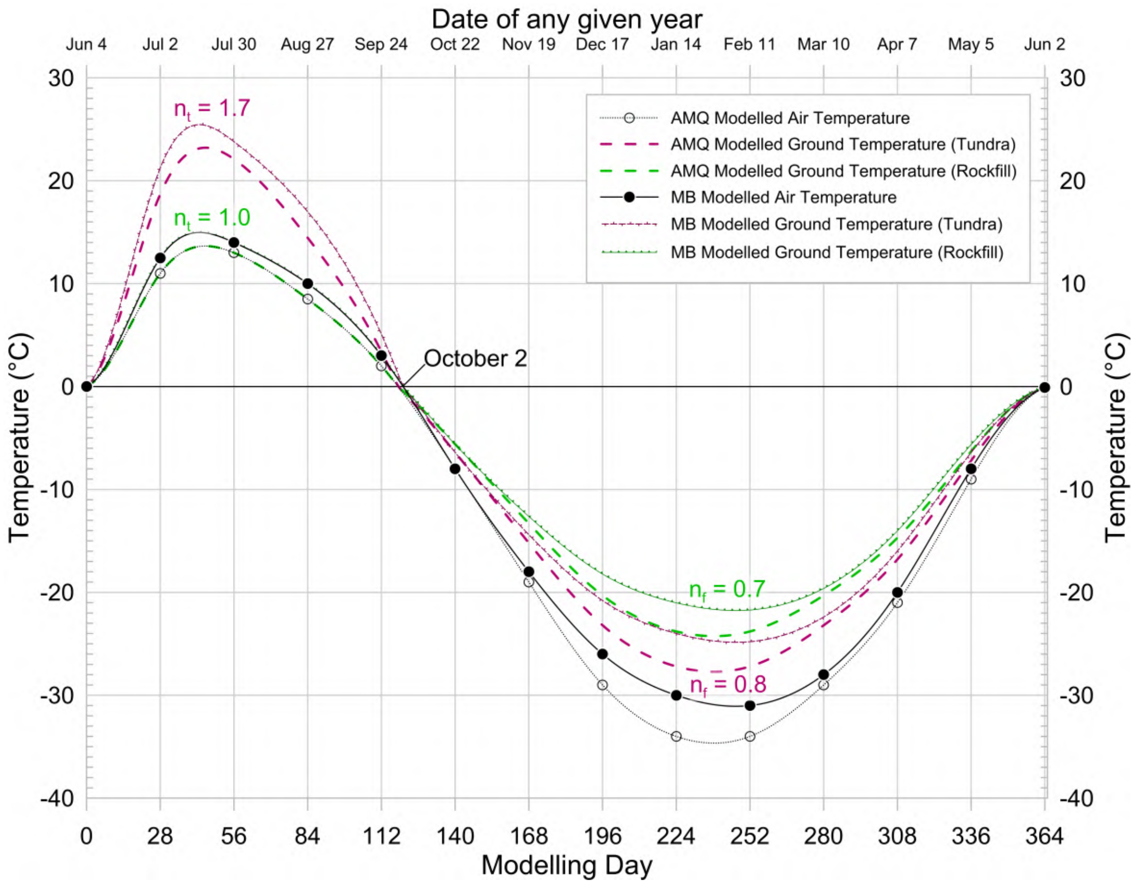


Figure 2-11: Ground surface boundary condition for tundra and rockfill materials

2.3.9.2 IVR Attenuation Pond

The water temperature during summer is set at 18°C (from June 10 to August 31 every given year) whereas the water pumped in the IVR attenuation pond during winter is set at a temperature of 4°C (September 1 to June 9 every given year).

2.3.9.3 Lower limit of the model

The bottom of the thermal model was set at 100 masl so that the variation in the thermal regime due to the changing upper boundary conditions are not tampered by the constant temperature boundary condition at the lower limit of the model. The constant temperature value of -5.4 °C for the Amaruq site and of -3.9°C at the Meadowbank site were calculated using the MAGT at the elevation 162.0 masl and the geothermal gradient.

2.3.9.4 Lateral limits of the model

Zero heat flux is imposed on the lateral limits of the model to avoid errors in the temperature distribution near the sides of the model.

2.3.9.5 Dike temperature

The initial temperature of the dike, which include all construction materials (rockfill, filters, FFAB), is fixed at -5 °C based on the modelled ground temperature as of April 30. The regional boundary condition is applied to the whole dike for one day in the transient analysis, after which the dike temperature boundary condition is removed.

2.3.9.6 Summary of boundary conditions

All the boundary conditions used in the thermal modelling are summarized in Table 2-5.

Table 2-5: Summary of boundary conditions used in thermal modelling

Name	Type	Location	Value	
			Calibration	Thermal Modelling
Bedrock temperature	Constant temperature	100 masl	-5.4°C	-3.9°C
Initial dike temperature	Constant temperature	IVR D-1 Dike	n/a	-5°C
MAGT	Constant temperature	Ground surface	-6.7°C	-5.2°C
No heat flux	Total flux	Sides of the model	0 kJ/day	0 kJ/day
Ground surface temperature (IVR tundra)	Thermal function	Natural ground surface	Refer to Figure 2-11	
Ground surface temperature (rockfill)	Thermal function	Dike surface		
Water temperature, winter	Constant temperature	IVR Attenuation Pond	n/a	4°C
Water temperature, summer	Constant temperature	IVR Attenuation Pond	n/a	18°C

2.4 Calibration of the model

The main objective of calibrating the model is to ensure that boundary conditions and thermal properties of the materials used in the model reflect what is observed on the field.

The model was calibrated using the four thermistor strings installed at the IVR D-1 Dike location as presented in Section 2.2. A thermal model was built for calibration purposes using a simplified column of soil with the average overburden thickness of three (3) metres encountered while drilling the four boreholes for the thermistor installation. The model is 20 m wide and 62 m high with a constant mesh size of one metre.

The calibration starts with a steady-state analysis where the ground surface boundary condition is a constant temperature of -6.7 °C which corresponds to the MAGT using the Amaruq average air temperature in 2019-2020 (refer to Section 2.3.9.1). For the entire calibration process, the lateral boundary conditions are zero heat flux and the bottom boundary condition at 100 masl is a constant bedrock temperature of -5.4 °C. The thermal profile obtained from the steady-state analysis corresponds to the linear interpolation between the constant temperature boundary conditions at both extremities of the model.

A 9-year transient analysis based on the steady-state initial conditions was then conducted to stabilize the annual temperature variations of the soil column within the model. Finally, a 373-day transient analysis with a tigher time step was carried out to assess the annual temperature variation on a daily basis. The modelling sequence is summarized in Table 2-6.

Table 2-6: Modelling sequence for the initial calibration of the model

Step #	Type of analysis	Duration	Time step	Saving increment	Parent analysis	Ground surface boundary condition
1	Steady-State	-	-	-	-	MAGT = -6.7 °C
1A	Transient	9 years	5 days	30 days	Step #1	Amaruq air temperature function with IVR tundra n-factors (n_t = 1.7, n_f = 0.8)
1B	Transient	373 days†	1 day	1 day	Step #1A	

†This corresponds to June 4 of any given year up to June 10 the year after.

The model was calibrated using a modifier function for the Amaruq air temperature function (Section 2.3.1). The modifier function is a 2-step data function comprising a value for the sub-zero temperatures on the one hand and another value for the positive temperatures on the other hand. Those factors correspond to the freezing and thawing n-factors, respectively. Those factors allow converting the air temperature dataset to ground surface temperature by accounting for net radiation, vegetation, snow cover, ground thermal properties, surface relief and subsurface drainage (Andersland & Ladanyi, 2004).

As mentioned in Section 2.3.6, the freezing n-factor n_f = 0.8 was computed using the available winter ground surface temperature data for the four thermistor strings at the IVR D-1 Dike location. However, the thawing n-factor n_t = 1.7 was empirically determined during the modelling process by trial and error simulations. Every time a different empirical value of n_t was set in the model, the MAGT value was adjusted because it is linked with the surface n-factors; the bottom of the model constant temperature boundary condition was also updated because it is linked to the MAGT using the geothermal gradient value. The thawing n-factor n_t was determined comparing the maximum and minimum temperature profile from December 12 to June 10 from the thermal model during the third step of the calibration with the trumpet curves from the thermistor readings of the four thermistor strings installed at the IVR D-1 Dike location. The modelled temperature and the actual thermistor readings matches as shown on Figure 2-12.

The agreement below three metres depth (in the bedrock) is good whereas some differences were noted for the overburden. These differences may lie in the assessment of the geothermal properties used for the saturated ice-poor till material. Nevertheless, using an unfrozen water vs temperature function with a specific surface area of 15 m²/g for the ice-poor till (Smith & Tice, 1988) yielded a much better fit with the thermistor readings compared to neglecting the presence of unfrozen water within the foundation soil.

In addition to the presentation of the thermal profile shown on Figure 2-12B, the evolution of the temperature over time at four (4) specific depths was compared between the thermal model and the actual thermistor readings from December 12, 2019 to June 9, 2020 (Figure 2-13).

The scatter between the output from the model and the actual thermistor readings decreases with increasing depth. However, there is some discrepancy noted between the thermistor strings; Thermistor BH-T2 tend to yield higher temperature readings especially at lower depths whereas Thermistor BH-4 generally yield lower temperature readings on the whole profile. This effect can also be seen on Figure 2-12A, where the whole thermal profile of BH-4 is shifted to the left (lower temperatures) compared to the rest of the thermistor strings, while the thermal profile of BH-T2 shifts to the right (higher temperatures) above six (6) metres depth. Nevertheless, the thermal model generally allows a replication of the general temperature trend given by the four (4) thermistor strings installed at the IVR D-1 Dike location.

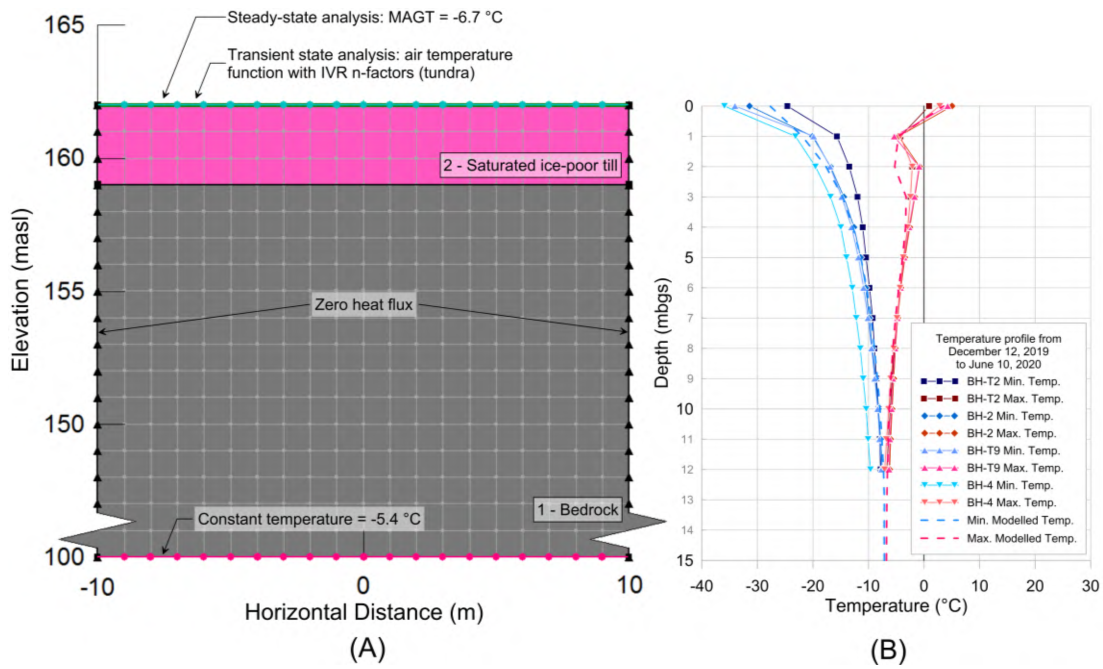


Figure 2-12: Thermal model for the initial calibration (A) and calibration results compared with *in situ* thermistor readings (B)

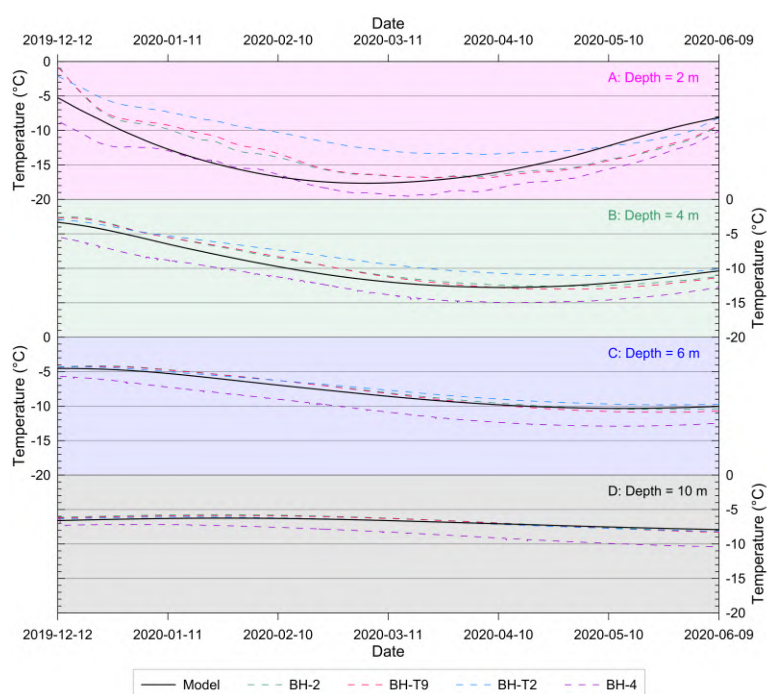


Figure 2-13: Comparison of the modelled temperature over time and thermistor readings at depths of (A) 2 metres, (B) 4 metres, (C) 6 metres and (D) 10 metres

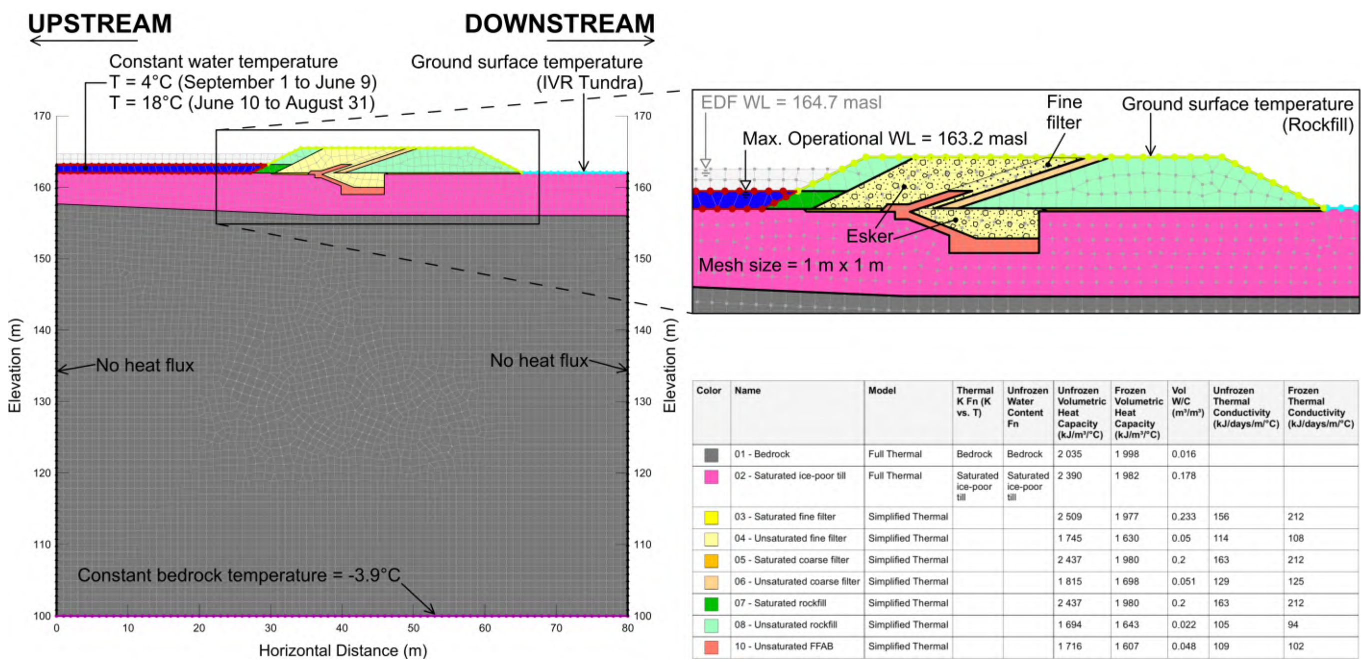
It should be noted that the thawing n-factor value n_t was determined assuming a fixed freezing n-factor value n_f = 0.8 computed from the partial dataset available during the 2019-2020 winter. The freezing n-factor for the entire winter could be different from 0.8 due to the varying weather conditions (snow cover, solar radiation, etc.) that were not taken into account from October to early December 2019.

Finally, the calibration of the model was done during summer 2020 and at that time, thermistor readings available up to June 2020 were available. That explains why the period covered by the calibration of the model is restricted to six (6) months of data.

3.0 Thermal Modelling

3.1 Modelling sequence and geometry

The geometry of the base case thermal model (Section B-B as shown on Figure 2-1) as well as the boundary conditions and mesh are shown on Figure 3-1. The geomembrane and safety berms were not considered in the thermal analysis to simplify the modelling process.



Color	Name	Model	Thermal K Fn (K vs. T)	Unfrozen Water Content Fn	Unfrozen Volumetric Heat Capacity (kJ/m³/°C)	Frozen Volumetric Heat Capacity (kJ/m³/°C)	Vol W/C (m³/m³)	Unfrozen Thermal Conductivity (kJ/days/m/°C)	Frozen Thermal Conductivity (kJ/days/m/°C)
	01 - Bedrock	Full Thermal	Bedrock	Bedrock	2 035	1 998	0.016		
	02 - Saturated ice-poor till	Full Thermal	Saturated ice-poor till	Saturated ice-poor till	2 390	1 982	0.178		
	03 - Saturated fine filter	Simplified Thermal			2 509	1 977	0.233	156	212
	04 - Unsaturated fine filter	Simplified Thermal			1 745	1 630	0.05	114	108
	05 - Saturated coarse filter	Simplified Thermal			2 437	1 980	0.2	163	212
	06 - Unsaturated coarse filter	Simplified Thermal			1 815	1 698	0.051	129	125
	07 - Saturated rockfill	Simplified Thermal			2 437	1 980	0.2	163	212
	08 - Unsaturated rockfill	Simplified Thermal			1 694	1 643	0.022	105	94
	10 - Unsaturated FFAB	Simplified Thermal			1 716	1 607	0.048	109	102

Figure 3-1: Thermal model of IVR D-1 Dike including boundary conditions and material properties

As described in Section 2.3.9, the bottom boundary condition applied for the whole duration of the modelling process is a constant bedrock temperature of -3.9°C. It is not expected that the change in thermal regime at the ground surface following the construction of the dike will affect the temperature 60 metres below ground surface considering the limited lifespan of the structure. Zero heat flux is considered on each side of the model as well for the whole duration of the modelling as well.

The ground surface boundary conditions depend on the type of material: engineered material (rockfill) have different thermal modifier functions (surface n-factors) than the natural tundra as explained in Sections 2.3.6 and 2.3.9.1.

The model was first calibrated for the Meadowbank field conditions. Similar to the calibration process described in Section 2.4, ten years of transient analysis were modelled for the calibration of the thermal model and they represent the last ten years (2010-2020) before construction assuming identical climate conditions throughout the years. The IVR D-1 Dike construction schedule was simplified by assuming the dike is fully constructed on a one-day period as of April 30, 2021. Fifteen (15) years of operations are then modelled at the maximum operational IVR Attenuation Pond water level (163.2 masl) including an annual 1:100 year spring flood (EDF) which raises the water level up to 164.7 masl during 45 days. These steps are described in Table 3-1.

Table 3-1: Modelling sequence for the thermal analysis at IVR D-1 Dike

Step #	Type of analysis	Duration	Time step	Saving increment	Date modelled		Initial conditions	Comment
					From	To		
1	Steady-state	-	-	-	-	-	-	MAGT = -3.9°C
1A	Transient	9 years	5 days	365 days	2010-06-04	2019-06-03	Step #1	For initial calibration
1B	Transient	371 days	1 day	1 day	2019-06-04	2020-06-09	Step #1A	Last year of calibration
1C	Transient	323 days	1 day	1 day	2020-06-10	2021-04-29	Step #1B	Initial conditions up to April 29, 2021
2	Transient	1 day	1 day	1 day	2021-04-30		Step #1C + Dike temperature at -5°C†	Excavation and dike construction as of April 30, 2021
3	Transient	41 days	1 day	1 day	2021-05-01	2021-06-09	Step #2	Operation up to June 9, 2021 (WL = 162.0 masl)
4A	Transient	45 days	1 day	1 day	2021-06-10	2021-07-24	Step #3	EDF event #1 (WL = 164.7 masl)
4B	Transient	37 days	1 day	1 day	2021-07-25	2021-08-31	Step #4A	Summer operation #1
4C	Transient	277 days	1 day	1 day	2021-09-01	2022-06-03	Step #4B	Winter operation #1
5	Transient	13 years	5 days	65 days	2022-06-04	2035-06-03	Step #4C	Annual EDF event
6	Transient	6 days	1 day	1 day	2035-06-04	2035-06-09	Step #5	June 4 to June 9, 2035
7A	Transient	45 days	1 day	1 day	2035-06-10	2035-07-24	Step #6	EDF event #15 (WL = 164.7 masl)
7B	Transient	37 days	1 day	1 day	2035-07-25	2035-08-31	Step #7A	Summer operation #15
7C	Transient	277 days	1 day	1 day	2035-09-01	2035-06-03	Step #7B	Winter operation #15
8	Transient	210	1 day	5 days	2036-06-04	2036-12-31	Step #7C	First year of closure

†Refer to Section 2.3.9.5.

Tighter time step and saving increment allowed the evaluation of the annual ground temperature amplitude, which was used to assess the active layer depth within the dike as a performance indicator of the design.

3.2 Modelling results

Different cases were studied in this thermal analysis and presented in this section:

> The base cross section with the dike geometry as presented in Figure 2-1 (Section B-B);
> The same cross section (B-B) but with a 12-m-long upstream thermal berm instead of 6 m;
> Section D-D at station 0+360 where the natural ground elevation is higher than the maximum operational water level;
> A longitudinal section at the west abutment (F-F) comprising a thermal berm;
> A sensitivity analysis on Section B-B with the 12-m berm where the construction and natural materials are in a looser state.

All the analyses were conducted using the same modelling sequence and boundary conditions described in Section 3.1 with the IVR Attenuation Pond water level shown on Figure 2-9. The only difference between the analyses resides in the geometry and location of the analysis, except for the sensitivity analysis where the geothermal properties are the variable parameters.

3.2.1 Base case cross section (Section B-B)

The base case model includes a dike geometry comprising of a 6-m-wide upstream berm at elevation 165.5 masl as shown on Figure 2-1. This cross section was selected for the base case thermal analysis since it is located at the lowest ground elevation (162.0 masl), that is 1.2 m below maximum operating pond level. It is thus subjected to heat inflow from the water ponding against the upstream slope. The dike performance is evaluated in terms of thaw front penetration which peaks in September of each year. The thermal profile of the IVR D-1 Dike and its foundation at the date corresponding to the maximum thaw front penetration during the first year of operation is shown on Figure 3-2.

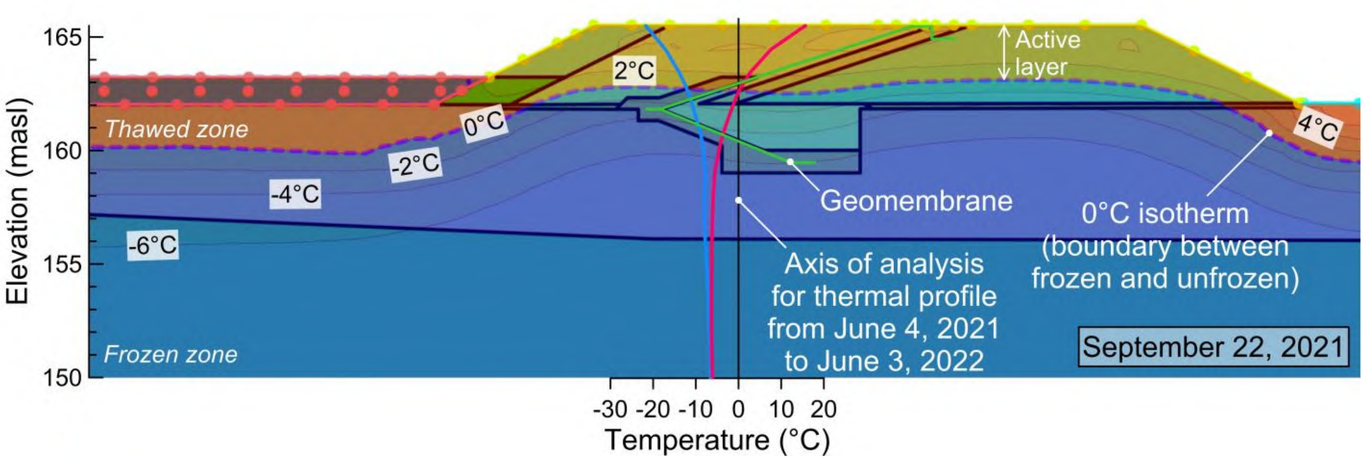


Figure 3-2: Thermal regime as of September 22, 2021 including temperature profile of the upstream berm and cut-off trench for the base case cross section (B-B)

The annual temperature variation of the upstream berm can be evaluated by the thermal profile drawn on Figure 3-2. Since the maximum temperature curve (in red) 0°C elevation matches the bottom of the active layer (0°C isotherm), it can be concluded that the thermal regime as of September 22 corresponds to the maximum thaw depth of the first year of operation.

The results presented on Figure 3-2 show that the active layer depth along the axis of analysis is approximately 3.2 m. This implies that the top portion of the FFAB (over elevation 162.3 masl) will be subjected to freeze and thaw cycles. The connection weld of the geomembrane at elevation 161.8 masl should stay marginally frozen as per the thermal modelling results. However, given the inherent uncertainty of the thermal model and the presence of bentonite in the FFAB layer, which lowers the freezing point of pore water, it is expected that the connection weld and its surrounding environment may reach unfrozen conditions at the end of the summer. The anchor of the geomembrane at the bottom of the cut-off trench is expected to remain at a temperature of about -5°C or lower throughout the year.

However, due to the upstream heat intake from the IVR Attenuation Pond, the thermal regime is expected to evolve throughout the years of the IVR D-1 Dike operation. The presence of water at the operational level at 163.2 masl will degrade the underlying permafrost in the IVR Attenuation Pond area. This effect can be observed by looking at the thermal profile of the IVR D-1 Dike and its foundation during the fifteenth year of operation, which corresponds to the last operational year modelled. Similar to the results shown on Figure 3-2, the thermal profile of the IVR D-1 Dike and its foundation at the date corresponding to the maximum thaw front penetration during the last year of operation is shown on Figure 3-3.

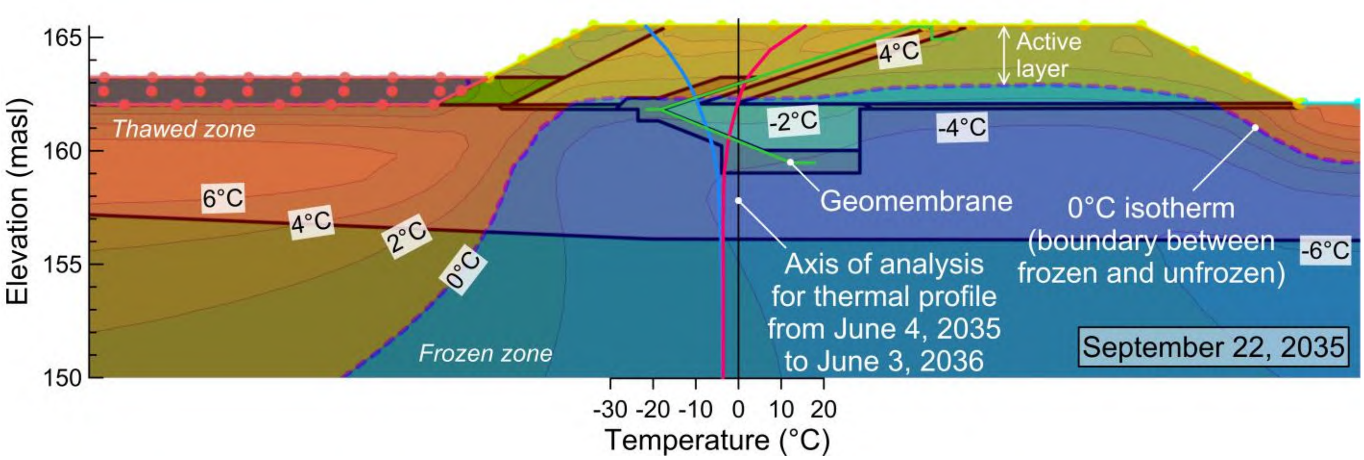


Figure 3-3: Thermal regime as of September 22, 2035 including temperature profile of the upstream berm and cut-off trench for the base case cross section (B-B)

There is also a difference in the thermal regime within the cut-off trench of the IVR D-1 Dike, where the maximum temperature at the anchor point of the geomembrane at the bottom of the cut-off trench increased from -5°C during the first year of operation to -3°C after 15 years. The 0°C isotherm is also closer to the connection weld, where the thermal regime at the end of summer after 15 years shows temperature close to 0°C in that area. The modelling of the IVR Attenuation Pond with heat transfer by conduction only shows a global warming from the upstream side of the structure.

However, an uncertainty remains as to the efficiency of the esker berm to minimize convective heat transfer towards the cut-off trench. As stated in Section 2.0, only heat transfer by conduction is considered in the current study; if heat transfer by convection became significant, the thermal regime estimated on Figure 3-3 would underestimate the actual foundation and dike temperatures. After 15 years of operation, when the thickness of the active layer reaches its maximum, the esker berm is expected to be entirely unfrozen. Since the rockfill material is pervious, the only barrier remaining between the IVR Attenuation Pond and the cut-off trench is the unfrozen esker material. If the esker material has a lower fines content than expected, thus having a higher hydraulic conductivity, the effect of convective heat transfer may be more significant than anticipated in the current thermal regime assessment. To account for that uncertainty, another iteration of Section B-B was studied where the upstream thermal berm width was extended to 12 m. The results are presented in Section 3.2.2.

3.2.2 Section B-B with extended 12-m-wide upstream thermal berm

A thermal analysis was carried out by extending the width of the esker thermal berm up from six (6) metres to 12 metres. The objective of modelling this geometry was to evaluate the difference in thermal regime especially in the cut-off trench of the IVR D-1 Dike.

The difference in thermal regime between the two geometries was assessed during the last year of operation to evaluate the benefits of the construction of a wider thermal berm in the long term. The thermal profile of the IVR D-1 Dike with the thermal berm extended to 12 metres width and its foundation at the date corresponding to the maximum thaw front penetration during the last year of operation is shown on Figure 3-4.

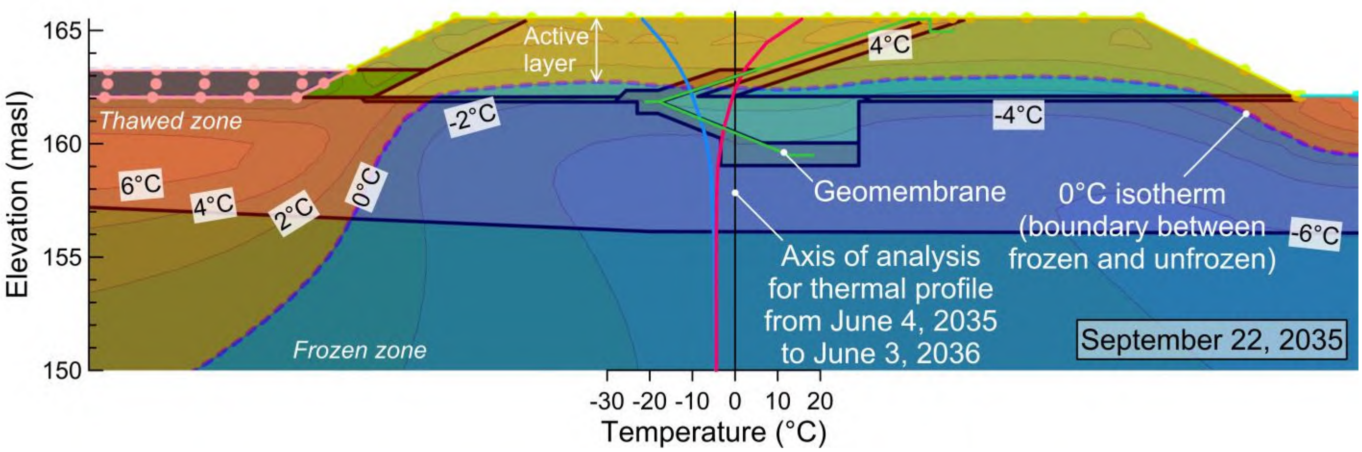


Figure 3-4: Thermal regime as of September 22, 2035 for Section B-B (with the thermal berm width extended to 12 m)

By comparing the thermal regime during the last modelled year of operation of 12-m-wide berm (Figure 3-4) and the 6-m-wide berm (Figure 3-3), there is a clear difference in the thermal regime of the cut-off trench. From the connection weld down to the bottom of the cut-off trench, the thermal regime of the 12-m-wide thermal berm geometry is around 1°C lower compared to the 6-m-wide berm, which confirms the gain in performance from widening the upstream thermal berm. Lower temperatures of around 0.5°C are also observed at the anchor point of the geomembrane at the bottom of the cut-off trench. A 0.5 to 1°C difference where the thermal regime is around -2 to -3°C may prove to be a significant difference given the potential freezing point depression of the FFAB material in the cut-off trench. Moreover, the base of the thermal berm should remain in the frozen state, thus acting as an additional seepage barrier from the IVR Attenuation Pond.

As mentioned in Section 3.2.1, the model assumes that no convective heat transfer from the water seeping through the thermal berm will affect the thermal regime locally. This assumption is only valid if the esker material has sufficient fines content to act as a seepage barrier and compacted during construction to minimize its hydraulic conductivity. Otherwise, water may seep through the esker berm and transfer heat closer to the cut-off trench, which could affect the thermal regime locally in the long term. According to the Canadian Foundation Engineering Manual (2006), water velocities generally must exceed 10^{-4} cm/s before convective heat flow starts to become significant.

SNC-Lavalin believes that the construction of a 12-m-wide berm would contribute to a cooler foundation while minimizing the risk of warming the foundation and cut-off trench due to the presence of water in the IVR Attenuation Pond. For these reasons, the rest of the analyses were conducted modelling a 12-m-wide upstream thermal berm made of esker material to evaluate the performance of building such a berm in different events and geometries.

3.2.2.1 Thermal regime during EDF event

The thermal regime during a 1:100 year spring flood (EDF) event was modelled assuming that 18°C water was ponding against the upstream berm for a duration of 45 days (refer to Figure 2-10). The thermal regime at the end of that 45-day period during the first year of operation is shown on Figure 3-5.

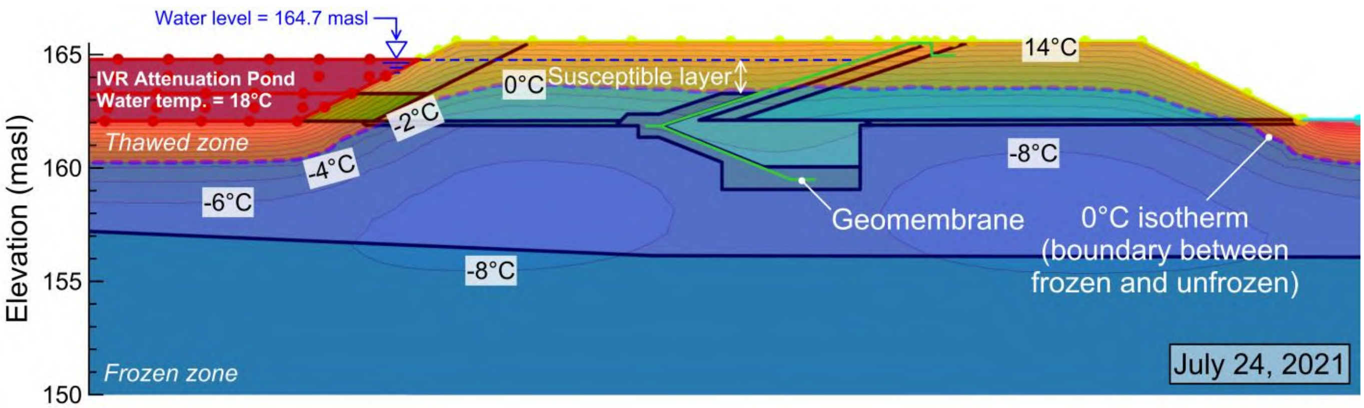


Figure 3-5: Thermal regime on July 24, 2021 during a 1:100 year spring flood (EDF) event

The thaw front represented by a dotted blue line on Figure 3-5 is at a higher elevation compared with the 0°C isotherm on previous figures because the thaw penetration is less important in July compared with September. However, a “seepage susceptible layer” was identified, that is between the thaw front elevation and the upstream water level. This layer was identified as seepage susceptible because the hydraulic barrier at this location does not benefit from the composite effect of mineral layer as there is no FFAB below or above the geomembrane. If a defect in the geomembrane were to be found above the elevation 163.2 masl, a preferential pathway could develop and lead to seepage during an EDF event.

For that reason, SNC-Lavalin recommends the extension of the FFAB cover up to the EDF water level of 164.7 masl for the construction of the IVR D-1 Dike.

3.2.2.2 Sensitivity Analysis – Density of natural and construction materials

The geothermal properties used in the thermal modelling, summarized in Table 2-3, were computed from either geotechnical campaign data (ice-poor till) or from Phase 1 construction as-built data (construction materials). As a result, the computed geotechnical properties of the materials are in a dense state, including the till foundation. These densities are at the upper bound and the low porosity values are reflected in the geothermal properties, where denser materials have higher thermal conductivity values. This is especially true for saturated materials because it was assumed that the void ratio was the same compared to unsaturated materials, and the absence of pore air in saturated materials contributes to high thermal conductivity values. Construction materials with a high frozen thermal conductivity will freeze faster compared to having a low thermal conductivity, which can lead to unconservative thermal regime assessment in the model since those high frozen thermal conductivity values promote quick freezing of the foundation.

For this reason, a sensitivity analysis was carried out using materials in a looser state. The ice-poor till water content was increased from 8% to 27%, the latter corresponding to the maximum water content from the samples retrieved from test pits along the IVR D-1 Dike. As a result, the porosity of the foundation material is increased, thus reducing its thermal conductivity. For the construction materials, void ratios from 0.25 to 0.32 were used in the base case analysis. In the sensitivity analysis, void ratio values ranging from 0.30 to 0.45 were chosen arbitrarily to represent materials in a looser state but still within the range of typical construction materials (Andersland & Ladanyi, 2004; Kermani, Konrad, & Smith, 2018). The geothermal properties of the materials used in the sensitivity analysis are summarized in **Appendix A**.

The same geometry, modelling sequence and boundary conditions from the results shown on Figure 3-4 were used for the sensitivity analysis, the only difference resides in the geothermal properties of the materials (except bedrock). Hence, the thermal profile of the IVR D-1 Dike and its foundation at the date corresponding to the maximum thaw front penetration during the last year of operation using materials in a looser state is shown on Figure 3-6.

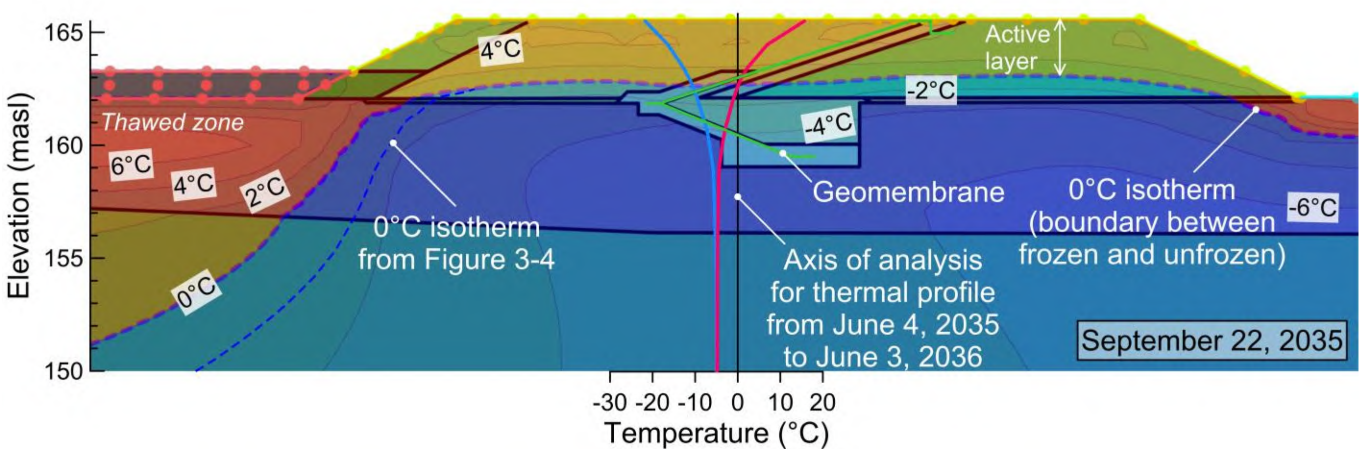


Figure 3-6: Thermal regime as of September 22, 2035 for Section B-B (with the thermal berm width extended to 12 m) simulating materials in a looser state

The thermal regime within the cut-off trench as shown by the thermal profile plotted on Figure 3-6 is similar to the one presented on Figure 3-4; cut-off trench temperature in the sensitivity analysis are even slightly lower compared to the main analysis. This implies that the geothermal parameters of the construction materials (esker and rockfill materials) are not very sensitive in terms of thaw penetration and freeze back processes. However, very loose construction materials may have a bigger impact on the results but since the technical specifications required those materials to be compacted during construction, high porosity values were not modelled because they are deemed not representative of the expected field conditions.

Moreover, the 0°C isotherm from Figure 3-4 was plotted in Figure 3-6 for comparison; it is noted that the 0°C isotherm from the sensitivity analysis is at a higher elevation from the upstream side (below the modelled IVR Attenuation Pond) to the upstream shoulder of the thermal berm. This means that the permafrost degradation of the upstream side of IVR D-1 Dike occurs more slowly in the sensitivity analysis compared to the base case. This is due to the higher water content in the foundation material in the sensitivity analysis, resulting in a higher heat capacity (more heat is required to thaw the glacial till due to the latent heat of pore water within the soil).

3.2.3 Cross Section D-D at station 0+360

Section D-D at station 0+360 was modelled using a similar geometry to that presented on Figure 3-4 (Section B-B with extended 12-m-wide upstream berm) and by keeping the upstream berm at the crest elevation of 165.5 masl. Because the natural ground is at a higher elevation at station 0+360, that is approximately 164.0 masl, the thickness of the thermal berm is reduced compared with Section B-B and there is less material covering the cut-off trench. The thermal profile of the IVR D-1 Dike and its foundation at the date corresponding to the maximum thaw front penetration during the first year of operation at station 0+080 is shown on Figure 3-7.

