Technical Memorandum N

Estimates of Receiving Water Quality for the Jericho Project, Nunavut

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1 Introduction

This report provides revised estimates of receiving water quality for the Jericho Project in Nunavut, as requested during the NIRB hearings in January 2004. These estimates supercede those presented in the *"Jericho Final EIS"* (Tahera 2003), supplemental memorandum *"Water Quality Impacts from Jericho Mine Drainages"*(AMEC 2003), and the errata *"Ammonia Discharges from PKCA"* issued during the final EIS hearings (AMEC 2004b).

The revised receiving water quality estimates were derived using additional dilution modelling to estimate the potential build-up of TDS, specific TDS components, nutrients and metals in Lake C3 and Carat Lake during mining and into the post-closure period. Minor changes in the discharge flow and water quality estimates resulting from minor revisions to the layout of the mine site facilities and water management plans are incorporated, and post-closure water quality estimates are provided.

The revised receiving water quality estimates are compared to the available CCME guidelines for receiving water quality and potential impacts to freshwater aquatic life and human health are discussed. A review of the potential environmental effects of TDS is also provided.

This report is organized as follows:

- Section 2 summarizes information on the discharge flows and concentrations from the updated water and load balance presented in the accompanying report *"Site Water Management* (SRK 2004a), and presents earlier estimates of receiving water flows for both average and low flow conditions.
- Section 3 presents the methods and results of dilution modelling completed by Lorax Environmental, that was used to calculate the available dilution capacity in the receiving environment;
- Section 4 presents final estimates of receiving water quality, and a discussion of potential impacts to the receiving environment;
- Section 5 presents a summary and conclusions; and
- Section 6 lists references to other work.

SRK would like to acknowledge significant contributions to this work made by Don Dunbar of Lorax Environmental (Princeton Ocean and CORMIX modelling), Bruce Ott of AMEC (impact assessment, review), and James Elphick of AMEC (Review of ecological effects of TDS).

2 Background Information

2.1 Discharge Flows and Concentrations

2.1.1 Operations

The updated water and load balance provided in the accompanying report "*Site Water Management*" (SRK 2004a) was used to estimate discharge flows and concentrations from the Processed Kimberlite Containment Area (PKCA) during operations. It should be noted that these differ slightly from the results presented in *"Technical Memorandum F – Water and Load Balance"* (SRK 2003a) of the supplemental EIS, due to minor changes to the layout of the waste rock dumps and water management plans. In addition, as requested by technical reviewers, specific components of the TDS are also included in the estimates. However, the total loading from the site, and therefore potential impacts to the receiving environment resulting from these changes, are lower than predicted in the EIS. Further discussion of the revised water and load balance, including the derivation of source concentrations for the TDS components, is provided in SRK 2004a.

Monthly discharge flows for average and low flow conditions used in the dilution modelling are presented in Table 1. It should be noted that these flows are approximately 5% higher than the final values presented in *"Site Water Management"* (SRK 2004a) due to adjustments made to the contributory catchment areas after the dilution modelling work had been initiated. The annual and monthly release volumes presented in SRK 2004a are considered final. Therefore, actual dilution is expected to be slightly higher and actual receiving water concentrations slightly lower than indicated in this report. Annual discharges from the site are expected to be approximately 510,000 m^3 for an average year, or 366,000 m^3 for a low flow year. The flows would be paced with receiving water flows to maximize dilutions in the receiving environment, as shown in Table 1.

Discharge concentrations are presented in Table 2. These reflect maximum concentrations expected in the PKCA discharges over the life of the mine. As illustrated in Figure 1, concentrations will increase over the first few years of the mine life, and will fluctuate seasonally due to seasonal inputs. For simplicity, the calculations used to estimate the changes in PKCA discharge concentrations over time assumed that the waste rock dumps and ore stockpiles would be fully in place starting in Year 1, and that seepage and runoff would reach peak concentrations in the first year of operations. In reality, the build-up of concentrations in the PKCA will be more gradual due to staged construction and wetting-up of these facilities over the first few years of the mine life. Therefore, it is expected that the initial concentrations will be substantially lower than the values presented in Table 2, and that the build-up of concentrations in the PKCA discharges will be more gradual than indicated in Figure 1.

Under base-case operating assumptions, water meeting the discharge criteria for the site will be released directly from the PKCA via Stream C3 to Lake C3 starting in the first year of operations. However, if necessary, the PKCA has sufficient capacity to store water for one to two years of operations, which will allow additional time in the PKCA for settling, attenuation and mixing with other inflows, all of which would result in improved water quality. The provision for storage would also allow sufficient time to develop the spray irrigation system, currently proposed as a contingency plan for water treatment. Flows from the PKCA, assuming storage during the first year of operations and release of all excess flows during second year, are presented in Table 3.

2.1.2 Post-Closure

Immediately following operations, flows from the waste rock dumps, coarse processed kimberlite (coarse PK) stockpile and low-grade stockpile will be directed to the open pit. Discharges from the PKCA will be reduced to a nominal level reflecting local runoff to the PKCA (Table 4). As noted in the preceeding section, the flows differ slightly from the values presented in "*Site Water Management*" (SRK 2004a) due to some minor adjustments in areas. The values in SRK 2004a are considered final, and the changes have a negligible effect the dilution modelling results.

The current closure plans for the PKCA call for placement of a cover of approximately 0.5 m of coarse PK on top of the fine PK, and possibly placement of soil or overburden to promote revegetation. As freezing of the underlying fine PK progresses, interaction between local runoff and materials in the PKCA will be dominated by the coarse PK layer, and discharge water quality will reflect interaction with this relatively thin layer of coarse PK and soil. Post-closure source concentrations for this cover were not estimated in the previous work (SRK 2003c). However, the general approach and basis for the estimates is similar:

1. Source concentrations for the coarse PK stockpile were compared to source concentration estimates for "disturbed ground":
   - if the concentrations for "disturbed ground" were higher than the concentrations for "unadjusted coarse PK stockpile concentrations", the "unadjusted coarse PK concentrations" were used to represent post closure runoff quality from the PKCA.
   - if the concentrations from "disturbed ground" were lower than the "unadjusted coarse PK stockpile concentrations", the coarse PK stockpile concentrations were divided by 10 to account for the differences in thickness between the stockpile and the PKCA cover, and:
     - if the values from "disturbed ground" were higher than the "adjusted coarse PK stockpile concentrations", the "disturbed ground concentrations" were used.
     - if the values from "disturbed ground" were lower than the "adjusted coarse PK stockpile concentrations", the "adjusted coarse PK stockpile concentrations were used.

2. In the case of iron and aluminum, concentrations were further adjusted by applying dissolved concentrations for these parameters. These were considered more representative of post-closure conditions, where suspended sediments are unlikely to be an issue.

The resulting post-closure concentrations for the PKCA are summarized in Table 5.

The closure plan assumes that all discharges from the waste rock dumps and stockpiles will be directed to the open pit following cessation of mining operations. Flows in Stream C1 will be maintained to a level that is sufficient to support fish habitat. Calculations from the water and load balance indicate that it will take 15 to 20 years for the pit to fill. This will allow sufficient time for flushing and removal of any blasting residues from the active layers of the pile. Freeze back of the dumps is also expected to occur in the first few years following deposition, which will reduce the exposed surface area and “lock-up” porewater, and therefore available loading from the rock. These processes are accounted for in the post-closure estimates of waste rock and pit lake water quality presented in Appendix B of the Abandonment and Restoration Plan (SRK 2004b, *in* AMEC 2004c). The post-closure water quality estimates indicate that concentrations of some metals could exceed CCME guidelines for freshwater aquatic life or CCME/Health Canada guidelines for drinking water in the pit lake.

Monitoring of seepage and runoff during operations and the post closure filling period will be needed to refine the estimates of long term water quality. If the updated estimates indicate the pit water will meet CCME guidelines for freshwater aquatic life or can be demonstrated to have negligible impacts on aquatic life, the diversion will be breached, the upper part of Stream C1 will be allowed to flow into the pit, and the pit will be allowed to spill into the original Stream C1 channel. If the revised estimates indicate the pit will not meet CCME guidelines, but could be discharged without significant impacts at the shore of Carat Lake, the diversion will be maintained, and water will be discharged via a constructed channel to the northeast of Stream C1 (see accompanying Drawing G-14). In the unlikely event that the pit water quality would be unacceptable for discharge, contingency measures such as in-pit biological treatment could be used to reduce concentrations to levels acceptable for discharge (*“Jericho Post Closure Pit Lake Water Treatment”* (SRK 2004c), *in* AMEC 2004c).

Stream C1 flows and pit discharge rates were estimated from the water and load balance. The timing of the peak flows from the pit was delayed by two weeks relative to that in Stream C1 to reflect storage in the waste dumps and open pit during the initial part of freshet. Final flow estimates are presented in Table 6. Current estimates of post-closure concentrations in the pit discharges are presented in Table 7.

2.2 Receiving Water Flows

Monthly estimates of average and 10 year low flows were made for:

- Jericho River immediately upstream of Lake C3,
- lateral inflows to Lake C3, and
- lateral inflows to Carat Lake.

The combination of all three synthesized records represents the outflow from Carat Lake. The receiving water flows were estimated using a technique known as Regional Analysis, which is a means of inferring the flows of an un-gauged stream using the measured flow records of streams in the region. The steps undertaken to estimate average flows in the Jericho River are described in *Technical Memorandum C: Supplemental Climate and Hydrology* (SRK 2003b). The analysis for estimating low flow conditions differs slightly, and is presented in Attachment N1 of this report. Average monthly and 10 year low flow estimates are provided in Table 8. Figure 2 shows two hydrographs for this location, one representing the flows during a 10-year drought and the other during average meteorological conditions.

For the dilution modelling, it was desirable to break the monthly flows into increments of one week. This was achieved by apportioning the monthly flows according to the average weekly hydrographs of regional stream-flow gauging stations. Table 9 summarizes the estimated weekly flows.

2.3 Lake Volumes

The volumes of Lake C3 and Carat Lake were estimated based on bathymetries prepared as part of the baseline studies (*"Jericho Final EIS, Appendix B.1.1 – Baseline Summary Report, Section 13.2"*, Tahera 2003). Lake C3 has a volume of approximately 4,740,000 m^3 and Carat Lake has a volume of approximately 27,200,000 m^3.

3 Dilution Modelling

3.1 Methods

3.1.1 Box Model

A simple spreadsheet based mixing model of the Lake C3/Carat lake system was set-up to model monthly variations in whole-lake concentrations in Lake C3 and Carat Lake from the start of construction to 5 years after the pit lake begins to spill into Carat Lake. The advantage of this type of model is that it can be used to rapidly simulate changes in concentration over time resulting from build-up of loading in the two lake system. However, because it assumes complete mixing of the discharges, it does not adequately simulate spatial variations in concentration at a given time-step resulting from time dependent mixing processes. Therefore, the output from this model was used as a starting condition for additional modelling using the Princeton Ocean Model (Section 3.1.2) to simulate spatial variations in the lakes.

The basic steps in the spreadsheet based model are:

1. Calculate the start-of-month inventory of load within each lake (lake volume x starting concentration).

2. Calculate the incremental loading from the discharge and/or the upstream environment (sum of concentration x flow for each inflow sources).

3. Calculate the end-of-month inventory by adding the incremental loading to the start-of-month inventory.

4. Calculate the overall concentration in each lake by dividing the end-of-month inventory by the total volume of water in the lake plus any inflows to the lake.

5. Calculate the load leaving the system by multiplying the concentration from above by the outflow.

6. Calculate the new starting inventory of load within the lake by subtracting the previous month's load out from the previous month's end-of-month inventory.

7. Repeat steps 2 through 6 for each subsequent month of simulation.

For convenience, discharge concentrations were assigned a nominal value of 1 mg/L, while background concentrations were assigned a value approaching 0 (0.0001 mg/L). This allowed calculation of a dilution factor ($D = C_o/C_t$), where C_o was the initial discharge concentration of 1, and C_t was the modelled concentration in the receiving water at time t. This approach is consistent with the approach used in previous dilution modelling on this project (*"Jericho Final EIS, Appendix D.1.2, Numerical Simulation of the Dilution of Polishing Pond Effluent in Lake C3"*, Tahera 2003, *"Numerical Simulation of the Dilution of Polishing Pond Effluent in Lake C3 and Carat Lake"*, Greisman 2003), and eliminates the need for separate dilution calculations for each parameter. However, as discussed in Section 4.1, a correction is needed to account for parameter specific background loading in the receiving environment.

The spreadsheet model was used to simulate a number of different scenarios of discharge and receiving water flows, including:

- *Scenario 1:* Release of average discharge flows into average flows in the receiving environment throughout operations (base case).

- *Scenario 2:* As above, with low flows in both discharges and receiving environment at years 2010 and 2013 (i.e. after build-up has occurred in the system).

- *Scenario 3:* Release of stored flows from two average years (one year of storage) into average flows in the receiving environment. *Scenario 3a* assumes the release of stored flows would be in the second year of operations, *Scenario 3b* assumes the release of stored flows would be in the fourth year of operation.

Discharge and receiving water flows for each of the above conditions were as presented in Sections 2.1 and 2.2.

3.1.2 Princeton Ocean Model

The results of the box model were used to calculate the increase and reduction of whole lake concentrations in Lake C3 and Carat Lake over the life of mine and into post closure. The Princeton Ocean Model (POM) was used to show how these concentrations could be distributed in the lakes after any build-up of concentration over time has occurred. The modelling was completed by Lorax Environmental, with the effluent and receiving water flow inputs provided by SRK.

The model is suitable for calculating time-varying physical properties in a variety of water bodies, and simulates all of the physical processes that affect circulation and mixing, including:

- Horizontal and vertical currents
- Vertical stratification by temperature and/or salinity
- Vertical and horizontal turbulent mixing
- Vertical fluctuations in surface elevation
- Freshwater discharges
- Surface wind stress and heat fluxes

The Princeton Ocean Model was used for earlier simulations of average and low flow conditions in the receiving environment (“*Jericho Final EIS, Appendix D.1.2”*, Tahera 2003, *”Numerical Simulation of the Dilution of Polishing Pond Effluent in Lake C3 and Carat Lake”*, Greisman 2003). Details on the model configuration and fixed environmental variables such as bathymetry, duration of ice cover, wind direction and speed, etc. were the same as in the earlier modelling work. Minor changes to the model configuration to reduce run times are documented in Attachment N2. Due to the long simulation times required for this model, the box model was used to generate starting concentrations that reflected any build-up of concentrations in the lakes from previous years of discharge.

Based on the results of the box model, two operational discharge scenarios and one post-closure discharge scenario were selected for modelling:

- *Scenario 4:* Release of average discharge flows into average flows in the receiving environment, with starting concentrations from the box model Scenario 1 outputs. The original 40 x 40 metre grid used in the December 2003 simulations (*”Numerical Simulation of the Dilution of Polishing Pond Effluent in Lake C3 and Carat Lake”*, Greisman 2003) was used for these runs, except the model domain was restricted to Lake C3. This scenario reflects expected conditions during operations.

- *Scenario 5:* Release of stored flows from two average years (one year of storage) into average flows in the receiving environment, with starting concentrations from the box model. The model grid was as above. This scenario reflects the probable maximum ratio of discharge to receiving water flows in this system.

- *Scenario 6:* Post-closure release of discharge from the shore of Carat Lake via an open channel, with average flow conditions in the discharge and receiving environment. In this run, the model grid was restricted to Carat Lake, and inflows from Lake C3 (via the Jericho River) were conservatively assigned dilutions of 60. This scenario represents one of the post-closure discharge scenarios explained in Section 2.1.2, and was used in conjunction with plume modelling to estimate the amount of dilution that could be expected with shoreline discharge of the pit outflow to Carat Lake. Final decisions regarding the post closure discharge scenario can only be made once site date is available to refine the water quality estimates.

Discharge and receiving water flows for each of the above scenarios were as presented in Sections 2.1 and 2.2.

3.1.3 CORMIX Plume Model

A plume model “CORMIX” was used to assess mixing in the near-shore environment as an alternative approach for the post-closure modelling of the discharges from the pit lake to Carat Lake. The modeling was completed by Lorax Environmental, with input assumptions provided by SRK.

The CORMIX model is a steady-state, three-dimensional model, designed to simulate the near-field concentration of positively or negatively buoyant plumes resulting from surface or subsurface effluent discharge. It is suited to water bodies that can be represented by relatively simple, idealized geometries such as a linear shoreline and constant bottom gradient. It is not well suited to rapidly changing conditions or complex shoreline or bottom morphology. However, it has the advantage of being sanctioned by the U.S. EPA, and has been verified against a large body of measurements. The intention of the plume model was to generate a broader understanding of the potential range of outcomes in this mixing problem, which provides a more robust means of evaluating the closure alternatives.

CORMIX differs significantly from POM in that the latter solves a set of mathematical equations representing the governing physical processes on a three-dimensional computational grid. Small-scale processes are not resolved. CORMIX, on the other hand, uses parameterizations of the physical processes governing several classes of effluent discharge and mixing, and provides a more detailed picture of the near-field dilution zone. CORMIX consists of three separate modules: CORMIX 1 and 2 for simulating subsurface discharge, and Cormix 3 for simulating surface discharge of effluent. In this study CORMIX 3 was used for all simulations.

CORMIX uses a simplified geometry to represent the receiving environment, as follows:

- The section of shoreline within the modelled region is straight.
- The receiving environment is effectively infinite in extent.
- The bottom slope is constant.
- The ambient current and wind, when specified, are spatially homogeneous and constant with time.

Four scenarios were evaluated including:

- June discharge flows, no wind (assuming ice cover is present) (Jun 16)
- June discharge flows, wind present (after break-up) (Jun 19)
- August discharge flows, no wind (Aug 01a)
- August discharge flows, wind present (Aug 01b)

Specific input parameters used for each of these scenarios are summarized in Table 10.

3.2 Results and Discussion

3.2.1 Operations

Box Model

The results of the box model are summarized in Figure 3 and Table 11.

Results for the base case simulation of average discharge flows into average receiving water flows (Scenario 1) indicate that minimum whole lake dilutions in Lake C3 (50) would be established within one season of discharge and minimum dilutions in Carat Lake (58) would be established within three seasons of discharge.

Results for the low flow simulations (Scenario 2) indicate minimum whole lake dilutions could be slightly lower in Lake C3 (41) and Carat Lake (53) during low flow years due to the relatively higher proportion of discharge flows resulting from the processing operations.

Results from the simulation of stored discharges into average receiving water flows during the first year of operations (Scenario 3a) indicate a minimum whole lake dilution of 27 in Lake C3, and a minimum whole lake dilution of 53 in Carat Lake. If these releases occur during year 4 of operations (Scenario 3b), the minimum whole lake dilution would be 27 in Lake C3 and 49 in Carat Lake.

In general, Carat Lake is less sensitive to a single year of stored release or low flow conditions than Lake C3 due to its larger volume.

Princeton Ocean Model

The results of the Princeton Ocean Model are provided in Attachment N3, with a summary for key locations in the system provided in Figures 4 and 5.

Results for the scenario with average discharge flows into average flows in the receiving environment and starting conditions from the box model (Scenario 4, Figure 4), indicate that minimum dilutions of approximately 20 could occur within 200 metres of the mouth of Stream C3 during the brief period when ice would still be present on the lake (assumed to be June 18th in the modelling), and would increase to approximately 40 by mid-July. At the outlet of Lake C3, minimal dilutions would be on the order of 30 for a short period immediately after the wind begins to mix the lake (on June 19th), and would also increase to approximately 40 by mid-July. Concentrations in Carat Lake are expected to be within the range predicted by the box model due to complete mixing in the section of the Jericho River that is between the two lakes. In general, the simulations indicate there would be rapid mixing in Lake C3, as would be expected from the relatively small volume of the lake, high flows from the Jericho River, and the comparatively small amount of effluent.

Results for the scenario with release of stored flows from one year of accumulation in the PKCA, and one year of normal inflows into average flows in the receiving environment (Scenario 5, Figure 5), indicated that minimum dilutions of approximately 10 could occur within 200 metres of the mouth of Stream C3 during the brief period immediately prior to break-up of the ice (assumed to be June 18th in the modelling). Dilutions would then increase rapidly to approximately 20 by the beginning of July. At the outlet of Lake C3, minimal dilutions would be on the order of 20 for a short period immediately after the wind begins to mix the lake (on June 19th), would increase to approximately 27 by mid-July.

