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Final Written Submission

Agnico Eagle Mine's In-Pit Tailings Disposal Modification (NIRB File No. 03MN107)

Natural Resources Canada

Submission to the Nunavut Impact Review Board

August 3, 2018

1. Introduction

Natural Resources Canada (NRCan) conducted a technical review to assess the completeness and technical merit of the information presented in Agnico Eagle Mine's In-Pit Tailings Disposal Modification. NRCan also considered the additional information provided by the proponent on June 26 and July 05, 2018 in response to direct requests for documents by NRCan. NRCan provided fifteen information requests for the Nunavut Impact Review Board (NIRB)'s consideration on July 9, 2018.

1.1. NRCan's Mandate

NRCan seeks to enhance the responsible development and use of Canada's natural resources and the competitiveness of Canada's natural resources products. We are an established leader in science and technology in the fields of energy, forests, and minerals and metals and use our expertise in earth sciences to build and maintain an up-to-date knowledge base of our landmass. NRCan develops policies and programs that enhance the contribution of the natural resources sector to the economy and improve the quality of life for all Canadians. We conduct innovative science in facilities across Canada to generate ideas and transfer technologies. We also represent Canada at the international level to meet the country's global commitments related to the sustainable development of natural resources.

1.2. NRCan's Participation in the review of the In-Pit Tailings Disposal Modification

NRCan has been participating in the review of the proposed In-Pit Tailings Disposal Modification in the context of our role as a federal department with expertise in permafrost and hydrogeology.

2. Specific Comments

2.1. Hydrogeology

2.1.1. Introduction

Agnico-Eagle Mines Limited (the proponent) operates the Meadowbank Mine, Nunavut, and has proposed to modify the storage of mine tailings at the site by disposing them in the Goose and Portage pits. Natural Resources Canada (NRCan) submitted Information Requests (IRs) to the Nunavut Impact Review Board (NIRB) on July 9, 2018 (NRCan, 2018). The proponent provided responses to these IRs on July 16, 2018 (AEM, 2018a). This report reviews these responses and provides technical comments and recommendations concerning hydrogeology to the NIRB.

2.1.2. References

AEM, 2018a. In-Pit Disposition. NR-CAN information request responses. 16 July 2018.

AEM, 2018b. In-Pit Disposition. Information request responses. 11 July 2018.

AEM, 2018c. Meadowbank Gold Project, Groundwater Monitoring Plan. Version 8, January 2018.

AEM, 2017a. Meadowbank Gold Mine, 2016 Mine Waste Rock and Tailings Management Report & Plan Update. November 2017 (Note: cover page indicates a date of November 2016 but subsequent footers and references in the document indicate 2017 dates).

AEM, 2017b. Updated NNL Calculations for Habitat Gains in Second and Third Portage Lakes. Technical memorandum from AEM to DFO. 17 November 2017.

Cumberland Resources Ltd., 2005. Meadowbank Gold Project, Mine Waste & Water Management, Final Report, October 2005.

Golder Associates Ltd., 2005. Technical Memorandum, Items #24A and 37 - Predictions of Regional Groundwater Flow Directions after mine Closure, Meadowbank. 05-1413-036A, October 5, 2005.

Golder Associates Ltd., 2004. Report on Hydrogeology Baseline Studies, Meadowbank Gold Project. 03-1413-078, February 3, 2004.

NRCan, 2018. Information Requests for Agnico Eagle Mine's In-Pit Tailings Disposal Modification (NIRB File No. 03MN107), Natural Resources Canada, Submission to the Nunavut Impact Review Board, July 9, 2018.

SNC-Lavalin, 2018a. Environmental Impact Study Review – Meadowbank In-Pit Tailings Deposition. Technical Note. 651196-0000-4EER-0001-B01 Rev 01, February 15, 2018.

SNC-Lavalin, 2018b. Groundwater Monitoring for In-Pit Tailings Deposition project – Meadowbank. Memorandum. 651196-3000-4WER-0002. July 3, 2018.

SNC-Lavalin, 2018c. In Pit Water Quality Assessment at Closure Technical Note. SNC No. 651196-2100-4EER-001 Rev. 00, 10 July 2018.

SNC-Lavalin, 2018d. Meadowbank-In-Pit Tailings Deposition Pit Lake Stratification Part B - Tailings Fine Resuspension Modelling. Memorandum. Ref. No. 651196-2100-4GCC-0002. 9 March 2018.

SNC-Lavalin, 2017a. Hydrogeological Modelling for In-Pit Deposition of Tailings. Technical Note. 643541-3000-4WER-0001 Rev A00, November 30, 2017.

SNC-Lavalin, 2017b. In-Pit Tailings Deposition Water Balance and Water Quality Forecast. Technical Note. 643541-5000-40ER-0002, Rev. B00. September 12, 2017.

SNC-Lavalin, 2017c. 2D ground thermal modeling – Portage In-Pit Deposition Prefeasibility Study. Memorandum. 643541-5000-4GCA-0002 Rev 01, September 20, 2017.

SNC-Lavalin, 2016a. In-Pit Tailings Deposition Concept. Tailings Storage Facility Extension Project – Phase 2, 637215-1000-4GER-0001. Version A00. November 4, 2016.

SNC-Lavalin, 2016b. Multiple Accounts Analysis for the Tailings Facility Extension Project. Technical Note. 637215-5000-4GER-0001. Version A00. October 24, 2016.

2.1.3. Technical comments and references

Review Comment Number	**NRCan-#1**
Original IR	NRCan-IR#1
Subject/Topic	Model extent
Summary	NRCan requested justification of the model extent and the decision not to extend the model to adjacent large lakes. The proponent asserts that the model extent is appropriate and indicated that this "is a site-scale model (width of 4 km). This modeling decision was made to simulate contaminant transport within the vicinity of the pits and to integrate the local conditions that were defined during the 10 years of operation of the Meadowbank Project." NRCan contends that extending the model to adjacent large lakes would ensure better estimates of the hydraulic heads and groundwater flow patterns in the sub-permafrost groundwater in the vicinity of the pits. The hydraulic heads imposed by the regional (sub-permafrost) groundwater flow system is an important control on vertical hydraulic gradients in the open talik.
Importance of issue to the impact assessment process	The issue of model extent is related to the issue of model boundary conditions (NRCan-IR#3). Ensuring appropriate model boundary conditions is one important element of developing the groundwater flow and transport models on which predictions of contaminant movement are based.
Detailed Review Comments	The proponent justifies excluding the adjacent lakes in the model because "Tehek Lake is not considered as a first potential receptor, compared to the Second Portage Lake and Third Portage Lake." Although NRCan agrees that Tehek Lake is not the first potential receptor, it notes that the primary reason to include the adjacent lakes is not to predict contaminant transport to Tehek Lake, but to ensure that appropriate hydraulic heads and flows directions are estimated in the sub-permafrost groundwater. NRCan notes that there are no measurements of sub-permafrost hydraulic heads; therefore, they must be estimated from the lake levels in surrounding large lakes (which are hydraulically connected to sub-permafrost groundwater via open talik). The hydraulic head pattern in the sub-permafrost groundwater is complex in the region surrounding the Meadowbank mine due to the varied elevation, size and distances of the adjacent lakes.
Recommendation/Request	NRCan recommends that the model be extended to adjacent lakes using large elements, since it allows the hydraulic heads in the sub-permafrost groundwater to be solved numerically, thereby taking into

	consideration the hydrogeological influence of varied lake sizes, elevations and distances. If the model is not extended, NRCan recommends that specified heads be assigned in the sub-permafrost groundwater according to the Golder (2004, 2005) results (i.e. around the domain, rather than just for two segments with specified heads and the remaining segments specified as no-flow boundaries). Furthermore, a sensitivity analysis on the specified heads in the sub-permafrost groundwater would be needed to assess their influence on groundwater flowpaths in the open talik and, in particular, on the vertical gradients and related vertical groundwater flow.

Review Comment Number	N/A
Original IR	NRCan-IR #2
Subject/Topic	Flow boundary descriptions
Summary	The boundary conditions have been described and this issue has been resolved.