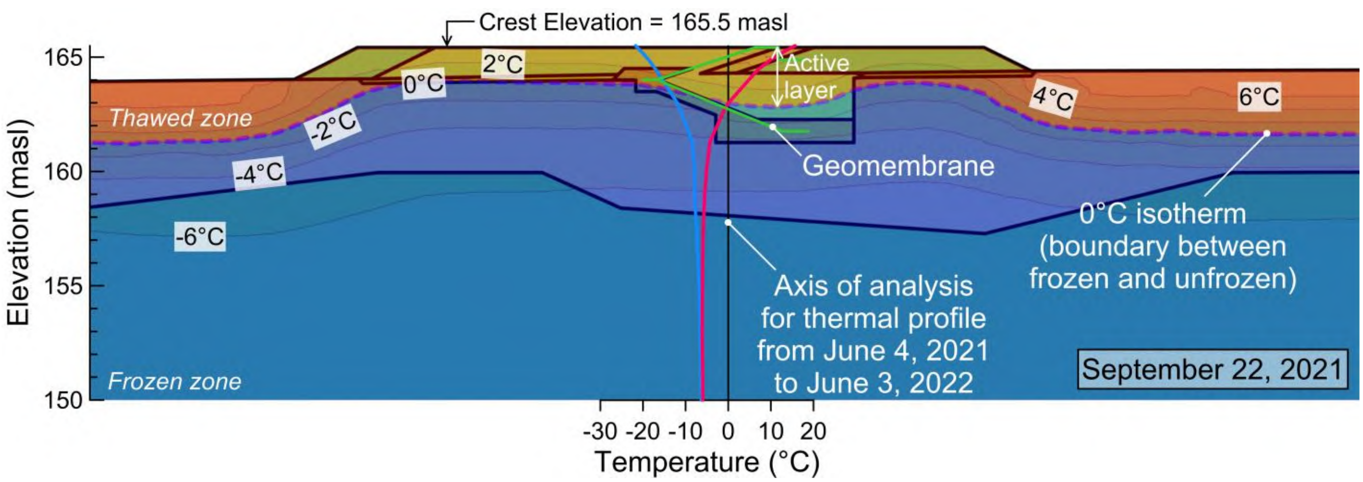


Figure 3-7: Thermal regime as of September 22, 2021 at Section D-D

Because there is less material covering the cut-off trench, the thaw front penetrates within the cut-off trench during the first summer of operation. The thaw front penetration is more significant in the cut-off trench compared to the thaw front penetration on either side because of the higher moisture content in the natural foundation. Because the Dike is initially constructed using unsaturated materials, the initial moisture content in the cut-off trench is expected to be low (around 2-3%) so the heat capacity of the construction materials is lower compared to surrounding glacial till, making the energy required to thaw the cut-off trench less important. The 0°C isotherm penetrates below the connection weld and the LLDPE anchor in the liner at the base of the cut-off trench is expected to stay marginally frozen at a temperature of around -2°C. However, the very bottom of the cut-off trench is expected to remain frozen.

Since the IVR D-1 Dike is expected to be constructed during winter in freezing temperature, an additional thermal capping will promote cooling of the cut-off trench and prevent the thaw front from penetrating within it. For example, the use of a constant thickness for the thermal berm of about three (3) metres instead of constructing the thermal berm at a constant elevation of 165.5 masl may prevent thawing of the cut-off trench, thus enhancing the performance of the structure against seepage. Another design consideration worth mentioning is the expose of the FFAB surrounding the connection weld of the geomembrane to seasonal thaw; preventing F-T cycles within the FFAB material as this sensitive location would also promote a better performance of the structure. Moreover, the construction of a thicker thermal berm will minimize heat intake from phenomena that were not taken into consideration in this study, for instance the convective heat transfer due a significant rain event.

SNC-Lavalin believes that the construction of a 3-m uniform thickness thermal berm along the IVR D-1 Dike where the natural ground elevation is equal or higher than the IVR Attenuation Pond water level reached during an EDF event (164.7 masl) would reduce risks of seepage and promote good performance of the structure. The actual berm thickness required could be determined based on thaw penetration monitored during the first summer of operation.

3.2.4 Longitudinal Section F-F at the west abutment

As discussed in Section 3.2.3, reducing the thickness of the thermal cover above the cut-off trench promotes the thaw front penetration deeper within the dike. Because the depth of the cut-off trench reduces from three (3) m to none at the abutments, where the natural ground surface is higher, a thermal cover at both abutments would be required to prevent thawing of the cut-off trench. A similar approach was done during the construction of Mammoth Dike during Phase 1, where a cover was added at both ends of the Dike to promote cooling of the abutments.

The longitudinal section of the west abutment along the IVR D-1 Dike centreline was selected to design the thermal cover that would prevent thawing of the cut-off trench. As for Phase 1 structures, rockfill was used as a construction material to assess the required berm dimensions in the longitudinal axis of the Dike to keep the abutment in the frozen state on an annual basis. The results are shown on Figure 3-8.

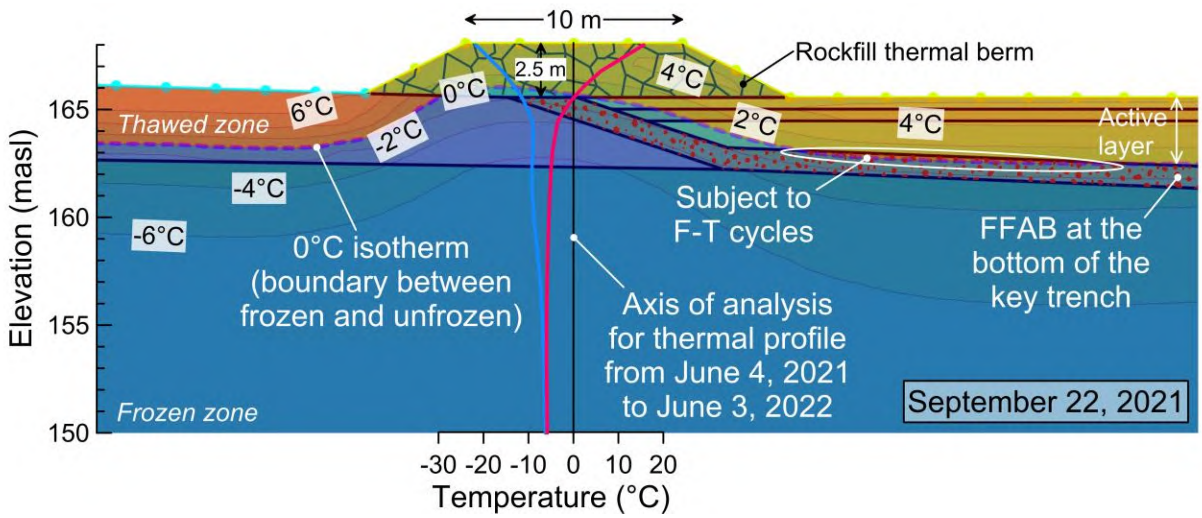


Figure 3-8: Thermal regime as of September 22, 2021 including temperature profile of the cut-off trench and foundation at the west abutment

The required dimensions of the thermal cover at the west abutment are 10 m length and 2.5 m thickness to keep the cut-off trench marginally frozen during an operational year. The width of the berm should cover at least the whole cut-off trench and may extend to the footprint limits.

However, there was a zone identified towards the centre of the dike that may be subject to freeze-thaw (F-T) cycles in the FFAB layer. It is recommended to add a layer of cover material above that zone if the maximum operational water level of 163.2 masl is maintained for an extended period of time since that zone is comprised between elevations 162.5 and 163.0 masl approximately. An additional metre of rockfill may suffice to maintain the FFAB in the frozen state close to the abutments.

In addition to the foregoing solutions to minimize thawing of the cut-off trench, it is recommended to monitor the temperature at the west abutment using a set of thermistor strings, especially given the presence of the spillway at that location. Similar to the esker berm thickness discussed in Section 3.2.3, the actual berm thickness required at the abutment could be determined during the first year of operation based on thermistor strings installed in rockfill material and adjusted at the end of the first winter of operation.

3.3 Discussion of results

The results of different geometries (cross section at the lowest natural ground elevation including an extended 12-m-wide berm, cross Section D-D at station 0+360 above the maximum operational water level and another Section F-F at the west abutment) as well as a sensitivity analysis for the extended Section B-B were presented in Section 3.2. In general, the results show that the anchor of the geomembrane in the FFAB at the bottom of the cut-off trench should stay frozen.

Moreover, given the fact that the IVR D-1 Dike should be constructed during winter (from February to April 2021), the structure should be in frozen condition when water from the IVR Attenuation Pond comes in contact with the upstream berm. The geometry of the current design with the proposed mitigation measures outlined in this technical note would meet the performance objective of no seepage bypassing the foundation.

However, the results presented on Figure 3-5 indicate the presence of a "seepage susceptible layer" comprised between the pond water level during a 1:100 year spring flood event (164.7 masl) and the top of the FFAB layer at elevation 163.2 masl. Should any defect occur in the geomembrane above elevation 163.2 masl, potential seepage pathways could develop as the dike materials thaw at the end of the spring flood event since the geomembrane is neither encapsulated in nor underlain by FFAB above this elevation. The dike performance would be enhanced if the hydraulic barrier benefited from the composite effect of a mineral layer (FFAB) and the geomembrane. In the light of these results, SNC-Lavalin recommends designing the barrier such that the FFAB elevation reaches the IVR Attenuation Pond water level following the 1:100 years spring flood event, which is elevation 164.7 masl.

Designing a constant elevation thermal berm can simplify the construction, however the main benefit from building such a berm is to cool the foundation and thus maintain the cut-off trench in the frozen state. Consequently, the construction of a thermal berm with a uniform thickness of three (3) metres would enhance the performance of the dike along its entire length and reduce risk of seepage, whereas the efficiency of a constant elevation thermal berm decreases with increasing natural ground elevation. The proposed uniform thickness of three (3) metres is based on the active layer depth modelled and past experience from the construction of Phase 1 Dikes; however, since esker material was not used in previous water management structures for the Whale Tail Project, the actual esker thickness required to maintain the cut-off trench including the FFAB surrounding the connection weld in the frozen state could be determined after the first summer of operation based on thermistor readings. Would any additional material be required on top of the existing thermal berm, such a construction could occur at the end of the first winter of operation to promote cooling of the foundation and avoid F-T cycles around the connection weld during the next thawing season.

The thermal model also suggests that constructing a 12-m-wide berm would help maintain the cut-off trench cooler compared to a 6-m-wide berm. This would also reduce the risk of convective heat transfer from water seeping through the esker material if the berm is wider. The intent of building the thermal berm is to protect the cut-off trench from F-T cycles from the annual thaw front penetration and to keep the ponded water further away from the core of the dike. No analyses were carried out in the current study to define the optimum width of berm required to ensure a "suitable" thermal regime within the cut-off trench because the optimisation of the width would be based on a phenomenon that is not taken into consideration in the study, that is convective heat transfer through the esker material. To account for these uncertainties, SNC-Lavalin studied another geometry simulating the construction of a 12-m-wide berm but acknowledges that in reality, a narrower berm of say 10 metres could suffice. However, based on its engineering judgment and to ensure a robust design, SNC-Lavalin recommends the construction of a thermal berm made of esker material on a width of 12 m along the IVR D-1 Dike.

It should be noted that the thermal regime after the end of the operation was not modelled as the IVR D-1 Dike will not retain any water after closure of the pit. Nevertheless, the dike temperature and its foundation should be monitored using thermistor strings to evaluate its performance over the lifespan of the structure.

3.3.1 Modelling limitations

Many simplifications were made in order to ease the thermal modelling as listed below:

- A semi-empirical model was used to assess the geothermal properties, which has an inherent margin of error regarding the thermal response of the materials;
- A constant temperature boundary conditions against the upstream berm face was used to simulate the heat intake coming from the IVR Attenuation Pond water. However, as the water is ponding against permeable materials such as rockfill, the thermal effect of convective heat transfer from water seeping through the core of the dike was not taken into account, which could underestimate the heat intake within the dike;
- The construction of the dike was simulated to take place in a one-day period, which obviously does not well replicate the actual construction schedule. As a result, the thermal regime of the foundation could differ from the model during the first year of operation, but it is expected that these differences will subside with time.

3.3.2 Meeting of objective

Despite the inherent limitations of using the TEMP/W software to model a simplified representation of the IVR D-1 Dike, the thermal regime of the structure and its foundation were modelled with a reasonable degree of confidence given the good agreement between the calibrated model and the thermistor readings in the ground at the dike location as well as past experience with dike construction at the site in earlier phases. Moreover, the thermal modelling process allowed the optimization of the design given the specific conditions in which the IVR D-1 Dike will be constructed.

4.0 Conclusions and recommendations

4.1 Conclusions

Thermal analyses were conducted on two different widths of the esker thermal berm and at different locations along the IVR D-1 Dike. The main conclusions drawn from these analyses are:

- The bottom of the cut-off trench where the geomembrane is anchored should stay in the frozen state on a yearly basis;
- A “seepage susceptible layer” was identified during the thermal simulation of a 1:100 year spring flood event, which highlighted the fact that the upper part of the hydraulic barrier solely relies on the geomembrane without the FFAB layer as a composite liner system to minimize seepage;
- It is expected that the construction of a 12-m-wide upstream berm would be more beneficial than 6-m-wide berm, especially considering convective heat transfer is not taken into account in the current study;
- The construction of an upstream thermal berm with a constant elevation (El. 165.5 masl) throughout the dike will promote cooling of the cut-off trench and foundation where the natural ground elevation is low (Section B-B) but the benefits decrease with increasing natural ground elevation (Section D-D). At Section D-D, the upper part of the cut-off trench will be subjected to seasonal thawing due the insufficient thickness required from an upstream berm protection;

> A sensitivity analysis was conducted on the geothermal properties of the natural and construction materials and showed that loose fill assumptions in the thermal conductivity did not have an important impact on the results. Furthermore, the impact is insignificant because it is specified in the technical specifications that the esker material is required to be well compacted;
> Thermal modelling at the west abutment showed that a thermal berm is required to maintain the cut-off trench in the frozen state as it gets close to the natural ground surface.

4.2 Recommendations

Following the main conclusions drawn from the thermal analyses, SNC-Lavalin makes the following recommendations:

> Consider extending the FFAB layer up to the IVR Attenuation Pond water level given a 1:100 year spring flood event, that is 164.7 masl to provide additional protection;
> Consider the construction of an upstream thermal berm using esker material with a uniform thickness of three (3) metres in order to keep the cut-off trench frozen on an annual basis, thus avoiding F-T cycles in the FFAB material surrounding the connection weld of the LLDPE geomembrane;
> Construct an upstream thermal berm made of esker material on a width of 12 metres in order to keep the water away from the cut-off trench to limit heat intake from seepage water and to promote cooling of the cut-off trench;
> Construct thermal berms at the abutments to keep the cut-off trench frozen along the entire length of the IVR D-1 Dike;
> Monitor the temperature of the dike and its foundation by installing thermistor strings during its construction and bring any adjustments to the Dike geometry (for instance, increasing the thickness of the thermal berm) at the end of the first winter of operation, if required.

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Appendix A
Geothermal parameters used in the sensitivity analyses

Table A-1: Geotechnical and geothermal properties of the materials used in the sensitivity analysis

Layer	1 - Bedrock	2 - Saturated ice-poor till	3 - Saturated fine filter	4 - Unsaturated fine filter	5 - Saturated coarse filter	6 - Unsaturated coarse filter	7 - Saturated rockfill	8 - Unsaturated rockfill	9 - Saturated FFAB	10 - Unsaturated FFAB
Description	Greywacke / sandstone	Silty and sandy gravel (GM)	Poorly graded sand (SP)	Poorly graded sand (SP)	Crushed rock / poorly graded gravel with no fines	Crushed rock / poorly graded gravel with no fines	Crushed rock	Crushed rock	Poorly graded sand (SP) amended with 6% bentonite	Poorly graded sand (SP) amended with 6% bentonite
Geotechnical Parameter										
Dry density, ρ_d (kg/m³)	2 755	1 552	2 000	2 000	2 074	2 154	2 240	2 154	1 862	1 862
Density of soil solids, ρ_s (kg/m³)	2 800	2 650	2 800	2 800	2 800	2 800	2 800	2 800	2 700	2 700
Bulk density, ρ (kg/m³)	2 771	1 966	2 286	2 047	2 333	2 122	2 385	2 175	2 172	1 906
Gravimetric water content, w	0.6%	26.7%	14.3%	2.3%	12.5%	2.3%	10.7%	1.0%	16.7%	2.3%
Volumetric water content, θ_w	1.6%	41.4%	28.6%	4.7%	25.9%	4.8%	23.1%	2.2%	31.0%	4.3%
Degree of saturation, S_r	100%	100%	100%	16%	100%	18%	100%	9%	100%	14%
Porosity, n	0.016	0.41	0.29	0.29	0.26	0.26	0.23	0.23	0.31	0.31
Void ratio, e	0.016	0.71	0.40	0.40	0.35	0.35	0.30	0.30	0.45	0.45
Specific surface area, S_s (m²/g)	6[(a)]	15[(b)]	40	0	0	0	0	0	40[(c)]	40[(c)]
Geothermal Parameters										
Unfrozen thermal conductivity, k_u (kJ/day/m/°C)	Refer to Figure 2-8	Refer to Figure 2-8	145	90	150	100	156	90	Refer to Figure 2-8	79
Frozen thermal conductivity, k_f (kJ/day/m/°C)			211	82	211	93	211	81		72
Unfrozen Heat capacity, C_u (kJ/m³/°C)	2 035	2 906	2 625	1 624	2 567	1 681	2 505	1 629	2 679	1 561
Frozen Heat capacity, C_f (kJ/m³/°C)	1 998	1 959	1 971	1 517	1 974	1 572	1 977	1 579	1 969	1 462

References:
(d) Basalt (Anderson & Tice, Predicting unfrozen water contents in frozen soils from surface area measurements, 1972)
(e) West Lebanon gravel (Smith & Tice, 1988)
(f) Fairbanks silt (Anderson, Tice, & McKim, 1973)

Appendix B

Stability Analyses

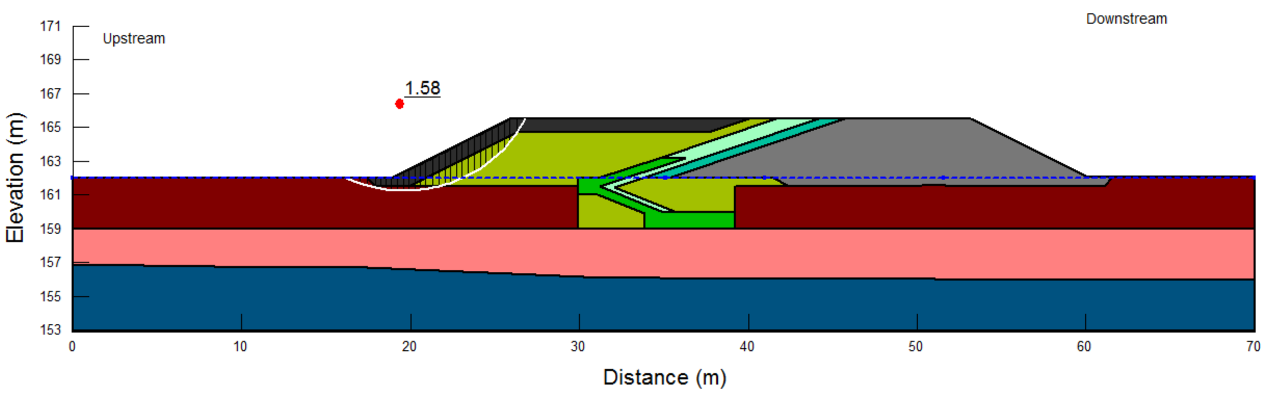
List of Figures:

Appendix B

Stability Analyses

B-1: Static analysis – End of construction - Upstream - Current ground level = 162 m

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	1. Riprap	Shear/Normal Fn.	22.2		
	2. Rockfill	Shear/Normal Fn.	22.2		
	3. Esker	Mohr-Coulomb	22.2	0	32
	4. Fine Filter	Mohr-Coulomb	22.2	0	32
	5. Fine Filter Amended Bentonite	Mohr-Coulomb	22.2	0	32
	6. Coarse Filter	Shear/Normal Fn.	22.2		
	7. Thawed Till	Mohr-Coulomb	20	0	30
	8. Ice poor till	Mohr-Coulomb	19.6	4	31.5
	9. Bedrock	Bedrock (Impenetrable)			

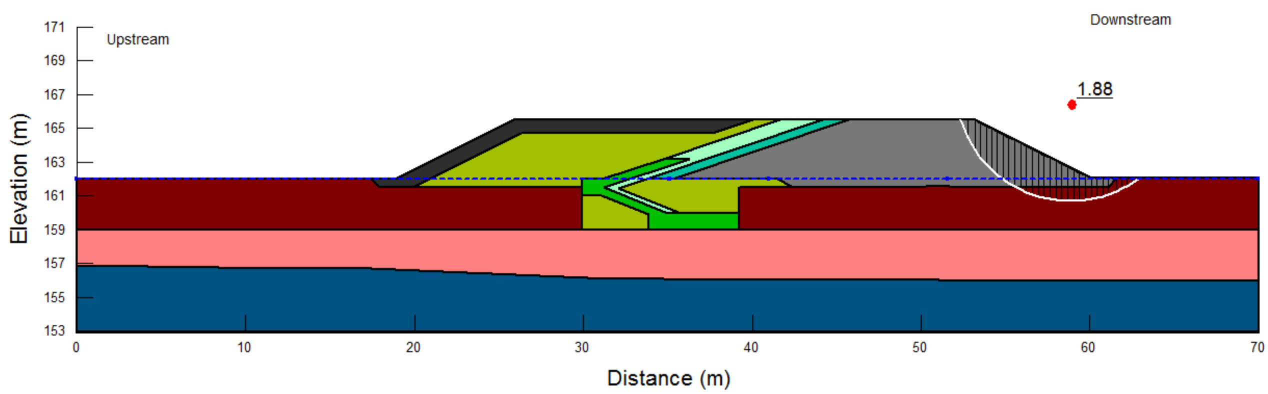


Appendix B

Stability Analyses

B-2: Static analysis – End of construction - Downstream - Current ground level = 162 m

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	1. Riprap	Shear/Normal Fn.	22.2		
	2. Rockfill	Shear/Normal Fn.	22.2		
	3. Esker	Mohr-Coulomb	22.2	0	32
	4. Fine Filter	Mohr-Coulomb	22.2	0	32
	5. Fine Filter Amended Bentonite	Mohr-Coulomb	22.2	0	32
	6. Coarse Filter	Shear/Normal Fn.	22.2		
	7. Thawed Till	Mohr-Coulomb	20	0	30
	8. Ice poor till	Mohr-Coulomb	19.6	4	31.5
	9. Bedrock	Bedrock (Impenetrable)			

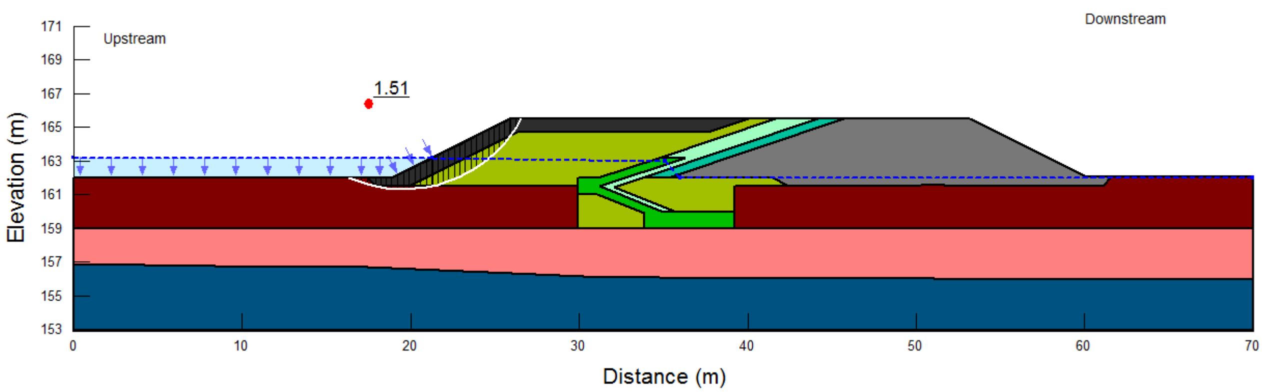


Appendix B

Stability Analyses

B-3: Static analysis – long-term - Upstream - Maximum operation level = 163.2 m

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	1. Riprap	Shear/Normal Fn.	22.2		
	2. Rockfill	Shear/Normal Fn.	22.2		
	3. Esker	Mohr-Coulomb	22.2	0	32
	4. Fine Filter	Mohr-Coulomb	22.2	0	32
	5. Fine Filter Amended Bentonite	Mohr-Coulomb	22.2	0	32
	6. Coarse Filter	Shear/Normal Fn.	22.2		
	7. Thawed Till	Mohr-Coulomb	20	0	30
	8. Ice poor till	Mohr-Coulomb	19.6	4	31.5
	9. Bedrock	Bedrock (Impenetrable)			

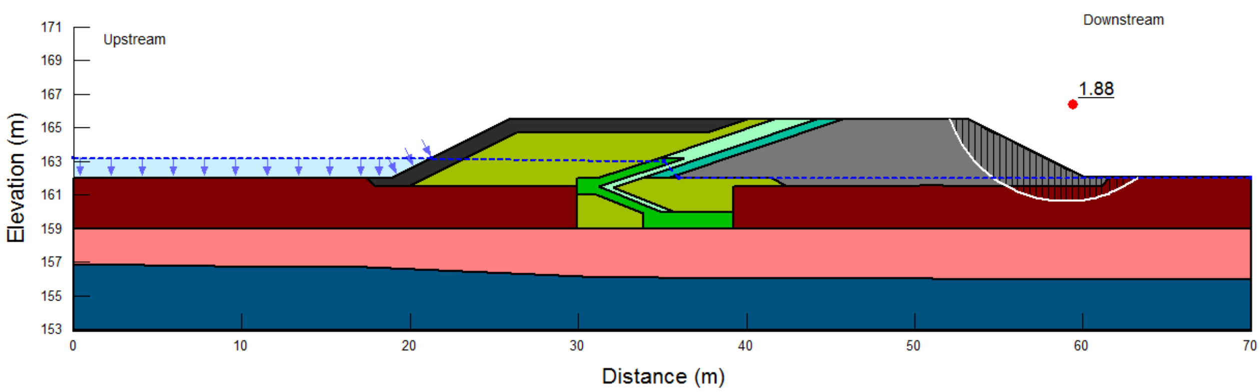


Appendix B

Stability Analyses

B-4: Static analysis – long-term - Downstream - Maximum operation level = 163.2 m

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	1. Riprap	Shear/Normal Fn.	22.2		
	2. Rockfill	Shear/Normal Fn.	22.2		
	3. Esker	Mohr-Coulomb	22.2	0	32
	4. Fine Filter	Mohr-Coulomb	22.2	0	32
	5. Fine Filter Amended Bentonite	Mohr-Coulomb	22.2	0	32
	6. Coarse Filter	Shear/Normal Fn.	22.2		
	7. Thawed Till	Mohr-Coulomb	20	0	30
	8. Ice poor till	Mohr-Coulomb	19.6	4	31.5
	9. Bedrock	Bedrock (Impenetrable)			

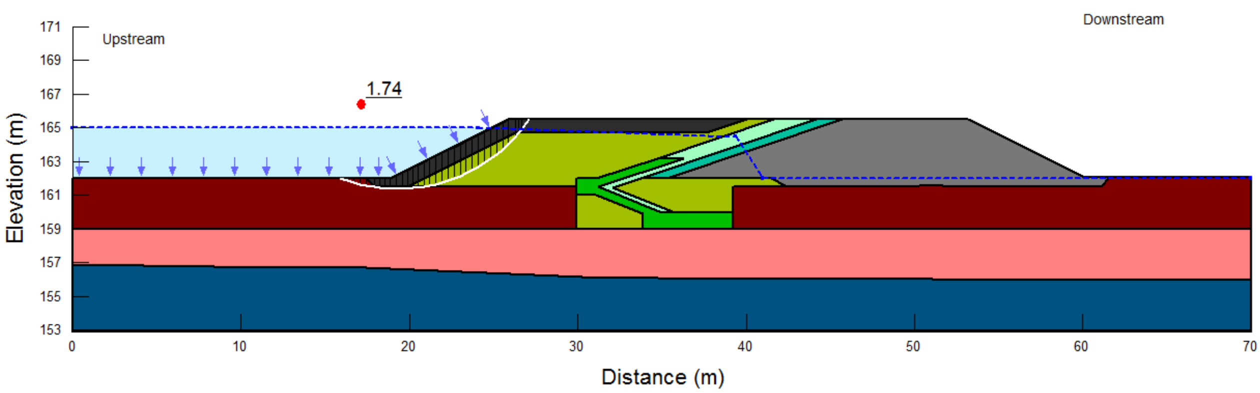


Appendix B

Stability Analyses

B-5: Static analysis – long-term - Upstream - PMF = 165 m

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	1. Riprap	Shear/Normal Fn.	22.2		
	2. Rockfill	Shear/Normal Fn.	22.2		
	3. Esker	Mohr-Coulomb	22.2	0	32
	4. Fine Filter	Mohr-Coulomb	22.2	0	32
	5. Fine Filter Amended Bentonite	Mohr-Coulomb	22.2	0	32
	6. Coarse Filter	Shear/Normal Fn.	22.2		
	7. Thawed Till	Mohr-Coulomb	20	0	30
	8. Ice poor till	Mohr-Coulomb	19.6	4	31.5
	9. Bedrock	Bedrock (Impenetrable)			

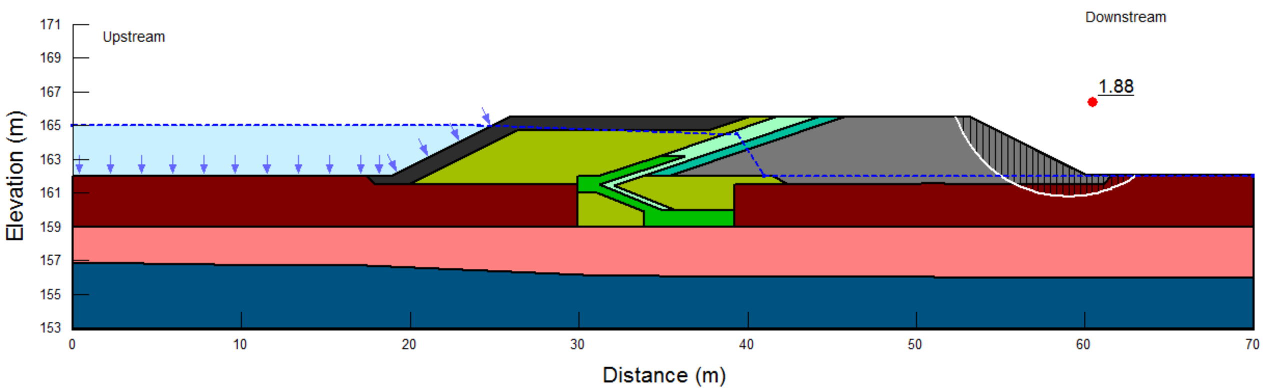


Appendix B

Stability Analyses

B-6: Static analysis – long-term - Downstream - PMF = 165 m

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	1. Riprap	Shear/Normal Fn.	22.2		
	2. Rockfill	Shear/Normal Fn.	22.2		
	3. Esker	Mohr-Coulomb	22.2	0	32
	4. Fine Filter	Mohr-Coulomb	22.2	0	32
	5. Fine Filter Amended Bentonite	Mohr-Coulomb	22.2	0	32
	6. Coarse Filter	Shear/Normal Fn.	22.2		
	7. Thawed Till	Mohr-Coulomb	20	0	30
	8. Ice poor till	Mohr-Coulomb	19.6	4	31.5
	9. Bedrock	Bedrock (Impenetrable)			

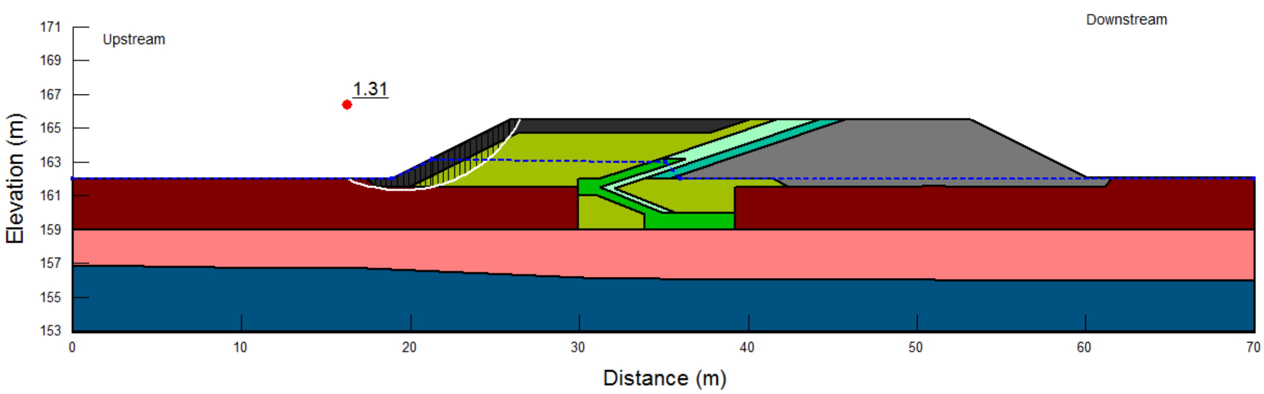


Appendix B

Stability Analyses

B-7: Full or partial rapid drawdown – Upstream

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	1. Riprap	Shear/Normal Fn.	22.2		
	2. Rockfill	Shear/Normal Fn.	22.2		
	3. Esker	Mohr-Coulomb	22.2	0	32
	4. Fine Filter	Mohr-Coulomb	22.2	0	32
	5. Fine Filter Amended Bentonite	Mohr-Coulomb	22.2	0	32
	6. Coarse Filter	Shear/Normal Fn.	22.2		
	7. Thawed Till	Mohr-Coulomb	20	0	30
	8. Ice poor till	Mohr-Coulomb	19.6	4	31.5
	9. Bedrock	Bedrock (Impenetrable)			



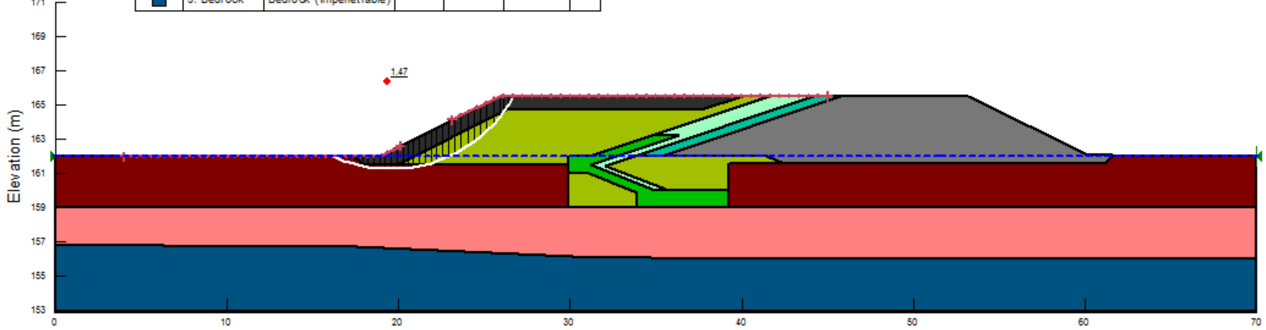
Appendix B

Stability Analyses

B-8: Pseudo static – End of construction - Upstream - Current ground level = 162 m

Horz Seismic Coef.: 0.027

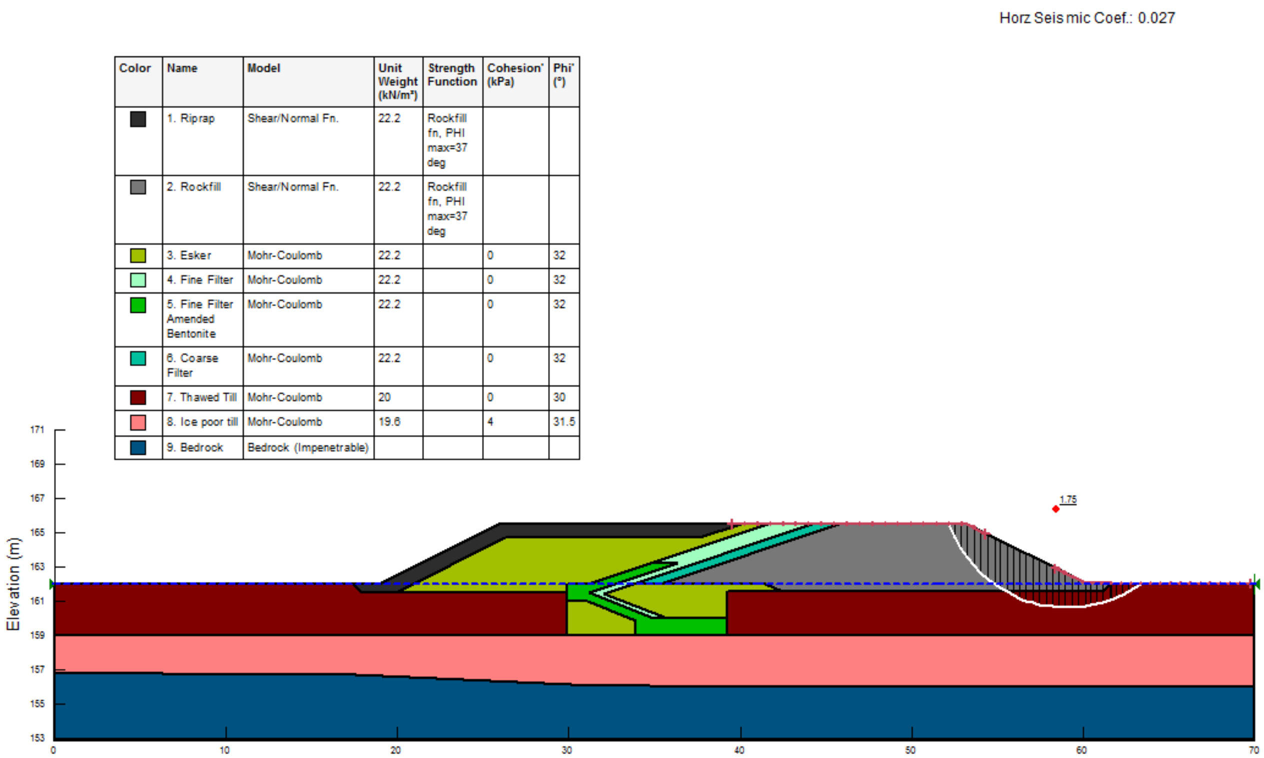
Color	Name	Model	Unit Weight (kN/m³)	Strength Function	Cohesion' (kPa)	Phi' (°)
	1. Riprap	Shear/Normal Fn.	22.2	Rockfill fn, PHI max=37 deg		
	2. Rockfill	Shear/Normal Fn.	22.2	Rockfill fn, PHI max=37 deg		
	3. Esker	Mohr-Coulomb	22.2		0	32
	4. Fine Filter	Mohr-Coulomb	22.2		0	32
	5. Fine Filter Amended Bentonite	Mohr-Coulomb	22.2		0	32
	6. Coarse Filter	Mohr-Coulomb	22.2		0	32
	7. Thawed Till	Mohr-Coulomb	20		0	30
	8. Ice poor till	Mohr-Coulomb	19.6		4	31.5
	9. Bedrock	Bedrock (Impenetrable)				



Appendix B

Stability Analyses

B-9: Pseudo static – End of construction - Downstream - Current ground level = 162 m



Color	Name	Model	Unit Weight (kN/m³)	Strength Function	Cohesion' (kPa)	Phi' (°)
	1. Riprap	Shear/Normal Fn.	22.2	Rockfill fn, PHI max=37 deg		
	2. Rockfill	Shear/Normal Fn.	22.2	Rockfill fn, PHI max=37 deg		
	3. Esker	Mohr-Coulomb	22.2		0	32
	4. Fine Filter	Mohr-Coulomb	22.2		0	32
	5. Fine Filter Amended Bentonite	Mohr-Coulomb	22.2		0	32
	6. Coarse Filter	Mohr-Coulomb	22.2		0	32
	7. Thawed Till	Mohr-Coulomb	20		0	30
	8. Ice poor till	Mohr-Coulomb	19.6		4	31.5
	9. Bedrock	Bedrock (Impenetrable)				

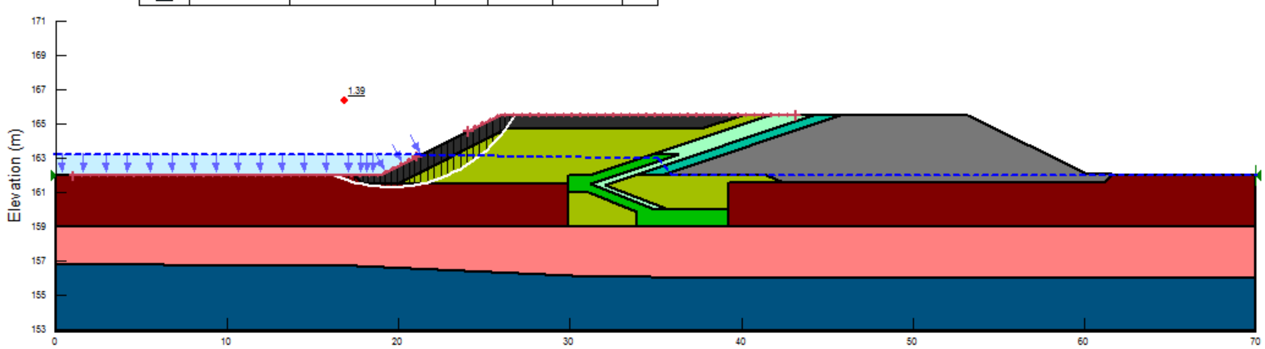
Appendix B

Stability Analyses

B-10: Pseudo static – long-term - Upstream - Maximum operation level = 163.2 m

Color	Name	Model	Unit Weight (kN/m³)	Strength Function	Cohesion' (kPa)	Phi' (°)
	1. Riprap	Shear/Normal Fn.	22.2	Rockfill fn, PHI max=37 deg		
	2. Rockfill	Shear/Normal Fn.	22.2	Rockfill fn, PHI max=37 deg		
	3. Esker	Mohr-Coulomb	22.2		0	32
	4. Fine Filter	Mohr-Coulomb	22.2		0	32
	5. Fine Filter Amended Bentonite	Mohr-Coulomb	22.2		0	32
	6. Coarse Filter	Mohr-Coulomb	22.2		0	32
	7. Thawed Till	Mohr-Coulomb	20		0	30
	8. Ice poor till	Mohr-Coulomb	19.6		4	31.5
	9. Bedrock	Bedrock (Impenetrable)				

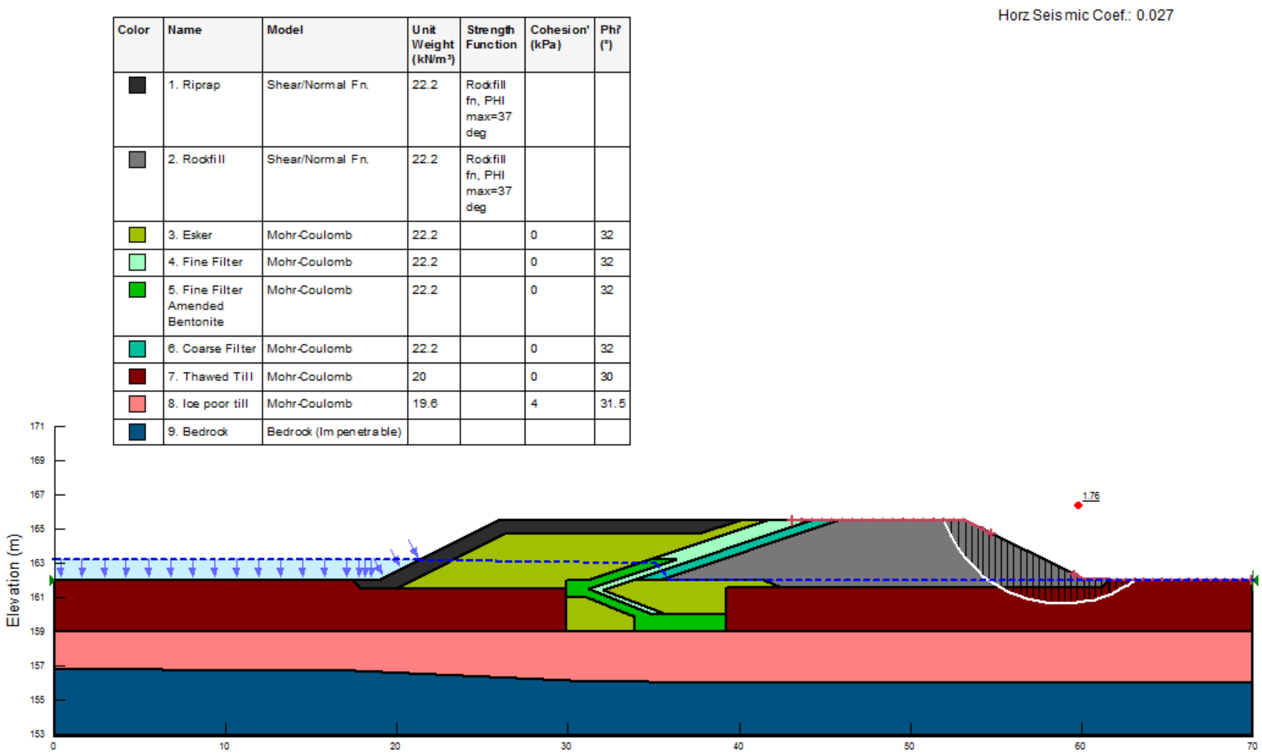
Horz Seismic Coef.: 0.027



Appendix B

Stability Analyses

B-11: Pseudo static – long-term - Downstream - Maximum operation level = 163.2 m



Color	Name	Model	Unit Weight (kN/m³)	Strength Function	Cohesion' (kPa)	Phi' (°)
	1. Riprap	Shear/Normal Fn.	22.2	Rockfill fn, PHI max=37 deg		
	2. Rockfill	Shear/Normal Fn.	22.2	Rockfill fn, PHI max=37 deg		
	3. Esker	Mohr-Coulomb	22.2		0	32
	4. Fine Filter	Mohr-Coulomb	22.2		0	32
	5. Fine Filter Amended Bentonite	Mohr-Coulomb	22.2		0	32
	6. Coarse Filter	Mohr-Coulomb	22.2		0	32
	7. Thawed Till	Mohr-Coulomb	20		0	30
	8. Ice poor till	Mohr-Coulomb	19.6		4	31.5
	9. Bedrock	Bedrock (Impenetrable)				

Appendix C

Technical Specifications

TITRE: **TECHNICAL SPECIFICATIONS FOR THE CONSTRUCTION OF IVR D-1 DIKE**

CLIENT: **AGNICO EAGLE MINES LIMITED – MEADOWBANK DIVISION**

PROJECT: **DETAILED ENGINEERING OF WATER MANAGEMENT AND GEOTECHNICAL INFRASTRUCTURE PHASE 2 WHALE TAIL EXPANSION**

PREPARED BY : Nina Quan, P.Eng.
#PEO: 100110574, NAPEG # L4589

Mathieu Durand-Jézéquel, P.Eng., M. Sc.
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REVIEWED BY : Philip Gomes, P.Eng.
#PEO: 90215062, #OIQ: 5052664

APPROVED BY
(as Project Manager) : Anh Long Nguyen, P.Eng.
#OIQ: 122858, NAPEG #L2716

Index of Revisions

	Revision				Revised pages	Remark
No.	Prep.	Rev	App.	Date		
00	NQ/MDJ	PSG	ALN	12/21/2020	All	Issued for construction

INSTRUCTION TO PRINT CONTROL: (Indicate X where applicable)

- [ ] Entire Criteria revised. Reissue all pages
- [ ] Reissue revised pages only

STAMP THE CRITERIA AS FOLLOWS:

- [ ] Released for internal revision
- [ ] Issued for comments and approval
- [ ] Released for bid
- [x] Released for construction (installation Specifications only)

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1.0 WORK DESCRIPTON

1.1 Project Description

Agnico Eagle Mines Limited, Meadowbank Division (AEM) is developing the Whale Tail Project, a satellite deposit located on the Amaruq property (Kivalliq Region of Nunavut, Canada). The Whale Tail Project construction is ongoing and commercial production has started in the third quarter of 2019. To continue mining and milling, AEM is proposing to expand the Whale Tail Project by expanding the Whale Tail pit, developing another open pit called the IVR pit and including underground mining operations. As part of the expansion project, new water management and geotechnical infrastructures shall be required for surface water management.

