Ekati Minesite -

Review of Closure Ecological Risk Assessment for the Independent Environmental Monitoring Agency

prepared for:

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Summary of This Review

The Independent Environmental Monitoring Agency (IEMA) has asked Dr. Kevin Morin of the Minesite Drainage Assessment Group (MDAG) to review and comment on the Ekati Closure Ecological Risk Assessment (ERA). This ERA is based on three documents: thermal modelling, water-quality modelling (including water-balance modelling), and the risk assessment. The focus of this review is the predicted closure water contamination and water quality, leading to my comments, concerns, and recommendations.

A version of this review was dated January 19, 2017. On January 24, 2017, Dominion Diamond Ekati Corporation held the Waste Rock Storage Areas Seepage Technical Session (the "Workshop"). This provided the opportunity for Dominion Diamond and stakeholders to discuss concerns and uncertainties. Some concerns were clarified, and Ekati can resolve some uncertainties at a later time. Therefore, there have been no major changes to this review. For ease of comparison to my previous review, the paragraphs and recommendations herein with the words, "the Workshop", contain additional or clarified comments.

The accuracy of the thermal modelling at Ekati, and the water-quality assumptions, significantly affect the accuracy of the predicted water contamination. In turn, the accuracy of this predicted water contamination affects the accuracy of the estimated ecological risks. As a result, there is a cascading "daisy chain" effect on accuracy through these documents.

Overall, I find the results of thermal modelling and water-quality modelling overly optimistic. Therefore, I expect closure water contamination would be significantly worse than predicted in the Closure ERA.

This is due to issues, including:
- simplistic modelling,
- best-case assumptions,
- lack of numerous sensitivity analyses for important assumptions, and
- questionable assumptions that can be resolved simply by collecting data at Ekati.

The oversimplifications, unreliable assumptions, and other issues are discussed in detail in this review, and recommendations are offered to overcome them. For example, the amounts of water flowing into Ekati waste-rock storage areas (WRSAs) are the starting points for water contamination and ecological risk. In this Closure ERA, Ekati inflows were based on unrepresentative small-scale "test piles" at Diavik. In reality, Ekati can and should measure this important parameter at its own full-scale minesite.

1. Introduction

The Independent Environmental Monitoring Agency (IEMA) has asked Dr. Kevin Morin of the Minesite Drainage Assessment Group (MDAG) to review and comment on the Ekati Closure Ecological Risk Assessment (ERA). The focus of this review is closure water contamination and water quality. IEMA specified these terms of reference:

- -provide general comments and recommendations on the Closure Seepage ERA with emphasis on the seepage water quality and thermal modelling;
- - review and comment on the Water Quality Model in general with focus on methods used and their ability to accurately predict seepage water quality at closure; and
- - highlight any concerns and recommendations.

The documents reviewed here are:

1) Tetra Tech EBA Inc. 2016. *Thermal Evaluation Of Panda/Koala, Misery, Coarse Pk, And Fox Waste Storage Areas, Ekati Diamond Mine, NT.* FILE: E14103219-04 Revision 2. Dated May 2016. ["A thermal model has been developed that models the rate of permafrost development within the WRSA for the closure period."]
2) Golder Associates. 2016. *Water Quality Modelling of Seepage from Waste Rock Storage Areas*. Reference No. 1522809-16035-R-Rev0-6000. Dated October 11, 2016. ["Calibrated water quality models were developed for each waste storage area to estimate seepage water quality during the remaining years of operation and into closure."]
3) ERM Consultants Canada. 2016. *Ekati Diamond Mine Waste Rock Storage Area - Closure Screening Level Ecological Risk Assessment*. Project #0211136-2012. Dated October 2016. ["Development of an ecological risk assessment (ERA) for the closure period. The thermal and water quality modeling results fed into the completion of this component."]

These were downloaded from:
http://www.mvlwb.ca/Boards/WLWB/SitePages/registry2.aspx?app=W2012L2-0001

The thermal modelling (Tetra Tech EBA, 2016) was used in the predictions of seepage water contamination (Golder, 2016), and the risk assessment (ERM, 2016) used the seepage predictions to estimate environmental risk. Thus, this closure work is directly and substantially affected by the modelling results of both freezing and water contamination. If those modelling results are questionable or unreliable, then all the estimated risks, no matter how well calculated, will also be questionable or unreliable. This is the focus of this review.

2. Thermal Modelling

2.1 Introduction

Tetra Tech EBA (2016) initially states formally,

> "This report and its contents are intended for the sole use of Dominion Diamond Ekati Corporation and their agents. Tetra Tech EBA Inc. (Tetra Tech EBA) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than Dominion Diamond Ekati Corporation. . . ."

Because I am not an agent of DDEC, it is not clear to me how Tetra Tech EBA's sole-use limitations apply to me. Also, because I am a third party using this report, I hereby understand that Tetra Tech EBA "does not accept any responsibility for [its] accuracy".

2.2 One-Dimensional Thermal Modelling vs. Realistic Three-Dimensional Modelling

In 1996-1997, when the Ekati Project was first being reviewed and approved, thermal modelling predicted that the waste-rock storage areas (WRSAs) would freeze fully and quickly. That initial modelling used a one-dimensional model, with no consideration of internal heat generation, pore-gas convection, and waste-rock complexity (MEND, 1997; Morin, 2003). Internal heat generation became a research target in those early years (Dawson and Morin, 1996).

Notably, the approach used in original modelling of 1996 is the approach used now by Tetra Tech EBA in 2016, about 20 years later. Thus, the original concerns remain about using a one-dimensional model with no internal heat generation and no thermal convection, for three-dimensionally complex minesite components.

Water movement and pore-gas movement in waste rock cannot be reliably modelled one dimensionally. We know that from many full-scale waste-rock studies around the world. So heat transport and freezing in Ekati WRSAs should not be modelled that way either. In fact, pore-gas movement would be linked to thermal convection, so at least two-dimensional thermal modelling is warranted for Ekati.

Due to the limitations of the modelling, it is possible that the current thermal model for Ekati WRSAs over-estimates the degree and extent of freezing, which would reduce the predicted freezing of covers. For example, the above-zero zones (e.g., +5°C, Figures 50-76 in the Tetra Tech EBA report) within the kimberlite waste rock of the Fox WRSA, and within the schist/granite waste rock of the Misery WRSAs, may be there because of ongoing internal heat generation. This heat may be created by geochemical reactions like metal hydrolysis or sulphide oxidation. The proposed additional of at least 1,000,000 m^3 of thermally reactive schist to the Misery WRSA could increase the heat content and heat generation within this WRSA.

As a result, these reactive zones would not cool below freezing as predicted by the current, limited one-dimensional model, but remain thawed and release ongoing contaminated seepage. In fact, the discovery of unfrozen water within the core of the Fox WRSA heightens this concern. If correct, predictions of water contamination would be too low, and in turn the environmental risks higher than estimated in this Closure ERA.

To the credit of many modellers, they will not use a model that is more complex than their input data allows. In Section 5.2.1, Tetra Tech EBA explains,

> "Since these areas are relatively far from pile slopes or water bodies, they behave as one-dimensional thermal bodies. As well, there are various unknowns and uncertainties regarding the construction history, boundary conditions, and geometry of the WSAs to yield reasonable results with two or three-dimensional models."

