NRCan's Final Comments on the Proposal for In-Pit Tailings Disposal at the Meadowbank Mine

Natural Resources Canada

Submission to the Nunavut Water Board

September 21, 2018

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.

Background

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 9 July 2018 (NRCan, 2018a). The proponent provided responses to these IRs on 16 July 2018 (AEM, 2018a). NRCan submitted its Final Written Submission on 3 August 2018 (NRCan, 2018b). The proponent provided its response to the NIRB on 17 August 2018 (AEM, 2018e). NIRB closed the registry and later released its reconsideration report and recommendations on 31 August 2018 (NIRB, 2018). The NIRB concluded in that report that “this proposed amendment to the Meadowbank Gold Mine may proceed to the licensing and permitting regulatory phase with no revisions to the existing Terms and Conditions of Project Certificate No. 004 required” and “that the environmental risks associated with the approach to tailings disposal set out in the In-Pit Tailings Disposal Proposal can be mitigated through the NWB technical assessment and regulatory process.”

Purpose of this report

The review process put in place by the NIRB did not allow for intervener response to the proponent's 17 August 2018 submission. Furthermore, the proponent sent a letter directly to NRCan (AEM, 2018d) on 16 August 2018 informing NRCan on the proposed boundary conditions for the sensitivity analysis (version 3 of the hydrogeological model). NRCan has remaining concerns regarding the detailed engineering study version (version 2) of the hydrogeological model (SNC-Lavalin, 2018b) and the proposed changes in the sensitivity analysis (version 3) model update (AEM, 2018d). The purpose of this report is to communicate NRCan's comments and feedback with respect to hydrogeological issues to the proponent, the NIRB and the Nunavut Water Board (NWB). This report may also help to direct discussion in a face-to-face meeting between NRCan and the proponent planned for 25 September 2018. NRCan begins by considering the proponents' proposed boundary conditions for the version 3 model (AEM, 2018d) and making recommendations for these boundary conditions. NRCan then responds to the AEM response (AEM, 2018e) to NRCan's Final submission (NRCan, 2018b). Finally, NRCan provides minor additional comments on the version 2 hydrogeological report.

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Features of sub-permafrost groundwater flow in the Golder (2004) model.

Groundwater flowlines were superimposed on the Golder (2004) sub-permafrost groundwater equipotential contours to indicate the approximate groundwater flowpaths in relation to the SNC-Lavalin (2017a; 2018e) model boundaries (Fig. 1). The flowpaths are challenging to interpret given the intersection of four sub-permafrost groundwater flow systems at the edge of the SNC-Lavalin modelling domain (Turn Lake to Tehek Lake, Turn Lake to lake with elevation 117 m, lake with elevation 153 m to Lake Tehek, and lake with elevation 153 m to lake with elevation 117 m (Fig. 1)). Three different groundwater flow systems overlap the SNC-Lavalin modelling domain; the Portage A and E pits are located in one flow system (Turn Lake to Lake Tehek), whereas the Goose Pit lies within another (lake with elevation 153 m to Lake Tehek). The SNC-Lavalin models (2017a; 2018e) assume there is one groundwater flow system originating at the NW model boundary and discharging beneath the Second Portage Lake. The proposed boundary conditions for the version 3 model (AEM, 2018d) also assumes a single groundwater flow system originating along the north and NE boundaries of the model and discharging to the SE boundary of the model.

NRCan recommendations for flow boundary conditions

Assuming that the model boundary is not extended to include large lakes outside the current modelling domain (see NRCan-#1 below), NRCan proposes the following recommendations for boundary conditions using the existing SNC-Lavalin modelling domain (SNC-Lavalin, 2017a, 2018e, AEM, 2018d).

The intent of these recommendations is to suggest boundary conditions that conform to the groundwater flow patterns of the Golder (2004) model. NRCan recognizes that the Golder (2004) model results also include uncertainty and their resulting groundwater flow patterns may not be definitive. However, because the proponent has chosen to exclude the adjacent large lakes from the modelling domain (see NRCan-#1 below), it must rely on the Golder (2004, 2005) model results to determine the boundary conditions for the smaller domain. NRCan provides its recommendations on boundary conditions but recognizes that implementation of the boundary conditions in the model might require some modification of these recommendations to conform to the groundwater flowpaths implied by the Golder (2004) model.

Because Golder's (2004) groundwater modelling used different lake levels than those used by SNC-Lavalin (2017a; 2018e), the Golder (2004) groundwater equipotential contours should be taken with respect to the lake levels used in their modelling. Golder (2004) had a 1 m difference between the levels of Second (132 m) and Third Portage Lakes (133 m) compared to the 0.7 m difference indicated by SNC-Lavalin (2017a; 2018e) so that the correction would be different for each lake (+0.9 m (132.9 -132 m) for Second Portage Lake; +0.6 m (133.6 – 133 m) for Third Portage Lake). NRCan recommends adding 0.6 m (to 0.9 m) to Golder (2004) contours/heads to maintain the hydraulic gradients with respect to the lakes.

