Sharon

From: Kathleen Racher [racherk@wlwb.ca]
Sent: Wednesday, July 02, 2008 10:15 AM
To: 'Ryan Fequet'; 'Registry'
Subject: FW: Review of Variability Study and LLCF Model

Attachments: 30 JUNE 08 Ms. Racher Variability Study.doc; 30 JUNE 08 Ms. Racher LLCF Water Quality Prediction.doc

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From: Don Hart [mailto:dhart@ecometrix.ca]
Sent: June-30-08 4:17 PM
To: Kathleen Racher
Cc: rnicholson@ecometrix.ca
Subject: Review of Variability Study and LLCF Model

Kathleen,

Our reviews of the Variability Study and the LLCF Model are attached. The latter was completed by Ron Nicholson who is more familiar with such modeling than I am. Again, if there is anything unclear in either review, feel free to insert comments and send it back. Or if you want to discuss anything, give Ron or me a call.

Our review of the BHP letter (Task 3) will follow shortly.

Don Hart, Ph.D.

Principal, Senior Ecotoxicologist

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30 June 2008

Ms. Kathleen Racher
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Reference: Review of the Ekati Diamond Mine Analysis of Variability in Water Quality, Sediment Quality and counts of Benthic Organisms in Two Lakes of the Koala Watershed.

Dear Ms. Racher:

As requested, EcoMetrix has reviewed the Rescan (2008) Variability Study, which was completed by Rescan on behalf of BHP Billiton, in fulfillment of Condition 6(b) of the April 19, 2007 approval by the Wek'eezhii Land and Water Board of the 2007-2009 AEMP Plan. The purpose of our review was to assess the technical/scientific soundness of the Variability Study, and whether it fulfills Condition 6(b) adequately.

Condition 6(b) in the April 19, 2007 approval letter reads as follows:

"6. February 2008 Report: In a letter to the Board dated December 31, 2006, BHPB wrote that *"BHP Billiton is committed to undertake a variability study and to evaluate the issue of effects size."* BHPB proposed to submit the results of this work to the Board in February 2008 following discussions with stakeholders. The Board accepts this proposal and expects BHPB to uphold its community engagement commitments. In addition, BHPB must include the following information in the February 2008 report under the identified sections:

b) Variability Study

- As committed to by BHPB, the variability study shall include a component on core sampling and whether or not there is any systemic bias related to this sampling method. The variability study is to address sediment deposition rate and, if necessary, consider 1 cm sampling depths (Tracking Numbers 9 and 31).
- The variability study is to include shallow water benthic sites and is to consider standardizing sampling on specific substrates and proportional representation of all substrate types for stratified sampling (Tracking Number 19).
- The variability study is to indicate what constitutes a valid replicate for the purpose of representing within-lake variability (Tracking Number 55)."

Reference: Review of the Ekati Diamond Mine Analysis of Variability in Water Quality, Sediment Quality and counts of Benthic Organisms in Two Lakes of the Koala Watershed.

Technical/Scientific Review

Overall, the Variability Study appears to be well designed and implemented. It was focused on two lakes in the Koala Watershed, Moose Lake and Slipper Lake, both downstream of the Long Lake Containment Facility (LLCF). The general objective was to describe the variability in measurements of water quality, sediment quality and counts of benthic invertebrates, in each study lake, and to identify the important components of that variability.

One specific objective is highlighted, as an aspect of spatial variability; this is the question of sample spacing, and how far apart samples must be to be considered as independent replicates. If adjacent samples are strongly correlated, they are not valid replicates, and it is inappropriate to treat them as such. This problem is called pseudo-replication.

The study was carefully designed, to represent the different basins within each lake, different water depths, and different sample spacings. For water quality, there were 73 locations in Moose Lake (106 samples, some at different levels in the water column) and 76 locations in Slipper Lake (116 samples). For sediment quality and benthos, there were 80 planned locations in Moose Lake (89 samples including fine scale replicates at some locations) and 86 planned locations in Slipper Lake (92 samples). However, due to lack of sediment at many locations, only 40 and 44 locations respectively, were sampled for sediments and benthos. All samples were collected in August/September 2007.

An attempt was made to obtain sediment core samples at several locations in each lake for chemical comparisons to the usual Ekman grab samples (top 2 cm). However, cores could not be obtained due to the “sandy and loose” texture of the sediments at most locations. Sandy sediments were indeed prevalent in Moose Lake, but less so in Slipper Lake. We do not fully understand the coring difficulties. A Ballcheck gravity corer was used. In our experience, this device produces a pressure wave that may disturb loose surficial sediments. If this was the nature of the problem, a K-B corer may be preferable.