One of the proposed structures is the IVR Attenuation Pond, which will be located within the former Lake A53. The objective of the IVR Attenuation Pond is to store surface contact water which will be transferred by pumping to the treatment plant prior to discharge to the environment through approved diffusers. IVR D-1 Dike was proposed to increase the storage capacity of the IVR Attenuation Pond.

Figure 1-1 presents the locations of the IVR Attenuation Pond and the IVR D-1 Dike while Figure 1-2 shows the general site layout of the Amaruq site.

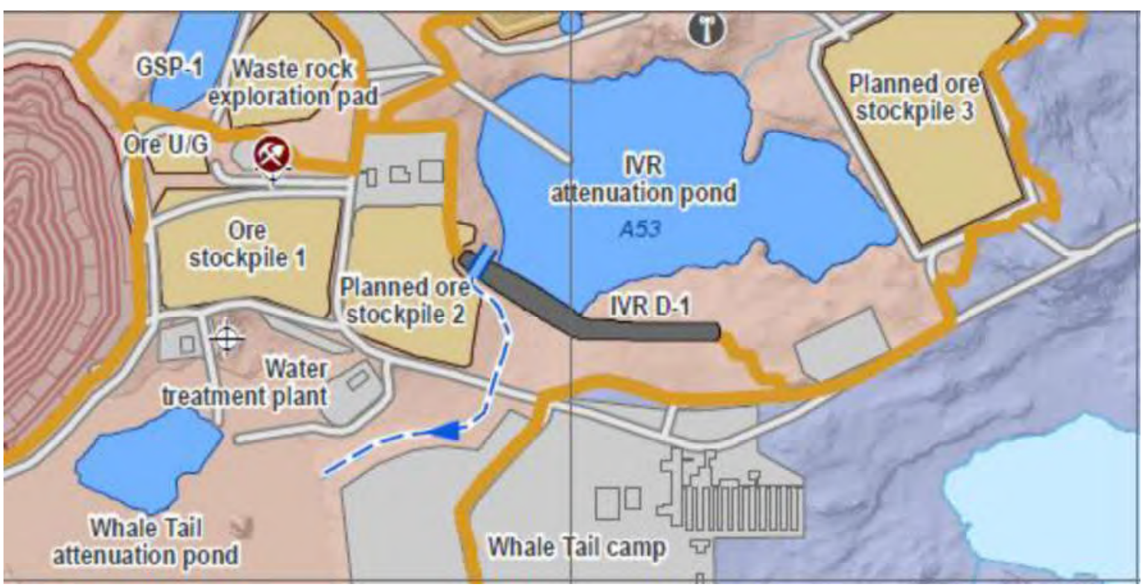
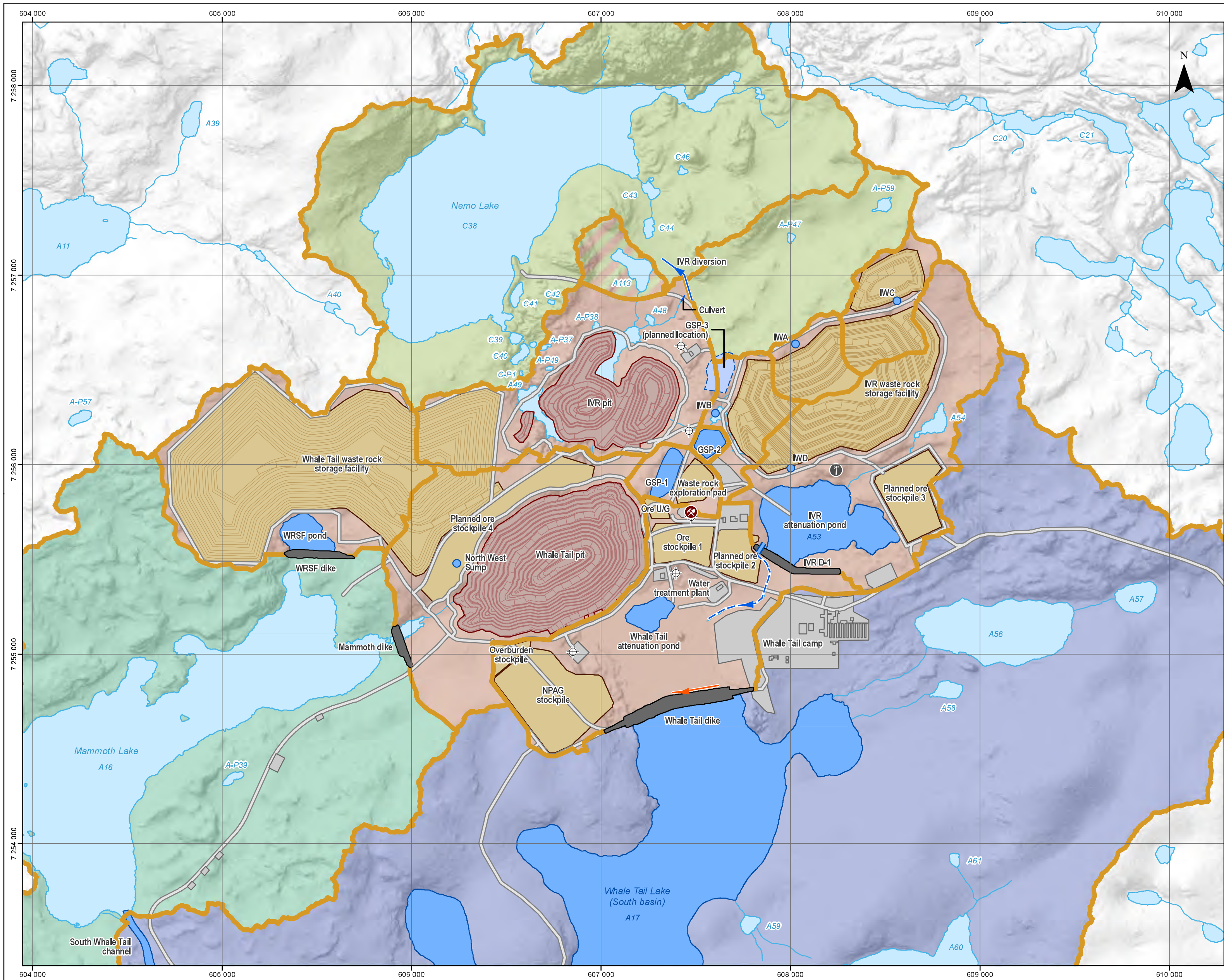


Figure 1-1: IVR Attenuation Pond and IVR D-1 Dike

The IVR D-1 Dike is designed with a central rockfill zone that supports an impermeable low-density polyethylene geomembrane on the upstream dike base and slope. The construction of the Dike is scheduled from mid February to end of April 2021.



PROJECT COMPONENTS (PHASE 2)

- Dike
- Spillway
- Spillway outlet
- Modified waterbody or pond
- Collection ditch
- Diversion ditch
- Sump
- Open pit
- Underground mine portal
- Ventilation raise
- Storage facility
- Industrial area
- Road
- Communication tower

HYDROGRAPHY

- Watercourse
- Lake
- Modified watershed

Contact water

- Attenuation pond and affluents

Non-contact water

- Mammoth Lake
- Nemo Lake
- Whale Tail Lake (South basin)

NOTE :
Ring road around IVR WRSF shown in this figure has been approximatively drawn by SNC-Lavalin. Final design will be carried out by AEM.

AGNICO EAGLE

SNC·LAVALIN

AMARUQ GOLD MINING PROJECT
Amaruq Phase II - Water Management & Infrastructure

Mine Layout Watersheds During Operation – Phase II

Sources:
Topography, PhotoSat, 2015
Project components : November 2020

Project: 668284
File: 668284-EG-001-F1-Wshd-201204.mxd

0 200 400 m
1:20 000
UTM projection, Zone 14, NAD83 (CSRS)

December 4, 2020 **Figure 1-2**

S:\INTC\MineAmaruq\668284 Phase 2 Detailed Engineering\Produit\001-Watershed\668284-EG-001-F1-Wshd-201204.mxd

1.2 Scope

This document presents the Technical Specifications for the construction of the IVR D-1 Dike which will take place in winter time, Q1-Q2 of 2021.

1.3 Abbreviations and Definitions

1.3.1 Abbreviations

The abbreviations listed below, where read in these Specifications, shall have the following meaning:

ASTM	American Society for Testing and Materials
GRI	Geosynthetic Research Institute
AEM	Agnico-Eagle Mines Limited, Meadowbank Division
NPAG	Non-Potentially Acid Generating
LLDPE	Linear Low-Density Polyethylene
QA	Quality Assurance
QC	Quality Control
Amaruq	Amaruq Site
FFAB	Fine Filter Amended with Bentonite

1.3.2 Definitions

Where used in these Specifications, the following terms shall have the meaning indicated below, unless otherwise clearly indicated by the context of their use.

Anchor Trench:	A long, narrow trench in which the edges of a geosynthetic sheet are buried to hold it in place.
Approval:	A written engineering or geotechnical opinion, concerning the progress and completion of the Work.
LLDPE Geomembrane	Impervious low-density liner made of polyethylene geomembrane that can be installed on surfaces that provide containment of liquids without leakage.
BGM	Bituminous geomembrane
Field Laboratory	The area provided for QC and QA testing at Amaruq Project site.
Fishmouth	The terminology used in the geosynthetic industry to describe a fold at the edge of a liner
Geomembrane and Liner	Used interchangeably mean the same thing

Ice-Poor Soil	Frozen soils that contain less than 10% visible ice volume or moisture content is less than 30% or ice lenses thinner than 10mm.
Ice-Rich Soil	Frozen soils that contain more than 10 percent visible ice volume or moisture content is equal or greater than 30% or ice lenses thicker than 10mm.
“Sound” or “Suitable” fill materials	Materials are being free from deleterious matter, having a gradation which permits compaction or placement to a stable state, and having the characteristics specified for the particular materials after handling, re-handling, processing and reprocessing have taken place.
“Unstable” or “Unsuitable” fill materials	Materials are being too wet, containing oversized or segregated particles, organic or other deleterious matter, such as ice or snow, or having poor characteristics which may result in undesirable settlement or other movement of the fill or within the fill, or otherwise not meeting the requirements of the Specifications. However, this definition permits drying, dewatering, watering, screening, raking and any other processing or reprocessing to make the material stable and suitable prior to incorporating it into the fill.
Work	All activities associated with the construction of IVR D-1 Dike and instrumentation.
Working Platform	The working platform is the surface of fill and/or excavated surface which the Work is conducted.

1.4 Work Included

The Work shall include mobilization of all necessary equipment and materials as well as providing supervision, technical personnel (including surveyors) and skilled labour for the construction of IVR D-1 Dike.

The Contractor shall prepare a detailed work plan outlining its proposed method of execution with particular focus on the cut-off trench excavation, LLDPE geomembrane installation and placement FFAB into which the LLDPE geomembrane will be keyed. The work plan shall be approved by the Owner.

It is important to note that the IVR D-1 Dike will be constructed in the winter time where average estimated air temperature ranges from -20^{o}C to -40^{o}C. The proposed execution method shall be in accordance with arctic winter conditions especially for the LLDPE geomembrane installation.

The Work includes but is not limited to the following items:

1. Site preparation including snow, ice, unsuitable materials and boulder removal and proper disposal;
2. Cut-off trench excavation or blasting expected to include overburden only, however rock excavation may be encountered;
3. Bedrock surface treatment to seal cracks and joints at the bottom of the cut-off trench (where encountered);
4. FFAB mixing and development of a procedure to minimize losses of bentonite during the mixing process;
5. Granular fill loading, hauling, placement and compaction;
6. Installation LLDPE geomembrane keyed into the FFAB;
7. Fill placement including before and after LLDPE installation on the upstream slope of the Dike and the FFAB on the bottom of the cut-off trench;
8. Controls including sampling and testing;
9. Installation of instrumentation (i.e., thermistors provided by the Owner).
10. Construction of the emergency spillway including the installation of BGM.

If judged necessary by the QA Inspectors, the QC Representatives, the Owner or the applicable representatives, additional tests shall be performed by an external laboratory.

1.5 Instrumentation

The IVR D-1 Dike will be instrumented with thermistor strings to be supplied and installed by AEM in holes that will be drilled by a third party. The locations where the thermistors will be installed are shown on the Drawings but shall be made easily accessible and once installed shall be protected against damage by construction equipment traffic, weather and animals.

1.6 List of Drawings

The list of Drawings is presented in Table 1-1. The Specifications define the requirements for carrying out the Work as outlined on the most recent revision of the Drawings as shown on Table 1-1. Should a discrepancy or omission be identified, a written request for clarification shall be submitted to the Owner's Representative. The Owner's Representative shall provide a written clarification following communication with the Designer.

Table 1-1: List of Drawings

Drawing No.	Title
61-695-230-204 (668284-5000-4GDD-0009)	Location Map and Drawing Index
61-695-210-200 (668284-0000-4GDD-0001)	General Site Layout
61-695-230-205 (668284-5000-4GDD-0002)	Field Investigation Location Plan and Soil Stratigraphic Section
61-695-230-206 (668284-5000-4GDD-0003)	Plan and Sections IVR D-1 Dike
61-695-230-207 (668284-5000-4GDD-0004)	Excavation Plan
61-695-230-208 (668284-5000-4GDD-0005)	Design Sections and Details
61-695-230-209 (668284-5000-4GDD-0006)	Spillway Design
61-695-230-210 (668284-5000-4GDD-0007)	Instrumentation Plan
61-695-230-211 (668284-5000-4GDD-0008)	Construction Sequence

2.0 GENERAL

2.1 Unit System

Unless indicated otherwise, Amaruq's coordinate system is used and all elevations are tied to the UTM Zone 14, NAD83 (CSR), and the metric unit system (SI) is used.

2.2 Codes and Standards

The publications listed in Sections 2.2.1 and 2.2.2 form part of these Specifications. Each publication shall be the latest revision and addendum in effect on the date of award of the contract unless noted otherwise. Except as modified by the requirements specified herein or the details of the Drawings, Work included in these Specifications shall conform to the applicable provisions of these publications.

The Contractor may suggest the application of alternative standards provided that the resulting final product is at least equal in quality to that specified.

2.2.1 ASTM Designations

ASTM D422	Standard Test Method for Particle-Size Analysis of Soils
ASTM D638	Test Method for Tensile Properties of Plastics
ASTM D698	Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (600 kN-m/m^3)
ASTM D746	Test Method for Brittleness Temperature of Plastics and Elastomers by Impact
ASTM D792	Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
ASTM D1004	Test Method for Initial Tear Resistance of Plastic Film and Sheeting
ASTM D1204	Test Method for Linear Dimensional Changes of Nonrigid Thermoplastic Sheeting or Film at Elevated Temperature
ASTM D1238	Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer
ASTM D1556	Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method
ASTM D1557	Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (2,700 kN-m/m^3)
ASTM D1603	Test Method for Carbon Black in Olefin Plastics
ASTM D2216	Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.
ASTM D3895	Test Method for Oxidative Induction Time of Polyolefins by Thermal Analysis
ASTM D4218	Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique
ASTM D4318	Standard Test Methods for Liquid Limit, Plastic Limit and Plasticity Index of Soils
ASTM D4354	Practice for Sampling of Geosynthetics for Testing
ASTM D4437	Practice for Determining the Integrity of Field Seams Used in Joining Flexible Polymeric Sheet Geomembranes
ASTM D4533	Standard Test Method for Trapezoid Tearing Strength of Geotextiles
ASTM D4632	Standard Test Method for Grab Breaking Load and Elongation of Geotextiles
ASTM D4751	Test Method for Determining Apparent Opening Size of a Geotextile
ASTM D4833	Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products
ASTM D5199	Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes

ASTM D5261	Standard Test Method for Measuring Mass per Unit Area of Geotextiles
ASTM D5323	Practice for Determination of 2% Secant Modulus for Polyethylene Geomembranes
ASTM D5397	Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test
ASTM D5461	Test Method for Geomembrane Seam Evaluation by Vacuum Chamber
ASTM D5596	Test Method for Microscopic Evaluation of the Dispersion of Carbon Black in Polyolefin Geosynthetics
ASTM D5617	Test Method for Multi-Axial Tension Test for Geosynthetics
ASTM D5721	Practice for Air-Oven Aging of Polyolefin Geomembranes
ASTM D5820	Test Method for Pressurized Air Channel Evaluation of Dual Seamed Geomembranes.
ASTM D5885	Test Method for Oxidative Induction Time of Polyolefin Geosynthetics by High Pressure Differential Scanning Calorimetry
ASTM D5994	Test Method for Measuring Core Thickness of Geomembranes
ASTM D6392	Standard Test Method for Determining the Integrity of Non-reinforced Geomembrane Seams Produced Using Thermo-Fusion Methods
ASTM D6693	Test Method for Determining Tensile Properties of Nonreinforced Polyethylene and Nonreinforced Flexible Polypropylene Geomembranes
ASTM D6938	Standard Test Methods for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

2.2.2 GRI Designations

Test Method GM 9	Cold Weather Seaming of Geomembranes
Test Method GM 11	Accelerated Weathering of Geomembranes using a Florescent UVA-Condensation Exposure Device
Test Method GM 19	Seam Strength and Related Properties of Thermally Bonded Polyolefin Geomembranes

All applicable codes and standards in effect in the territory of Nunavut.

2.3 Stakeholders

1. AEM is the **Owner** and is responsible for overseeing the execution and coordination of the entire Work. AEM will also be responsible for the supply of rockfill, fine and coarse filters, esker material, geotextile, LLDPE as well as all instrumentation.
2. SNC-Lavalin will act as The **Designer** for the IVR D-1 Dike.

3. SNC-Lavalin Inc. (SNC-Lavalin) will also act as the Quality Assurance (**QA**) Inspector.
4. The **Contractor** is represented by Kivalliq Contractors Group (KCG) and includes the surveyors and all subcontractors including LLDPE geomembrane installer. Contractor/Installer shall mean a firm that undertakes the contract to provide labour and equipment to install the LLDPE geomembrane.
5. Quality Control (**QC**) is represented by the contractor or a subcontractor of AEM and is responsible of QC for the entire Work.

2.4 Line of Communication

The line of communication follows the organizational chart shown on Figure 2-1.

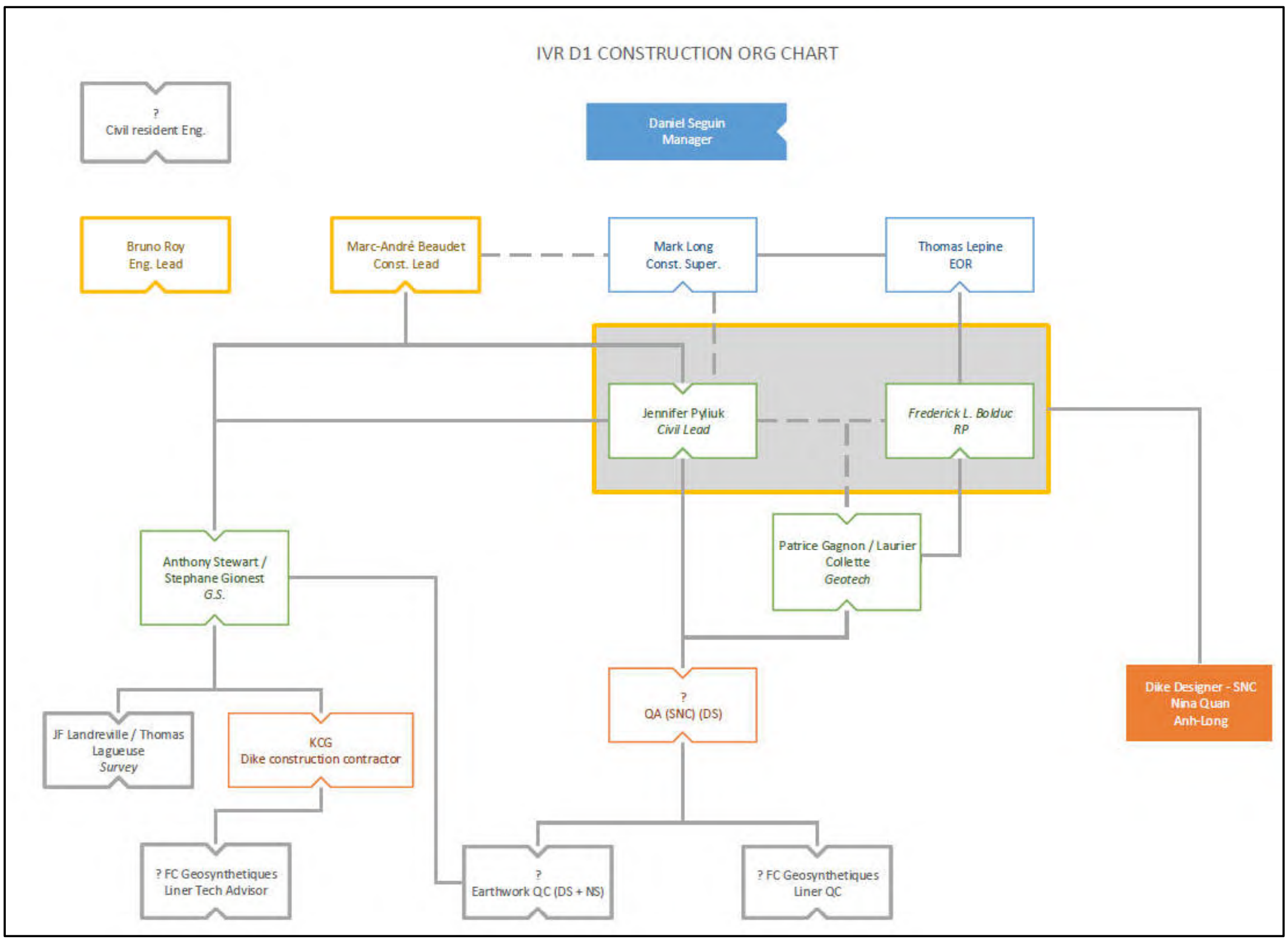


Figure 2-1: Organization Chart

2.5 Scope of Responsibilities

The responsibilities of each stakeholder are defined as follows.

2.5.1 Owner's Representative (AEM)

The Owner's Representative consists of the Civil Lead (Ms. Jennifer Pyliuk), the Meadowbank Complex Responsible Person (Mr. Frederick Bolduc) and the Meadowbank Complex Geotechnical Engineers (Mr. Patrice Gagnon and Mr. Laurier Collette).

- Review working plan and documents from the Contractor to confirm that it is in accordance with the Design.
- Identify changes to be made in the Design or Drawings, collect information and share it with the Designer.
- Oversee the execution and coordination of the entire Work.
- Primary point of contact for the QA Inspectors, QC Representatives and the Contractor.
- Inform the Designer on the construction schedule and the advancement of the Work.
- Review Work and monitoring of construction.
- Share data with QA Inspectors and QC Representatives including but not limited to layout, scope limit control and data collection for as-built drawings and report.
- Review quantities.
- Coordination, daily interaction with QA and QC personnel.
- Follow-up the construction schedule.
- Confirm the waste disposal area.
- Plan or approve platforms to stockpile materials.
- Responsible of the health and safety and Environmental issues and procedures on site.
- Supply rockfill, fine filter, coarse filter and esker material, geotextile, LLDPE geomembrane, BGM and instrumentation.

2.5.2 Quality Control Representative (contractor or a subcontractor of AEM)

- Inspection and documentation of work procedures to ensure the Work meets the Drawings (lines and grades) and the Specifications.
- QC testing as required by the Specifications.
- Prepare daily QC reports.
- Prepare approval forms.
- Work under the supervision of the Owner's Representative as applicable.

> Request additional testing when required.
> Review survey data.
> Manage samples delivery and testing by external laboratories, if applicable.

2.5.3 Quality Assurance Inspector (SNC-Lavalin)

> Inspection, documentation and review QC work to ensure that the control meets the Specifications and the Design.
> QA Inspector may perform occasional independent checks. The Contractor shall co-operate in a timely manner during sampling and testing. Loading and disposal of sampling materials, when no longer required by AEM or its subcontractor, shall be carried out by the Contractor.
> Carry out a general bedrock mapping at the bottom of the cut-off trench, if applicable.
> Request additional testing when required and review QC testing and procedures.
> Collect signed forms (approval and non-conformity forms) and give copy to Owner's Representative.
> Report Design deviations to the Designer.
> Prepare daily QA reports.
> Prepare as-built report, including testing results, drawings and reports.

2.5.4 Contractor (KCG)

> Construction of the IVR D-1 Dike in compliance with the requirements of the Drawings and the Specifications.
> Carry out all survey and stake out and provide all material volumes to the Owner's Representative, QA Inspectors and QC Representatives.
> Carry out the installation of LLDPE geomembrane and prepare the installation report.
> Supervise all its sub-contractors.
> Share all collected data with Owner's Representative, QA Inspectors and QC Representatives.
> Prepare construction drawings, collect information and share it with the Owner's Representative.

2.5.5 AEM Geotechnical Engineers and Responsible Person

> Communicate with the Designer for any technical questions or issues.

2.5.6 Designer (SNC-Lavalin)

> Review documentation requested from the Contractor prior to the beginning of the Work.

> The Designer's Representative is the QA Inspector. The Designer will make Design change(s) when required based on the available information.

> Send a sealed technical memorandum to the AEM Geotechnical Engineer within appropriate timeframe to confirm the Design deviation(s).

2.6 Work Method and Equipment

The Contractor shall submit to the Owner's Representative its working methods with the specific equipment and procedures he plans to use at least thirty (30) days prior to the start of the Work. The complete list of documentation to be provided prior the beginning of the Work is presented in Section 2.13.

2.7 Subsurface Conditions

The subsurface conditions herein is a summary of the information presented in the IVR D-1 design report.

The overburden encountered at the IVR D-1 Dike consists of an organic layer underlain by glacial till followed by bedrock. The depth of the organic layer ranges from 0.1 to 0.3 metres below ground surface (mbgs). The glacial till unit includes a mixture of various sub-units which are grouped as sand to silty sand, silt to sandy or gravelly silt, gravel to sand and gravel, silt sand and gravel mixture, and sandy silt clay. The thickness of glacial till varies from 1.3 to 7.4 mbgs. Based on the test pit logs, the active layer is estimated about 1.5 to 2.1 mbgs. Ice was observed at the interface of soil and cobbles or soil and rock interface in most boreholes. Presence of ice was noted in most test pit logs at depth around 1.2 to 1.8 mbgs. However, no ice lenses thicker than 10 mm was observed in the soil core retrieved from the geotechnical borehole drilling. The total moisture content (moisture content plus ice content) analyzed from samples taken from test pits and boreholes varies from 1.9% to as high as 27% except at borehole IVR DDH8 where the total moisture content at depth of 1.5 and 3 mbgs is greater than 30%. Ice rich till is defined as frozen soil that contain more than 10 percent visible ice volume or moisture content is equal or greater than 30% or ice lenses thicker than 10 mm. The glacial till is considered as ice-poor till except at a localized spot below 1.5 mbgs at borehole IVR DDH8.

Bedrock was encountered in the geotechnical boreholes ranging from 2.1 to 6.7 mbgs. The bedrock was described as highly fractured/completely weathered to moderately fractured with ice filled in joints. It is noted that on the upstream side, east of the Dike, about 1.5 m thick layer of ice was observed in one of borehole drilled on the east side (IVR BH T23) at about 4.6 mbgs.

2.8 Lines, Grades and Tolerances

> Lines and grades shall be obtained from the Drawings.

> Bench marks for the layout of the Dike will be provided by the Contractor's surveyor.

> The Contractor's surveyor shall be responsible for all staking and other survey requirements such as lines and grades specified or shown on the Drawings.

> Lines and grades are subject to modifications by the Designer and additional lines and grades may be required as the Work progresses. Tolerance on lines and grades is of ± 25 mm of the theoretical lines in zones 2A and 2B, ± 50 mm for 3 and 4 while ± 100 mm in zone 1. All excavation and blasting shall be completed to be within 300 mm horizontally and vertically of specified lines and grades. Over excavation/blasting shall be backfilled with Zone 2B FFAB and/or Zone 4 Esker, as directed by AEM. Slopes shall be within ± 0.2H:1V of those shown on the Drawings. However, when a minimum dimension or elevation is specified in the Drawings, the actual line or grade must meet the minimum dimension specified and not exceed by more than what is specified above.

> The Contractor shall use the applicable control points to complete the layout of all the Work. Any additional control point required to execute the Work adequately shall be provided by AEM.

> If the Contractor or any of its subcontractors or any of their representatives or employees move, destroy or render inaccurate any survey control point, such control point shall be replaced at the Contractor's expense.

2.9 Additional Drawings

The Designer may provide additional Drawing(s) if considered necessary. These Drawings shall form part of the contractual document and will be the result of a Design deviation.

2.10 Land, Lake, Environment and Infrastructure Protection

> The Contractor shall limit traffic to the area inside the boundary established by the Owner's Representative.

> The Contractor shall respect the Environmental procedures of AEM.

> The Contractor shall present an Environmental Mitigation Control Plan for the Work. This shall include, but not limited to, a Water Management Plan during construction and appropriate controls on site to implement before and during the Work. The Contractor is responsible of the performance of these mitigation controls.

> Fires are not allowed on site.

- The Contractor shall make sure that all personnel under his responsibility will do everything possible to protect the environment.
- Unless approved by the Owner's Representative, once construction is completed, no fill material shall be left at the construction site.
- All frozen excavated materials must be disposed of as directed by the Owner's Representative.
- Unless approved by the Owner's Representative, all excavated snow shall be disposed of as per AEM's Snow Management Plan.

2.11 Site Cleanup

The Contractor is responsible for the cleanup and removal of garbage and other foreign materials from the construction site to the satisfaction of the Owner's Representative.

2.12 Health and Safety

- All construction work shall be conducted in accordance with AEM's sustainable development and Health and Safety standards and regulations.
- All personal protection equipment appropriate for the Work shall be used by all workers.
- Detailed work procedures for every construction task shall be provided by the Contractor and approved by the Owner's Representative.
- A daily coordination meeting shall be held between the Contractor, QA and QC Inspectors and AEM Representatives to discuss planning and safety.
- Since the course of the Work will occur during wintertime, an evacuation procedure shall be developed jointly between AEM and the Contractor in case of a snowstorm/blizzard and shall be communicated to all stakeholders.

2.13 Submittals

At least thirty (30) days prior to the beginning of the Work, the Contractor shall submit the following documents:

- The location of the stockpile area(s) he plans to use as well as the location of borrow sources and access roads.
- The proposed construction schedule, construction method and a list of specific tools and equipment which will be used during the Work.
- The proposed method for cut-off trench excavation in frozen state, including slope and cut-off trench bottom alignment, grade controls and surface cleaning before fill placement.

> The proposed method of cleaning bedrock cracks and joints where encountered in the cut-off trench bottom or at the abutment and their treatment (sealing) to cut-off all potential seepage beneath the Zone 2B FFAB. The Contractor shall demonstrate that the product he proposes to use to seal the crack and joints has been used in similar cold weather application.

> The proposed procedure and technique of fill placement for Zone 1 rockfill, Zones 2A and 2B fine filters, Zone 3 coarse filter and Zone 4 esker material.

> The proposed LLDPE geomembrane installation technique in cold temperature (the installation will take place between March to April and the QA/QC plan for the installation.

> Procedure and technique for the Zone 2B FFAB mixing, transportation and placement with an emphasis on how to minimize losses of bentonite in the process, including the list of specific equipment it plans to use.

> A detailed written procedure for water management and an Environmental Mitigation Control Plan for the Work.

3.0 CONSTRUCTION MATERIALS

3.1 General

> Only sound and suitable materials meeting the requirements of this document and approved by the QC and/or QA personnel shall be used.

> Great care shall be taken to limit particle segregation during stockpiling, loading and placement of fill materials. Occasionally, the QC Representatives and/or the QA Inspectors may ask the Contractor to modify its construction procedures to meet this requirement.

> The placement of materials shall be done on a dry or snow and ice-free surface to the approval of QA/QC personnel.

> Fill materials shall be free from all organic matter or other deleterious, unapproved, unstable or unsuitable materials such as ice/snow, frozen fill or peat.

> Unless approved by the Owner's Representative as well as supported by random inspections by the QC and/or QA personnel, all fill materials shall only be obtained from stockpiles or sources identified at the beginning of the construction work.

> All materials shall be manufactured from NPAG rock.

3.2 Materials and Gradation Specifications

Materials for construction of the IVR D-1 Dike are to be as shown on the Drawings and are identified by a zone number together with an abbreviated description as follows:

- Zone 1: Rockfill
- Zone 2A: Fine Filter
- Zone 2B: Fine Filter Amended with Bentonite (FFAB)
- Zone 3: Coarse Filter
- Zone 4: Esker

Materials for each zone shall conform to the gradation given below and the grain size distribution limits shown on the figures attached at the end of this document.

3.2.1 Rockfill (Zone 1)

Rockfill shall consist of sound, hard, durable, inert, well graded rock fragments free from any possible effect by water or the elements. It shall be free from snow, ice, frozen chunks, organic matters, debris and other unsuitable matters.

The rockfill gradation shown below is for guidance purposes. The Owner's Representative will evaluate the suitability of this rockfill after the gradation of the blasted rock has been determined. Adjustment to blasting may be required to produce satisfactory rockfill. The gradation limits for the rockfill shall be as indicated in Table 3-1 and Figure 3-1.

Table 3-1: Zone 1 – Rockfill Gradation

Dimension or US Standard Sieve Size	Finer than (%)
1000 mm	100
500 mm	80-100
200 mm	20-100
100 mm	0-60
30 mm	0-25
No. 4 (4.75mm)	0-15

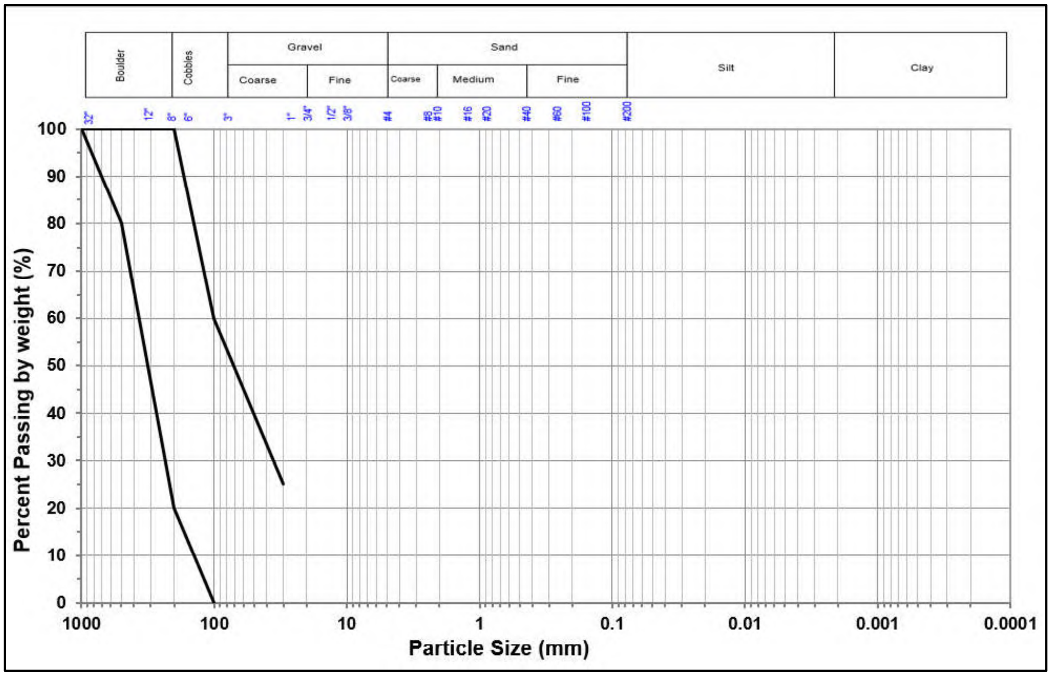


Figure 3-1: Rockfill Gradation - Zone 1 (minus 1000 mm)

3.2.2 Fine Filter (Zone 2A)

Fine filter falls within the gradation limits as shown below and free from clay, organic matters, debris, cinders, ash, refuse, snow, ice and other unsuitable material. The fine filter shall be produced by crushing rock and only have a maximum particle size of 19 mm. The material can only have a maximum of 35% of the particle size above 13mm. It is noted that this material is used for bedding and cover for the LLDPE geomembrane.

The gradation limits for the fine filter fall shall be as indicated in Table 3-2 and Figure 3-2.

Table 3-2: Zone 2A – Fine Filter Gradation

Dimension or US Standard Sieve Size	Finer than (%)
19 mm	100
13 mm	65-100
#4 (4.75 mm)	30-65
#10 (2 mm)	17-41
#16 (0.85 mm)	11-27
#40 (0.425 mm)	9-18
#100 (0.15mm)	7-13
#200 (0.075 mm)	6-10

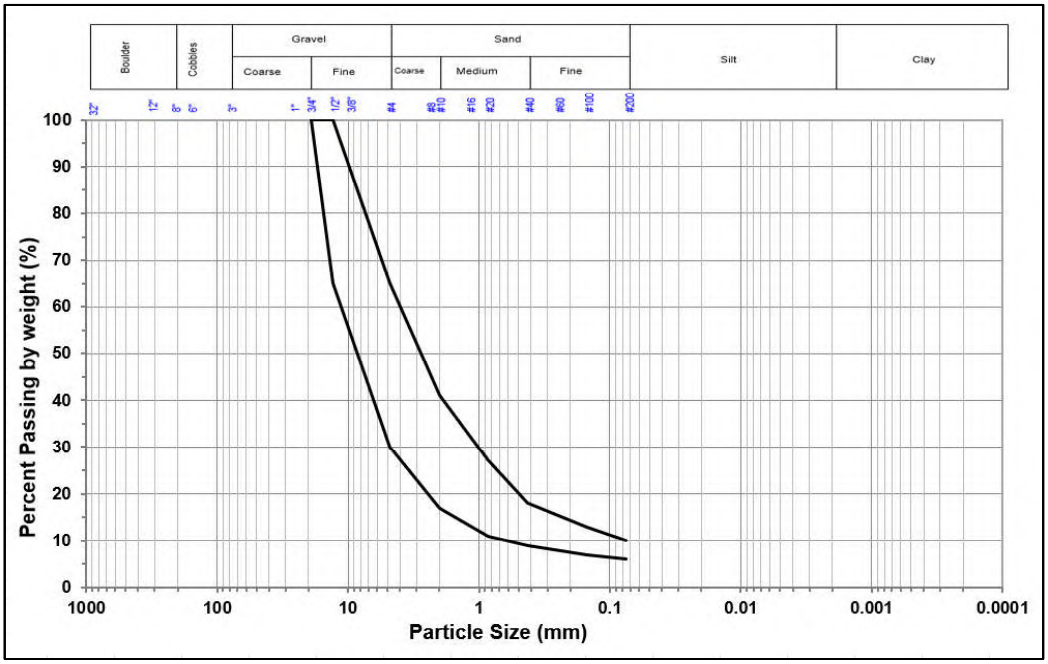


Figure 3-2: Fine Filter - Zone 2A (minus 19mm)

3.2.3 Fine Filter Amended with Bentonite (FFAB – Zone 2B)

The FFAB shall be mixed homogeneously and granular sodium bentonite shall be added mechanically to fine filter or by other method(s) approved by the QC and QA personnel.

The ratio of bentonite in the FFAB shall be at least 6% of the fine filter (weight basis) after mixing, loading, hauling, unloading and placement but before compaction. The initial ratio of bentonite (when mixing) may be higher than 6% to meet this requirement.

The bentonite shall be free flowing, high swelling, granular sodium bentonite, American Colloid Company, Volclay SG-40; Wyo-Ben, Evirogel-10; or equivalent. The bentonite shall have a free swell of at least 18 mL/2 g, measured by ASTM Standard Test Method D-5890 and shall meet the gradation shown in Table 3-3 and Figure 3-3.

Table 3-3: Bentonite Gradation

Dimension or US Standard Sieve Size	Finer than (%)
#10 (2 mm)	100
0.850	60-100
# 200 (0.075 mm)	0-20

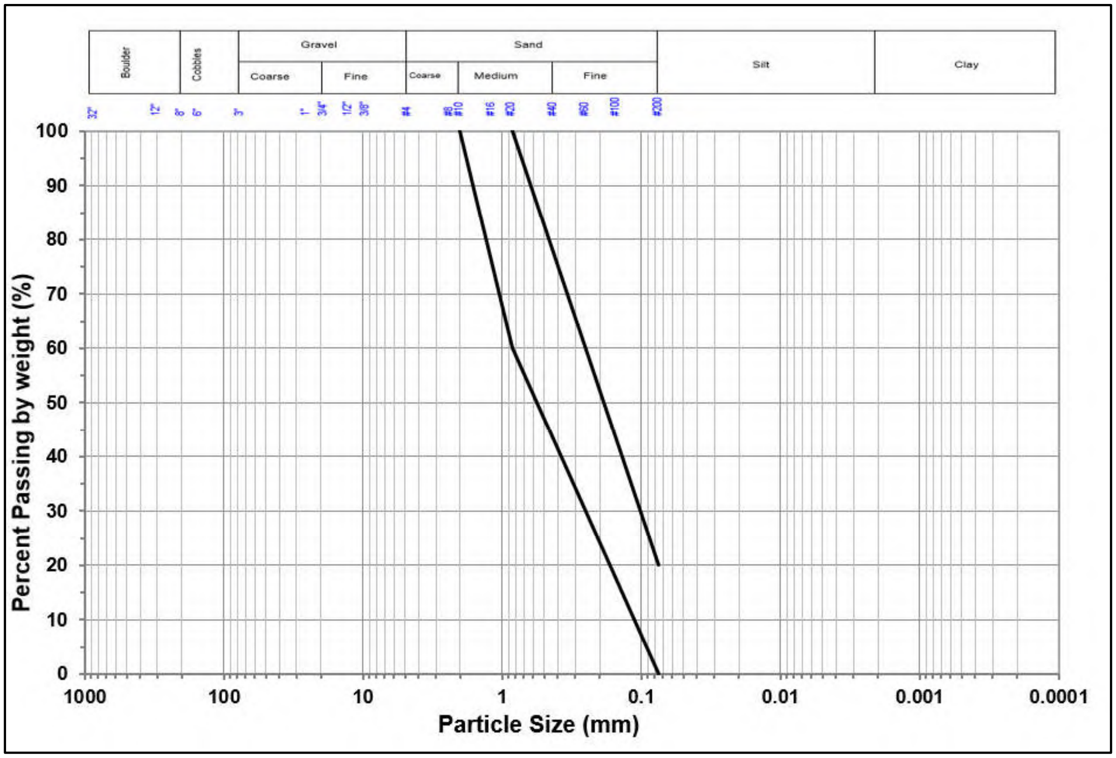


Figure 3-3: Bentonite Gradation

The FFAB shall be mixed in an area protected from prevailing winds. No FFAB mixing, loading, hauling and placement shall occur when weather conditions promote excessive loss of fines based on the judgment of QC and QA personnel.