Thermal convection and internal heat generation would refute the first sentence, as do the observations that:

(1) many Ekati thermistors are installed near the outer portions of the WRSAs (e.g., Figures 2, 5, and 8),
(2) a minimum of two-dimensional modelling is needed to define "relatively far from pile slopes", and
(3) convective cooling was discussed by Tetra Tech EBA.

The second sentence of that quotation tells us two- or three-dimensional modelling may not be possible with current information. If this is the case, freezing cannot be accurately predicted at Ekati, and predictions of water contamination should consider both frozen and unfrozen scenarios (a recommendation in Section 3.6 of this review).

Table A1 of Tetra Tech EBA (2016) lists 30 thermistor strings ("GTC") installed across the entire Ekati site, and some have been permanently lost, such as for the Misery WRSA, or provide sporadic/inconsistent data. This puts the onus on Ekati to collect sufficient input data to support more realistic modelling.

In contrast, Ekati's comment, on Board Directive Number 18 of *Table of Concordance with September 9, 2015 Board Directives,* says that thermistor monitoring is sufficient for the minesite components where operations have ended. For some components still operational, additional thermistors will be needed for "closure monitoring" (apparently not for modelling purposes). The responses to Board Directive Numbers 19 and 22 say the Lynx WRSA "will contain only geochemically stable granite waste rock that has no potential for environmental impact from seepage", although "geochemically stable" does not automatically mean non-reactive and non-heat-generating.

Thus, it is not clear if there may already be sufficient data for at least two-dimensional modelling with convection and internal heat generation, or if more installations and monitoring may be needed. Either way, more realistic, thermal modelling in at least two dimensions, including thermal convection and internal heat generation, backed by additional measured Ekati data, is warranted at Ekati. Such modelling is important for improving predictions of freezing and thawing, which in turn has a large effect on predictions of water contamination and the environmental risks after closure (discussed further in Sections 3 and 4 of this review).

At the Workshop, there was a discussion of the distance from the WRSA side slopes needed before one-dimensional modelling may be appropriate. This answer would require at least two-dimensional modelling. As this was not done, there is no technical justification that one-dimensional modelling is justified at the modelled locations.

At the Workshop, some concerns were raised that side slopes may experience more freeze and thaw, and thus a thicker active layer, than one-dimensional modelling would predict. Tetra Tech EBA will consider these issues.

In summary, my opinion is that the degree and extent of freezing have been over-estimated in this risk assessment by ignoring internal heat generation. Similarly, the degree and extent of freezing have been over-estimated or under-estimated in this risk assessment by ignoring convection. Tetra Tech EBA (2016) suggests "convective cooling" may occur in places, but convective heating can also take place. If correct, then water contamination and ecological risk could be worse than stated in the Closure ERA, and the predicted environmental value of proposed covers remains uncertain. This warrants further examination and monitoring.

2.3 The Proprietary GEOTHERM Model and Uncertainty in Modelling Results

Tetra Tech EBA (2016) explained that thermal modelling at Ekati was conducted using its own proprietary two-dimensional finite-element computer model named GEOTHERM. The software was reportedly used successfully on many arctic and subarctic projects, referenced as EBA documents. A search using Google Scholar did not identify any independent or academic validation of the model.

Details of the GEOTHERM model, such as how it simulates heat capacity and moisture contents, were not provided in this Ekati report. The one parameter discussed in the report was thermal conductivity ("k") of the mine materials. In simple terms, thermal conductivity is the rate at which heat moves through these materials, so that they will eventually freeze, or not freeze. This does not include the effect of thermal convection, which can have more influence.

There are other important parameters for realistic thermal modelling at Ekati, but conductivity is the only one discussed in the Tetra Tech EBA report. So I will use it here to illustrate how uncertain the results of the thermal modelling at Ekati can be.

Section 5.3.2 of Tetra Tech EBA (2016) presents the following equation on which thermal conductivity at Ekati was estimated:

$k_{dry} = 0.039\ n^{-2.2}$, where k is thermal conductivity (Watts/m•K) and n is porosity.

This equation is attributed to "Johansen, 1975". This equation is fundamentally critical to the modelling, but "Johansen, 1975" is not in the Tetra Tech EBA reference list.

"Johansen, 1975" is a Ph.D. thesis from the Norwegian Technical University, entitled "Thermal Conductivity of Soils", from more than 40 years ago. Although mine waste materials are not "soils", Johansen did look at some examples of crushed rock, but not Ekati rock. The equation above is

Equation 6 in Johansen's thesis.

This equation is very sensitive to porosity due to the exponent "-2.2". In other words, a minor change in porosity can result in a significant change in conductivity. In turn, a minor uncertainty in porosity can result in a major error in conductivity. Therefore, measuring porosity carefully, in three dimensions, throughout each Ekati WRSA, is important to improve the reliability thermal modelling.

However, porosity was apparently not measured throughout the Ekati WRSAs, because the values were not reported in the Tetra Tech EBA report. Presumably, some value of porosity was assumed, perhaps one value for each WRSA? This would not be reliable, as porosity likely varies from point to point in three dimensions in each WRSA, as a visual inspection would show. Also, porosity measurements in waste rock generally cannot be measured with sufficient accuracy for use in Johansen's sensitive equation.

Section 5.6 of Golder (2016) says that an assumed single value of porosity of 24% was used for some or all Ekati work. This unmeasured, single-value approach would not yield reliable estimates for Ekati thermal conductivities using Johansen's equation.

Therefore, the only fundamental thermal parameter that I can evaluate for the Ekati thermal modelling is likely based on overly simplified, unmeasured values of porosity at Ekati, entered into a 40-year-old Norwegian thesis equation that is very sensitive to porosity. The predictions of freezing at Ekati are so sensitive to this missing measured porosity that is difficult to consider the current thermal predictions as reliable. This cascades over to the water-quality model and the risk assessment, reviewed in sections below.

A sensitivity analysis of porosity and thermal conductivity would have told us how sensitive the freezing predictions at Ekati are to these assumptions. However, Tetra Tech EBA (2016) does not contain a sensitivity analysis on porosity or conductivity. I suspect the sensitivity is high. This would make the predictions of freezing less reliable.

Furthermore, the calculated conductivity values for kimberlite in Table 2 of the modelling suggest porosity was assumed to be around 0.2%. However, Johansen had no values below roughly 0.23% on which to ensure an accurate equation.

Finally, and most important, thermal conductivity can actually be measured under laboratory and field conditions. For this important Ekati Closure ERA, conductivity should not be calculated from poorly accurate porosity measurements (if measured at all at Ekati) using a sensitive equation developed from some crushed rock samples many decades ago in Norway.

Accompanying his equation, Johansen (1975) listed some methods for measuring thermal conductivity more than 40 years ago. Johansen's equation was used by Tetra Tech EBA, but not his, or others, methods for measuring thermal conductivity.

Thermal modelling and predictions of freezing are so important to environmental risk and water contamination that Ekati should have a database of dozens or more thermal conductivity values for

Ekati WRSAs. However, there are apparently no Ekati measurements of this critical parameter for the modelling of freezing.

As mentioned above, there are other parameters and equations on which the GEOTHERM model is based. However, these were not discussed in Tetra Tech EBA (2016), so I cannot evaluate the uncertainties associated with them.

Other uncertainties in thermal predictions include the proposed addition of more than 1,000,000 m^3 of thermally reactive schist to the Misery WRSA. At the Workshop, Tetra Tech EBA said this additional source of internal heat would not change the model predictions. This is correct about the current modelling that does not include internal heat generation, but in reality the additional heat and convection could change expectations of freezing.

