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EA-SnapLake

From: Ramsey, John [jramsey@NRCan.gc.ca]

Sent: Friday, February 14, 2003 12:16 PM

To: EA-SnapLake; Alan Ehrlich; Anne Wilson (E-mail); Bridgette Larocque; 'Buddy Williams (E-mail) ' (E-mail); 'CARC (E-mail) ' (E-mail); 'Chamber of mines ED (E-mail) ' (E-mail); 'Chris (E-mail) ' (E-mail); 'Chuck. Blyth (E-mail) ' (E-mail); Colleen English (E-mail); 'CPAWS (E-mail) ' (E-mail); Dawn' 'Kelly (E-mail); 'Dennis Bevington (E-mail) ' (E-mail); 'DFO David (E-mail) ' (E-mail); 'DFO Marc Lange (E-mail) ' (E-mail); 'Doug Soloway (E-mail) ' (E-mail); 'Ecology North (E-mail) ' (E-mail); 'Eric Denholm (E-mail) ' (E-mail); 'Fairman Fraser (E-mail) ' (E-mail); 'Football Adeline (E-mail) ' (E-mail); 'Galbraith Empson (E-mail) ' (E-mail); 'Gavin_More (E-mail) ' (E-mail); 'General MVLWB (E-mail) ' (E-mail); Glenda Fratton (E-mail); 'Golder Green Leslie (E-mail) ' (E-mail); 'Golder Machtans Hillary (E-mail) ' (E-mail); "Government Akaitcho (E-mail) ' (E-mail) ' (E-mail); 'Health Canada 2 (E-mail) ' (E-mail); 'J. Michael Thoms NSMA (E-mail) ' (E-mail); 'Jagtar_Sandhu (E-mail) ' (E-mail); 'Janet Hutchison (E-mail) (E-mail) ' (E-mail); Jason Lepine (E-mail); Jason McNeill (E-mail); 'Jennifer Keith (E-mail) ' (E-mail); 'Joan Freeman (E-mail) ' (E-mail); 'John Donihee (E-mail) ' (E-mail); 'John Donihee (E-mail2) ' (E-mail); 'John McConnell (E-mail) ' (E-mail); 'Judy Langford (E-mail) ' (E-mail); 'Julie Dahl (E-mail) ' (E-mail); 'Kevin Ledrew (E-mail) ' (E-mail); 'Letha MacLachlan letha (E-mail) ' (E-mail); Lisa Best (E-mail); 'LKDFN Wildlife Lands Environment Ctte (E-mail) ' (E-mail); 'Lutsel K'e Dene First Nation (E-mail) ' (E-mail); 'Lutselk'e Agatha (E-mail) ' (E-mail); 'Mark Dahl (E-mail) ' (E-mail); 'Mary Tampsell (E-mail) ' (E-mail); 'Matt Bender (E-mail) ' (E-mail); 'Mike Fournier [Yel] (E-mail) ' (E-mail); 'Morison Steve (E-mail) ' (E-mail); 'Nick Lawson (E-mail) ' (E-mail); 'NSMA Bob Turner (E-mail) ' (E-mail); 'Nunavut Impact Review Board (E-mail) ' (E-mail); Rachel Crapeau (E-mail); 'Rae-Edzo Metis Local #64 (E-mail) ' (E-mail); Robin Johnstone (E-mail); Roland Semjanovs; 'Roy Ellis (E-mail) ' (E-mail); 'S. Kristyn (E-mail) ' (E-mail); 'Sierra Legal Defence Fund (E-mail 2) ' (E-mail); 'Stephen Harbicht (E-mail) ' (E-mail); 'Steve Mathews (E-mail) ' (E-mail); 'Steve Wilbur (E-mail) ' (E-mail); 'Sue I. (E-mail) ' (E-mail); 'Tamara Hamilton (E-mail) ' (E-mail); 'Tim Byers (E-mail) ' (E-mail); 'Tony Pearse (E-mail) ' (E-mail); Vern Christensen, Executive Director; 'Wha Ti First Nation (E-mail) ' (E-mail); 'William (Bill) Carpenter (E-mail) ' (E-mail); 'WWF - Peter J. Ewins (E-mail) ' (E-mail); 'WWF Tony Y. (E-mail) ' (E-mail); 'YK Chamber of Commerce (E-mail) ' (E-mail)

Cc: Burgess, Margo; Hogan, Charlene; Clausen, Scott; Kasemets, Juri; Tupper, Rennie

Subject: De Beers Snap Lake Project - NRCan Technical Report

Hi Glenda:

Please find attached NRCan's technical report (including the one-page non-technical summary) on the Snap Lake Diamond Mine Environmental Assessment.

This technical report focuses on permafrost/geotechnical and hydrogeology issues. This report has been compiled based on our expert review of the EA report, Information requests (NRCan's and others) and De Beers responses to these, supporting technical material and reports, the discussions at the Technical Sessions (TS) in Yellowknife, November-December 2002, and material received subsequent to the TS but prior to February, 2003. Our report does not take any more recently distributed material into consideration.

NRCan raised several issues of concern at the TS and indicated at that time that it would need to take the TS discussions, and new information arising from these, into account before determining whether the issues had been resolved to our satisfaction. Our attached detailed technical report provides our more complete technical rationale and discussion of these issues. For each we have summarized what our recommendations were at the time of the technical sessions, how they now stand, and whether the issue has been resolved.

There remain areas that are not yet fully resolved. However, there are only two of these that we see as

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being most important, and these are the ones that we have summarized in the requested attached one page non-technical summary of our technical report.

We look forward to continuing to work with you as we move toward the next phases of the EA review, and preparing for the pre-hearing conference on February 28 and the hearings in late March.

Sincerely,

John Ramsey
Senior EA Officer, Office of Environmental Affairs
Agent principal d'évaluation environnementale, Bureau des affaires environnementales
phone/téléphone: (613) 947-1591 fax/télécopieur: (613) 995-5719
jramsey@nrcan.gc.ca / jramsey@rncan.gc.ca

Natural Resources Canada, 3rd Floor, 580 Booth Street, Ottawa, Ontario K1A 0E4
Ressources naturelles Canada, 580 rue Booth, 3e étage, Ottawa (Ontario) K1A 0E4
Government of Canada / Gouvernement du Canada

Non-Technical Summary of Natural Recources Canada's Technical Comments on the De Beers Canada Mining Inc. Snap Lake Diamond Project Environmental Assessment

Natural Resources Canada (NRCan) has submitted 15 specific detailed technical comments on the Snap Lake Environmental Assessment. The majority of these comments were addressed, although not necessarily resolved, at the MVEIRB public Technical Session (TS) held in Yellowknife between November 25th and December 6th, 2002. This non-technical summary focuses on the two most important unresolved issues, one of which was formulated after the TS, and in light of discussions concerning the North Lakes hydrogeological study held on the afternoon of Day 3 (November 27th 2002). The proponent has not yet had an opportunity to respond to this comment.

1. **Issue: Groundwater flow quantities and directions / Water Quality**
   Reference : ToR lines 221, 250, 389; EAR Sec. 9.2 (p.9-30); North Lakes Report Sec. 4.0, 5.0, 6.0

NRCan believes that DeBeers' understanding of deep groundwater flow and movement of dissolved chemicals from Snap Lake to other lakes is based on a small number of measurements that appear to contradict one another. Unless DeBeers obtains more data to confirm their understanding beyond a reasonable doubt, they should investigate other possible ways that groundwater affected by the mine can affect the quality of water in nearby lakes. NRCan is particularly concerned with the possibility that dissolved chemicals will move straight up from the back-filled mine to the bottom of Snap Lake, by the process known as diffusion. Diffusion is a very slow process whereby dissolved chemicals move from where they are highly concentrated, as in pore-water in the mine back-fill, to areas where they are less concentrated, as in Snap Lake. This process becomes important if the groundwater beneath Snap Lake is not flowing anywhere, as some of the DeBeers data suggest.