Only small stockpiles of FFAB are permitted to be produced in order to minimize loss of fines by the wind and/or excessive particle segregation. The FFAB shall be placed and compacted within 24 hours after mixing or before weather conditions deteriorate.

3.2.4 Coarse Filter (Zone 3)

The coarse filter shall consist of sound, hard, durable, inert, well graded rock fragments free from any possible effect by water or the elements. It shall be free from snow, ice, frozen chunks, organic matters, debris and other unsuitable matters. The gradation limits for the coarse filter shall be as indicated in Table 3-4 and Figure 3-4.

Table 3-4: Zone 3 – Coarse Filter Gradation

Dimension or US Standard Sieve Size	Finer than (%)
150 mm	100
100 mm	60-100
30 mm	20-57
10 mm	5-32
# 4 (4.75 mm)	0-24
#10 (2 mm)	0-17
#40 (0.425 mm)	0-10
#200 (0.075 mm)	0-5

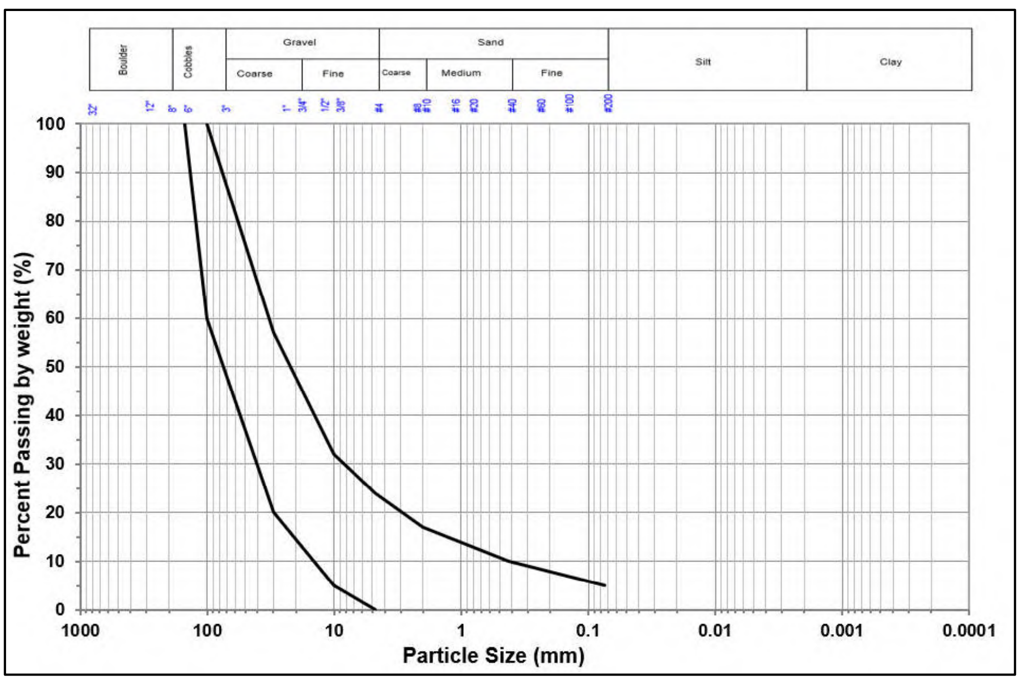


Figure 3-4: Coarse filter – Zone 3 (minus 150 mm)

3.2.5 Esker (Zone 4)

This material shall be free from ice, snow, frozen chunks, organic matters, debris or other unsuitable materials. The material can have a wide variation in gradation with a maximum particle size of 200 mm. The selected esker used for construction of the thermal berm and backfilling the cut-off trench should have fines content (<0.075 mm in size) of 7% to 20% by weight to have a relatively low hydraulic conductivity. The gradation limits for esker shall be as indicated in Table 3-5 and Figure 3-5.

Table 3-5: Zone 4 – Esker Gradation (as provided by AEM)

Dimension or US Standard Sieve Size	Finer than (%)
200 mm	100
100	85-100
56 mm	79-100
31.5 mm	59-93
19 mm	47-86
#4 (4.75 mm)	27-71
#10 (2 mm)	20-62
#40 (0.475) mm	10-45
#200 (0.075 mm)	7-20

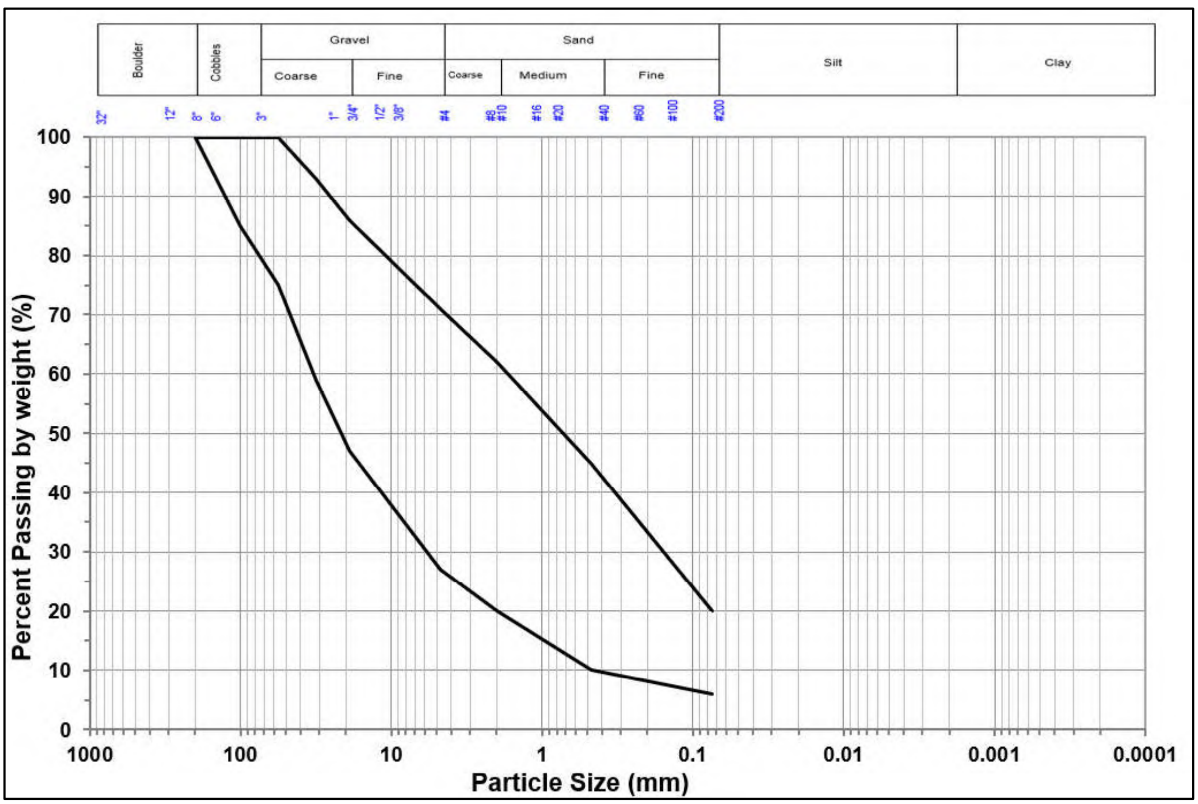


Figure 3-5: Zone 4 - Esker Gradation

3.2.6 Sealing of cracks and joints

The product required to fill cracks and joints after exposure of the bedrock surface on the bottom of the cut-off trench and at the abutment shall be adapted to the conditions that is encountered during the construction and shall be pre-approved by the Owner's Representative.

3.2.7 Non-Conforming Material

Where and when directed by the QC Representative or the QA Inspector, the Contractor shall excavate and/or remove all unsuitable materials to the designated spoil or dump.

4.0 EXECUTION OF WORKS

The Contractor's attention is drawn to the fact that the Work will be executed during arctic winter conditions (from February to April 2021). Some of the activities will take place in a protected area (in an environmental context). Special care shall be taken to ensure the safety of all employees, to avoid damage to the land and surrounding area outside the designated working area.

4.1 Work Method and Sequence

The method of construction and the sequence of execution shall be adapted to conditions that may change often, in order to minimize fill cross contamination and foundation disturbance and to maximize removal of all ice-rich till (when encountered), pockets of gravel, cobbles and boulders in the cut-off trench below the FFAB.

Heavy equipment traffic shall be adapted to the site conditions that may change often so to minimize surface disturbance and the formation of ruts in the work area. The Contractor shall restore disturbed areas as close as possible to the original condition to the satisfaction of the Owner's Representative.

4.2 Test Pads

4.2.1 FFAB Test Pad

The Contractor shall develop test pad(s) located at the bottom of the cut-off trench on a minimal length of 10 m placed in two 250 mm compacted lifts using the FFAB as to establish the number of passes required to reach the *in situ* maximum dry density. The Contractor is free to choose the compaction equipment but shall achieve a minimum dry density of 98% Standard Proctor Dry Density using FFAB in the laboratory at the same water content that the FFAB placed on the field. In other words, the *in situ* dry density shall not be compared with the Standard Proctor value at the optimum water content but using the FFAB material sampled at the mixing pad location and compacted following the Standard Proctor test procedure.

The *in situ* dry density shall be measured using the nuclear densometer or other equivalent method approved by the QC and QA personnel. Each test pad shall be located at the bottom of the cut-off trench during the construction of the IVR D-1 Dike. The required number of test pad(s) is dependant on the nature of the substratum encountered during the excavation of the foundation: a test pad shall be developed for every type of material encountered at the bottom of the cut-off trench (e.g., ice-poor till, bedrock, etc.).

The FFAB test pads shall be compacted with the same equipment used for the construction of the cut-off trench of the IVR D-1 Dike. It is expected that the Contractor shall use compaction with vibration to reach the required *in situ* dry density.

4.2.2 Esker Material Test Pad

Similar to the FFAB test pad, the Contractor shall develop test pad(s) located at the bottom of the cut-off trench on a minimal length of 10 m placed in two 30 cm compacted lifts using the esker material as to establish the number of passes required to reach the *in situ* maximum dry density. The Contractor is free to choose the compaction equipment but shall achieve a minimum dry density of 95% Modified Proctor Dry Density using esker in the laboratory at the same water content that the esker material placed on the field. In other words, the *in situ* dry density shall not be compared with the Modified Proctor value at the optimum water content but using the esker material at its natural water content and compacted following the Modified Proctor test procedure.

The esker material test pads shall be compacted with the same equipment used for the construction of the cut-off trench and thermal berm of the IVR D-1 Dike. It is expected that the Contractor shall use compaction with vibration to reach the required *in situ* dry density.

4.3 Site Preparation

4.3.1 General

- The Contractor shall remove snow, ice, boulders, loose materials, excess organics and ice-rich till within the IVR D-1 Dike footprint prior to any fill placement and shall keep the work area dry.
- The QC Representative may occasionally request that additional soil stripping and removal of snow and ice be carried out from areas in the Dike footprint shown on the Drawings. If the excavated/blasted surface in the overburden exposes large ice lenses or ice rich material and thaw softening layer(s), additional excavation is required to remove all the ice and thawed soil to an appropriate foundation such as ice poor till or bedrock. Within the cut-off trench, the area shall be backfilled with compacted esker or FFAB to the required elevation as shown on Drawing to the satisfaction of the QC Representative.

> The material removed shall be stockpiled separately in areas approved by Owner's Representative.

> The prepared foundation shall be approved by the QC/QA personnel and by the Owner's Representative and the area shall be surveyed by the Contractor prior to fill placement.

> All survey shall be done by the Contractor.

> The approval and visual inspection forms shall be prepared by QC personnel.

4.3.2 Access Roads

> The Contractor shall use in a proper manner the access road that leads to the construction site.

> If required, the Contractor shall submit to the Owner's Representative full details of all temporary construction roads, ramps and access planned for the construction of the channel. Details related to these temporary works shall include location, alignment, required safety berm or traffic signs, period of use, materials used and plan for their removal.

> The Contractor shall maintain in good condition all existing or new access roads used for the execution of the Work such as the access roads connecting the work area to stockpiles and waste dump areas to the satisfaction of the Owner's Representative.

> All the temporary access roads shall be constructed on top of the existing ground. No stripping or excavation shall be undertaken unless approved by the Owner's Representative.

> The Contractor shall supply and install all required traffic signs and safety equipment to ensure worker safety on the construction site for the complete duration of the Work.

> Access road maintenance shall be planned and executed in such a way that worker safety is not compromised. Access roads shall be kept clean of snow and if required, sprinkled with abrasive materials such as gravel to the satisfaction of the Owner's Representative.

> Once the construction work is completed, waste shall be disposed of as directed by the Owner's Representative.

4.4 Water Management during Construction

The Contractor shall be responsible for the construction of temporary swales, ditches and sumps and be equipped with all the necessary pumps, hoses, and other equipment needed to maintain excavations dry for the complete duration of the Work and to the satisfaction of the QC and the QA personnel. The pumped water shall be discharged into the Attenuation Pond for subsequent treatment or other location approved by the Owner's Representative. However, a detailed written procedure of water management during construction shall be submitted to the Owner's Representative for approval prior to the beginning of the Work (Section 2.13).

4.5 Foundation Preparation

4.5.1 General

Foundation preparation involves making sure that the footprint of the IVR D-1 Dike is free of snow, ice, boulders, ice-rich material and any other deleterious materials or soft/loose pockets of material at all times during the first layer of fill placement regardless of the type or fill zone.

4.5.2 Cut-off trench Excavation and Bedrock Treatment

> Based on the available geotechnical information described in Section 2.7, the active zone is about 1.5 to 2 m depth below ground surface (mbgs). The cut-off trench excavation is expected to be mostly in overburden; however, depending on the thickness of the later, the cut-off trench bottom could be partly on the bedrock surface.

> The excavation will require an open cut excavation through frozen foundation soils using drilling and blasting methods.

> The minimum depth of cut-off trench excavation is 3 m (except for the abutments) below ground to ensure at least 1m below the active zone. However, to avoid bedrock excavation or cut-off trench bottom ending in the surficial gravel, cobbles and boulders layer, the bottom of the cut-off trench must be established on or below the glacial till surface or on bedrock surface. If the surficial gravel, cobbles and boulders layer is thicker than 3 m, the excavation must continue until this material has been completely removed. The over excavated area will be backfilled with compacted esker or FFAB to the required depth.

> The bedrock surface at the bottom of the cut-off trench, if encountered, shall be carefully cleaned. All pockets, cracks and depressions filled with soil and rock fragments shall be cleaned to the satisfaction of the QC/QA personnel. The cleaning may require the use of compressed air to allow the QA Inspector to conduct a general bedrock mapping.

> The final cut-off trench depth as well as longitudinal and lateral dimensions shall meet those shown on the Drawings and shall be approved by the Owner's Representative and the QC/QA personnel prior to any fill placement.

> Remove all sharp objects and large stones. Excavated materials shall be set aside separately or stockpiled in areas approved by the Owner's Representative.

> The QC/QA personnel may, from time to time, request that additional soil stripping or cleaning of the bedrock surface be carried out.

> The excavation shall be dewatered (when applicable) and all thawed soil removed prior to any backfilling. Ice or ice-rich material shall be completely removed from the bottom of the cut-off trench before any fill placement to the satisfaction of the QC/QA personnel.

4.6 Stockpile and Disposal Areas

> Unless authorized otherwise, all excavated materials including ice and soil shall be disposed in the area approved by the Owner's Representative. During the construction, any other waste disposal area requires written authorization by the Owner's Representative.

> The Contractor shall develop its stockpiles to facilitate drainage and minimize fill segregation to the satisfaction of the QC personnel.

4.7 Fill Placement and Compaction

4.7.1 General

The Contractor shall construct structures to the lines, grades and cross-sections shown on Drawings using only suitable materials approved by the Owner's Representative.

Methods of carrying out fill placement and compaction shall be subject to approval of the Owner's Representative. The Contractor shall demonstrate equipment suitability, methods of working, rate of progress and quality of work during the initial stages of the Work. In the event that the work performance is unsatisfactory for either quality or schedule requirements, immediately implement such changes as are required to ensure the required quality and scheduled completion of the Work.

No water, snow or ice shall be allowed on the surface of the fill or foundations. No material shall be placed on any part of the foundation until the foundation has been inspected and approved by the QA Inspector and/or Owner's Representatives. No material shall be placed when satisfactory work cannot be performed due to rain, snow, unsatisfactory materials or any other unsatisfactory conditions. Any embankment material that has been damaged by rain, seepage or any other cause shall be removed and replaced with satisfactory material as specified herein before placing succeeding layers.

Compact fill materials shall be placed and compacted in horizontal lifts beginning in the lowest area of the foundations unless specified otherwise. Mixing of the materials from adjoining zones shall be avoided.

Fill materials shall be placed in accordance with the best modern practice and the equipment best adapted to the Work to be performed. Materials shall be placed so that each zone is homogeneous, free of horizontal stratification, lenses, pockets, ruts or layers of material of different texture or grading not conforming to the requirements specified for the material of each zone.

Materials shall be transported by means of hauling units having enough bearing surface to prevent rutting. The Contractor shall ensure hauling units do not follow tracks. If, however, rutting occurs, the Contractor shall scarify and compact to produce an even surface.

The Contractor shall transport, dump and spread materials in such a manner as to avoid segregation before compaction; and provide a material that conforms, after placement, to the grading requirements as specified herein. During dumping and spreading, any waste materials such as, but not limited to, all debris, organics, vegetation or any other unsuitable material shall be removed. Accumulations of oversized stones, particularly between different material zones and abutment contacts shall be removed and replaced with suitable materials as specified herein.

All materials shall be placed in a direction parallel to the axis of the earthwork structures, exceptions shall be approved by the Owner's Representative.

Placement of fill shall be discontinued if unacceptable pore pressures in the foundations develop, as determined by the Owner's Representative. The Contractor shall re-commence the fill operations when the pore pressures dissipate sufficiently, as determined by the Owner's Representative.

4.7.2 Rockfill (Zone 1)

> The Contractor shall sort out boulders bigger than 1000 mm prior to fill placement at the quarry. If there are any boulders larger than 1000 mm, they shall be pushed outside of the Dike footprint for later removal by the Contractor.

> Rockfill shall be placed in layers not exceeding 1500 mm uncompacted thickness. Special precautions shall be taken to ensure that no significant voids exist in this zone.

> A finer rockfill material (less than 600 mm) shall be placed on the upstream slope side of the Dike.

> Individual rockfill lifts shall be overbuilt by a width of 1 m in both upstream and downstream directions, where applicable. Overbuilds should be cut back in both directions especially before placement of Zone 3 on the upstream slope.

> The Contractor shall compact each lift with at least 6 passes of a minimum 10-tonne vibratory rock compactor or equivalent.

> Haul trucks shall dump their load on horizontal surface and not in slope to limit fill segregation and the formation of voids.

> Great care shall be taken to limit particle segregation during placement. Occasionally the QC and/or QA personnel may request the Contractor to modify his construction procedures to meet this requirement.

> Placement and compaction of fill must be performed to the satisfaction of the QC and QA personnel.

4.7.3 Fine Filter (Zone 2A)

> The fine filter is used as bedding for and cover on the liner.

> The maximum loose lift thickness of fine filter shall be 0.3 m on the downstream side of the liner and 0.5 m on the upstream side of the liner. The contractor shall avoid excessive handling of the fine filter material to prevent particle segregation.

> Compaction of fine filter shall be carried out using the bucket of the excavator.

> Controlled placement of fine filter shall be performed to avoid damaging the LLDPE geomembrane.

> The surface shall be smooth with no sharp or abrupt changes in grade.

> The material shall not be sprayed with water during bucket compaction.

> Hall trucks shall dump their load on horizontal surface and not in the slope to limit fill segregation.

> The QC Representative shall carry out three (3) particle size analyses from the fine filter stockpile before the start of the Work to ensure that the material meets the gradation specified in Table 3-2. Ideally, these tests shall be conducted during crushing operations of the rock material in order to allow the Contractor adjusting his screening, if required. The QC Representative shall then carry out one (1) particle size analysis per every 1000 m^3 of fine filter placed during construction.

> Placement and compaction of this material shall be carried out to the satisfaction of the QC and QA personnel.

> Down-slope placement of material is prohibited.

4.7.4 Fine filter amended with bentonite (FFAB) – Zone 2B

> Prior to the FFAB material placement, the QC Representative shall conduct at least one (1) Standard Proctor test on the FFAB material to fully define the moisture content versus dry density relationship. QA Inspector may request additional Standard Proctor tests to be carried out, if deemed necessary.

> The Contractor shall mix the materials near the construction site and following a pre-approved procedure by the QC/QA personnel and by the Owner's Representative. The mixing procedure shall be adjusted depending on wind direction and/or intensity to minimize bentonite loss.

> The Contractor shall demonstrate that he can mix bentonite and fine filter material with an accuracy of ±0.5% of the target bentonite ratio of 6% (by weight of fine filter). The Contractor may need to add more bentonite to ensure that the ratio of 6% is reached or slightly exceeded given the potential inherent imprecision of its method to mix the FFAB.

> The Contractor is not allowed to pre-mix and stockpile the FFAB for periods longer than 24 hours.

> The Contractor shall proceed with the mixing process in such way that the material can be placed immediately without requiring double handling.

> The Contractor is responsible for planning the mixing process to respect the construction schedule.

> The FFAB at the bottom of the cut-off trench shall have a minimum compacted thickness of 1 m built in four layers: two lifts of 250 mm for the first 0.5m (bottom) layer and two lifts of 250 mm for the second 0.5m (top). The actual thickness is expected to vary locally depending on deeper pockets of gravel, cobbles, and boulders that need to be removed as well as the topography of the exposed bedrock surface and the need to provide a horizontal surface that will allow anchoring of the LLDPE with full contact to the FFAB. The Contractor's attention is drawn to the fact that where the FFAB is thicker than 0.5 m, it shall be placed and compacted in maximum lift thicknesses of 300 mm.

> Placement and bucket compaction of FFAB layer over the LLDPE along the slope shall be carried out in the same procedure as specified in Section 4.7.3.

> Each lift must be placed with great care to limit fine losses of bentonite powder due to wind and/or particles segregation during placement. Occasionally the QA and QC Representatives may ask the Contractor to modify his construction procedure to meet this requirement.

> Under the liner, each lift must be compacted with the optimum number of passes which will be determined following the completion of the test pad work outlined in Section 4.2.1 in order to achieve 98% of the maximum dry density using the Standard Proctor compaction procedure on a sample at its natural water content.

> The dry density testing of the FFAB shall be conducted after compaction of the FFAB layers. However, the particle size analysis of the FFAB shall be conducted on material sampled before compaction.

> The QC Representative shall carry out three (3) particle size analyses using the FFAB placed in the cut-off trench for the FFAB test pad before compaction. The test results shall be compared with the particle size analyses conducted in the fine filter stockpile to assess the actual proportion of bentonite in the FFAB. The QC Representative shall then carry out one (1) particle size analysis per every 1000 m³ of FFAB placed during construction.

> FFAB shall not be sprayed with water during compaction.

> Placement and compaction of the fill must be performed to the satisfaction of the QC personnel.

4.7.5 Coarse Filter – Zone 3

- The Contractor shall avoid excessive handling of the coarse filter to prevent particle segregation.
- Haul trucks shall dump their load on horizontal surface and not in the slope to limit fill segregation.
- The QC Representative shall carry out two (2) particle size analyses from the coarse filter stockpile before the start of the Work to ensure that the material meet the gradation specified in Table 3-4. Ideally, these tests shall be conducted during crushing operations of the rock material in order to allow the Contractor adjusting his screening, if required. The QC Representative shall then carry out one (1) particle size analysis per every 1000 m³ of placed coarse filter during construction.
- The QA Inspector and/or the QC Representative may request additional gradation analyses of the coarse filter over the course of the Work if deemed necessary.
- The coarse filter will have to be placed in freezing temperatures. Any snow and ice accumulated on the previous lift shall be removed before placement of the new lift.
- Each lift shall be placed with a maximum lift thickness of 0.5 m upstream and downstream of the liner, and at 0.3 m elsewhere. Great care must be taken to limit particle segregation during placement. Occasionally the QC and QA personnel may ask the Contractor to modify his construction procedure to meet this requirement.
- Compaction of the coarse filter shall be carried out using a 10-tonne compactor with a minimum of 6 passes.
- Below the liner
- The coarse material shall not be sprayed with water during compaction.
- Placement and compaction of the fill must be performed to the satisfaction of the QC and QA personnel.

4.7.6 Esker – Zone 4

- Each lift must be compacted with the optimum number of passes which will be determined following the completion of the test pad work outlined in Section 4.2.2.
- The QC Representative shall carry out three (3) particle size analyses from the esker material before the start of the Work to ensure that the material meet the gradation specified in Table 3-5. The QC Representative shall then carry out one (1) particle size analysis per every 1000 m³ of placed coarse filter during construction.
- Haul trucks shall dump their load on horizontal surface and not in the slope to limit fill segregation.

> Any snow and ice accumulated on the previous lift shall be removed before placement of the new lift.

> Each lift shall be placed with a maximum lift thickness of 0.5 m. Great care must be taken to limit particle segregation during placement. Occasionally the QC and QA personnel may ask the Contractor to modify his construction procedure to meet this requirement.

> In the cut-off trench, the maximum lift thickness shall be reduced to 0.3 m.

> Placement and compaction of the Zone 4 material shall be performed to the satisfaction of the QC and QA personnel.

4.8 Adverse Conditions

The Contractor shall not carry out any excavation, placement or compaction of fill materials when conditions are such that in the opinion of the QC Representative and the QA Inspector, the quality of the Work or adjacent works would be adversely affected. After any operation has been stopped owing the adverse conditions, operations shall not be re-started without the approval of the QC Representatives and/or the QA Inspectors and the Owner's Representative.

4.9 Acceptance

The Contractor shall submit works or sections of works completed in accordance to the lines and grades shown on the Drawings for the Owner's Representative approval.

4.10 LLDPE Geomembrane

4.10.1 General

4.10.1.1 Scope of Work

These Specifications cover the requirements to be met for the installation a 1.5 mm thick double sided textured LLDPE liner in the IVR D-1 Dike. The work covered by this Specification includes, but not limited to:

By Owner:

> Ordering the LLDPE geomembrane;

> Handling and transport of the LLDPE geomembrane to the mine site;

> Receiving and unloading rolls of the LLDPE geomembrane at the mine site;

> Preparing a suitable temporary storage area for the rolls of the LLDPE geomembrane and protecting them from damage or environmental degradation while in temporary storage.

By the Contractor/Installer:

> Transporting the rolls of LLDPE geomembrane from the temporary storage area to the installation site. The LLDPE geomembrane is required to be preheated and cannot be installed at ambient temperatures (see Section 4.10.3.1.4).
> Placing the LLDPE geomembrane in accordance with the Manufacturer's instructions and the Specifications, to the lines, grades and dimensions shown on the Drawings.
> Providing all materials, equipment and labour required to position and install the LLDPE geomembrane, as shown on Drawings;
> Carrying out the non-destructive and destructive tests required in the Specifications, employing industry standard techniques and equipment.
> Clean up the site.
> Preparation of pre-installation and as-built panel layout drawings, and
> Preparation of the liner installation report.

4.10.1.2 Qualifications and Experience

The geomembrane liner installation as specified herein shall be carried out only by a qualified Contractor/Installer experienced in cold temperature liner installation and fully certified by IAGI (International Association of Geosynthetic Installers) or approved equal certification body.

The Contractor/Installer shall have adequate field QA/QC and performance warranty programs, as approved by the Owner's Representative.

All personnel performing seaming operations shall have been trained in the operation of the specific seaming equipment being used. Contractor/Installer's Site Supervisor shall have installed a minimum of 500,000 m^2 of liner. The Master Seamer shall be a welding technician with a minimum of 100,000 m^2 of liner seaming work and may function as Site Supervisor, if qualified as above.

4.10.1.3 Type of Geomembrane

The LLDPE geomembrane to be installed in the IVR D-1 Dike shall be Micro Spike, 1.5 mm thick double-sided textured geomembrane which is supplied by AEM.

4.10.1.4 Shop Drawings

Prepare and submit for review by the Owner, shop drawings of the panel layout showing proposed welding method between each panel.

4.10.1.5 Warranty

The Contractor/Installer shall warrant the geomembrane seams to be free from defects in the installation and workmanship for two (2) years commencing with the date of final acceptance by the Owner. Said warranty shall apply to normal use and service by the Owner and specifically excludes mechanical abuse or puncture by machinery, equipment or people, exposure of the liner to harmful chemicals, heavy traffic, etc. Such written warranty shall provide for the total and complete repair or replacement of the defect or defective areas of liners upon written notification and demonstration by the Owner of the specific non-conformance of the liner or installation with the project Specifications. Such defects or non-conformance shall be repaired or replaced within a reasonable period of time at no cost to the Owner.

4.10.1.6 Handling and Storage

The geomembrane shall be handled using proper equipment to avoid damage to the material. The material shall be stored on a surface that is free of irregularities that can damage the liner and, in an area, approved by the Owner's Representative. However, no more than three (3) rolls shall be stacked on top of each other.

The geomembrane shall be protected against puncture, tear or other such defect to the satisfaction of the Owner's Representative during storage and transport for installation.

4.10.2 Materials

4.10.2.1 Code and Standards

For Code and Standards refer to Section 2.2.

4.10.2.2 Test Definitions

Throughout the Specifications, unless otherwise stated, the following definitions shall apply:

> Density test shall mean the measurement of the mass per unit volume of the LLDPE resin or liners determined by the density column method in accordance with the latest ASTM D1505.

> Melt index test shall mean the determination of the weight of a molten resin or molten liner extruded through a standard orifice under a constant pressure in accordance with the latest ASTM D1238.

> Carbon black content shall mean the determination of the carbon black content of plastics in accordance with the latest ASTM D1603.

> Carbon black dispersion refers to the determination of the uniformity of carbon black of plastics in accordance with the latest ASTM D5596.

> Tensile strength and elongation at yield and break test shall mean the determination of the tensile properties of plastics using standard dumbbell-shaped test specimens under defined conditions of pre-treatment temperature, humidity and testing method and speed (strain rate) in accordance the latest ASTM D6693.

> Tear resistance shall mean the determination of the resistance to initiate tearing of flexible plastic film and sheeting at very low rates of loading (51 mm/min) in accordance with the latest ASTM D1004.

> Puncture resistance shall mean the determination of the index puncture resistance of geotextiles, geomembranes, and related products in accordance with the latest ASTM D4833.

> Stress crack resistance test shall mean the determination of the cracking resistance of a standard liner test specimen immersed in a standard solution maintained at a temperature of 50°C. The resistance to cracking failure of the liner is reported in terms of hours to failure as described in the ASTM D 5397.

> Oxidative Induction Time shall mean the determination of oxidative-induction time (OIT) of the high-density and linear low-density polyethylene (HDPE and LLDPE) polymeric material by differential scanning calorimetry to examine the depletion of antioxidants from geomembranes as a result of their exposure to various environments.

> Air-Oven Aging refers to the methods for estimating the resistance of geomembranes to thermal aging in the presence of air.

> UV Resistance refers to the test used to assess the resistance of geomembrane to degradation by ultra-violet rays.

> Wide strip tensile test refers to the measurement of the tensile strength and elongation on a minimum 200 mm wide test strip. This test differs from that covered by ASTM D6693 which uses a 6 mm wide dumbbell shaped sample.

4.10.2.3 General Requirement for Geomembrane

4.10.2.3.1 Material

> The geomembrane shall comprise unsupported low-density polyethylene material manufactured of new, first-quality products designed and manufactured specifically for the purpose of liquid containment in hydraulic structures.

> The geomembrane shall be so produced as to be free of holes, blisters, undispersed raw materials or any sign of contamination by foreign matter. Any such defect shall be repaired using extrudate welding in accordance with the manufacturer’s recommendations.

> All compound ingredients of the geomembrane shall be randomly sampled on delivery to the manufacturing plant to ensure compliance with purchase specifications. Tests to be carried out per batch of resin shall include Density (ASTM 1505) and Melt Index (ASTM D1238 procedure A, condition E) and others as specified below.

> Samples of the production run shall be taken and tested by the manufacturer according to ASTM D6693 to ensure that thickness, tensile strength at yield and break, elongation at yield and break, meet the minimum specifications. A quality control certificate shall be issued with the material.

> The liner material shall be supplied with a minimum seamless roll width of approximately 7 m. However, the specified minimum 7 m roll width may be obtained by factory seaming with no more than one factory seam per roll. Labels on the roll shall identify the thickness, texture, width and manufacturer’s mark number and date of manufacture.

> All welding material shall be of type recommended and supplied by the manufacturer and shall be delivered in the original sealed containers-each with an indelible label bearing the brand name, manufacturer's mark number and complete directions as to proper storage.

The liner shall be produced from new first quality LLDPE resin. The resin and liner shall meet or exceed the specification values given in Table 4-1. The material conformance tests listed on Table 4-1 copied from the website of the GRI.

Table 4-1: Textured LLDPE Geomembrane Conformance Test Results

Table 2(b) – Linear Low Density Polyethylene (LLDPE) Geomembrane (TEXTURED)

Properties	Test Method	Test Value								Testing Frequency (minimum)
		0.50 mm	0.75 mm	1.00 mm	1.25 mm	1.50 mm	2.00 mm	2.50 mm	3.00 mm	
Thickness (min. ave.) - mm • lowest individual for 8 out of 10 values • lowest individual for any of the 10 values	D 5994	nom. -5% -10 -15	nom. -5% -10 -15	nom. -5% -10 -15	nom. -5% -10 -15	nom. (5% -10 -15	nom. -5% -10 -15	nom. -5% -10 -15	nom. -5% -10 -15	per roll
Asperity Height mm (min. ave.)	D 7466	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	Every 2nd roll *(1)*
Formulated Density (max.) - g/cc	D 1505/D 792	0.939	0.939	0.939	0.939	0.939	0.939	0.939	0.939	90,000 kg
Tensile Properties *(2)* (min. ave.) • break strength - N/mm • break elongation - %	D 6693 Type IV	5 250	9 250	11 250	13 250	16 250	21 250	26 250	31 250	9,000 kg
2% Modulus (max.) - N/mm	D 5323	210	315	420	520	630	840	1050	1260	per formulation
Tear Resistance (min. ave.) - N	D 1004	50	70	100	120	150	200	250	300	20,000 kg
Puncture Resistance – (min. ave.) - N	D 4833	100	150	200	250	300	400	500	600	20,000 kg
Axi-Symmetric Break Resistance Strain (min.) - %	D 5617	30	30	30	30	30	30	30	30	per formulation
Carbon Black Content (range) - %	D 4218 *(3)*	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	20,000 kg
Carbon Black Dispersion	D 5596	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	20,000 kg
Oxidative Induction Time (OIT) (min. ave.) *(5)* (g) Standard OIT - min. — or — (h) High Pressure OIT - min.	D 3895 D 5885	100 400	100 400	100 400	100 400	100 400	100 400	100 400	100 400	90,000 kg
Oven Aging at 85°C *(6)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 3895 D 5885	35 60	35 60	35 60	35 60	35 60	35 60	35 60	35 60	per formulation
UV Resistance *(7)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(9)*	D 7238 D 3895 D 5885	N. R. *(8)* 35	N.R. *(8)* 35	N.R. *(8)* 35	N.R. *(8)* 35	N.R. *(8)* 35	N.R. *(8)* 35	N.R. *(8)* 35	N.R. *(8)* 35	per formulation

(1) Alternate the measurement side for double sided textured sheet
(2) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
- Break elongation is calculated using a gage length of 50 mm at 50 mm/min.

(3) Other methods such as D 1603 (tube furnace) or D 6370 (TGA) are acceptable if an appropriate correlation to D 4218 (muffle furnace) can be established.
(4) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
- 9 in Categories 1 or 2 and 1 in Category 3

(5) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.
(6) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.
(7) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.
(8) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.
(9) UV resistance is based on percent retained value regardless of the original HP-OIT value.

4.10.2.3.2 Field Seams

The field seam properties of the LLDPE geomembrane for this project shall meet or exceed the minimum values in Table 4-2.

Table 4-2: LLDPE Geomembrane Field Seam Properties

Property	Test Method	Minimum Value (1.5mm LLDPE Liner)
Hot Wedge (Fusion) Seam[1]		
• Shear strength [2], N/25 mm	ASTM D6392 GRI-GM19	394
• Shear elongation at break [3], %		50
• Peel strength [2], N/25 mm		328
• Peel separation, %		25
Extrusion Fillet Seams		
• Shear strength [2], N/25 mm	ASTM D6392 GRI-GM19	394
• Shear elongation at break [3], %		50
• Peel strength [2], N/25 mm		290
• Peel separation, %		25

Notes:

1. Also, for hot air and ultrasonic seaming methods.
2. Values listed for shear and peel strengths are for 4 out of 5 test specimens, the 5th specimen can be as low as 80% of the listed values.
3. Elongation should be observed but measurements should be omitted for field testing.

4.10.2.3.3 Extrusion Weld

All extrusion welding material (extrudate), shall be of type recommended and supplied by the manufacturer and shall be delivered in the original sealed containers-each with an indelible label bearing the brand name, manufacturer's mark number and complete directions as to proper storage. Extrusion welding material shall be supplied by the Owner.

4.10.2.4 Quality Control

1. A quality-control technician shall visually inspect each geomembrane seam. All areas showing defects shall be marked and repaired in accordance with the manufacturer's repair procedures.

2. The Contractor/Installer shall employ on-site, physical non-destructive testing during daylight hours on all welds to ensure watertight and continuous seams. Testing of geomembrane seams shall be by air pressure in the channel between the double weld and vacuum or electric wire testing of single extrusion welds. Any defective seams shall be repaired and retested.

3. A test weld 1.0 m long from each welding machine shall be run each day prior to geomembrane liner welding and under the same conditions as exist for the liner welding. The test weld shall be marked with date, ambient temperature, and welding machine number. Samples of weld 25 mm wide shall be cut from the test weld and pulled in shear and peel. Seams shall be stronger than the material. The weld sample shall be kept for subsequent testing on laboratory tensiometer equipment in accordance with the applicable ASTM tests. Random weld samples may be removed from the installed welded sheeting at a frequency to be agreed at the time of installation.

4. The Owner's Representative reserves the right of access for inspection of any or all phases of this installation and testing.

5. As built records shall be kept throughout construction. The records shall be submitted to the Owner Representative as they are produced, and a complete copy of the records shall be kept by Contractor/Installer for a minimum of 2 years after the end of the liner installation. These shall include layout of panels, seam locations, details of cut-off trench anchorage and location of the liner within the embankment fills.

6. A record of all field geomembrane seam testing shall be kept.

A report comprising information such as liner specifications, as-built records and test results shall be provided to the Owner's Representative.

4.10.2.5 Adverse Conditions

The Contractor/Installer shall not carry out any geomembrane deployment and seaming operations when conditions are such that in the opinion of the Owner's Representative, the quality of the Work or adjacent works would be adversely affected. After any operation has been stopped owing to adverse conditions it shall not be re-started without the approval of the Owner's Representative.

4.10.2.6 Removal of Unsuitable Materials

Where directed by the Owner's Representative the Contractor/Installer shall cut and remove unsuitable materials to a disposal or recycle facility to the satisfaction of the Owner's Representative. Small pieces of geomembrane that will not affect the quality of the backfill maybe left in the trench at the discretion of the Owner's Representative.

4.10.2.7 Site Road and Access

The Contractor shall submit to the Owner full details of all temporary site roads, ramps and access planned for the installation of the geomembrane. Such details on construction access shall include location, period of use, materials used in construction and proposals for removal or reinstatement on completion as required by the Owner's Representative.

4.10.3 Execution

4.10.3.1 Geomembrane Handling and Installation

4.10.3.1.1 Preparation

1. The Contractor shall use survey information and plans supplied by the Owner and prepare panel layouts specifying approximate lengths and sequence of placement and submit to Owner.

2. All materials shall be delivered to a site storage area approved by the Owner's Representative.

3. Surfaces to be lined shall be approved and certified in writing before commencement of Work.

4. Schedule for the installation with the preparation of the surfaces to be lined shall be coordinated to ensure that the prepared surfaces are not exposed to damages by inclement weather (snow/blizzard or wind). A schedule for the installation shall be submitted to the Owner.

5. The Contractor shall mobilize field supervisor, labor, materials, tools and equipment to carry out installation.

The Contractor/Installer shall have met the manufacturer's minimum requirements to become a licensed installer of the manufacturer's product using the manufacturer's state-of-the-art equipment and seaming methods.

4.10.3.1.2 Deployment of Geomembrane

1. The Contractor shall pre-cut geomembrane panels in-plant or on site, to the extent possible, to the planned lengths and transport to the work area or equivalent method as approved by Owner’s Representative

2. Rolls of geomembrane shall be placed on the prepared subgrade such that seams are generally up and down the slope, i.e. perpendicular to the longitudinal axis of the slope.

3. Geomembrane shall be anchored in trench as shown in the Drawings.

4. Any damage to the liner during installation or subsequent work shall be repaired to the satisfaction of the Owner's Representative with no additional cost to the Owner.

5. No vehicular traffic shall travel on the geomembrane other than a low ground pressure vehicle or equivalent approved by the Owner’s Representative.

6. Sand bags or equivalent ballast shall be used as necessary to temporarily hold the geomembrane material in position under the foreseeable and reasonably expected wind conditions.

7. The Contractor shall not proceed with liner placement and seaming during high winds which may blow liner out of control nor during periods of snowfall or snow drifting.

8. The Contractor shall unpack and place into position only those sheets of liner that can be anchored and sealed together that same day/shift.

9. Deployment equipment shall not damage the subgrade. Only low ground pressure, rubber tired all terrain vehicles (ATV) shall be used on the liner. The Contractor shall take care to avoid damage and excessive traffic.

10. The Contractor shall install the liner in a relaxed condition free from tension or stress upon completion of the installation. The liner shall not be stretched to fit. Enough slack shall be incorporated during placement to ensure that harmful stresses do not occur in service, and that allowance is made for thermal contraction in accordance with Section 4.10.3.1.9. The Contractor shall ensure that stones or debris are not trapped beneath the liner.

4.10.3.1.3 Seaming

1. Individual panels of geomembrane shall be overlapped by a minimum of 75 mm for hot shoe and extrusion welding respectively or as approved by the Owner's Representative. Extreme care shall be taken by the Contractor/Installer in the preparation of the geomembrane to be welded. The geomembrane to be welded shall be dried and cleaned and prepared according to the procedures laid down by the manufacturer. All sheeting shall be seamed to produce a double weld by means of a hot wedge except in difficult areas such as corners between two slopes, local repairs or other such areas approved by the Owner's Representative where a single weld by means of an extrusion bonding process is permitted. For all extrusion welds, the composition of the extrudate shall have similar composition as the liner material.

2. The welding equipment used shall be capable of continuously monitoring and controlling the temperatures of the hot wedge or extrudate so as to ensure that changes in environmental conditions will not affect the integrity of the weld.

3. Trial welds shall be produced and tested at least once a day at the beginning of the shift. Additional tests shall be performed in cases of inclement weather or due to other relevant reasons which will affect the quality of the Work as directed by the Owner's Representative.

4. No "fish mouths" shall be allowed within the seam area. Where "fish mouths" occur, the material shall be cut, overlapped, and an overlap-extrusion weld shall be applied. All welds on completion of the Work shall be tightly bonded. Any geomembrane area showing injury due to excessive scuffing, puncture, or distress from any cause shall be replaced or repaired with an additional piece of the specified liner material.

5. All field seams shall be made generally perpendicular to the longitudinal axis of slopes except locally in areas where conditions do not permit.

6. All fusion welds shall be non-destructively air pressure tested over the entire length of the seam.

7. Extrusion welds shall be non-destructively tested over the entire length of the seam using either the vacuum box method, the electric wire method or equivalent method(s) approved by the Owner's Representative.

8. Panels shall be overlapped to permit welding without having to splice small sections of material into the general panel layout.

4.10.3.1.4 Cold Temperature Installation

The Contractor/Installer shall demonstrate to Owner's Representative that he can install and weld liner at low temperatures on site to conform with requirements of this Specification.

The Contractor/Installer shall not seam when it is snowing, sleeting or hailing on liner area to be seamed. Frost from exposing surfaces shall be removed where seaming is to be performed. Residual moisture shall be removed with a hand-held hot air device if necessary. Application of excessive heat resulting in damage to the liner shall be avoided.