As noted in the previous section, the Golder (2004) sub-permafrost groundwater equipotential contours indicate the intersection of four sub-permafrost groundwater flow systems (Fig. 1) along the edge of the SNC-Lavalin modelling domain. Three different groundwater flow systems overlap the SNC-Lavalin modelling domain; the Portage A and E pits are located in one flow system, whereas the Goose Pit lies within another. NRCan's recommendations for boundary conditions attempt to maintain these different flow systems within the established modelling domain. The current (SNC-Lavalin, 2017a, 2018e) and proposed boundary conditions (AEM, 2018d) result in one flow system with groundwater flow paths and directions that differ in important ways from the Golder (2004) model. NRCan's suggested boundary conditions for sub-permafrost groundwater attempt to maintain the regional flow implied by the Golder (2004) model and are explained below for each segment of the SNC-Lavalin model boundary (labelled A to K in Figure 2).

Segment A-B) (flowtube A in Fig. 1) shows that there is outflow along this segment of the model boundary to the NW as discussed by Golder (2004). NRCan recommends a constant head of 133.6 m (the 133 m contour plus the 0.6 m correction discussed above).

Segment B-C) No change is required. The segment is a flow divide (Fig. 1) and is represented appropriately as a no-flow boundary.

Segment C-D) (flowtube B in Fig. 1) shows that there is inflow to the model from the west along this boundary. This inflow influences the regional groundwater flowpaths as it flows to the SE and deflects flow from the north (Turn Lake) towards the east (influencing flowpaths around the pits) (Fig. 1). It suggests that the source of water flowing beneath the Goose Pit may not originate from the Turn Lake area, but rather from the lake with an elevation of 153 m (Fig. 1). Setting this boundary is challenging. Assigning a head of 133.6 m (at C) to 133.2 m (at D) would be consistent with the Golder (2004) model results. However, these values may not give the desired result, as it could produce outflow along this segment rather than inflow as suggested by the Golder (2004) model (see Fig. 1). NRCan recommends some testing of the boundary conditions along segment C-D in order to produce groundwater inflow along this model segment.

Segment D-E) No change is required. This segment is oriented approximately along a groundwater flowline and a no-flow boundary is appropriate.

Segment E-F) Figure 1 demonstrates that the Golder (2004) model indicates groundwater outflow along this segment. NRCan recommends a constant head boundary condition in the sub-permafrost groundwater varying from 132.9 m at E (approx. 132.3 + 0.6 m) to 132.7 m at F (approximately 0.2 m lower than Second Portage Lake, see segment F-G).

Segment F-G) The 132 m contour in the Golder (2004) model crosses the SE portion of Second Portage Lake. Consequently, the area to the SE of the contour has a lower hydraulic head than the lake (specified at 132 m in Golder (2004), which indicates downward flow within the talik). Therefore, NRCan recommends that the hydraulic heads along the F-G segment vary from 132.7 m at F to 132.9 m at G.

Segment G-H) No change is required. This segment is oriented approximately along a groundwater flowline and a no-flow boundary is appropriate.

Segment H-I) NRCan recommends adding 0.6 m (to 0.9 m) to maintain the relative difference in elevations between the groundwater equipotential and lake levels (i.e. 135.6 to 136.6 m).

Segment I-J) NRCan recommends adding 0.6 m (to 0.9 m) to maintain the relative difference in elevations between the groundwater equipotential and lake levels (i.e. 136.6 m).

Segment J-K) NRCan recommends adding 0.6 m (to 0.9 m) to maintain the relative difference in elevations between the groundwater equipotential and lake levels (i.e. 136.6 to 135.6 m).

Segment K-A) No change required. This segment is oriented approximately along a groundwater flowline and a no-flow boundary is appropriate.

As recommended in NRCan-#1 (NRCan, 2018b), a sensitivity analysis on the specified heads in the sub-permafrost groundwater is warranted to assess their influence on groundwater flowpaths in the open talik and, in particular, on the vertical gradients and related vertical groundwater flow.

NRCan is in agreement with the boundary conditions for the top of the model shown in Figure 3 of AEM (2018d).

Summarizing, NRCan has provided recommended boundary conditions to be consistent with the presence of different groundwater flow systems implied by the Golder (2004) modelling results. The proponent may need to modify these boundary conditions to obtain the intended flow directions across the model boundaries and within the modelling domain.