The Princeton Ocean model concentrations are thought to be lower than those predicted by the Box model for two reasons: 1) Flows into the west arm of Lake C3 do not mix with the effluent, and therefore do not contribute to the dilution; and, 2) A large amount of un-impacted water from the Jericho River may pass through the main part of Lake C3 before the ice is off the lake and wind driven mixing begins to take effect. Once mixing occurs, the resident contaminant load begins to mix with the Jericho River water, but it takes a few weeks to reach steady state mixing. The Princeton Ocean model results are considered conservative because observations by field staff (*pers. comm.* Rick Pattenden) indicate that the ice cover in Lake C3 breaks-up more rapidly than on Carat Lake, therefore wind driven mixing is likely to start at least one week sooner. This should result in a significantly smaller effluent plume and therefore higher dilutions when the wind driven mixing begins.

3.2.2 Post Closure

Box Model

Results of the box model (Table 11, Figure 3) indicate that following operations, the whole lake dilution will increase to approximately 200 in both lakes during the period in which the pit is filling and will then decrease to approximately 60 in Carat Lake once the pit starts to spill.
For the purposes of estimating post-closure concentrations at the outlet of Carat Lake, the box model approach is considered reasonable. However, concentrations near the point of discharge will depend on largely on shoreline mixing processes. These are complex and difficult to predict given the presence of lake ice through to early June, variability in wind conditions, local bathymetry, and uncertainties in timing of flows from the site.

Observations of ice conditions made during the baseline studies (*pers. comm.*, Bruce Ott), indicate that a shore lead typically forms in Carat Lake between Stream C1 and the Stream C4. This is expected to allow more rapid dispersion of the discharges along the shoreline, and thereby enhance mixing during the very short period when there are discharges, but ice is still present on the lake. Further studies, such as tracer studies, are likely needed to quantify mixing during this period. Results from the Princeton Ocean Model and the CORMIX Plume model discussed below also provide some further insight into the available near shore dilution.

Princeton Ocean Model

The Princeton Ocean Modelling was used to simulate the 2 dimensional mixing in the lake from the start of discharge in early June (prior to break-up of the lake ice), through to the end of June, when wind is expected to be the dominant influence on mixing. Although the simulations include the period of ice cover (by assuming no wind is present), it is not possible to include the potential effects of the ice lead discussed above. Therefore results from the Princeton model are likely to provide conservative estimates of mixing during the period of ice cover.

Results for the scenario with post-closure release of discharge from the shore of Carat Lake via an open channel (Scenario 6) are presented in Attachment N4 and summarized in Figure 6. The results indicate that the dilution prior to ice break-up could be as low as 3 at a distance of up to 300 metres from the channel mouth for an approximately two week period in early June. As soon as the ice breaks-up, the plume will disperse rapidly, dilutions 40 metres of the channel mouth will fluctuate between 5 and 20, and dilutions 80 metres from the channel mouth will fluctuate between 10 and 45. At the outlet of Carat Lake, the apparent dilution would be on the order of 43. However, this is an artefact of conservatively setting the dilution of the Lake C3 inflows to 60. Actual dilutions are expected to remain close to the whole lake average concentrations of 60 predicted by the box model.

CORMIX Plume Model

The CORMIX Plume model was used to simulate mixing processes in the near shore environment, but does not accurately represent the influence of other inflows to the lake. Therefore, it may also provide conservative estimates of mixing during the post-closure period.

Results for the plume model, reflecting post-closure discharges from an open channel, are provided in Figure 7. The results indicate that, during periods of peak discharge in mid-June (i.e. prior to ice break-up), a dilution of approximately 8 could be expected at a distance of 50 metres from the channel, and a dilution of approximately 10 could be expected within a distance of 100 metres. The dilution during a period of relatively low flow (i.e. August), would be greater than 20 within 50 metres of the channel, and would increase during windy periods.

The results for the two models suggest that a reasonable degree of mixing (i.e. dilutions between 5 to 10 at a distance of 40 metres from the channel, 10 to 45 at a distance of 80 metres from the channel, and approximately 60 at the outlet of Carat Lake) can be sustained through most of the year. However, localized accumulation of the discharge, and dilutions between 3 and 8 may occur for an approximately 2 week period prior to break-up of the ice for a distance of up to 300 metres from the channel mouth. Due to the limitations of modelling dilution at this fine scale, further studies are recommended to quantify the assimilative capacity of Carat Lake if monitoring data indicate that post-closure water quality is likely to exceed applicable guidelines for receiving water quality.

4 Receiving Water Quality Estimates

4.1 Methods

Receiving water concentrations at a number of locations in the receiving environment were estimated by dividing the PKCA discharge concentrations (Section 2.1 and 2.2) by the dilution estimates (Section 3), and adding measured background concentrations in the Jericho River system (*“Jericho Final EIS, Appendix B.1.1, Baseline Summary Report, Section 6.4 and Table 6.3”*, Tahera 2003) to this value, i.e.:

$$C_R = \frac{C_D}{D} + C_B$$

Where:

C_D = Estimated Discharge Concentrations (as summarized in Section 2)
D = Dilution Factor (from Section 3)
C_B = Background Concentrations
C_R = Estimated Receiving Water Concentrations

The addition of the background concentrations corrects for background loadings irrespective of variations in the ratios of discharge and background flows.

The results are compared to CCME guidelines for freshwater aquatic life and Health Canada drinking water guidelines, as discussed in the following section. These estimates supercede those presented in the *“Jericho Final EIS”* (Tahera 2003), supplemental memorandum *“Water Quality Impacts from Jericho Mine Drainages”*(AMEC 2003), and the errata *“Ammonia Discharges from PKCA”* issued during the final EIS hearings (AMEC 2004b).

The one exception to this approach was for pH. The PKCA discharge is expected to have a relatively consistent pH of 8.1, resulting from equilibration with calcite, a naturally occurring mineral in the kimberlite. To estimate the pH in the receiving environment, PHREEQ, a geochemical equilibrium model, was used to estimate the receiving water pH at different mixing ratios. The results indicate receiving water pH’s would be in the range of 6.72 to 6.97, which are only marginally higher than the baseline Jericho River pH of 6.63. Therefore, we anticipate that there will be no impacts to the receiving environment resulting from slightly alkaline pH’s in the discharges.

Location	Mixing Ratio*	Receiving Water pH
Outlet of Lake C3.	50	6.97
Minimum dilutions at edge of Mixing Zone	10	6.72

* ratio of receiving water to discharge flows in Lake C3. The dilution modelling indicates dilutions on the order of 45 under typical conditions, and local minimum ratios on the order of 10 under worst case assumptions of discharge.

4.2 Results and Discussion

4.2.1 Water Quality Impacts on Lake C3 and Carat Lake from PKCA Discharges during Operations

Typical Operating Conditions (Average Discharge Flows)

Expected dilutions and receiving water quality estimates for three key locations in the Lake C3/Carat Lake system during normal operations (i.e. dilution modelling Scenarios 1 and 4) are provided in Tables 12 and 13. For consistency with the EIS, summaries of predicted aluminum, copper, cadmium and uranium concentrations are provided in the following tables, and values that exceed the criteria are shown in bold.

The receiving water quality estimates based on **average source concentration estimates** (Table 12) indicated potential exceedances of CCME guidelines are predicted only for cadmium as follows:

Parameter	Stream C3 outlet + 200 m (mg/L)	Lake C3 Outlet (mg/L)	Carat Lake (mg/L)	CCME Guideline (mg/L)	Background Concentrations (mg/L)
Aluminum	0.077	0.063	0.061	0.1	0.052
Cadmium*	**0.000091**	**0.000068**	**0.000064**	**0.000017**	**<0.00005**
Copper	0.0030	0.0024	0.0023	0.002 to 0.004	0.002
Uranium	0.0063	0.0029	0.0023	0.02	0.0002

Notes: * Assumes background concentrations are at the detection limit of <0.00005. Actual concentrations could be significantly lower.

Predicted cadmium concentrations are only marginally above the background concentration of <0.00005 mg/L. However, because the background concentration is at the analytical detection limit, and is approximately three times higher than the CCME guideline, it is not possible to determine whether CCME guidelines for cadmium are currently exceeded or whether they can be met in this system. It should be noted that the CCME guideline for this parameter is an interim guideline, based on an applying a ten times safety factor to the lowest measured effects level for the most sensitive aquatic organism (i.e. 0.00017 mg/L). A review of toxicity data for cadmium completed as part of this project (Attachment O1 of "*Technical Memorandum O: Proposed Discharge Limits for the Jericho Project, Nunavut*" (SRK 2004) indicated that aquatic effects would be unlikely to occur at concentrations of 0.000091 mg/L at a hardness of approximately 50, which is the expected hardness at a dilution of 20. All of the estimated concentrations are below this value.

The background concentration for copper is approximately 0.002 mg/L, which is at the CCME guideline for waters with low alkalinity. The predicted copper concentrations would be only marginally above this value during mining operations. A review of toxicity data for copper completed as part of this project (Attachment O1 of "*Technical Memorandum O: Proposed Discharge Limits for the Jericho Project, Nunavut*" (SRK 2004) indicated that aquatic effects would be unlikely to occur at concentrations of 0.004 mg/L.

Predicted aluminum and uranium concentrations are below the CCME guidelines.

The receiving water quality estimates based on **maximum source concentration estimates** (Table 13) indicated potential exceedances of CCME guidelines are predicted only for cadmium and uranium as follows:

Parameter	Stream C3 outlet + 200 m (mg/L)	Lake C3 Outlet (mg/L)	Carat Lake (mg/L)	CCME Guideline (mg/L)	Background Concentrations (mg/L)
Aluminum	0.097	0.072	0.068	0.1	0.052
Cadmium*	**0.00011**	**0.000075**	**0.000069**	**0.000017**	**<0.00005**
Copper	0.0030	0.0025	0.0024	0.002 to 0.004	0.002
Uranium	**0.034**	0.015	0.012	**0.02**	**0.0002**

Notes: * Assumes background concentrations are at the detection limit of <0.00005. Actual concentrations could be significantly lower.

Concentrations of cadmium are predicted to be slightly higher than in the preceding scenario due to higher discharge concentrations. Uranium concentrations at the edge of the mixing zone could slightly exceed the CCME guideline for drinking water supplies in which there is ongoing and sustained use of the water by humans. However, the concentrations are well below levels where occasional use of this water would result in impacts to human health. Therefore, no impacts are predicted. Aluminum and copper would remain below the CCME guidelines. These concentrations represent probable maximum concentrations in the discharge and were estimated using several conservative assumptions.

As indicated in Tables 12 and 13, TDS concentrations are expected to be 65 mg/L and 93 mg/L at a distance of 200 metres from the stream outlet, for average and maximum source concentrations respectively. Concentrations of individual TDS components (i.e. Ca, Mg, Na, K, SO4, and Cl) are well below criteria for chloride and sulphate that have been proposed in other jurisdictions. A discussion of the potential impacts of TDS on the receiving environment presented in Attachment N5 indicates that there would be little potential for toxicological effects at TDS concentrations below 400 mg/L.

Contingency Release of Stored flows from the PKCA

Expected dilutions and receiving water quality estimates at various locations in the Lake C3/Carat Lake system for the release of one year stored flow (i.e two years worth of discharges) into average receiving water flows (i.e. dilution modelling Scenarios 2 and 5) are provided in Tables 14 and 15.

The receiving water quality estimates based on **average source concentration estimates** (Table 14) indicate potential exceedances of CCME guidelines are predicted for aluminum and copper at the edge of the mixing zone, and cadmium in all three locations as follows:

Parameter	Stream C3 outlet + 200 m (mg/L)	Lake C3 Outlet (mg/L)	Carat Lake (mg/L)	CCME Guideline (mg/L)	Background Concentrations (mg/L)
Aluminum	**0.10**	0.072	0.062	0.1	0.052
Cadmium*	**0.00013**	**0.000083**	**0.000066**	**0.000017**	**<0.00005**
Copper	**0.0040**	0.0028	0.0024	0.002 to 0.004	0.002
Uranium	0.012	0.0051	0.0026	0.02	0.0002

Notes: * Assumes background concentrations are at the detection limit of <0.00005. Actual concentrations could be significantly lower.

The receiving water quality estimates based on **maximum source concentration estimates** (Table 15) indicate potential exceedances of CCME guidelines are predicted for aluminum, cadmium, copper and uranium at the edge of the mixing zone, uranium throughout Lake C3, and cadmium in all three locations, as follows:

Parameter	Stream C3 outlet + 200 m (mg/L)	Lake C3 Outlet (mg/L)	Carat Lake (mg/L)	CCME Guideline (mg/L)	Background Concentrations (mg/L)
Aluminum	**0.14**	0.088	0.070	0.1	0.052
Cadmium*	**0.00016**	**0.000095**	**0.000072**	**0.000017**	**<0.00005**
Copper	**0.004**	0.0028	0.0024	0.002 to 0.004	0.002
Uranium	**0.069**	**0.028**	0.014	0.02	0.0002

Notes: * Assumes background concentrations are at the detection limit of <0.00005. Actual concentrations could be significantly lower.

As indicated in Tables 14 and 15, TDS concentrations are expected to be 118 mg/L and 174 mg/L at a distance of 200 metres from the stream outlet, for average and maximum source concentrations respectively. As discussed in the above section, concentrations of individual TDS components would be well below the applicable guidelines and toxicity thresholds, indicating little potential for toxicological or environmental effects.

4.2.2 Post-Closure Discharges from the PKCA to Lake C3

After closure, discharges from the PKCA will be limited to direct precipitation and local runoff to the PKCA. Therefore flows from the PKCA will be approximately six times less than during operations, and overall dilution in Lake C3 will be approximately 170. As indicated in Section 2.1.2, post-closure concentrations from the PKCA will also be significantly less than during operations. Therefore, impacts to Lake C3 and Carat Lake are expected to be negligible after closure of the facility.

4.2.3 Post-Closure Discharges from the Open Pit to Carat Lake

As discussed in Section 3.2.2, after break-up of the ice, discharges from the shoreline are expected to disperse and mix rapidly, reaching a minimum of five times dilution within 40 metres of the outfall, a minimum of ten times dilution within 80 metres of the outfall, and a minimum of sixty times dilution at the Jericho River outlet of Carat Lake. Estimates for the two week period period prior to break-up indicate that locally lower dilutions could occur, but these are highly dependent on fine-scale mixing processes that cannot be accurately simulated in any of the available models. Tracer studies during operations can be used to quantify the near shore mixing processes well in advance of the pit reaching its spill point, should refined estimates of post-closure water quality indicate that the discharges from the pit lake would not meet receiving water quality.

Post-closure receiving water quality estimates at these locations are provided in Table 16. Although copper concentrations are predicted to approach the upper CCME guideline, cadmium is the only parameter predicted to exceed the CCME guideline as follows:

Parameter	40 m from Channel (mg/L)	80 m from Channel (mg/L)	Outlet of Carat Lake (mg/L)	CCME Guideline (mg/L)	Background Concentrations (mg/L)
Aluminum	0.083	0.067	0.055	0.1	0.052
Cadmium*	**0.00011**	**0.000081**	**0.000055**	**0.000017**	**<0.00005**
Copper	0.0039	0.0029	0.0022	0.002 to 0.004	0.002
Uranium	0.013	0.0065	0.0013	0.02	0.0002

Notes: * Assumes background concentrations are at the detection limit of <0.00005. Actual concentrations could be significantly lower.

Predicted TDS concentrations were 85 and 48 mg/L at 40 and 80 metres distance respectively. As in the previous estimates, these are well below the available guidelines and toxicity thresholds defined for any individual TDS component, and are not expected to result in adverse effects to the aquatic ecosystem.

5 Summary and Conclusions

Dilution modelling was used to estimate receiving water concentrations for TDS, major ions, metals and nutrients during mining operations and through the first 25 years of closure. The results indicate that, under typical operating conditions, concentrations of all parameters except cadmium are close to background, or within CCME guidelines. Cadmium is the only parameter which may exceed the CCME guidelines for freshwater aquatic life beyond a 200 metre mixing zone from the outlet of Stream C3. However, the predicted cadmium concentrations based on assuming background cadmium concentrations are at the detection limit of 0.00005 mg/L, are only slightly higher than the detection limit for cadmium, and are below the lowest effects level reported in the CCME guidelines fact sheet. Local exceedances of aluminum, copper and uranium may occur near the edge of the mixing zone under worst case discharge conditions, or if effluent concentrations approach the probable maximum values estimated for this site.

After closure, discharges from the PKCA will be limited to direct precipitation and local runoff to the PKCA. Therefore flows from the PKCA will be much lower and dilution in Lake C3 will be substantially higher. Post-closure concentrations from the PKCA will also be significantly lower than during operations. Therefore, impacts to Lake C3 and Carat Lake will be minimal after closure of the facility.

After closure, discharges from the waste dumps and stockpiles will be directed to the open pit. Post-closure discharges from the pit would only occur after the pit reaches its spill point. Depending on the quality of the pit water, the discharge may be returned to the original Stream C1 channel, or directed via a constructed channel directly to Carat Lake. Modelling of the constructed channel discharge indicates that the available dilution after break-up of the ice would be on the order of five to ten times at distances of 40 to 80 metres from the channel outlet. With the exception of cadmium, all parameters would meet CCME guidelines for freshwater aquatic life and human health beyond this mixing zone. In the case of cadmium, the predicted concentrations are below the lowest effects levels reported in the CCME (1999) guidelines. The available dilution prior to break-up of the ice depends on the development of the ice-free lead along the shoreline and fine scale mixing processes that cannot be accurately quantified by the available models. Should refined estimates of post-closure water quality indicate that discharges from the pit lake would not meet receiving water quality guidelines, a tracer study could be conducted to quantify the available dilution.

6 References

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TABLES

Table 1
Discharge Flows During Operations

Month	Average Flows in Jericho River above Lake C3		Monthly Percent Flows Jericho River		Average Discharge Flows from PKCA	
	Average Year	10 Year Low Flow	Average Year	10 Year Low Flow	Average Year	10 Year Low Flow
	m3/mo	m3/mo	%	%	m3	
May	607,611	51	2.6%	0.0%	13,330	1
Jun	13,367,450	8,473,163	57.5%	64.5%	293,252	236,052
Jul	3,711,356	2,691,305	16.0%	20.5%	81,419	74,976
Aug	2,118,429	853,425	9.1%	6.5%	46,474	23,775
Sep	2,939,525	938,619	12.6%	7.1%	64,487	26,149
Oct	509,080	185,900	2.2%	1.4%	11,168	5,179
Nov	0	0	0.0%	0.0%	0	0
TOTAL	23,253,451	13,142,463	100.0%	100.0%	510,129	366,133

Notes: 1. See Table 9 for Source of Jericho River Flows

2. Discharge Flows from PKCA were estimated using the site water and load balance (SRK 2004a), and were distributed in proportion to the monthly Jericho River Flows

3. In the Princeton Ocean Model, discharge flows from May were added to the June flows, and flows from October were added to the September flows to reduce run times to a four month period.