Review Comment Number	**NRCan-#2**
Original IR	NRCan-IR #3
Subject/Topic	Justification of flow boundary descriptions
Summary	The proponent explained how each boundary condition was determined. The proponent concluded that "that regional groundwater flow was adequately reproduced by the site-wide model and does not need to be extended". NRCan observes that the discrepancies between the boundary conditions head values and the heads modelled by Golder (2004, 2005) has not been explained as requested. NRCan notes some of the potential implications of the specified boundary conditions.
Importance of issue to the impact assessment process	Ensuring appropriate model boundary conditions is an important element of developing the groundwater flow and transport models on which predictions of contaminant movement are based. In this model, the boundary conditions around the model exterior control the hydraulic heads and groundwater flow in the sub-permafrost groundwater flow system, which also influence the vertical groundwater flow patterns in the open talik.
Detailed Review Comments	3a) NRCan's IR indicated that the proponent and Golder (2004, 2005) head values do not match along the NW (135 m) boundary. The proponent explained how the value was calculated but did not justify the discrepancy with the Golder model results. NRCan notes that the proponent's boundary condition was oriented along a topographic ridge, which is unrelated to hydraulic heads in sub-permafrost groundwater. 3b) NRCan's IR stated that the Golder models (2004, 2005) showed sub-permafrost groundwater flow from the west beneath Third

	Portage Lake. The proponent stated that the boundary condition in the sub-permafrost groundwater beneath the lake is a no-flow boundary (NRCan-IR#2a). The proponent did not justify the boundary condition as requested, NRCan would appreciate a justification. 3c) The N-S oriented boundary condition (132.9 m) along Second Portage Lake is applied from the lake surface (top of the model) to the base of the model at -800 m. The proponent notes the small vertical gradient that results in the talik when no vertical gradient is specified on the model boundary conditions. This example demonstrates that the regional hydraulic gradient in the sub-permafrost groundwater can produce vertical hydraulic gradients in the talik. Sub-permafrost heads in the proponents' model range from 132.9 to 135 m (2.1 m head loss), whereas the same area in the Golder model has approximately twice the range in heads. 3d) The proponent presents a regional map with arrows, showing the regional groundwater flow directions. However, this map does not indicate groundwater contours (as do the Golder (2004, 2005) model results); the groundwater flow directions are not supported by data. Specifically, the arrow in Turn Lake (elevation 139.18 m) points towards Drill Trail Lake (elevation 137 m, not identified on map), even though there is a larger component of hydraulic gradient towards Second Portage Lake (elevation 132 m). In NRCan's opinion, the Golder (2004, 2005) interpretations of regional groundwater flow directions are more soundly based on data and modelling results. The boundary conditions in the proponent's models are different than those determined by Golder's regional groundwater modelling (2004, 2005). The consequences are that regional groundwater flow directions in the sub-permafrost groundwater are different in both sets of models. There are only two specified boundary conditions in the sub-permafrost groundwater flow system of the proponent's model which result in NW to SE sub-permafrost groundwater flow. A further consequence is that sub-permafrost hydraulic heads also differ from the Golder (2004, 2005) models, which may influence vertical hydraulic gradients within the open talik.
Recommendation/Request	NRCan finds that the proponent has not adequately justified the exterior boundary conditions for their models. The differences between the proponent's specified boundary conditions and the hydraulic heads modelled by Golder (2004, 2005) have the potential to influence some of the proponent's model results. NRCan's recommendations to the NIRB for this issue are as stated in relation to NRCan-IR#1: i) a preference to extend the model to adjacent lakes, or ii) if the model is not to be extended, to vary the sub-permafrost boundary conditions to reflect the entire range of boundary conditions implied by Golder (2004, 2005) model results and use a sensitivity

	analysis to assess their impact on vertical groundwater flow in the open talik.

Review Comment Number	**NRCan-#3**
Original IR	NRCan-IR #4
Subject/Topic	Extent of the permafrost in the groundwater model
Summary	The proponent indicated that the permafrost extent in Figure 21 provides a “good indication of permafrost limits” for the contaminant transport models. NRCan disagrees that the extent of permafrost shown in Figure 21 is suitable for the contaminant transport modelling of post-closure scenarios and dis agrees that the proponent has justified this extent of permafrost. In NRCan’s opinion, the specified extent of permafrost prevents contaminant transport from Portage Pit E to the Second Portage Lake and significantly delays contaminant transport from Portage Pit A to the Second Portage Lake.
Importance of issue to the impact assessment process	The extent of permafrost is of utmost importance to the groundwater flow and contaminant transport modelling since permafrost is considered impermeable and, therefore, is excluded from the groundwater models. Groundwater flow (and, therefore, contaminant transport) can only occur within the non-permafrost portions of the model and are influenced by the distribution of permafrost. These models are the basis for the proponent’s main conclusion of contaminant transport results over 2500 years. Therefore, the extent of permafrost directly affects the proponent’s assessment of travel times to Second Portage Lake and anticipated project impacts.
Detailed Review Comments	The proponent indicated that the permafrost extent shown in Figure 12 was only used for model calibration. “For contaminant transport simulations permafrost was removed inside each pit shell.” In response to a request to provide a map showing the extent of permafrost and talik for a post-closure scenario, the proponent stated that “Figure 21 of the PFS report provides a good indication of permafrost limits.” The proponent further indicated that since only 40 m of permafrost degradation was anticipated after 100 years and that the model mesh “was about that size”, the degradation was not included in the contaminant transport simulations. NRCan points out that the proponent’s contaminant transport modelling of Scenarios 3 and 4 assesses post-closure conditions. Scenario 3 was modeled to 2500 years and Scenario 4 to 6000 years (SNC-Lavalin, 2017). The results of Scenario 3 are the basis for the report’s main conclusion of maximum contaminant transport distance over 2500 years. It appears that the proponent has not assessed the change in permafrost extent that will occur over the post-closure period and that this extent has not been included in contaminant transport scenarios.

	In response to NRCan-IR#1, the proponent indicated that "This modeling decision was made to simulate contaminant transport within the vicinity of the pits and to integrate the local conditions that were defined during the 10 years of operation of the Meadowbank Project." Furthermore, 2D ground thermal modelling was only extended to "about a 100 years after tailings deposition" (SNC-Lavalin, 2017b). NRCan notes the absence of any permafrost predictions or estimates applicable to the post-closure period. The impact that an inappropriate permafrost extent can have on the assessment of contaminant transport is demonstrated for Portage Pit E. Figure 21 shows that there is a continuous barrier of permafrost on the north side of Portage Pit E. Although permafrost may have been present there prior to and during mining, this area will be flooded during post-closure conditions and, therefore, will be expected to thaw rapidly (as demonstrated in the thermal modelling). As noted in Figure 2 of the fish habitat compensation report (AEM, 2017b), the water depth in this area will be in excess of 4 m, which would further suggest the development of an open talik in this area. However, because the permafrost is present on the north end of Portage Pit E, there can be no groundwater flow and no contaminant transport from Portage Pit E directly to Second Portage Lake. Therefore, contaminant transport cannot be assessed along this pathway. Instead, groundwater contaminant transport is assessed along the southern end of Portage Pit E between the pit and the Third Portage Lake (SNC-Lavalin, 2017a, Figure 27), for which there is minimal groundwater flow because the pit and lake will have the same water level in the post-closure period. Similarly, the presence of permafrost also affects the assessment of post-closure contaminant transport from Portage Pit A to Second Portage Lake. Figure 21 shows the presence of permafrost that wraps around the SE end of Portage Pit A and blocks the shortest and most direct flowpath between the pit and the lake. This area of permafrost will also be flooded during post-closure with a water depth of greater than 4 m (AEM, 2017b, Figure 2), such that the permafrost will thaw. Contaminant transport is assessed from the SW corner of Portage Pit A to Second Portage Lake (Figures 25 and 26, SNC-Lavalin, 2017a), whereas a more direct pathway with higher hydraulic gradients from the SE corner of Portage Pit A to Second Portage Lake should be assessed in the absence of the excessive permafrost. NRCan does not accept the proponent's results for contaminant transport modelling results for post-closure conditions (Scenarios 3 and 4) because of the incomplete assessment of permafrost conditions for the post-closure conditions and because of the substantial effect of permafrost extent on the modelling results. Consequently, NRCan cannot find itself in agreement with the proponent's assessment of impacts.