NRCan response to proponent responses

Review Comment Number	NRCan-#1
Subject/Topic	Model extent
Summary	NRCan contends that extending the hydrogeological model to include adjacent large lakes would ensure better estimates of the hydraulic heads and groundwater flow patterns in the sub-permafrost groundwater near the pits. The proponent believes that version 2 of the model is "consistent with what was predicted in the original FEIS". The proponent proposes to conduct a sensitivity analysis (version 3 of the model) by adjusting the boundary conditions. NRCan points out discrepancies between the flow fields of the original FEIS Golder models (2004, 2005) and all three versions of the proponent models.
Importance of issue	The assessment of horizontal groundwater flow and hydraulic heads depends on the influence of large lakes that are outside the proponent's current modelling domain because there are no head measurements in the sub-permafrost groundwater. The hydraulic heads imposed by the regional (sub-permafrost) groundwater flow system also form an important control on vertical hydraulic gradients in the open talik, which can affect the interaction between the pits and the overlying lake.
Detailed Review Comments	The proponent did not extend the model boundaries to include larger lakes outside the current modelling domain. Despite the advantages of such an approach, the proponent's decision incited NRCan to recommend an alternate approach in which the boundary conditions would be modified to replicate those of Golder (2004, 2005). As noted in the previous two sections, the groundwater flow field, indicated by the Golder (2004) model, differs in important ways from that of all versions of the proponents' models (SNC-Lavalin, 2017a, 2018e; AEM, 2018d). The Golder (2004) model results suggest that there are three groundwater flow systems within the proponent's modelling domain, whereas the proponent models include only one groundwater flow system in the modelling domain. Consequently, hydraulic heads and groundwater flow directions differ between the Golder (2004) and SNC-Lavalin (2017a, 2018e) models (see NRCan-#2).

Recommendations	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. Recognizing that the proponent declined to extend the model, NRCan provided its recommendations on boundary conditions to replicate the hydraulic heads and flow field of Golder (2004) in the above section entitled "NRCan recommendations for flow boundary conditions".

Review Comment Number	NRCan-#2
Subject/Topic	Justification of flow boundary conditions
Summary	NRCan has highlighted discrepancies between the boundary conditions and resulting groundwater flow patterns between the Golder (2004) and proponent (SNC-Lavalin, 2017a, 2018e) models. The proponent agreed to modify boundary conditions for the version 3 model (AEM, 2018d). NRCan has provided its recommendations on boundary conditions to replicate the hydraulic heads and flow field of Golder (2004) in the section entitled "NRCan recommendations for flow boundary conditions".
Importance of issue	Boundary conditions can influence both the direction and magnitude of groundwater flow in the hydrogeological model. Uncertainty in groundwater flow direction and magnitude can influence estimated migration of groundwater contaminants (i.e. plumes) as well as the design of groundwater monitoring networks (e.g., the locations and depths of monitoring wells).
Detailed Review Comments	The proponent (AEM, 2018e) suggests that "Versions 1 and 2 of the hydrogeological models and the Golder (2004, 2005) regional model are showing similar hydraulic heads at the boundary conditions used for Versions 1 and 2 hydrogeological models" as shown in Figure 2.1 of AEM (2018e). NRCan has already discussed the difference in groundwater flow systems between the Golder (2004) and SNC-Lavalin results (2017a, 2018e) in the section entitled "Features of sub-permafrost groundwater flow in the Golder (2004) model". NRCan also observes in Figure 2.1 (AEM, 2018e) that Golder and SNC-Lavalin groundwater equipotentials are at considerable angles to each other showing that groundwater flow directions differ significantly. Furthermore, the hydraulic gradients in the Golder (2004) model are higher than those in the SNC-Lavalin models. These

	differences in flow directions and hydraulic gradients result directly from differences in boundary conditions. Although the proponent considers version 3 of the model to be a "sensitivity analysis" (AEM, 2018e), NRCan does not consider its recommended boundary conditions to be a sensitivity analysis, but rather a part of the detailed engineering study. A separate sensitivity analysis that varies the boundary conditions proposed by NRCan is also recommended since the surrounding lake levels and sub-permafrost hydraulic heads are likely to vary from the estimated mean values assumed in the Golder (2004, 2005) and SNC-Lavalin models (2017a, 2018e). The proponent did not agree with NRCan's recommendation to extend the model to include surrounding lakes because they suggest that "using a larger model and elements could lead to numerical dispersion and to numerical errors" for the contaminant transport simulations. NRCan notes that the contaminant plume would still be located within the smaller elements so that additional large elements outside the contaminant plume should not produce numerical dispersion.
Recommendations	NRCan maintains its preference to extend the model boundaries to adjacent lakes. If the current model boundaries are maintained, NRCan has provided its recommendations on boundary conditions to replicate the hydraulic heads and flow field of Golder (2004) in the section entitled "NRCan recommendations for flow boundary conditions". NRCan does not consider its recommended boundary conditions to be a sensitivity analysis, but rather a part of the detailed engineering study. A separate sensitivity analysis, which varies the boundary conditions proposed by NRCan, is also recommended since the surrounding lake levels and sub-permafrost hydraulic heads are likely to vary.