Table 2
Maximum Discharge Concentrations from the PKCA during Operations

Parameter	Estimated Discharge Concentration (mg/L)	
	Average Source Conc.	Maximum Source Conc.
Nutrients		
NH4-N	1.8	2.9
NO2-N	0.16	0.23
NO3-N	5.0	7.4
P	0.087	0.087
Physical		
TDS	1074	1635
TSS	6.3	7.4
Major Ions		
Alk	42	70
Ca	101	202
Cl	487	647
K	36	64
Mg	175	206
Na	21	36
SO4	184	380
Dissolved Metals		
DAl	0.12	0.21
DFe	0.26	0.64
Total Metals		
TAl	0.49	0.90
TAs	0.0013	0.0021
TCd	0.0008	0.0011
TCr	0.0047	0.0099
TCu	0.020	0.021
TFe	0.63	1.0
TMo	0.075	0.14
TNi	0.042	0.062
TPb	0.0038	0.0040
TU	0.12	0.68
TZn	0.015	0.034

Notes:
1) Data extracted from the water and load balance (SRK and Clearwater 2004)
2) 2013 used as representing typical seasonal maximums in concentration
3) Maximum concentrations typically occur in August/September in PKCA & Settling Pond, minimum concentrations in April/May, See Figure 1 For seasonal patterns
4) Source parameter concentrations provided by SRK (April 15, 2004)
5) All concentrations in mg/L

Table 3
Discharge Flows assuming 1 year storage and release of excess flows the following year

Month	Average Flows in Jericho River above Lake C3		Release of Stored Flows from PKCA
	m3/mo	monthly %	m3
May	607,611	2.6%	25,071
Jun	13,367,450	57.5%	551,570
Jul	3,711,356	16.0%	153,138
Aug	2,118,429	9.1%	87,411
Sep	2,939,525	12.6%	121,291
Oct	509,080	2.2%	21,006
Nov	0	0.0%	0
TOTAL	23,253,451	100.0%	959,487

NOTES

1) Releases from PKCA shown above are assumed to occur during the second year of operation and consist of cumulative net excess runoff and process flows from the first two years of operation assuming average precipitation conditions.
2) Monthly release volumes in June & July maximized based on available excess water in the system.
3) All flow rates & flow volumes for the Jericho River system are for estimated average conditions

Table 4
Post Closure Flows from the PKCA

Month	Post-Closure Flows from PKCA m3/mo
May	0
Jun	52,512
Jul	8,247
Aug	13,144
Sep	6,467
Oct	0
TOTAL	80,370

Table 5
Post-Closure Water Quality from the PKCA

Parameter mg/L, or specified	Runoff Disturbed Areas	Coarse Kimberlite Stockpile	Adjusted Coarse Kimberlite Stockpile	Estimated Post-Closure Water Quality from PKCA
pH	na	na	na	8.2
Ammonia - N (unionized) (calculated)*				0.014
Ammonia - N (total)	0.007	3.30	0.33	0.33
Nitrate - as N	0.041	8.3	0.83	0.83
Nitrite - as N	0.001	0.24	0.024	0.024
Phosphorus - P	0.01	0.01	0.00	0.01
Total Dissolved Solids	180	4395	440	440
Total Suspended Solids	3	10	1	3
Sulphate - SO4	13	717	72	72
Alkalinity (mg CaCO3 eq/L)	31	100	10	31
Chloride	29	2379	238	238
Calcium	29	155	16	29
Magnesium	6	861	86	86
Sodium	4.0	37	4	4
Potassium	2.0	146	15	15
Total Metals				
Aluminum - Al	0.085	0.019	0.002	0.019
Arsenic - As	0.00075	0.0037	0.0004	0.00075
Cadmium - Cd	0.00005	0.0042	0.0004	0.0004
Chromium - Cr	0.0005	0.012	0.001	0.0012
Copper - Cu	0.0056	0.0031	0.0003	0.0031
Iron - Fe	0.18	0.21	0.02	0.18
Lead - Pb	0.0185	0.0012	0.0001	0.0012
Molybdenum - Mo	0.0026	0.72	0.07	0.072
Nickel - Ni	0.0034	0.17	0.02	0.017
Uranium - U	0.28	0.080	0.008	0.080
Zinc - Zn	0.012	0.027	0.003	0.012

Notes: Source concentrations for "Disturbed Areas" and the "Coarse PK Stockpile" are from Technical Memorandum I (SRK 2003c

Table 6
Post Closure Flows from the Pit Lake and Stream C1

Month	Pond A	Pond B	Pond C	Pit Pond	Total Flows from Pit Lake	Stream C1 Diversion Upstream of Pit Lake	Stream C1 Diversion with Pit Flows Returned to Original Channel
Jan	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0
Apr	0	0	0	0	0	0	0
May	5,071	1,950	4,762	1,305	13,088	8,487	21575
Jun	65,334	25,261	60,480	21,497	172,572	122,771	295343
Jul	23,282	8,926	22,058	3,170	57,436	35,977	93413
Aug	22,299	8,586	20,887	5,315	57,087	38,203	95290
Sep	10,682	4,116	9,986	2,833	27,617	18,607	46224
Oct	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0
Total	126,668	48,839	118,173	34,120	327,800	224,045	551,845

Notes: 1) Monthly flow volumes from Table W2 in Site Water Management Report (SRK 2004a)
2) Monthly net runoff flows (m3) for Ponds A, B, C, Pit Pond, C1 Diversion correspond to
to period when the pit is full & overflowing/spilling to Carat Lake (starting approx year 2029).

Table 7
Post-Closure Estimates of Pit Water Quality

Parameter	1) Discharge from Pit Lake without Stream C1	2) Long-term Discharge from Pit Lake with Stream C1 redirected to pit.	*CCME Aquatic Life Guidelines*	*Health Canada Guidelines*	*Carat Lake Baseline Data*
TDS	372	231	*na*	*500*	*11*
TSS	2	2	*na*	*na*	*1.4*
Alk	16	14	*na*	*na*	*4.7*
Ca	38	24	*na*	*na*	*2.3*
Cl	161	96	*na*	*250*	*3.4*
K	13	8	*na*	*na*	*2.0*
Mg	62	37	*na*	*na*	*0.8*
Na	8	5	*na*	*na*	*2.0*
SO4	70	42	*na*	*500*	*1.2*
TAl*	0.15	0.13	*0.1*	*0.1*	*0.052*
TAs	0.0005	0.0004	*0.005*	*0.025*	*0.00016*
TCd	0.0003	0.0002	*0.000017*	*0.005*	*0.00005*
TCr	0.0017	0.0012	*0.0089*	*0.05*	*0.0025*
TCu	0.009	0.007	*0.002*	*1.0*	*0.0020*
TFe*	0.20	0.24	*0.3*	*0.3*	*0.025*
TMo	0.032	0.019	*0.073*	*na*	*0.00005*
TNi	0.015	0.009	*0.025*	*na*	*0.0005*
TPb	0.0020	0.0013	*0.001*	*0.01*	*0.00005*
TU	0.063	0.038	*na*	*0.02*	*0.00020*
TZn	0.006	0.004	*0.03*	*5*	*0.0020*

Notes:

Assumptions and Calculations are provided in SRK memo "Post-Closure Pit Water Quality" (prepared May 6, 2004, Kelly Sexsmith), provided as an appendix to the Abandonment and Reclamation Plan (AMEC, 2004)

1. Assumes all sources of water entering the pit have reached post-closure water quality by the start of filling
2. Reflects mixed water quality in the pit in the long term, once steady-state mixing has been reached (approximately 30 years after pit is filled)

Table 8
Estimated Flows for Jericho River During 10 Year Drought and Average Meteorological Conditions

Month	Monthly Average Discharge (m^3/s)							
	Jericho River above Lake C3		Lateral inflows to Lake C3		Lateral inflows to Carat Lake		Jericho River at outlet of Carat Lake	
	10-Year Drought	Average Conditions	10-Year Drought	Average Conditions	10-Year Drought	Average Conditions	10-Year Drought	Average Conditions
Jan	0	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0	0
Apr	0	0	0	0	0	0	0	0
May	0	0.23	0	0.029	0	0.034	0	0.29
Jun	3.2	5.1	0.41	0.65	0.47	0.74	4.1	6.5
Jul	1.0	1.4	0.13	0.18	0.15	0.20	1.3	1.8
Aug	0.32	0.80	0.041	0.10	0.047	0.12	0.41	1.0
Sep	0.36	1.1	0.045	0.14	0.052	0.16	0.45	1.4
Oct	0.071	0.19	0.009	0.025	0.010	0.028	0.090	0.25
Nov	0	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0
Average	0.41	0.73	0.053	0.093	0.060	0.11	0.53	0.93

Note: These flows exclude releases from the PKCA and runoff from the areas controlled by the collection ponds and the PKCA.

Table 9
Estimated Weekly Hydrograph for Average and 10 Year Low Flow Conditions (excludes releases from PKCA and flows from areas controlled by collection ponds and PKCA

Start Date of Week	Weekly Average Flow (m^3/h) - Average Conditions				Weekly Average Flow (m^3/h) - 10 Year Low Flow Conditions			
	Jericho River above Lake C3	Lateral inflows to Lake C3	Lateral inflows to Carat Lake	Jericho River at outlet of Carat Lake	Jericho River above Lake C3	Lateral inflows to Lake C3	Lateral inflows to Carat Lake	Jericho River at outlet of Carat Lake
May 18	13	2	2	16	0	0	0	0
May 25	3635	463	529	4627	0	0	0	0
Jun 01	9355	1191	1361	11906	6400	815	931	8145
Jun 08	29506	3755	4292	37553	12791	1628	1861	16280
Jun 15	23672	3013	3443	30128	14833	1888	2157	18878
Jun 22	13236	1685	1925	16846	13488	1717	1962	17166
Jun 29	7426	945	1080	9452	6867	874	999	8740
Jul 06	6672	849	970	8492	4150	528	604	5282
Jul 13	3868	492	563	4923	3045	387	443	3875
Jul 20	4675	595	680	5950	2568	327	374	3268
Jul 27	3032	386	441	3859	2251	287	327	2865
Aug 03	2088	266	304	2658	1321	168	192	1682
Aug 10	2091	266	304	2661	1113	142	162	1417
Aug 17	2200	280	320	2799	1009	128	147	1284
Aug 24	4945	629	719	6293	999	127	145	1272
Aug 31	5562	708	809	7079	1264	161	184	1608
Sep 07	4944	629	719	6292	1649	210	240	2099
Sep 14	3136	399	456	3991	1437	183	209	1829
Sep 21	2832	360	412	3605	1084	138	158	1380
Sep 28	2707	345	394	3446	707	90	103	900
Oct 05	880	112	128	1119	360	46	52	459
Oct 12	726	92	106	924	196	25	28	249
Oct 19	237	30	34	302	121	15	18	154
Oct 26	61	8	9	78	19	2	3	24
Nov 02	0	0	0	0	0	0	0	0
Nov 09	0	0	0	0	0	0	0	0

Table 10
Input Parameters for CORMIX3 Plume Model

Parameter		June 16	June 19	Aug 1a	Aug 1b
Ambient					
Average Depth of Discharge Zone	m	3.5	3.5	3.5	3.5
Current	m/s	0.001	0.05	0.03	0.03
Wind	m/s	0	4	0	3.5
Effluent					
Flow rate	m3/s	0.28	0.28	0.034	0.034
Conc.	mg/l	100	100	100	100
Discharge					
Bottom slope	%	5	5	5	5
Depth at point of discharge	m	0.5	0.5	0.5	0.5
Channel width	m	3	3	3	3
Channel depth	m	0.3	0.3	0.3	0.3
Mixing Zone					
Region of interest	m	250	250	250	250

Table 11
Summary of Box Model Results

Scenario	Discharge Flows	Receiving Flows	Years to Steady State		Dilution Factors							
			Lake C3	Carat Lake	Operations				Post-closure - Pit Filling		Post-Closure - Long-term	
					Lake C3*		Carat Lake		Lake C3	Carat Lake	Lake C3	Carat Lake
					Minimum Winter	Minimum Monthly	Minimum Winter	Monthly Minimum	Monthly Minimum	Monthly Minimum	Monthly Minimum	Monthly Minimum
1	Average	Average	1	3	56	50	58	58	168	199	168	60
2	Periodic Low	Periodic Low	1	3	43	41	54	53	168	199	168	60
3a	Stored Release (yr2)	Average	1	3	30	27	54	53	168	199	168	60
3b	Stored Release (yr4)	Average	1	3	30	27	49	49	168	199	168	60

Notes: * The duration of minimum dilutions from periodic low flow years or from stored release would be limited to one year in Lake C3.

Table 12
Receiving Water Quality Estimates - Average Source Concentrations, Average Receiving Water Flows

Parameter **mg/L, or specified**	**Polishing Pond** Avg Source Conc.	**Carat Lake** Background Conc.	**Receiving Water Quality Estimates** **Stream C3 Out + 200 m** 20	**Lake C3 Outlet** 45	**Carat Lake Water Intake** 58	**Guidelines** **CCME Fresh Water Aquatic Life** **min**	**max**	**Note**	**CCME/Health Canada Drinking 2003**
Aluminum - Al	0.49	0.052	0.077	0.063	0.061	0.005	**0.1**	a	**0.1**
Ammonia - N (unionized) (calculated)*	0.075	0.000	0.004	0.0017	0.0013	**0.016**		*	
Ammonia - N (total)	1.8	0.009	0.10	0.050	0.041	**0.59**	60	b	
Arsenic - As	0.0013	0.00016	0.0002	0.0002	0.0002	**0.005**			**0.025**
Barium - Ba						na			**1**
Boron - B						na			**5**
Cadmium - Cd	0.0008	0.00005	0.000091	0.000068	0.000064	**0.000017**			**0.005**
Calcium - Ca	101	2.4	7.4	4.6	4.1	na			na
Chloride - Cl	487	3.4	28	14	12	na			**250**
Chromium - Cr	0.0047	0.0002	0.0004	0.0003	0.0003	**0.0089**			**0.05**
Copper - Cu	0.020	0.0020	0.0030	0.0024	0.0023	0.002	**0.004**	c	**1**
Iron - Fe	0.63	0.025	0.056	0.039	0.036	**0.3**			**0.3**
Lead - Pb	0.0038	0.00005	0.00024	0.00013	0.00012	**0.001**	0.007	d	**0.01**
Magnesium - Mg	175	0.84	9.6	4.7	3.8	na			na
Manganese - Mn						na			**0.05**
Mercury - Hg						**0.00001**			**0.001**
Molybdenum - Mo	0.075	0.00005	0.0038	0.0017	0.0013	**0.073**			
Nickel - Ni	0.042	0.0005	0.0026	0.0014	0.0012	**0.025**	0.15	e	
Nitrate - as N	5.0	0.18	0.43	0.29	0.27	**4.0**			**10**
Nitrite - as N	0.16	0.001	0.009	0.0047	0.0038	**0.06**			**1**
pH	8.2	6.63	6.8	6.80	6.8	6.5	9	f	
Phosphorus - P	0.087	0.0077	0.012	0.010	0.009	na			
Potassium - K	36	2	3.80	2.80	2.62	na			na
Selenium - Se						**0.001**			**0.01**
Silver - Ag						**0.0001**			
Sodium - Na	21	2	3	2	2	na			**200**
Sulphate - SO_4	184	1.2	10	5	4	na			**500**
Sulphide (as H_2S)						na			**0.05**
Thallium - Tl						**0.0008**			
Total Dissolved Solids	1074	11	65	35	30	na			**500**
Total Suspended Solids	6.3	1.4	2	2	2	5	25	g	
Uranium - U	0.12	0.0002	0.0063	0.0029	0.0023	na			**0.02**
Zinc - Zn	0.015	0.002	0.003	0.002	0.002	**0.03**			**5**

Notes: Bolded guidelines were the applicable criteria
Blue highlighting indicates >5x dilution required to meet criteria
* Polishing Pond concentration is calculated at temperature of 15oC and estimated pH of 8.2. Actual receiving water pH's and temperatures will generally be much lower, resulting in a shift in equilibrium to less un-ionized ammonia (units are in N equivalents)

a - Guidelines indicate value of 0.1 is appropriate where the pH is greater than 6.5

b - Range reflects pH's from 6.5 to 8 and temperatures of 0 to 15 C. Actual range is pH 6.1 to 7.73, with mean values of 6.85 in Lake C3 and 6.74 in Carat Lake
c - Guidelines indicate lower value of 0.002 is appropriate where the hardness is less than 120 mg CaCO3 eq/L
d - Guidelines indicate lower value of 0.001 is appropriate where the hardness is less than 60 mg CaCO3 eq/L
e - Guidelines indicate lower value of 0.025 is appropriate where the hardness is less than 60 mg CaCO3 eq/L
f - The pH must be within this range

g - The total suspended sediments must not exceed background levels by more than 5 mg/L on average, nor 25 mg/L from background levels on
short-term exposure (24 hours)

Table 13

Receiving Water Quality Estimates - Maximum Source Concentrations, Average Receiving Water Flows

Parameter mg/L, or specified	**Polishing Pond**	**Carat Lake**	**Receiving Water Quality Estimates**			**Guidelines**			
	Max. Source Conc.	Background Conc.	**Stream C3 Out + 200 m** 20	**Lake C3 Outlet** 45	**Carat Lake Water Intake** 58	**CCME Fresh Water Aquatic Life** **min**	**max**	**Note**	**CCME/Health Canada Drinking 2003**
Aluminum - Al	0.90	0.052	0.097	0.072	0.068	0.005	**0.1**	a	**0.1**
Ammonia - N (unionized) (calculated)*		0.000	0.000	0.000	0.000	**0.016**		*	
Ammonia - N (total)	2.9	0.009	0.16	0.074	0.060	**0.59**	60	b	
Arsenic - As	0.0021	0.00016	0.0003	0.0002	0.0002	**0.005**			**0.025**
Barium - Ba						na			**1**
Boron - B						na			**5**
Cadmium - Cd	0.0011	0.00005	0.00011	0.000075	0.000069	**0.000017**			**0.005**
Calcium - Ca	202	2.4	12.5	6.9	5.9	na			na
Chloride - Cl	647	3.4	36	18	15	na			**250**
Chromium - Cr	0.0099	0.0025	0.0030	0.0027	0.0027	**0.0089**			**0.05**
Copper - Cu	0.021	0.0020	0.0030	0.0025	0.0024	0.002	**0.004**	c	**1**
Iron - Fe	1.0	0.025	0.08	0.048	0.043	**0.3**			**0.3**
Lead - Pb	0.0040	0.00005	0.00025	0.00014	0.00012	**0.001**	0.007	d	**0.01**
Magnesium - Mg	206	0.84	11.1	5.4	4.4	na			na
Manganese - Mn						na			**0.05**
Mercury - Hg						**0.00001**			**0.001**
Molybdenum - Mo	0.14	0.00005	0.007	0.0031	0.0024	**0.073**			
Nickel - Ni	0.062	0.0005	0.0036	0.0019	0.0016	**0.025**	0.15	e	
Nitrate - as N	7.4	0.18	0.55	0.35	0.31	**4.0**			**10**
Nitrite - as N	0.23	0.001	0.012	0.0060	0.0049	**0.06**			**1**
pH	8.2	6.63	6.8	6.8	6.8	6.5	9	f	
Phosphorus - P	0.087	0.0077	0.01	0.01	0.01	na			
Potassium - K	64	2	5.2	3.4	3.1	na			na
Selenium - Se						**0.001**			**0.01**
Silver - Ag						**0.0001**			
Sodium - Na	36	2	4	3	3	na			**200**
Sulphate - SO_4	380	1.2	20	10	8	na			**500**
Sulphide (as H_2S)						na			**0.05**
Thallium - Tl						**0.0008**			
Total Dissolved Solids	1635	11	93	47	39	na			**500**
Total Suspended Solids	7.4	1.4	2	2	2	5	25	g	
Uranium - U	0.68	0.0002	0.034	0.015	0.012	na			**0.02**
Zinc - Zn	0.034	0.002	0.004	0.003	0.003	**0.03**			**5**

Notes: Bolded guidelines were the basis for the calculated dilutions

* Polishing Pond concentration is calculated at temperature of 15oC and estimated pH of 8.2. Actual receiving water pH's and temperatures will generally be much lower, resulting in a shift in equilibrium to less un-ionized ammonia, values are given in N

a - Guidelines indicate value of 0.1 is appropriate where the pH is greater than 6.5

b - Range reflects pH's from 6.5 to 8 and temperatures of 0 to 15 C. Actual range is pH 6.1 to 7.73, with mean values of 6.85 in Lake C3 and 6.74 in Carat Lake

c - Guidelines indicate lower value of 0.002 is appropriate where the hardness is less than 120 mg CaCO3 eq/L

d - Guidelines indicate lower value of 0.001 is appropriate where the hardness is less than 60 mg CaCO3 eq/L

e - Guidelines indicate lower value of 0.025 is appropriate where the hardness is less than 60 mg CaCO3 eq/L

f - The pH must be within this range

g - The total suspended sediments must not exceed background levels by more than 5 mg/L on average, nor 25 mg/L from background levels on a short-term exposure (24 hours)

Table 14

Receiving Water Quality Estimates - Average Source Concentrations, Release of Stored Flows