For thermal fusion welding, underside of lower sheet shall be free of frost so that lower drive wheels can move evenly and do not slip. If necessary, additional rub sheet beneath area being seamed to separate liner from frozen subgrade shall be used.

Rate of seaming at temperatures shall be decreased below 0°C, and with decreasing liner temperature. Hoarding or heated shack for welding operation shall be provided as necessary.

Grinding of liner surfaces in preparation for placing extrudate during extrusion welding shall not proceed more than 5 m ahead of extrusion gun. At discretion of Contractor and Owner's Representative, base of extrusion gun barrel may be shaped rectangularly, to minimize cooling rate in thinner extrudate regions.

The Contractor/Installer shall use following additional alternative cold weather precautions as appropriate:

- Keeping the liner warm until the moment before installation.
- Keeping the liner under a tarpaulin with a heater.
- Using a warm air heater directed at the liner.

The Contractor/Installer shall use movable enclosures, traveling along with the welding device, during conditions of high winds.

4.10.3.1.5 Contractor's Quality Control

The Contractor/Installer shall provide a QA/QC plan to be approved by the Owner's Representative prior to starting as specified in Section 2.13.

The Contractor/Installer QC Representative shall provide on-site supervision, equipment and testing during the installation period for inspection of completed liner bed preparation, liner materials and placement and joining of the liner, as required to warrant the entire liner installation. He shall maintain and clean all equipment on a regular basis to ensure good working order.

4.10.3.1.6 Non-Destructive Test

Each weld shall be tested to ensure its water tightness, integrity and continuity. Non-destructive testing shall consist of air channel testing for double-wedge fusion welds or vacuum box testing on extrusion welds. Air pressure testing shall be performed in accordance with ASTM D5820. Vacuum testing shall be performed in accordance with ASTM D5641. Other types of non-destructive testing will be performed only upon written approval of the Owner's Representative. The Contractor/Installer shall document his non-destructive tests by providing the following information for each weld, a copy of which shall be submitted to the Owner's Representative for approval:

a. Date and time;

b. Weld identification number, including the roll(s) information;

c. Identification number of welding equipment used;

d. The test results;

e. Identification of non-conformance;

f. Identification of the technician

4.10.3.1.7 Destructive Tests

Destructive tests shall be performed by the Contractor/Installer in order to check the mechanical strength of the geomembrane welds. The location of the destructive tests will be selected by the Owner's Representative, who reserves the right to request tests every 150 m of seam length depending on the results of the first test performed in the morning of a given day. The test samples will be collected at the end of a panel or in anchor trenches so as to preserve the integrity of the liner.

At each location selected by the Owner's Representative, the Contractor/Installer shall remove a sample 1000 mm by 300 mm, where the weld is centered along the width of the sample. The Contractor/Installer shall then proceed with field verification of the seam resistance to peeling (five (5) samples tested on both sides) and shearing (five (5) specimens tested) using a portable calibrated tensiometer. Four (4) out of the five (5) specimens tested, shall meet the minimum seam resistance indicated in Table 4-1 of this Specification and the fifth (5^{th}) result shall not be less than 80% of the specified value.

The Contractor/Installer shall submit a portion of the sample to the Owner's Representative, who may carry out at his own cost, additional tests by an independent laboratory for corroboration of the field results. In the event where the laboratory test results are negative or contradict the results obtained in the field, the corresponding seam could be considered not in conformance with the requirements unless proven otherwise.

In the event of at least one negative result from the field or laboratory tests, the Contractor/Installer shall proceed to identify the extent of the corresponding non-conformance using a method of his choice. The chosen method shall however offer the assurance that each non-conforming seam is bounded on each side of the test location by conclusive tests. All non-conforming seams or part of a seam shall be subject to a repair in accordance with Section 4.10.3.1.8. The Contractor/Installer shall document all the destructive test procedures by providing the following information, a copy of which shall be submitted to the Owner’s Representative for approval:

a. Date and time;

b. Identification of the destructive test;

c. Identification of the seam, including the roll(s) information;

d. The test results;

e. Location of the destructive test;

f. Identification of the technician.

4.10.3.1.8 Repair

All liner and/or seam repairs shall be performed by the Contractor/Installer using the same procedures as those described in Section 4.10.3.1. In addition, in the event where the total replacement of a fusion weld is necessary, the entire non-conforming seam shall be replaced by a panel of at least 50 cm welded by extrusion. A seam repaired totally shall be considered a regular seam and shall meet the requirements of Section 4.10.3.1.7.

4.10.3.1.9 Thermal Contraction

The Contractor/Installer shall incorporate sufficient slack at installation to account for thermal contraction at lowest operation temperature, when liner will be taut.

4.10.3.2 Ballast

The Contractor/Installer shall submit to Owner’s Representative, a detailed plan showing his proposed method and material to secure the liner against wind uplift. The Contractor/Installer is responsible for the implementation and installation of temporary construction ballasts during construction (Section 4.10.3.1.2– Point 6).

4.10.3.3 Acceptance of Liner

After completion of all Work, Contractor/Installer and Owner's Representative shall conduct a final inspection of the liner to confirm that:

- All seams and repairs have been satisfactorily completed.
- Associated testing and documentation are complete.
- All scrap, trash and debris has been removed from the site.

The liner shall not be covered until Owner's Representative has approved liner installation in writing.

4.10.3.4 Liner Cover

Standing water, ice and snow shall be removed before placing fill. Cover materials shall be stockpiled close to the Work location and placed right upon liner placement and approval.

Liner shall be covered with material zones as shown on Drawings. Equipment with ground pressures less than 50 kPa shall be used to place first lift of cover material over liner. The Contractor shall end dump material off liner, or on previously placed fill, and spread in such a manner and with such equipment as he may choose. He shall demonstrate to Owner's Representative that such a manner and such equipment will not damage the liner. Sensitivity of liner to damage increases as the ambient temperature decreases. The Contractor/Installer shall repair damage to liner as directed by Owner's Representative. Material shall be placed from the bottom to the top of the slope.

The Contractor shall use a wide pad dozer or other small piece of equipment to push cover material perpendicular to the road to create a thin lift throughout the lined area. The dozer blade or tracks of the construction equipment shall not be allowed to come into contact with the membrane during filling. The Contractor shall ensure that the fill rolls off the bottom of the blade end does not introduce a shearing force along the surface of the liner. Sharp turns, spin wheels or travel at speed exceeding 10 km/h on the liner or on a thin layer of fill with equipment shall be avoided.

4.11 Geotextile

4.11.1 Purpose

This specification defines the installation of the non-woven geotextile as shown on the Drawings of IVR D-1 Dike.

4.11.2 Codes and Standards

For Codes and Standards refer to Section 2.2.

4.11.3 Geotextile Material

The geotextile shall be Tencate Mirafi 1600 or equivalent, polypropylene, continuous filament, needle punched and non-woven and meet the properties specified in Table 4-3.

Table 4-3: Required Properties of Geotextile Fabric

Property	Unit	Required Value	Test Method
Weight	g/m^2	16oz/yd^2	ASTM D5261
Thickness	Mm	4.1	ASTM D5199
Grab Tensile Strength	N	1650	ASTM D4632
Elongation at Break	%	45 to 105	ASTM D4632
Trapezoid Tear Strength	N	600	ASTM D4533
Mullen Burst	MPa	5.0	ASTM D3786
Apparent Opening Size	µm	150	ASTM D4751

The geotextile will be placed on either side of the geomembrane for liner protection.

4.11.4 Placement

The geotextile shall be placed on the prepared, smooth, foundation surface, as approved by the QA Inspector and/or Owner's Representative, before the LLDPE liner installation and directly on the liner surface after the liner installation. The geotextile shall be held down with sand bags until the placement is complete.

The geotextile shall be joined by a minimum of 0.6 m overlap.

Any damaged geotextile shall be promptly repaired or replaced.

4.11.5 Quality Control and Quality Assurance

4.11.5.1 Inspection

The QC representative shall carry out a visual examination to examine any manufacturing defects when the geotextile rolls arrive at the site and when they are unrolled over the prepared foundation surface. The QC Representative shall check for openings, cuts, weak/thin areas and sewing defects, if any, and take proper remedial measures, as necessary.

4.11.5.2 Submittals

The Contractor shall submit test results from manufacture that show the geotextile meets minimum Specifications.

4.12 Bituminous Geomembrane (BGM) Liner

4.12.1 Purpose

This specification defines the installation of the Bituminous geomembrane as shown on the IVR D-1 Spillway Drawing.

4.12.2 Codes and Standards

For Codes and Standards refer to Section 2.2.

4.12.3 Material

1. Bituminous geomembrane liner shall be Colentanche Product ES2 with a nominal thickness of 4.0 mm;
2. Rolls shall be stored in accordance with the supplier's specifications;
3. The technical specifications from the manufacture shall meet the minimum requirements presented in the Appendix 2;
4. The Contractor shall demonstrate his ability to adequately weld seams and make patches on side under artic winter conditions.

4.12.4 Execution

The spillway sill and downstream chute areas shall be lined with BGM.

BGM Installation

1. The Contractor shall store, handle, roll-out, place, and weld the BGM in accordance with the manufacture's specifications included in Appendix 2.
2. The Contractor shall roll-out the BGM panels vertically along the slope.
3. The BGM shall be free of folds. Cutting and patching maybe performed to meet this requirement.
4. All welding and preparation work shall be carried out under the supervision of an experienced and certified technician in the presence of the QC and QA personnel.
5. The Contractor shall take all necessary precautions to ensure that the BGM is not accessed by construction equipment tracks.
6. Patch dimensions shall overlap all defects by at least 0.2 m.
7. The connection of BGM panel shall not be in the vicinity of the LLDPE liner to ensure the LLDPE is not damaged.

4.12.5 Quality Control and Quality Assurance Program

1. The QA/QC approval form is included in the Appendix 1 and the tasks for QA/QC are presented in Section 5.3.
2. Full time visual inspection during BGM welding will be carried out by the QC Representative to ensure that the welding meets the design requirements.

4.13 Instrumentation - Thermistor Strings (under AEM's Responsibility)

1. The Owner shall store, handle and install the thermistor strings with care to minimize damage. No damage to Dike structure or integrity shall be allowed.
2. The Owner shall install thermistor strings that have been both tested and verified. A data sheet must be available for each thermistor string installed.
3. For each thermistor string installed, the Owner shall note the identification number, location, and the spacing between each thermistor beads.
4. The thermistor strings must be installed during the Dike construction.
5. The Owner shall survey and record the top (upper) thermistor bead coordinates and elevation of each thermistor string.
6. Thermistor connection to a data logger must be performed by an experienced and certified technician. The data logger and connections shall be protected against traffic equipment, weather and animals in a proper shelter with a door fitted with a lock.
7. An as-built report of the instrumentation installation shall be completed within sixty (60) days upon completion of the IVR D-1 Dike Construction.

The Owner shall take all the necessary precautions to ensure that the thermistor strings are not damaged during installation.

5.0 QUALITY CONTROL AND QUALITY ASSURANCE PLAN

5.1 Scope of Work

The scope of this Plan is to outline a Quality Assurance/Quality Control (QA/QC) Plan for the construction of the IVR D-1 Dike. It summarizes the responsibilities, quality assurance requirements, field inspections and testing requirements, and as-built information requirement for both the QC Representative and the QA Inspector.

5.2 Site Inspection and Testing

The Contractor shall construct the IVR D-1 Dike and QC Representative shall provide quality control during construction. The QA Inspector shall observe and monitor construction to ensure that the Dike is constructed according to Design Specifications and that geometrical adjustments required to suit actual foundation conditions are consistent with the Design criteria. The areas that will be monitored closely are:

Pre-construction activities:

> Surveying of Dike and cut-off trench alignment;

> Preparation of the Dike foundations;

> Stockpiling construction materials.

Construction activities:

> Excavation of the cut-off trench;

> Quality of all construction materials;

> Installation of the liner;

> Placement of rock and earth fill for the Dike construction; and

> Final site clean-up.

The responsibilities of the QC Representative and QA Inspector for Quality Assurance are presented in the following sections.

5.2.1 Pre-Construction Activities

The criteria and responsibilities of the pre-construction activities are listed in Table 5-1.

Table 5-1: Quality Assurance/Quality Control Responsibilities for Pre-Construction Activities

Activities	Criteria	Responsibility			
		Contractor (including Liner Installer)	QC Representative	QA Inspector	Owner's Representative
Survey	◆ Survey conforms with latest Drawings.	◆ Provide qualified surveyor; ◆ Dike alignment, central lines and chainage conform with Drawings; ◆ Maintain survey cross sections; ◆ Provide protection of the survey stakes.		◆ Review survey lines, chainage and layout; ◆ Determine need for adjustments in field; ◆ Verify contractor's QC program is performed;	◆ Survey for pre-condition condition, initial layout of the Work
Stockpiles of Materials	◆ Stockpiles with homogeneous materials	◆ Ensure materials meet Specifications;	◆ Perform required testing; ◆ Check if the stockpile configuration promotes material segregation.	◆ Perform visual inspection of the materials; ◆ Perform random sampling and testing; ◆ Review testing results; ◆ Verify storage quantities; ◆ Provide photo record.	◆ Provide sufficient quantities.
Foundation Preparation	◆ Remove snow or ice rich soil; ◆ Remove boulders protruding 150 mm above ground; ◆ Remove other identified loose and unsuitable materials.	◆ Specify removal methods for unsuitable materials; ◆ Report problems encountered; ◆ Report unusual conditions.	◆ Report problems encountered; ◆ Report unusual conditions.	◆ Review material removal methods; ◆ Witness foundation excavation and preparations; ◆ Inspect the prepared foundation; ◆ Provide changes or adjustments for unusual conditions; ◆ Provide photo record.	◆ Identify storage areas for removed material.

5.2.2 Construction Activities

The construction criteria and responsibilities for the construction activities are listed in Table 5-2.

Table 5-2: QA/QC Responsibilities for Construction Activities

Activities	Criteria	Responsibility			
		Contractor (including Liner Installer)	QC Representative	QA Inspector	Owner's Representative
Dike Foundation Excavation, Cut-off trench Excavation & Backfill	• Cut-off trench min. 3 m below ground • Soil is ice rich if any one, or a combination of the following apply: • 10% visible ice volume; • Ice lenses thicker than 10 mm; • WC ≥ 30%.	• Survey lines conform with Drawings; • Plan excavation and material storage; • Provide excavation records; • Ensure backfill materials conform with Specifications; • Report any unusual conditions, e.g. thawed ground; • Survey extent of unusual condition; • Ensure placement and extent as per Drawings; • Perform as-built survey.	• QC testing on placed material gradations, water content and density; • Report unusual conditions; • Inspect fill surfaces prior to subsequent fill placement; • Ensure backfill materials conform with Specifications; • Ensure placement and extent as per Drawings; • Provide compaction records for backfill; • Perform testing on backfilled material.	• Review survey lines and locations; • Review proposed excavation methods; • Observe foundation excavation; • Inspect soil conditions during excavation; • Inspect trench conditions before backfilling; • Inspect fill surface prior to subsequent fill placement; • Perform QA testing of placed material including gradations, water content, and density; • Review testing results; • Review open fracture treatment procedures; • Report problems and provide resolutions; • Review as-built survey report; • Provide photo record of the cut-off trench.	• QC of fill gradations at crusher and placed in the Dike; and • Review as-built survey report and approve quantities.
Liner Installation	• Liner meets specification; • No snow or blowing snow during installation; • All seams and welds to be tested and passed.	• Provide experienced installer; • Provide sheet layout; • Perform required field seaming and welding tests; • Perform required bedding material tests; • Provide testing results; • Ensure installation as per Drawings; • Provide record on bedding/cover compaction; • Provide records on repairs performed; • Carry out destructive and non-destructive testing and sampling; • Provide as-built drawings and installation warranty.		• Inspect received material certification; • Witness seaming and welding tests; • Verify layout and contractor's QC program is performed; • Report deficiencies of material; • Witness installations; • Verify repaired work; • Witness all destructive and non-destructive sampling and testing; • Verify bedding and cover construction are in accordance with Design; • Verify and record weather conditions; • Specify retesting when required; • Verify liner anchoring; • Review testing results; • Report problems during installation; • Keep liner samples for independent testing, if required; • Provide photo record.	• Receive liner at Amaruq, storage and inventory; • Provide liner manufacture's certificates; • Review as-built survey report and approve quantities.

Activities	Criteria	Responsibility			
		Contractor (including Liner Installer)	QC Representative	QA Inspector	Owner's Representative
BGM Installation	◆ Liner meets specification ◆ No apparent defect	◆ Provide experienced installer	◆ Periodic visual assessment	◆ Periodic visual assessment	
Geotextile Installation	◆ Geotextile meets specification.	◆ Ensure placement and extent as per Drawings; ◆ Perform QC testing and provide results; ◆ Report any unusual conditions or problems and provide resolutions; ◆ Inspect bedding material conforms to Specification and suitable geotextile placement.		◆ Review of required documentation; ◆ Review QC testing results; ◆ Report problems; ◆ Approval of geotextile rolls for deployment; ◆ Observation of unrolled material for damage; ◆ Observation of seaming procedure, overlaps, and completed seams; and ◆ Documentation including photographic records.	◆ Receive geotextile at Amaruq, storage and inventory; ◆ Review as-built survey report and approve quantities.
Dike Fill Placement	◆ Fill material quality and gradations meet the Specifications; ◆ Fill compaction conforms with the requirements; ◆ Control material segregation.	◆ Ensure placement as per Design Drawings; ◆ Report on fill lift thickness and compaction efforts; ◆ Reporting problems encountered; ◆ Survey as-built condition.	◆ Perform required tests on stockpiles; ◆ Perform required sampling and testing on fill materials; ◆ Reporting problems encountered.	◆ Conduct independent material tests on stockpiles; ◆ Witness fill and compaction activities; ◆ Visual assessment of material quality; ◆ Conduct independent soil tests on placed materials; ◆ Visual inspection and confirmation of placed materials; ◆ Review Contractor's testing results and reports; ◆ Provide photo record.	

5.3 Field Testing Program and Fill Compaction Requirement

The quality control and quality assurance testing requirements and frequency are listed in Table 5-3.

Table 5-3: Quality Control and Quality Assurance Testing Requirements and Frequency

Item	Material	Quality Assurance Inspector			Quality Control			Owner's Representative – Geotechnical Engineer
		Task	Frequency	Form to be filled	Task	Frequency	Form to be filled	
Survey	All placed materials	Review daily drawings for grade limits	Periodically	Daily report	Ensure that the surveyors use the latest information, bench marks and other data and have a good understanding of the Project and meet requirements	Continuously	Daily report	Coordinate and compile information
Material Placement and Compaction	Rockfill	Visual assessment	Periodically	Daily report	Visual inspection	Continuously	Daily report	Evaluation of NPAG material. Coordination to change the borrow source if required
	Coarse filter	Visual assessment	Periodically	Daily report	Visual inspection - Grain size distribution	Continuously 2 during crushing, then every 1000 m³	Daily report	Modify the source or the method of crushing and/or processing
	Fine filter liner bedding and cover	Visual inspection Review QC data and procedure	Periodically as requested	Daily report	Visual inspection - Grain size distribution	Continuously 3 during crushing, then every 1000 m³	Daily report	Collect and assess the QC results. Adapt the screening if required
	Fine Filter amended with bentonite (FFAB)	Ensure that mixing location and procedures are respected. Review QC data and procedure	Periodically As requested	Daily report	- Sampling for external laboratory - Grain size distribution - Standard Proctor - Dry density reading using nuclear densometer	Once 3 during FFAB test pad, then every 1000 m³ 1 or as requested As requested	Daily report Gradation report Std. Proctor report Compaction report	Collect, review and compile completed QC/QA forms
	Esker	Visual inspection Review QC data and procedure	Periodically As requested	Daily report	- Grain size distribution - Dry density reading using nuclear densometer	3 before the start of the Work, then every 1000 m³ As requested	Gradation report Compaction report	Collect, review, compile completed QC/QA forms and sign off.
	Geotextile	Visual assessment and manufactory datasheet	Daily during its installation	Daily report	- Visual inspection of its installation and verifications of the manufactory testing datasheet	Continuously	Daily report	Request changes on the installation technique of the Contractor. Be sure that the material is adequate. Reject non-conform rolls.
Storage	Bentonite and LLDPE liner	Visual inspection	Once	Daily report	Visual inspection	Once	Daily report	Ensures that the storage is in conformity with the manufacturer's specifications
Foundation approval (footprint)	Deleterious material (snow, ice and boulders) and ice-rich till	Visual inspection	Periodically prior to filling of footprint	Daily report / QA / QC approval form	Visual inspection to detect any unsuitable material and coordination with Contractor to ensure specifications are met. Manage the clearing limits with the surveyor	Continuously	Daily report / QA / QC approval form	Collect, review and compile completed QC/QA forms
Foundation approval (cut-off trench)	Ice-poor till, bedrock	Visual inspection for foundation approval and verifies the excavation limit with the surveyor	Periodically prior to fill placement	Daily report / QA / QC approval form	Visual inspection to detect any unsuitable material / unfrozen water. Coordination with the Contractor to remove all undesirable material. Verify the excavation limits with the surveyor	Continuously	Daily report / QA / QC approval form	Collect, review and compile completed QC/QA original forms

Work	Quality Assurance (QA)		Quality Control (QC)			
	Task	Frequency	Responsible	Task	Frequency	Requirement
Sample Collection for Conformance Testing	Visual Inspection of sampling. Determination of Conformance Testing to be Performed	As requested	Liner Installer	Collect sample of LLDPE geomembrane	At the request of the QA Representative	1 m wide sample cut across width of roll, not within 1 m of roll end. Label roll number, machine direction, date and name of sampler.
Rolls	Visual Inspection	Each roll	Liner Installer	Visual inspection of the unrolled panels for holes, blisters, undispersed raw materials and marking for repair or rejection	Each Roll	
Test Welding Equipment	Visual Inspection, Oversee Testing	All QC tests	Liner Installer	Calibration Test Seams	Each welder and piece of equipment that will be seaming, at the beginning of each day, and a minimum of once during the middle of the shift	Load at failure for all samples meets or exceeds values in Table 4-2 (Field Seam Properties) for peel and shear, and all samples receive an FTB (Film Tearing Bond).
Testing	Determine Location of Samples, Oversee Testing	1 every 5 QC tests	Liner Installer	Destructive Testing	1 per 150 m seam length or 1 per crew per day (whichever is greater).	Minimum sample size 1000 mm by 300 mm where the weld is centered along the width of the sample. Min. strength properties, as per Table 4-2. Peel and shear testing performed as per ASTM D6392
				Non-Destructive Testing – Vacuum Box	All extrusion welds and patches	
Placement Extent	Oversee Testing	All QC tests	Liner Installer	Non-Destructive Testing – Air Channel	All seams	
				Visual Inspection of seams and panels	Continuously	

5.4 Documentation

5.4.1 QC Daily Summary Report

The Contractor's daily report shall include at a minimum the following:

> Date, project name and location;

> Parties on-site participating in meetings and discussions;

> Daily summary, reporting meetings and/or discussions with the Owner's Representative summarizing QC daily activities;

> Daily Construction activities;

> Daily weather observations and temperature;

> Compaction equipment (type and weight) and typical number of passes;

> Equipment used to place and spread materials;

> Daily field test results data sheets;

> Laboratory test results data sheets; and

> Design and Specification modification/clarification document.

For the LLDPE geomembrane installation, the Contractor shall prepare a standalone liner QC Daily Summary Report which includes the following:

> Summary of work completed;

> List of equipment working on project;

> Number of personnel in each shift;

> Results of QC field and laboratory testing and test data sheets;

> Repair records including documentation the location of all repair on layout plan;

> Description of incidents and problems and steps to sold them;

> Additional information for cold weather seaming including windchill;

> Method of removing frost from area to be seamed, as well as drying and cleaning of surface;

> Condition of subgrade beneath seamed area;

> Identification of seaming system used, including preheat, seaming rate and use of enclosure; and

> Unusual conditions with respect to personnel, equipment, sampling and testing attributes to weather conditions.

5.4.2 QA Daily and Weekly Summary Report

QA Daily and Weekly Reports shall summarize the activities for the day/week and will include the followings:

> Date, project name and location;

> Parties on-site participating in meetings and discussions;

> Summary of meetings and discussions attended;

> Laboratory test results data sheets;

> Documentation of all observations of construction and QC/QA activities/test results with photographs showing locations of field tests and locations of sampling for laboratory testing;

> Methods used to correct construction deficiencies;

> Summary of construction progress and work completed;

> Summary of issued encountered and their resolutions.

5.5 As-Built Report

Upon completion of the IVR D-1 Construction, the QA team shall prepare an As-Built Report under the direction of the Designer. The report shall be submitted to Owner within 10 weeks after completion of all construction. The As-Built Report shall provide all relevant supporting documentation compiled during implementation of the QA/QC Plan.

The As-Built Report shall include, but not be limited to, the following information:

> As-Built drawings based on as-built survey information provided by the Contractor;

> A description of Design changes and modifications made during construction;

> A description of all major construction activities and variable site conditions;

> A summary of all test sample locations, collection methods and test results;

> Summary of construction problems and resolutions;

> A set of photographs showing the various stages of construction;

> A recommendation for continued monitoring of dam performance during operation phases.

END OF DOCUMENT

APPENDIX 1
Approval Form

SNC·LAVALIN

Sustainable Mining
Mining & Metallurgy
195 The West Mall
Toronto (Ontario)
Canada M9C 5K1

Telephone: (416) 252-5315
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www.snclavalin.com

APPROVAL FORM

PROJECT : **IVR D-1 Dike Construction**

PROJECT #: ____________________ **DATE:** ____________

DOCUMENT #: ____________________ **TIME:** ____________

(YYYYMMDD-DS/NS-01) DS/NS = Day/Night shift (24 hour clock)

APPROVAL FOR :

- ☐ Foundation approval (footprint)
- ☐ Foundation approval (cut-off trench)
- ☐ Fill placement: ____________________
- ☐ Other: ____________________

LOCATION	**PREVIOUS APPROVALS**
Station ____________	**Station:** ____________
Inclination: ____________	**Details:** ____________
ELEVATION: ☐ varies ________ m	

COMPLIANCE WITH TECHNICAL SPECIFICATIONS:

(Add additional items if needed)

	VERIFICATIONS DONE BY:				
	QA		QC		N/A
	Y	N	Y	N	
1. Lines and Grades					
2. Free of ice/snow/water					
3. Cleaning of cut-off trench					
4. Gradation (visual assessment)					
5. Placement (lift thickness, segregation, etc.)					
6. Compaction					
7. Foundation on bedrock – cleaning and mapping					
8. As built survey completed					
9.					
10.					
11.					
12.					
13.					
14.					
15.					
16.					

DETAILS (Refer to list above for item #)		**APPROVED BY:** **QA**		**QC**	
ITEM		**Y**	**N**	**Y**	**N**

APPROVED BY:	**NAME**	**SIGNATURE**	**DATE**
CONTRACTOR REPRESENTATIVE			
QC REPRESENTATIVE			
QA REPRESENTATIVE			
OWNER'S REPRESENTATIVE			

APPENDIX 2A
LLDPE Data Sheet
LLDPE Installation Manual

agru
The Plastics Experts.

MicroSpike® Liner

LINEAR LOW DENSITY POLYETHYLENE

AGRU America's structured geomembranes are manufactured on state-of-the-art manufacturing equipment using the flat die calender manufacturing process, a method that produces a more consistent core thickness than other processes, such as the blown film extrusion process. AGRU uses only the highest-grade HDPE and LLDPE resins manufactured in North America.

PRODUCT DATA

Property	Test Method	Frequency	Minimum Average Values			
Thickness (nominal), mil (mm)	ASTM D5994	Per Roll	40 (1.0)	60 (1.5)	80 (2.0)	100 (2.5)
Thickness (min avg), mil (mm)			38 (0.95)	57 (1.43)	76 (1.9)	95 (2.38)
Thickness (min 8 of 10), mil (mm)			36 (0.90)	54 (1.35)	72 (1.8)	90 (2.25)
Thickness (lowest individual), mil (mm)			34 (0.85)	51 (1.28)	68 (1.7)	85 (2.13)
Asperity Height mils, (mm)	ASTM D7466	2nd Roll	20 (0.51)	20 (0.51)	18 (0.46)	18 (0.46)
Density, g/cc, maximum	ASTM D792, Method B	200,000 lb	0.939	0.939	0.939	0.939
Tensile Properties (both directions)	ASTM D6693, Type IV					
Strength @ Break, lb/in width (N/mm)	2 in/minute	20,000 lb	112 (19.6)	168 (29.4)	224 (39.2)	280 (49)
Elongation @ Break, % (GL=2.0in)			400	400	400	400
Tear Resistance, lb,s. (N)	ASTM D1004	45,000 lb	25 (111)	36 (160)	50 (222)	60 (267)
Puncture Resistance, lbs. (N)	ASTM D4833	45,000 lb	50 (222)	70 (310)	90 (400)	115 (512)
Carbon Black Content, % (range)	ASTM D4218	20,000 lb	2-3	2-3	2-3	2-3
Carbon Black Dispersion (Category)	ASTM D5596	45,000 lb	Only near spherical agglomerates: 10 views Cat.1 or 2			
Oxidative Induction Time, minutes	ASTM D3895, 200°C, 1 atm O_2	200,000 lb	≥140	≥140	≥140	≥140

AGRU America's geomembranes are certified to pass Low Temp. Brittleness via ASTM D746 (-80°C), Dimensional Stability via ASTM D1204 (±2% @ 100°C). Oven Aging and UV Resistance are tested per GRI GM 17. These product specifications meet or exceed GRI's GM17.

SUPPLY INFORMATION (STANDARD ROLL DIMENSIONS)

THICKNESS mil	THICKNESS mm	WIDTH ft	WIDTH m		LENGTH ft	LENGTH m	AREA (APPROX.) ft²	AREA (APPROX.) m²
40	1.0	23	7	Double-Sided	750	229	17,250	1,603
				Single-Sided	800	244	18,400	1,709
60	1.5	23	7	Double-Sided	540	165	12,420	1,154
				Single-Sided	560	171	12,880	1,197
80	2.0	23	7	Double-Sided	410	125	9,430	876
				Single-Sided	425	130	9,775	908
100	2.5	23	7	Double-Sided	335	102	7,705	716
				Single-Sided	340	104	7,820	726

Note:

Average roll weight is 3,900 lbs (1,770 kg). All rolls are supplied with two slings. Rolls are wound on a 6" core. Special length available upon request. Roll length and width have a tolerance of ±1%. The weight values may change due to project specifications (i.e. average or absolute minimum thickness) or shipping requirements (i.e. international contanerized shipments).

All information, recommendations and suggestions appearing in this literature concerning the use of our products are based upon tests and data believed to be reliable; however, it is the users responsibility to determine the suitability for their own use of the products described herein. Since the actual use by others is beyond our control, no guarantee or warranty of any kind, expressed or implied, is made by AGRU America as to the effects of such use or the results to be obtained, nor does AGRU America assume any liability in connection herewith. Any statement made herein may not be absolutely complete since additional information may be necessary or desirable when particular or exceptional conditions or circumstances exist or because of applicable laws or government regulations. Nothing herein is to be construed as permission or as a recommendation to infringe any patent.

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Revision Date: March 21, 2018

GEOMEMBRANE AND DRAINAGE INSTALLATION SPECIFICATION

The information provided in this manual uses current quality control and quality assurance standards within the geomembrane industry. It is the sole responsibility of the user to determine the suitability and use of the information and/or discusses material (s). Agru America, Inc. is not an installer of Geosynthetics Membranes. This manual is provided only as a guideline and is not meant as an authority. Agru America will not be held liable for the installation of Geosynthetic Membranes by others. 09-11-2020

Contents

Article I. GENERAL

Section 1.01 SUMMARY

This specification includes furnishing and installing HDPE and LLDPE geomembranes as well as geonets and geocomposite. The HDPE formulated sheet density is 0.940 g/cc or greater. The LLDPE formulated sheet density is ≤0.939 g/cc. Both smooth and textured geomembrane surfaces are included.

Section 1.02 REFERENCES

(a) American Society for Testing and Materials (ASTM), ASTM International, West Conshohocken, PA www.astm.org :

(i) ASTM Standard D6392-12, “Standard Practice for Determining the Integrity of Field Seams Used in Joining Flexible Polymeric Sheet Geomembranes”

(ii) ASTM Standard D5641-94 (2011), “Standard Practice for Geomembrane Seam Evaluation by Vacuum Chamber”

(iii) ASTM Standard D5820-95 (2011), “Standard Practice for Pressurized Air Channel Evaluation of Dual Seamed Geomembranes”

(iv) ASTM Standard D6365-99 (2011), “Standard Practice for the Nondestructive Testing of Geomembrane Seams using the Spark Test”

(v) ASTM Standard D7240-06 (2011), “Standard Practice for Leak Location using Geomembranes with an Insultating Layer in Intimate Contact with a Conductive Layer via Electrical Capacitance Technique."

(vi) ASTM Standard D6747-15 (2015), “Standard Practice for Selection of Techniques for Electrical Leak Location of Leaks in Geomembranes"

(b) Geosynthetic Research Institute (GRI), Folsom, PA www.geosynthetic-institute.org :

(i) GRI GM 9 (2013), “Cold Weather Seaming of Geomembranes”

(ii) GRI GM 13 (2012), “Test Properties, Testing Frequency for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes”

(iii) GRI GM 14 (2013), “Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using the Method of Attributes”

(iv) GRI GM 17 (2012), “Test Methods, Test Properties and Testing Frequency for Linear Low Density Polyethylene (LLDPE) Smooth and Textured Geomembranes”

(v) GRI GM 19, (2013), “Seam Strength and Related Properties of Thermally Bonded Polyolefin Geomembrane”

Section 1.03 SUBMITTALS

(a) Submit the following to the project engineer or property owner, for review and approval, within a reasonable time, to expedite shipment and/or installation of the Geomembrane:

(i) Documentation of Manufacturer's Qualifications

(ii) Manufacturer's Quality Control Program Manual

(iii) Material Properties Sheet

(iv) Material Sample

(v) Documentation of Installer's qualifications;

1) Submit a list of at least ten facilities completed by installer. (For each installation, provide the name of facility, location, date of installation, type and thickness of geomembrane used and surface area of the installed geomembrane.)

2) Submit resumes or qualifications of the installation supervisor, master seamer and Technicians assigned to this project.

3) Installer's Quality Control Program

(vi) Material and Liner Installation Warranties;

1) Submit a copy of all material warranties.
2) Submit a copy of all liner installation warranties.

(b) Shop Drawings

(i) Submit copies of shop drawings for engineer's approval within a reasonable time. Shop drawings shall show the proposed panel layout identifying seams and details. Seams should generally follow the direction of the slope. Butt seams or roll-end seams should not occur on a slope unless approved by the owner's representative. However, if allowed, these seams should be staggered.

(ii) Placement of geomembrane should not occur until owner's representative has received and approved the shop drawings.

(c) Additional Submittals (To be provided during and after installation is complete.)

(i) Manufacturer's warranty

(ii) Geomembrane installation warranty

(iii) Daily written acceptance of sub-grade surface

(iv) Low-temperature seaming procedures if applicable

(v) Prequalification test seam samples

(vi) Field seam non-destructive test results

(vii) Field seam destructive test results

(viii) Daily field installation reports

(ix) Installation record drawing

Section 1.04 QUALITY CONTROL

(a) Manufacturer's Qualifications: The manufacturer shall have at least five (5) years experience in the manufacturing of the specified or similar geomembrane product and shall have manufactured at least 1,000,000 m^2 (10,000,000 ft^2) of the specified type of geomembrane or a similar product during the last five years.

(b) Installer's Qualifications

(i) The geomembrane installer shall be an approved installer by the manufacturer.

(ii) The geomembrane installer shall have at least three (3) years experience installing the specified or similar geomembrane and shall provide a list outlining at least ten (10) projects totaling 500,000 m^2 (5,000,000 ft^2) of the specified type of geomembrane or similar completed within the past three (3) years.

(iii) A field installation supervisor performs and assumes responsibility throughout the geomembrane installation including geomembrane panel layout, seaming, patching, testing, repairs, and all other outlined responsibilities. The field installation supervisor shall have experience in or supervision in the installation and seaming of at least ten (10) projects totally 500,000 m^2 (5,000,000 ft^2) of geomembrane or the type specified or similar product.

(iv) Seaming shall be performed under the direction of a master seamer (who may also be the field installation supervisor or crew foreman) with seaming experience of a minimum of 300,000 m^2 (3,000,000 ft^2) of the geomembrane type specified or similar product, using the same type of seaming apparatus to be used in the current project. During the seaming, the field installation supervisor and/or master seamer are present.

(v) Qualified technicians employed by the geomembrane installer complete all seaming, patching, testing, and other welding operations.

Section 1.05 DELIVERY, STORAGE AND HANDLING

(a) Manufacturer labels must be on all rolls delivered to the project.

(b) A firmly affixed label attached to the selvage edge, shall clearly state the manufacturer's name, product identification, material thickness, roll number, roll type, roll dimensions and roll weight.

(c) The manufacturer protects the geomembrane from mud, dirt, dust, puncture, cutting or any other damaging or deleterious conditions.

(d) Continuously and uniformly supported, rolls are stored away from high traffic areas on a smooth, level surface. Chocks keep the rolls secure when necessary.

Section 1.06 PROJECT CONDITIONS

Do not install geomembrane in the presence of standing water, while precipitation i s occurring, during excessive winds, or when material temperatures are outside the limits specified in Section 3.02.

Section 1.07 MATERIAL WARRANTY

Material manufacturer shall guarantee material against defects and premature aging from environmental conditions on a pro rata basis for a specified period of time acceptable to owner and manufacturer.

Section 1.08 GEOMEMBRANE INSTALLATION WARRANTY

The geomembrane installer shall guarantee the geomembrane installation against defects in the installation and workmanship for a time period satisfactory to all parties commencing with the date of final acceptance.

Section 1.09 GEOMEMBRANE PRE-CONSTRUCTION MEETING

(a) A pre-construction meeting held at the site prior to installation of the geomembrane will include the geomembrane installer, owner, owner’s representative (Engineer and/or CQA Firm), and the earthwork contractor. Topics for this meeting shall include:

(i) Health and Safety

(ii) Lines of authority and communication, resolution of any project document ambiguity.

(iii) Methods for documenting, reporting and distributing documents and reports

(iv) Procedures for packaging and storing archive samples.

(v) Review of time schedule for all installation and testing.

(vi) Review of panel layout and numbering systems for panels and seams including details for marking on geomembrane

(vii) Procedures and responsibilities for preparation and submission of as- built panel and seam drawings

(viii) Temperature and weather limitations, installation procedures for adverse weather conditions, defining acceptable sub grade, geomembrane, or ambient moisture and temperature conditions for working during liner installation

(ix) Sub grade conditions, dewatering responsibilities and sub grade maintenance plan

(x) Deployment techniques including allowable sub grade for the geomembrane

(xi) Plan for controlling expansion/contraction and wrinkling of the geomembrane

(xii) Covering of the geomembrane and cover soil placement

(xiii) Measurement and payment schedules

(xiv) Responsibilities of each party

(b) A designated person will document the meeting and send a copy of the minutes to each person in attendance.

Article II. PRODUCTS

Section 2.01 SOURCE QUALITY CONTROL

(a) Manufacturing Quality Control

(i) The test methods and frequencies used by the manufacturer for quality control/quality assurance of the above geomembrane prior to delivery, shall be in accordance with the latest revision of the GRI GM 13 for HDPE geomembrane or GRI GM 17 for LLDPE geomembrane, or modified as required for project specific conditions.

(ii) The manufacturer's geomembrane quality control certifications, including results of quality control testing of the products, must be supplied to the owner's representative to verify that the materials supplied for the project are in compliance with all product and or project specifications. The certification, signed by a responsible party employed by the manufacturer, such as the QA/QC Manager, production m anager, or technical services manager, includes lot and roll numbers and corresponding shipping information.

(iii) The manufacturer provides production/manufacturing certification that the geomembrane and welding rod supplied for the project are from the same material type and are compatible.

Section 2.02 GEOMEMBRANE

(a) The geomembrane shall consist of new, first quality products designed and manufactured specifically for the purpose of this work. The product will satisfactorily complete testing demonstrating its suitability and durability for the purposes intended. The geomembrane rolls shall be seamless, high density polyethylene (HDPE - Formulated Sheet Density ≥ 0.94g/cc) or linear low density polyethylene (LLDPE - Formulated Sheet Density ≤ 0.939 g/cc) containing no plasticizers, fillers or extenders and shall be free of holes, blisters or contaminants, and leak free verified by 100% in line spark or equivalent testing. The geomembrane supplied is a continuous sheet with no factory seams in rolls. The geomembrane will meet the property requirements as shown in GRI GM13 (HDPE) or GRI GM 17 (LLDPE).

(b) Material conformance testing by the owner's representative, if required, will be conducted using in-plant sampling or as specified for the project.

(c) The geomembrane seams shall meet the property requirements as shown in Section 5 or as required by project specifications.

Article III. EXECUTION

Section 3.01 SUB-GRADE PREPARATION

(a) The sub grade shall be prepared in accordance with the project specifications. The geomembrane sub grade shall be uniform and free of sharp or angular objects that may damage the geomembrane prior to installation of the geomembrane.

(b) The geomembrane installer and owner's representative shall inspect the surface before covering with the geomembrane on each day's operations to verify suitability.

(c) The geomembrane installer and owner's representative shall provide daily a written acceptance of the surface before covering with the geomembrane. During installation, the Installer and owner's representative must ensure daily surface maintenance ensuring sub-grade suitability.

(d) Prior to placement of the geomembrane, the installer and owner's representative must repair all sub grade damaged by construction equipment and deemed unsuitable for geomembrane deployment. The installer and owner's representative provides approval for all repairs. All damage and repair protocol including contractor and Installer responsibilities, are outlined in the preconstruction meeting.

Section 3.02 GEOMEMBRANE PLACEMENT

(a) The owner's representative approves all applicable certifications and quality control certificates within the timeframe specified in the contract documents. If the material does not meet project specifications, the contractor removes it from the work area.

(b) The geomembrane installation must follow the limits shown on the project drawings and essentially as shown on approved Panel Placement Drawings. Submit any changes made to Panel Placement Drawings before deployment of liner materials. The Installer must receive approval for the changes prior to deployment of liner materials.

(c) When temperatures are lower than 0°C (32°F), unless approved by the owner's representative, no geomembrane material can be unrolled and/or deployed. The owner's representative may adjust the minimum temperature for material deployment. The installer and owner's representative defines temperature limitations during the preconstruction meeting. Only deploy the quantity of geomembrane that can be anchored and seamed together in one day.

(d) No vehicular traffic shall travel on the geomembrane other than an approved low ground pressure vehicle or equivalent. The owner's representative may suggest that a test pad simulating the methods to be used and showing no damage to the liner will result, be performed prior to implementation of the proposed method.

(e) Use sand bags or equivalent ballast as necessary temporarily holding the geomembrane material in position under the foreseeable and reasonably expected wind conditions. Sand bag material shall be sufficiently close knit to prevent fines from working through the bags and discharging on the geomembrane.

(f) Installer and owner’s representative should not place geomembrane if moisture prevents proper sub grade preparation, panel placement, or panel seaming. Defined in the preconstruction meeting, the moisture limitations provide direction for the installer and owner’s representative. Damaged and rejected panels (or portions) shall be marked, removed from the work area, and the removal recorded/documented.

(g) The geomembrane should not "bridge over" voids or low areas in the sub grade. The geomembrane shall rest in intimate contact with the sub grade.

(h) Wrinkles caused by panel placement or thermal expansion should be minimized.

(i) Considerations on site geometry: In general, seams shall be oriented parallel to the line of the maximum slope. In corners and odd shaped geometric locations, minimization of the total length of field seams is required. Seams shall not be located at low points in the sub-grade unless geometry requires seaming at such locations and if approved by the owner's representative.

(j) All panels must overlap prior to the seaming process. This overlap affects a weld and allows for proper testing. In no case shall this overlap be less than 75 mm (3”)

(k) Sharp stones or other hard objects that could potentially damage the membrane should not be within 1” (25 mm) of the surface to be lined.

(l) Sub-grade should be firm, unyielding and able to support deployment equipment without damage or rutting to the sub-grade.

Section 3.03 SEAMING PROCEDURES

(a) Cold weather installations should follow guidelines as outlined in GRI GM9.

(b) The seaming process shall not occur when liner temperatures are less than 0°C (32°F) unless the installer and/or owner’s representative complies with the following conditions.

(i) The seaming of the geomembrane at material temperatures below 0°C (32° F) only transpires when the geomembrane installer can demonstrate the following to the owner’s representative using prequalification test seams.

1) Field seams comply with the project specifications.

2) The safety of the crew ensured.

3) Geomembrane material can be fabricated (i.e. pipe boots, penetrations, repairs. etc.) at sub-freezing temperatures.