Review Comment Number	NRCan-#3
Subject/Topic	Extent of the permafrost in the groundwater model
Summary	This is the most significant point of disagreement between the proponent and NRCan. The proponent disagrees with NRCan's review comment NRCan-#3 and refers to the thermal modelling report (SNC-Lavalin, 2018f) and the version 2 hydrogeological

	modelling report (SNC-Lavalin, 2018e) as supporting evidence. The proponent states that the version 2 model (SNC-Lavalin, 2018e) "already addressed NRCan recommendations NRCAN-03" (AEM, 2018e). NRCan does not agree that thermal modelling, which simulates ground temperature to 100 years into post-closure, is appropriate to determine permafrost extent for groundwater modelling over 10 000 years. NRCan also comments that the 2-D thermal modelling cross-sections are not located in the areas critical to groundwater contaminant migration.
Importance of issue	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 is influenced by the distribution of permafrost. These models are the basis for contaminant transport predictions following closure. Therefore, the extent of permafrost directly affects the proponent's assessment of flowpaths and travel times to lakes.
Detailed Review Comments	NRCan did not accept the contaminant transport modelling results (version 1, SNC-Lavalin, 2017a) in its Final submission (NRCan, 2018b) because the 100-year duration of the (pre-feasibility) thermal modelling was not comparable to the 2500- to 6000-year durations of the contaminant transport modelling scenarios (version 1, SNC-Lavalin, 2017a). The duration of the detailed engineering thermal modelling (SNC-Lavalin, 2018f) is 100 years post-closure. Therefore, the proponent cannot consider the potential impacts of dyke breaching and pit flooding on permafrost extent beyond 100 years. The engineering study hydrogeological modelling uses the results of the 100-year thermal modelling for contaminant transport modelling to 10 000 years. In its Final submission (NRCan, 2018b), NRCan recommended that "The delineation of permafrost should be justified either by thermal modelling or by making assumptions to delineate a "worst case" scenario of permafrost thawing." The proponent (AEM, 2018e) considers that the "thermal modelling assumptions were representative of a worst case scenario of permafrost thawing." NRCan does not consider 100-year thermal simulations to be representative of worst-case permafrost conditions with respect to permafrost thawing since the permafrost will continue to thaw after 100 years post-closure. Flooding of the pits and adjacent areas with water depths of greater than 4 m during post-closure is expected to result in thawing of permafrost beneath flooded areas and the

	formation of open talik. The permafrost extent used by the proponent for groundwater flow and contaminant transport modelling is based on 100-year duration thermal modelling and does not include open or through talik that will develop in these areas. Consequently, the proponent's extent of permafrost (100 years post-closure) minimizes the possibility of contaminant migration between the Portage pits and the Second and Third Portage Lakes (i.e. more of a best case scenario rather than a worst case scenario). The longer-term (beyond 100 years) evolution of the thermal regime and the spatial configuration of permafrost and taliks have not been considered. Running the simulations with the lake bottom temperature of 4°C to steady state conditions (with no climate warming) could be done to estimate the time required for a through or open talik to form. NRCan notes that analysis included in recent EIS for other mining projects has considered time periods beyond 100 years in order to characterize future permafrost conditions (see for e.g., EIS for Kiggavik and Back River projects). The 2-D thermal modelling did not include cross-sections in areas critical for groundwater flow and contaminant transport. As noted in NRCan's Final written submission (NRCan, 2018b), two areas critical to permafrost thawing and contaminant transport are the SE corner of Portage Pit A and the northern portion of Portage Pit E. None of the thermal modelling sections was pertinent to these critical hydrogeological sections. All modelled cross-sections were located near the middle of the pits and oriented across the narrow dimension of the pits. Consideration of the vertical flow through the tailings and into Third Portage Lake (post-closure) will require consideration of the thawing of deeper permafrost beneath the pits and talik development since these will affect vertical gradients beneath the pits and potential migration from the tailings to the overlying lake. Portage Pit A is of particular importance since it is located upgradient (in the direction of higher sub-permafrost groundwater heads). Thermal modelling along a north-south cross-section through all the pits is needed to consider the development of talik beneath the pits. NRCan notes that a north-south cross-section was considered in the conceptual understanding of permafrost distribution and sub-permafrost groundwater flow in the Meadowbank mine FEIS (see cross-section 2 located in Fig. 6-2, and shown in Fig. 6-3 in Meadowbank Gold Project Baseline Physical Ecosystem Report, Cumberland Resources Ltd., 2005b). Some thermal modelling results (SNC-Lavalin, 2018f) appear to be inconsistent with observed pre-mining permafrost conditions. For