NRCan recommends that DeBeers thoroughly investigate the impact of upward solute diffusion from the back-filled mine on Snap Lake water quality. This represents a conservative, "worse-case", situation which should be checked unless DeBeers can demonstrate that, after mine closure, there will be significant downward flow of groundwater beneath Snap Lake, preventing upward movement of dissolved chemicals.

2 **Issue: Thermal Condition of the North Pile**

Reference: ToR line# 307-310, EA Report Section 10.2.2.5.3 (p. 10-46 to 10-49), 10.2.2.7 and 10.2.2.8 (p. 10-53 to 10-54). Also Appendix IX.1 section 6.2.1, pg. IX.1-53 and IR3.4.15

DeBeers has concluded that the North Pile (NP) will freeze completely in two years and a surface active layer 2 metres thick will then develop. The thermal modelling done however is not adequate to determine the thermal condition of the NP, the rate of freezing, or if the NP will remain in a frozen or unfrozen state over the length of the project and beyond. The input parameters used for the thermal model are inadequately defined and in some cases not strongly justified. The thermal model must be revised to include appropriately defined parameters including: using air temperature data that represents current conditions and the range of conditions expected over the life of the project; an adequate representation of surface conditions including snow cover; thermal properties of the processed kimberlite paste, and the natural underlying heat flow from the earth. This must be done to properly evaluate the thermal condition of the pile and to determine the quantity and quality of seepage water.

February 14, 2003

SNAP LAKE - TECHNICAL REPORT
submitted by
NATURAL RESOURCES CANADA

Introduction

Natural Resources Canada (NRCan), is pleased to submit the following technical comments on the De Beers Canada Mining Inc. - Snap Lake Diamond Project Environmental Assessment report and its supporting documents and technical sessions. NRCan's comments are provided in its capacity of expert advisor in the earth sciences and are restricted to the subjects of hydrogeology, permafrost and ground thermal regime.

The technical comments on permafrost and impacts on the proposed development on the thermal milieu relate specifically to the following:

- impact on permafrost physical conditions including physical strength
- impact of modified permafrost temperatures and ground ice conditions on project facilities and structures (roads, buildings, containment structures etc.)
- impact of thermal erosion in relation to altered drainage
- thermal conditions of the North Pile
- the impact of climate change on the above

Technical comments on hydrogeology relate to the following topics:

- mine inflow: model calibration
- summary of field hydraulic data
- mine inflow: uncertainty and sensitivity
- mine inflow: leakance factors
- groundwater flow quantities and direction / water quality

Each specific technical comment states the developer's conclusion, NRCan's conclusion, rationale /evidence, and recommendations. In addition we have indicated whether resolution was achieved on each comment at the MVEIRB public Technical Sessions (TS) held in Yellowknife between November 25th and December 6th, 2002.

There are several issues identified by NRCan prior to the TS that remain unresolved following the TS. There are two that NRCan is flagging as being of principal concern: 1) groundwater flow quantities and direction / water quality and 2) thermal conditions of the North Pile.

Specific Comments

A. PERMAFROST and THERMAL MILIEU

1. Thermal condition of North Pile

Reference: ToR line# 307-310, EA Report Section 10.2.2.5.3 (p. 10-46 to 10-49), 10.2.2.7 and 10.2.2.8 (p. 10-53 to 10-54)
Also Appendix IX.1 section 6.2.1, pg. IX.1-53
IR3.4.15

Developer's Conclusion:
Based on thermal modelling, the North Pile (NP) will freeze completely in 2 years. A surface active layer 2m thick will then develop.

Our Conclusion:
Complete freezing of the North Pile (NP) may require more than two years. The resulting active layer may be thicker than that predicted by the model especially if climate warming is considered.

Our Rationale:
Long-term mean monthly air temperatures based on 1942-2001 (Table 9.3-4) temperatures at Yellowknife and Lupin have been averaged to represent that at the Snap Lake site. However these temperatures are lower than those recorded at Snap Lake for the period 1998-2001 (Table 7.2-6). For example the mean annual air temperature over the observation period at Snap Lake is -5.9°C and the Yellowknife/Lupin average is -8.3°C, a difference of 2.4°C. For all months the mean monthly air temperatures observed at Snap Lake are higher than the mean monthly values obtained by averaging the Yellowknife and Lupin data. Examination of climate records indicates that air temperatures have increased in the past decade (Fig. 1, attached to the end of the technical report). The 30 year normal mean annual air temperature for Yellowknife was -5.2°C for the period 1971-2000 and -4.6°C for 1961-1990 (Environment Canada data). Golder (2001) provides a table of air temperature data used for thermal model input is based on Yellowknife and Lupin data (Table 2.2 in Golder report, also Table 9.3-4 in EA) which is based on the period 1942-2001. The proponent however does appear to contradict themselves in the caption for table 10.2-8 in EA report which mentions that the air temperature used as an input to the thermal model is based on Yellowknife and Lupin data over the period of 1998-2000.

The use of mean temperatures over a longer period (as done in this study) may not be representative of the current situation. In other words, the air temperatures used to drive the thermal model may be too low. Results of model calibration (Golder 2001) predict foundation temperatures that are up to 3°C lower than those observed and also predict a thinner active layer. This difference in temperature is significant as temperatures within the NP are predicted to be close to the freezing point. Use of air temperatures that are lower than those likely experienced currently at the project site therefore could result in an under estimate of the period of time required for freezing of the NP and of the thickness of the resulting active layer. The proponent has not adequately considered the impact of climate change or variability over the project life time in modelling of thermal conditions of North Pile. In addition, the EA does not indicate if thermal modelling has been conducted to determine the impacts of climate warming on the thermal regime of the North Pile beyond the life of the project. The proponent mentions the impact of a 3°C increase in monthly air temperature between May and September would result in a 0.1m increase in active layer thickness. A recent warming trend (since the 1970s) has been observed in air temperature records as shown in figure 1 for the Yellowknife station. Winter air temperatures are also observed to have increased since the 1970s (Fig. 2, attached to the end of the technical report). This change in winter temperatures must also be considered in evaluating the impacts of climate warming on the thermal condition of the pile.

The values used for n–factors used in the thermal modelling are not strongly justified and use of inappropriate values could also be a reason for the difference between simulated and observed ground temperatures. A value of 0.5 was used for the winter n–factor but this value may be somewhat lower depending on the snow depth. The snow depth measured in the Snap Lake area over three winters varies from 19.1 cm in upland areas to over 100 cm in lowland areas (Table 9.3-14). There are no observations in the area of the North Pile and the closest site would appear to be a lowland site southeast of the NP where snow depths are greater than 80 cm. The reviewer's analysis of data from tundra sites in the Mackenzie Delta where snow depth is about 30 cm or more indicates that the winter n-factor is generally less than 0.5 and may be about 0.1 where snow depths are 70 cm. The proponent's use of a winter n–factor that may be too high results in an underestimate of the ground temperatures.

Golder 2001. Snap Lake Diamond Project Surface Engineering Optimization study, North Pile Management Report. Submitted to AMEC Simons Mining and Metals, Dec. 2001.