At the Workshop, discussions revealed unfrozen water was encountered when drilling into the core of the Fox WRSA. This water was reportedly sampled and analyzed. This information should be reviewed in detail, and used for improving predictions of freezing and water quality.

The Workshop included a discussion on the need for more measured information at Ekati, like thermal conductivities and temperature profiles. Tetra Tech EBA will consider these issues.

2.4 Recommendations for Improving Thermal Modelling

My recommendations for improving the reliability of thermal modelling at Ekati are as follows.

- Expand the one-dimensional thermal model to at least two dimensions. The side slopes of the WRSAs are particularly important, because their freezing-thawing could lead to thick reactive active layers. WRSAs are three-dimensionally complex and variable. Water and pore-gas movements within mining waste rock are not reliably simulated in one dimension, so heat transport and freezing should not be simulated that way either.

- Include at least two-dimensional thermal convection, which can substantially affect heat transport and freezing in three dimensions. Thermal convection with pore-gas movement is important for more reliable predictions of freezing in Ekati waste rock.

- Include internal heat generation, which can substantially reduce freezing in three dimensions. The lack of any internal heat generation in the thermal modelling means that the current predictions of freezing in Ekati WRSAs are unrealistic best-case scenarios. At the Workshop, Ekati agreed to look at the potential of using humidity-cell data to estimate internal heat generation.

- Inquire if sufficient input data are available for at least two-dimensional thermal modelling. If not, this should be the primary goal before additional modelling is undertaken. Modelling of a WRSA when results cannot be calibrated or verified is not worth the time and effort. At this time, freezing cannot be accurately predicted at Ekati, and predictions of water contamination for the Closure ERA should consider frozen, partially frozen, and unfrozen scenarios.

- Request the assumed or measured values of porosity used in the thermal modelling, to learn if this fundamentally critical parameter in the modelling was thoroughly addressed. If Ekati does not have a detailed database of porosity values measured throughout the WRSAs, then there is no basis for believing the estimates of thermal conductivity and the resulting predictions of freezing.

- Determine why no measurements of the fundamental and important parameter of thermal conductivity were conducted at Ekati. Assumptions, based on an old equation from Norway using porosity, are not sufficiently reliable for the very important task of estimating closure ecological risk at Ekati. Measurements of this, and other, important parameters at Ekati are needed to more reliably simulate closure conditions and estimate ecological risk at Ekati. At the Workshop, Ekati agreed to consider the value and importance of such measurements.

- Update the thermal modelling of the Misery WRSA by including the proposed addition of heat-generating schist.

- Based on the Workshop, incorporate the findings of unfrozen water within the core of the Fox WRSA into the modelling of freezing and water quality.

3. Modelling and Prediction of Water Contamination and Quality

3.1 Introduction

Under "Study Limitations", Golder (2016) stated formally,

> "All third parties relying on this document do so at their own risk. . . .This document, including all text, data, tables, plans, figures, drawings and other documents contained herein, as well as all electronic media prepared by Golder are considered its professional work product and shall remain the copyright property of Golder."

I acknowledge that Golder owns the copyright on the report and associated materials, and I, as a third party, rely on the report at my own risk.

Golder (2016) explained that the objectives of the WRSA seepage water quality (contamination) model were to:

- "develop a water quality model for the Panda/ Koala/Beartooth, Fox and Misery WRSAs and the CKRSA for the purpose of understanding the physical and geochemical processes that may influence seepage water quality;
- project future change in seepage water quality from the Misery, Fox, and Panda/Koala/Beartooth WRSAs through closure;
- evaluate the effect of cover thickness;
- evaluate the effect of high and low seepage rates; and,
- provide input source terms to future iterations of the risk assessment."

3.2 Water-Quality Modelling by GoldSim

Section 3.1 of Golder (2016) explains that Golder's proprietary model called "GoldSim" was used for water-quality modelling. It is based on "individual objects or elements linked together by mathematical expressions". The strengths and weaknesses of water-quality modelling for the Ekati Closure ERA thus depend on two primary factors.

The first primary factor in GoldSim is how the "objects or elements" in the model were defined for Ekati. For example, a lake can be defined as one object, or can be divided into zones like various inlet portions, central portions, and outlet portions. GoldSim considered Ekati lakes as single objects. Thus, any contaminated water entering through one inlet portion would be mathematically diluted down in GoldSim by the remaining lake water. As a result, any toxic effects at that inlet would not be predicted by the GoldSim model. This issue is discussed later in this review.

The second primary factor in GoldSim is the "mathematical expressions" that link the objects. Nature is notoriously difficult to express as mathematical equations, so some simplification is almost invariably needed for modelling purposes. If the simplifications go too far, or are not appropriate, then the resulting predictions of water quality and contamination are unreliable. This issue is the primary focus of this part of my review.

3.3 The Importance of Freezing to Predictions of Water Quality and Contamination

In Section 2.1, Golder (2016) states,

> "Permafrost growth through the WRSA is a key component for WRSA chemical stability at closure. Thermal modelling was completed in order to evaluate the aggradation of permafrost into each WRSA (Tetra Tech EBA 2016)."

Section 3.2 of Golder (2016) adds,

> "All the WRSAs are expected to develop a frozen core, but the timing as to when that occurs and the impacts of climate change on the thermal regime within the pile, differs (Tetra Tech EBA, 2016). The frozen core is assumed not to contribute load to seepage water due to a number of factors: 1) a lower rate of mineral reaction due to the temperature of this material, and 2) coating of mineral particles by ice which both impedes oxygen ingress and prevents the transport of load through the core."

Please note this extreme assumption of zero contribution from the frozen cores entirely eliminates all contamination by the WRSA cores. This extreme assumption is not warranted.

First, frozen conditions do not rule out at least some contaminant release and transport (e.g., Dawson and Morin, 1996), even if minimal.

Second, the thermal modelling is not sufficiently reliable to assume zero contaminant release from the cores (see Section 2 of this review). The discovery of unfrozen water in the core of the Fox WRSA illustrates this.

Third, by ignoring the WRSA cores, only the outermost active layer, "assumed to be 5 m" by Golder (2016), contributes contaminated water to the environment. Tetra Tech EBA (2016) says that the thickness of the active layers in the WRSAs is up to 13 m.

It would be difficult to reduce predicted water contamination any further than this from Ekati WRSAs, except to assume the active layers themselves never thaw at all.

The thermal uncertainty, and the additional uncertainties in water-quality modelling below, will "daisy chain" and can magnify as they are carried through into the assessment of risk to the environment. In other words, significant uncertainties in the inputs to the risk assessment, namely thermal and water-quality predictions, can lead to significant uncertainties in predicted ecological risk. In turn, this leads to questions about the reliability of ERM (2016)'s conclusion about risk:

> "Therefore, the current assessment provides a conservative measure of risk and would be expected to overestimate the true risk associated with seepage exposure to aquatic life and wildlife in most cases."

ERM (2016) is discussed further in Section 4 of this review.

Based on this, I find that predicted closure water contamination, and associated risk to the environment, will likely be higher than stated in the Closure ERA documents. A prudent approach would be to assume some WRSA cores never freeze, partially freeze, and freeze only after much longer times. In effect, this becomes a sensitivity analysis on core freezing, to show how sensitive water contamination and environmental risk are to WRSA freezing (see also Sections 3.4 and 3.5 of this review). Such a sensitivity analysis was not made for the Ekati Closure ERA (Section 4.4 of Golder, 2016).