Recommendation/Request	NRCan recommends that the NIRB not accept the SNC-Lavalin (2017a) contaminant transport modelling results for post closure scenarios because the assessment of permafrost conditions for the post-closure conditions remains incomplete and because of the substantial effect of permafrost extent on the modelling results. NRCan recommends that the permafrost extent be delineated for post-closure conditions. The permafrost extent should be mapped for several model layers to indicate the distribution of thawed permafrost with depth. The delineation of permafrost should be justified either by thermal modelling or by making assumptions to delineate a "worst case" scenario of permafrost thawing. NRCan recommends to the NIRB that the post-closure permafrost extent be used for updated groundwater modelling of post-closure conditions (as described in NRCan-IR#12).

Review Comment Number	**NRCan-#4**
Original IR	NRCan-IR #5
Subject/Topic	Waste rock and tailings within pits
Summary	The proponent provided an estimate of hydraulic conductivity of waste rock material deposited in the Goose Pit (Goose Dump) and of tailings from in-pit deposition.
Importance of issue to the impact assessment process	The high hydraulic conductivity of the waste rock material in the Goose Dump will provide a preferred vertical flowpath inside the Goose Pit. The Goose Dump could affect hydraulic head patterns and groundwater flowpaths within and surrounding the Goose Pit.
Detailed Review Comments	The proponent has assumed a hydraulic conductivity of the waste rock material of 10^{-3} m/s applicable to both the Central Dump and Goose Dump. The proponent does not expect this to change post-closure contaminant transport results because the Goose Dump is contained within the Goose Pit and is surrounded by lower hydraulic conductivity bedrock. A hydraulic conductivity of 10^{-7} m/s is used for the tailings based on laboratory results. Given the proponent response, NRCan assumes that the waste rock material was not included in the proponent's models. NRCan agrees that adding the waste rock to the *current* model would probably have a minimal effect on the contaminant transport from the Goose Pit towards Portage Pit E (Scenario 1) or towards the Third Portage Lake on the other side of the dike (Scenario 3). However, it is not clear what effect the presence of the Goose Dump may have on the vertical gradients and flowpaths within Goose Pit. The Goose Dump could affect the groundwater flowpaths between the tailings deposited in the Goose Pit and the Third Portage Lake (overlying the Goose Pit).
Recommendation/Request	Although this issue is not a critical issue with respect to the assessment of contaminant transport, NRCan nonetheless

	recommends that the higher hydraulic conductivity values of the Goose Dump be included in any subsequent groundwater simulations of the Meadowbank site (for times after the waste rock was deposited).

Review Comment Number	**NRCan-#5**
Original IR	NRCan-IR #6
Subject/Topic	Water level controls during in-pit deposition periods
Summary	The proponent provided information on the timing, levels and water transfers related to the South Cell tailing, the pits, and the flooding by Third Portage Lake. NRCan is satisfied with the additional information and notes an inconsistency.
Importance of issue to the impact assessment process	The additional information was requested to better understand the controls on water levels, as well as the timing and predicted levels in order to assess the boundary conditions in the models and the potential effects of the seepage into the Central Dike D/S Pond.
Detailed Review Comments	The proponent indicated that Central dike seepage rates should decrease and then stop tailings and that South Cell tailings will take approximately 10 years to freeze. This is similar to the timeframe for the in-pit tailings deposition (8 years). NRCan seeks to ensure that residual seepage from the South Cell tailings does not influence contaminant migration from the Portage pits. In response to NRCan-IR#6a iv) the proponent has indicated. "Flooding of the pit will reduced also hydraulic head in between South Cell TSF and Portage Pit. Seepage rate, if still observed, will be low." NRCan notes that the meaning of this response is not clear. The proponent noted that the target water level in the pits at the end of Period 4 is approximately 131.6 masl, or 2 m below the Third Portage Lake level. They also indicated that the water levels in the pits will not be permitted to flood beyond the extent of the Goose, Portage A and E pits prior to reconnection. NRCan does not understand how it is possible to achieve a water level of 2 m below the Third Portage Lake level without flooding the areas surrounding the pits. As shown in Figure 2 of AEM (2017b), the pit areas and the areas surrounding the pits are anticipated to have a water depth of > 4 m below the Third Portage Lake. Allowing the pit water levels to rise to 131.6 m would likely flood the areas surrounding the pits. The proponent agreed that "Groundwater contamination simulations should have been assigned to Period 5, right after the end of deposition." NRCan notes that the boundary conditions are, indeed, closer to those of Period 5 when the dikes have not been breached to those of Period 6 when the dikes have been breached.
Recommendation/Request	NRCan recommends that the proponent should clearly state the anticipated pit water levels during Periods 4 and 5 and resolve the

	apparent contradictions between pit water levels and flooding of the areas surrounding the pits. The proponent should state when the area surrounding the pits will be flooded and whether this will result from natural drainage or pumping, or breaching of the dikes. NRCan recommends that "post-closure" groundwater contaminant simulations towards Second Portage Lake should begin when pit water levels exceed those of the Second Portage Lake.

Review Comment Number	**NRCan-#6**
Original IR	NRCan-IR #7
Subject/Topic	Tailings as a contaminant source
Summary	The initial simulations assume the contaminant source is in the first 6 layers of the model. The proponent has provided new contaminant transport simulations that assume the entire pit shell is a contaminated source (AEM, 2018a). The simulations appear to provide similar results regarding concentration and time to reach receptors. NRCan also considers the results of these new simulations unacceptable because of the incorrect distribution of permafrost, as discussed in NRCan-IR#4.
Importance of issue to the impact assessment process	It is important to distinguish between the tailings as a potential source of contamination and not just the reclaim water. Reclaim water will be treated, whereas the water in the tailings will not. Therefore, it is important to evaluate the potential for all tailings to contaminate surface water explicitly.
Detailed Review Comments	The initial simulations assume the contaminant source is in the first 6 layers of the model. The proponent has provided new contaminant transport simulations that assume the entire pit shell is a contaminated source (AEM, 2018a). The simulations show that a deeper contamination plume is observed, but the concentration and time to reach the receptors remains the same. The proponent notes that the assumptions about the source are conservative. The point of this IR was to ensure that the tailings are considered a potential source of contaminants. NRCan notes that such an assumption was easily included in the model to produce updated simulations. Although the proponent has indeed, used conservative assumptions for the concentration source, the extent of permafrost is identical to previous simulations, which remains problematic as discussed in NRCan-IR#4. Ensuring the entire tailings are considered a potential source of contaminants is particularly relevant in assessing the potential for tailings to contaminate the overlying water in Third Portage Lake when the pits are flooded.
Recommendation/Request	NRCan recommends that the entire extent of tailings should be included in any subsequent groundwater simulations of the Meadowbank site.