A principle components analysis (PCA) was performed prior to univariate analysis of variance (ANOVA). The PCA identified coarse spatial patterns in each lake, using the water quality data set, and also using the sediment quality data set. In both cases, but particularly for water quality, the PCA results showed distinct groupings of locations in patterns that corresponded to the physical sub-basins within each lake. These groupings, or “sections,” were considered in subsequent analysis of variability for each parameter.

The ANOVA model used to partition the variance in each parameter considered lake sections, depth, easting, northing, and E-N interaction as fixed effects, and sampling day (within section) and location (within section) as random effects. Three model types were considered: Model 0 (no location effect), Model 1 (locations assumed independent) and Model 2 (locations with a correlation structure). An information criterion was used to select the best model.

Reference: Review of the Ekati Diamond Mine Analysis of Variability in Water Quality, Sediment Quality and counts of Benthic Organisms in Two Lakes of the Koala Watershed.

After selecting the best model, the significance of each fixed effect was tested. If Model 2 was selected, the spatial correlation was examined as a function of distance between locations. The distance corresponding to a correlation coefficient of 0.1 or less was taken as the distance needed for statistical independence.

The variance attributed to random effects was considered to be "sampling error," as distinct from the environmental variance associated with fixed factors such as lake section and depth. This sampling error for each water quality parameter was compared to the standard error "using data and methods presented in the 2007 AEMP." It was concluded that the sampling component of error was generally small in relation to the latter, and therefore, that there was little to be gained in further optimizing the program to reduce sampling error.

We were generally able to reproduce the "sampling error" in Table 4.3-2 from the variance components presented in Table 4.3-1. However, we were unable to reproduce the "sampling error" for nitrite, where a unit's transformation is involved. Also, we were unable to reproduce the "sampling error" for aluminum, where the variance component is given as 0.00 in table 4.3-1. In these cases, the derivation of "sampling error" is not transparent.

Similarly, the derivation of the "standard error" from the 2007 AEMP is not transparent. From examination of the 2007 AEMP (Rescan, 2008) we understand the relevant error to be the residual standard error around the time trend model for each lake. However, the "SE Fit" values in Appendix C of the 2007 AEMP a) vary between lakes and b) do not match the 2007 AEMP errors as given in Table 4.3-2. Given the importance of the comparison being made in this table, the derivation of the 2007 AEMP error should be clarified.

A correlation structure was evident for 7 out of 15 water quality parameters in Slipper Lake, and 1 out of 15 in Moose Lake. In these cases, the data suggested a 200-300 m distance between stations will reduce the correlation coefficient to 0.1, the criterion used for independence. For sediments, only arsenic in Slipper Lake showed a correlation structure, and a distance of 40 m was suggested for near independence. It was noted that small sample sizes and the tendency for clustering of sediment samples may limit the ability of the study to detect a correlation structure in sediments.

In Table 4.3-3, the spatial correlation coefficient of 0.019 for arsenic in Slipper lake sediment samples seems very small to result in selection of Model 2 as the preferred model. We wonder if this value is correct, and if it is, how accounting for such a weak correlation can significantly improve the model. A discussion of this in the report would be helpful.

<u>Fulfillment of Condition 6(b)</u>

The Rescan (2008) Variability Study provides a great deal of information about sources of variability in measurements of water quality, sediment quality and benthic invertebrate counts in Moose and Slipper Lakes, and by extention in other watershed lakes.

Reference: Review of the Ekati Diamond Mine Analysis of Variability in Water Quality, Sediment Quality and counts of Benthic Organisms in Two Lakes of the Koala Watershed.

A key finding of the study is that “sampling error” (among days and locations within lake section) is small in relation to the relevant error around the trend line for a lake in the 2007 AEMP. However, further explanation is required to explain how the “2007 AEMP error” as presented in the Variability Study derives from the 2007 AEMP study.

Another key finding is that lake section has a strong influence on most measured water and sediment parameters. It is unclear to what extent this factor contributes to the relevant error in the 2007 AEMP. If the same lake sections have been consistently sampled over the years, it may contribute little; otherwise it may be an important factor. Discussion of this is the Variability Study would be appropriate.

The question of sample independence (3rd bullet in Condition 6b) has been well answered in the Variability Study, particularly for water. Uncertainties remain with respect to sediments, but this seems to be due to the patchy distribution of sediments and may be difficult to resolve further.