	example, the initial conditions along cross-sections GG'2 (Figure A-11) indicates permafrost under Goose Island at elevations of approximately -130 m (depths of ~250 m), whereas thermistor measurements indicate a permafrost depth of about 125 m depth (see Fig. 6.7 in Cumberland Resources Ltd., 2005b). Similarly, Figure A-19 suggests the freeze-back of talik beneath Third Portage Lake (see Figure 4-1 for section and lake locations) to an elevation of about -150 m (depth > 200 m) within 15 years of mining. These results suggest that setting the initial thermal conditions to a time after mining is complete may not adequately represent actual conditions.
Recommendations	NRCan recommends that the proponent address NRCan's comments about permafrost thawing beneath the pits and between the Portage A and E pits and Second Portage Lake. These concerns have not been adequately addressed in previous responses. NRCan requests answers to the following specific questions: 3a) How long will it take for permafrost to thaw sufficiently to create a through or open talik beneath each of the pits (i.e. to form a hydraulic connection between sub-permafrost groundwater and each pit)? 3b) How long will it take for permafrost between Portage Pit E and the Central Dump to thaw sufficiently to form a hydraulic connection between Portage Pit E and the Central Dump? 3c) How long will it take for permafrost between the SE portion of Portage Pit A and the Central dump to thaw sufficiently to form a hydraulic connection between the SE portion of Portage Pit A and the Central Dump? NRCan recommends that all thermal modelling simulations be extended for the duration of the hydrogeological modelling. A suggested approach is to run simulations with the flooded pit lake bottom temperature to steady state conditions. This will allow better estimates of the time required for thawing of permafrost and development of through or open taliks. NRCan recommends that the proponent conduct thermal modelling along three cross-sections key to the potential migration of groundwater contaminants: i) a NW-SE cross-section through the SE corner of Portage pit A (where permafrost is preventing groundwater flow), ii) an approximate N-S cross-section through the northern portion of Portage Pit E (where the distance between the

	pre-mining extents of Second and Third Portage Lakes is smallest), and iii) a N-S section through all three pits and extending north of Portage Pit A (similar to cross-section 2 of Fig. 6.2 in Cumberland Resources, 2005b). NRCan recommends that the thermal modelling be initiated prior to pit development to represent the evolution of the thermal regime (after the pits are excavated) and model the thermal response through the mining period, in-pit deposition and post-closure conditions).

Review Comment Number	NRCan-#4
Subject/Topic	Waste rock and tailings within pits
Summary	NRCan recommended (NRCan, 2018b) that the higher hydraulic conductivity values of the Goose Dump be included in any subsequent groundwater simulations of the Meadowbank site. The proponent agreed to include the changes in version 3 of the hydrogeological modelling. NRCan is satisfied with the proponent's response.

Review Comment Number	NRCan-#5
Subject/Topic	Water level controls during in-pit deposition periods
Summary	NRCan recommended (NRCan, 2018b) that the proponent should clearly state the anticipated pit water levels during Periods 4 and 5 and related clarifications. The proponent provided relevant information about pit water levels, pit crest elevations and controls on water levels. NRCan is satisfied with the information provided.

Review Comment Number	NRCan-#6
Subject/Topic	Tailings as a contaminant source
Summary	NRCan recommended (NRCan, 2018b) that the entire extent of tailings should be included in any subsequent groundwater

	simulations of the Meadowbank site. The proponent made the changes to version 2 of the hydrogeological modelling. NRCan is satisfied with the action taken.

Review Comment Number	NRCan-#7
Subject/Topic	In-pit deposition periods and contaminant transport scenarios
Summary	NRCan notes that the model boundary conditions for the version 1 and 2 groundwater flow model do not appear to correspond to actual water levels for the flooded areas and Portage Lakes following pit lake reconnection (periods 5-b and 6). NRCan supports proposed boundary conditions for the flooded areas and the Second and Third Portage Lakes in the version 3 model (AEM, 2018d).
Importance of issue	The assessment of hydrogeological impacts on in-pit deposition relies on the predictions made using contaminant transport simulations into periods 5-b and 6. Models should include the boundary conditions that will be present in the surface waters at that time.
Detailed Review Comments	The proponent responses to NRCan-#7 did not present any information to address the detailed review comments (NRCan, 2018b), but instead responded to the resulting opinion expressed by NRCan in its recommendations. Although the proponent disagreed with the NRCan recommendations, the proponent proposed to implement new boundary conditions for the flooded area and the surfaces of Second and Third Portage Lakes. Version 1 of the hydrogeological modelling (SNC-Lavalin, 2017a) presented four contaminant transport scenarios with generic concentrations. Version 2 (SNC-Lavalin, 2018e) presented one contaminant transport scenario for two specific contaminants with different transport characteristics (non-retarded and retarded). NRCan notes that the model boundary conditions for the version 2 groundwater flow model appear to be the same as version 1 and do not appear to correspond to actual water levels for the flooded areas and Portage Lakes following pit lake reconnection (periods 5-b and 6). As noted in NRCan recommendations for flow boundary conditions above, NRCan is satisfied that the proposed boundary conditions for the flooded areas and Portage Lakes in the version 3 model (AEM, 2018d) should correspond to surface water levels.

	The extent of permafrost is also pertinent to post-closure contaminant transport scenarios but this issue is addressed in NRCan-#3.
Recommendations	The head boundary conditions for the entire flooded areas and the Second and Third Portage Lakes should be implemented in version 3 of the hydrogeological model as intended by the proponent (AEM, 2018d).