Review Comment Number	NRCan-#7
Original IR	NRCan-IR #8
Subject/Topic	In-pit deposition periods and contaminant transport scenarios
Summary	The proponent suggests that contaminant transport simulations represent “worst case” scenarios. NRCan disagrees with their assessment of “worst case” scenarios. NRCan concludes that the contaminant transport scenarios presented by the proponent do not adequately simulate the post-closure conditions and, therefore, cannot be relied upon for assessment of post-closure impacts.
Importance of issue to the impact assessment process	The assessment of hydrogeological impacts on in-pit deposition relies heavily on the predictions made using contaminant transport simulations, in particular Scenario 3 for the post-closure period. Ensuring that the models have been developed to simulate the conditions present during post-closure is essential to rely on the model results for assessing potential impacts.
Detailed Review Comments	Contaminant transport modelling Scenario 1 presents a 2-year simulation of transport from the Goose Pit, showing a plume velocity of about 25 m/year. This suggests that the plume may migrate “over 200 m toward Pit E after 8 years, without reaching it”. However, the value of this simulation is not put to any practical use since there is no evaluation of what happens to this plume during Periods 4 through 6 from pit closure, through monitoring and post-closure. Initial conditions for Scenario 3 (post-closure) modelling of Goose Pit assumes all the contaminant plume is contained within the pit area. As noted in NRCan’s IR#8, contaminant transport modelling Scenario 2 does not appear to correspond to any specific tailings deposition periods. Scenario 2 assumes Portage Pit A and Goose Pit are filled with tailings, whereas Portage Pits A and E are to be filled alternately. The proponent suggests that the simulation “presents a worst case” of Period 3. NRCan notes that Scenario 2 assumes that Portage Pit A is filled to an elevation of 125.8 m (SNC-Lavalin, 2017a), yet the response to NRCan-IR#8b (v) indicates that “the hydraulic head at Pit A location is 116 masl”. This condition would leave the uppermost tailings unsaturated, which is not part of the management plan. Considering that the Central Dike D/S pond seepage face is set at 115 m, only 1 m below the head of Portage Pit A, the hydraulic gradient between Portage Pit A and the Central Pond is not at its maximum and would not represent the “worst case” for contaminant transport during this period. As noted in NRCan’s IR submission and within this review, the contaminant transport simulations of Scenarios 3 and 4 do not

	adequately represent the post-closure conditions implied by the long time duration of the simulations. Firstly, the permafrost conditions do not represent those expected to develop following flooding of the pits and surrounding areas (NRCan-IR#4). Secondly, the simulations have not specified boundary conditions at the model surface that are representative of conditions during post-closure conditions. In response to NRCan's IR#8c regarding the boundary conditions and pit levels during post-closure, the proponent responded "Not having a fixed head on the flooded pit areas is based on: • Water from the tailings deposition does not represent groundwater level. • If a constant head had been fixed on Portage Pit A and Goose Pit during the Portage Pit E dewatering (Scenario 2), all of the water drained by Pit E would have come from Pit A and Goose Pit." This response does not address Scenarios 3 and 4 or the post-closure period. The proponent confirmed that the constant head value of 132.9 m was only applied to the surface of the lake at the exterior SE boundary of the model. This contradicts the stated boundary conditions in SNC-Lavalin (2017a, p. 21 and Figure 12), which indicates that the entire lake has a constant head boundary condition. This has the effect of reducing the hydraulic head at the edge of the Second Portage Lake adjacent to the East Dike. Consequently, the hydraulic gradients are substantially under-estimated, as are the groundwater velocities and the estimates of contaminant transport to the Second Portage Lake. NRCan-IR#8f) specifically requested that the proponent justify the permafrost extent at the north of Portage Pit E for *post-closure* modelling (i.e. Scenarios 3 and 4). The response stated that: "- This zone was initially frozen; - It is at the limit of Central Dump (material very permeable to air) which was supposed potentially frozen on the surface; - The hydrogeological field investigation held in Summer 2017 (borehole IPD-17-08) confirmed that the upper part of Central Dump was frozen which supports our choice of the PFS to have maintained this contact frozen" This response only considered the past and present conditions; it does not address the long term thawing that will occur because of flooding. The response does not justify permafrost conditions for 2500 or 6000 years. Furthermore, the extent of permafrost does not represent a "worst case" scenario. In response to the error noted in Figure 25 (NRCan-IR#8d), the proponent corrected the figure and noted that "permafrost does exist

	beneath the pits". This further demonstrates that, although open talik should be expected to develop beneath flooded pits during post-closure, it has not been included in the contaminant transport models. The responses to NRCan's IR#8 do not provide satisfactory justification of the contaminant transport modelling scenarios. In NRCan's opinion, the contaminant transport simulations cannot be relied upon to assess potential contaminant transport during the post-closure period.
Recommendation/Request	NRCan's opinion is that the contaminant transport simulations presented by the proponent cannot be relied upon to assess potential contaminant transport during the post-closure period. NRCan recommends that current hydrogeological modelling be considered insufficient for the assessment of potential effects. NRCan recommends that the groundwater model be updated using revised scenarios, permafrost extent and boundary conditions that appropriately represent expected conditions at the site (see NRCan-#11).

Review Comment Number	**NRCan-#8**
Original IR	NRCan-IR #9
Subject/Topic	Assessment of contaminant migration to Third Portage Lake
Summary	The proponent referred to responses provided to IR ECCC#1b, IR ECCC#3a and IR ECCC#3c and noted that "Feflow Software do not allow to couple groundwater and surface water modelling." NRCan notes that none of these responses specifically addresses the potential for contaminant migration from the tailings to overlying surface water due to groundwater flow. NRCan's opinion is that updated hydrogeological modelling could be used to assess this possible contaminant transport pathway.
Importance of issue to the impact assessment process	The proponent is proposing to have mine tailings in direct contact with the Third Portage Lake. The Third Portage Lake is the closest receptor to the tailings and the flooded pit; surrounding areas are intended to become fish habitat. Groundwater flow and diffusion could transport contaminants from the tailings to the overlying lake.
Detailed Review Comments	NRCan requested an assessment of potential discharge of contaminated groundwater from the tailings to the overlying surface water following the breaching of the dikes and the flooding of the pits, in addition to a justification for not using the hydrogeological modelling to assess potential contaminant transport to the overlying Third Portage Lake. The proponent response to ECCC#1b refers to the results of sediment resuspension modelling (SNC-Lavalin, 2018d). NRCan was clearly referring to hydrogeological modelling and this response does not address NRCan's IR#9.

	IR ECCC#3a requests "a rationale for the 8m water cover depth." The proponent response again references the sediment resuspension study (SNC-Lavalin, 2018d). The proponent response does not address NRCan's IR#9. The proponent response to ECCC#3c refers to the results of surface water quality modelling of the pits before and after reconnection to the Third Portage Lake (SNC-Lavalin, 2018c). Three scenarios are modelled, including two scenarios that include "mass flux rates and associated 1st order decay constants" that are meant to represent tailings consolidation and diffusion from the tailings pore water. There is no specific consideration of the movement (advection) of contaminants due to groundwater flow. Sediment consolidation will initially be large and decrease over time, whereas groundwater flow through the tailings will persist. Vertical groundwater flow in the open talik will also flow through the in-pit tailings. Vertical groundwater flow will occur preferentially in the tailings (or in the waste rock deposited in the pits) because the tailings are more permeable than the surrounding bedrock. NRCan notes that the hydraulic heads in the sub-permafrost groundwater system will influence vertical gradients in the open talik. The hydraulic heads are not measured and are estimated in the Golder (2004, 2005) regional groundwater models. Consequently, the magnitude and direction (upward or downward) of groundwater flow through the tailings are not well defined. NRCan IR#9b) did not suggest that the proponent prepare a coupled surface water-groundwater model. FEFLOW can be used to model the groundwater flow to the top of the tailings (i.e. the model boundary). The boundary fluxes (water and potential contaminants) from the tailings into the surface water can be calculated and either compared or integrated into surface water quality modelling. The proponent has not assessed the potential flux of contaminants to the lake due to groundwater flow. In NRCan's opinion, an updated hydrogeological model could be used to assess the possible range of mass flux to the lake due to advection and dispersion (which includes diffusion).
Recommendation/Request	NRCan recommends that the proponent use updated groundwater modelling to assess the potential for groundwater flow through the tailings to transport contaminants to surface water overlying the tailings. If significant, groundwater contaminant fluxes could be integrated into surface water quality modelling.