Parameter mg/L, or specified	**Polishing Pond**	**Carat Lake**	**Receiving Water Quality Estimates**			**Guidelines**			
	Avg Source Conc.	Background Conc.	**Stream C3 Out + 200 m** 10	**Lake C3 Outlet** 25	**Carat Lake Water Intake** 50	**CCME Fresh Water Aquatic Life** **min**	**max**	**Note**	**CCME/Health Canada Drinking 2003**
Aluminum - Al	0.49	0.052	0.10	0.072	0.062	0.005	**0.1**	a	**0.1**
Ammonia - N (unionized) (calculated)*	0.075	0.000	0.008	0.0030	0.0015	**0.016**		*	
Ammonia - N (total)	1.8	0.009	0.19	0.083	0.046	**0.59**	60	b	
Arsenic - As	0.0013	0.00016	0.0003	0.0002	0.0002	**0.005**			**0.025**
Barium - Ba						na			**1**
Boron - B						na			**5**
Cadmium - Cd	0.0008	0.00005	0.00013	0.00008	0.00007	**0.000017**			**0.005**
Calcium - Ca	101	2.4	12	6.4	4.4	na			na
Chloride - Cl	487	3.4	52	23	13	na			**250**
Chromium - Cr	0.0047	0.0025	0.0030	0.0027	0.0026	**0.0089**			**0.05**
Copper - Cu	0.020	0.0020	0.0040	0.0028	0.0024	0.002	**0.004**	c	**1**
Iron - Fe	0.63	0.025	0.088	0.050	0.038	**0.3**			**0.3**
Lead - Pb	0.0038	0.00005	0.00043	0.00020	0.00013	**0.001**	0.007	d	**0.01**
Magnesium - Mg	175	0.84	18	7.8	4.3	na			na
Manganese - Mn						na			**0.05**
Mercury - Hg						**0.00001**			**0.001**
Molybdenum - Mo	0.075	0.00005	0.0075	0.0030	0.0015	**0.073**			
Nickel - Ni	0.042	0.0005	0.0047	0.0022	0.0013	**0.025**	0.15	e	
Nitrate - as N	5.0	0.18	0.68	0.38	0.28	**4.0**			**10**
Nitrite - as N	0.16	0.001	0.017	0.0076	0.0043	**0.06**			**1**
pH	8.2	6.63	6.8	6.8	6.8	6.5	9	f	
Phosphorus - P	0.087	0.0077	0.02	0.01	0.01	na			
Potassium - K	36	2	5.6	3.4	2.7	na			na
Selenium - Se						**0.001**			**0.01**
Silver - Ag						**0.0001**			
Sodium - Na	21	2	4	3	2	na			**200**
Sulphate - SO_4	184	1.2	20	9	5	na			**500**
Sulphide (as H_2S)						na			**0.05**
Thallium - Tl						**0.0008**			
Total Dissolved Solids	1074	11	118	54	32	na			**500**
Total Suspended Solids	6.3	1.4	2	2	2	5	25	g	
Uranium - U	0.12	0.0002	0.012	0.005	0.003	na			**0.02**
Zinc - Zn	0.015	0.002	0.004	0.003	0.002	**0.03**			**5**

Notes: Bolded guidelines were the basis for the calculated dilutions
Blue highlighting indicates >5 x dilution required to meet criteria
* Polishing Pond concentration is calculated at temperature of 15oC and estimated pH of 8.2. Actual receiving water pH's and temperatures will generally be much lower, resulting in a shift in equilibrium to less un-ionized ammonia, values are given in N

a - Guidelines indicate value of 0.1 is appropriate where the pH is greater than 6.5

b - Range reflects pH's from 6.5 to 8 and temperatures of 0 to 15 C. Actual range is pH 6.1 to 7.73, with mean values of 6.85 in Lake C3 and 6.74 in Carat Lake

c - Guidelines indicate lower value of 0.002 is appropriate where the hardness is less than 120 mg CaCO3 eq/L

d - Guidelines indicate lower value of 0.001 is appropriate where the hardness is less than 60 mg CaCO3 eq/L

e - Guidelines indicate lower value of 0.025 is appropriate where the hardness is less than 60 mg CaCO3 eq/L

f - The pH must be within this range

g - The total suspended sediments must not exceed background levels by more than 5 mg/L on average, nor 25 mg/L from background levels on short-term exposure (24 hours)

Table 15
Receiving Water Quality Estimates - Maximum Source Concentrations, Release of Stored Flows

Parameter **mg/L, or specified**	**Polishing Pond**	**Carat Lake**	**Receiving Water Quality Estimates**			**Guidelines**			
	Max. Source Conc.	Background Conc.	**Stream C3 Out + 200 m** 10	**Lake C3 Outlet** 25	**Carat Lake Water Intake** 50	**CCME Fresh Water Aquatic Life** **min**	**max**	**Note**	**CCME/Health Canada Drinking** **2003**
Aluminum - Al	0.90	0.052	0.14	0.088	0.070	0.005	**0.1**	a	**0.1**
Ammonia - N (unionized) (calculated)*		0.000	0.000	0.000	0.000	**0.016**		*	
Ammonia - N (total)	2.9	0.009	0.30	0.127	0.068	**0.59**	60	b	
Arsenic - As	0.0021	0.00016	0.0004	0.0002	0.0002	**0.005**			**0.025**
Barium - Ba						na			**1**
Boron - B						na			**5**
Cadmium - Cd	0.0011	0.00005	0.00016	0.00009	0.00007	**0.000017**			**0.005**
Calcium - Ca	202	2.4	23	10.5	6.4	na			na
Chloride - Cl	647	3.4	68	29	16	na			**250**
Chromium - Cr	0.0099	0.0025	0.0035	0.0029	0.0027	**0.0089**			**0.05**
Copper - Cu	0.021	0.0020	0.0041	0.0028	0.0024	0.002	**0.004**	c	**1**
Iron - Fe	1.0	0.025	0.13	0.067	0.046	**0.3**			**0.3**
Lead - Pb	0.0040	0.00005	0.00045	0.00021	0.00013	**0.001**	0.007	d	**0.01**
Magnesium - Mg	206	0.84	21.4	9.1	5.0	na			na
Manganese - Mn						na			**0.05**
Mercury - Hg						**0.00001**			**0.001**
Molybdenum - Mo	0.14	0.00005	0.014	0.0055	0.0028	**0.073**			
Nickel - Ni	0.062	0.0005	0.0067	0.0030	0.0017	**0.025**	0.15	e	
Nitrate - as N	7.4	0.18	0.92	0.48	0.33	**4.0**			**10**
Nitrite - as N	0.23	0.001	0.024	0.0101	0.0055	**0.06**			**1**
pH	8.2	6.63	6.8	6.8	6.8	6.5	9	f	
Phosphorus - P	0.087	0.0077	0.02	0.01	0.01	na			
Potassium - K	64	2	8.4	4.5	3.3	na			na
Selenium - Se						**0.001**			**0.01**
Silver - Ag						**0.0001**			
Sodium - Na	36	2	6	3	3	na			**200**
Sulphate - SO_4	380	1.2	39	16	9	na			**500**
Sulphide (as H_2S)						na			**0.05**
Thallium - Tl						**0.0008**			
Total Dissolved Solids	1635	11	174	76	44	na			**500**
Total Suspended Solids	7.4	1.4	2	2	2	5	25	g	
Uranium - U	0.68	0.0002	0.068	0.028	0.014	na			**0.02**
Zinc - Zn	0.034	0.002	0.005	0.003	0.003	**0.03**			**5**

Notes: Bolded guidelines were the basis for the calculated dilutions
Blue highlighting indicates >5 x dilution required to meet criteria
* Polishing Pond concentration is calculated at temperature of 15oC and estimated pH of 8.2. Actual receiving water pH's and temperatures will generally be much lower, resulting in a shift in equilibrium to less un-ionized ammonia, values are given in N

a - Guidelines indicate value of 0.1 is appropriate where the pH is greater than 6.5
b - Range reflects pH's from 6.5 to 8 and temperatures of 0 to 15 C. Actual range is pH 6.1 to 7.73, with mean values of 6.85 in Lake C3 and 6.74 in Carat Lake
c - Guidelines indicate lower value of 0.002 is appropriate where the hardness is less than 120 mg CaCO3 eq/L
d - Guidelines indicate lower value of 0.001 is appropriate where the hardness is less than 60 mg CaCO3 eq/L
e - Guidelines indicate lower value of 0.025 is appropriate where the hardness is less than 60 mg CaCO3 eq/L
f - The pH must be within this range
g - The total suspended sediments must not exceed background levels by more than 5 mg/L on average, nor 25 mg/L from background levels on short-term exposure (24 hours)

Table 16

Receiving Water Quality Estimates - Post Closure Estimates of Receiving Water Quality in Carat Lake

Parameter **mg/L, or specified**	**Pit Lake**	**Carat Lake**	**Receiving Water Quality Estimates**			**Guidelines**			
	Post-Closure Estimates	Background Conc.	**40 m from Channel** 5	**80 m from Channel** 10	**Outlet of Carat Lake** 60	**CCME Fresh Water Aquatic Life** **min**	**max**	**Note**	**CCME/Health Canada Drinking Water 2003**
Aluminum - Al	0.15	0.052	0.08	0.067	0.055	0.005	**0.1**	a	**0.1**
Ammonia - N (unionized) (calculated)*						**0.016**		*	
Ammonia - N (total)		0.009				**0.59**	60	b	
Arsenic - As	0.0005	0.00016	0.0003	0.0002	0.0002	**0.005**			**0.025**
Barium - Ba						na			**1**
Boron - B						na			**5**
Cadmium - Cd	0.00031	0.00005	0.00011	0.00008	0.00006	**0.000017**			**0.005**
Calcium - Ca		2.4				na			na
Chloride - Cl	161	3.36	36	19	6	na			**250**
Chromium - Cr	0.0017	0.0025	0.0028	0.0027	0.0025	**0.0089**			**0.05**
Copper - Cu	0.0094	0.0020	0.0039	0.0029	0.0022	0.002	**0.004**	c	**1**
Iron - Fe	0.20	0.025	0.06	0.045	0.028	**0.3**			**0.3**
Lead - Pb	0.0020	0.00005	0.00046	0.00025	0.00008	**0.001**	0.007	d	**0.01**
Magnesium - Mg		0.84				na			na
Manganese - Mn						na			**0.05**
Mercury - Hg						**0.00001**			**0.001**
Molybdenum - Mo	0.032	0.00005	0.006	0.0032	0.0006	**0.073**			
Nickel - Ni	0.015	0.0005	0.0036	0.0020	0.0008	**0.025**	0.15	e	
Nitrate - as N		0.18				**4.0**			**10**
Nitrite - as N		0.001				**0.06**			**1**
pH		6.63				6.5	9	f	
Phosphorus - P		0.0077				na			
Potassium - K		2				na			na
Selenium - Se						**0.001**			**0.01**
Silver - Ag						**0.0001**			
Sodium - Na	8.0	2	4	3	2	na			**200**
Sulphate - SO_4	70	1.2	15	8	2	na			**500**
Sulphide (as H_2S)						na			**0.05**
Thallium - Tl						**0.0008**			
Total Dissolved Solids	372	11	85	48	17	na			**500**
Total Suspended Solids	2.0	1.4	2	2	1	5	25	g	
Uranium - U	0.063	0.0002	0.013	0.007	0.001	na			**0.02**
Zinc - Zn	0.006	0.002	0.003	0.003	0.002	**0.03**			**5**

Notes: Bolded guidelines were the basis for the calculated dilutions

Blue highlighting indicates >5 x dilution required to meet criteria

* Polishing Pond concentration is calculated at temperature of 15oC and estimated pH of 8.2. Actual receiving water pH's and temperatures will generally be much lower, resulting in a shift in equilibrium to less un-ionized ammonia, values are given in N

a - Guidelines indicate value of 0.1 is appropriate where the pH is greater than 6.5

b - Range reflects pH's from 6.5 to 8 and temperatures of 0 to 15 C. Actual range is pH 6.1 to 7.73, with mean values of 6.85 in Lake C3 and 6.74 in Carat Lake

c - Guidelines indicate lower value of 0.002 is appropriate where the hardness is less than 120 mg CaCO3 eq/L

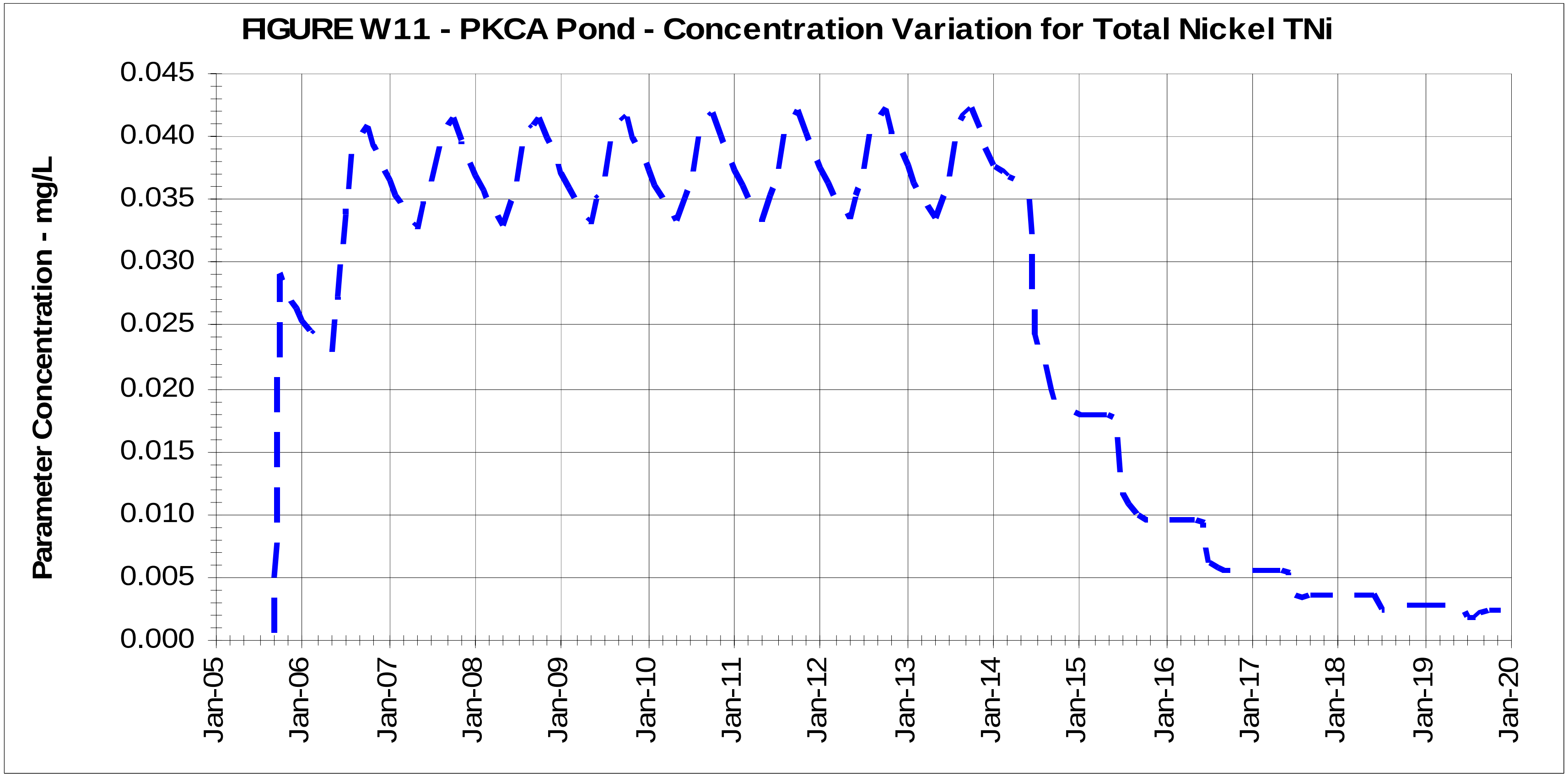
d - Guidelines indicate lower value of 0.001 is appropriate where the hardness is less than 60 mg CaCO3 eq/L

e - Guidelines indicate lower value of 0.025 is appropriate where the hardness is less than 60 mg CaCO3 eq/L

f - The pH must be within this range

g - The total suspended sediments must not exceed background levels by more than 5 mg/L on average, nor 25 mg/L from background levels on a short-term exposure (24 hours)

FIGURES



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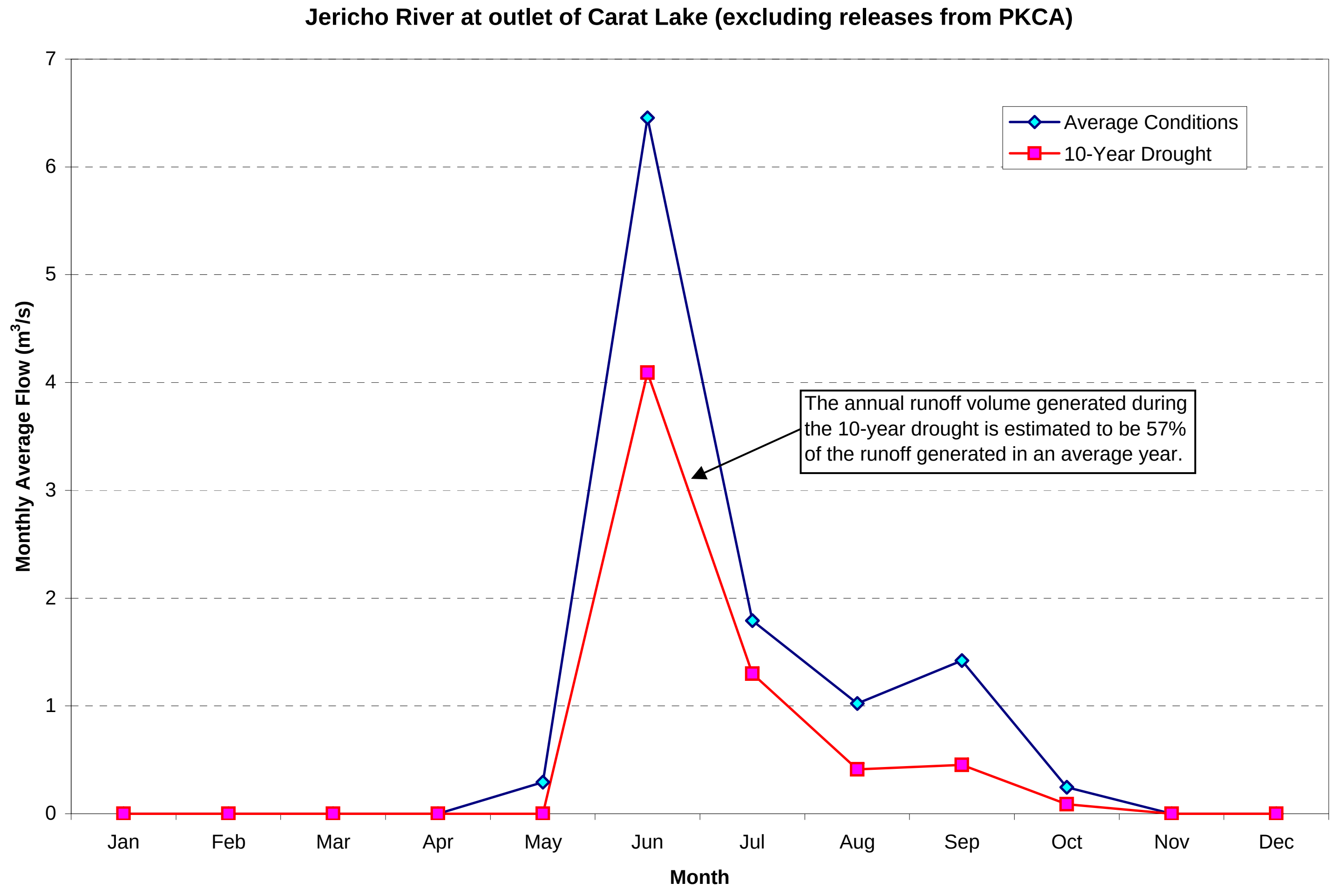
Diamond Corporation

Jericho Project
Water Licence Application

Typical Concentration Profile for the PKCA during Operations

PROJECT	DATE	APPROVED	FIGURE
1CT004.06	July 2004		**1**

FILE REF: WQ_Impacts_Figures_ck.xls



The annual runoff volume generated during the 10-year drought is estimated to be 57% of the runoff generated in an average year.