Discussion at Technical Sessions (Day 7, December 3, 2002)

The proponent was asked to clarify how the air temperature conditions representing current Snap Lake conditions were derived and if warmer conditions were considered in the thermal model. The proponent indicated that stability of the pile was the focus of thermal modelling and that air temperatures that may better reflect current conditions or the possibility of warmer conditions over the life of the project were not considered.

Recommendation:

The proponent should consider the warmer temperature scenario for modelling freezing of the pile during its development to provide estimates of rate of freezing and active layer thickness. This is required to provide the range of conditions that may occur and what impacts these may have on pile performance, seepage etc. In addition, the proponent should consider using available warming scenarios (such as CCCMa model results) to assess the possible impact of climate warming on the thermal regime of the North Pile. The proponent should also consider using more appropriate values for n–factors in the thermal model. We believe that this recommendation should be followed to adequately define the upper boundary conditions (air temperature and n–factors) of the thermal model and to better describe the thermal conditions of the pile (during the project and beyond) and the rate of freezing. Temperatures within the NP are expected to be close to the freezing point and it is important to adequately define the parameters used in the model to determine whether the NP will be frozen or unfrozen. Changes to the surface conditions that may occur during the reclamation phase should also be taken into account in modelling the thermal conditions after mine closure.

We also agree with the Department of Indian and Northern Affairs Canada (discussion at Technical Session Day 7) that other parameters such as the geothermal heat flux and the thermal properties of the processed kimberlite (PK) paste have not been adequately defined in the model. In particular, the freezing characteristic curve (unfrozen water content vs temperature curve) for PK paste has not been defined and this must be done to properly define the thermal properties of the PK paste.

> ***Resolution: Issue not resolved***
> *It is recommended that the proponent revise the thermal model to adequately define the upper boundary condition (air temperature and n–factors) as described above, the lower boundary condition (geothermal heat flux) and the thermal properties of the PK paste. This is required to properly evaluate the thermal condition of the pile (internal temperatures and active layer thickness), whether it remains frozen or unfrozen over the length of the project and after mine closure and freezing rates. The quantity and quality of seepage water should then been determined using the revised model results.*

2. Impact of environment on proposed development and activities forming part of the proposed development - Climate impacts on Tibbitt to Contwoyto Lake winter road and other winter access roads associated with project

Reference: ToR 2.8 line #518-525, IR 3b 4.3.3, EA Report Section 6.6.1.2 (p. 6-92 to 6-94)

Developer's Conclusion:
The proponent has estimated that over the period of peak traffic (present to 2010), the operating window for the winter road will be between 60-90 days with a median of 78 days. This conclusion is based on an analysis in the trend of the freezing index for Yellowknife from 1944 to 2001 and a relationship between the freezing index and actual operating window between 1995-2000. Environment Canada in IR 4.3.3 (IR 3b) suggested that a projection based on long-term trend analysis will not provide a conservative approach and use of a shorter term trend analysis for the last 20 years would result in an estimate of an operational window for the road under more current climatic conditions. The proponent was asked to provide an estimate of the window of operation that best reflects the current climate. The proponent responded that use of more recent data in trend analysis would not necessarily reflect current climate conditions as the three warmest years on record occurred in the late 1990s and these data would too heavily skew

the results.

Our Conclusion:
We agree with the suggestion of Environment Canada that a trend analysis of data from the last 20 years would better represent current climatic conditions and provide a more conservative approach. The approach taken by the proponent may tend to over estimate the length of the window of operation for the road. In addition, use of the air freezing index only may also lead to errors in the analysis as the timing and amount of snow is an important factor influencing the onset and rate of freezing and the onset of thaw in the spring. The proponent does acknowledge that snow cover is important and the year 2001 does not fit their established correlation between air freezing index because the 2000-01 season, while a normal year for temperature was severely affected by an early season snowfall in October. This resulted in a delay in opening of the road of 2 weeks. A fairly small data set was used to establish the correlation utilized by the proponent and a large amount of scatter could exist in this relationship due to variations in snow cover. Use of this relationship therefore could result in errors in estimates of the operational window for the road.

Our Rationale:
Fitting a straight line trend to a data set that is not inherently linear does not provide the best representation of the change in air temperature over time. Both the records of mean annual air temperature and the mean winter temperature for Yellowknife (Environment Canada data) show a decreasing trend from 1944 to the late 1960s to early 1970s which is then followed by an increasing trend (Figs. 1 and 2). If a low order polynomial is used instead of a linear fit, an increase in the rate of change is also observed from the 1970s to the present. A more appropriate approach would be to break the data set into two sections and determine the linear trend for both or to fit a non linear equation to the entire data set. The proponent's analysis does not consider that there is an increasing trend in air temperature (decreasing trend in air freezing index) over the last 30 years of the record and underestimates the increase in temperature that has occurred over the last 30 years (Figs. 1 and 2). The proponent's analysis therefore probably does not represent current conditions and extrapolation of this trend will likely underestimate air temperatures (or overestimate the freezing index) in future years. This could have important implications for the operating window of the road over the lifetime of the project even if traffic volumes over the last 15 years are reduced from the peak values.

Normally when solving problems such as rate of freezing of the active layer, the freezing index for the ground surface is used. This index takes into account the effect that snow cover has on determining the response of the ground thermal regime to changes in air temperature. An empirical n–factor (see for example Lunardini, 1978) is often used to describe the relationship between air and ground freezing indices. By only considering the air freezing index, the proponent has not taken into account the impact of the variability in timing and amount of snow in influencing the onset of freezing and thawing of the ground or ice beneath the winter road.

Lunardini, V.J., 1978. Theory of N–Factors and Correlation of Data. Proceedings of the Third

International Conference on Permafrost, Volume 1, Edmonton, Canada.

Recommendation:

Pre -Technical Session Recommendation

The proponent should at a minimum conduct a trend analysis for the last 20 to 30 years of air temperature data to produce a more conservative estimate of the operational window of the winter road over the life of the project to consider what impact a shorter season may have on the project.

Discussion at Technical Sessions (Day 8, December 4 2002)

Results of analysis considering the trend in air temperature over the last 30 years was presented by EBA on behalf of the proponent. The operating window for the winter road was determined to be between 66 and 84 days with a median of 75 days. We are satisfied that this revised analysis has considered current climatic conditions and provides a more conservative estimate of the operating window for the winter road.

Resolution: *Issue resolved*

3. Impacts of aggregate use - terrain disturbance associated with ground ice thaw

Reference: ToR 2.6.2 line#311-312, EA section 10.2.2.2, 10.2.2.3 (p. 10-36 to 10-43) and 10.2.1.5 (p. 10-31 to 10-34)

Developer's Conclusion:

The proponent has concluded that no zones of massive ground ice were encountered during the aggregate investigation program and there was only minor ice lensing except beneath peat deposits. The EA report does not comment on the potential for ground ice thaw associated with aggregate extraction from the esker and related terrain disturbance. It must be assumed then that the proponent believes that massive ice does not exist in the esker deposit.

Our Conclusion:

We do not necessarily agree with the proponent's conclusion that massive ice is not present in the esker deposit. It is not clear how the proponent reached their conclusion and sufficient evidence may not exist to support the conclusion. Evidence does however exist that massive ice possibly exists in the esker deposit.

Our Rationale:

It appears from the geotechnical investigations performed by Golder (2001) that two boreholes were drilled in the esker deposit. A map however is not provided in this report that shows the location of the boreholes. The proponent's conclusion that no massive ice is present in these sediments appears to be based on observations made in these two boreholes. An excess ice content of 10-20% is reported to occur in one of the boreholes. Photographs are presented in the report by Golder (2001) which show a pond formed in the middle of the esker due to suspected massive ice that has melted out. Massive ice could therefore be present in this area. Massive ice has been observed in similar deposits such as in the esker sediments at Ekati (see for example Dredge et al., 1999).