Review Comment Number	**NRCan-#9**
Original IR	NRCan-IR #10
Subject/Topic	Groundwater monitoring following dike breaching
Summary	NRCan requested information concerning the duration, frequency and locations of groundwater monitoring during the post-closure periods after the pits are flooded. The proponent indicated it will review the frequency of groundwater sampling and will continue sampling at post-closure. NRCan makes some observations concerning the current and proposed groundwater monitoring.
Importance of issue to the impact assessment process	Adaptive management of potential groundwater contaminant migrations requires an effective groundwater monitoring plan with strategically positioned groundwater monitoring wells and an appropriate frequency of groundwater monitoring.
Detailed Review Comments	NRCan requested information concerning the duration, frequency and locations of groundwater monitoring during the post-closure periods after the pits are flooded. NRCan noted in its IR that the proponent's proposed groundwater monitoring frequency would decrease during the post-closure period at a time when groundwater contaminants were just starting to migrate towards the Second Portage Lake. The proponent did not provide any specific information, but indicated it will review the frequency of groundwater sampling and will continue sampling at post-closure. NRCan is concerned that some groundwater monitoring wells may be lost when the pits and surrounding areas are flooded. The proponent indicated that "construction of jetties and extension of the monitoring well above lake water elevation could be done after pit flooding to pursue groundwater monitoring activities". The proponent also referred to IR ECCC#5b, which indicates that "The 3D hydrogeological model was used to locate each new monitoring wells in the predicted groundwater flow paths in talik areas from the pits to the lakes." and that "New monitoring wells have been installed close to the pits for "warning" purpose, to indicate contaminant traces, if it occurs, before they reach the lakes". The response to IR ECCC#5a indicates that the depths of six existing groundwater monitoring wells are between 50 and 180 m deep. NRCan notes that the hydrogeological modelling results reported in Figures 26, 28 and 30 show the peak concentrations to be shallower; predicted concentrations at the measurement depths are much lower. Consequently, the effectiveness of these groundwater monitoring wells as sentinels of groundwater contamination will need to be reassessed.
Recommendation/Request	NRCan recommends that the NIRB seek commitments from the proponent to ensure sufficient, relevant groundwater monitoring into

	the post-closure period to observe potential groundwater contaminant migration caused by flooding of the pits and surrounding areas. NRCan recommends that updated groundwater modelling (NRCan-IR#12) be used to assess the predicted breakthrough curves of groundwater contaminants at existing monitoring wells and assess the suitability of these wells which may be too deep to serve as sentinels of groundwater contamination.

Review Comment Number	**NRCan-#10**
Original IR	NRCan-IR #11
Subject/Topic	High permeability near the Central Dike
Summary	The proponent indicated that the upper bedrock is responsible for the high groundwater flow beneath the Central Dike. NRCan comments on the potential implications of the uncertainty in upper bedrock and fault zone hydraulic conductivity.
Importance of issue to the impact assessment process	The predictions of contaminant migration are based on estimated values and distributions of hydraulic conductivity. The uncertainty in hydraulic conductivity leads to uncertainty in the modelling results. The high permeability beneath the Central Dike could occur elsewhere and result in higher groundwater flow (and contaminant migration) velocities than predicted.
Detailed Review Comments	The high permeability beneath the Central Dike has resulted in much higher than expected groundwater flows and pumping, and, ultimately, a recommendation from the Dike Review Board to deposit tailings in the pits rather than in the South Cell. These are actual consequences that result from the uncertainty in the hydraulic conductivity. The proponent indicated that “multiple field investigations, instrumentation analysis and review” were used to establish that the upper bedrock is responsible for the high groundwater flow beneath the Central Dike. The proponent stated that “contamination transport through till and fracture bedrock could lead to superficial migration, whereas transport through Second Portage Fault could lead to deeper contaminant migration located along the fault plane.” The proponent also indicated that the sensitivity analysis showed that doubling the hydraulic conductivity of the faults had no major impact on Central Dike seepage. NRCan notes that the hydraulic conductivity of the upper bedrock in the Central Dike region was specified to be more than two orders of magnitude higher than that of the faults, so no significant difference in modelled flow rates would be expected given the assigned values. Other evidence would be required to demonstrate that the high permeability occurs in the upper fractured bedrock and not the Second Portage Fault. The calibrated hydraulic conductivity of the upper bedrock in the Central Dike area is four orders of magnitude (10 000 times) higher

	than that of weathered bedrock at comparable depths in the rest of the model (SNC-Lavalin, 2017a, Table 8) and 17 times greater than the maximum reported measured hydraulic conductivity in bedrock for Meadowbank (SNC-Lavalin, 2017a, Table 2). This value of hydraulic conductivity is also more than three orders of magnitude higher than the highest value used in the Golder (2004, 2005) models. Hydrogeological models generally use some form of averaged hydraulic conductivity. The range of hydraulic conductivity for the upper bedrock greatly exceeds the two-fold increase in hydraulic conductivity used in the groundwater flow sensitivity analysis. A sensitivity analysis on transport parameters (effective porosity and dispersivity) was also performed (SNC-Lavalin, 2017a, Section 10.3). However, the variations in contaminant transport migration resulting from these parameters is likely much smaller than the sensitivity related to the uncertainty in upper bedrock hydraulic conductivity. Updated modelling should include a sensitivity analysis of contaminant transport modelling results to the uncertainty in upper bedrock hydraulic conductivity. A tenfold variation in hydraulic conductivity would be more appropriate for such an analysis. Given the uncertainty in upper bedrock hydraulic conductivity, the results of contaminant transport modelling should be interpreted with caution. If higher upper bedrock hydraulic conductivity also exists elsewhere in the region, groundwater contaminant velocities could be much higher than predicted.
Recommendation/Request	Unexpectedly high seepage rates beneath the Central Dike should be regarded as a warning that hydrogeological predictions at the Meadowbank site are subject to the uncertainty in upper bedrock hydraulic conductivity. NRCan recommends to the NIRB that updated hydrogeological modelling (NRCan-IR#12) should include a sensitivity analysis of contaminant transport modelling results to a tenfold variation in upper bedrock hydraulic conductivity.

Review Comment Number	**NRCan-#11**
Original IR	NRCan-IR #12
Subject/Topic	Updated hydrogeological modelling
Summary	NRCan suggested that IRs #1, 3, 4, 5, 7, 8 and 9 could be addressed by updating the hydrogeological modelling. The proponent disagrees with NRCan’s request and does not consider that an update of the hydrogeological modelling is required. NRCan disagrees with the proponent’s response. NRCan recommends to the NIRB that current hydrogeological modelling be considered insufficient for the assessment of potential effects and that updated hydrogeological modelling is required.
Importance of issue to the impact assessment process	The assessment of hydrogeological impacts on in-pit deposition relies heavily on the predictions made using contaminant transport

	simulations, in particular Scenario 3 for the post-closure period. Ensuring that the models have been developed to simulate the conditions present during post-closure is essential to rely on the model results for assessing potential impacts.
Detailed Review Comments	From NRCan-IR#12a. The proponent states that their model i) reproduces groundwater flow and vertical gradients and ii) ensures a conservative approach. As noted in comments for NRCan-IR#1 and #3, the groundwater flow regime produced by the proponent differs in groundwater flow directions and hydraulic heads to those modelled by Golder (2004, 2005). Only two constant head boundaries are specified in the sub-permafrost groundwater system and these determine sub-permafrost groundwater flow and hydraulic heads. The Golder results (2004, 2005) indicate that the sub-permafrost groundwater flow system is more complex. The proponent suggests that the *presence* of vertical gradients in Figure 20 is evidence that the model *reproduces* vertical hydraulic gradients. NRCan disagrees and notes that the vertical hydraulic gradients implied by the Golder (2004, 2005) results are different than those implied by the proponent's modelling. The proponent's "conservative approach" is justified by: • focusing on the study objective "to simulate contaminant transport to immediate receptors"; • "We think that with fixed heads on the entire lake areas, it would not be possible to reproduce adequately, and in conservative approach, the contaminant transport, since the model will be too constraint"; • "although we think that the Golder's model allows sub-permafrost groundwater gradients reproduction, it would not allow the direct simulation of contaminant transport towards Second Portage Lake, as adequately reproduce by the SNCL model." In NRCan's opinion, none of these statements justify that the proponent is using a conservative approach. The first statement discusses the study objective and not any model assumptions, and ignores that the purpose of extending the model is to simulate correctly the complex boundary conditions and sub-permafrost hydraulic heads. The second statement is difficult to understand, but seems to attempt to justify why constant head boundaries were not used on lake surfaces. As noted in response to NRCan-IR#8, the consequence is to reduce hydraulic gradients towards the lake and increase the travel times, which is inconsistent with a conservative assumption. The third statement is not related to the "conservative" nature of a model but instead supports NRCan's position that the Golder (2004, 2005) model allows sub-permafrost groundwater heads and gradient reproduction.