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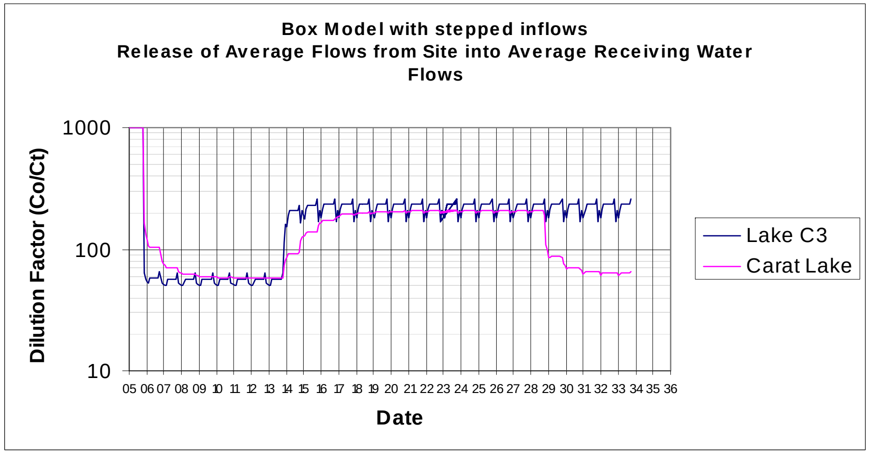
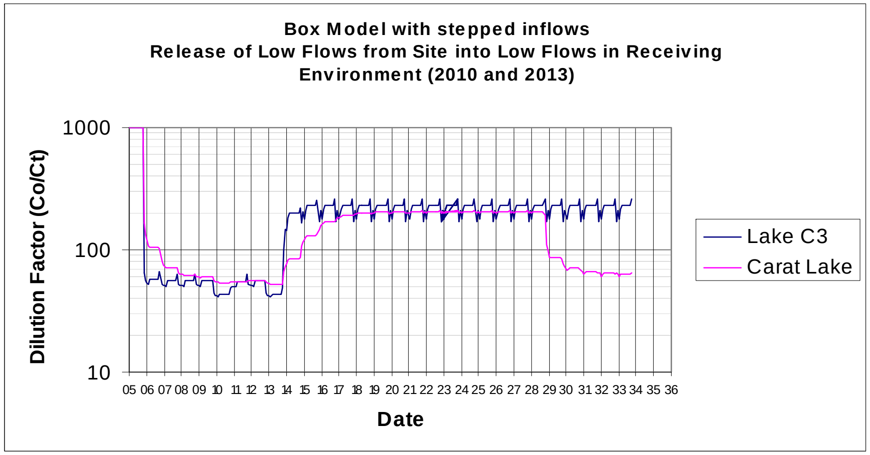
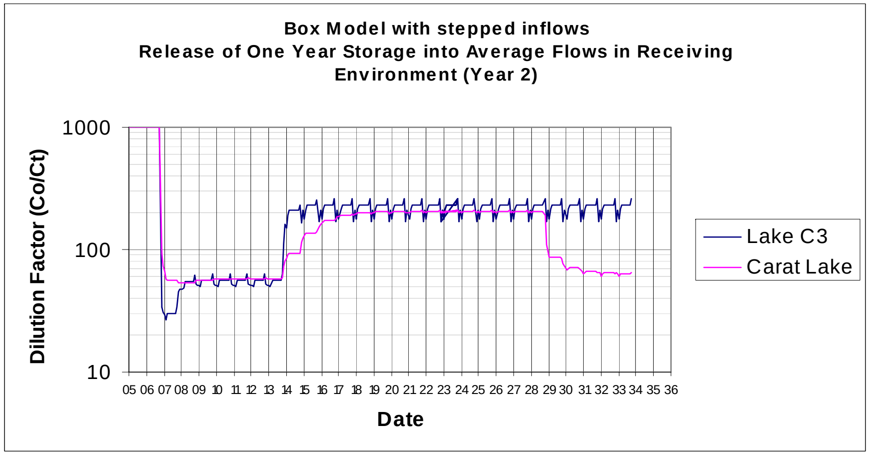
Hydrograph of Jericho River at outlet of Carat Lake (exclu. releases from PKCA)

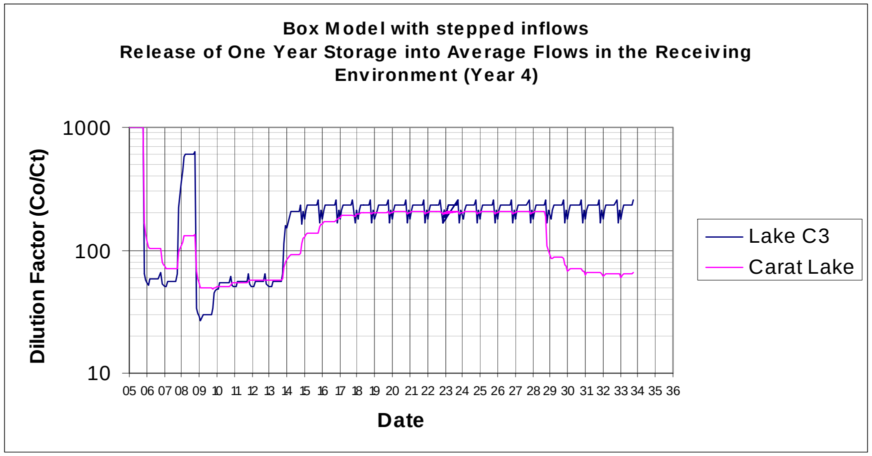
PROJECT	DATE	APPROVED	FIGURE
1CT004.06	July 2004		2

FILE REF: WQ_Impacts_Figures_ck.xls


Box Model with stepped inflows
Release of Average Flows from Site into Average Receiving Water Flows


Box Model with stepped inflows
Release of Low Flows from Site into Low Flows in Receiving Environment (2010 and 2013)


Box Model with stepped inflows
Release of One Year Storage into Average Flows in Receiving Environment (Year 2)


Box Model with stepped inflows
Release of One Year Storage into Average Flows in the Receiving Environment (Year 4)

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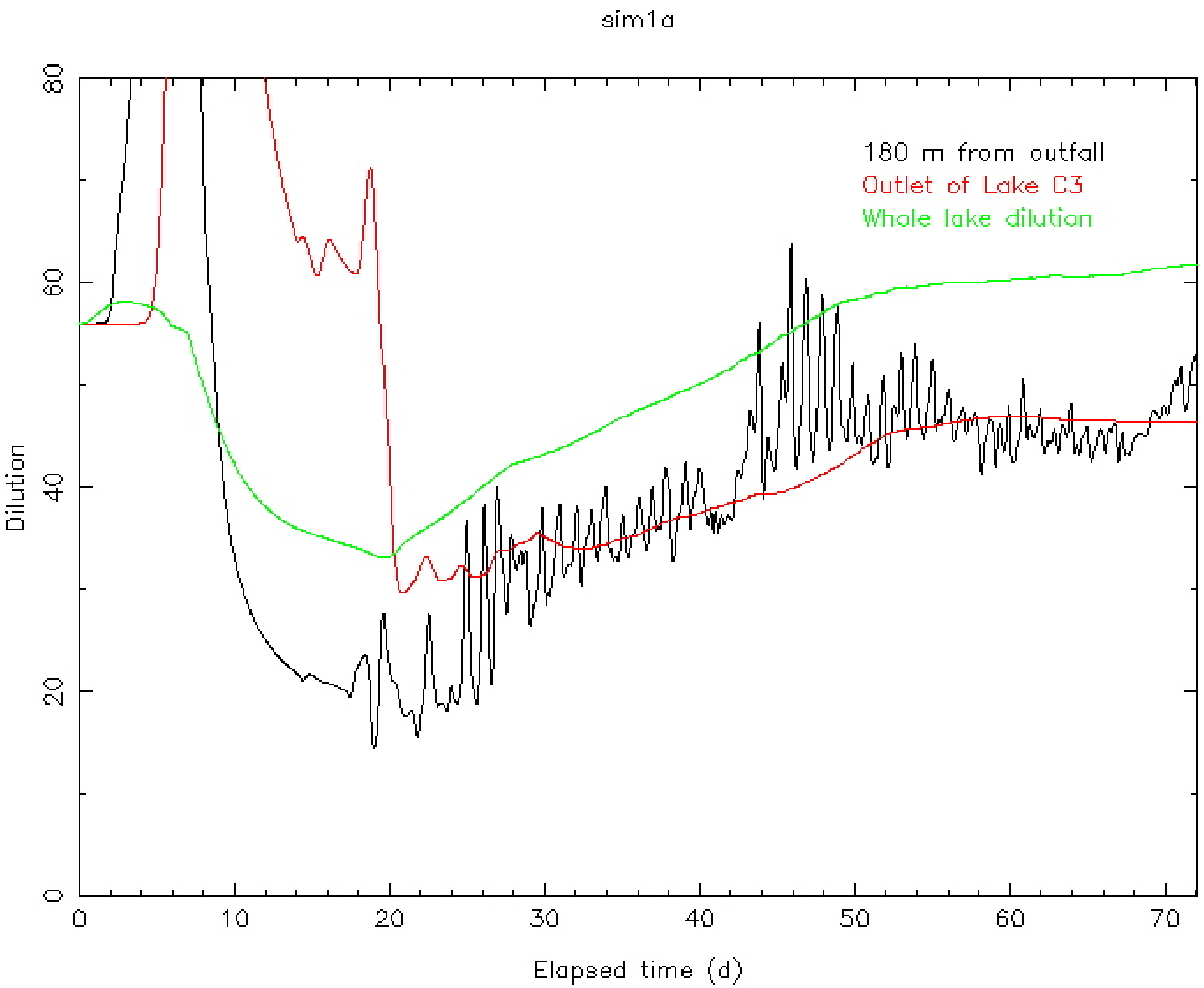
Box Model Results
(Scenarios 1 through 3)

PROJECT	DATE	APPROVED	FIGURE
1CT004.06	July 2004		3

FILE REF: WQ_Impacts_Figures_ck.xls



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Summary of Princeton Ocean Model Results for Scenario 4

PROJECT:	DATE:	APPROVED:	FIGURE:
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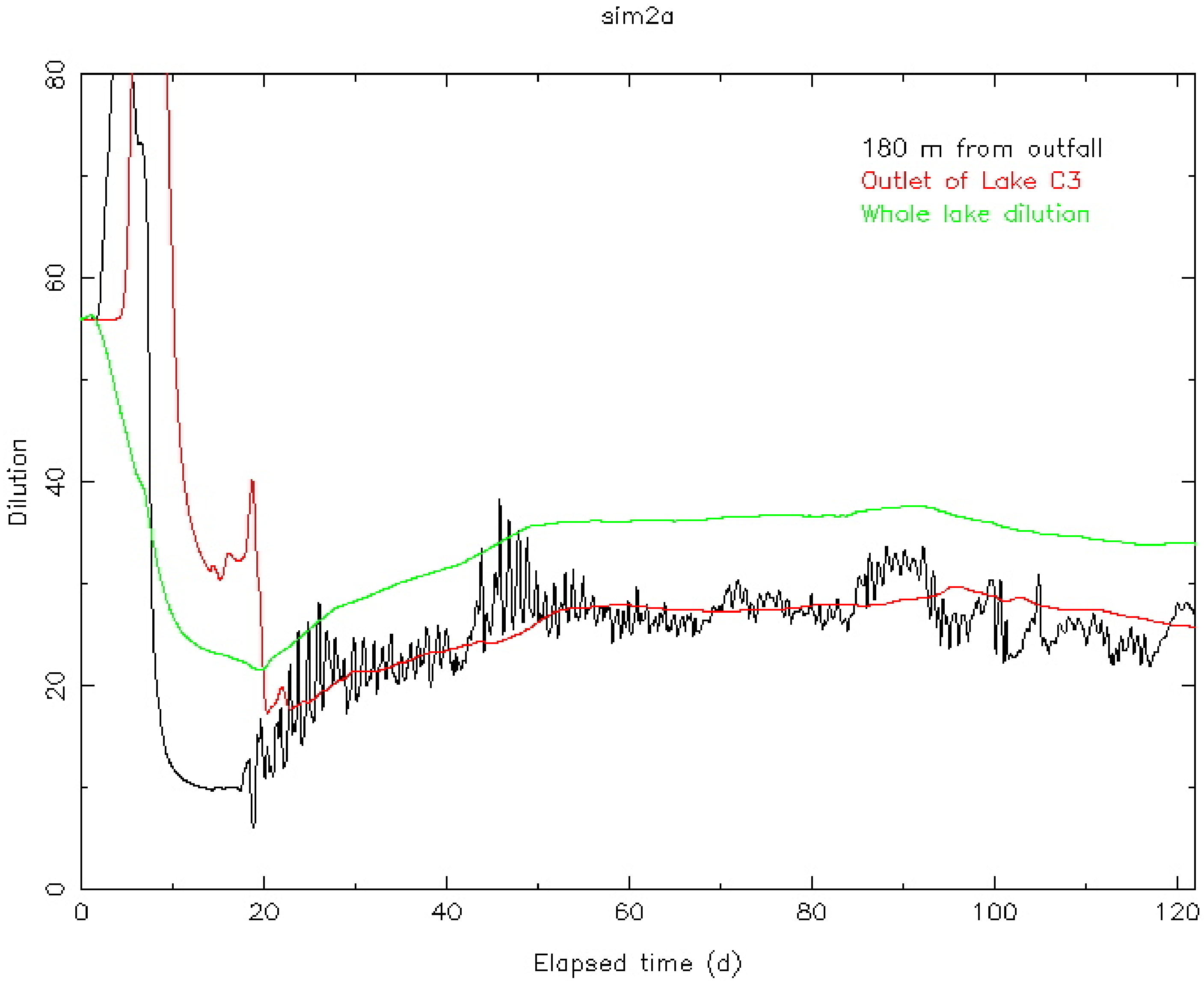

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Summary of Princeton Ocean Model Results for Scenario 5

PROJECT:	DATE:	APPROVED:	FIGURE:
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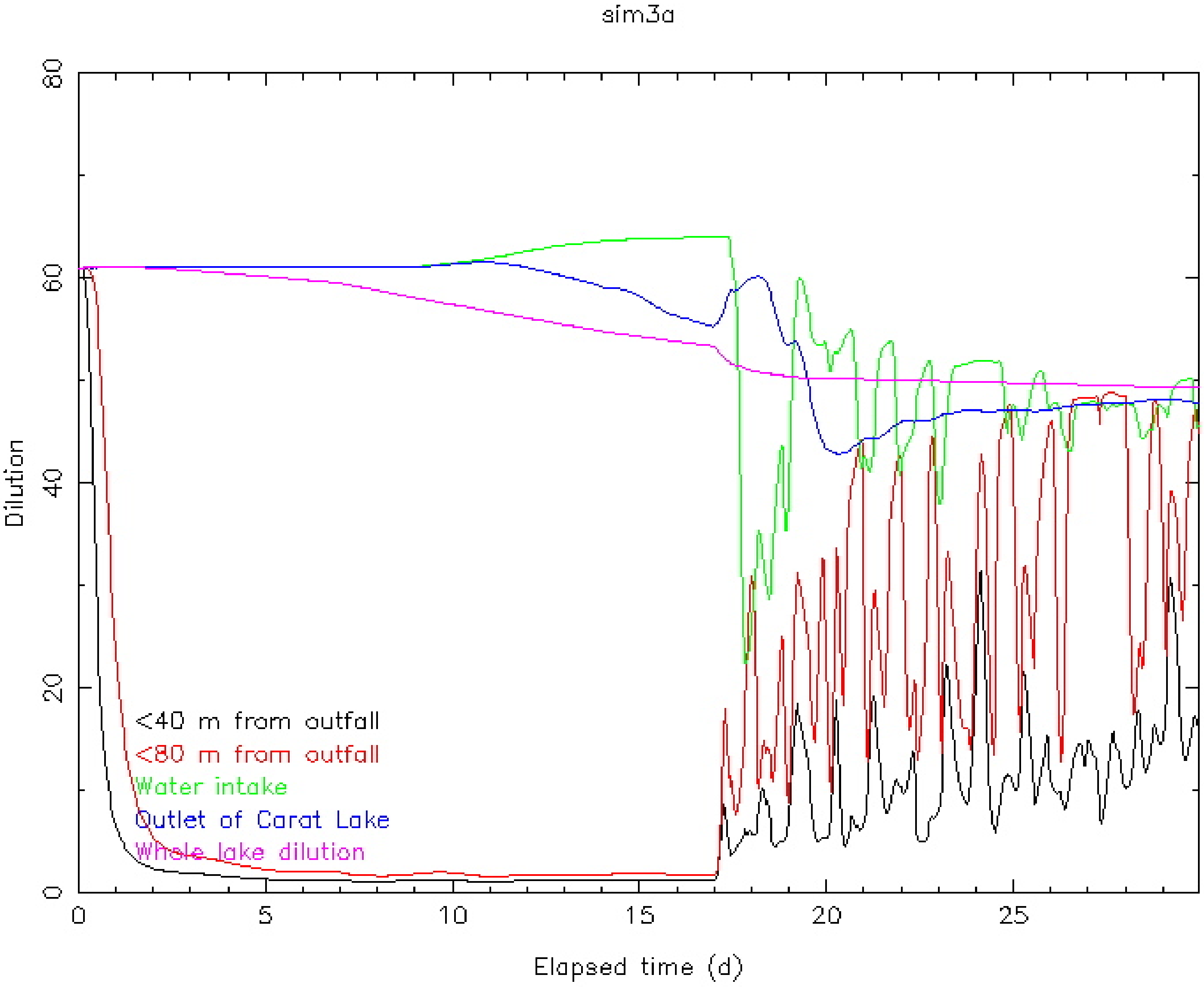

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Summary of Princeton Ocean Model Results for Scenario 6

PROJECT:	DATE:	APPROVED:	FIGURE:
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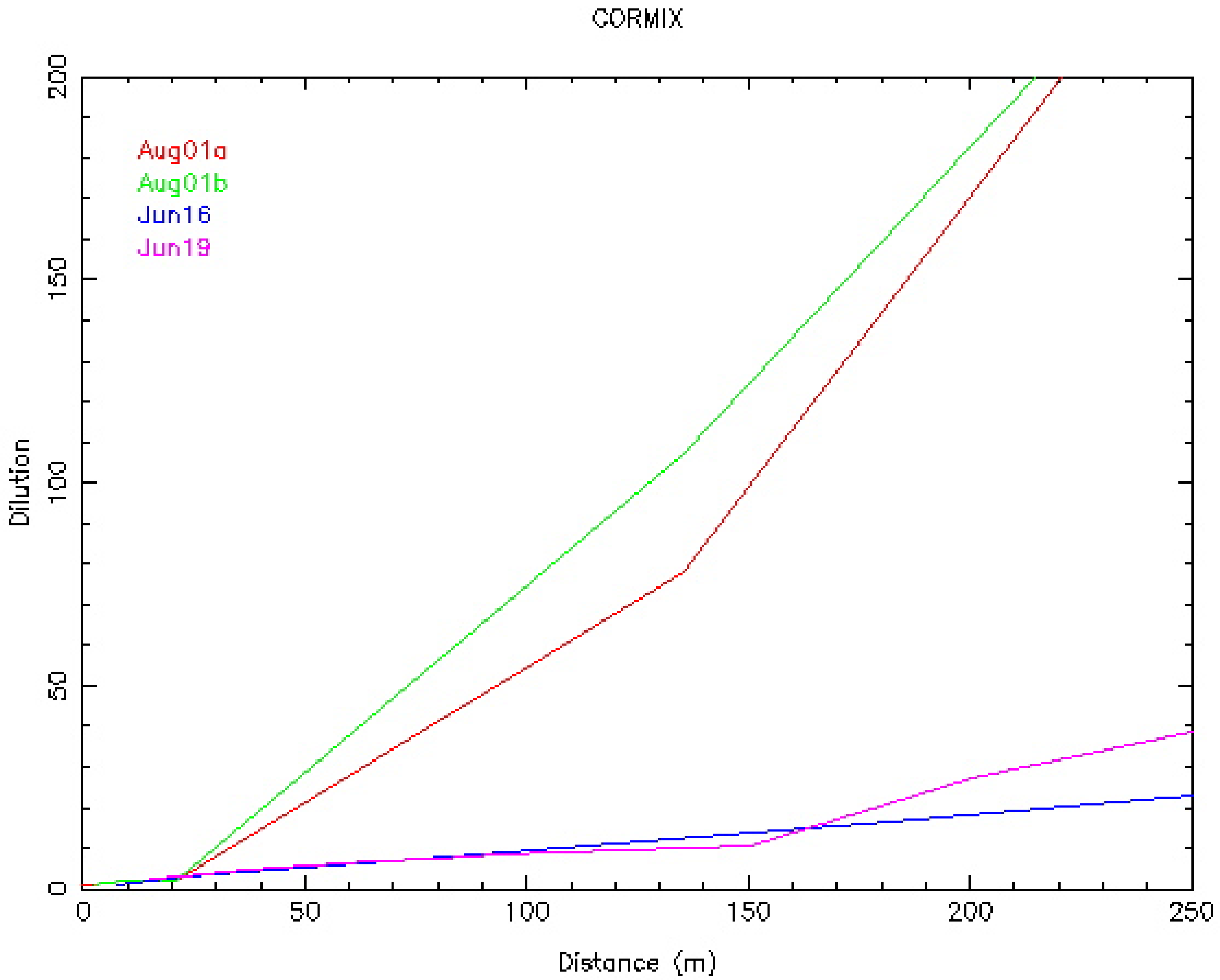

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Summary of CORMIX Model Results

PROJECT:	DATE:	APPROVED:	FIGURE:
1CT004.06	July 2004		7

ATTACHMENT N1

Estimation of 10 Year Drought Hydrograph for Jericho River

Estimation of 10-Year Drought Hydrograph for Jericho River

Introduction

A water quality model was developed by SRK to estimate potential impacts of the proposed Jericho Diamond Project on the water quality of the receiving environment. One of the primary inputs to the model was a synthesized monthly record of flows for the Jericho River. The synthesized record spanned a period of several years and contained flows representing a mix of average and drought conditions. The average conditions were estimated using a technique outlined in the document entitled "Technical Memorandum C: Supplemental Climate and Hydrology" (SRK, 2003). To estimate drought conditions for the Jericho River, it was necessary to conduct an additional hydrological study that investigated the low-flow regime of arctic streams. This memorandum documents this new study.