The “purpose of representing within-lake variability,” as mentioned in condition 6b, seems less important in the context of the 2007 AEMP, since within-lake error is not specifically used in hypothesis testing. As we understand the method, lake means for each year are used in a time trend regression model, and the relevant error is the residual error around the fit line, essentially a year-to-year variability. Thus, within-lakes spatial variability is important only insofar as year-to-year differences in sampling patterns within the lake may affect the lake mean.

An attempt was made to address the question of core sampling vs. Ekman sampling of sediments (1st bullet in condition 6b); however, the investigators were unable to obtain intact cores. The nature of the coring problem has not been well described. Different coring methods might prove more satisfactory; however, in our opinion, carefully collected Ekman samples can provide good samples of the top 2 cm as intended.

A discussion of sediment deposition rates, as mentioned in Condition 6b, has been included in the Variability Study. Cited literature supports the notion that the top 2cm of sediment represent approximately 15 years of natural deposition, and possibly a sorter period downstream of the mine site.

Shallow water benthic sites were included in the Variability Study (2nd bullet in Condition 6b) however, we find no discussion of their variability in relation to other depths (the stated reason for dropping them in the 2007 AEMP), or of standardizing on specific substrates, or of proportionally representing all substrate types. Review of the box and whisker plots in Appendix 4.3-2 does not suggest inordinate variability of shallow sites in terms of sediment quality or benthic counts.

Section 3.1.4 notes that there are areas of rocky substrate in both lakes, where it is difficult to obtain sediments, and that these areas are predominately near the shoreline or where the lake narrows. Many of the planned samples were not obtained due to the rocky substrate. This may be one reason for targeting mid-depth and deep areas for sediment collection.

Reference: Review of the Ekati Diamond Mine Analysis of Variability in Water Quality, Sediment Quality and counts of Benthic Organisms in Two Lakes of the Koala Watershed.

Summary

The Variability Study has adequately addressed the question of sample independence, which was part of Condition 6b. It has not resolved the question of core sampling vs. Ekman sampling of sediments, since cores could not be obtained. Data relevant to variability in shallow water benthic sites were obtained, but not discussed in the context of sediment and benthos sampling design.

The report could be improved by further discussion of several issues, as noted above, and particularly by description of the “2007 AEMP error” against which the sampling error within lake sections is said to be small. Further, it would be helpful to clarify whether the larger spatial patterns of within lake variability, eg., between sections, may contribute appreciably to the “2007 AEMP error”, and how sampling should be conducted relative to these larger patterns.

Closure

I hope that these comments have addressed the issues of interest to the Land and Water Board as regards to the Variability Study. If you have any questions regarding the comments, I will be happy to discuss them with you.

Yours truly,

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30 June 2008

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Reference: Review of the Ekati Diamond Mine Long Lake Containment Facility Water Quality Prediction Model (LLCFWQPM) Version 1.0 and Long Lake Containment Facility Water Quality Prediction Model Version 2.0.

Dear: Ms. Racher

As requested, EcoMetrix has reviewed the Rescan (2008) LLCF Water Quality Prediction Model report, which was completed by Rescan on behalf of BHP Billiton, in fulfillment of Condition 8 of the April 19, 2007 approval by the Wek'eezhii Land and Water Board of the 2007-2009 AEMP Plan. The purpose of our review was to assess the technical/scientific soundness of the Water Quality Prediction Model, and whether if it fulfills Condition 8 adequately.

Condition 8 in the April 19, 2007 approval letter reads as follows:

"8. LLCF Water Quality Modeling: The Board appreciates BHPB's efforts to improve the LLCF water quality modeling. Although this isn't a requirement of BHPB's water licenses, the Board has given a number of approvals, most notably for the use of chloride in the process plant and the Wastewater and Processed Kimberlite Management Plan, on the understanding that the results of this modeling would be provided to the Board in the near future. BHPB must complete this modeling and update the plan for the AEMP if necessary to address any trends of concern identified in the modeling results. The changes, if any, are to be proposed in the February 2008 Report so that they can be reviewed by the Board (Tracking Number 1). The Board itself may require changes to be made to the plan based on the modeling results."

The Issue

Steadily increasing chloride concentrations in Cell E of the Long Lake Containment Facility (LLCF) as a result of increased loadings from underground mine water and the use of calcium chloride ($CaCl_2$) in the processing plant have raised concerns regarding the potential impact of elevated chloride concentrations on the receiving environment. Modeling was performed by Rescan Environmental Services Ltd. (Rescan) to estimate the occurrence of and intensity of the peak chloride concentration in Cell E.