At the Workshop, the discussion of unfrozen water within the core of the Fox WRSA highlights this important issue of whether the core of the WRSAs will freeze entirely and not release any contamination at all. The data on this unfrozen water should be used to improve the current extreme assumption of complete freezing and no contaminant release except for a relatively thin active layer.

3.4 Movement of Water Into, and Seepage from, the Ekati WRSAs

Chapter 4 of Golder (2016) explains how the water balance for each modelled WRSA was determined. This is important. The contamination of water by WRSAs begins with water infiltrating into a WRSA, due to rainfall during non-frozen months and due to snowmelt during freeze-thaw months and subsurface heat transport.

The amount of infiltration into each WRSA is critical for Ekati, but existing outflow measurements of seepage are not sufficient to determine this. Measured seepage outflows are just the water staying visible above the land surface. There could be much more below the surface, moving through the active layer. Golder (2016) recognizes this by explaining,

> "It is anticipated the flow at the seepage monitoring locations does not represent the total WRSA and CKRSA discharges due to very low flow conditions. Furthermore, it is expected that shallow groundwater flows (interflow) are traveling under the monitoring locations. As such, it was not possible to calibrate the water balance model discharge volumes to measured seepage volume monitoring data."

Therefore, current monitoring information at Ekati cannot be used to estimate how much water enters and leaves the WRSAs. Instead, assumptions and analogues have to be used, which introduces significant uncertainty into the water balances and the predicted contamination used in the Closure ERA. More monitoring at Ekati would eliminate the need for many uncertain assumptions and analogues.

Golder (2016) turned to the Diavik minesite to estimate Ekati infiltration. The Diavik minesite is sponsoring university research projects, focussing on "test piles". These test piles are only 15 m high, and were found to freeze entirely throughout during winter. These, and other differences, mean that the Diavik test piles are not representative of full-scale Ekati WRSAs. For example, a test pile that is frozen throughout will reject infiltration for a longer time during thawing. Also, test piles specially built for research cannot include all the variability and the zones of large rock sizes like a full-scale WRSA, so infiltration can be expected to less than full scale.

Those unrepresentative test piles at Diavik were all that Golder (2016) used to estimate full-scale Ekati infiltration. Ekati sorely needs its own measured data on full-scale infiltration. During the Workshop, Ekati and Golder agreed to consider additional monitoring at Ekati to define Ekati's water balance better.

Golder (2016) considered two infiltration scenarios, which became the only sensitivity analysis for the water-balance model of Ekati WRSAs (Golder Section 4.4). This is a major issue in the prediction of contamination and associated risk. The "high seepage" scenario allowed 58% of rainfall to infiltrate (the maximum infiltration value at the fine-grained test pile at Diavik). The "low seepage" scenario used 37% of rainfall (the average infiltration value at the fine-grained test pile at Diavik).

Please note that dividing a mass loading of contamination (discussed below in Section 3.5) by maximum infiltration will yield the most diluted contaminant concentration possible (Golder's high-seepage scenario). One would then expect the low-seepage scenario to yield the highest contaminant concentrations due to the usage of minimal infiltration and dilution. However, that is not Golder's low-seepage scenario, which used average Diavik test-pile infiltration. If Golder predictions are accurate, we can expect a significant percentage of Ekati full-scale closure concentrations to be higher than Golder's current worst predictions, but worse by some unknown amounts.

At the Workshop, Golder explained that Diavik recently experienced relatively dry years. As a result, if directly applicable to Ekati, the high-seepage scenario may be closer to average infiltration rates, and the low-seepage scenario may be closer to somewhat-drier infiltration rates. In any case, some significant percentage of higher contaminant concentrations still would not be considered under either scenario. As a result, neither seepage scenario can be considered "conservative", representative of upper annual concentrations for Ekati, or even representative of driest years at Ekati.

When up to half of closure concentrations will be worse than the highest given by Golder (2016), then the resulting Closure ERA will under-estimate risk up to half the time if proportional to predicted concentration. Please note that this approach does not likely meet the spirit of Board Directive 14 in the *Table of Concordance with September 9, 2015 Board Directives.*

Furthermore, full-scale waste-rock studies have shown that large amounts of water infiltrate quickly through the coarse-rough surface of a waste pile. It then flows downwards through coarse channels within hours to days, with the remainder of the water moving slowly through the finer material. Rapid infiltration is not seen in smaller "test piles" like Diavik's, because they are not constructed like full-scale, run-of-mine WRSAs. They cannot include the coarse-rock channels found in full-scale WRSAs.

Also, some modellers of waste-rock test piles say most flow does not pass through coarse channels due to "capillary tension", and most water flows through the finer layers (the "matrix"). That may be true of test piles like Diavik's, but full-scale piles often show markedly different trends. Nevertheless, Golder (2016) uses the smaller Diavik test piles to conclude the following about the much larger Ekati WRSAs,

> "The dominant transport mechanism of water through a waste rock pile is the matrix, which is material less than 5 mm in size (Momeyer 2014, Krentz 2014)."

This is important here, because Golder (2016) assumed no seepage would flow from WRSAs until the matrix became saturated. This issue can be resolved now, if sufficient monitoring data existed at Ekati. It has not been collected.

Time-series plots of daily or hourly measurements of precipitation, superimposed on daily or hourly measurements of seepage flows, would show how much water passes through Ekati WRSAs quickly, without requiring 100% matrix saturation. However, most Ekati seepages are sampled only twice a year. Thus, an assessment of Golder water-balance modelling assumptions could be done with frequent monitoring data, but Ekati has not collected data to do this. Instead, an assumption, which I consider invalid but can easily be evaluated at Ekati, is made in the Closure ERA.

Despite these discrepancies and missing data, the most important issue is how well the calibrated water-balance model matched measured seepage flows at Ekati. Section 4.5 (Water Balance Results) of Golder (2016) says,

> "The water balance results for each of the WRSAs and the CKRSA are summarized below and in Appendix A. Seepage flows were modelled for the historic period (2009 to 2013), the remaining years of operation (2014 to 2018) and the closure period (2019 to 2114). Model results are presented both for the high and low seepage scenarios."

Golder's Appendix A does indeed contain the modelling results for the "historic period" of 2009 to 2013. However, there are no real measured Ekati flow data in that Appendix to show how well the water balance was estimated. This is a major issue: we cannot tell how real and accurate the water balance is for Ekati WRSAs. If the water balance contains substantial errors, the predicted water quality will contain substantial errors (see Section 3.5 below), and the resulting risk assessment will contain substantial errors. *No one can tell if this is the case due to the lack of measured data at Ekati*. It does not have to be this way.

Golder (2016) mentioned in places there were "bi-annual site inspections" of seepage (likely from the annual Seepage Surveys of Ekati). Therefore, there were flows measured, but these values were not compared to water-balance values. In any case, these few bi-annual values would not be sufficient to check the water-balance model, particularly when the model predicts highly varying flows each day (see Golder Appendix A). Again, we must debate the validity of assumptions that instead can be resolved by frequently monitoring seepage at Ekati.

At the Workshop, Ekati explained seepage was monitored for flow and chemistry during some rain storms. This additional monitoring occurred in summer months between the bi-annual seepage monitoring, and would be valuable for calibrating predicted flows and chemistries between the bi-annual values. Ekati will identify which documents contain the additional seepage monitoring, and Golder will check if the additional monitoring was used in the calibration.