The drought flows for Jericho River were estimated using a technique known as Regional Analysis. In essence, this technique provides a means of inferring the low flow regime of an ungauged location from the streamflow records of measured streams in the region. The development of the Regional Analysis involved four steps, as outlined below.

Step 1: Data Assembly

The first step entailed data gathering. The network of streamflow gauging stations operated by the Water Survey of Canada (WSC) was searched to find suitable data for developing the Regional Analysis. The emphasis of the search was to identify stations that: i) had long periods of record; ii) were in reasonably close proximity to the mine site; iii) were located north of the treeline; iv) measured flows from a wide range of catchment areas; and v) were sited on streams with zero flow during the winter months (i.e., the catchments drained by the streams were devoid of large lakes that could maintain a baseflow during the prolonged freezing conditions). Table 1 provides details of the six stations that were identified in the search.

To facilitate development of the low-flow analysis, a total of nine annual series were extracted from each streamflow record. The first series comprised the annual average flow for each complete year of record (or, at least, for each year in which the gauge was operational over the open water season). The remaining series focussed on monthly average flows for a specific month of the year. Individual series were extracted for the months of May through December. It was not necessary to extract series for the winter months, January to April, since flow in this period is almost always zero. The lengths of the series of annual average flows ranged from 8 to 27 years. The lengths of the series of monthly average flows were at least as long as, and often longer than, the corresponding series of annual values (i.e., an incomplete year would not provide an annual average value but would provide data for several of the calendar months). On completion of this step of the analysis, a total of 54 annual series had been extracted (6 stations x 9 annual series per station).

Step 2: Statistical Analysis

This step was aimed at estimating extreme low flows at the six WSC stations. Initially, the focus was on estimating annual low flows for a range of return periods. For each station, the series of annual average flows was fitted to a theoretical frequency distribution (Gumbell III) to provide estimates of the 2-, 5-, 10- and 20-year return period annual low flows. All fittings were done using Version 2.0 of the LFA program (Environment Canada, 1994).

Table 1 presents the estimated annual droughts at the six regional stations determined by the frequency analyses. The catchment areas controlled by these stations range over four orders of magnitude from 15 km^2 to 16900 km^2. To facilitate comparison of the flows from these widely differing catchment areas, the flow rates in Table 1 have been expressed as normalized values in units of $L/s/km^2$ (i.e., the absolute flow rate has been divided by the contributing catchment area).

Examination of Table 1 indicates that the normalized flow rates do not vary much from station to station. For example, the 10-year low annual flows range from 3.4 to 5.7 $L/s/km^2$. If the station with the smallest catchment area is excluded (Akkutuak Creek), then the range narrows to 3.4 to 4.6 $L/s/km^2$. This narrow range exists despite the very large difference in catchment areas controlled by the WSC stations.

The objective of this study was to estimate the 10-year drought flows for the Jericho River on a monthly time step. Accordingly, the study could not end at assessing the average annual flow during a 10-year drought. The study had to also provide a way of apportioning the annual volume of water amongst the twelve months of the year. Although described in greater detail later, the adopted method of dividing the annual volume into monthly components required an understanding of how flows are distributed within each of the months. This understanding was obtained by fitting a theoretical frequency distribution to the annual series of monthly average flows to estimate a range of low flow events. The fitting of the distributions was facilitated using a suite of hydrological programs developed by the U.S. Geological Survey, known as IOWDM, SWSTAT and ANNIE (Lumb et al., 1990). This same suite of programs was also used in Step 1 to extract the annual series of monthly values.

Table 2 summarizes the flow patterns at the six WSC stations on a month by month basis. All statistics in this table represent the average flow over the entire month. The frequency analyses described above provided the estimates of monthly average low flows for return periods of 3-, 5- and 10-year return periods. Also shown on this table, are the average, extreme maximum and extreme minimum monthly average flows observed at the WSC stations. The information contained in Table 2 is graphically displayed in Figures 1 and 2. The average and extreme minimum flows observed at the stations provided a check on the frequency analyses. Because the streamflow records were generally greater than 10 years in length, one would expect the 3-, 5- and 10-year low events to all fall between the average and extreme minimum flows. This turns out to be the case at all six WSC stations.

Step 3: Define 10-Year Drought at WSC Stations

A wide range of climatological conditions can lead to an annual runoff volume equal to the 10-year drought. For instance, an average spring freshet hydrograph can be followed by an extremely dry summer. Alternatively, a small freshet might be followed by a moderately wet summer. Given this, a sensible method was sought to define the monthly hydrograph of the 10-year drought. As inferred in Step 2, the adopted method involved using the frequency analyses for the individual months of the year. The basic premise was that the flow for all twelve months should have the same return period. So, for example, if all months experienced their 5-year low flow, the total volume for the twelve months may add up to equal a 10-year annual drought. Before applying this method, it was known that the return period for the individual months must be something less than 10 years. If every month of the year was to individually experience its 10-year event, the resulting annual event would be very extreme indeed, probably exceeding the 100-year annual event.

Figures 1 and 2 show how the 10-year low annual runoff volume for each WSC station was distributed amongst the twelve months of the year (bold line on plots). For four of the WSC stations, the 10-year event could be generated if each month of the year experienced its 3-year low event. For Atitok Creek, a sequence of 5-year monthly low events was required to generate an annual volume equal to the 10-year drought. For Ellice River, a sequence of 4-year events was required.

Step 4: Estimate 10-Year Drought for Jericho River

The final step in the analysis was to transpose the 10-year drought hydrographs at the WSC stations to the mine site. Figure 3 shows the graph used to facilitate the transposition. This graph shows the defined 10-year hydrographs for the six WSC stations superimposed on one another. Using the same convention as in Step 3, all flows are expressed as discharges per unit area with units of L/s/km^2.

The following observations were made about the hydrographs in Figure 3:

- The monthly flows for four of the hydrographs (Akkutuak, Qinguq, Kendall and Ellice) match one another very closely in the period July to November, and this is despite the very large difference in the catchments that generated these flows.

- The monthly average flows are zero, or very nearly so, for all stations from November to May.

- The flows of Atitok Creek are considerably lower than experienced at the other five WSC stations in July and August. The catchment of Atitok Creek has a significantly greater relief and a significantly smaller proportion of lakes than the catchment of Jericho River. Accordingly, the data from Atitok Creek are probably not representative of the conditions in the Jericho River. The greater relief and lower number of lakes would lead the catchment of Atitok Creek to have greater drainage efficiency than that of Jericho River.

- The Gordon River exhibits a slower recession than the remaining five WSC stations, which suggests greater lake storage in this river's catchment than experienced in the catchments of the other stations.

- The flows in June exhibit an inverse relationship with drainage area. The smaller the drainage area, the greater is the unit monthly average flow.

The above observations suggest that, except for the month of June, the normalized low flow rate is generally independent of drainage area. The relief of a catchment and the relative amount of lake storage cause variations in the flow response during dry conditions. Given these observations, the 10-year drought hydrograph for Jericho River was estimated to equal the median flow of all six stations. By using a median, this had the effect of discarding the two stations that are likely unrepresentative of conditions on Jericho River, namely Atitok Creek (with its high relief and low proportion of lakes) and Gordon River (with its slower recession relative to the other WSC stations). A higher flow would have been adopted for the month of June if the inverse relationship between flow and drainage area was used as basis for prediction of conditions on Jericho River, rather than the median. To be conservative, the lower estimate provided by the median was selected. The adopted 10-year drought hydrograph for the Jericho River is shown as a bold line superimposed on the rest of the WSC hydrographs presented in Figure 3.

The estimated long-term average annual runoff generated by the Jericho River is 210 mm, expressed as an equivalent depth of water spread uniformly over the contributing catchment. The runoff generated by the estimated 10-year drought hydrograph works out to 119 mm, or 57% of the runoff generated in an average year.

References

Environment Canada, 1994. Low Flow Frequency Analysis Package, Version 2.0. Climate/Water Information Branch, Atmospheric Environment Service.

Lumb, A.M., Kittle, J.L. Jr., and Flynn, K.M., 1990. Users manual for ANNIE, a computer program for interactive hydrologic analyses and data management: U.S. Geological Survey Water-Resources Investigations Report 89-4080.

Steffen Robertson and Kirsten (Canada) Inc., 2003. Technical Memorandum C: Supplemental Climate and Hydrology, Jericho Project, Nunavut. Report prepared for Tahera Corporation.

Table 1 Estimated Annual Low Flows at Regional WSC Streamflow Gauging Stations

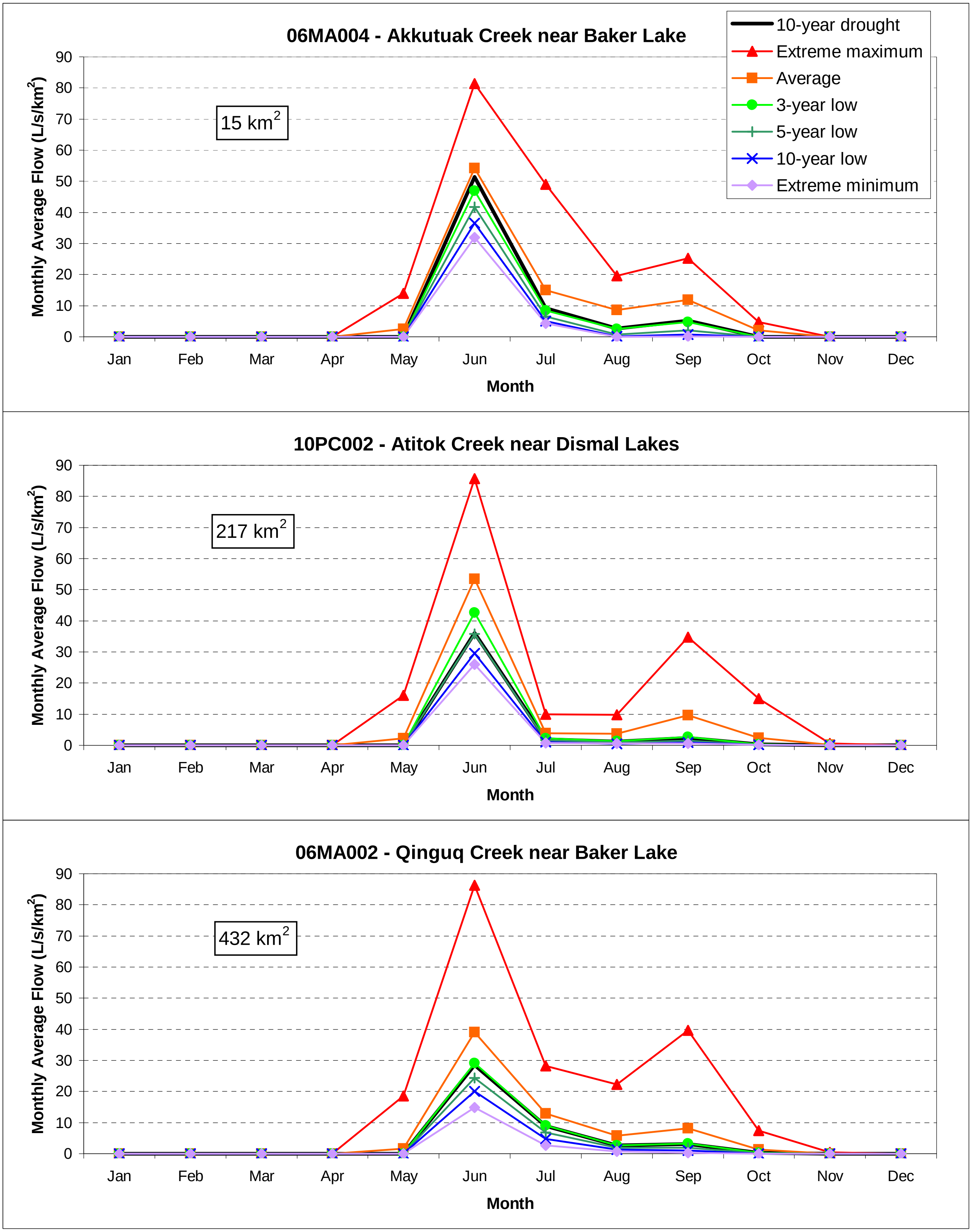
WSC Streamflow Gauging Station		Drainage Area (km^2)	Sample Size (years)	Annual Average Low Flow ($L/s/km^2$) for the following Return Periods:				Observed Minimum Annual Flow ($L/s/km^2$)
ID No.	**Name**			**2-Year**	**5-Year**	**10-Year**	**20-Year**	
06MA004	Akkutuak Creek near Baker Lake	15	11	7.9	6.4	5.7	5.2	5.4
10PC002	Atitok Creek near Dismal Lakes	217	8	6.2	4.3	3.5	2.9	3.4
06MA002	Qinguq Creek near Baker Lake	432	22	5.4	4.1	3.6	3.4	3.3
10QC002	Gordon River near the mouth	1530	16	6.1	5.1	4.6	4.4	4.0
10PC001	Kendall River near outlet of Dismal Lakes	2790	12	5.3	4.5	4.1	3.8	3.5
10QD001	Ellice River near the mouth	16900	27	4.8	3.8	3.4	3.1	2.8

Table 2 Monthly Statistics for Regional WSC Streamflow Gauging Stations

WSC Station	Item	Monthly Average Flow (L/s/km^2)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Akkutuak Creek near Baker Lake	Extreme maximum	0	0	0	0	13.9	81.3	49.1	19.6	25.3	4.7	0	0
	Average	0	0	0	0	2.5	54.3	15.1	8.6	11.9	2.1	0	0
	3-year low	0	0	0	0	0	47.0	8.5	2.5	4.8	0	0	0
	5-year low	0	0	0	0	0	41.8	6.6	0.8	2.1	0	0	0
	10-year low	0	0	0	0	0	36.6	5.1	0.2	0.7	0	0	0
	Extreme minimum	0	0	0	0	0	31.9	4.3	0	0.1	0	0	0
Atitok Creek near Dismal Lakes	Extreme maximum	0	0	0	0	16.0	85.7	10.0	9.8	34.8	15.0	0.5	0
	Average	0	0	0	0	2.2	53.5	3.8	3.7	9.6	2.4	0.1	0
	3-year low	0	0	0	0	0	42.6	2.2	1.4	2.7	0.3	0	0
	5-year low	0	0	0	0	0	35.8	1.6	0.9	1.6	0.2	0	0
	10-year low	0	0	0	0	0	29.5	1.1	0.5	0.8	0.1	0	0
	Extreme minimum	0	0	0	0	0	25.9	0.7	0.5	0.6	0.1	0	0
Qinguq Creek near Baker Lake	Extreme maximum	0	0	0	0	18.6	86.3	28.2	22.3	39.6	7.4	0.4	0
	Average	0	0	0	0	1.6	39.1	13.0	5.8	8.2	1.3	0	0
	3-year low	0	0	0	0	0	29.1	9.1	2.7	3.2	0.4	0	0
	5-year low	0	0	0	0	0	24.3	6.8	1.9	1.9	0.1	0	0
	10-year low	0	0	0	0	0	20.0	4.8	1.3	1.0	0	0	0
	Extreme minimum	0	0	0	0	0	14.9	2.7	0.8	0.3	0	0	0
Gordon River near the mouth	Extreme maximum	0	0	0	0	17.3	56.1	32.7	19.9	20.9	8.2	1.3	0.1
	Average	0	0	0	0	1.6	31.2	18.4	9.2	9.5	4.0	0.6	0
	3-year low	0	0	0	0	0	24.7	14.2	6.7	6.6	2.7	0.4	0
	5-year low	0	0	0	0	0	19.7	11.8	5.8	5.1	2.1	0.2	0
	10-year low	0	0	0	0	0	14.8	9.5	5.1	3.7	1.5	0.1	0
	Extreme minimum	0	0	0	0	0	8.6	8.0	4.9	2.4	1.1	0	0
Kendall River near outlet of Dismal Lakes	Extreme maximum	0	0	0	0	8.5	49.1	23.9	16.8	17.1	7.0	2.2	0.4
	Average	0	0	0	0	1.1	34.2	13.5	5.8	5.8	2.5	0.4	0
	3-year low	0	0	0	0	0	30.4	11.0	4.4	3.0	0.9	0	0
	5-year low	0	0	0	0	0	27.8	9.4	3.9	2.2	0.5	0	0
	10-year low	0	0	0	0	0	25.2	8.0	3.5	1.5	0.3	0	0
	Extreme minimum	0	0	0	0	0	23.8	6.6	2.8	1.1	0.1	0	0
Ellice River near the mouth	Extreme maximum	0.1	0	0	0	8.2	45.4	35.4	14.9	23.0	5.6	1.2	0.2
	Average	0	0	0	0	0.4	29.8	14.9	5.3	6.6	2.2	0.3	0
	3-year low	0	0	0	0	0	26.7	10.5	3.6	3.8	1.2	0.1	0
	5-year low	0	0	0	0	0	21.5	8.5	2.9	2.8	0.9	0.1	0
	10-year low	0	0	0	0	0	15.9	6.7	2.4	2.0	0.6	0	0
	Extreme minimum	0	0	0	0	0	5.7	4.6	1.7	1.5	0.4	0	0

Table 3 Synthesized 10-Year Drought Hydrographs for Regional WSC Streamflow Gauging Stations

WSC Streamflow Gauging Station		Drainage Area	Monthly Average Flow for Synthesized 10-Year Drought Hydrograph (L/s/km^2)												Annual 10-Year Low Flow	
ID No.	**Name**	**(km^2)**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**(L/s/km^2)**	**(mm)**
06MA004	Akkutuak Creek near Baker Lake	15	0	0	0	0	0	51.4	9.3	2.7	5.2	0	0	0	5.7	179
10PC002	Atitok Creek near Dismal Lakes	217	0	0	0	0	0.01	36.1	1.9	1.2	2.3	0.3	0	0	3.4	109
06MA002	Qinguq Creek near Baker Lake	432	0	0	0	0	0	28.5	8.9	2.7	3.1	0.4	0	0	3.6	114
10QC002	Gordon River near the mouth	1530	0	0	0	0	0.02	24.9	14.3	6.7	6.7	2.8	0.4	0	4.6	147
10PC001	Kendall River near outlet of Dismal Lakes	2790	0	0	0	0	0	30.0	10.8	4.3	2.9	0.9	0	0	4.1	128
10QD001	Ellice River near the mouth	16900	0	0	0	0	0	23.7	9.3	3.2	3.3	1.1	0.1	0	3.4	107
Estimated drought flows for Jericho River			**0**	**0**	**0**	**0**	**0**	**29.2**	**9.3**	**2.9**	**3.2**	**0.6**	**0**	**0**	**3.8**	**119**