Review Comment Number	NRCan-#8
Subject/Topic	Assessment of contaminant migration to Third Portage Lake
Summary	Mine tailings deposits in the pits will be in direct contact with the Third Portage Lake after the dykes are breached. The potential for groundwater flow through the mine tailings into the overlying Third Portage Lake has not been assessed from a hydrogeological perspective (advection by groundwater flow and diffusion). The proponent agreed to assess groundwater flow through the tailings in the version 3 hydrogeological modelling, but predicts groundwater flow through the tailings to be predominantly downward. NRCan notes evidence of possible upward flow through the tailings when permafrost thaws.
Importance of issue	This issue is significant because mine tailings are proposed to be in direct contact with the Third Portage Lake. The Third Portage Lake is the closest receptor to the tailings; flooded areas are intended to become fish habitat. Groundwater flow and diffusion could transport contaminants from the tailings into the overlying lake.
Detailed Review Comments	The proponent (AEM, 2018e) “agrees to provide further information to address the NRCan recommendation and will proceed to update groundwater modeling to assess the potential for groundwater flow through the tailings.” The response also predicts that “Groundwater flow through the tailings is expected to be dominated by downward flow”. NRCan notes that the modelled equipotentials in sub-permafrost groundwater beneath the northern half of Portage Pit E (Golder 2004, 2005) are higher than the modelled level of Third Portage Lake; upward vertical flow would be expected when the permafrost beneath Third Portage Lake thaws. Higher permeability within the pits could also influence groundwater flow patterns and vertical flow within the pits.
Recommendations	NRCan recommends that groundwater flow modelling be used to assess the vertical groundwater flow from the sub-permafrost groundwater, through the tailings and into the overlying Third

	Portage Lake. NRCan emphasizes the importance of considering vertical groundwater flow at a time when the permafrost beneath the tailings has thawed and the talik is open or through. NRCan recommends that where groundwater flows through the tailings into the overlying Third Portage Lake, contaminant transport modelling be conducted to assess the potential for advection and diffusion of contaminants from the in-pit tailings into the lake.

Review Comment Number	NRCan-#9
Subject/Topic	Groundwater monitoring following dike breaching
Summary	The proponent (AEM, 2018e) is committed "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 has expressed the concern that some of the groundwater monitoring wells may be too deep to serve as effective sentinels of groundwater contaminant migration.
Importance of issue	Adaptive management of potential groundwater contaminant migration requires an effective groundwater monitoring plan with strategically positioned groundwater monitoring wells and an appropriate frequency and duration of groundwater monitoring.
Detailed Review Comments	The proponent indicated that groundwater monitoring well "installation depths have been selected with a detailed drilling log and thermal investigation completed in 2017 to target the most permeable zone at the selected locations". Although NRCan endorses the targeting of permeable zones within the contaminant plume, monitoring wells will not be effective if they are not suitably located within the contaminant plume(s). The proponent has neither provided evidence substantiating the effectiveness of the monitoring wells, nor has it made a commitment to demonstrate this effectiveness. In the absence of evidence demonstrating the appropriate placement of monitoring wells, NRCan remains concerned about the effectiveness of the groundwater monitoring network.
Recommendations	NRCan recommends that the proponent commits to and demonstrates that monitoring wells are expected to be effective monitors of potential groundwater contaminant migration. This should be demonstrated through groundwater modelling of breakthrough curves

	and plan and vertical sections of predicted contaminant plumes showing monitoring well locations. NRCan recommends that the proponent provide a table of all anticipated groundwater monitoring wells to be used following the flooding of the pits. The table should indicate the locations and depths monitored, when a conservative tracer (e.g., chloride) of groundwater contamination is expected to intercept each well, when the concentration will peak, and the maximum modelled concentration at each well location.

Review Comment Number	NRCan-#10
Subject/Topic	High permeability near the Central Dike
Summary	The proponent disagreed with NRCan's recommendation to consider the effect of a high permeability shallow bedrock hydraulic conductivity on contaminant transport results. The proponent reports that field investigations and pit wall monitoring results indicate that a high permeability structure is located in the Second Portage Lake area and "has not been observed on the full extent of the Second Portage Lake area". NRCan accepts that a high permeability zone is not likely to be widespread. However, localized areas of high hydraulic conductivity (related to fractured bedrock or faulting) could influence groundwater flow and contaminant migration locally.
Importance of issue	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.