(ii) The geomembrane installer shall submit to the owner’s representative for approval, detailed procedures for seaming at low temperatures, possibly including the following:

1) Preheating of the geomembrane,

2) Using a tent or other device preventing heat loss during seaming and rapid heat loss subsequent to seaming,

3) Completion of a number of test welds to determine appropriate seaming parameters.

(c) If the geomembrane sheet temperature is above 75° C (170° F) as measured by an infrared thermometer or surface thermocouple, seaming transpires only with the approval by the owner's representative. This approval depends upon the recommendations by the manufacturer and on a field demonstration by the geomembrane installer using prequalification test seams to demonstrate that seams comply with the specification.

(d) Seaming shall primarily be performed using automatic fusion welding equipment and techniques. Use of extrusion welding takes place where fusion welding is not possible such as at pipe penetrations, patches, repairs and short (less than a roll width) runs of seams. Note: Flaps should not be removed as part of the welding process as this may damage the seam.

(e) In the case of fish mouths or excessive wrinkles at the seam overlap section, cut along the ridge of the wrinkles on the back into the panel if necessary. Terminate the cut with a keyhole cut (nominal 10 mm (1/2") diameter hole) minimizing the crack/tear propagation. Then, seam the overlay. Patch the key hole cut with an oval or round patch of the same base geomembrane material extending a minimum of 150 mm (6") beyond the cut in all directions.

(f) When extrusion welding 60 mil (1.5mm) or greater HDPE, it is advisable to bevel the top portion of the seam in a lengthwise direction to maximize intimate contact of material and improve continuity of weld.

(g) Prior to seaming, confirm the area for welding is free of moisture, dirt and any foreign matter that can affect the integrity of the weld on an ongoing basis.

(h) Take precaution and safety of the liner technicians, in extreme heat or cold, which can affect the health of the individuals.

(i) Seaming should run through the anchor trench to terminate at the end of the sheet goods.

Section 3.04 PIPE AND STRUCTURE PENETRATION SEALING SYSTEM

(a) Provide penetration-sealing system as shown in the Project Drawings.

(b) Construct all penetrations from the base geomembrane material, flat stock, prefabricated boots and accessories as shown on the Project Drawings. In the case of Structured Liners such as SuperGripNet™, DrainLiner™ or similar materials offered by Agru America, Inc., use the smooth or textured liner of the same density for such fabrications. Weld the pre-fabricated or field fabricated assembly to the geomembrane as shown on the Project Drawings to prevent leakage. Once complete, test the assembly. If the Installer cannot perform the field non-destructive testing, attachments will be field spark tested by standard holiday leak detectors in accordance with ASTMD 6365. Spark testing should be done in areas where both air pressure testing and vacuum testing is not possible.

(i) Equipment for Spark testing shall be comprised of but not limited to; a hand held holiday spark tester, and conductive wand that generates a high voltage.

(ii) The testing steps performed by the geomembrane installer include:

1) Place an electrically conductive tape or wire beneath the seam prior to welding.

2) Complete a calibration test on a trial seam containing a non-welded segment ensuring the identification of such a defect (non-welded segment) under the planned machine settings and procedures.

3) Upon completion of the weld, enable the spark tester and hold approximately 25mm (1 in) above the weld moving slowly over the entire length of the weld in accordance with ASTM 6365. If no spark occurs, the weld is leak free.

(iii) A spark indicates a hole in the seam. The geomembrane installer locates, repairs, and retests the faulty area.

(iv) When flammable gasses are present, use special care and precautions in the area to be tested.

Section 3.05 FIELD QUALITY CONTROL

The owner's representative must receive information prior to all pre qualification and production welding and testing, or as agreed upon in the pre construction meeting.

(a) Prequalification Test Seams

(i) The geomembrane installer tests seams and prepares seams verify seaming parameters (speed, temperature and pressure of welding equipment) are adequate.

(ii) Each welding technician creates seams and tests each in accordance with ASTM D 6392 at the beginning of each seaming period. Welding technicians test the seaming under the same conditions and with the same equipment and operator combination as production seaming. The test seam shall be approximately 3.3 meters (10 feet) long for fusion welding and 1 meter (3 feet) long for extrusion welding with the seam centered lengthwise. At a minimum, each welding technician creates one test seam after seaming 4–6 hours; additional tests may be required with changes in environmental conditions.

(iii) Two 25 mm (1 in) wide specimens shall be die-cut by the geomembrane installer from each end of the test seam. The specimens tested by the geomembrane installer require using a field tension meter testing both tracks for peel strength and shear strength. Each specimen should fail in the parent material and not in the weld, "Film Tear Bond"(FTB). When the seam separation is equal to or greater than 25% of the track width, it is a failed test.

(iv) Tables in Section 6 provide the minimum acceptable seam strength values obtained for all specimens tested. Four specimens out of five must meet the acceptable seam strength values for consideration as passing.

(v) If a test seam fails, the welding technician must immediately conduct an additional test seam. If the additional test seam fails, the welding technician rejects the seaming apparatus. The technician must correct the apparatus deficiencies and produce a successful test seam before using the apparatus for any other/additional production seaming.

(vi) The technician labels a sample from each test seam. The label indicates the date, geomembrane temperature, number of the seaming unit, technician performing the test seam and pass or fail description. The technician then gives the sample to the owner's representative for archiving.

(b) Field Seam Non-destructive Testing

(i) The technician non-destructively tests over the full seam length before the geomembrane installer covers it. Numbered or otherwise designated, each seam's label includes the location, date, test unit, name of tester and outcome of all non-destructive testing. Once recorded, the technician submits the information to the owner's representative.

(ii) Testing should be done as the seaming work progresses, not at the completion of all field seaming, unless agreed to in advance by the owner's representative. All defects found during testing shall be numbered and marked immediately after detection. The technician must repair, retest, and remark all defects indicating the acceptable completion of the repair.

(c) Non-destructive testing shall be performed using vacuum box, air pressure or spark testing equipment.

(d) Experienced technicians familiar with the specified test methods perform all non-destructive tests. The geomembrane installer demonstrates all test methods verifying the validity of said test procedures for the owner's representative.

(e) The geomembrane installer tests all extrusion seams using a vacuum box in accordance with ASTM D 6392 and ASTM D 5641 and the following equipment and procedures:

(i) Equipment for testing extrusion seams is not limited to but should include:

1) Vacuum box assembly consisting of a rigid housing

2) Transparent viewing window

3) Soft rubber gasket attached to the base

4) Port hole or valve assembly and a vacuum gauge

5) Vacuum pump assembly equipped with a pressure controller and pipe connections

6) Rubber pressure/vacuum hose with fittings and connections

7) Plastic bucket

8) Wide paintbrush or mop

9) Soapy solution

(ii) The geomembrane installer must charge the vacuum pump and adjust the tank pressure to approximately 35 kPa (5 psig).

(iii) The geomembrane installer shall create a leak tight seal between the gasket and geomembrane interface by wetting a strip of geomembrane approximately 0.3m (12 in) by 1.2m (48 in) (length and width of box) with a soapy solution, placing the box over the wetted area, and then compressing the box against the geomembrane. The geomembrane installer shall then close the bleed valve, open the vacuum valve, maintain initial pressure of approximately 35 kPa (5 psig) for approximately 3-4 seconds. The Installer must continuously examine the geomembrane through the viewing window for the presence of soap bubbles, indicating a leak. If no bubbles appear after 3-4 seconds, consider the area leak free. Once the area is leak free, depressurize the box and move it over the next adjoining area with an appropriate overlap and the process repeated.

(iv) All areas where soap bubbles appear shall be marked, repaired and then retested.

(v) At seam locations where the Installer is unable to non-destructively test, such as pipe penetrations, the Installer must substitute alternate non-destructive spark testing or equivalent.

(vi) All seams that are vacuum tested shall be marked with the date tested, the name of the technician performing the test and the results of the test.

(f) Double Fusion seams with an enclosed channel shall be air pressure tested by the geomembrane installer in accordance with ASTM D5820 and ASTM D6392 and the following equipment guidelines and procedures.

(i) Equipment for testing double fusion seams shall be comprised of but not limited to: an air pump equipped with a pressure gauge capable of generating and sustaining a pressure of 210 kPa (30 psig), mounted on a cushion to protect the geomembrane; and a manometer equipped with a sharp hollow needle or other approved pressure feed device.

(ii) The geomembrane installer completes all testing activities. Both ends of the seam to be tested are sealed and a needle or other approved pressure feed device inserted into the tunnel created by the double wedge fusion weld. The air pump shall be adjusted to a pressure of 210 kPa (30 psig), and the valve closed. Allow 2 minutes for the injected air to come to equilibrium in the channel, and sustain pressure for 5 minutes.

(g) If pressure loss does not exceed 28 kPa (4 psig) after the five-minute period, the Installer considers the seam leak tight. Release pressure from the opposite end verifying pressure drop on needle to ensure testing of the entire seam. The needle or other approved pressure feed device shall be removed and the feedhole sealed.

(i) If loss of pressure exceeds 28 kPa (4 psig) during the testing period or pressure does not stabilize, the geomembrane installer locates, repairs and retests the faulty area.

(ii) Record all results of the pressure testing on the liner at the seam tested and on a pressure testing record.

(iii) If release of pressure from opposite end of tested seam does NOT deflate seam, the Installer takes measures to determine the cause and remedies to air test 100% of the seam under scrutiny.

(h) Destructive Field Seam Testing

(i) The Installer analyzes one destructive test sample per 150 linear m (500 linear ft) seam length or the geomembrane installer shall take another predetermined length in accordance with GRI GM 14 from a location specified by the owner's representative. The geomembrane installer receives the sample locations without advance notice of the locations. The geomembrane installer cuts samples as directed by the owner's representative before the complete installation and as seaming progresses.

(ii) All field samples shall be marked with their sample number and seam number including the sample number, date, time, location, and seam number recorded. The geomembrane installer shall repair all holes in the geomembrane resulting from obtaining the seam samples. All patches shall be vacuum box tested or spark tested. If the installation of a permanent patch over the test location the same day of sample collection is not possible, place a temporary patch either tack welded or hot air welded over the opening until affixing a permanent patch.

(iii) Testing requires the destructive samples size at least 300 mm (12") wide, 1m (36") long, with the seam centered lengthwise. The sample shall be cut into three equal sections and distributed as follows: one section given to the owner's representative as an archive sample; one section given to the owner's representative for laboratory testing as specified in paragraph 5 below; and one section retained by the geomembrane installer for field testing as specified in paragraph 4 below.

(iv) For field-testing, the geomembrane installer shall cut 10 identical 25 mm (1") wide replicate specimens from his sample. The geomembrane installer shall test five specimens for seam shear strength and five for peel strength. The geomembrane installer performs peel tests on both the inside and outside weld tracks. To be acceptable, four (4) of five (5) test specimens must pass the stated criteria in section 2.02 with less than 25% separation. If four (4) of five (5) specimens pass, the sample qualifies for testing by the testing laboratory if required.

(v) If the specifications require an independent seam testing, conduct the testing in accordance with ASTM 5820 or ASTM D6392.

(vi) Prepare and submit all reports of the results of examinations and testing to the owner's representative.

(vii) For field seams, if a laboratory test fails, it is an indicator of the possible inadequacy of the entire seamed length corresponding to the test sample. The geomembrane installer should take additional destructive test portions at locations indicated by the Engineer; (typically 3 m (10 ft) on either side of the failed sample) and perform additional laboratory seam tests. Passing tests shall be an indicator of adequate seams. Failing tests shall be an indicator of non-adequate seams. When seams fail the destructive test, the Installer re-seams or repairs seams with a cap-strip. Cap-strip seams shall be non- destructively vacuum box tested until achieving adequacy of the seams. The geomembrane installer must destructively test all Cap strip seams exceeding 50 M in length (150 FT).

(viii) The Installer keeps all samples out of critical areas such as in the bottom of ponds and other locations such as slopes and sumps.

(i) Identification of Defects

(i) The Installer and owner's representative inspects panels and seams during and after panel deployment to identify all defects, including holes, blisters, un-dispersed raw materials and signs of contamination by foreign matter.

(j) Evaluation of Defects: The Installer must complete a non-destructive test for each suspect location on the liner (both in seam and non-seam areas) using one of the methods described in Section 3.05.B. Each location failing non-destructive testing is marked, numbered, measured and posted on the daily "installation" drawings and subsequently repaired.

(i) If a destructive sample fails the field or laboratory test, the geomembrane installer shall repair the seam between the two nearest passed locations on both sides of the failed destructive sample location.

(ii) All repairs of defective seams, tears or holes use either re-seaming or applying an extrusion welded cap strip process.

(iii) Re-seaming may consist of either:

1) Removing the defective weld area and re-welding the parent material using the original welding equipment; or

2) Re-seam the defective weld area by extrusion welding along the overlap at the outside seam edge left by the fusion welding process.

3) Cap stripping entire faulty seam.

(iv) The Installer repairs blisters, larger holes, and contamination by foreign matter using required patches and/or extrusion weld beads. Each patch shall extend a minimum of 150 mm (6 in) beyond all edges of the defects.

(v) Locate, measure and record all repairs.

(k) Verification of Repairs on Seams: Each repair requires a non-destructive test using either vacuum box or spark testing methods. An indication of a successful repair includes areas passing the non-destructive test. Areas failing the tests require re-seaming and retesting until results show a passing test. Requirements for areas failing the tests include re-seaming and retesting until passing test results. The Installer records the number, date, location, technician and test outcome of each patch.

(l) Daily Field Installation Reports: At the beginning of each day's work, the Installer shall provide the Engineer with daily reports for all work accomplished on the previous workday. Reports shall include the following:

(i) Total amount and location of geomembrane placed

(ii) Total length and location of seams completed, name of technicians doing seaming and welding unit numbers

(iii) Drawings of the previous day's installed geomembrane showing panel numbers, seam numbers and locations of non-destructive and destructive testing

(iv) Results of pre-qualification test seams

(v) Results of non-destructive testing

(vi) Results of vacuum testing of repairs

(m) Prior to covering the liner, report all Destructive test results.

(n) Perform and complete all quality assurance no more than 72 hours after geomembrane deployment.

Section 3.06 Liner Acceptance

The owner's representative accepts the geomembrane liner when:

(a) The entire installation is completed or an agreed upon subsection of the installation is finished.

(b) The Installer submits all completed QC documentation to the owner.

(c) Verification of the adequacy of all field seams and repairs and associated geomembrane testing is complete.

(d) All submittals are accepted.

Section 3.07 Anchor Trench

Construct as specified on the project drawings.

Section 3.08 Disposal of Scrap Materials

(a) On completion of installation, the geomembrane installer shall dispose of all trash and scrap material in a location approved by the Owner, remove equipment used in connection with the work herein, and shall leave the premises in a neat acceptable manner. Finally, remove all scrap material from the surface of the geomembrane.

Article IV. MEASUREMENT AND PAYMENT

The project specifications document/outline the required measurements and payment of services. All parties sign all documents prior to project start up.

Article V. GEOTEXTILES, GEONETS AND GEOCOMPOSITES

Section 5.01 Geotextiles

The general arrangement of Geotextiles includes aligning seams parallel to the prevailing slope and seams finished by either heat seaming with an approved hand held or self motivated thermal device or by sewing with a stitching approved by the engineer. Whichever stitching method is used, the thread should be compatible with the fabric and have similar chemical resistance to the liner used. Geotextile should be covered by soil or geomembrane within 14 days of deployment to minimize UV exposure.

Section 5.02 GEONET

Geonet may be butt joined or lapped if specified. At five-foot 1.5m (5') intervals along the edge, the Installer applies Nylon/plastic cable ties to the net edge. Complete end splices as follows:

(a) On slopes, the ends will overlap two feet 2' (0.6m) with uphill panels on top and two (2) rows of cable ties applied at 6" spacing or per engineers specification.

(b) In flat areas, the ends will overlap a minimum to six inches 6" (15 cm) and one (1) row of three (3) cable ties applied.

Section 5.03 GEOCOMPOSITES

Geocomposites can overlap with the net portion tied and the Geotextile portion thermally bonded or seamed as required by the project specifications.

Section 5.04 REPAIRS

Repair any holes, tears, or burns through the Geotextile from thermal seaming by patching with the same Geotextile. The patch will be a minimum of twelve inches 12" (30cm) larger – in all directions – than the area repaired and will be spot bonded thermally. Repair all geonet holes and/or tears using a patch of the same geonet. Patches are a minimum of twelve inches 12" (30cm) larger in all directions than the area repaired. Tie the patch in place using a minimum of four (4) nylon cable ties.

6.0 - TABLES

"This section shall include the current GRI GM13 (HDPE) or GRI GM17 (LLDPE) manufacturer's specification or a revision of GRI GM13 (HDPE) or GRI GM 17 (LLDPE) specific to the unique project requirements and/or standards, as determined by the owner or owners' agent." TO BE INSERTED BY COMPANY PREPARING SUBMITTALS TO GUARANTEE MOST CURRENT GRI SPECIFICATION.

SEAM STRENGTHS - HDPE and LLDPE GRI GM 19

TABLE 1: Seam Strength and related Properties of Thermally Bonded Smooth and Textured High Density Polyethylene (HDPE) Geomembrane (English Units)

Geomembrane Nominal	**30 mils**	**40 mils**	**50 mils**	**60 mils**	**80 mils**	**100 mils**	**120 mils**
Hot Wedge Seams (1)							
shear strength(2), lb/in.	**57**	**80**	**100**	**120**	**160**	**200**	**240**
shear elongation at	50	50	50	50	50	50	50
peel strength (2), lb/in.	**45**	**60**	**76**	**91**	**121**	**151**	**181**
peel separation, %	25	25	25	25	25	25	25
Extrusion Fillet Seams							
shear strength(2), lb/in.	**57**	**80**	**100**	**120**	**160**	**200**	**240**
shear elongation at	50	50	50	50	50	50	50
peel strength (2), lb/in.	**39**	**52**	**65**	**78**	**104**	**130**	**156**
peel separation, %	25	25	25	25	25	25	25

Notes for Table 1 – (Used also for hot air and ultrasonic seaming methods.)

(a) Value listed for shear and peel strength are for 4 out of 5 test specimens; the 5th specimen can be low as 80% of the listed values

(b) Elongation measurements should be omitted for field testing

TABLE 2: Seam Strength and related Properties of Thermally Bonded Smooth and Textured Linear Low Density Polyethylene (LLDPE) Geomembrane (English Units)

Geomembrane Nominal	30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils
Hot Wedge Seams [1]							
shear strength[2], lb/in.	**45**	**60**	**75**	**90**	**120**	**150**	**180**
shear elongation at break[3], %	50	50	50	50	50	50	50
peel strength [2], lb/in.	**38**	**50**	**63**	**75**	**100**	**125**	**150**
peel separation, %	25	25	25	25	25	25	25
Extrusion Fillet Seams [1]							
shear strength[2], lb/in.	**45**	**60**	**75**	**90**	**120**	**150**	**180**
shear elongation at break[3] %	50	50	50	50	50	50	50
peel strength [2], lb/in.	**34**	**44**	**57**	**66**	**88**	**114**	**136**
peel separation, %	25	25	25	25	25	25	25

Notes for Table 2 - Also for hot air and ultrasonic seaming methods

(i) Value listed for shear and peel strength are for 4 out of 5 test specimens; the 5th specimen can be low as 80% of the listed values

(ii) Elongation measurements should be omitted for field testing

Non-Destructive Air Channel Test

Table 3: Initial Pressure Schedule

Field Testing		
Material	Minimum PSI	Maximum PSI
30 mil	15	30
40 mil	20	30
60 mil	24	30
80 mil	24	30
100 mil	24	32

Table 4: Maximum Allowable Pressure Drop

Material Field Test (after five minutes) 30 mil 4 PSI

40 mil 4 PSI

60 mil 4 PSI

80 mil 4 PSI

100 mil 4 PSI

Note: At all times before heat sealing the end of the seam, the operator should insure that the void or air channel is free of obstruction.

AGRU AMERICA, INC. IS NOT AN INSTALLER OF GEOSYNTHETICS AND DOES NOT REPRESENT AS SUCH. AGRU AMERICA, INC. DEVELOPED THIS MANUAL ONLY AS A GUIDELINE AND NOT AS AN AUTHORITY OF EXACTITUDE. AGRU AMERICA WILL NOT BE HELD LIABLE FOR THE INSTALLATION OF OTHERS.

APPENDIX 2B
Geotextile Data Sheet

TEXEL160E

TECHNICAL DATASHEET

Product	Needlepunched nonwoven short staple fibers geotextile
Composition	Polypropylene[1]
Main function	Protection

TEXEL 160E belongs to the E Series, which presents a large variety of polyvalent geotextiles with physical, mechanical and hydraulic properties adapted for protection applications (sealing systems, banks, etc.). These geotextiles remain inert in contact with chemical and biological agents naturally found in soils. The E Series consists of performant, durable and adapted products for different environmental and civil engineering projects.

Property	Test Method	Metric	Imperial
Physical			
Weight	ASTM D5261	542 g/m²	16 oz/yd²
Thickness	ASTM D5199	4.1 mm	160 mils
Mechanical			
Tensile strength	ASTM D4632	1891 N	425 lbs
Elongation at break	ASTM D4632	50 %	
Trapezoid tear	ASTM D4533	667 N	150 lbs
CBR puncture	ASTM D6241	5340 N	1200 lbs
UV resistance	ASTM D4355	70 %/500h	
Hydraulic			
Flow rate	ASTM D4491	1833 lpm/m²	45 gpm/ft²
Permittivity	ASTM D4491	0.57 s-1	
Permeability	ASTM D4491	0.3 cm/s	
AOS[2]	ASTM D4751	150 µm	100 us sieves
Dimensions			
Width	N/A	3.81 - 4.57 - 5.25 m	12.5 - 15 - 17.2 ft
Length	N/A	91.44 m	300 ft

All values are MARV except when specified.
Our quality management system is certified by ISO-9001 standard.
Our internal laboratory is certified by the Geosynthetic Accreditation Institute - Laboratory Accreditation Programm (GAI-LAP).

1-May contain polyester / 2- Maximum average roll value

Revision: 06-27-2016

APPENDIX 2C
BGM Data Sheet

COLETANCHE®

www.coletanche.com

Axter Coletanche® Inc.
1030, rue Beaubien est, Suite 301
Montreal, QC, H2S 1T4
CANADA

Prepared: 29/04/2013
Cancels and replaces: 07/01/2013
Code : 1876001
Manufacture source Courchelettes (59-France)
Technical ref: FT AXTER ES2 ASTM

PRODUCT DATA SHEET

COLETANCHE ES 2

DESCRIPTION

COLETANCHE ES 2 is an SBS elastomeric modified bituminous geomembrane.

USE

Moderate level of mechanical resistance, for use an environmental protection and groundworks waterproofing, in particular :
- To cover landfill,
- Hydraulic ponds,
- Containment of Industrial liquid wastes,
- Canals ,
- Contamined land.

Product use must be validated by Axter

APPLICATION METHOD

Torched

STORAGE

Rolls must not be stored directly on the ground. They must be laid supported on concrete blocks, trestles or timber beams) min 35 cm height, placed under the mandrel ends.

COMPOSITION *(indicative)*

Reinforcement (g/m²) :	Glass mat	50
Reinforcement (g/m²) :	Non-woven geotextile	250
Binder (g/m²) :	Elastomeric SBS	4300
Surface finish (g/m²) :	Sand	200
Under surface finish (g/m²) :	Polyester antiroot film	15

CHARACTERISTICS

		STANDARD	UNITS	VALUES	Tolerance Min	Tolerance Max
Dimensions	Length	-	*m*	79	≥	
Dimensions	Width	-	*m*	5.01	≥	
Thickness (on finished product)		*ASTM D 5199*	mm	4.00	*3.80*	*4.40*
Surface mass		*ASTM D 3776*	kg/m²	4.85	*4.50*	*5.20*
Resistance to tearing	Longitudinal	*ASTM D 4073*	N	825	*619*	
Resistance to tearing	Cross direction	*ASTM D 4073*	N	700	*525*	
Tensile properties : maximum tensile strength	Longitudinal	*ASTM D 7275*	kN/m	27	*20.3*	
Tensile properties : maximum tensile strength	Cross direction	*ASTM D 7275*	kN/m	24	*18*	
Tensile properties : elongation	Longitudinal	*ASTM D 7275*	%	60	*48*	
Tensile properties : elongation	Cross direction	*ASTM D 7275*	%	60	*48*	
Tensile properties : maximum tensile strength	Longitudinal	*ASTM D 4595*	kN/m	25	*19*	
Tensile properties : maximum tensile strength	Cross direction	*ASTM D 4595*	kN/m	21	*16*	
Tensile properties : elongation	Longitudinal	*ASTM D 4595*	%	80	*60*	
Tensile properties : elongation	Cross direction	*ASTM D 4595*	%	80	*60*	
Static Puncture		*ASTM D 4833*	N	530	*477*	
Flexibility at low temperature	Surface	*ASTM D 5147*	°C	-20		
Flexibility at low temperature	Under surface	*ASTM D 5147*	°C	-20		
Water permeability (liquid tightness)		*ASTM E 96*	*m/s*	6.10^{-14}		
Gas permeability (gas tightness)		*ASTM D 1434-82*	*m3/(m².j.atm)*	$< 2{,}3.10^{-14}$		

NOTE: AXTER COLETANCHE INC. may modify the composition and/or utilisation of its products without prior notice. Consequently orders will be filled according to the latest specification.
The manufacturer reserves the right to modify, at any time, the characteristics of its products.

AXTER

Appendix D

Construction Drawings

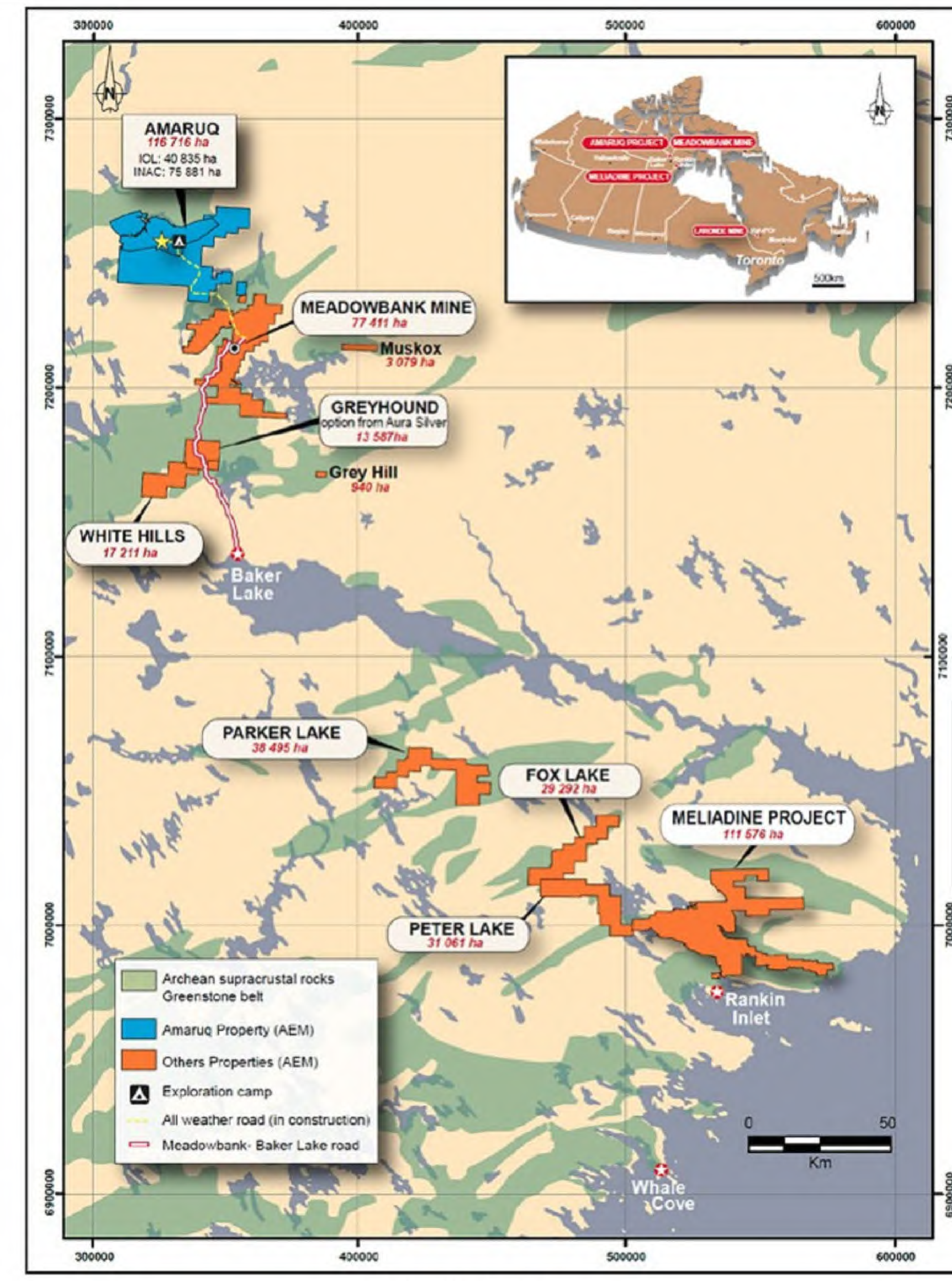
NO. DESSIN DRAWING NO. 61-695-230-204

AGNICO EAGLE – MEADOWBANK DIVISION

IVR D1 DYKE ATTENUATION POND PROJECT

IVR D1 DYKE DRAWINGS

SNC DOCUMENT No.	AEM DOCUMENT No.	TITLE	REVISION	DATE
668284-5000-4GDD-0009	61-695-230-204	LOCATION MAP AND DRAWING INDEX	E00	2020-12-22
668284-0000-4GDD-0001	61-695-210-200	GENERAL SITE PLAN	E00	2020-12-22
668284-5000-4GDD-0002	61-695-230-205	FIELD INVESTIGATION - LOCATION PLAN AND SOIL STATIGRAPHIC SECTION	E00	2020-12-22
668284-5000-4GDD-0003	61-695-230-206	DESIGN PLAN AND LONGITUDINAL SECTION	E00	2020-12-22
668284-5000-4GDD-0004	61-695-230-207	EXCAVATION PLAN AND SECTIONS	E00	2020-12-22
668284-5000-4GDD-0005	61-695-230-208	SELECTED DESIGN SECTIONS	E00	2020-12-22
668284-5000-4GDD-0006	61-695-230-209	SPILLWAY DESIGN	E00	2020-12-22
668284-5000-4GDD-0007	61-695-230-210	INSTRUMENTATION	E00	2020-12-22
668284-5000-4GDD-0008	61-695-230-211	CONSTRUCTION SEQUENCE	E00	2020-12-22



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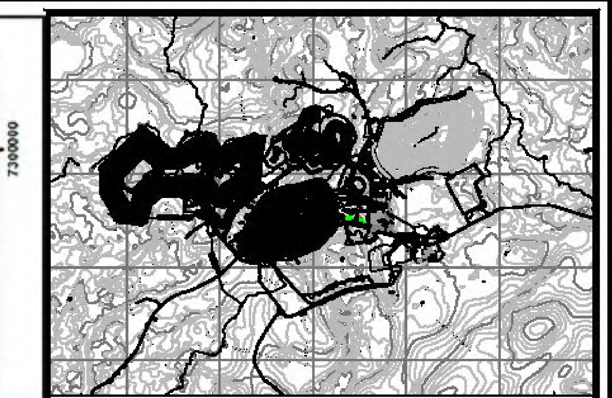

PLAN CLÉ / KEY PLAN

SNC-LAVALIN
Mining & Metallurgy
5500, des Galeries Blvd., bur. 200, Quebec (Quebec), Canada G2K 2E
Telephone (418) 621-5500, Fax (418) 621-8887

PROJECT No	SUBDIVISION	SUBJECT	SERIAL	REV.
668284	5000	4G DD	0009	E00

NOTES GÉNÉRALES / GENERAL NOTES

DESSINS EN RÉFÉRENCE / REFERENCE DRAWINGS

TITRE / TITLE	# DWG

AGNICO EAGLE

REV.	DATE	DESCRIPTION	PAR/BY	APP.	CLIENT
R0	2020-12-22	ISSUED FOR CONSTRUCTION	M.S./N.Q.	A.L.N.	
RB	2020-11-16	ISSUED FOR CLIENT REVIEW	M.S./N.Q.	A.L.N.	

REVISIONS

REGISTERED PROFESSIONAL ENGINEER
Q.N. QUAN
LICENSEE
NT/NU

PERMIT TO PRACTICE
SNC-LAVALIN INC.
Signature
Date 2020-12-22
PERMIT NUMBER: P 260
The Association of Professional Engineers, Geologists and Geophysicists of NWT/NU

TITRE / TITLE
AGNICO EAGLE – AMARUQ DIVISION
695 – WATER MANAGEMENT
230 – GENERAL EARTHWORKS

WMGI PHASE 2 – IVR D1 DYKE
LOCATION MAP AND DRAWING INDEX

DESSINÉ PAR / DRAWN BY	MARK SYKES	DATE 2020-12-22
VERIFIÉ PAR / CHECKED BY	NINA QUAN / PHILIP GOMES	2020-12-22
APPROUVÉ PAR / APPROVED BY	ANH-LONG NGUYEN	2020-12-22
ÉCHELLE / SCALE	AS SHOWN	DATE 2020-12-22

NO. DESSIN DRAWING NO. 61-695-230-204

NO. PROJET / PROJECT NO.	REVISION	FEUILLE / SHT
6127	R0	1 / 1

FILE NO.

NO. DESSIN DRAWING NO. 61-695-210-200

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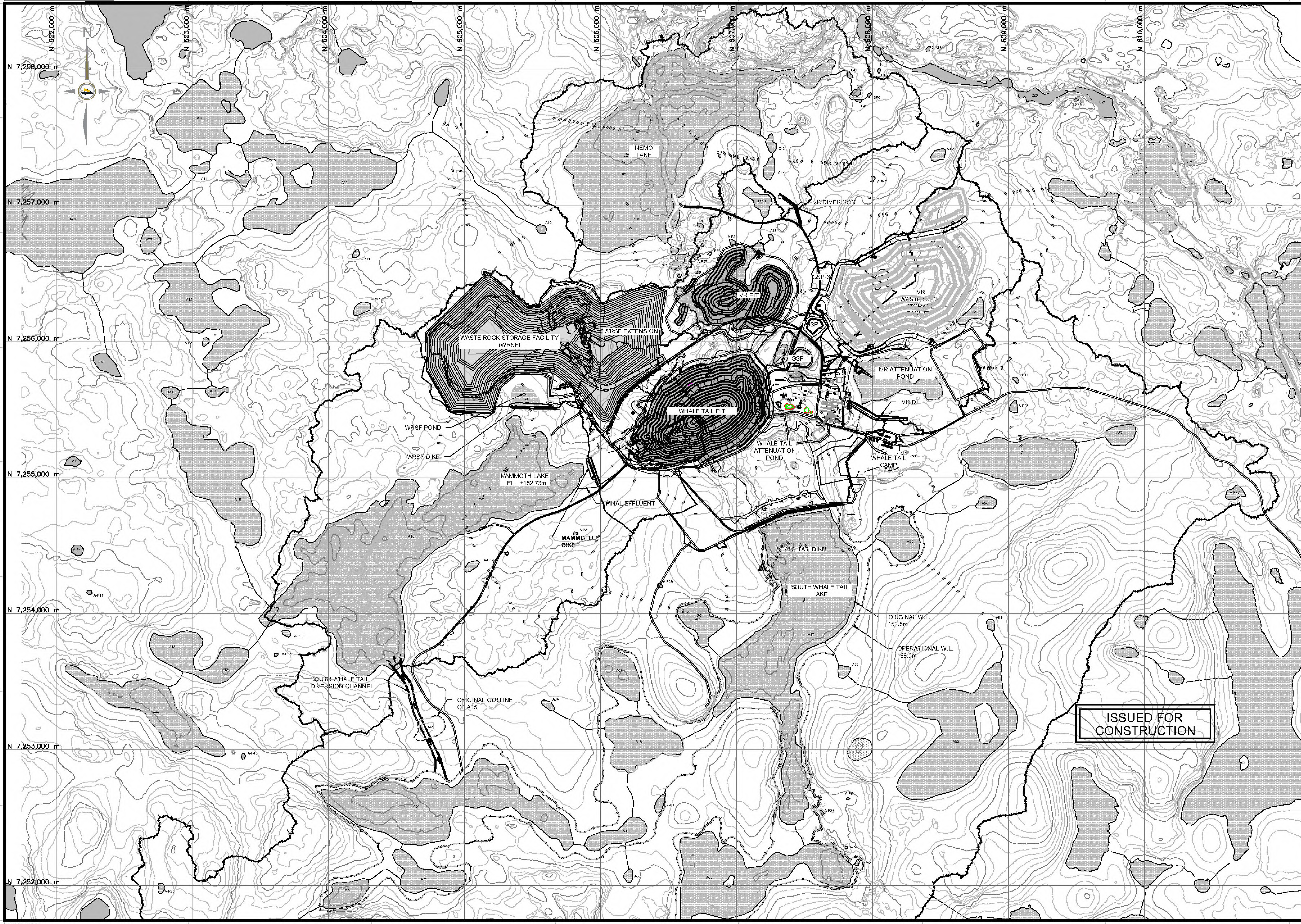

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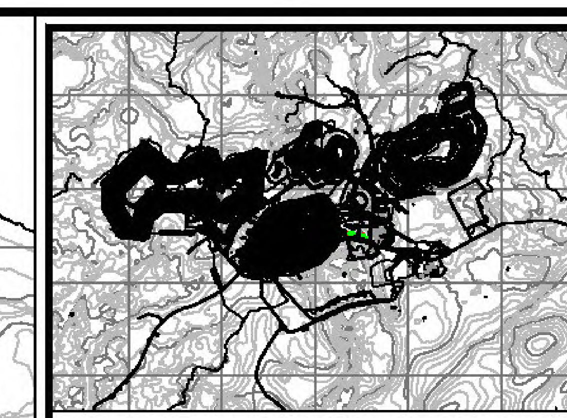

PLAN CLÉ / KEY PLAN

SNC-LAVALIN

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PROJECT No	SUBDIVISION	SUBJECT	SERIAL	REV.
668284	0000	4G DD	0001	E00

NOTES GÉNÉRALES / GENERAL NOTES

LEGEND

- WATERSHED
- POND OR FLOODED AREA AT SOUTH WHALE TAIL LAKE
- ARCHAEOLOGICAL SITE
- ARCTIC FOX HABITAT (D&N & NEC.2015)

DESSINS EN RÉFÉRENCE / REFERENCE DRAWINGS

TITRE / TITLE	# DWG

AGNICO EAGLE

REV.	DATE	DESCRIPTION	PAR/BY	APP.	CLIENT
R0	2020-12-22	ISSUED FOR CONSTRUCTION	M.S/N.Q.	A.L.N.	
RD	2020-11-16	ISSUED FOR CLIENT REVIEW	M.S/N.Q.	A.L.N.	
RC	2020-03-09	ISSUED FOR CLIENT REVIEW	M.S/N.Q.	A.L.N.	
RB	2020-2-25	ISSUED FOR CLIENT REVIEW	M.S/N.Q.	A.L.N.	

REVISIONS

REGISTERED PROFESSIONAL ENGINEER A. L. NGUYEN LICENSEE NT/NU 2020-12-22

PERMIT TO PRACTICE
SNC-LAVALIN INC.
Signature
Date 2020-12-22
PERMIT NUMBER: P 260
The Association of Professional Engineers, Geologists and Geophysicists of NWT/NU

TITRE / TITLE
AGNICO EAGLE – AMARUQ DIVISION
695 – WATER MANAGEMENT
230 – GENERAL EARTHWORKS

WMGI PHASE 2
GENERAL ARRANGEMENT

DESSINÉ PAR DRAWN BY	MARK SYKES	DATE 2020-12-22
VERIFIÉ PAR CHECKED BY	NINA QUAN / PHILIP GOMES	2020-12-22
APPROUVÉ PAR APPROVED BY	ANH LONG NGUYEN	2020-12-22
ÉCHELLE SCALE 1:12500	DATE 2020-12-22	

NO. DESSIN DRAWING NO. 61-695-210-200

NO. PROJET PROJECT NO.	REVISION	FEUILLE / SHT
6127	R0	1 / 1

FILE NO.

NO. DESSIN DRAWING NO. 61-695-230-205

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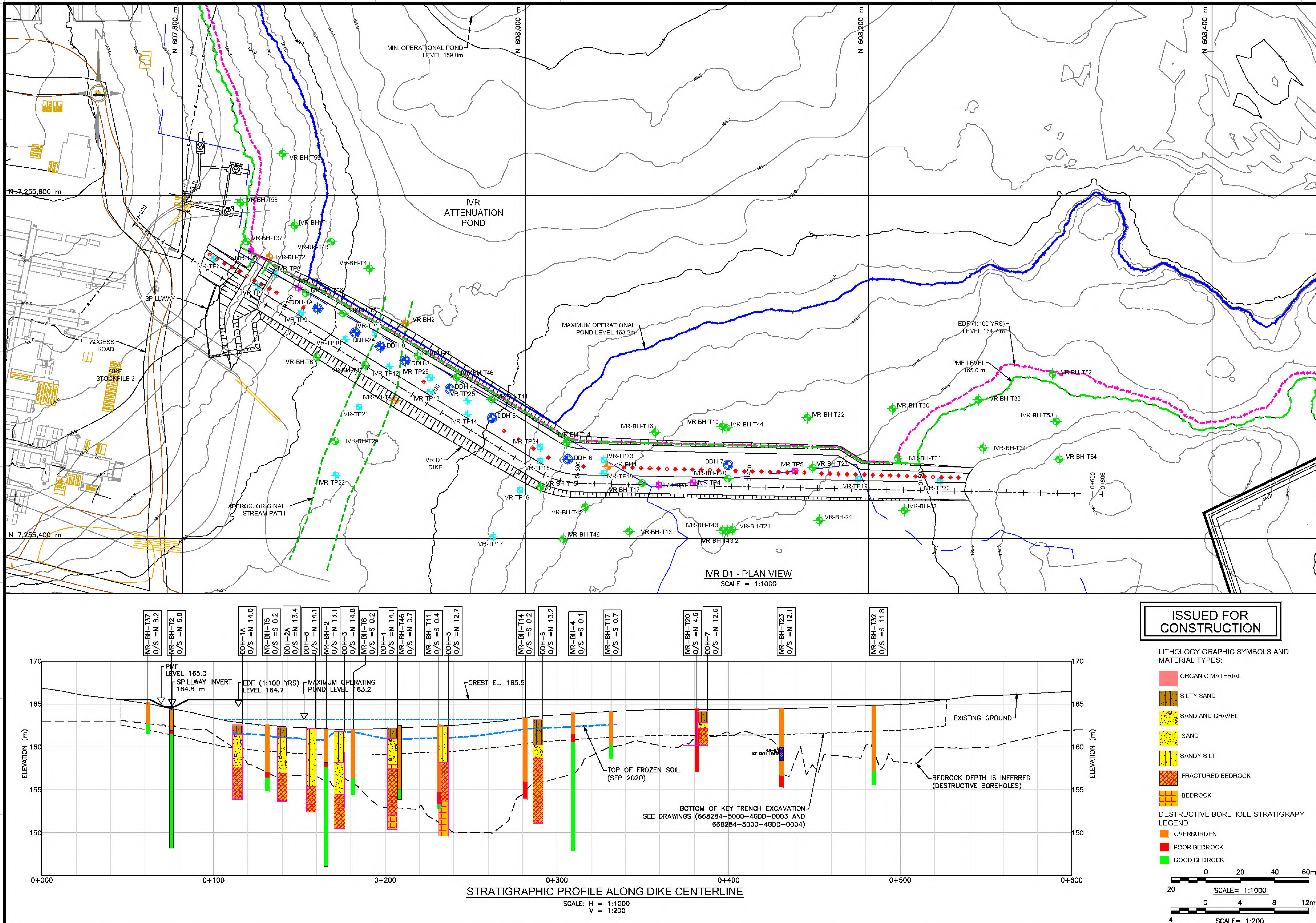

PLAN CLÉ / KEY PLAN

SNC-LAVALIN
Mining & Metallurgy
5500, des Galeries Blvd., bur. 200, Quebec (Quebec), Canada G2K 2E2
Telephone (418) 621-5500, Fax (418) 621-8887

PROJECT No	SUBDIVISION	SUBJECT	SERIAL	REV.
668284	5000	4G DD	0002	E00

NOTES GÉNÉRALES / GENERAL NOTES

NOTES:

1. THIS DRAWING ILLUSTRATES FIELD INVESTIGATION LOCATIONS AT IVR D-1 DIKE WITH INFERRED SOIL STRATIGRAPHIC SECTION.
2. ALL DIMENSIONS AND ELEVATIONS SHOWN ON THIS DRAWING ARE IN METRES. ALL ELEVATIONS ARE TIED TO MEAN SEA LEVEL DATUM. CO-ORDINATES ARE BASED ON NAD83 CSRS ZONE 14N PROJECTION.
3. SECTION A-A ILLUSTRATES THE TOPOGRAPHY AND INFERRED SOIL STRATIGRAPHIY ALONG THE CENTERLINE OF THE IVR D-1 DIKE.
4. THE WORKS SHOWN ON THIS DRAWING SHALL BE EXECUTED IN ACCORDANCE WITH THE TECHNICAL SPECIFICATIONS.
5. BEDROCK DEPTH IS INFERRED FROM DESTRUCTIVE BOREHOLES.