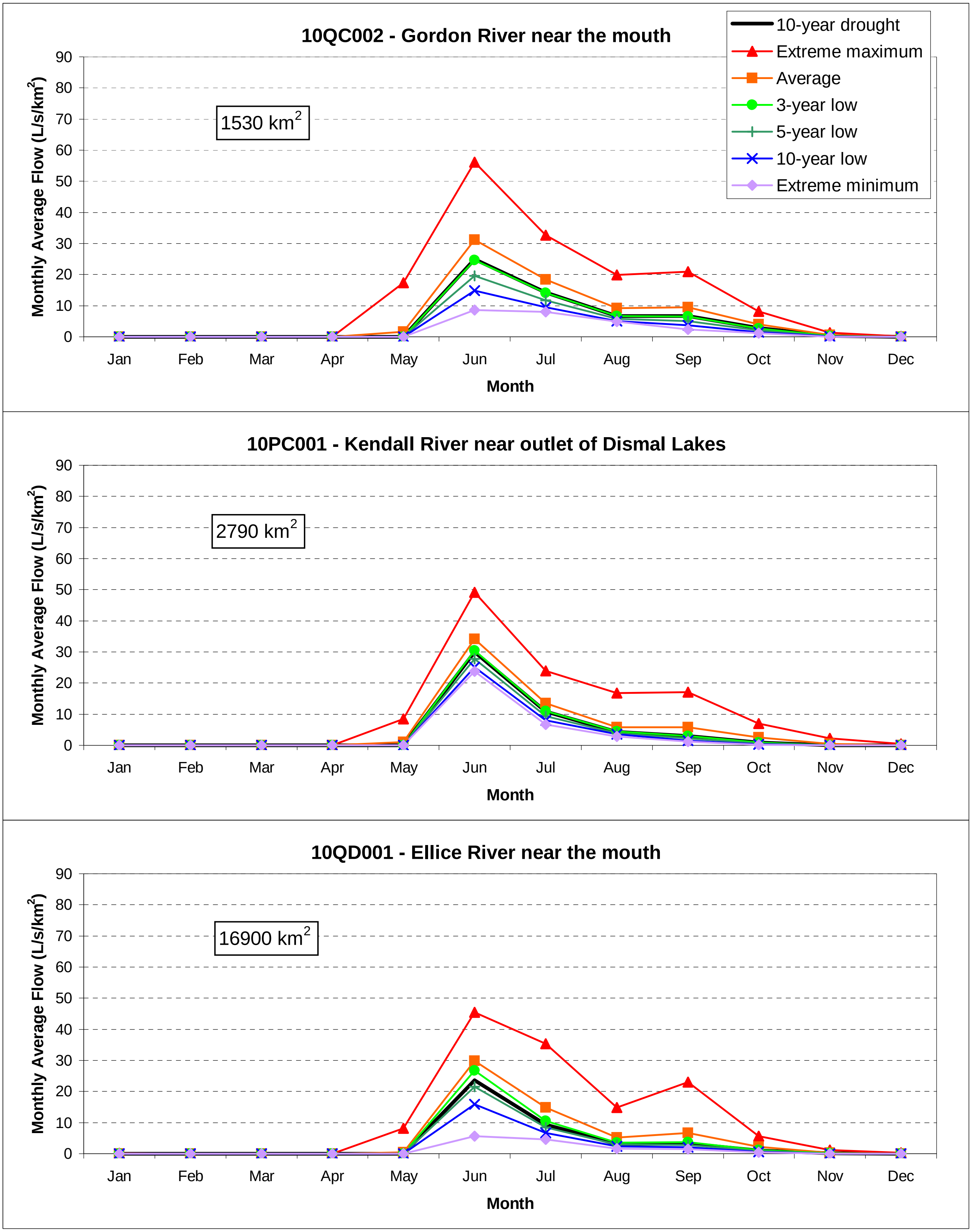


06MA004 - Akkutuak Creek near Baker Lake

10PC002 - Atitok Creek near Dismal Lakes

06MA002 - Qinguq Creek near Baker Lake

Figure 1: Synthesized 10-Year Drought Hydrographs for Akkutuak, Atitok and Qinguq Creeks



10QC002 - Gordon River near the mouth

10PC001 - Kendall River near outlet of Dismal Lakes

10QD001 - Ellice River near the mouth

Figure 2: Synthesized 10-Year Drought Hydrographs for Gordon, Kendall and Ellice Rivers

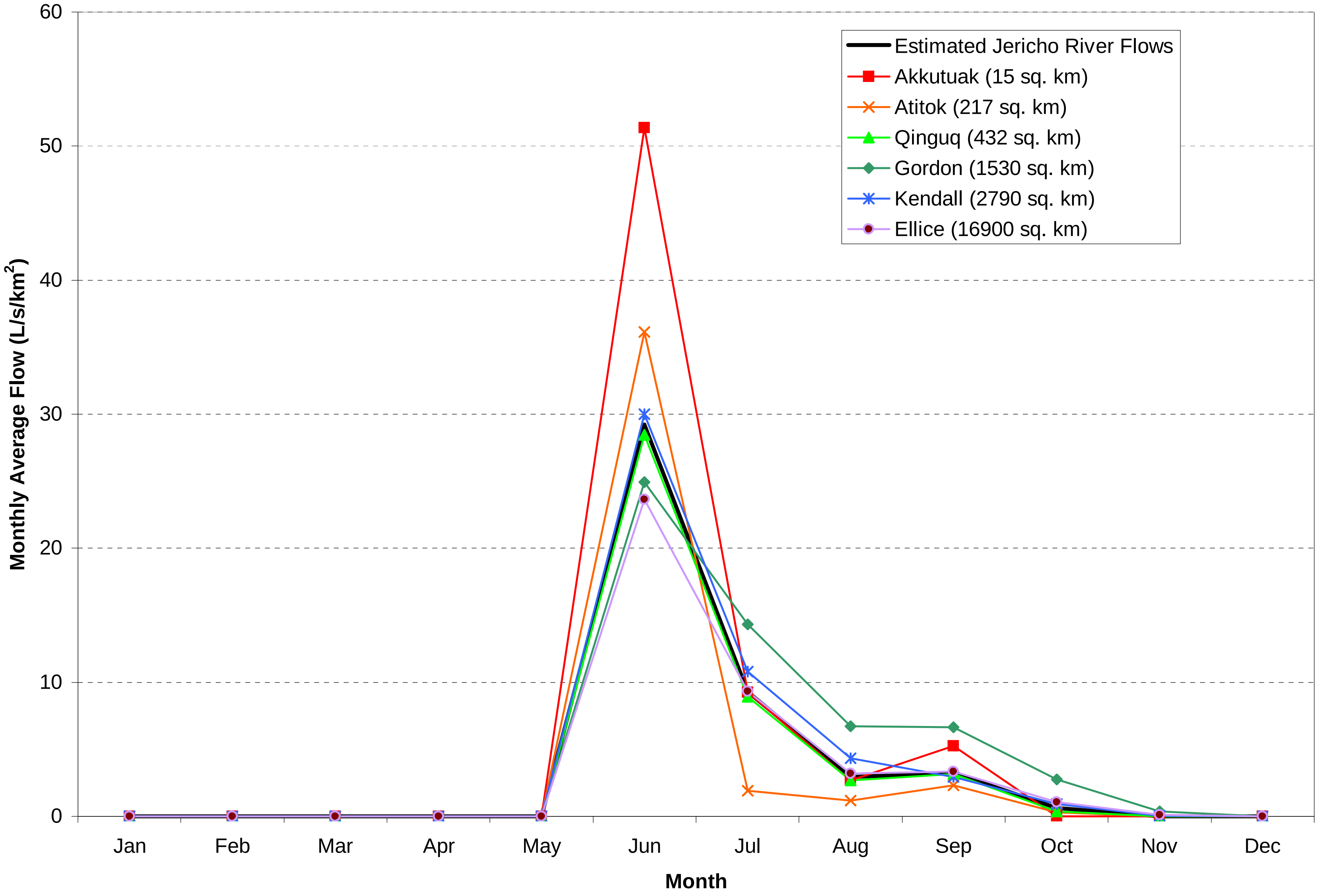


Figure 3: Synthesized 10-Year Drought Hydrographs for Jericho River and Regional WSC Stations

ATTACHMENT N2

Jericho Effluent Modeling (Lorax 2004)

LORAX
ENVIRONMENTAL

MEMORANDUM

To:	Kelly Sexsmith
From:	Don Dunbar, Lorax
Subject:	Jericho Effluent Modeling
Project:	
Date:	2004/8/11
Copies:	

Dilution model results for the Jericho Project in Nunavut are provided in the attached files.

Don Dunbar of Lorax Environmental Services Ltd. performed all of the three-dimensional numerical model simulations of effluent dilution as well as the CORMIX near-field dilution simulations. Dr. Dunbar used input data provided by SRK to initialize both models. Model results were subsequently provided to SRK by Lorax.

All model assumptions and inputs for the present set of POM simulations are the same as those used previously, except for the following:

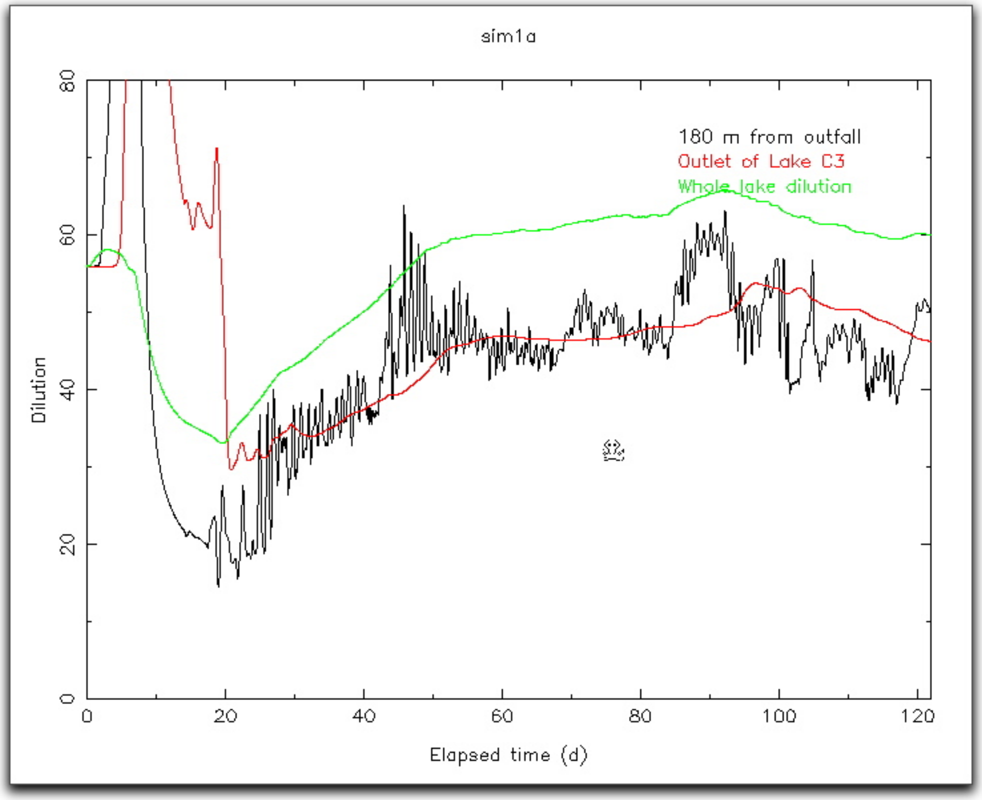
1. Jericho R. and effluent inflows have been adjusted to reflect changes in the water management plans. These flows were provided by SRK, and are documented in the accompanying report by SRK.
2. The vertical thermal structure has been removed and a constant temperature used.
3. Shoreline inflow of freshwater to both C3 and Carat Lakes has been concentrated into a few areas in the simulations, rather than being distributed evenly along the shore.
4. POM grid cell size has been decreased from 60 m to 40 m to increase the model resolution.
5. The number of vertical layers in the models was reduced from 21 to 11 to decrease execution time.

ATTACHMENT N3

Dilution Modelling Results – Discharges from the PKCA during Operations (results provided by Lorax)