Review Comment Number	NRCan-#11
Subject/Topic	Updated hydrogeological modelling
Summary	NRCan suggested (NRCan, 2018b) that review comments #1, 2, 3, 4, 6, 7 and 8 could be addressed by updating the hydrogeological modelling. Comment #6 has been addressed in version 2 of the model. The proponent has agreed to update version 3 of the model to address review comments #1, 2, 4, 6, and 8. However, NRCan is not in full agreement with the model extent (NRCan-#1) or the boundary conditions (NRCan-#2) proposed in AEM (2018f). The proponent

	disagrees with NRCan-#3 (permafrost extent), #7 (scenarios) and #10 (high permeability sensitivity analysis). NRCan disagrees with the proponent's assessment of review comment NRCan-#3. This disagreement about permafrost extent is the most significant issue with respect to hydrogeological modelling and contaminant migration. NRCan-#7 will be addressed, in part, in version 3 of the model and the proponent has indicated that high permeability (NRCan-#10) is not likely to be widespread.
Importance of issue	The assessment of hydrogeological impacts of in-pit deposition relies heavily on the predictions made using contaminant transport simulations, in particular 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 predicting potential impacts.
Detailed Review Comments	The boundary conditions for the groundwater flow model are apparently the same for the version 1 and 2 models. Consequently, several concerns raised in detailed review comments (within NRCan-#2 and NRCan-#11) in NRCan's Final written submission (NRCan, 2018b) are still applicable and have not been re-iterated here. Additional comments are noted above in NRCan-#2 and in the section "features of sub-permafrost groundwater flow in the Golder (2004) model". Comments about model extent are noted above in NRCan-#1. NRCan and the proponent disagree about the extent of permafrost to be used in the hydrogeological modelling. Detailed review comments are provided above in NRCan-#3. NRCan-#6 has been addressed in version 2 of the model. NRCan-#4 and 7 should be resolved in version 3 of the model. Although the proponent indicates that NRCan-#8 (assessment of contaminant migration to Third Portage Lake) should also be assessed in version 3 of the model, NRCan recommends that this assessment needs to consider times when open talik exists beneath the pits (NRCan-#8). The proponent has indicated that high permeability (NRCan-#10) is not likely to be widespread.
Recommendations	NRCan recommends that the proponent update the hydrogeological modelling according to recommendations in NRCan-#1, 2, 3, 4, 7 and 8 and the section entitled "NRCan recommendations for flow boundary conditions".

Review Comment Number	NRCan-#12
Subject/Topic	Updated groundwater monitoring plan
Summary	The proponent has agreed to update the groundwater monitoring plan, "if deemed appropriate by NIRB and NWB".
Importance of issue	The proponent has previously 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	"If deemed appropriate by NIRB and NWB", the proponent has agreed to update the groundwater monitoring plan which would include: - monitoring wells to be maintained in the post closure period, their monitoring and sampling frequencies; - contingency measures to address any potential contaminant migration issues; - a monitoring approach to further evaluate the potential for groundwater contaminant migration from the in-pit tailings to the overlying surface water following flooding of the pits. NRCan supports the timely update of the groundwater monitoring plan with these elements. Section 5.0 of the version 2 model (SNC-Lavalin, 2018e) acknowledges the specific limitations of this hydrogeological modelling. The considerable uncertainty in predictive ability that results from these numerous limitations and the specific modelling concerns expressed by NRCan in this report are the reasons why NRCan must reiterate the importance of implementing a comprehensive groundwater monitoring plan with contingency measures. The plan should be verified and updated regularly and should incorporate new data, information and knowledge, as it becomes available.
Recommendations	NRCan recommends that the NWB establish a timetable for an update of the groundwater monitoring plan and the required content of the plan.

	NRCan recommends that the effectiveness of the monitoring well locations and depths be assessed following NRCan-#9. NRCan recommends that the monitoring plan be verified and updated regularly as new data, information and knowledge become available.

Additional NRCan comment on hydrogeological model version 2 (SNC-Lavalin, 2018e)

NRCan has observed that conceptual figures 9 and 11 show the Second Portage Fault dipping towards the north along cross-sections A-A'. However, the text clearly describes the fault dipping towards the southwest. Presumably, this is only a drafting error in the figure and not in the numerical model.

Conclusions

The proponent and NRCan disagree on the extent of permafrost to be used in the hydrogeological modelling. The extent of permafrost has significant consequences, not only for groundwater flow directions, velocities and contaminant travel times and directions, but also for whether or not groundwater flow and contaminant transport are even considered along certain pathways. The proponent considers that the permafrost extent used in the hydrogeological modelling is supported by the thermal modelling. NRCan does not consider that thermal modelling to 100 years post-closure is sufficient to define the extent of permafrost for hydrogeological modelling over hundreds or thousands of years in an environment where the changes in boundary conditions caused by flooding of permafrost will cause permafrost to thaw completely.

The proponent and NRCan do not fully agree on the model extent and boundary conditions but are coming closer to agreement over the flow boundary conditions to be used for groundwater flow modelling. The proponent considers their version 2 model to be sufficient and considers the proposed version 3 of the model to be a sensitivity analysis. NRCan does not consider version 2 to be sufficient and has provided recommendation for boundary conditions that are more consistent with the modelling results from Golder (2004).

Progress has been made with respect to the update of the groundwater monitoring plan and the validation of groundwater modelling locations. The proponent has committed to update aspects of the groundwater monitoring program if deemed necessary by NIRB and NWB. NRCan has made recommendations regarding the update of the groundwater monitoring plan and the validation of groundwater modelling locations.