Recommendation:

Recommendation/Question at Technical Sessions (Day 8, December 4 2002)
The proponent does not indicate whether other subsurface investigations such as geophysical surveys (e.g. ground penetrating radar (GPR)) have been carried out at the esker. Golder et al. (2001) refers to geophysical surveys in the plant area and the air strip but not the esker. A report containing details of the esker investigation (Golder, 2000) is referred and may contain information regarding the results of further subsurface investigations. Examination of this report (Golder, 2000) is required to determine whether aggregate use may lead to terrain disturbance related to ground ice thaw.

References:
Dredge, L.A., Kerr, D.E. and Wolfe, S.A., 1999. Surficial materials and related ground ice conditions, Slave Province, N.W.T., Canada; Canadian Journal of Earth Sciences, 36: 1227-1238.

Golder Associates Ltd. 2001. Report on Snap Lake Diamond Project Surface Engineering Optimization Study Geotechnical Factual Report. Report No. 012-1436/5211 submitted to AMEC Simons Mining & Metals.

Golder Associates Ltd. 2000. Factual Report on Site Investigation Programs, Snap Lake Advanced Exploration Project, NWT. Report No. 002-2401.5240 submitted to Winspear Resources Ltd. dated February 2000.

Discussion at Technical Sessions (Day 8, December 4 2002)
DeBeers responded that no geophysical surveys such as GPR had been carried out on the esker to determine if massive ice was present. DeBeers also indicated that the area affected has been small in the past and material would only be extracted from the top and sides of the deposit (ie. excavation would not be deep or to the level of possible massive ice) and thaw of massive ice if present would not be a concern. DeBeers committed to conduct a ground penetrating survey before any future work is done on the esker site. We recommend that DeBeers honour this commitment and attempt to avoid areas of massive ice in extracting material from the esker because disturbance of the surface of the esker would result in changes to the ground thermal regime and may lead to thawing of any ground ice that may be present. DeBeers will need to consider thaw of massive and surface settlement in its reclamation plans if areas of massive ice are not avoided during removal of material of the esker.

> ***Resolution: Issue resolved*** *providing DeBeers conducts the GPR surveys it has committed to do and attempts to avoid removal of material from areas where massive ice*

may be present.

4. Impact of project on permafrost thermal regime

Reference: ToR 2.6.2 line# 299-310, EA Report Section 10.2.2.5 (p. 10-44 to 10-52), 10.2.2.8 (p. 10-53 to 10-54).

4a. Impact of underground mine on ground thermal regime.

Additional reference: ToR line# 293-295, MVEIRB IR#1, GLL IR 1.13, p. 66

Developer's Conclusion:
Some warming of the ground surrounding the ramp and ventilation raises in the permafrost zone is expected due to movement of warm air from the mine to the surface. Upon closure of the mine, it is expected these openings will freeze once workings are sealed and movement of warm air stops. The ground thermal regime and active layer however may vary from pre-development conditions. The issue of thermal erosion associated with seepage at the vertical interface of frozen and unfrozen rock below the shoreline of Snap Lake was raised by another reviewer in GLL IR 1.13 who asked if this had been taken account in making estimates of seepage into the mine. DeBeers replied that thaw erosion effects were not directly considered in seepage estimates but this volume of flow is expected to be negligible compared to the overall inflows into the mine.

Our Conclusion:
We agree with the proponent's conclusion that warming and permafrost thaw will occur in the ground surrounding the ramp and ventilation raises. Increased subsurface water flow associated with permafrost thaw however can further enhance thaw. Thaw of permafrost may result in changes in the position of frozen/unfrozen interfaces and change in the configuration of taliks.

Our Rationale:
No thermal modelling has been done and the proponent has not given any indication of the magnitude of permafrost thaw in the ground surrounding the ramp and ventilation raises. The proponent has also not considered what the additional impact of climate change over the length of the project and beyond may have on permafrost in the vicinity of the mine. Ground temperatures are fairly warm in the vicinity of Snap Lake (Golder, 2001) and warming of the permafrost due to mine development could possibly result in changes in the position of the frozen/unfrozen interfaces and changes in the configuration of taliks. It is not clear from the EAR if the proponent has considered these effects.

We agree with the proponent that seepage related to permafrost thaw may be quite low. However an increase in subsurface flow will accompany permafrost thaw and this will provide a mechanism for heat transfer (convective) to the surrounding frozen ground. As thaw of permafrost occurs therefore, this increase in subsurface water flow may further enhance the warming of the ground (see for example Michel and van Everdingen, 1994) - in other words the additional seepage may promote further warming of the permafrost.

Recommendation:

Question at Technical Sessions (Day 8, December 4 2002)

Can the proponent comment on the effect that the additional seepage associated with permafrost thaw will have on the thermal regime of the ground surrounding the ramp and ventilation raises and whether this will result in significant changes in position of frozen/unfrozen interfaces and configuration of taliks? Climate change should also be considered in this analysis to determine what the effect of mine development may have on the surrounding ground thermal regime and permafrost distribution over the length of the project and beyond.

Golder Associates Ltd. 2001. Report on Snap Lake Diamond Project Surface Engineering Optimization Study Geotechnical Factual Report. Report No. 012-1436/5211 submitted to AMEC Simons Mining & Metals.

Michel, F.A. and van Everdingen, R.O. 1994. Changes in hydrogeologic regimes in permafrost regions due to climatic change. Permafrost and Periglacial Processes, 5, 191-195.

Discussion at Technical Sessions (Day 8, December 4 2002)

The proponent adequately indicated that seepage related to thaw of permafrost will be small.

Resolution: *Issue resolved*

4b. Impact of roads, airstrip, mill and ancillary facilities etc. on ground thermal regime.

Developer's Conclusion:

Warming beneath these structures is expected to occur. Thaw stable fill will be used for construction of roads and the air strip and other structures will be constructed on intact bedrock. Noticeable settlement is therefore not expected. Following closure, the ground thermal regime may be different than that of pre-development conditions. The resulting active layer may be thicker than under pre-development conditions due to the presence of fill materials (which absorb more radiation). The depth of the active layer will depend on the depth and thermal conductivity of fill materials placed at these locations.

Our Conclusion:

We agree with the proponent's conclusion but the proponent has not indicated the magnitude of the changes in the ground thermal regime and has not considered the impact of climate change except for mentioning that the active layer could double in thickness (no evidence for this is presented however). Although thaw settlement may not be an issue, permafrost thaw and increases in active layer thickness can have implications for drainage and subsurface water flow.

Our Rationale:
Due to limited surface buffering effect and thermal properties of materials, thick active layers (7 to 8 m thick) develop in this region. The ground thermal regime therefore may be expected to be sensitive to surface disturbance and climate change, and active layers may increase significantly in response to warming. In areas where thick organic layers (up to 3 m thick) presently exist such as at the sites of air strip expansion and North Pile, the active layer is likely much thinner (and mean ground temperatures cooler) than in surrounding non organic terrain. Removal of this organic material prior to construction would result in significant increases in mean ground temperatures and active layer thickness. Although climate change may have minimal impact on the integrity of mine facilities and structures during the lifetime of the project, it may have an important impact on the ground thermal regime when coupled with disturbance effects that extend beyond the lifetime of the project.