	12b) NRCan refers to the comments for NRCan-IR#4 and NRCan-IR#8 that discuss the post-closure distribution of permafrost used in the contaminant transport modelling. NRCan emphasizes that this issue alone is sufficient to require updated groundwater modelling; modelling with the assumption of impermeable permafrost in areas where it may not exist in reality can invalidate the model. 12c) NRCan refers to the comments for NRCan-IR#5. 12d) NRCan refers to the comments for NRCan-IR#7. 12e) As justified in NRCan-IR#8, NRCan concludes that the contaminant transport scenarios presented by the proponent do not adequately simulate the post-closure conditions and, therefore, cannot be relied upon for assessment of post-closure impacts. In an attempt to clarify NRCan's expectations, NRCan provided a suggested modelling scenario for Goose Pit (NRCan-IR#12e i). The proponent states that "simulations results (Scenario 1) have not shown an extensive migration during this period and thus, we did not see the benefit of using this scenario as an initial source at post-closure period." However, NRCan notes in NRCan-IR#9 that the proponent has not assessed the potential for groundwater contaminant migration to the overlying Third Portage Lake during the post-closure period. If there is a pre-existing plume that extends beyond Goose Pit, then this plume should be used as an initial condition for assessing groundwater contaminant migration. NRCan also presented recommendations for post-closure modelling of all pits (NRCan-IR#12e ii). NRCan also refers to the comments for NRCan-IR#8. The proponent indicates that "as no water treatment was assumed at closure to evaluate worst case scenario for contaminant transport and surface water quality modeling, the report presents this situation as dike are not breached as water quality to not meet surface water quality objective as per Licence 2AM-MEA 1525, Part E Item 7 condition." NRCan does not fully understand how the proponent is attempting to justify a conservative approach here. It appears that they are trying to suggest that, by assuming no treatment of surface water, the model simulations are conservative. The hydrogeological model is simulating groundwater flow and transport, the contaminant source is in the tailings, and the modelling is generic (assuming an arbitrary concentration of 100 mg/L); therefore, NRCan's opinion is that an assumption related to surface water (treated or not) does not produce conservative groundwater flow simulation results.

Recommendation/Request	NRCan recommends to the NIRB that the current hydrogeological modelling be considered insufficient for the assessment of potential effects. NRCan recommends that the Proponent update the hydrogeological modelling. NRCan recommends that the following elements be included in the updated hydrogeological modelling: a) Use an updated post-closure extent of permafrost and talik for simulations of post-closure scenarios (NRCan-IR#4). b) Update the boundary conditions on the Second and Third Portage Lakes and pits to represent the actual post-closure hydraulic heads in the model (NRCan-IR#8). Specifically, i) the entire surface and water body of the Second Portage Lake should be a specified head equal to lake level; ii) the entire surface and water body of the Third Portage Lake, including the entire water body of the flooded area inside the dikes following their flooding, should be a specified head equal to lake level. c) Update the boundary conditions on the sub-permafrost groundwater (NRCan-IR#1 and NRCan-IR#3). As noted in NRCan-IR#1, this could be accomplished using two approaches: i) the model can be extended to adjacent lakes using large elements since it allows the hydraulic heads in the sub-permafrost groundwater to be solved numerically, thereby taking into consideration the hydrogeological influence of varied lake sizes, elevations and distances. This is NRCan's preference as it removes more uncertainty in sub-permafrost boundary conditions than does approach ii). ii) If the model area is not extended, NRCan recommends that specified heads be assigned in the sub-permafrost groundwater according to the Golder (2004, 2005) results (i.e. around the domain, rather than just for two segments with specified heads and the remaining segments specified as no-flow boundaries). Furthermore, a sensitivity analysis on the specified heads in the sub-permafrost groundwater is recommended to assess their influence on groundwater flowpaths in the talik and, in particular, on the vertical gradients and related vertical groundwater flow. d) Conduct a sensitivity analysis of contaminant transport scenarios by varying the hydraulic conductivity of the upper bedrock hydraulic conductivity (NRCan-IR#11). A tenfold variation in hydraulic conductivity is recommended in NRCan-IR#11. e) Assess the potential for groundwater contaminant transport from the tailings into the overlying Third Portage Lake during the post-closure period as a result of groundwater flow (NRCan-IR#9). This requires careful consideration of the vertical hydraulic gradients in the

	sub-permafrost groundwater beneath each of the pits (NRCan-IR#1 and #3). f) Include the entire extents of tailing deposition in the Goose and Portage Pits as sources of contamination (NRCan-IR#7). This modification was easily accomplished in the proponent response to IR#7. The inclusion of the entire extent of tailings deposition may be more relevant for the assessment of groundwater contaminant transport from the tailings into the overlying Third Portage Lake during the post-closure period (e). g) Include the waste rock deposited in the Goose Pit as a hydrostratigraphic unit in the model (NRCan-IR#5). This could be easily accomplished in the model and may be relevant for the assessment of groundwater contaminant transport from the tailings into the overlying Third Portage Lake during the post-closure period (e). h) Update the modelling scenarios to represent planned conditions (and BCs) during and following in-pit deposition with a greater emphasis on predicting contaminant migration to natural receptors. Scenario 1) Goose Pit filled with tailings for the entire duration of Portage Pit filling (Period 3). Although this scenario represents flow and transport towards an artificial receptor (Portage Pit E), the hydraulic gradients are high during this period and could produce a plume that may subsequently migrate towards natural receptors during subsequent periods when gradients and flowpaths change. The source concentration should apply to the entire depth of the tailings (f). The Goose dump should be included, since it may provide a more permeable flowpath (g). The duration of the simulation should be the entire duration of the Portage Pit deposition (Period 3) and, therefore, may require variable head BCs on the Portage pits. As the water level in Goose Pit is to be managed (i.e. pumped at times), a specified BC may be more appropriate. Scenario 2) Post-closure, all pits filled with tailings and flooded (Period 6). This scenario needs to assess the transport from each pit to possible natural receptors, including the surface water above the pits (which will become part of Third Portage Lake) (e), Second Portage Lake and, if appropriate, Lake Tehek. The source concentration should apply to the entire depth of the tailings in each pit (f). To make use of the Scenario 1 results, the initial concentrations for the Goose Pit should be based on results from the Scenario 1 simulations with the contamination extending beyond Goose Pit (h, i). The extent of permafrost in the model (a) and the hydraulic head BCs (b, c) should be representative of post-closure conditions with dikes breached (i.e. flooded).

	Other scenarios, such as variable source BCs over time, could be considered. However, evidence that the tailings act as a variable source should be provided. NRCan recommends to the NIRB that the updated modelling be fully documented and present all the pertinent results to allow for the assessment and review of the proposed project modification. A sensitivity analysis of the contaminant transport scenarios by varying the hydraulic conductivity of the upper bedrock hydraulic conductivity should be included (d). An assessment and discussion specific to the potential for the migration of contaminants from the tailings into the overlying Third Portage Lake during the post-closure period is also required (e). In general, the approach used in the SNC-Lavalin (2017a) report is satisfactory; plan and cross-sectional views show the dominant contaminant migration pathways and concentrations. Such figures should be provided along the flowpaths to each of the main receptors from each of the pits. Since the BCs used to simulate the groundwater flow in Figures 18 and 19 do not apply to the transport scenarios, hydraulic head maps for both shallow and deep (sub-permafrost) model layers should be provided for each contaminant transport scenario.