LEGEND

- TAMROCK BOREHOLE – NOV. 2020
- TAMROCK BOREHOLE – MAY 2020
- TAMROCK BOREHOLE WITH THERMISTOR INSTALLED
- TEST PIT – SEP. 2019
- GEOTECHNICAL BOREHOLE – NOV. 2020
- TEST PIT – SEP. 2020

DESSINS EN RÉFÉRENCE / REFERENCE DRAWINGS

TITRE / TITLE	# DWG

AGNICO EAGLE

REV.	DATE	DESCRIPTION	PAR/BY	APP.	CLIENT
R0	2020-12-22	ISSUED FOR CONSTRUCTION	M.S./N.Q.	A.L.N.	
RB	2020-11-16	ISSUED FOR CLIENT REVIEW	M.S./N.Q.	A.L.N.	

REVISIONS

PERMIT TO PRACTICE
SNC-LAVALIN INC.
Signature
Date 2020-12-22
PERMIT NUMBER: P 260
The Association of Professional Engineers, Geologists and Geophysicists of NWT/NU

TITRE / TITLE
AGNICO EAGLE – AMARUQ DIVISION
695 – WATER MANAGEMENT
230 – GENERAL EARTHWORKS
WMGI PHASE 2 – IVR D1 DYKE
FIELD INVESTIGATION LOCATION PLAN AND SOIL STRATIGRAPHIC SECTION

DESSINÉ PAR DRAWN BY	MARK SYKES	DATE	2020-12-22
VERIFIÉ PAR CHECKED BY	NINA QUAN \ PHILIP GOMES		2020-12-22
APPROUVÉ PAR APPROVED BY	ANH-LONG NGUYEN		2020-12-22
ÉCHELLE SCALE	AS SHOWN	DATE	2020-12-22

NO. DESSIN DRAWING NO. 61-695-230-205

NO. PROJET PROJECT NO.	REVISION	FEUILLE / SHT
6127	R0	1 / 1

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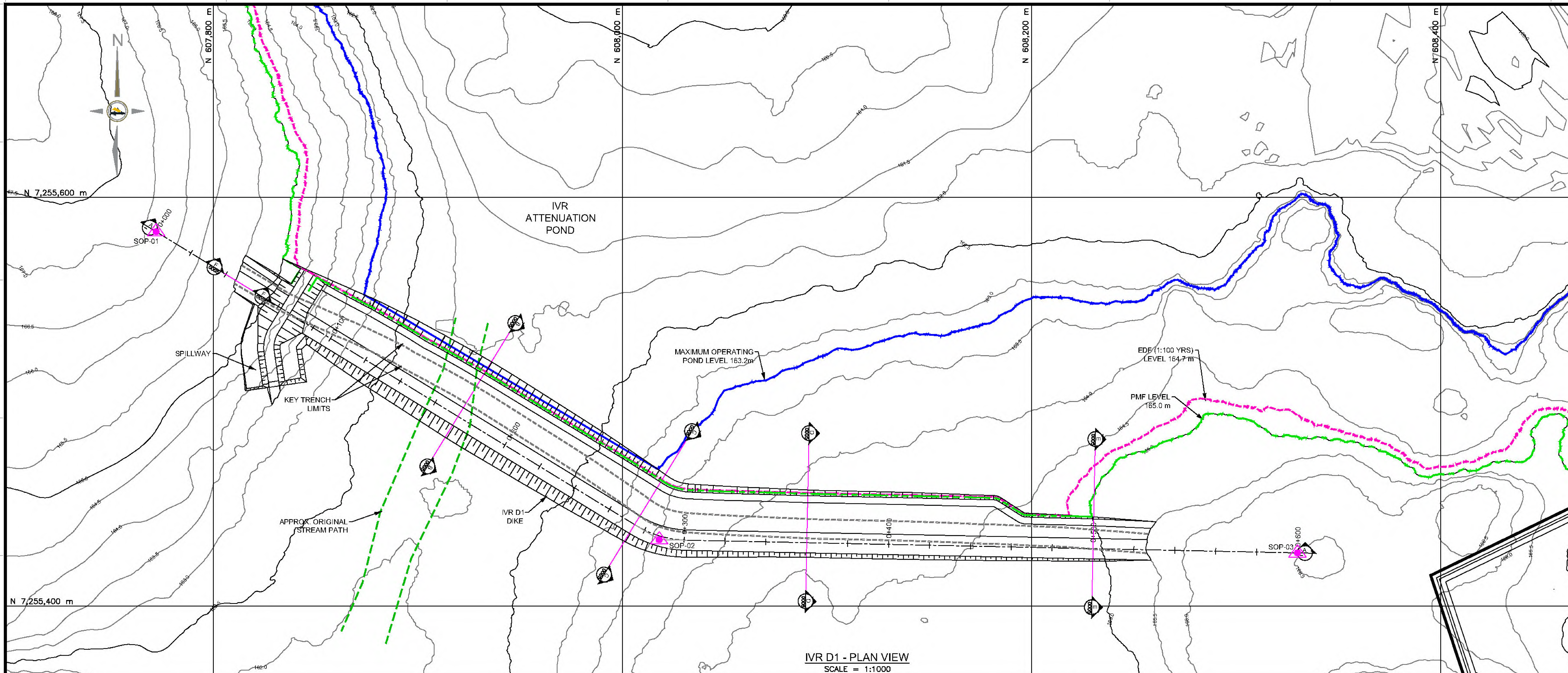
FILE NO.

NO. DESSIN DRAWING NO. 61-695-230-206



IVR D1 - PLAN VIEW
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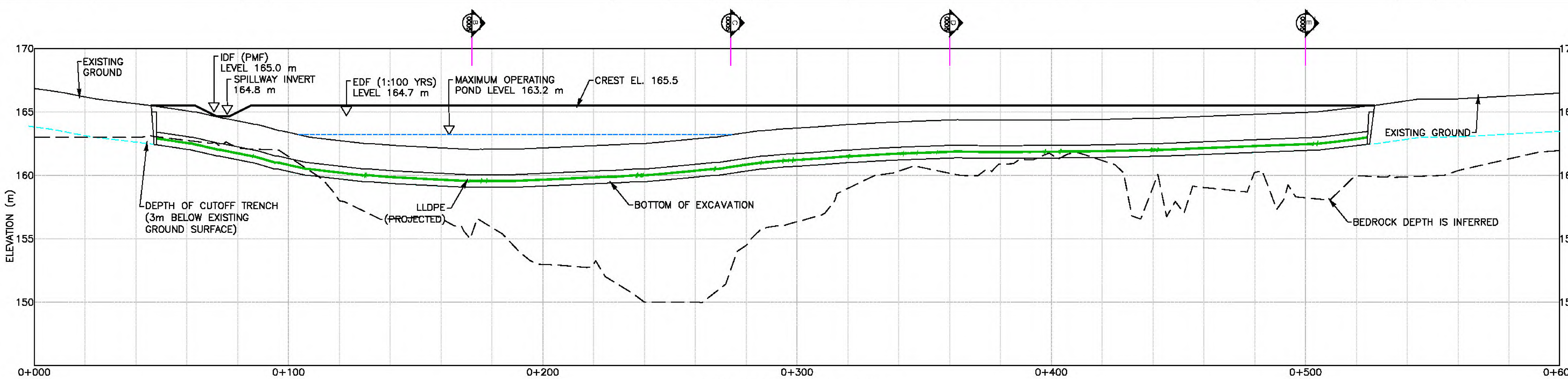

SECTION A - IVR D1 DIKE
SCALE: H = 1:1000
V = 1:500

ISSUED FOR CONSTRUCTION

LEGEND

- (1) ROCKFILL
- (2A) FINE FILTER
- (2B) FINE FILTER AMENDED BENTONITE
- (3) COARSE FILTER
- (5) ESKER
- LLDPE
- GEOTEXTILE
- SETTING OUT POINT

0 20 40 60m
SCALE= 1:1000

0 4 8 12m
SCALE= 1:200

TABLE 1 - SETTING OUT POINTS AND RADII OF CURVATURES

POINT	NORTHING (m)	EASTING (m)	STATION	RADIUS (m)	Δ(deg.)	T (m)
SOP-1	7255583.12	607771.95	0+000	–	–	–
SOP-2	7255432.46	608017.92	–	50.0	30.34	13.56
SOP-3	7255425.94	608330.03	0+600	–	–	–

PLAN CLÉ / KEY PLAN

SNC-LAVALIN
Mining & Metallurgy
5500, des Galeries Blvd., bur. 200, Quebec (Quebec), Canada G2K 2E2
Telephone (418) 621-5500, Fax (418) 621-8887

PROJECT No	SUBDIVISION	SUBJECT	SERIAL	REV.
668284	5000	4G DD	0003	E00

NOTES GÉNÉRALES / GENERAL NOTES

NOTES:
1. THIS DRAWING SHOWS THE PLAN OF IVR D-1 DIKE AND WAS PREPARED USING THE TOPOGRAPHIC DATA PROVIDED BY AGNICO EAGLE.
2. FOR SECTIONS, SEE DRAWINGS 668284-5000-4GDD-0004 AND 668284-5000-4GDD-0005.
3. ALL DIMENSIONS AND ELEVATIONS SHOWN ON THIS DRAWING ARE IN METRES. ALL ELEVATIONS ARE TIED TO MEAN SEA LEVEL DATUM. CO-ORDINATES ARE BASED ON NAD83 CSRS ZONE 14N PROJECTION.
4. THE ROAD WIDTH (SINGLE LANE) IS BASED ON AGNICO EAGLE'S STANDARD DESIGN FOR 150 TON HAUL TRUCKS.
5. THIS DRAWING SHALL BE READ IN CONJUNCTION WITH THE TECHNICAL SPECIFICATIONS.
6. THE WORKS SHOWN ON THIS DRAWING SHALL BE EXECUTED IN ACCORDANCE WITH THE TECHNICAL SPECIFICATIONS.
7. MATERIAL GRADATIONS ARE SHOWN IN TECHNICAL SPECS.

DESSINS EN RÉFÉRENCE / REFERENCE DRAWINGS

TITRE / TITLE	# DWG

AGNICO EAGLE

REV.	DATE	DESCRIPTION	PAR/BY	APP.	CLIENT
R0	2020-12-22	ISSUED FOR CONSTRUCTION	M.S/N.Q.	A.L.N.	
R0	2020-11-18	ISSUED FOR CLIENT REVIEW	M.S/N.Q.	A.L.N	

REVISIONS

PERMIT TO PRACTICE
SNC-LAVALIN INC.
Signature
Date 2020-12-22
PERMIT NUMBER: P 260
The Association of Professional Engineers, Geologists and Geophysicists of NWT/NU

TITRE / TITLE
AGNICO EAGLE – AMARUQ DIVISION
695 – WATER MANAGEMENT
230 – GENERAL EARTHWORKS
WMGI PHASE 2 – IVR D1 DYKE
PLAN AND SECTION
IVR ATTENUATION POND D1

DESSINÉ PAR / DRAWN BY	MARK SYKES	2020-12-22
VERIFIÉ PAR / CHECKED BY	NINA QUAN \ PHILIP GOMES	2020-12-22
APPROUVÉ PAR / APPROVED BY	ANH-LONG NGUYEN	2020-12-22
ÉCHELLE / SCALE	AS SHOWN	DATE 2020-12-22
NO. DESSIN / DRAWING NO.	61-695-230-206	
NO. PROJET / PROJECT NO. 6127	REVISION R0	FEUILLE / SHT 1 / 1

FILE NO.

NO. DESSIN DRAWING NO. 61-695-230-207

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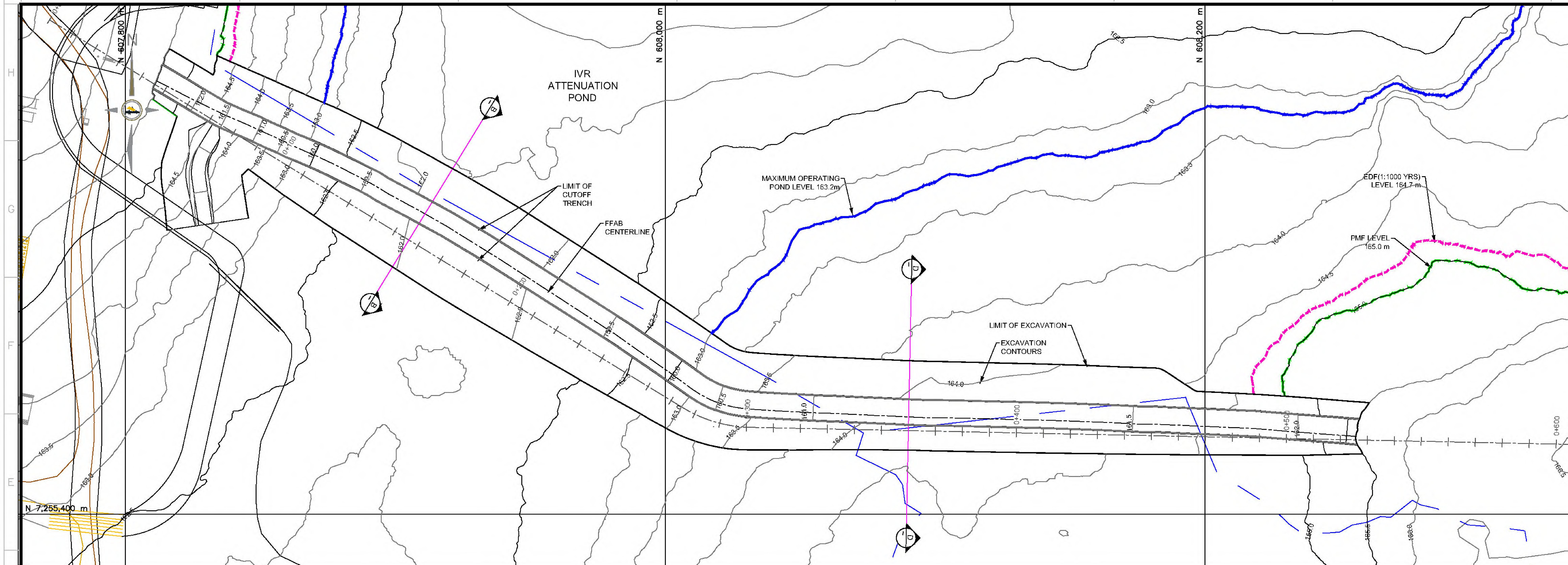

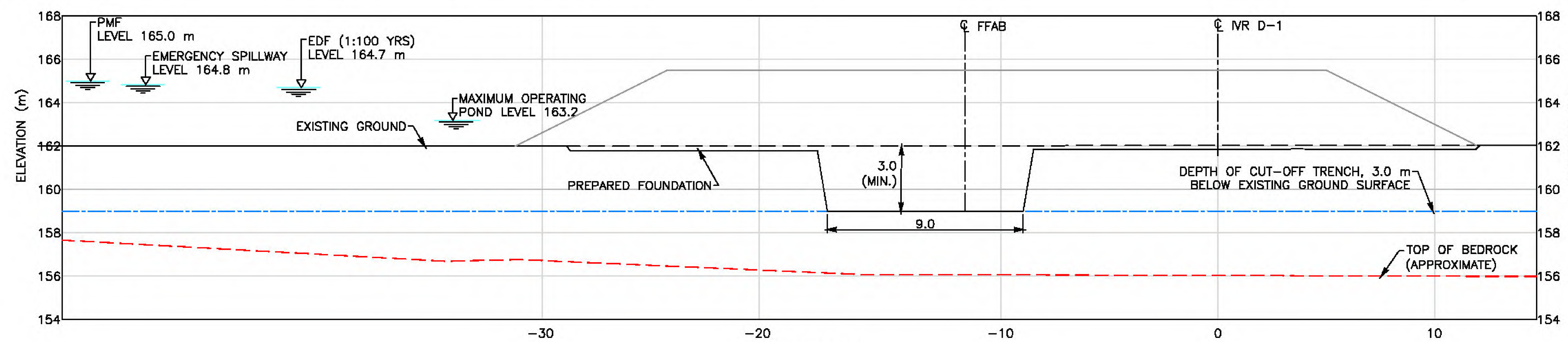

SECTION B-B
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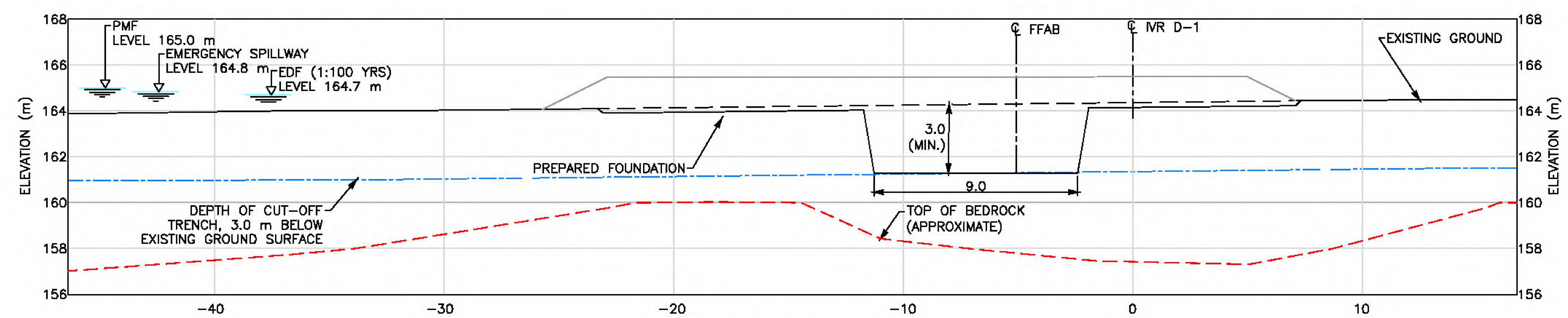

SECTIOND-D
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ISSUED FOR CONSTRUCTION

PLAN CLÉ / KEY PLAN

SNC-LAVALIN
Mining & Metallurgy
5500, des Galeries Blvd., bur. 200, Quebec (Quebec), Canada G2K 2E
Telephone: (418) 621-5500, Fax (418) 621-8887

PROJECT No	SUBDIVISION	SUBJECT		SERIAL	REV.
668284	5000	4G	DD	0004	E00

NOTES GÉNÉRALES / GENERAL NOTES

NOTES:

1. ALL DIMENSIONS AND ELEVATIONS SHOWN ON THIS DRAWING ARE IN METRES. ALL ELEVATIONS ARE TIED TO MEAN SEA LEVEL DATUM. CO-ORDINATES ARE BASED ON NAD83 CSRS ZONE 14N PROJECTION.
2. THIS DRAWING SHALL BE READ IN CONJUNCTION WITH THE TECHNICAL SPECIFICATIONS.
3. THE WORKS SHOWN ON THIS DRAWING SHALL BE EXECUTED IN ACCORDANCE WITH THE TECHNICAL SPECIFICATIONS.
4. IF POCKET OF ICE IS ENCOUNTERED, ICE POCKET SHALL BE REMOVED AND BACKFILLED WITH ESKER.
5. FOR DEPTH OF EXCAVATION SEE DRAWING 668284-5000-4GDD-0003.

DESSINS EN RÉFÉRENCE / REFERENCE DRAWINGS

TITRE / TITLE	# DWG

AGNICO EAGLE

REV.	DATE	DESCRIPTION	PAR/BY	APP.	CLIENT
R0	2020-12-22	ISSUED FOR CONSTRUCTION	M.S/N.Q.	A.L.N.	
RB	2020-11-16	ISSUED FOR CLIENT REVIEW	M.S/N.Q.	A.L.N.	

REVISIONS

PERMIT TO PRACTICE
SNC-LAVALIN INC.
Signature
Date 2020-12-22
PERMIT NUMBER: P 260
The Association of Professional Engineers, Geologists and Geophysicists of NWT/NU

TITRE / TITLE
AGNICO EAGLE – AMARUQ DIVISION
695 – WATER MANAGEMENT
230 – GENERAL EARTHWORKS
WMGI PHASE 2 – IVR D1 DYKE
EXCAVATION PLAN AND SECTIONS

DESSINÉ PAR DRAWN BY	MARK SYKES	DATE 2020-12-22
VERIFIÉ PAR CHECKED BY	NINA QUAN \ PHILIP GOMES	2020-12-22
APPROUVÉ PAR APPROVED BY	ANH-LONG NGUYEN	2020-12-22
ÉCHELLE SCALE	AS SHOWN	DATE 2020-12-22

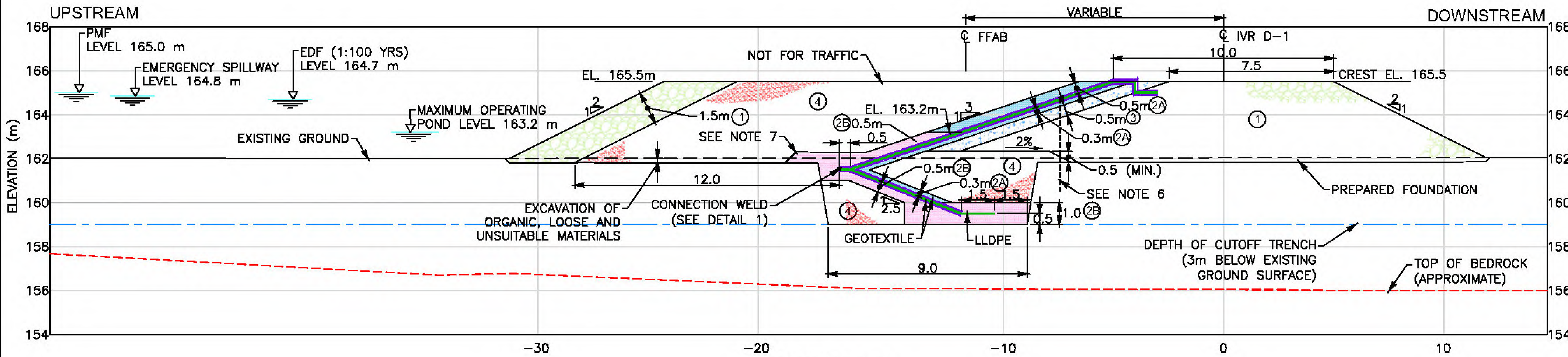
NO. DESSIN DRAWING NO. 61-695-230-207

NO. PROJET PROJECT NO.	REVISION	FEUILLE / SHT
6127	R0	1 / 1

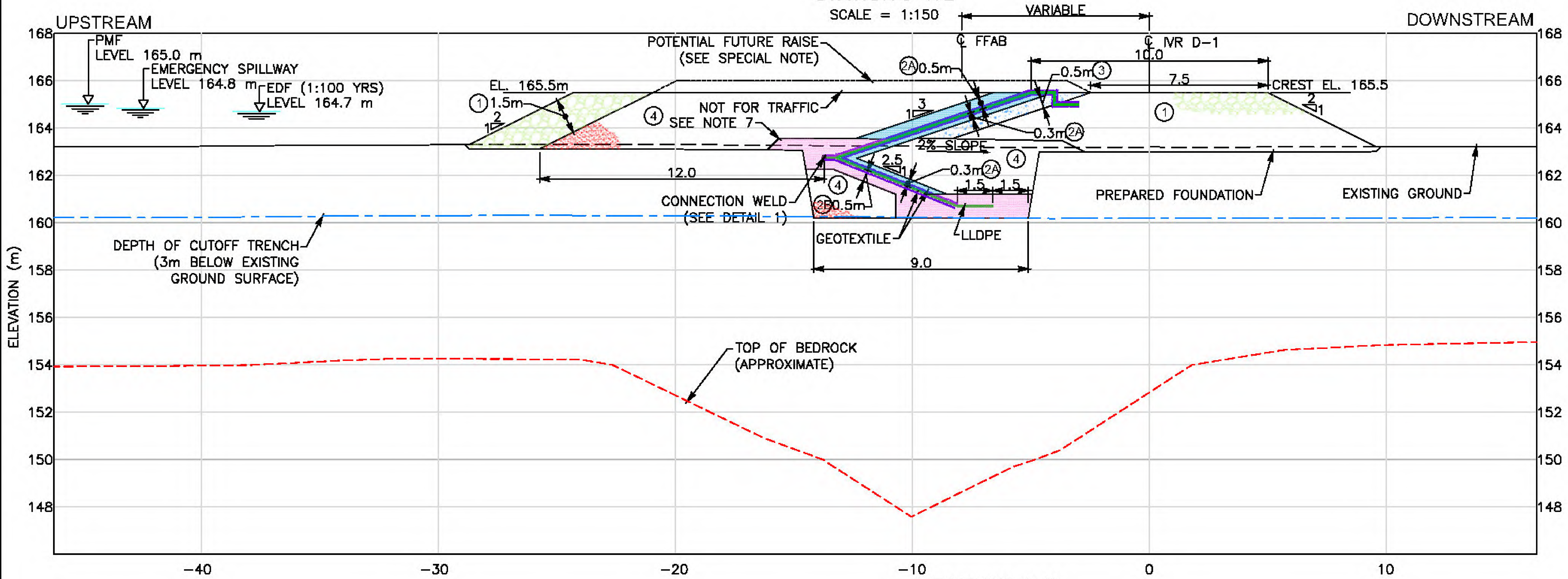
FILE NO.

AE-CART-ARCH D

NO. DESSIN DRAWING NO. 61-695-230-208



SECTION B-B
STATION 0+172
SCALE = 1:150



SECTION C-C
STATION 0+274
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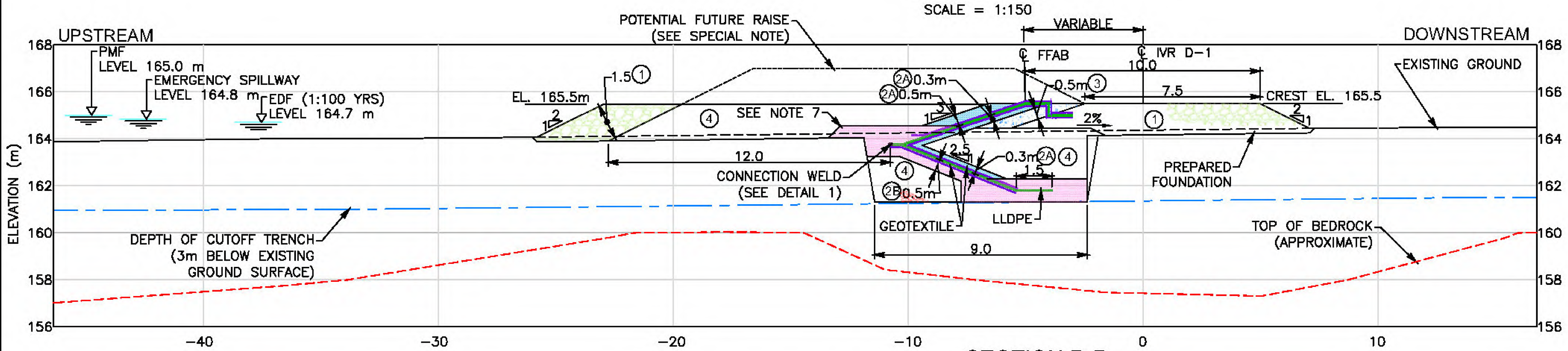
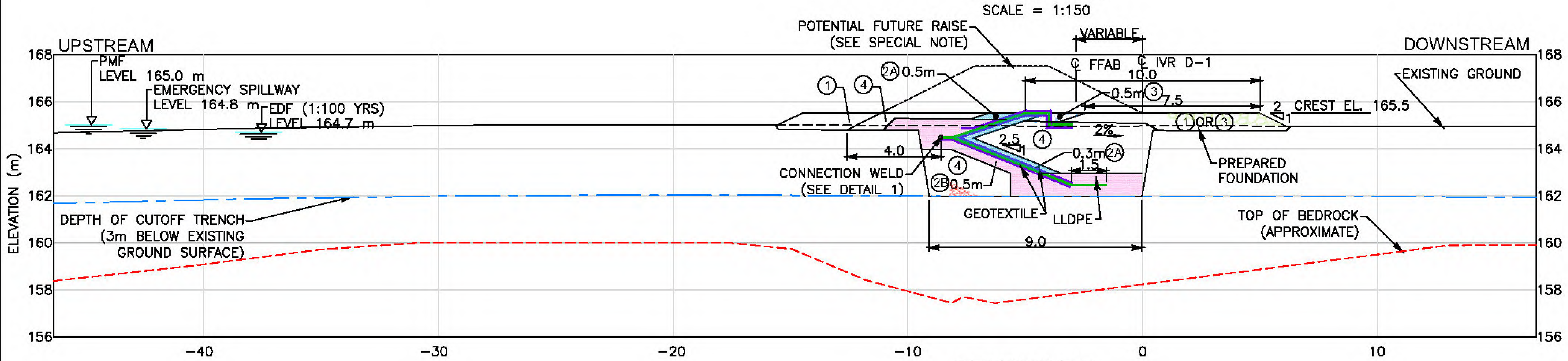


SECTION D-D
STATION 0+360
SCALE = 1:150



SECTION E-E
STATION 0+500
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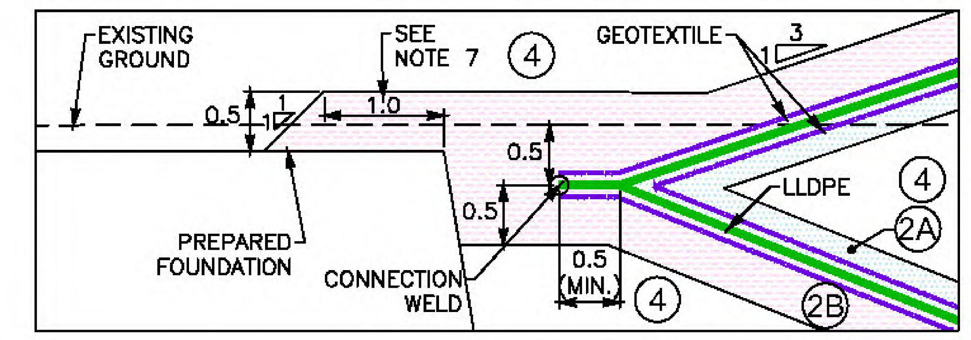

DETAIL 1
CONNECTION WELD DETAIL
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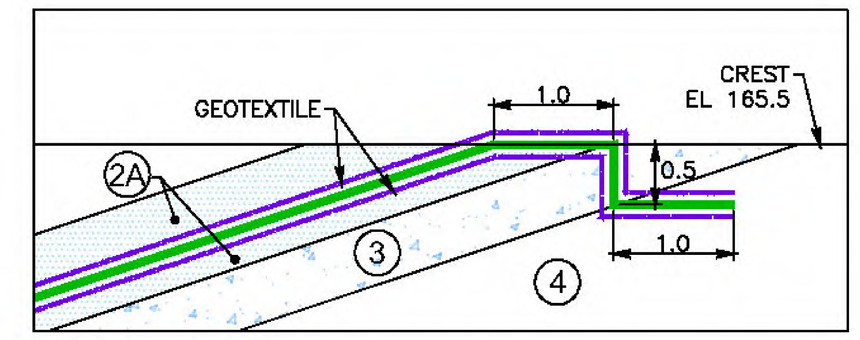
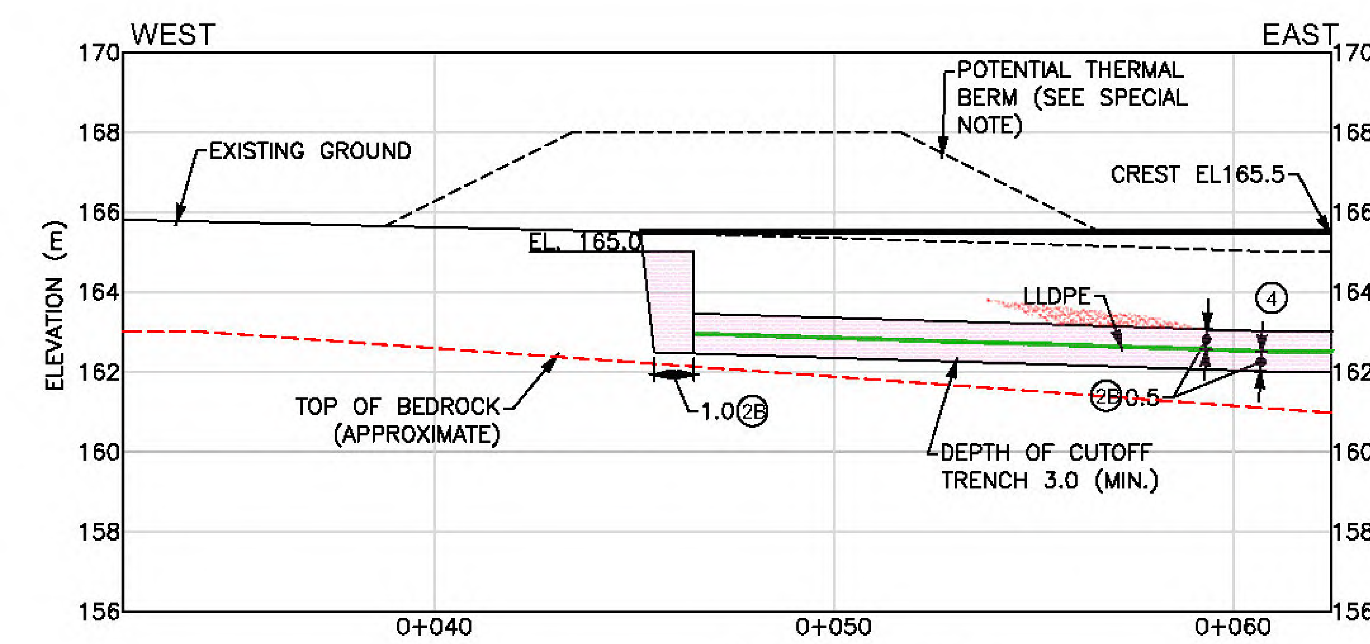


DETAIL 2
CREST DETAIL
SCALE = 1:50

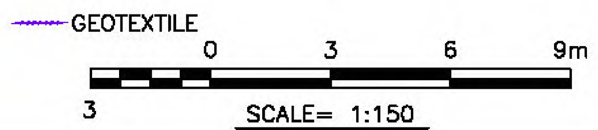


SECTION F-F
WEST ABUTMENT
SCALE = 1:150

SPECIAL NOTE:
INSTALLATION OF A BERM AT THE ABUTMENTS AND/OR RAISING THE BERM / DIKE CREST MAY BE REQUIRED IN THE FUTURE DEPENDING ON THE THERMAL PERFORMANCE OF THE DIKE STRUCTURE (TO BE BASED ON THE GROUND TEMPERATURE MONITORING DATA).

ISSUED FOR CONSTRUCTION

LEGEND
- (1) ROCKFILL
- (2A) FINE FILTER
- (2B) FINE FILTER AMENDED BENTONITE
- (3) COARSE FILTER
- (4) ESKER
- LLDPE
- GEOTEXTILE



PLAN CLE / KEY PLAN

SNC-LAVALIN
Mining & Metallurgy
5500, des Galeries Blvd, bur. 200, Quebec (Quebec), Canada G2K 2E
Telephone (418) 621-5500, Fax (418) 621-8887

PROJECT No	SUBDIVISION	SUBJECT	SERIAL	REV.
668284	5000	4G DD	0005	E00

NOTES GÉNÉRALES / GENERAL NOTES

NOTES:
1. THIS DRAWING SHOWS SELECTED SECTIONS OF THE IVR D-1 DIKE.
2. FOR THE LOCATIONS OF THE SECTIONS, SEE DRAWING 668284-5000-4GDD-0003.
3. ALL ELEVATIONS AND DIMENSIONS ARE IN METERS AND TIED TO MEAN SEA LEVEL.
4. THE BOTTOM OF THE KEY TRENCH SHALL BE ESTABLISHED BELOW GRAVEL, COBBLES AND BOULDER LAYER ON BEDROCK SURFACE (BRS), OR GLACIAL TILL (GT).
5. WHERE THE FFAB LAYER WILL BE INSTALLED DIRECTLY ON THE BEDROCK SURFACE, CRACKS AND JOINTS FILLED WITH SOIL OR ROCK FRAGMENTS SHALL BE CLEANED. ALL LOOSE ROCK FRAGMENTS SHALL BE REMOVED AND CLEANED PRIOR TO THE PLACEMENT OF FILL MATERIALS AS APPROVED BY SITE ENGINEER.
6. NATURAL SOIL UNDER THE LINER AREA AT EL. 164.7m MAYBE REQUIRED AS DIRECTED BY AEM. TO BE EXCAVATED AND BACKFILLED WITH ESKER OR ENGINEERING FILL.
7. FFAB LAYER HAS TO BE EXTENDED AT 1M MIN BEYOND THE EXCAVATION WALL.
8. THE WORKS SHOWN ON THIS DRAWING SHALL BE EXECUTED IN ACCORDANCE WITH THE TECHNICAL SPECIFICATIONS.
9. MATERIAL GRADATIONS ARE SHOWN IN TECHNICAL SPECIFICATIONS.

DESSINS EN RÉFÉRENCE / REFERENCE DRAWINGS

TITRE / TITLE	DWG

AGNICO EAGLE

REV.	DATE	DESCRIPTION	PAR/BY	APP.	CLIENT
R0	2020-12-22	ISSUED FOR CONSTRUCTION	M.S/N.Q.	A.L.N.	
RB	2020-11-18	ISSUED FOR CLIENT REVIEW	M.S/N.Q.	A.L.N.	

REVISIONS

REGISTERED PROFESSIONAL ENGINEER
Q.N. QUAN
LICENSEE
NT/NU

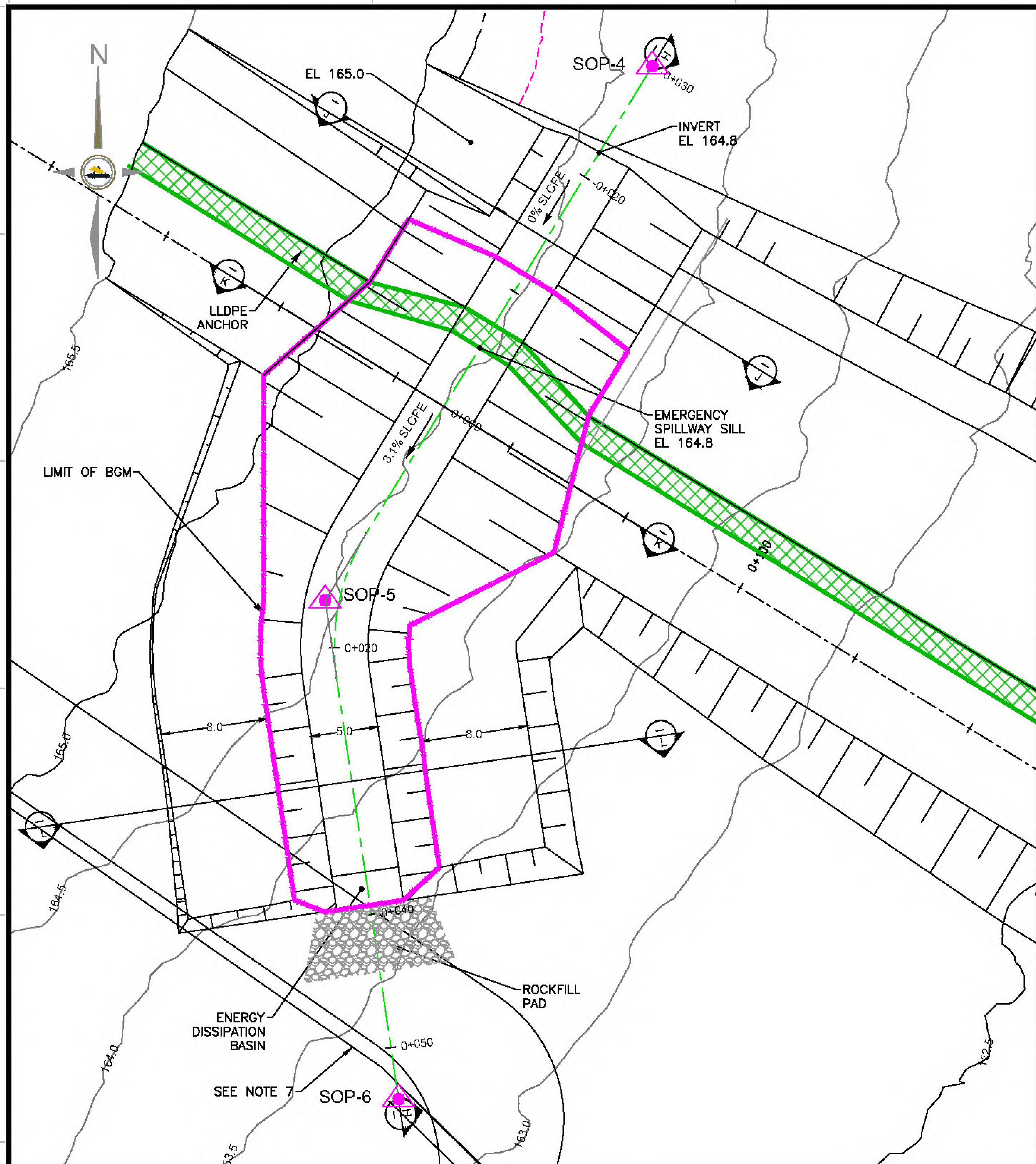
PERMIT TO PRACTICE
SNC-LAVALIN INC.
Signature
Date 2020-12-22
PERMIT NUMBER: P 260
The Association of Professional Engineers, Geologists and Geophysicists of NWT/NU

TITRE / TITLE
AGNICO EAGLE – AMARUQ DIVISION
695 – WATER MANAGEMENT
230 – GENERAL EARTHWORKS
WMGI PHASE 2 – IVR D1 DYKE
DESIGN SECTIONS AND DETAILS

DESSINÉ PAR DRAWN BY	MARK SYKES	DATE 2020-12-22
VERIFIÉ PAR CHECKED BY	NINA QUAN \ PHILIP GOMES	2020-12-22
APPROUVÉ PAR APPROVED BY	ANH LONG NGUYEN	2020-12-22
ÉCHELLE SCALE	AS SHOWN	DATE 2020-12-22
NO. DESSIN DRAWING NO.	61-695-230-208	
NO. PROJET PROJECT NO. 6127	REVISION R0	FEUILLE / SHT 1/1