It is true that at least some seepage water is not visible on the surface (see the first quotation of this subsection). Nevertheless, a very important and valuable estimate, which can be done now with available information, is the ratio of measured flow (from seepage surveys) to predicted flows (from Appendix A of Golder, 2016). For example a value around 0.1 would mean that about 90% of the predicted flow at that location is not seen or detected; it flows beneath the surface unseen.

In turn, this would help the risk assessment, because ERM (2016) makes a "conservative" assumption that seepage reaches nearby water bodies when it is reportedly often not seen doing that. Perhaps most of the flow does indeed report to nearby lakes, as shallow seepage zones in the lake bottoms, but is not seen doing that.

Finally, Table A-1 of Golder (2016) contains "Total Discharge" of seepage under the high-seepage and low-seepage scenarios. The high-seepage scenario results in more seepage than the low-seepage scenario. However, Table A-1 shows Total Discharge is higher for low seepage, and lower for high seepage, in every case. At the Workshop, Golder explained the estimated flows in Table A-1 were incorrectly switched. The "high-seepage" flows are actually estimates of "low-seepage" flows.

3.5 Water-Quality Modelling

Water-quality modelling in Golder (2016) can be divided into two steps: (1) estimate a mass loading (like mg/day) of contaminants leaving the WRSAs and (2) divide the mass loadings by the estimated flows (like L/day). This gives the desired predictions in mg/L.

3.5.1 Flows Divided into Mass Loadings to Predict Contaminant Levels

The second step involving flow was discussed above in Section 3.4. Golder (2016) estimated flows for two scenarios. The "high seepage" scenario allowed 58% of rainfall during drier years to infiltrate, based on the maximum value from test piles at Diavik that were not representative of full-scale WRSAs at Ekati. This high seepage, when divided into the estimated mass loadings, provides the lowest, minimum, most diluted contaminant concentrations.

The "low seepage" scenario used 37% of rainfall for infiltration was derived from average infiltration in the unrepresentative test piles at Diavik, reportedly during somewhat dry years at Diavik. Low-seepage flows, when divided into the estimated mass loadings, provide the highest contaminant concentrations. The serious problem here is that the highest predicted concentrations for Ekati were based only on average values from somewhat dry years. Therefore, up to half of contaminant concentrations at Ekati will be higher than the maximum predicted and used in this Closure ERA.

In other words, Golder (2016) estimated the lowest and the somewhat-average contaminant concentrations, but no higher. Golder Section 5.6 incorrectly states,

> "The loading rates were the same under both the high and low seepage scenarios. This assumption yields conservative water quality predictions for the low seepage scenario."

Ignoring up to half the contaminant concentrations that would be above a drier-year average is not "conservative".

3.5.2 Assumption of Unlikely 1:1 Dilution at Ekati

Another point about this modelling approach is that the division of mass loading by flow is a simple 1:1 dilution model. If flow is doubled, then predicted concentration is halved.

In flows at full-scale minesites, I have not seen aqueous contaminant concentrations inversely correlating 1:1 with flow. Often there is little to no correlation. Sometimes, concentrations even increase as flows increase, due to processes like first flush such as after a dry summer or during spring thawing of an active layer.

This can be resolved now for Ekati, by plotting aqueous concentrations in seepages against seepage flow. If there is no inverse 1:1 correlation, then this approach to water-quality modelling in the Closure ERA is wrong for Ekati.

3.5.3 Scaling Up Mass Loadings from 1-kg Laboratory Samples to Multi-Million Tonnes of On-Site Waste Rock, Using "Scaling Factors"

The first step in Golder's water-quality modelling (see Section 3.5) of estimating a mass loading can be difficult, especially since such loadings vary from day to day, and even hour to hour, at full-scale minesites. Golder (2016) started with laboratory-scale humidity cells, which often contain about 1 kg.

Scaling up the mass loadings from a 1-kg sample in a laboratory, to tens to hundreds of millions of tonnes of waste rock under on-site conditions, involves an impressive weight-scale difference of at least 10^{10} orders of magnitude. Predicting large-scale conditions across such a huge difference in scale, and from controlled laboratory conditions to open site conditions, would obviously be complex and difficult, and easily unreliable.

Golder (2016) conducted this huge scaling up for the Ekati closure ERA, simply by multiplying the small laboratory mass loadings by single values called "scaling factors" (Golder Section 5.4.3). These scaling factors were applied to the lowest rates obtained from the humidity cells ("the last five weeks"), minimizing all predicted contaminant concentrations and heat generation from the start.

Therefore, the lowest possible laboratory rates were scaled upwards. Moreover, these last-five-week cell rates were not stable (Golder Section 5.6), and could thus increase substantially any time later. This instability could lead to higher, unpredicted contamination at Ekati through closure, and unexpected ecological damage.

Golder (2016) was not concerned about such potential under-estimation of closure water contamination, because "the waste management plan is designed to encapsulate reactive material within the frozen core." This again highlights the heavy reliance by Golder and Ekati on freezing, which thermal modelling cannot yet reliably predict and that unfrozen water in the Fox WRSA core contradicts (see Sections 2 and 3.3 of this review).

Golder (2016) references Kempton (2012) as one source for scaling factors, but Golder (2016) did not list the numerical values of scaling factors used in this Ekati water-quality modelling. The numerical values should be included in the Golder report, because no reviewer can tell if the values are reasonable for Ekati. Based on Golder Section 5.4.3, all values were likely less than 1.0.

After adjusting for weight, it is difficult to imagine how simple multiplication (Golder Equation 3) of a small-scale, controlled laboratory rate by values consistently less than 1.0 would reliably predict huge-scale on-site dynamic values. Table 14 lists "Scaling Factors" much less than 1.0, but this table is under Section 6.1, "Model Calibration", which suggests the values are "calibration" values distinct from "scaling factors" in Golder (2016).

Because each scaling factor is multiplied by the others, Kempton's approach, and thus Golder's approach, would have likely lowered the laboratory-based mass loading by orders of magnitude. It was then divided by the annual maximum flow or annual near-average flow, but not significantly less-than-average annual flows expected frequently. This lowered the full-scale predictions again and again and again.

In reality, some scaling factors not selected by Golder are greater than 1.0, which would raise the full-scale prediction. Golder should be asked to provide the numerical values of the scaling factors used in this water-quality modelling, and to explain why those values were chosen.

This might be the reason for Board Directive 14 in *Table of Concordance with September 9, 2015 Board Directives*, which asked for "an explanation of how uncertainties associated with small sample sizes will be addressed when evaluating potential risk in the Closure ERA." Such uncertainties related to scaling up of small-scale humidity cells were not discussed by Golder (2016) and not mentioned in *How Directive was Addressed* for Board Directive 14. They should be discussed in detail.

Furthermore, Directive 16 shows the Board wanted a discussion of "the level of conservatism and confidence in the scaling factors applied". I could not find this discussion, but it is important to include in the Closure ERA.

After the Workshop, I believe that Board Directives 14 and 16 are even more important. For this reason, I will elaborate on scaling factors as applied to Ekati.