Review Comment Number	**NRCan-#12**
Original IR	NRCan-IR #13
Subject/Topic	Updated groundwater monitoring plan
Summary	NRCan requested information regarding the groundwater monitoring plan. The proponent provided more detailed information and agreed with some of NRCan's requests. Given the new information, NRCan has made some recommendations regarding the monitoring plan.
Importance of issue to the impact assessment process	The proponent has committed to using an adaptive management approach. Adaptive management of potential groundwater contaminant migration requires an effective groundwater monitoring plan with strategically positioned groundwater monitoring wells.
Detailed Review Comments	In IR # 11, NRCan has highlighted the actual consequences that result from the uncertainty in the hydraulic conductivity. This uncertainty can also have analogous actual consequences on contaminant migration in groundwater. Increased seepage rates were quickly observed in the Central Dike D/S Pond, whereas increased contaminant migration in groundwater may not be recognized as readily. This fact emphasizes the importance of an effective groundwater monitoring plan that would allow for adaptive management of contaminant migration in groundwater. In response to NRCan-IR#13a, the proponent referred to NRCan-IR#9a, which also refers to responses provided to IR ECCC#1b, IR

	ECCC#3a and IR ECCC#3c; these are not pertinent to this issue. NRCan assumes the proponent was referring to NRCan-IR#10. In response to NRCan-IR#10, NRCan noted that the existing monitoring wells, including those intended to be sentinel wells, appear to be installed too deep to intercept the main pathway of modelled groundwater contaminant migration. The responses suggest that the proponent will update the monitoring plan "after the dikes are breached and the pits are flooded". In NRCan's opinion, the monitoring plan needs to be re-assessed prior to in-pit deposition to assure that correct monitoring locations are secured and background groundwater samples are collected. An issue raised in NRCan-IR#13a and in the face-to-face meeting (July 9, 2018) with the proponent, but not addressed in the proponent responses, was the monitoring of groundwater contaminant migration in the tailings to the overlying surface water. Given that the tailings will be in contact with the Third Portage Lake, some form of groundwater (pore water) monitoring of the tailings will be needed for each pit to ensure that benthic pore water and surface water are not contaminated by groundwater flow through the tailings. Such monitoring should be included in the groundwater monitoring plan. NRCan is in favor of developing a contingency plan as discussed in NRCan-IR#13d. The proponent indicates that the final closure plan will include "potential contingency plans". NRCan is unsure of the timing of the final closure plan. NRCan encourages the timely development of a contingency plan and contingency measures. NRCan is in agreement with the proponent's suggestion to change Period 6 to Groundwater monitoring and add a Period 7 Post-closure. NRCan has retained the previous nomenclature (i.e. Period 6, Post-closure) for the rest of this report.
Recommendation/Request	NRCan recommends that NIRB or NWB (Nunavut Water Board) should establish a timetable for the update of the groundwater monitoring plan. NRCan recommends that the groundwater monitoring plan should be re-assessed prior to in-pit deposition. NRCan recommends that the groundwater monitoring plan should explicitly state which monitoring wells will be maintained in the post-closure period (and groundwater monitoring period) and their monitoring and sampling frequencies. NRCan recommends that the groundwater monitoring plan should discuss contingency measures to deal with potential contaminant migration issues. NRCan recommends to the NIRB that the proponent develop a monitoring approach to assess groundwater contaminant migration from the in-pit tailings to the overlying surface water following flooding of the pits.

	NRCan recommends that the updated groundwater modelling (#IR12) be used to assess the groundwater monitoring well locations; they appear to be too deep and may not be ideal sentinels of contaminant migration. The modelling of breakthrough curves at observation points in FEFLOW is simple and would require little additional effort. NRCan recommends that these curves be used to evaluate the effectiveness of the monitoring locations in comparison to the predicted plumes.

2.2. Conclusions

NRCan and the proponent disagree about most issues related to groundwater modelling. NRCan and the proponent agree on some issues related to groundwater monitoring. NRCan recommends to the NIRB that several elements of the groundwater monitoring plan should be updated prior to in-pit tailings deposition, whereas the proponent is proposing to update the groundwater monitoring plan at a later date "after the dikes are breached and the pits are flooded."

In addition to the recommendations that have already been made in responses to the information requests, NRCan would like to point out, respectfully, that the use of English was confusing in several of the information request responses and technical documents, which not only makes them laborious to read but also hinders clear communication of the technical information to be conveyed. Consequently, NRCan recommends that the proponent adopt careful proofreading of future communications to ensure a suitable use of English and clear communication of the technical content.

The most significant of NRCan's recommendations to the NIRB is that the current hydrogeological modelling be considered insufficient for the assessment of potential effects related to groundwater contaminant migration. NRCan has justified many shortcomings of the hydrogeological modelling; some of these have substantial implications for the contaminant transport results and their use for the assessment of potential impacts.

The detailed recommendations to the NIRB are listed in the tables above in response to each issue. Most of the recommendations are summarized in NRCan-IR#12 and NRCan-IR#13, which make detailed recommendations to update the hydrogeological modelling (NRCan-IR#12) and update the groundwater monitoring plan (NRCan-IR#13).

NRCan would like to thank the NIRB for this opportunity to participate in this review.

2.3. Summary of Recommendations

2.3.1. NRCan-#1

NRCan recommends that the model be extended to adjacent lakes using large elements, since it allows the hydraulic heads in the sub-permafrost groundwater to be solved numerically, thereby taking into consideration the hydrogeological influence of varied lake sizes, elevations and distances.

If the model is not extended, NRCan recommends that specified heads be assigned in the sub-permafrost groundwater according to the Golder (2004, 2005) results (i.e. around the domain, rather than just for two segments with specified heads and the remaining segments specified as no-flow boundaries).

Furthermore, a sensitivity analysis on the specified heads in the sub-permafrost groundwater would be needed to assess their influence on groundwater flowpaths in the open talik and, in particular, on the vertical gradients and related vertical groundwater flow.

2.3.2. NRCan-#2

NRCan finds that the proponent has not adequately justified the exterior boundary conditions for their models. The differences between the proponent's specified boundary conditions and the hydraulic heads modelled by Golder (2004, 2005) have the potential to influence some of the proponent's model results.

NRCan's recommendations to the NIRB for this issue are as stated in relation to IR#1:

i) a preference to extend the model to adjacent lakes, or

ii) if the model is not to be extended, to vary the sub-permafrost boundary conditions to reflect the entire range of boundary conditions implied by Golder (2004, 2005) model results and use a sensitivity analysis to assess their impact on vertical groundwater flow in the open talik.

2.3.3. NRCan-#3

NRCan recommends that the NIRB not accept the SNC-Lavalin (2017a) contaminant transport modelling results for post closure scenarios because the assessment of permafrost conditions for the post-closure conditions remains incomplete and because of the substantial effect of permafrost extent on the modelling results.

NRCan recommends that the permafrost extent be delineated for post-closure conditions. The permafrost extent should be mapped for several model layers to indicate the distribution of thawed permafrost with depth. The delineation of permafrost should be justified either by thermal modelling or by making assumptions to delineate a "worst case" scenario of permafrost thawing.

NRCan recommends that the post-closure permafrost extent be used for updated groundwater modelling of post-closure conditions (as described in NRCan-IR#12).

2.3.4. NRCan-#4

Although this issue is not a critical issue with respect to the assessment of contaminant transport, NRCan nonetheless recommends that the higher hydraulic conductivity values of the Goose Dump be included in any subsequent groundwater simulations of the Meadowbank site (for times after the waste rock was deposited).

2.3.5. NRCan-#5

NRCan recommends that the proponent should clearly state the anticipated pit water levels during Periods 4 and 5 and resolve the apparent contradictions between pit water levels and flooding of the areas surrounding the pits. The proponent should state when the area surrounding the pits will be flooded and whether this will result from natural drainage or pumping, or breaching of the dikes.

NRCan recommends that “post-closure” groundwater contaminant simulations towards Second Portage Lake should begin when pit water levels exceed those of the Second Portage Lake.

2.3.6. NRCan-#6

NRCan recommends that the entire extent of tailings should be included in any subsequent groundwater simulations of the Meadowbank site.