Recommendation:
Pre Technical Session Recommendation/Question
We recommend that the proponent consider the combined effects of the disturbance associated with the construction of mine facilities and infrastructure and climate change on the permafrost thermal regime and associated changes in active layer thickness over the lifetime of the project and beyond. This should be considered when evaluating impacts of the project on drainage and subsurface water flow.
Discussion at Technical Sessions (Day 7 and 8, December 3 and 4 2002)
The proponent agrees that warming of the ground and increases in active layer thickness may be associated with removal of active layer and establishment of ponds at the site of the North Pile. This could result in some water bypassing ditches. This is being considered in the seepage model.

Resolution: *Issue resolved*

4c. Impact of Water Management Pond

Additional reference EA section 10.2.1.5 (p. 10-31 to 10-34)

Developer's Conclusion:
A talik exists beneath Dam 1and seepage beneath the dam has been considered. The existence of a talik is confirmed by ground temperature measurements in a borehole 18 m deep (BH2). Subzero temperatures are not observed in BH2 (Golder, 2001), so the talik extends to at least 18 m. The proponent however has not given an estimate of the base of the talik. The dams are founded on bedrock so thaw settlement related to ground ice thawing is not of concern. The EA report however concludes that additional thawing related to climate change may result in increased seepage from the water management pond. Dam 1 and Dam 2 will need to be raised by 2m to increase storage capacity as underground flows increase, possibly in year 2 although timing depends on the flows. No comments are made on the impact expansion of the pond may have on the ground thermal regime and the size of the talik.

Our Conclusion:
Impoundment of water to form the water management pond (WMP) would result in warming of the surrounding ground and this increase in ground temperature would be expected to continue as the WMP expands. The talik therefore could increase in size as a result and climate warming could lead to further expansion of the talik. We are therefore mostly in agreement with the proponent's conclusions. It is not clear however, what the vertical and lateral extent of this talik is and how this may change over time in response to the impoundment of water, expansion of WMP and climate change.

Our Rationale:
The existence of unfrozen ground to depths of 18 m is confirmed by the ground temperatures measured in BH2 (Golder, 2001). Extrapolation of the temperature profile would indicate that the talik extends to just below 20 m. We had some difficulty interpreting the profiles provided due to the numerous lines presented on the graph but the direction of the gradient would appear to suggest that warming is occurring and the unfrozen zone is possibly expanding. Further expansion of the pond would lead to an increase in the area covered by water and lead to further warming of the ground and expansion of the unfrozen zone. This coupled with the effects of climate warming could lead to increases in seepage from the WMP.

Recommendation:
Pre Technical Session Recommendation/Question
Although the proponent mentions that increased thawing of permafrost due to climate change may result in increased seepage from the WMP, it does not appear that an estimate has been made on how much thawing will occur. The impact of the expansion of the WMP on the permafrost regime also does not appear to be considered. We recommend that the proponent consider the effects of both climate change and WMP expansion on the ground thermal regime to determine the change in the extent of the talik and associated seepage that may occur.

Golder Associates Ltd. 2001. Report on Snap Lake Diamond Project Surface Engineering Optimization Study Geotechnical Factual Report. Report No. 012-1436/5211 submitted to AMEC Simons Mining & Metals.

Discussion at Technical Sessions (Day 8, December 4 2002)
The proponent indicates that over the past two years there has not been any changes in thermal conditions in the area of the dam. Some seepage will occur as warming of the bedrock occurs and this has been incorporated in the water quality model and water management plan. To the proponent's knowledge no observations of seepage around the water management pond itself.

> ***Resolution: Issue resolved*** *providing additional seepage is adequately accounted for in the water management plan.*

5. Current subsurface distribution of permafrost and taliks and impacts of development and climate change on this distribution

Reference: ToR 2.6.2 line#293-295, EA Report Section 10.2.1.5 (p.10-31 to 10-34), ToR

2.6.2 line# 299-310, EA Report Section 10.2.2.5 (p. 10-44 to 10-52), 10.2.2.8 (p. 10-53 to 10-54) IR 3.10.6 IR 1.48, IR 2.1.5

Developer's Conclusion:

Evidence from ground temperature measurements in boreholes ranging in depth from 8 to 300 m indicate that permafrost up to 225 m thick exists in inland areas while taliks exist beneath large lakes which extend to the deep groundwater zone (data presented in Golder 2001 and 2002). Taliks exist beneath smaller lakes but permafrost separates these taliks from deep groundwater. Permafrost north of Snap Lake is reported to be 225 thick. Permafrost is absent beneath Snap Lake and the talik extends to 20 to 40 m from Snap Lake. Permafrost gradually increases in thickness with distance from Snap Lake. Only one borehole (about 200 m from Snap Lake) in the mine facilities area is deep enough to allow an estimate of permafrost thickness. The base of permafrost at this location is estimated to be between 140 and 150 m deep. A talik also exists at the outfall of small lake IL1 (now the WMP) which is probably due to flowing outfall water limiting permafrost development. Active layer thicknesses are generally between 5 and 7 m except in areas where thick peat covers exist.

Our Conclusion - and additional questions and comments:

We generally agree with the proponent's conclusion. It is however difficult to get an idea of the vertical and lateral extent of taliks and permafrost. This is particularly true in the area of the WMP. Cross-sections showing the configuration of taliks and permafrost derived from borehole temperature data may have been useful. There is no evidence that thermal modelling has been done to better define the extent of taliks. Adequate delineation of taliks and permafrost is required to determine the groundwater flow regime.

The Snap Lake Project will result in disturbance of the ground thermal regime adjacent to Snap Lake where permafrost is reported to be warm and thin. There will also be disturbance in the area surrounding the WMP where a significant talik presently exists. Given the discussion above regarding Issue #4 (Impact of development on permafrost thermal regime) of possible impacts of both development and climate change on the ground thermal regime, there could be expansion of taliks as permafrost thaws. Expansion of the talik surrounding Snap Lake would result in a larger zone through which surface and deep groundwater would be connected leading to greater interaction between surface water and deep ground water. As already pointed out above, infiltration and subsurface flow may increase as active layer thickness increases. These impacts may have implications for the water balance as well as water quality.

It is not clear from the EA report if expansion of taliks and the possible increase in interaction between surface and ground water has been considered.

References:

Golder Associates Ltd, 2002. Report on Snap Lake Diamond Project Environmental Information North Lakes Program. Submitted by De Beers Mining Inc.

Golder Associates Ltd. 2001. Report on Snap Lake Diamond Project Surface Engineering Optimization Study Geotechnical Factual Report. Report No. 012-1436/5211 submitted to AMEC Simons Mining & Metals.

Recommendation/Discussion at Technical Sessions (Day 8, December 4 2002)
The proponent did not conduct any thermal modelling to determine the distribution of taliks. They state they have enough data to determine where through taliks exist beneath lakes. Issues related to talik beneath the WMP were discussed in 4c.

Resolution: *Issue resolved.*

B. HYDROGEOLOGY

1. Mine Inflow : Model Calibration

Reference : ToR lines 351-355; EAR Appendix IX.3, Appendix A, Attachment 1

Developer's Conclusion:
On page 10 of Appendix IX.3, the proponent's consultant, HCI, states that there is no water level (head) data with which to calibrate the numerical model of groundwater inflow to the mine workings.

Our Conclusion:
In responses 2.6.2 and 2.6.3 to NRCan Information Requests for head data characterizing the deep groundwater flow system, the proponent has provided Attachment 1 of Appendix A of Appendix IX.3 of the EAR. This attachment contains shut-in head measurements performed during the 2001 AEP.

Our Rationale:
NRCan questions why the proponent has not provided HCI with the head data. NRCan would also like to know how simulated heads from the model compare to these data, and how simulated mine inflow compares to actual inflow.