During the Workshop, Golder explained that many studies have shown that contaminant loadings from humidity cells are "orders of magnitude" higher than full-scale on-site loadings, and that papers from various International Conferences on Acid Rock Drainage (ICARD) show this. These statements are wrong. Rumours of many studies showing "orders of magnitude" lower full-scale, like rumours that bacteria accelerate sulphide oxidation by one million times, are based on undocumented, unverifiable statements. Here are some relevant facts.

- First, there are few published, scientifically verifiable comparisons of humidity-cell values to full-scale on-site values. By "scientifically verifiable", I mean published case studies that include the identification and details of the minesite, detailed discussions of the cell data and full-scale monitoring, numerical values, etc.

- Second, the few scientifically verifiable comparisons show that the "cumulative scaling factor", which represents all applicable physical, geochemical, and biological scaling factors multiplied together, are in the range of 0.05-0.60. This is not "orders of magnitude", and is mostly less than a factor of 10. Board Directives instructed Golder to discuss "the level of conservatism and confidence in the scaling factors applied" and "uncertainties associated with small sample sizes", which are missing from the Closure ERA. Golder can start filling this critical gap by reviewing a summary of verifiable comparisons in Morin (2013 and 2014).

- Third, Kempton (2012) is listed by Golder as discussing scaling factors However, that document discusses only some scaling factors, and not complete sets. Because each applicable scaling factor is multiplied by the next, Kempton's incomplete list cannot result in reliable scaling.

- Fourth, Golder used unspecified and unverifiable values for the few scaling factors selected by Golder. These, multiplied together, apparently greatly reduced the humidity-cell predictions, presumably unrealistically by "orders of magnitude". Golder then multiplied the partially cumulative scaling factor by "calibration factors", some of which were less than 1.0 and some at 25-50. It is possible that some Golder "calibration factors" represented the combination of all the other scaling factors applicable at Ekati. If correct, then the multiplication of all Golder scaling factors, multiplied by the calibration factors, may represent the applicable cumulative scaling factor for an Ekati WRSA. However, evaluating this is not possible due to missing values in the Golder report.

3.5.4 Prediction of Full-scale Water Quality, Which Typically Varies Significantly from Day to Day and Even Hour to Hour

The flows and chemistries of seepage can vary strongly with time, sometimes even from hour to hour. This is typical of minesite drainage where monitored frequently. Golder Section 4 recognized this for flow, and predicted dynamic flows day by day (see also Golder Appendix A).

It makes sense that the aqueous concentrations in these variable flows will vary also, at least day by day. However, Section 5.2.3 on baseline water quality used only median values for aqueous concentrations from samples collected between 1994 and 2013 (one value each for nearly 20 years). This is not reality.

Can we tell if seepage concentrations from Ekati WRSAs are highly dynamic and variable over short and long terms, as already predicted for their flow rates, and as seen at many minesites? No. Seepage concentrations (and flows) at Ekati were often measured only twice a year, if at all at some locations. Thus, their variabilities and peak values are not reliably known.

In Section 5.6, Golder explains that "seepage water quality can differ spatially and possibly temporally." There is no "possibly" about it. This "possibly temporally" variability is actually shown in Golder Appendix B2 for previous, monitored years.

However, have the actual variabilities and peak toxic concentrations been predicted accurately at Ekati? Ekati has not collected sufficient data to characterize it - typically just twice a year when at all. This means that the day-by-day Golder simulations cannot be calibrated, or evaluated as reasonable.

Even as is, the simulations in Golder Appendix B2 of previous monitored years do not match most of the few measured concentrations well. How much worse could contaminant concentrations be between the two bi-annual samples? No one knows, but the Golder model (Appendix B2) suggests it is often significantly worse between the measured bi-annual data. Is this correct - has water quality between the past Ekati sampling events really been much worse? No one knows, but the calibrated model says it is much worse than monitoring has shown.

At the Workshop, Ekati explained that monitoring data exist for some summer rain storms. Ekati will identify which reports released this information. It may provide additional data for calibrating the water-balance and water-quality models. Golder should pay close attention to this.

Section 5.4 on Model Calibration Approach explained that,

> "Modelled concentrations from 2009 to 2013 were then compared to the measured data to calibrate the model. Modelled constituents that had a good agreement with observed data were identified, and used to develop scaling factors and calibration factors."

This is a problem. As explained above in several places, so many aspects of this water-quality model render the results unreliable. Yet this model was calibrated only to those on-site data that "had a good agreement" with the model. Of much greater importance would be reconciling this model with real, on-site data that was <u>not</u> predicted well. That is where the concern lies.

In Section 5.4.4 and Figure 5, Golder (2016) may have overcome some problems in the modelling raised above. Board Directive 14 in *Table of Concordance with September 9, 2015 Board Directives* instructs Ekati to compare predicted contaminant concentrations with those measured in seepages. This apparently revealed some major discrepancies, requiring the predictions to be adjusted by "calibration factors" after the unspecified scaling factors were applied. Again, the bi-annual sampling was not sufficient for reliable comparisons, and the modelling showed there have been even higher concentrations between past bi-annual values. Thus, that instruction in Board Directive 14 cannot be reliably done with available Ekati data.

Please note that comparing a day-by-day model to limited bi-annual datapoints from past years, with estimated concentrations between the few measurements fluctuating substantially to higher levels, cannot confirm model calibration. A visual scan of Golder Appendix B2 is enough to see that

- existing data (solid dots in Appendix B2) are not sufficient to calibrate the model (lines in Appendix B2) and,
- even worse, higher levels of contamination may have entered the environment around Ekati in past years without being monitored and confirmed (lines between the datapoints).

At the Workshop, Golder explained that the model was calibrated to measured on-site concentrations, yet the predicted high peaks of contamination in past years between measured values were considered "conservative" and thus unlikely. I asked questions about this, but could not understand how a model calibrated to measured data was "conservative" between the measured data. I remain confused by this. In reality, a model is not calibrated if it estimates unlikely, too-high concentrations between measured values. Additional monitoring data between the bi-annual values, including the existing rainstorm data, may help ensure calibration of the model.

All this means that Board Directive 14 in *Table of Concordance with September 9, 2015 Board Directives* was not fulfilled reliably, and this may not even be possible with existing data. Much more frequent and spatially distributed monitoring is desperately needed at Ekati, including monitoring of "interflow" in the active layer which may represent most of the contaminant migration to nearby lakes. Golder recommends this in its Section 7.

In the end, Section 5.5 of Golder (2016) explained the sensitivity analyses for water-quality modelling involved using the highly diluting high-seepage scenario and the incorrectly labelled low-seepage scenario that is actually somewhat-dry seepage. This ignored up to half the higher concentrations, including the worst contaminant concentrations predicted for at Ekati. These two more-diluted scenarios were combined with granite covers of either 1 m or 5 m thickness, using the unreliable one-dimensional thermal modelling discussed above in Section 2 of this review. All this led to the "input" of contaminant concentrations used in the risk assessment (ERM, 2016), whose risk estimates cannot be any more reliable than the "inputs" reviewed here.

3.5.5 Prediction of Total Contaminant Concentrations from Dissolved Concentrations

Some aspects of the water-quality modelling do not make sense to me. Thus, I cannot say whether I agree or disagree with them. Many are not even needed if Ekati would simply measure the on-site conditions.

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For example, total-metal concentrations had to be calculated from dissolved concentrations (Golder Section 5.3). Why are total concentrations not always measured with dissolved ones, as is standard for seepage monitoring at other minesites? This is another example at Ekati where important information for a reliable risk assessment can be measured, but was not and instead had to be assumed with unknown reliability.