2.3.7. NRCan-#7

NRCan’s opinion is that the contaminant transport simulations presented by the proponent cannot be relied upon to assess potential contaminant transport during the post-closure period. NRCan recommends that current hydrogeological modelling be considered insufficient for the assessment of potential effects.

NRCan recommends that the groundwater model be updated using revised scenarios, permafrost extent and boundary conditions that appropriately represent expected conditions at the site (see NRCan-#11).

2.3.8. NRCan-#8

NRCan recommends that the proponent use updated groundwater modelling to assess the potential for groundwater flow through the tailings to transport contaminants to surface water overlying the tailings. If significant, groundwater contaminant fluxes could be integrated into surface water quality modelling.

2.3.9. NRCan-#9

NRCan recommends that the NIRB seek commitments from the proponent to ensure sufficient, relevant groundwater monitoring into the post-closure period to observe potential groundwater contaminant migration caused by flooding of the pits and surrounding areas.

NRCan recommends that updated groundwater modelling (NRCan-IR#12) be used to assess the predicted breakthrough curves of groundwater contaminants at existing monitoring wells and assess the suitability of these wells which may be too deep to serve as sentinels of groundwater contamination.

2.3.10. NRCan-#10

Unexpectedly high seepage rates beneath the Central Dike should be regarded as a warning that hydrogeological predictions at the Meadowbank site are subject to the uncertainty in upper bedrock hydraulic conductivity. NRCan recommends to the NIRB that updated hydrogeological modelling (NRCan-IR#12) should include a sensitivity analysis of contaminant transport modelling results to a tenfold variation in upper bedrock hydraulic conductivity.

2.3.11. NRCan-#11

NRCan recommends to the NIRB that the current hydrogeological modelling be considered insufficient for the assessment of potential effects.

NRCan recommends that the Proponent update the hydrogeological modelling.

NRCan recommends that the following elements be included in the updated hydrogeological modelling:

a) Use an updated post-closure extent of permafrost and talik for simulations of post-closure scenarios (NRCan-IR#4).
b) Update the boundary conditions on the Second and Third Portage Lakes and pits to represent the actual post-closure hydraulic heads in the model (NRCan-IR#8). Specifically,
   i. the entire surface and water body of the Second Portage Lake should be a specified head equal to lake level;
   ii. the entire surface and water body of the Third Portage Lake, including the entire water body of the flooded area inside the dikes following their flooding, should be a specified head equal to lake level.
c) Update the boundary conditions on the sub-permafrost groundwater (NRCan-IR#1 and NRCan-IR#3). As noted in NRCan-IR#1, this could be accomplished using two approaches:
   i. the model can be extended to adjacent lakes using large elements since it allows the hydraulic heads in the sub-permafrost groundwater to be solved numerically, thereby taking into consideration the hydrogeological influence of varied lake sizes, elevations and distances. This is NRCan's preference as it removes more uncertainty in sub-permafrost boundary conditions than does approach ii).
   ii. If the model area is not extended, NRCan recommends that specified heads be assigned in the sub-permafrost groundwater according to the Golder (2004, 2005) results (i.e. around the domain, rather than just for two segments with specified heads and the remaining segments specified as no-flow boundaries). Furthermore, a sensitivity analysis on the specified heads in the sub-permafrost groundwater is recommended to assess their influence on groundwater flowpaths in the talik and, in particular, on the vertical gradients and related vertical groundwater flow.

d) Conduct a sensitivity analysis of contaminant transport scenarios by varying the hydraulic conductivity of the upper bedrock hydraulic conductivity (NRCan-IR#11). A tenfold variation in hydraulic conductivity is recommended in NRCan-IR#11.
e) Assess the potential for groundwater contaminant transport from the tailings into the overlying Third Portage Lake during the post-closure period as a result of groundwater flow (NRCan-IR#9). This requires careful consideration of the vertical hydraulic gradients in the sub-permafrost groundwater beneath each of the pits (NRCan-IR#1 and #3).
f) Include the entire extents of tailing deposition in the Goose and Portage Pits as sources of contamination (NRCan-IR#7). This modification was easily accomplished in the proponent response to IR#7. The inclusion of the entire extent of tailings deposition may be more relevant for the assessment of groundwater contaminant transport from the tailings into the overlying Third Portage Lake during the post-closure period (e).
g) Include the waste rock deposited in the Goose Pit as a hydrostratigraphic unit in the model (NRCan-IR#5). This could be easily accomplished in the model and may be relevant for the assessment of groundwater contaminant transport from the tailings into the overlying Third Portage Lake during the post-closure period (e).
h) Update the modelling scenarios to represent planned conditions (and BCs) during and following in-pit deposition with a greater emphasis on predicting contaminant migration to natural receptors.

Scenario 1) Goose Pit filled with tailings for the entire duration of Portage Pit filling (Period 3). Although this scenario represents flow and transport towards an artificial receptor (Portage Pit E), the hydraulic gradients are high during this period and could produce a plume that may subsequently migrate towards natural receptors during subsequent periods when gradients and flowpaths change. The source concentration should apply to the entire depth of the tailings (f). The Goose dump should be included, since it may provide a more permeable flowpath (g). The duration of the simulation should be the entire duration of the Portage Pit deposition (Period 3) and, therefore, may require variable head BCs on the Portage pits. As the water level in Goose Pit is to be managed (i.e. pumped at times), a specified BC may be more appropriate.

Scenario 2) Post-closure, all pits filled with tailings and flooded (Period 6).
This scenario needs to assess the transport from each pit to possible natural receptors, including the surface water above the pits (which will become part of Third Portage Lake) (e), Second Portage Lake and, if appropriate, Lake Tehek. The source concentration should apply to the entire depth of the tailings in each pit (f). To make use of the Scenario 1 results, the initial concentrations for the Goose Pit should be based on results from the Scenario 1 simulations with the contamination extending beyond Goose Pit (h, i). The extent of permafrost in the model (a) and the hydraulic head BCs (b, c) should be representative of post-closure conditions with dikes breached (i.e. flooded).

Other scenarios, such as variable source BCs over time, could be considered. However, evidence that the tailings act as a variable source should be provided.

NRCan recommends to the NIRB that the updated modelling be fully documented and present all the pertinent results to allow for the assessment and review of the proposed project modification. A sensitivity analysis of the contaminant transport scenarios by varying the hydraulic conductivity of the upper bedrock hydraulic conductivity should be included (d). An assessment and discussion specific to the potential for the migration of contaminants from the tailings into the overlying Third Portage Lake during the post-closure period is also required (e). In general, the approach used in the SNC-Lavalin (2017a) report is satisfactory; plan and cross-sectional views show the dominant contaminant migration pathways and concentrations. Such figures should be provided along the flowpaths to each of the main receptors from each of the pits. Since the BCs used to simulate the groundwater flow in Figures 18 and 19 do not apply to the transport scenarios, hydraulic head maps for both shallow and deep (sub-permafrost) model layers should be provided for each contaminant transport scenario.

2.3.12. NRCan-#12

NRCan recommends that NIRB or NWB (Nunavut Water Board) should establish a timetable for the update of the groundwater monitoring plan.

NRCan recommends that the groundwater monitoring plan should be re-assessed prior to in-pit deposition.

NRCan recommends that the groundwater monitoring plan should explicitly state which monitoring wells will be maintained in the post-closure period (and groundwater monitoring period) and their monitoring and sampling frequencies.

NRCan recommends that the groundwater monitoring plan should discuss contingency measures to deal with potential contaminant migration issues.
NRCan recommends to the NIRB that the proponent develop a monitoring approach to assess groundwater contaminant migration from the in-pit tailings to the overlying surface water following flooding of the pits.

NRCan recommends that the updated groundwater modelling (NRCan-#IR12) be used to assess the groundwater monitoring well locations; they appear to be too deep and may not be ideal sentinels of contaminant migration. The modelling of breakthrough curves at observation points in FEFLOW is simple and would require little additional effort. NRCan recommends that these curves be used to evaluate the effectiveness of the monitoring locations in comparison to the predicted plumes.