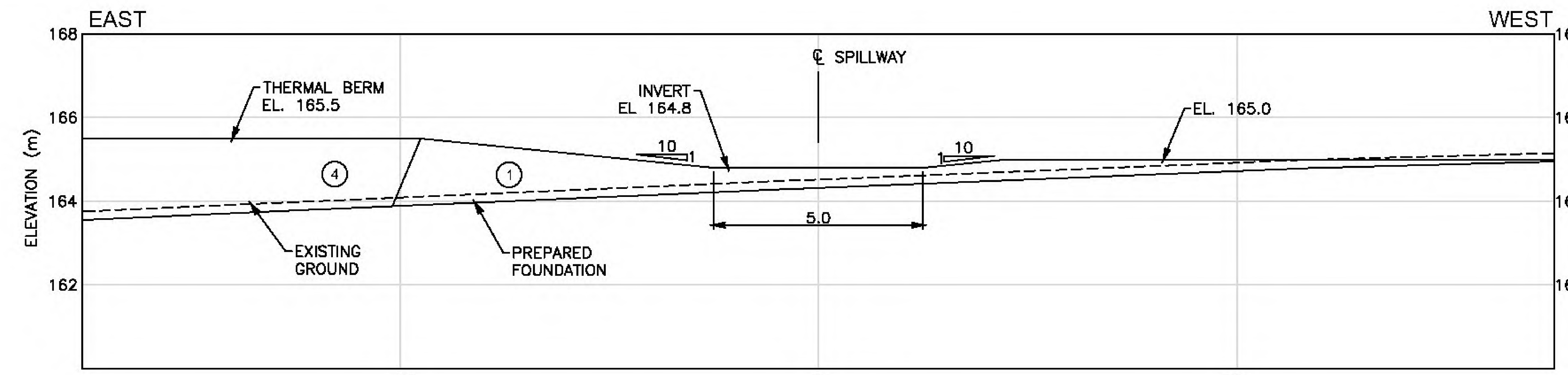
FILE NO.
AE-CART-ARCH D
FORMAT ARCHD

NO. DESSIN / DRAWING NO. 61-695-230-209



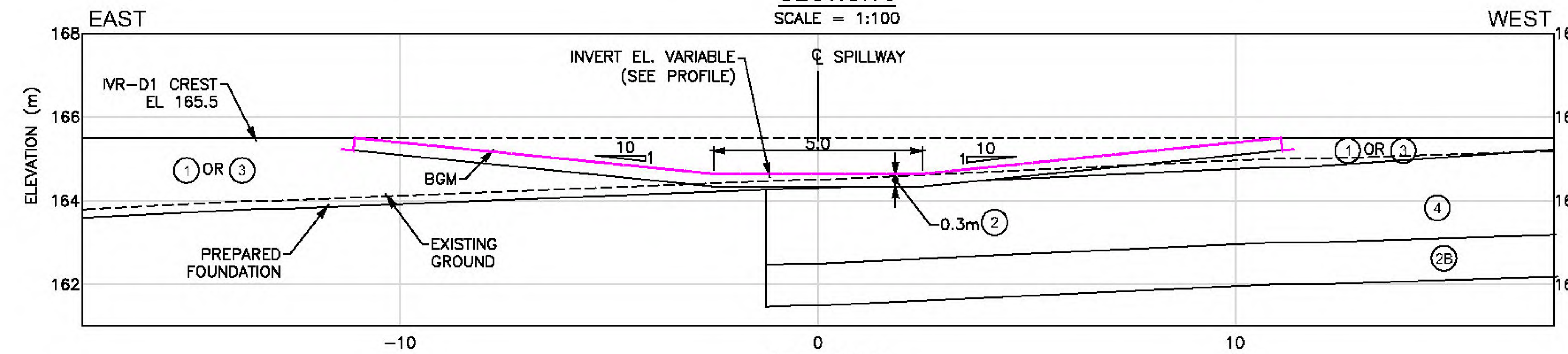
IVR D1 SPILLWAY - PLAN VIEW

SCALE = 1:250



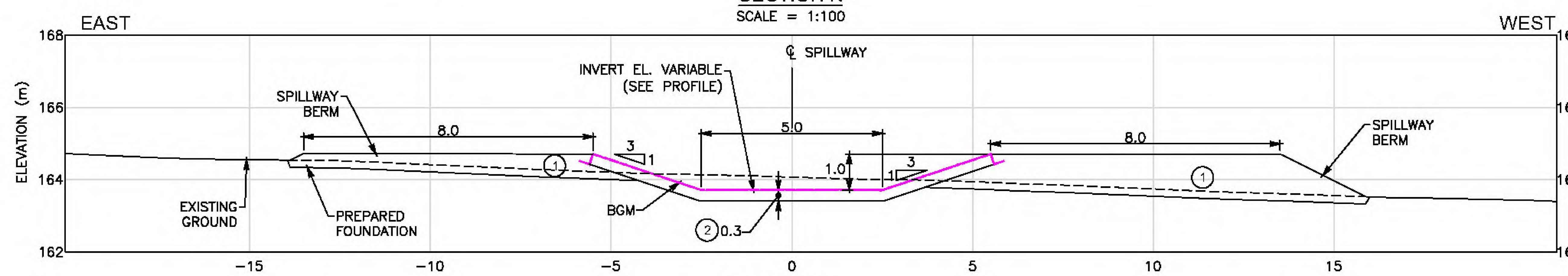
SECTION J

SCALE = 1:100



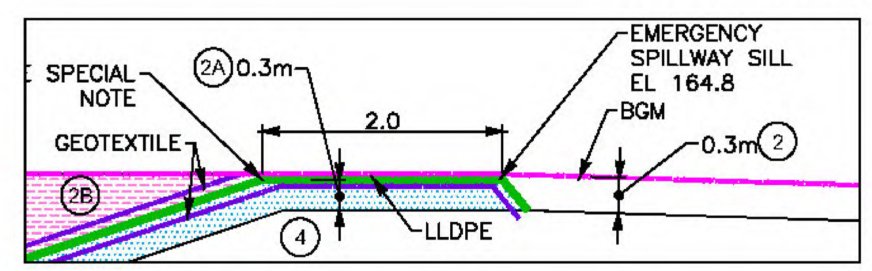
SECTION K

SCALE = 1:100



SECTION L

SCALE = 1:100



DETAIL 1

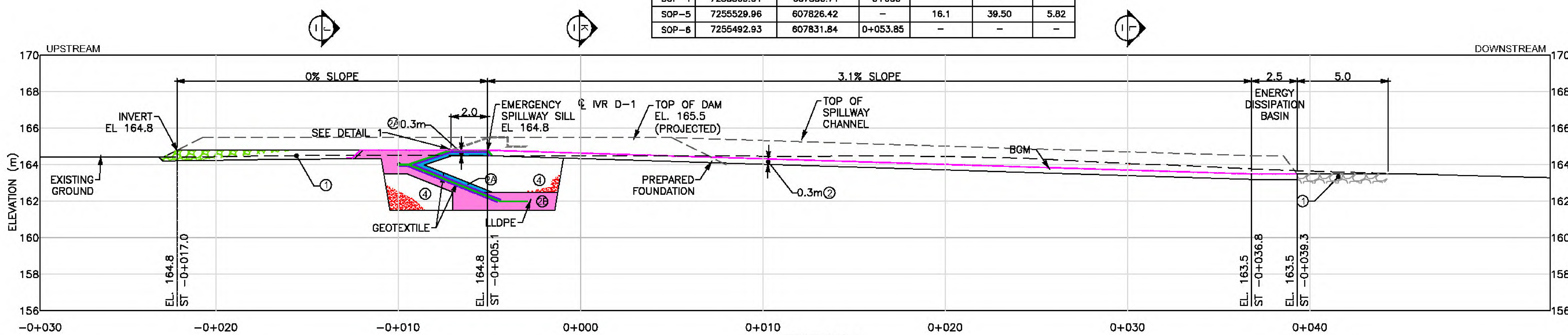
SCALE = 1:50

LEGEND

- 4 ROCKFILL
- 2A FINE FILTER
- 2B FINE FILTER AMENDED BENTONITE
- 1 COARSE FILTER
- 3 ESKER
- LLDPE
- BGM
- GEOTEXTILE
- SETTING OUT POINT

TABLE 1 - SETTING OUT POINTS AND RADII OF CURVATURES

POINT	NORTHING (m)	EASTING (m)	STATION	RADIUS (m)	Δ(deg.)	T (m)
SOP-4	7255569.64	607850.71	-0+030	-	-	-
SOP-5	7255529.96	607826.42	-	16.1	39.50	5.82
SOP-6	7255492.93	607831.84	0+053.85	-	-	-

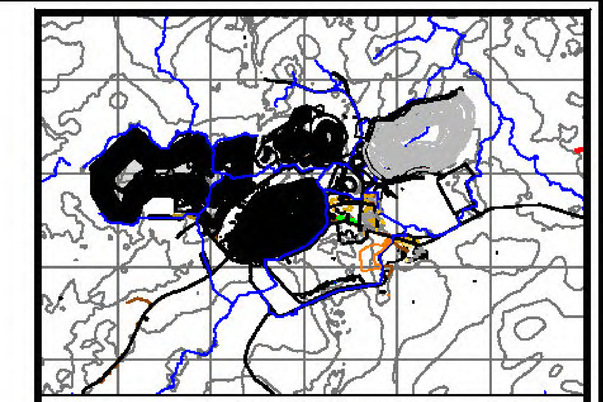


SECTION H

SCALE = 1:150

SPECIAL NOTE:
NO WELDING OF BGM IN THE VICINITY OF THE LLDPE LINER

ISSUED FOR CONSTRUCTION



PLAN CLÉ / KEY PLAN

SNC-LAVALIN

PROJECT No	SUBMISSION	SUBJECT		SERIAL	REV.
668284	5000	4G	DD	0006	E00

NOTES GÉNÉRALES / GENERAL NOTES

NOTES:

1. FOR THE LOCATION OF THE SPILLWAY SEE DRAWING 668284-5000-4GDD-0003.
2. ALL DIMENSIONS AND ELEVATIONS SHOWN ON THIS DRAWING ARE IN METRES. ALL ELEVATIONS ARE TIED TO MEAN SEA LEVEL DATUM. CO-ORDINATES ARE BASED ON NAD83 CSRS ZONE 14N PROJECTION.
3. FFAB LAYER SHALL BE EXTENDED AT 1m MINIMUM BEYOND OPENING.
4. THIS DRAWING SHALL BE READ IN CONJUNCTION WITH THE TECHNICAL SPECIFICATIONS.
5. THE WORKS SHOWN ON THIS DRAWING SHALL BE EXECUTED IN ACCORDANCE WITH THE TECHNICAL SPECIFICATIONS.
6. MATERIAL GRADATIONS ARE SHOWN IN TECHNICAL SPECIFICATIONS.
7. PROPOSED SPILLWAY ALIGNMENT TO BE COORDINATED WITH EXISTING AND/OR PLANNED ROAD AND PIPELINE BASED ON SITE CONDITIONS.

DESSINS EN RÉFÉRENCE / REFERENCE DRAWINGS

AGNICO EAGLE

REV.	DATE	DESCRIPTION	PAR/BY	APP.	CLIENT
R0	2020-12-22	ISSUED FOR CONSTRUCTION	M.S./N.Q.	A.L.N.	
RB	2020-11-18	ISSUED FOR CLIENT REVIEW	M.S./N.Q.	A.L.N.	

REVISIONS

PERMIT TO PRACTICE SNC-LAVALIN INC.
PERMIT NUMBER: P 260
The Association of Professional Engineers, Geologists and Geophysicists of NWT/NU

TITRE / TITLE
AGNICO EAGLE - AMARUQ DIVISION
695 - WATER MANAGEMENT
230 - GENERAL EARTHWORKS
WMGI PHASE 2 - IVR D1 DYKE
SPILLWAY - PLAN SECTIONS AND DETAILS

		DATE
DESSINÉ PAR / DRAWN BY	MARK SYKES	2020-12-22
VÉRIFIÉ PAR / CHECKED BY	NINA QUAN / HOLMAN TELLEZ / PHILIP COMES	2020-12-22
APPROUVÉ PAR / APPROVED BY	ANH-LONG NGUYEN	2020-12-22
ÉCHELLE / SCALE	AS SHOWN	2020-12-22

NO. DESSIN / DRAWING NO. 61-695-230-209

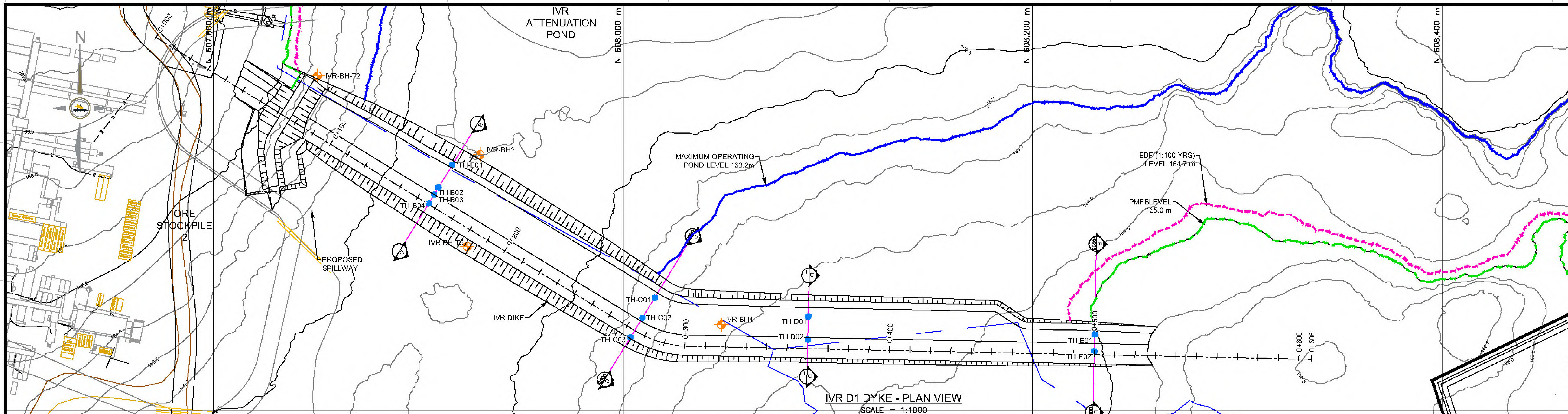
NO. PROJET / PROJECT NO.	RÉVISION	FEUILLE / SHT
6127	R0	1 / 1

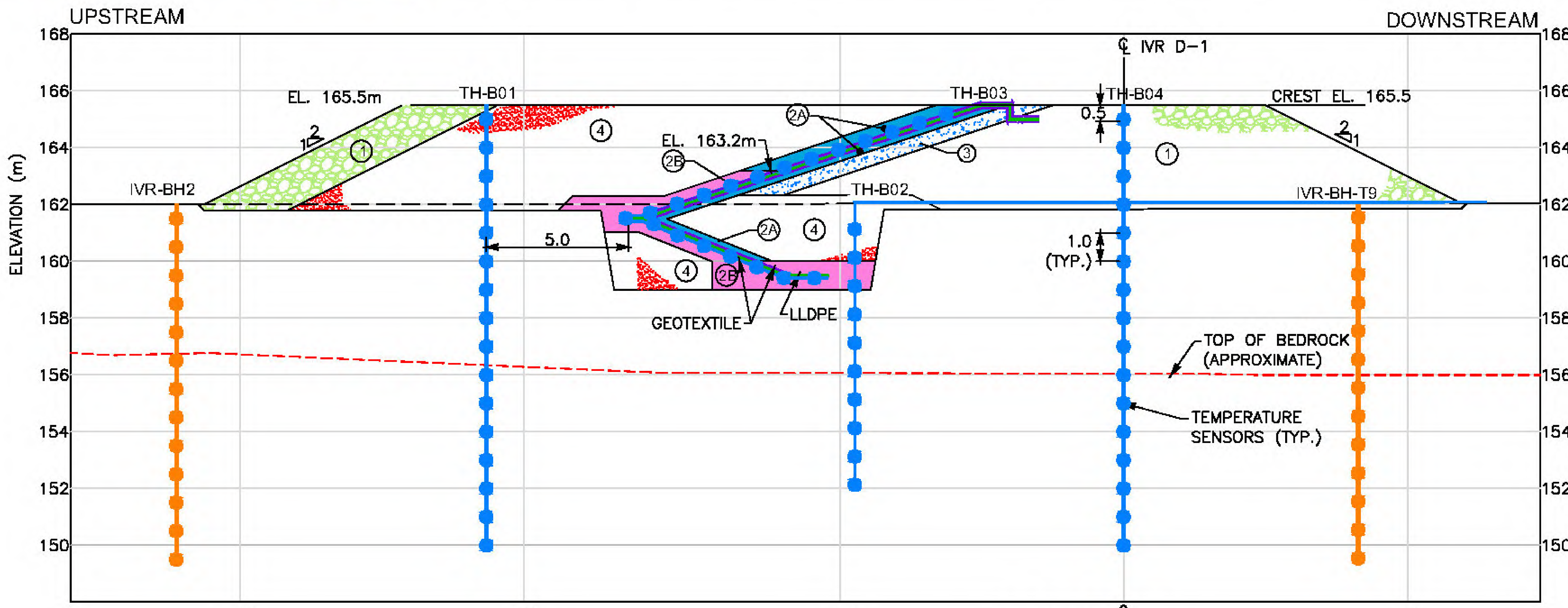
SCALE = 1:100

FORMAT ARCHD

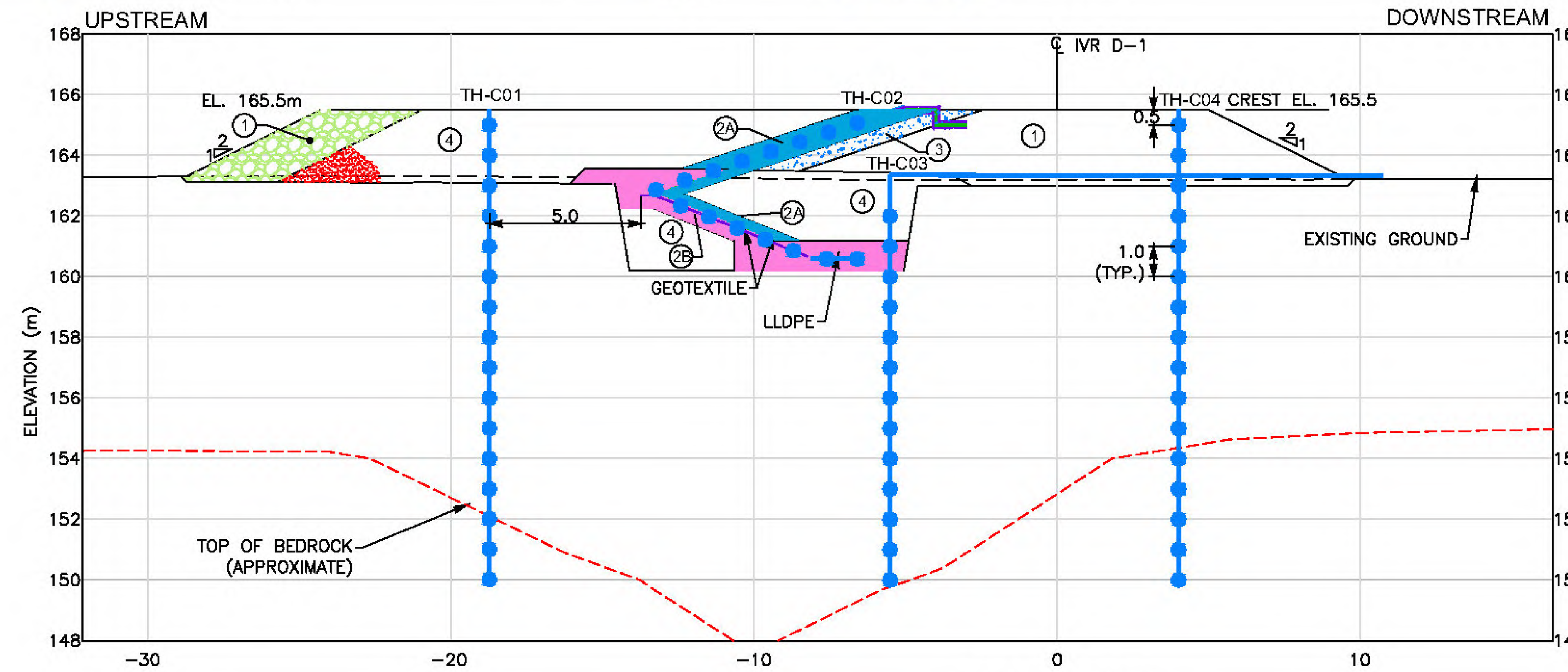
NO. DESSIN DRAWING NO. 61-695-230-205

FORMAT ARCHD

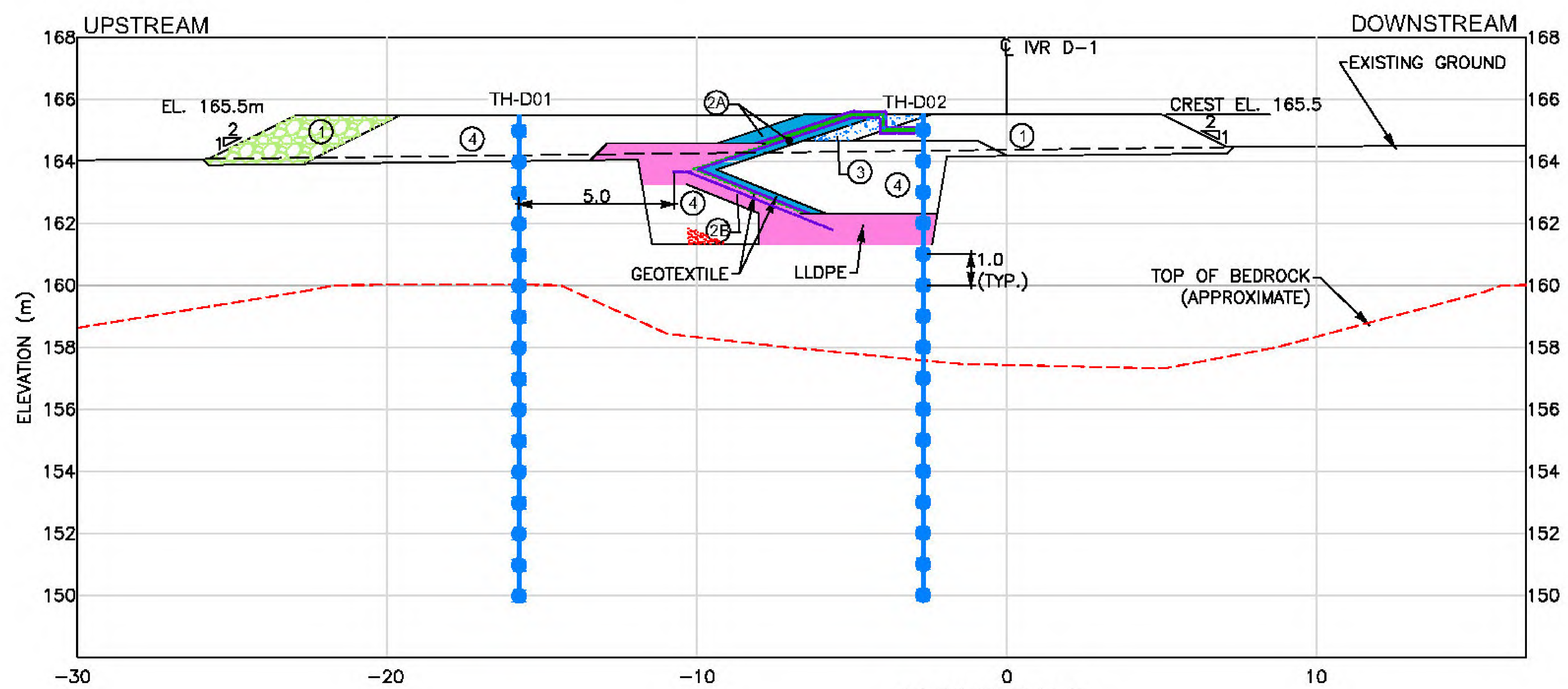




SECTION B-B
SCALE: 1:150



SECTION C-C
SCALE: 1:150



SECTION D-D
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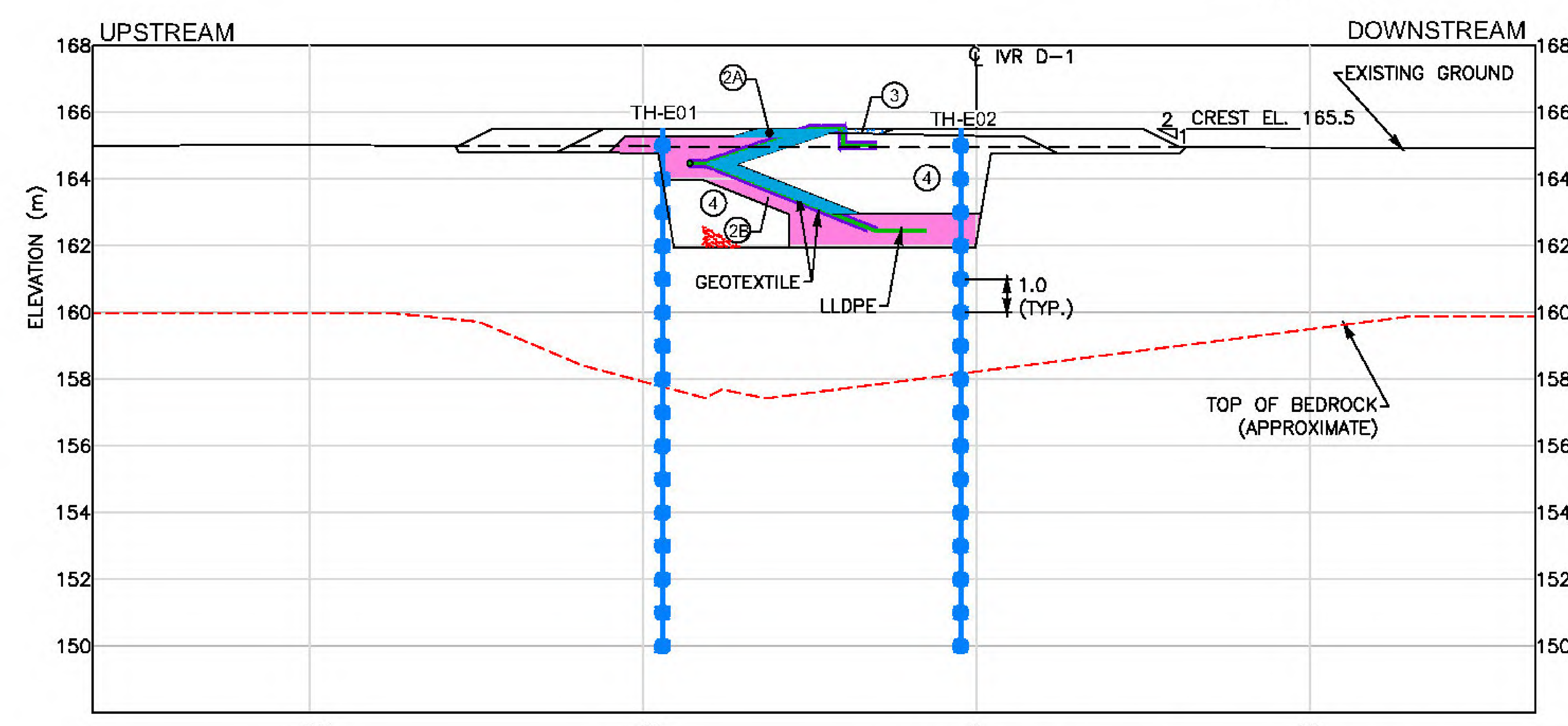
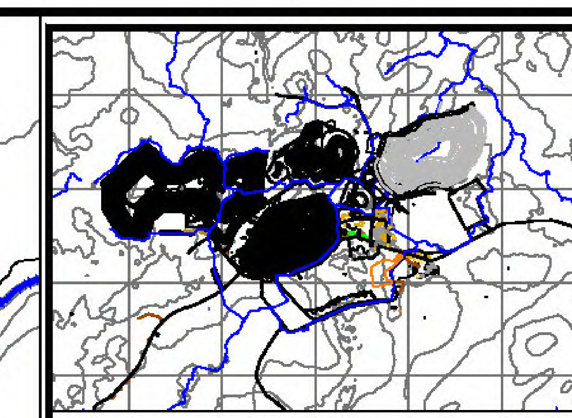


SECTION E-E
SCALE: 1:150

0 20 40 60m
SCALE= 1:1000

0 4 8 12m
SCALE= 1:200

ISSUED FOR CONSTRUCTION



PLAN CLÉ / KEY PLAN

SNC·LAVALIN
Mining & Metallurgy
5500, des Galeries Blvd., bur. 200, Quebec (Quebec), Canada G2K 2E2
Telephone: (418) 621-5500, Fax (418) 621-0687

PROJECT No	SUBDIVISION	SUBJECT		SERIAL	REV.
668284	5000	4G	DD	0007	E00

NOTES GÉNÉRALES / GENERAL NOTES

NOTES:

1. ALL DIMENSIONS AND ELEVATIONS SHOWN ON THIS DRAWING ARE IN METRES. ALL ELEVATIONS ARE TIED TO MEAN SEA LEVEL DATUM. CO-ORDINATES ARE BASED ON NAD83 CSRS ZONE 14N PROJECTION.
2. THIS DRAWING SHALL BE READ IN CONJUNCTION WITH THE TECHNICAL SPECIFICATIONS.
3. THE WORKS SHOWN ON THIS DRAWING SHALL BE EXECUTED IN ACCORDANCE WITH THE TECHNICAL SPECIFICATIONS.

LEGEND

EXISTING THERMISTOR

PROPOSED THERMISTOR

DESSINS EN RÉFÉRENCE / REFERENCE DRAWINGS

TITRE / TITLE	DWG

AGNICO EAGLE

REV.	DATE	DESCRIPTION	PAR/BY	APP.	CLIENT
R0	2020-12-22	ISSUED FOR CONSTRUCTION	M.S./N.Q.	A.L.N.	
RB	2020-11-18	ISSUED FOR CLIENT REVIEW	M.S./N.Q.	A.L.N.	

REVISIONS

PERMIT TO PRACTICE
SNC-LAVALIN INC.
PERMIT NUMBER: P 260
The Association of Professional Engineers, Geologists and Geophysicists of NWT/NU

TITRE / TITLE
AGNICO EAGLE – AMARUQ DIVISION
695 – WATER MANAGEMENT
230 – GENERAL EARTHWORKS
WMGI PHASE 2 – IVR D1 DYKE
INSTRUMENTATION PLAN

		DATE
DESSINÉ PAR / DRAWN BY	MARK SYKES	2020-12-22
VÉRIFIÉ PAR / CHECKED BY	NINA QUAN \ PHILIP GOMES	2020-12-22
APPROUVÉ PAR / APPROVED BY	ANH-LONG NGUYEN	2020-12-22
ÉCHELLE / SCALE	AS SHOWN	2020-12-22

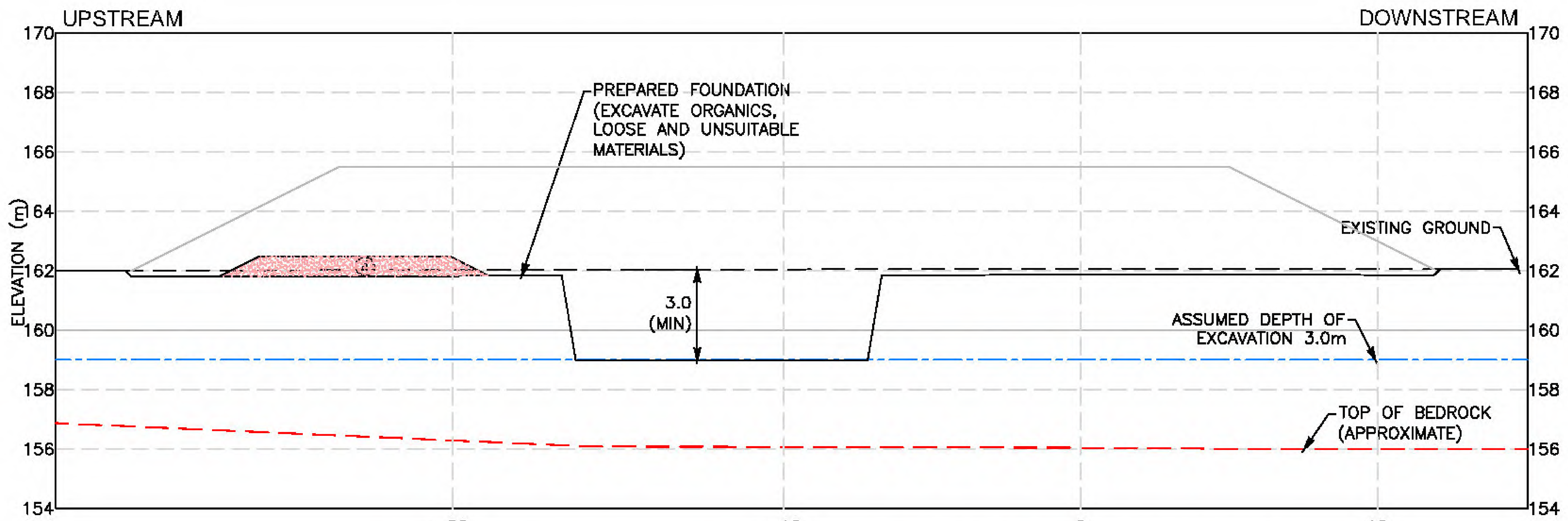
NO. DESSIN / DRAWING NO. 61-695-230-210

NO. PROJET / PROJECT NO.	REVISION	FEUILLE / SHT
6127	R0	1 / 1

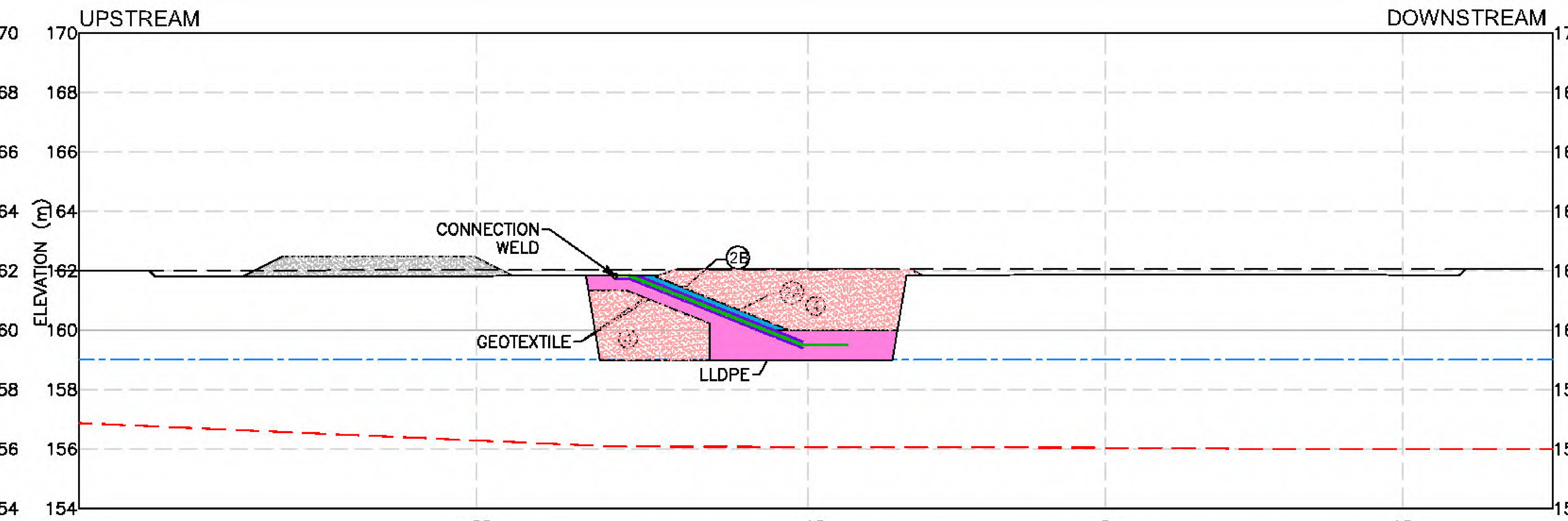
AE-CART-ARCH D

FILE NO.

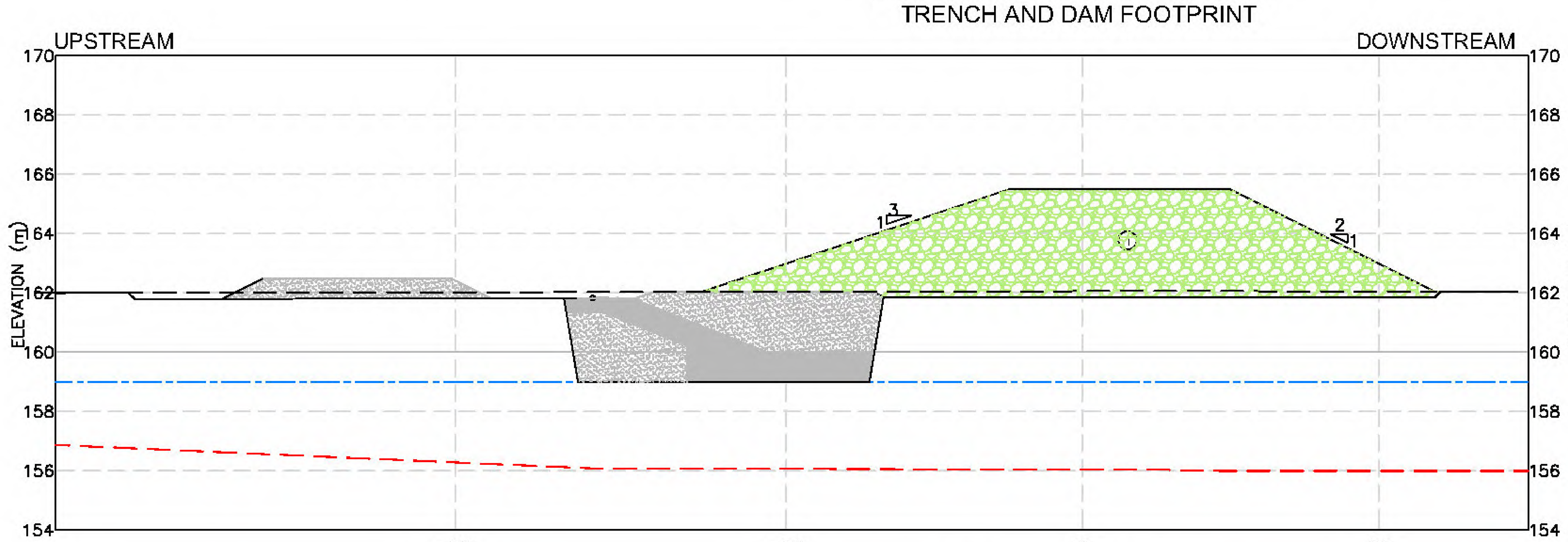
NO. DESSIN DRAWING NO. 61-695-230-211



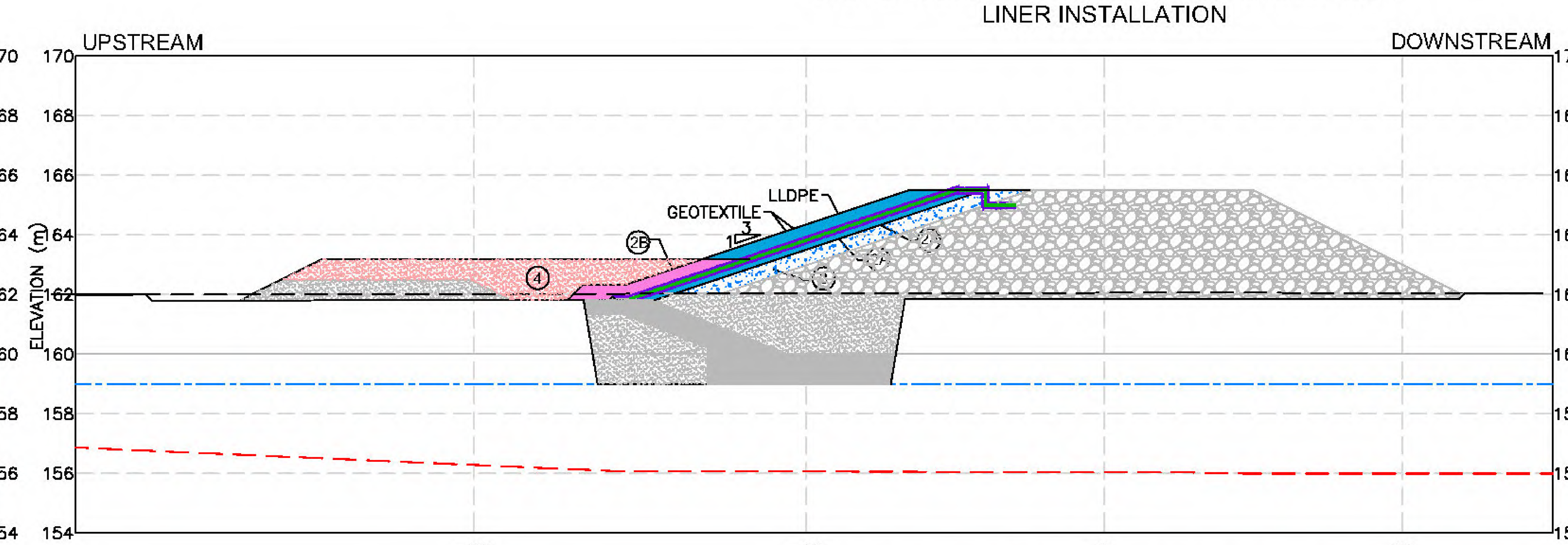
STEP 1 - EXCAVATION FOR CUTOFF TRENCH AND DAM FOOTPRINT



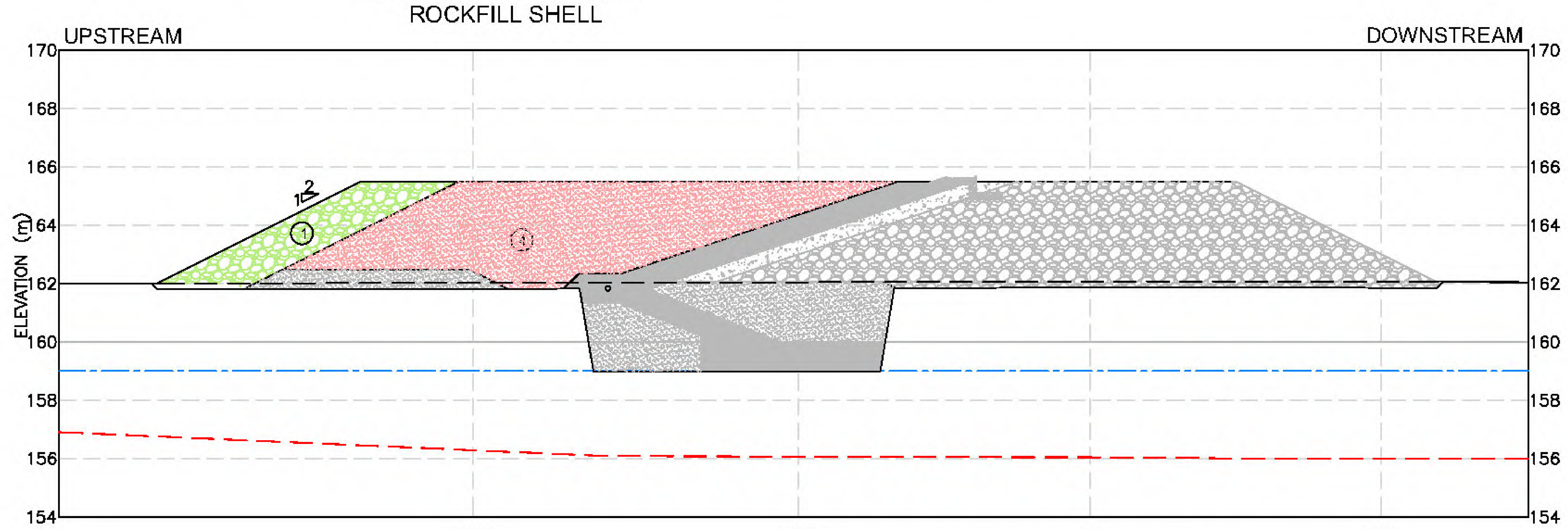
STEP 2 - CUTOFF TRENCH BACKFILL AND PHASE 1 LINER INSTALLATION



STEP 3 - DOWNSTREAM ROCKFILL SHELL



STEP 4 - UPSTREAM FILL MATERIAL AND 2ND PHASE LINER INSTALLATION



STEP 5 - UPSTREAM ESKER PLACEMENT AND ROCKFILL PROTECTION

LEGEND

- 1 ROCKFILL
- 2A FINE FILTER
- 2B FINE FILTER AMENDED BENTONITE
- 3 COARSE FILTER
- 4 ESKER
- LLDPE
- GEOTEXTILE

ISSUED FOR CONSTRUCTION

0 3 6 9m

SCALE= 1:150

PLAN CLÉ / KEY PLAN

SNC-LAVALIN
Mining & Metallurgy
5500, des Galeries Blvd., bur. 200, Quebec (Quebec), Canada G2K 2E
Telephone (418) 621-5500, Fax (418) 621-0087

PROJECT No	SUBDIVISION	SUBJECT	SERIAL	REV.
668284	5000	4G DD	0008	E00

NOTES GÉNÉRALES / GENERAL NOTES

NOTES:
1. THIS DRAWING SHOWS THE PROPOSED SEQUENCE OF THE IVR D-1 CONSTRUCTION.

DESSINS EN RÉFÉRENCE / REFERENCE DRAWINGS

TITRE / TITLE	# DWG

AGNICO EAGLE

REV.	DATE	DESCRIPTION	PAR/BY	APP.	CLIENT
R0	2020-12-22	ISSUED FOR CONSTRUCTION	M.S./N.Q.	A.L.N.	
RB	2020-11-16	ISSUED FOR CLIENT REVIEW	M.S./N.Q.	A.L.N.	

REVISIONS

PERMIT TO PRACTICE
SNC-LAVALIN INC.
Signature
Date 2020-12-22
PERMIT NUMBER: P 260
The Association of Professional Engineers, Geologists and Geophysicists of NWT/NU

TITRE / TITLE
AGNICO EAGLE – AMARUQ DIVISION
695 – WATER MANAGEMENT
230 – GENERAL EARTHWORKS

WMGI PHASE 2 – IVR D1 DYKE
CONSTRUCTION SEQUENCE SECTIONS

DESSINÉ PAR / DRAWN BY	MARK SYKES	DATE 2020-12-22
VÉRIFIÉ PAR / CHECKED BY	NINA QUAN \ PHILIP GOMES	2020-12-22
APPROUVÉ PAR / APPROVED BY	ANH LONG NGUYEN	2020-12-22
ÉCHELLE / SCALE	1:150	DATE 2020-12-22
NO. DESSIN / DRAWING NO.	61-695-230-211	
NO. PROJET / PROJECT NO. 6127	REVISION R0	FEUILLE / SHT 1 / 1

FORMAT ARCHD

FILE NO.