Recommendation:
NRCan recommends that the proponent provide its consultants, HCI, with all available head data in order to better calibrate their flow model. Alternatively, the proponent should explain why head data were disregarded.

Resolution:
The proponent has explained (TS, Day 2, AM) that the underground head measurements are viewed as unrepresentative of normal in-situ conditions and have been ignored in the

modeling. NRCan's concerns are largely unresolved.

2. Summary of Field Hydraulic Data

Reference : ToR lines 351-355; EAR Appendix IX.3, Appendix A, Attachment 1

Developer's Conclusion:
Attachment 1 of Appendix A reports all the field hydraulic data obtained from the 2001 AEP including measurements of shut-in head and hydraulic conductivity from flow tests and shut-in recovery tests.

Our Conclusion:
NRCan acknowledges receipt of the field hydraulic conductivity data but has questions relating to how these data were derived and how they were combined to yield the conductivity values used in the numerical groundwater flow model.

Our Rationale:
NRCan would like references for the methods used to derive hydraulic conductivities from the flow and the shut-in recovery tests. The test analysis does not appear familiar and the equation used is not documented. Also, some justification should be given for the weighting scheme that is used to derive geometric average values for each borehole.

Recommendation:
NRCan recommends that the proponent and its consultants, HCI, better document the derivation of hydraulic conductivity values from borehole tests. NRCan recommends that the proponent pool measurements from all boreholes and display histograms of (log) hydraulic conductivity for each rock type. The proponent would then be in a better position to clearly justify a choice of representative value (geometric mean or otherwise) as well as the variability and uncertainty in measurements (See item 3).

> ***Resolution:***
> *The proponent provided a verbal reply to this comment at the evening Hydrogeology Breakout Session on day 2 of the TS. NRCan's concerns are resolved.*

3. Summary of Field Hydraulic Data

Reference : ToR lines 351-355; EAR Appendix IX.3, Appendix A, Attachment 1

Developer's Conclusion:

In Attachment 1 of Appendix A of Appendix IX.3, the proponent's consultant, HCI, reports logs of groundwater discharge along boreholes of the 2001 AEP.

Our Conclusion:
In some boreholes, there are zones of elevated discharge. These zones include the Snap fault (and other hydraulically significant structures) and the granite-metavolcanic contact (apparent in UG-45).

Our Rationale:
The borehole logs of groundwater discharge provided in Attachment 1 clearly reveal active hydraulic features with corresponding high hydraulic conductivities.

Recommendation:
NRCan recommends that active hydraulic features including the Snap fault and the granite-metavolcanic contact be featured explicitly in revised numerical groundwater flow models.

> ***Resolution:***
> *The proponent has given a verbal reply to this comment at the TS (day 2-AM) but did not accept to make any revisions to the numerical flow model. NRCan's concern is unresolved.*

4. Mine Inflow : Uncertainty and Sensitivity

Reference : ToR lines 351-355; EAR Appendix IX.3, Appendix A, Attachment 1, Appendix B

Developer's Conclusion:
The proponent assumes that a logarithmic standard deviation of 0.576 provides a physically realistic representation of the variability of lognormally distributed parameters such as hydraulic conductivity (App. IX.3,p. 12 and App. B, p.B-1).

Our Conclusion:
NRCan believes that a logarithmic standard deviation of 0.576 is unrealistically low for hydraulic conductivity and related parameters such as leakance. Therefore, the uncertainty in estimated groundwater inflow is likely to be significantly understated.

Our Rationale:
Based on in-house experience, a survey of the literature (see for example Gelhar, L.W., Stochastic Subsurface Hydrology, Prentice-Hall, 1993) and data presented by the proponent in Attachment 1, NRCan believes that a more realistic, and conservative, logarithmic standard deviation for hydraulic conductivities in fractured igneous rocks would be 2 to 4 times greater than the specified value of 0.576. For example, the logarithmic standard deviations of hydraulic

conductivities measured in boreholes UG-83 (metavolcanics), UG-84 (metavolcanics) and UG-175 (hanging wall granite) are 3.11, 0.85 and 1.47, respectively. While these values reflect measurement variability and not the uncertainty in the overall effective conductivity, the proponent should nonetheless justify its choice of standard deviation using its own data.

Recommendation:
NRCan recommends that the proponent revise its uncertainty estimates for groundwater influx to the mine workings using more realistic standard deviations of log hydraulic conductivity based on actual data from the site.

> ***Resolution:***
> *At the TS (day 2 –AM), the proponent defended the sensitivity analysis and the choice of standard deviations that were used. NRCan's concern is minor but unresolved.*

5. Mine Inflow : Leakance Factors

Reference : ToR lines 351-355; EAR Appendix IX.3, Appendix C

Developer's Conclusion:
On page 12 of Appendix IX.3, the proponent concludes that estimates of groundwater inflow to mine workings are most sensitive to changes in the leakance values used for haulage drifts and mine panels. However, in Appendix C, the proponent concedes that the selection of parameter values used in their leakance formulas is rather arbitrary and is best made from calibration to actual inflow data.

Our Conclusion:
NRCan concludes that leakance values are far too important in the modeling of groundwater inflow to the mine, which is itself an important part of the EA, to be specified by more-or-less ad-hoc formulas provided without documentation or reference.

Our Rationale:
Considering the importance of leakance factors in the groundwater modeling exercise, NRCan believes that it would be worthwhile to develop more physically-based and defensible formulas for leakance, or search the literature more thoroughly for such formulas. For example, it should be possible to derive simple leakance formulas for inflow to drifts and mine panels assuming local steady-state radial or linear flow, respectively.

Recommendation:
NRCan recommends that the proponent adopt more realistic physically-based and defensible formulas for calculating leakance factors, the most important parameter affecting groundwater influx to the mine.

Resolution:
At the TS (day 2- AM, and evening Hydrogeology Breakout Session), the proponent defended the leakance values which were determined by trial-and-error model calibration rather than on the basis of physical principles. NRCan's concern is partially resolved.

6. Groundwater Flow Quantities and Directions

Reference : ToR line 221; EAR Section 9.2 (p.9-30); North Lakes Report Sections 5.2.1, 5.2.3 (p.41,48)

Developer's Conclusion:
Based on mass balance calculations, the proponent concludes that groundwater influx to North Lake is between 9 and 24 m3/d (or less than 1% of the value used in the EAR) and that influx to Northeast Lake is between 40 and 160 m3/d (or less than 20% of the value used in the EAR). The proponent's calculations assume steady-state conditions and perfect mixing of lake waters. The same fluxes, when estimated using a numerical flow model, are 5 to 10 times greater (Section 5.3). However, in section 5.4 (p.60), the proponent concludes that the (lower) values derived by mass balance calculation are the most reliable.

Our Conclusion:
NRCan believes that the proponent's estimates of groundwater fluxes to the northern lakes are very sensitive to assumptions made in the mass balance calculations, particularly that of perfectly mixed lake waters. The proponent should provide a more thorough discussion of the mixing assumption with supporting field data.

NRCan also believes that the proponent has dismissed the higher flux estimates from numerical modeling without sufficient justification. If the proponent believes that flux estimates from mass balance calculations are the most reliable, then these fluxes should be used to calibrate the regional numerical flow model.

Our Rationale:
NRCan believes that dense, saline groundwaters flowing into the northern lakes may accumulate in troughs on the lake bottom associated with structural lineaments representing the outlets of preferential regional flow paths. Such troughs may also contain the thickest deposits of fine-grained lake sediments where saline pore-water would tend to be retained. This scenario would invalidate the proponent's flux estimates based on mass balance calculations.