The fewer samples having both total and dissolved were used to calculate total values for the many other non-total samples. The difference can vary with time, such as after first flush like after a dry summer or during thawing of the active layer. The difference will also vary from sample to sample due to suspended solids. The difference will also vary by chemical element, depending on the mineralogy of the suspended solids. This calculation of total concentrations used by Golder is not reliable, and thus the ecological risks estimated from these calculated total levels cannot be reliable.

In any case, Golder Section 5.3 explains that (1) only values above detection were used, (2) any sample with dissolved higher than total "was not used to calculate a multiplication factor", and (3) any sample with total higher than dissolved "was not carried forward to calculate a multiplication factor". This tells me only samples above detection, where total and dissolved were the same, were used. That does not make sense to me.

3.5.6 Golder (2016) Explains That Predicted Concentrations Should Not Be Used as "Absolute Concentrations"

In Section 5.6 (Model Assumptions and Limitations), Golder (2016) says,

> "Given the inherent uncertainties, the water quality model should be viewed as a tool to aid in the design of monitoring programs and mine planning, development of mitigation strategies, and identification of potential risks rather than to provide absolute concentrations. Conservative assumptions have been incorporated where uncertainty is known to exist, so that predicted concentrations are likely to exceed actual future concentrations."

The first sentence of the quotation is prudent, but overlooks the fact that the predicted "absolute concentrations" were indeed used for the Closure risk assessment. Based on explanations in this review, the second sentence is, at a minimum, unreliable and likely wrong.

3.5.7 The Predicted Ongoing Accumulations of Contamination within WRSAs at Ekati

Golder Section 5.6 says,

> "[When unfrozen], it is assumed that 5% of the load prior to pile saturation and 10% of the load following pile saturation reports to the toe of the storage area. This is likely a conservative assumption. Given the dimensions of the storage areas it is likely that most of the load is stored in the core and/or in the underlying permafrost."

The first sentence appears to discuss another scaling factor not mentioned earlier, where most of the mass of the contaminant loading is not released from WRSAs, but is retained inside. It means that, every year, 90-95% of the generated contamination is kept inside each WRSA. This happens again the next year, the next year, the next decade, etc.

Another way to say this is that, each year, only 5-10% of the contaminant load is released annually to the environment; this is what is seen, at least in part, by monitoring at Ekati. In turn, about 10-20 times more than the year's release is accumulated within the WRSAs. The next year only 5-10% is released, and now 20-40 times the annual release is accumulated inside. After ten years, 100-200 times more than the annual release is now accumulated inside the WRSAs.

This continues through time. As a result, a large and growing mass of contamination is held inside each WRSA, and it gets worse each year.

The second sentence says Golder considers this assumption "conservative". So massive accumulation of contamination each year at Ekati could be even worse than Golder assumed.

How is this massive contamination held inside the WRSA, and is it secured from later release? Golder assumes that it "likely . . . is stored in the core and/or underlying permafrost". This is a very important issue, as illustrated by the following points.

- If this ongoing annual accumulation stops, then much more contamination (more than 10-20 times more) would be released each year than currently detected at Ekati.
- If this ongoing accumulation only becomes weaker (less than 10-20 times the annual release currently estimated at Ekati), then large amounts of additional contamination would be released each year from the WRSAs.
- If this ongoing accumulation becomes "leaky" or reverses, then large amounts of additional contamination would be released from the WRSAs.
- In the worst case, a complete reversal of this accumulation process in one year could release hundreds of times more contamination than currently detected each year at Ekati.

If the accumulation process is freezing, then thawing of any WRSA core, even partially, such as due to long-term climate change, would reverse the accumulation process. This would release the massive amounts of long-term accumulated contamination from the WRSAs in future years, and would invalidate the current Closure ERA. The reported unfrozen water in the core of the Fox WRSA may show evidence for this.

What if the increasingly massive loads of contamination are not held in frozen cores, but in another fashion. What could lead to a catastrophic release of this type of stored contamination? Such issues are not addressed in the Closure ERA.

Ekati should focus major efforts to find where, why, and how the massive, continually increasing loads of contamination are stored within the WRSAs. Then the potential for weakening, stopping, and reversal of the accumulating contamination can be better estimated.

This ongoing accumulation of large amounts of contamination within Ekati WRSAs is not addressed in the risk assessment, yet its impact on ecological risk becomes increasingly enormous as years and decades pass. It is a proverbial "elephant in the closet" at Ekati.

Upon reading the Golder report, I thought I understood this accumulation. However, after discussions at the Workshop, I am confused. For example, Golder explained that at least part of the contaminant load generated and stored each year is actually "not generated". If so, then un-generated contamination would not be considered part of the contaminant load. After several questions, I still do not understand this. Golder's statement that "it is likely that most of the load is stored in the core and/or in the underlying permafrost" was said by Golder to be "poorly worded". This issue of contaminant accumulation requires detailed clarification and numerical examples so that all stakeholders understand the corresponding environmental liability.

3.6 Recommendations for Improving Predictions of Closure Water Quality and Contamination

My recommendations for improving the reliability of modelling of Ekati water balances and water quality are as follows.

Water-Balance Modelling

- Conduct a sensitivity analysis using various degrees of core freezing and non-freezing, to show how sensitive water contamination and environmental risk are to predictions of WRSA freezing. Unfrozen water reported in the core of the Fox WRSA may highlight the value of this sensitivity study.

- Obtain details from Ekati on how infiltration and water balances in the future will be based on measured data at Ekati, instead of small-scale unrepresentative test piles at Diavik.

- Ask why the sensitivity study, with the near-average "low seepage" and diluted "high seepage" scenarios, did not use the higher contaminant concentrations for Ekati at closure. When up to half of closure concentrations will be worse than the highest given by Golder (2016), then the resulting closure ERA will under-estimate risk up to half the time if proportional to predicted concentrations.

- Create time-series plots of daily measurements of precipitation, superimposed on daily measurements of seepage flows, to show how much water passes through Ekati WRSAs quickly. This would be in contrast to the current assumption that water only moves relatively slowly through finer-grained materials, and then seeps from WRSAs only after the finer material becomes saturated. Such time-series plots cannot likely be done with current information, but would require at least one year of daily monitoring at Ekati. This would reduce the need for such uncertain assumptions.

- Request the ratios of measured flow (from seepage surveys) to predicted flows (from Appendix A of Golder, 2016). For example a value of 0.1 would mean that 90% of the predicted flow at that location is not seen or detected. In turn, this would help the risk assessment, because the risk assessment makes a "conservative" assumption that seepage reaches nearby water bodies when it is reportedly often not seen doing that. Maybe most flow does indeed report to nearby lakes, as seepage zones in the lake bottoms, but is not seen doing that.

- Have Golder confirm that Total Discharge values in Table A-1 were incorrectly switched. It would be helpful if a note were attached to the Golder report about this, so people in the future will use the correct flows.

Water-Quality Modelling

- Instead of using the 1:1 dilution model rarely seen at full-scale minesites (where chemical loadings are divided directly 1:1 by flow), predict contaminant concentrations using other, more typical full-scale relationships as a valuable sensitivity analysis.

- Obtain the numerical values of scaling factors used for the scaling of mass contaminant loadings, from 1 kg, to tens to hundreds of millions of tonnes. Board Directive 16 showed the Board wanted a discussion of "the level of conservatism and confidence in the scaling factors applied", which was not provided by Golder. Due to the importance of scaling factors at Ekati, the Board's directive for a detailed justification, plus numerical values used, should be required.