Reference: Review of the Ekati Diamond Mine Long Lake Containment Facility Water Quality Prediction Model (LLCFWQPM) Version 1.0 and Long Lake Containment Facility Water Quality Prediction Model Version 2.0.

Modelling Approach

Rescan used a mass balance approach to model chloride concentrations throughout the LLCF. Chloride is stable in an aqueous environment and can be used as a conservative tracer, thus modeling of environmental chloride concentrations can be accurately performed using a mass balance approach. The modeling used time-varying inputs to predict monthly average chloride concentrations.

Accurate modeling of chloride in Cell E requires complete consideration of all inputs to the LLCF, including knowledge of all chloride mass loading rates as well as the hydrodynamics of the system. These inputs included:

- Natural inflow from watershed areas
- Pumped flow from mine dewatering and processing activities
- Chloride mass loading from underground and pit mine water
- Chloride mass loadings from the process plant discharge
- Chloride mass loading from camp sewage

Two models were considered by Rescan; the Goldsim model that is a mass balance mixing model and CE-Qual_W2 that is a two dimensional model allowing layering in the basins. Although the two dimensional model was calibrated and was reported to have replicated stratification in the basin, the mixing model (Goldsim) was applied to the probabilistic modelling for practical purposes. No comment was made on the degree of agreement attained between the models for the prediction of chloride concentrations. Therefore, the importance of stratification for predicting concentrations could not be determined from the Rescan reports.

Key Assumptions and Sources of Uncertainty

Estimation of future chloride concentrations in Cell E requires estimation of the future values of the model input variables, including natural inflow (i.e., precipitation), pit and underground pumping rates and chloride concentrations, changes in chloride loading from ore processing, and calcium chloride addition to the process plant. Prediction of the behaviour of these variables over operating period of the facility is difficult and adds a degree of uncertainty to the estimated chloride concentrations. Uncertainties were minimized by using available historical data and best estimates of procedural practices to make projections of the input variable values over time. The assumptions made to predict the future behaviour of the input variables are discussed in detail in the report, as follows:

- Natural inflow: Estimation of future natural water inputs to the system is more complex than using an average value for annual precipitation. Hydrological data collected since 1997 were used to estimate water added to the LLCF from precipitation. Natural processes such as precipitation and evaporation can alter the volume of water in the system and have an effect on concentration estimates by running a Monte Carlo simulation, using a probability distribution of historical meteorological data. This procedure is common in the industry for predicting probable future precipitation patterns. The simulation resulted in an estimate of the expected average, upper bound, and lower bound chloride concentrations, solely due to reasonable application of historical precipitation patterns. The study concluded that variations in meteorological inputs can result in less than 10% error in chloride concentration estimates. In our opinion this procedure was reasonable and logical. Our review did not include checks on the accuracy of the data used in the model.

- Pumped liquids: Estimates of future pumped water rates from the process plant, pit mine sumps, underground mine sumps, and camp sewage were based on historical values and the Mine Projection Plan provided by BHP Billiton. Use of these data for future projections of LLCF flow inputs appeared reasonable.

- Chloride loads from mine dewatering: Estimation of the future chloride loading to the LLCF is difficult. Rescan determined that the primary source of chloride to the LLCF was from the underground mine water. However, estimation of future chloride concentration trends in the underground mine water is very difficult since concentrations are dependent on highly uncertain variables. Historical values of the chloride concentrations for all pumped liquids were used to compute average concentration values, which were assumed to remain constant over operation of the facility. Such an assumption is reasonable since there is little else that can be done. Chloride concentration percent error estimates were determined to be nearly linearly related to chloride mass loads percentage fluctuations. Future estimates may be refined by the addition of more data to the model as time progresses.

- Calcium chloride addition to the process facility: An accurate estimate of future $CaCl_2$ mass loading due to addition to the process facility is difficult. The model assumed an annual average of 207 t/a $CaCl_2$ will be added to the process facility based on an average of all previous loadings. Examination of the monthly $CaCl_2$ mass addition data indicates that the mass added is not consistent over time; the mass added in 2006 was approximately double that added in 2007. The average value used in the model may not accurately represent future chloride loads. However, given the small amount of loading data, use of an average value is the current best option. This value may be updated as more data becomes available. The importance of an accurate estimation of future chloride loads from $CaCl_2$ addition to the process facility is less important as compared to chloride loading from mine dewatering because the mass process related chloride is relatively small compared to that in the mine water annually. No estimate of the degree of uncertainty due to variation in the mass of $CaCl_2$ added to the process facility was reported.