If there are different flux estimates based on numerical modeling and mass balance calculations, NRCan believes that reviewers should not be asked to accept the lower of the two estimates.

Recommendation:
NRCan recommends that the proponent provide stronger support for the lake mixing assumption

by documenting salinity (or electrical conductivity) profiles in the deepest portions of the northern lakes, at times of the year when stratification likely would be observed.

The proponent should also make further attempts to reconcile groundwater flux estimates based on the mass balance and numerical modeling methods.

Resolution:
Results of the proponent's North Lakes study were discussed at the evening Hydrogeology Breakout Session (TS day 2) and at the public TS (day 3 – PM). NRCan's concerns are unresolved.

7. Groundwater Flow Quantities and Directions

Reference : ToR line 221; EAR Section 9.2 (p.9-30); North Lakes Report Sections 5.2.2 (p.46)

Developer's Conclusion:
In Table 5.1 (p.46), the proponent estimates that the inflow to Northeast Lake from North lake is 1296908 m3/yr whereas the total outflow from North Lake is indicated as 989432 m3/yr.

Our Conclusion:
NRCan concludes that there may be an error in Table 5.1 (p.46).

Our Rationale:
NRCan does not understand how the inflow to Northeast Lake from North Lake can be greater than the total outflow from North Lake.

Recommendation:
NRCan recommends that the proponent check the figures presented in Table 5.1 (p.46).

Resolution:
At the public TS (day 3 –PM), the proponent agreed that there was an error in Table 5.1. NRCan's concern is resolved.

8. Issues : Groundwater flow quantities and directions / Water Quality

Reference: ToR lines 221, 250, 389; EAR Sec. 9.2 (p.9-30); North Lakes Report Sec. 4.0, 5.0, 6.0

Developer's Conclusion:
Under the proponent's model for the post-closure deep groundwater flow regime, groundwater flows downward from Snap Lake, and then outward, beneath the permafrost layer, to discharge

in surrounding lakes, including North and Northeast Lakes. Dissolved species such as chromium or phosphate are transported by advection from the flooded mine to discharge seeps in these lakes. However, the discharge of mine-affected groundwater to Northeast Lake is not expected to cause any water quality parameter to exceed its guideline threshold at any time. No mine-affected groundwater is expected to discharge in North Lake.

Our Conclusion:
In NRCan's opinion, the proponent's model for the post-closure deep groundwater flow regime and the transport of solutes is based on limited and ambiguous field observations. Unless additional data, conclusively supporting the model, are obtained, the proponent should investigate the impact of mine-affected groundwater discharge on surrounding lakes for a variety of possible scenarios. NRCan is particularly concerned about the possibility of diffusion-dominated solute transport from the back-filled mine, upward to Snap Lake. This would occur if groundwater beneath Snap Lake is essentially stagnant.

Our Rationale:
NRCan's conclusion is based on a review of the following information pertaining to the deep groundwater flow regime beneath Snap Lake :

- On page 9-30 of section 9.2.1.4.2 of the EA Report, it is stated that "hydraulic heads measured in underground boreholes are virtually identical to the elevation of water level in Snap Lake"
- Field hydraulic data from the 2001 AEP, presented in Attachment 1 of Appendix A of Appendix IX.3, show that heads in boreholes UG-83, UG-84, UG-175 and UG-176 are significantly greater than the water level elevation of Snap Lake (444 m asl). Upon questioning by NRCan during the MVEIRB Technical Sessions (Technical Session Notes, Day Two, Morning), the proponent stated that these data have been ignored since they were obtained during short static tests and are not believed to represent steady-state, long-term values. The proponent also stated that no abnormal heads have been observed around Snap Lake. However, it is unclear to NRCan how shut-in head values, even for short tests, can exceed the head in Snap Lake, a regional headwater lake.
- Head data for monitoring well MW02-04 (between Snap and North Lakes), presented in Table 4.3 (p.38) of the 2002 North Lakes Program Report, are higher than heads in Snap Lake. As the proponent points out in section 4.4.2 of this report, this is a physical impossibility under their conceptual model. While NRCan acknowledges the technical difficulties encountered with these measurements, the proponent's explanation is not fully satisfactory.
- Head data for monitoring well MW02-05 (on the shore of Snap Lake), presented in Table 4.3 (p. 38) of the 2002 North Lakes Program Report, indicate a weak downward head gradient beneath Snap Lake, based on a head difference of 0.08m over a vertical distance of about 120m. However, given the observed transient fluctuations of head in the monitoring well (possibly due to barometric effects) and uncertainties in lake level measurements, it is unclear if these data can provide a reliable estimate of any true steady downward head gradient.

- In Table 5.2 of the 2002 North Lakes Program Report, the proponent presents an estimate of average total groundwater discharge from Snap Lake of 3700 m^3/day. This estimate was calculated from water level declines in Snap Lake. Assuming vertical downward flow, a lake area of 7.9 E+06 m^2 and a hydraulic conductivity of 5.0 E-06 m/s (Table 5.4, K_H for hanging wall granite), this flux corresponds to a downward head gradient of about 0.001.

NRCan concludes from this list of conflicting evidence that a downward groundwater flux beneath Snap Lake has not been demonstrated conclusively. In NRCan's opinion, based on this information, there is a distinct possibility that groundwater beneath Snap Lake will be essentially stagnant after closure of the mine, despite the relatively high conductivities that are observed. In such a case, diffusion would become the dominant solute transport process. Although diffusive transport is quite slow, the distance from the mine to Snap Lake is quite small and a large solute concentration gradient between water in the back-fill paste and in the lake could persist for a long time.

NRCan has conducted a preliminary, steady-state, analysis of advective-dispersive transport between the back-filled mine and the bottom of Snap Lake. According to this analysis, upward transport of solutes is possible if the following condition is met :

$$\mathrm{Ln}\,(C_M / C_L) > v\,L / D = Pe$$

Where C_M and C_L are the solute concentrations in the mine and lake, respectively; Ln denotes the natural logarithm; v is the downward seepage velocity; L is the distance from the mine to the lake bottom; D is the hydrodynamic dispersion coefficient; and Pe is the Peclet number. However, given the difficulty in determining an appropriate value for D, it would be conservative to simply consider the maximum possible upward solute flux f which occurs for v=0 (unless v is directed upwards, of course) :

$$f = -D_e\,(C_M - C_L) / L$$

Where D_e is the effective diffusion coefficient for the fractured medium. Considering chloride, for example, and assuming that D_e = 4.48 E-02 m^2/yr, C_M = 0.661kg/m^3, C_L = 0.001 kg/m^3, L = 100 m and a mine foot-print area of 1.226 E+06 m^2, the mass flux into Snap Lake is approximately 360 kg/yr. While NRCan's analysis considered only steady transport of a conservative species, a more thorough analysis should consider transient transport with adsorption, and diffusive exchange between fractures and the rock matrix. The model of Sudicky and Frind (WRR, 18(6) 1634-1642, 1982) may be applicable here, letting v go to zero.

Recommendation:

NRCan recommends that the proponent thoroughly investigate the impact of upward solute diffusion from the backfilled mine on Snap Lake water quality. This represents a conservative, "worse-case", scenario which should be documented unless the proponent can demonstrate that there will be a significant post-closure downward groundwater flux beneath Snap Lake effectively preventing upward migration of solutes.

Resolution:

This technical comment was prepared after the public Technical Sessions in November-

December 2002, in consideration of the discussions held on the North Lakes hydrogeological study during the afternoon session of Day 3. The proponent has not yet had an opportunity to respond. Therefore it is not resolved.