- Request measurements, at least daily, of flows and chemistries of seepages from WRSAs, to determine if Golder's predicted high variabilities and predicted high contaminant peaks during recent years are reasonable.

- Recognize that the instruction in Board Directive 14 to compare contaminant predictions to measured levels cannot be done reliably with existing monitoring data. Measured levels were typically determined only twice a year, if at all, and current predictions suggest high day-to-day variability with many predicted concentrations much higher than the bi-annual samples. Based on the Workshop, there may be additional data from rainstorm modelling. This information should be reviewed and incorporated into the comparisons of predicted and measured concentrations in past years.

- Find out why total contaminant concentrations had to be calculated from dissolved contaminant concentrations, rather than just measuring them during laboratory analysis, and how reliable this calculation is month-to-month. They are not reliably calculated at Ekati, because they depend on factors like the concentrations of suspended solids and the mineralogy of those solids that Ekati did not measure. From here on, total concentrations should be measured with dissolved concentrations in every water sample collected at Ekati, since they are obviously important to the risk assessment, but not reliably calculated.

- Request detailed information, data, and studies on the major accumulation of contamination with Ekati WRSAs, where most yearly contamination (currently estimated by Golder at 90-95% each year) is repeatedly held inside, year after year, decade after decade. Should this massive ongoing accumulation be released from an Ekati WRSA, such as by thawing or reversal of whatever unidentified process is causing this contaminant accumulation, then there could be massive ecological damage in downstream receptors. The potential for gradual or fast release of the ongoing contaminant accumulation, or even the potential for a decrease in each year’s accumulation leading to worse annual water quality, is not addressed in the current Closure ERA. After the Workshop, I am more confused about this, because at least part of the accumulated contaminant loading is reportedly “not generated”. Clarification and details of this accumulation are needed.

- Review details of the unfrozen water found within the core of the Fox WRSA and incorporate them into the water-quality modelling. This includes the effect on the modelling assumption that all WRSAs will freeze and not release any contamination.

4. Ecological Risk Assessment Based on Thermal and Water-Quality Modelling

4.1 Underestimation of Risk in the Closure ERA Based on Preceding Comments

As explained above in Sections 2 and 3 of this review, the predictions from the thermal and water-quality modelling currently are not sufficiently reliable for a reasonable closure ecological risk assessment. In fact, those current modelling exercises have likely under-estimated the contamination coming from the WRSAs through closure, and thus in turn ERM (2016) may substantially under-estimate the closure risk to the surrounding environment.

I understand that ERM (2016) does not agree. For example,

> "Therefore, the current assessment provides a conservative measure of risk and would be expected to overestimate the true risk associated with seepage exposure to aquatic life and wildlife in most cases."

The following paragraphs explain why this is not so.

Golder (2016) states that its modelling results of predicted concentrations should be used as a "tool" and not as "absolute concentrations". Yet ERM (2016) says,

> "Furthermore, the conservative modelling approaches in this assessment result in high predicted sulphate concentrations which may never be experienced in WRSA seepage (Golder 2016)."

Therefore, ERM appears to take the predicted sulphate concentrations as absolute.

Part of this disagreement arises because ERM (2016) does not fully understand the water-quality modelling. For example, ERM talks about a "conservative" assumption.

> "WRSA seepage flow was assumed to be active full time from June to September each year (Golder 2016). This is a conservative assumption as most seeps are only active sporadically or periodically after rainfall events or during freshet. Additionally, it was conservatively assumed that all seeps flow into their designated receiving environments. In fact, many seeps have been observed to be of such low flow that water is held on the tundra surface for evaporation (i.e., does not flow as far as an aquatic receiving environment). This assumption would overestimate potential risk to aquatic receptors that reside only in waterbodies."

In reality, Golder (2016), and my Section 3 above, discuss subsurface flow that is not seen in the surficial seepages. It is likely, although Ekati may not have collected sufficient information on this, that much of the seepage is not seen on the surface. This would allow much more contaminated water to enter nearby lakes unseen. Thus, ERM is wrong that the assumption of allowing seepage to report to receptors is "conservative". At most, ERM could be correct about some minor, visible portion of seepage.

Also, ERM (2016) used only the high-seepage scenario for risk estimates, which yields the most dilute concentrations. Therefore, the finding of no significant risk, based on the lowest contaminant concentrations, is not a reliable risk assessment.

At the Workshop, ERM explained that risk in the lakes was based on geochemical loadings rather than concentrations. This is apparently due to the way GoldSim calculates mixing and dilution (see Section 3.2 of this review). As a result, risk in the receptors was not dependent on the low-seepage or high-seepage scenario, but only on the under-estimated contaminant loadings discussed in Section 3.5 of this review.

Furthermore, toxicity can occur locally where surface and subsurface seepages enter a lake. There have been legal prosecutions under the Canadian Fisheries Act for such point-source discharges into water bodies, even when they are rapidly diluted by mixing. Golder's GoldSim model considers the nearby lakes around Ekati as instantaneously mixed fully throughout. As a result, potential point-source toxicity on lake beds, such as by Golder's "interflow" that carries contamination, was not addressed in the Closure ERA.

In comparison to risk in the lakes, risk in the seepages was dependent on flow. Thus, risk from seepage was further underestimated by using only the diluted high-seepage scenario.

From Workshop discussions with ERM, ERM could not say if low-seepage, less diluted seepage entering a lake would or would not pose a significant risk to benthic organisms. This should be addressed, because it would highlight how important measurements of unseen seepage would be.

Ekati explained that studies of some lakes showed no evidence of full-strength WRSA seepage entering those lakes. Ekati will point out which reports contain these lake-seepage studies. However, the recalled techniques used to check for subsurface seepage would not reliably show any contaminant inflow to the level used in DFO prosecutions.

Finally, Golder (2016) pointed out that 90-95% of generated contamination is held inside each WRSA, year after year, decade after decade (see Section 3.5.7 of this review). With time, this produces a phenomenally massive load of stored contamination, whose sudden release would cause catastrophic ecological damage. Golder (2016) could not confirm the internal locations or the mechanisms of this increasing contaminant storage, so its release could be unexpected and sudden. ERM (2016) did not discuss the ecological results of such a massive release of stored contamination after closure.

At the Workshop, Golder explained that at least part of the generated contamination was actually not generated and thus not accumulated. This remains confusing to me (see Section 3.5.7) and requires detailed clarifications from Golder.

4.2 Recommendations for Improving the Ecological Risk Assessment

My recommendations for improving the reliability of the risk assessment for Ekati are as follows.

- Request that the risk in lakes be re-evaluated using any revisions to the geochemical loads in the Golder report. This should include the potential for rapid release of accumulated contaminant load once Golder clarifies what portion of this load is actually generated.

- Request that risk in seepages be re-evaluated using concentrations higher than the lowest or near-average values.

- Request that risk to benthic organisms in lakes be re-evaluated using above-average concentrations in seepage under the assumption that this seepage passes over benthic life before mixing and diluting in a lake. Attenuation, as defined by the simplistic concept of adsorption between the WRSAs and the lakes, should be ignored. This is because adsorption is finite process that was likely exhausted within the roughly 20 years that Ekati has operated so far. This will show the relative importance of unseen and unmonitored seepage on ecological risk.

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