- Chloride concentrations during ice up: The model makes predictions of the chloride concentration in Cell E during ice up using a mass balance technique. It is assumed that chloride is excluded from the ice crystal lattice and remains in the bulk liquid. The volume of liquid sequestered as ice is removed from the mass balance, resulting in enrichment of chloride in the liquid phase, which is observed as increasing chloride concentrations in the residual unfrozen water during winter months. The primary uncertainty in this process is estimation of ice thickness. Though it is certain that the chloride concentration will increase during ice up, the actual concentration value depends on the amount of ice formed, which is difficult to estimate and should be viewed as uncertain. The relevance of ice in predicting the chloride concentration in Cell E should be examined further to bound the uncertainty. Its importance depends strongly on the timing of discharge at the end of winter, relative to the timing of ice melt. To address this uncertainty, it would be prudent to obtain monitoring data for the end of winter period prior to discharge.

Chloride Concentration Trend in Cell E

A rough check of the modeled trend of the chloride concentration in Cell E was performed. A trend in the modeled concentration was visually determined from Figure 3.1-1 (LLCFWQPM-v2.0) using the data pertaining to the open water season only. The mass of chloride required to raise the concentration from approximately 49 $mg \cdot L^{-1}$ in January 2006 to approximately 152 $mg \cdot L^{-1}$ in January 2010 was compared to an estimate of the chloride mass loading to the system for that period based on loading data predictions provided in Appendix 1a and Table 2.1-3 and 2.1-4 (LLCFWQPM-v2.0). Volumes of the basins in the LLCF were required and were estimated using Figures 2.1-1 and 2.1-3 (LLCFWQPM-v1.0). The estimated mass of chloride modeled by Rescan was 0.62 Mkg (or 10^6 kg) while the estimated mass based on independent calculation with loading data was 0.58 Mkg, a difference of only 6.6%. The modeled concentrations were determined to be reasonable for the period of record.

Rescan Conclusions

- The primary source of chloride mass loading is from the underground and pit mine water that reports to the LLCF

- The relationship between predicted variability in chloride concentration and input variability in chloride mass loading from mine water addition to the LLCF is approximately linear

- The effect on chloride concentration in Cell E due to chloride mass loading from addition of $CaCl_2$ to the process facility is low compared to loadings from mine water addition

- The overall trend of chloride concentrations will exhibit increases up to about 2020 when thereafter the last planned mine ends operation and concentrations will decrease.

- Peak chloride concentrations in the future during operation were estimated to be between 300 $mg \cdot L^{-1}$ and 370 $mg \cdot L^{-1}$.

- Due to the uncertainties involved in estimating future chloride loads to the LLCF, the modeling results should be considered as best estimates only based on the currently available data.

Reference: Review of the Ekati Diamond Mine Long Lake Containment Facility Water Quality Prediction Model (LLCFWQPM) Version 1.0 and Long Lake Containment Facility Water Quality Prediction Model Version 2.0.

Reviewer's Conclusions

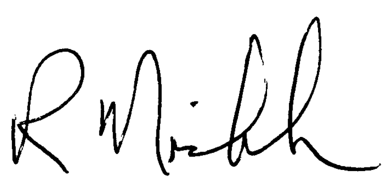
- The modeled chloride concentrations are technically acceptable based on the data currently available, and adequately fulfill Condition 8 in the April 19, 2007 approval letter.
- Given that the prediction of some future input variable values is very difficult, the assumptions made by Rescan are acceptable.
- The prediction of maximum chloride concentrations around 2020 appears reasonable and it is evident that the predicted decline in concentrations after that time coincides with the planned cessation of mining. The predicted rate of decline in chloride concentrations seems reasonable, but could not be verified with the available information.
- Given the relatively high uncertainty in chloride concentrations during ice formation due to variations in annual ice thickness, the model uncertainty for the end of winter period should be bounded, and monitoring data for this period should be obtained prior to discharge.
- Due to the uncertainty in predicted chloride concentrations during non-frozen periods, the estimates should be viewed as a guide to trends and approximate concentrations. The model predictions can be used as a management guide.

Closure

I hope that these comments have addressed the issues of interest to the Land and Water Board as regards to the LLCF Water Quality Prediction Model. If you have any questions regarding the comments, I will be happy to discuss them with you.

Yours truly,

ECOMETRIX INCORPORATED



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