This report provides the proponent, NIRB and NWB an understanding of NRCan's current opinions on permafrost and hydrogeology, with intent to foster useful discussion in a face-to-face meeting between the proponent and NRCan planned for September 25th, 2018.

Figure 1. Groundwater flowpaths in sub-permafrost groundwater based on Golder (2004) modelling results. Black arrows have been added by NRCan to indicate approximate groundwater flowpaths. Background colours have also been added by NRCan to emphasize the different groundwater flow systems in the vicinity of the Meadowbank Mine site. The dashed red line indicates the approximate boundary of the SNC-Lavalin (2017a, 2018e) hydrogeological model.

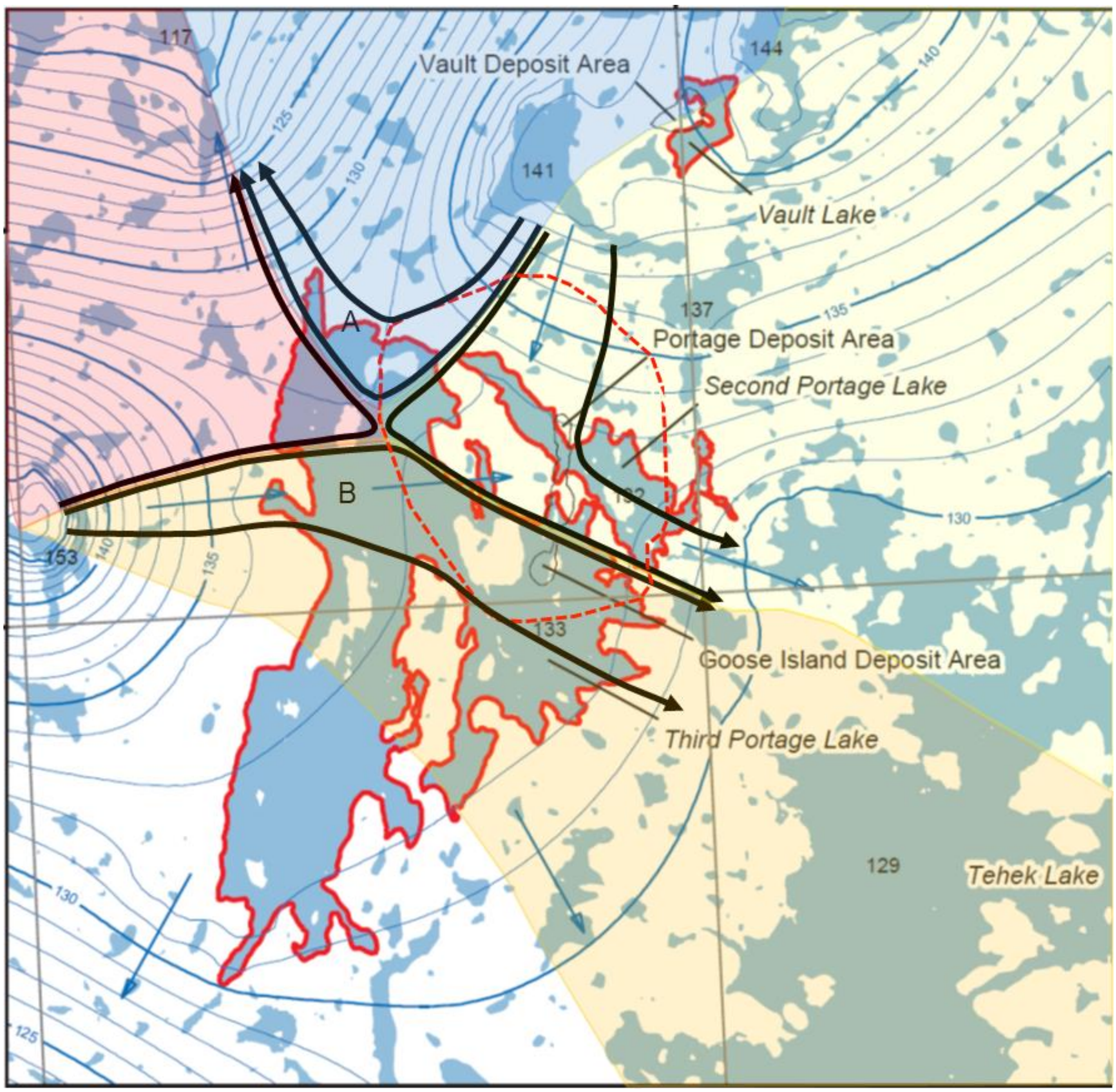

Figure 2. Hydraulic head boundary conditions in the sub-permafrost groundwater for the Meadowbank Mine hydrogeological model (from AEM, 2018e, Figure 2). NRCan has added circled letters (A to K) to identify specific segments of the model boundary that are discussed in the text.