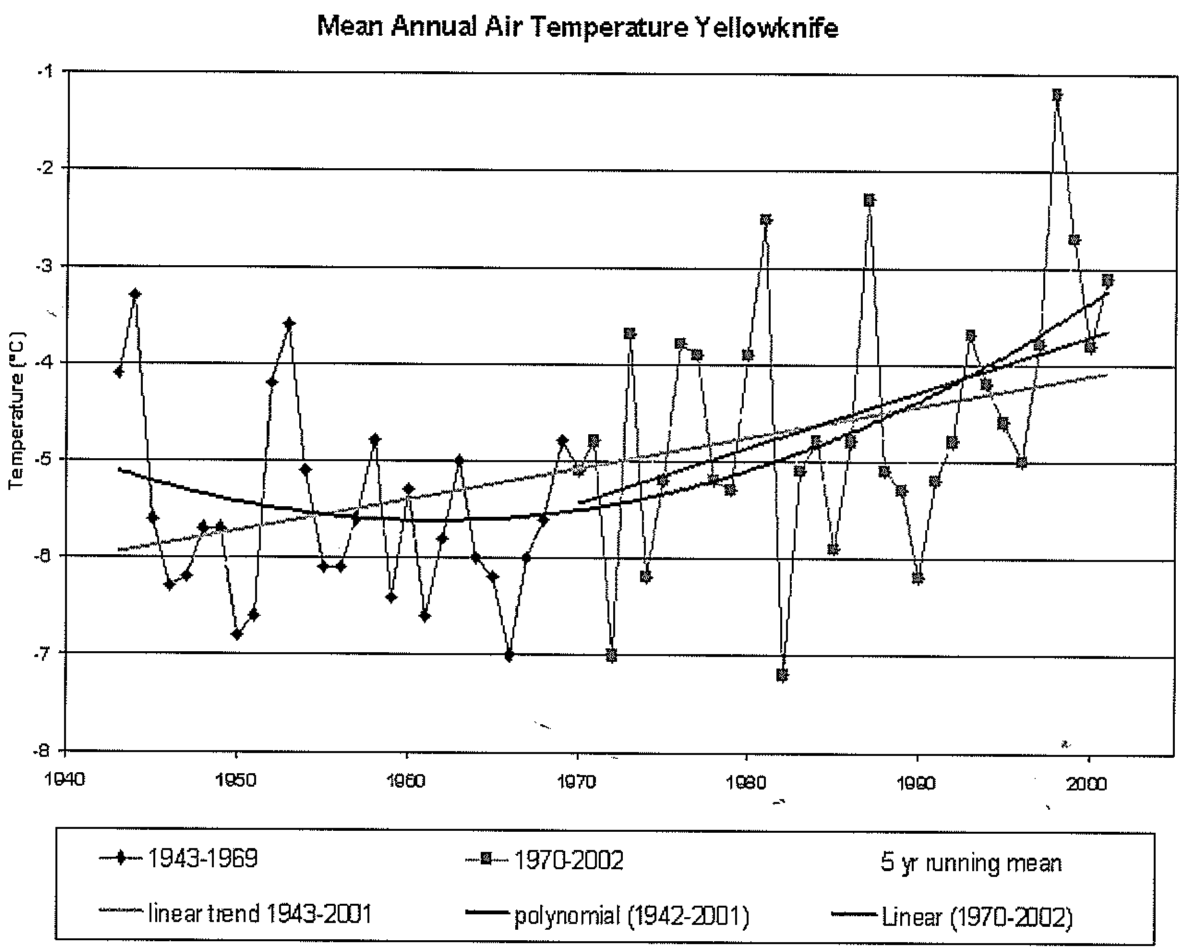

Figure 1. Mean annual air temperature for Yellowknife from 1943 to 2001 (Data from Environment Canada)

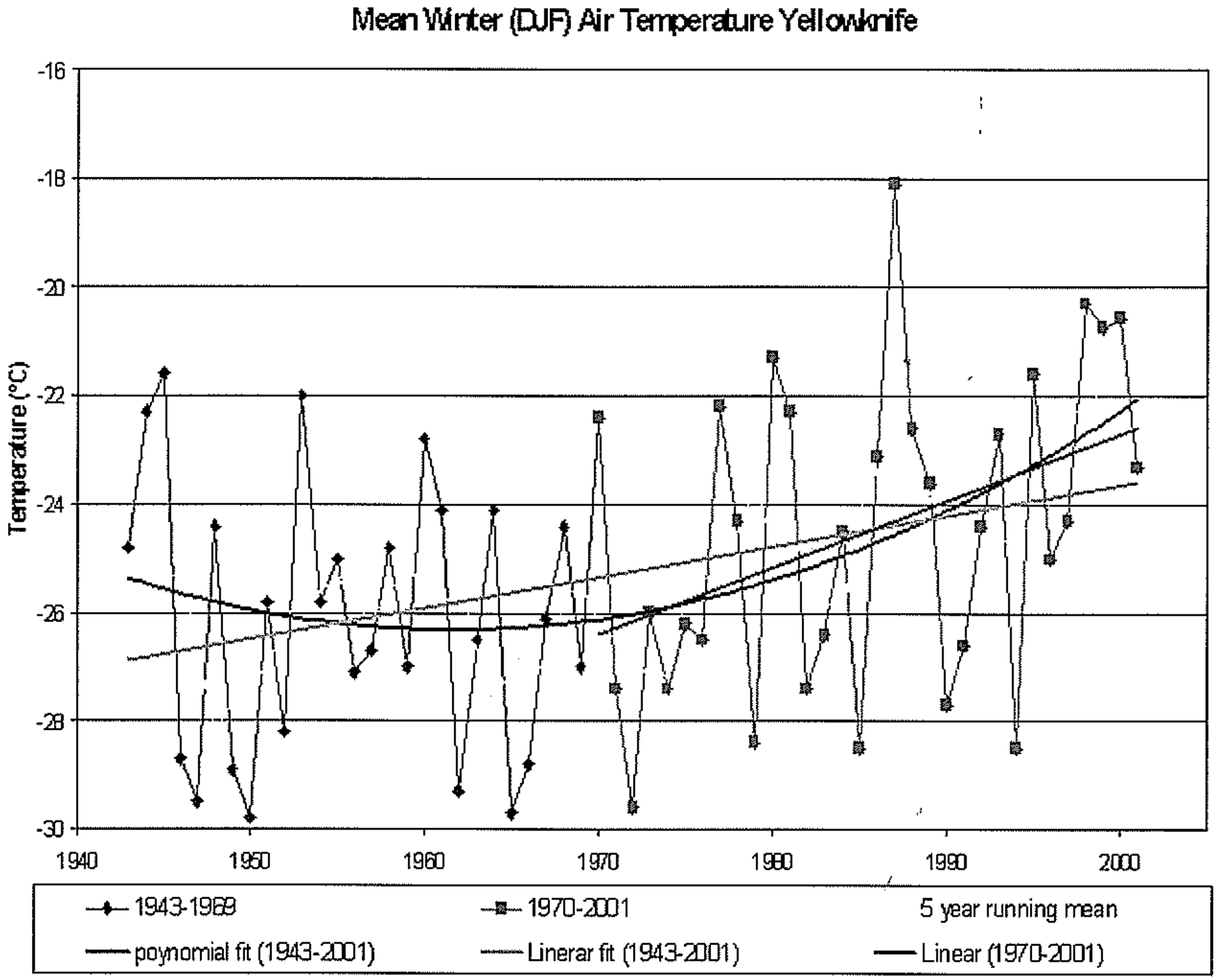

Figure 2. Mean winter (December, January, February) air temperature for Yellowknife (Data from Environment Canada).