ATTACHMENT N3A

Expected Discharge Conditions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Outlet of Lake C3
Whole lake dilution
Dilution
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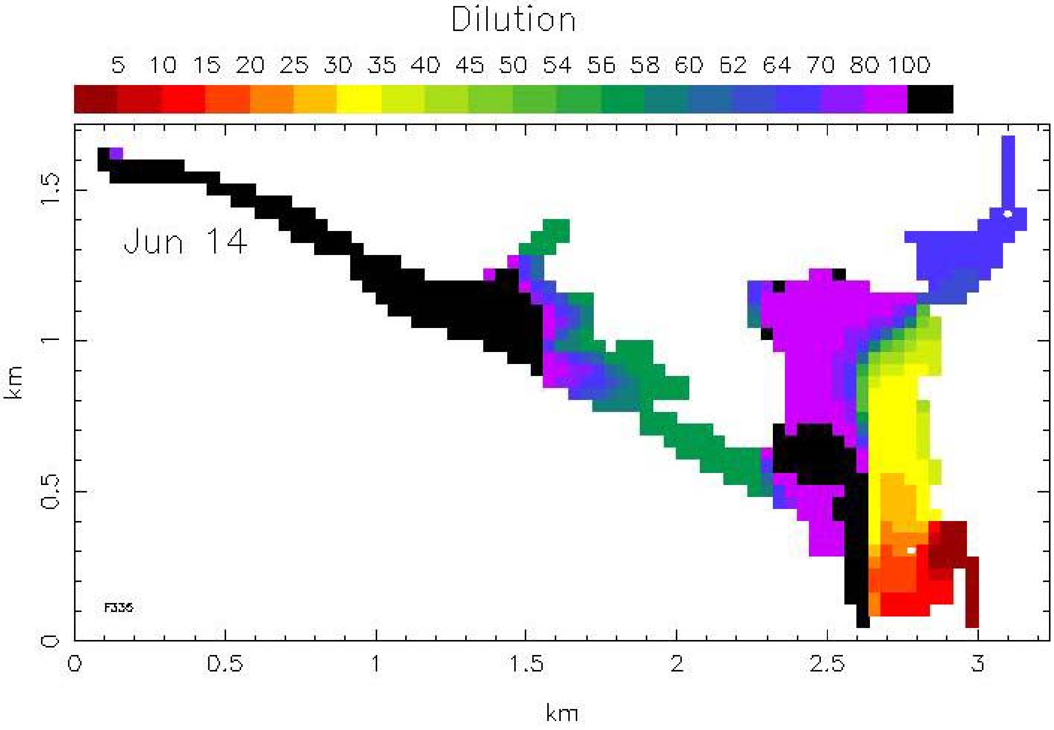
20
40
60
80
0
20
40
60
80
100
120
Elapsed time (d)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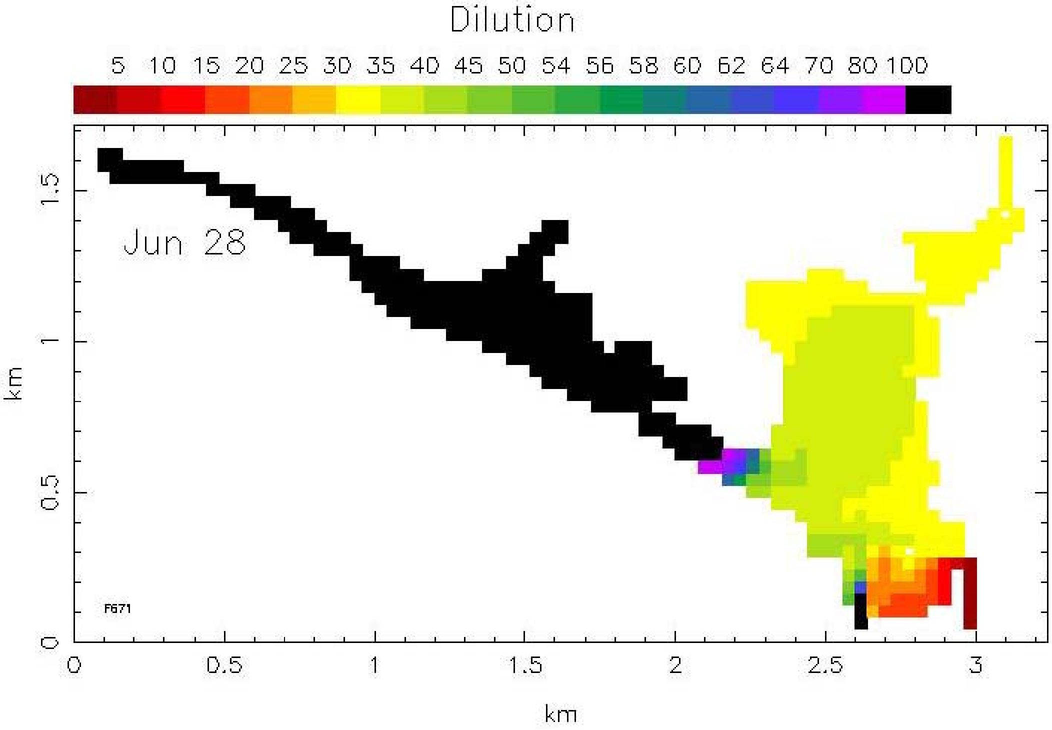
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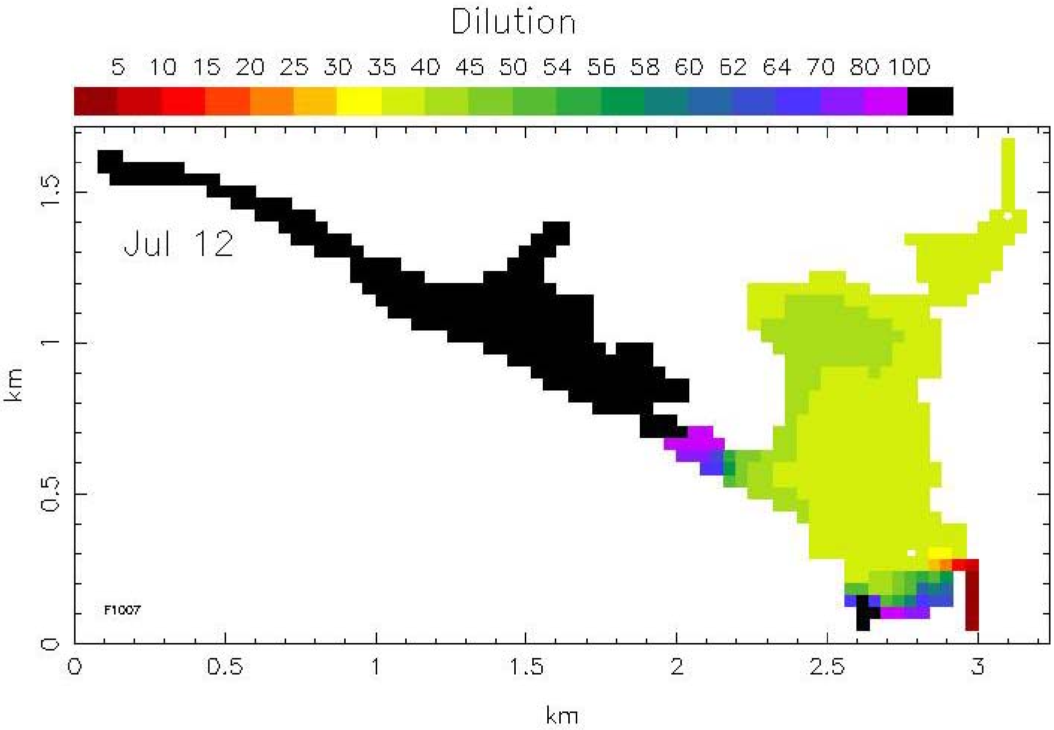
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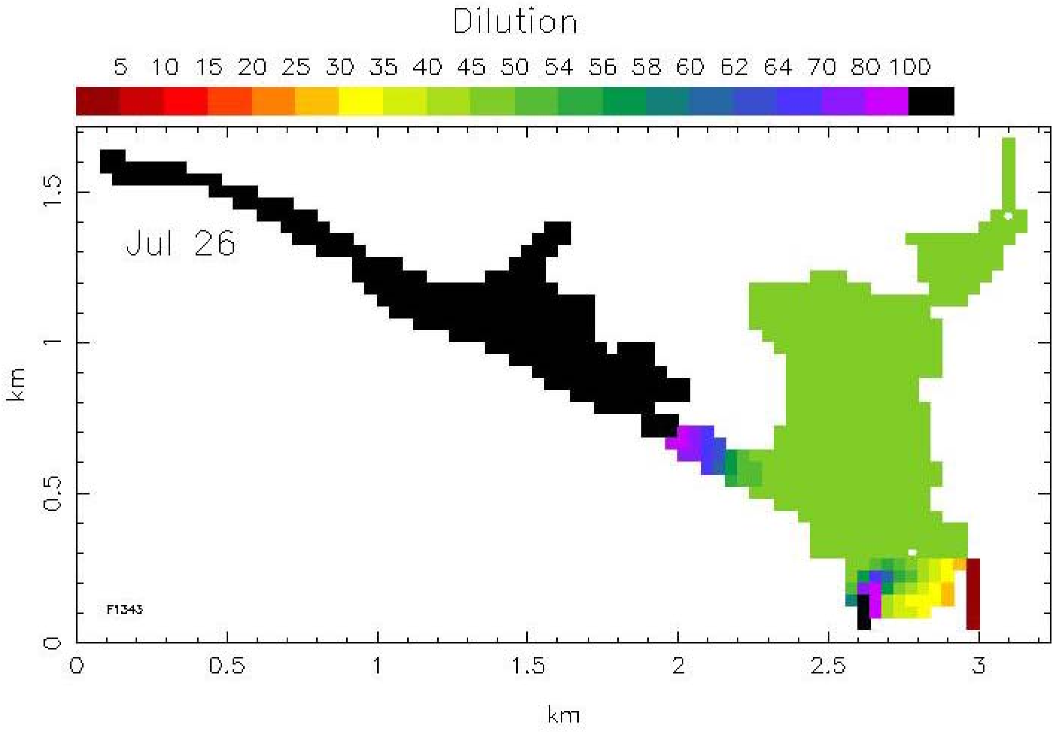
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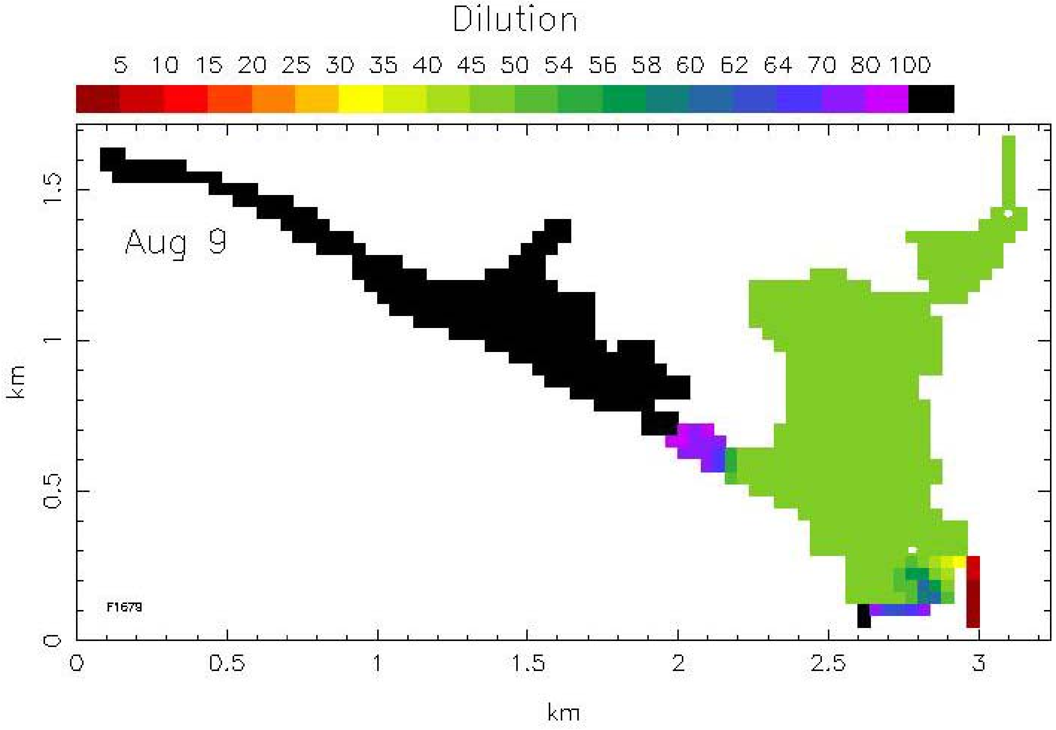
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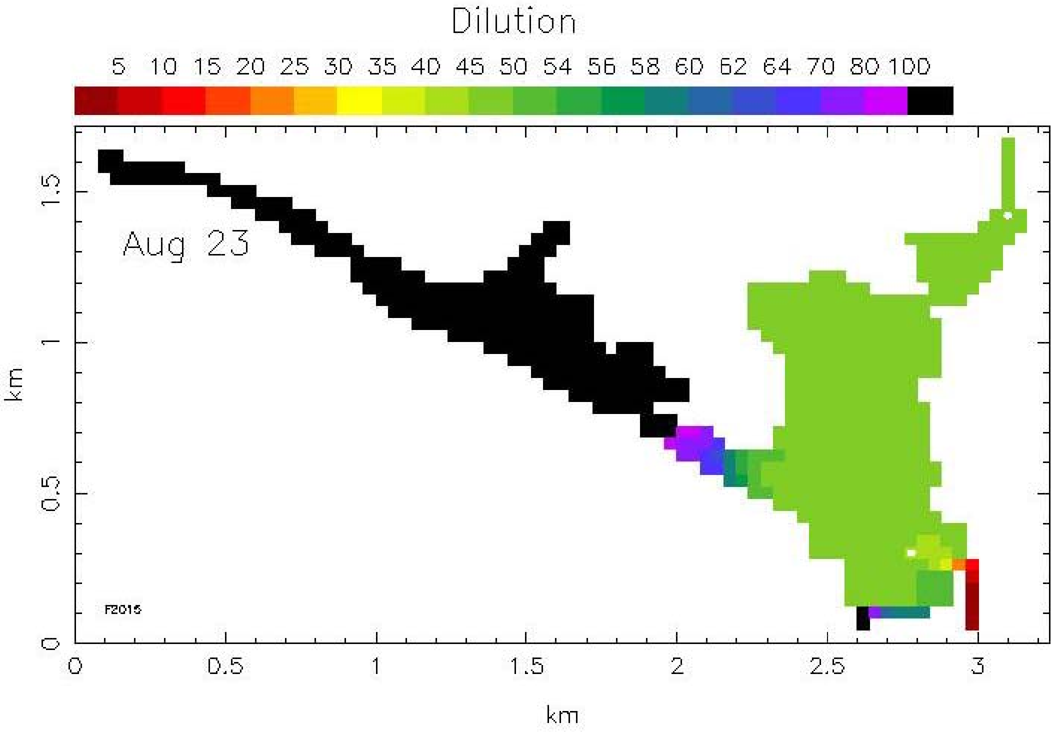
Dilution
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Aug 23
F2015
km
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km
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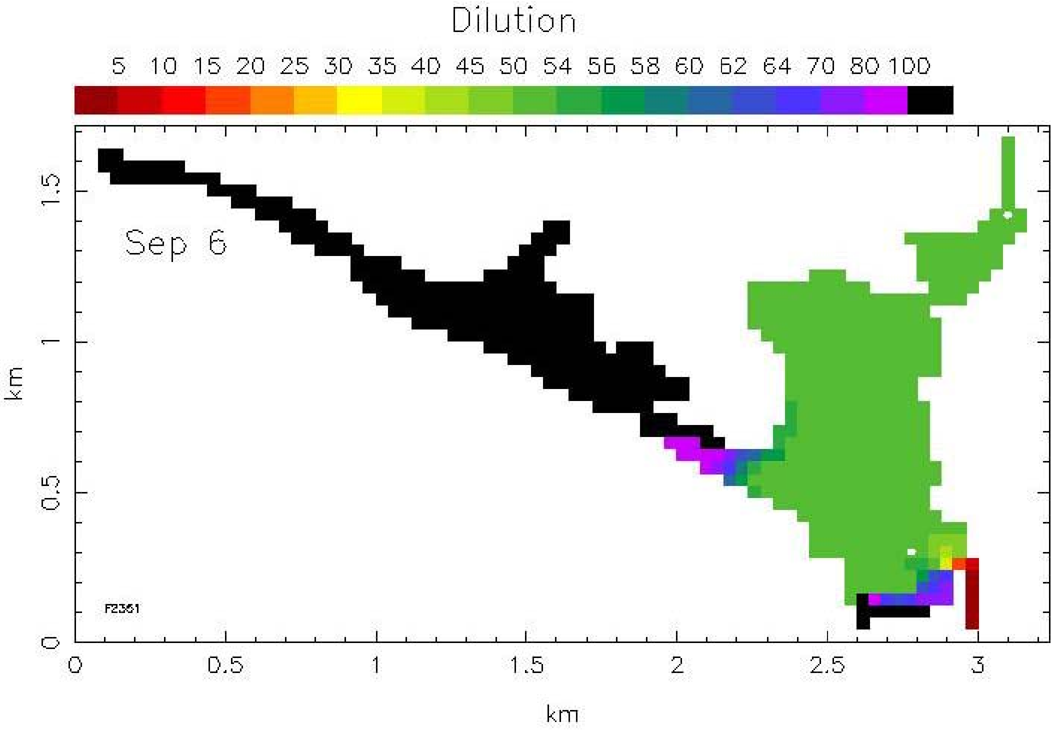
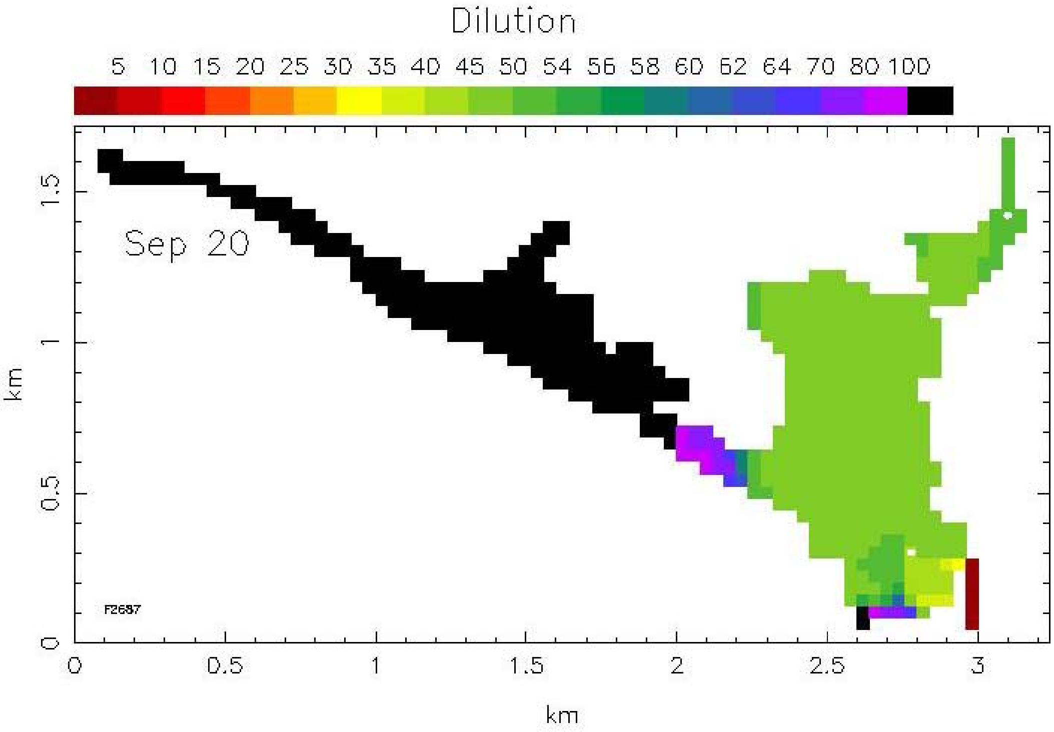
1
1.5
2
2.5
3


Dilution
5 10 15 20 25 30 35 40 45 50 54 56 58 60 62 64 70 80 100
Sep 6
F2361
km
0
0.5
1
1.5
km
0
0.5
1
1.5
2
2.5
3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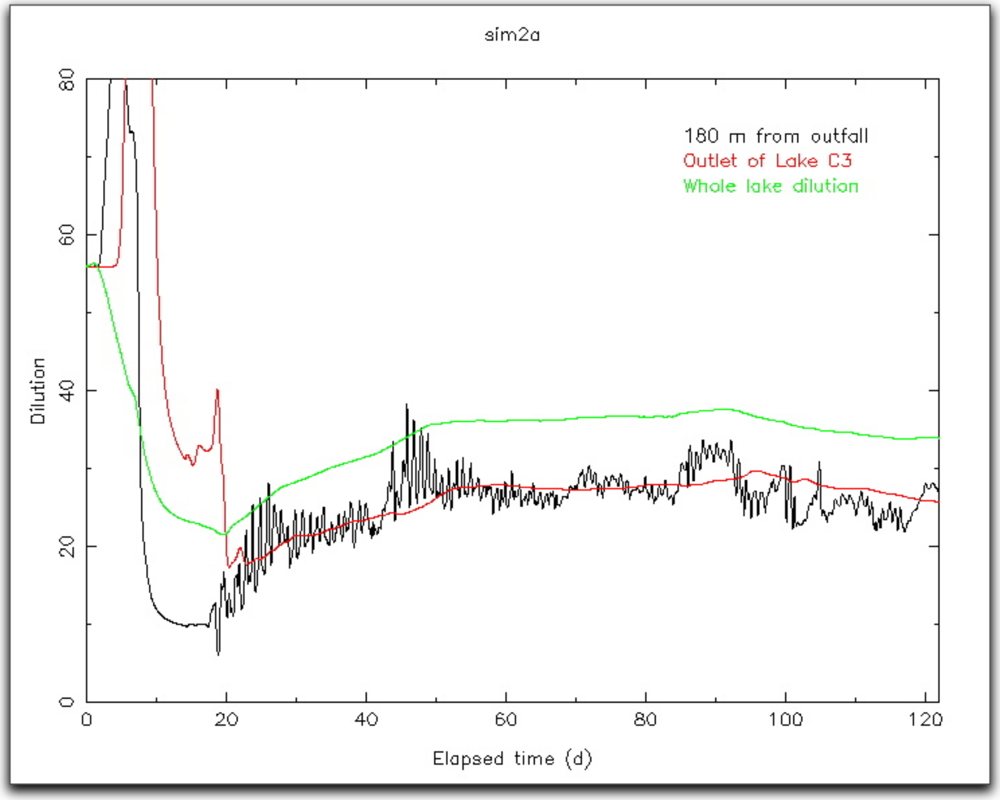
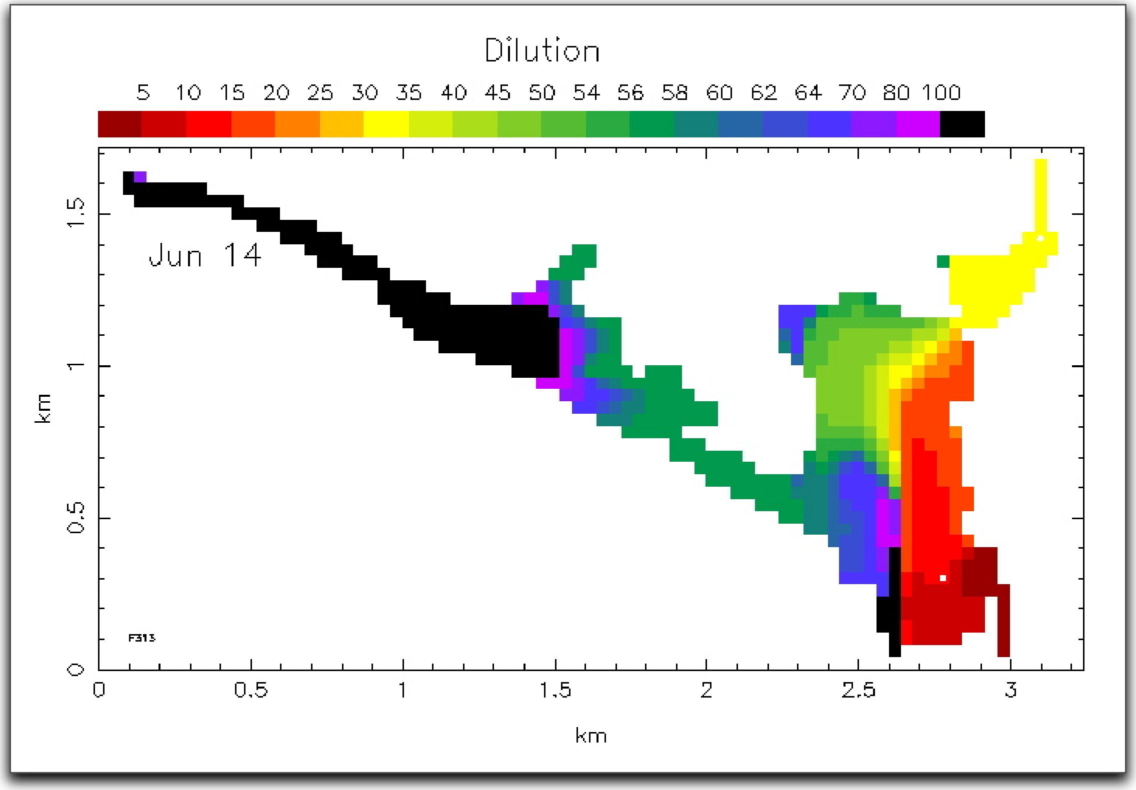
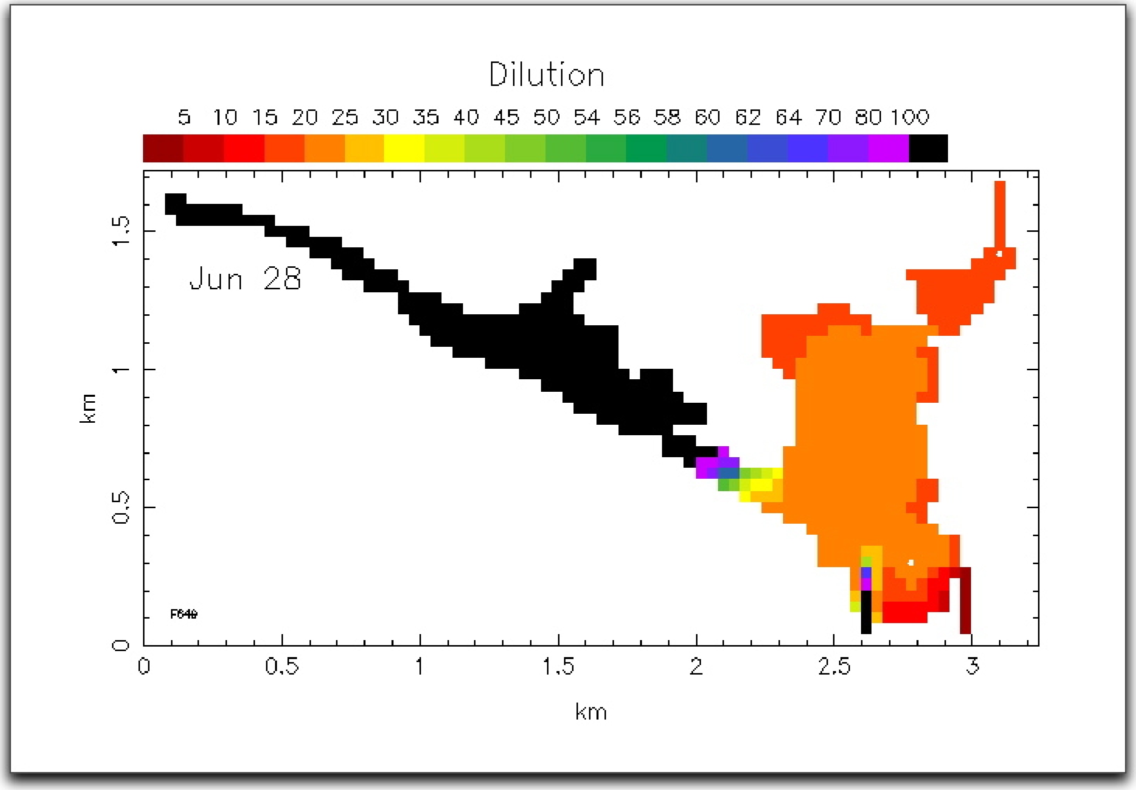
Sep 20
F2687
km
0
0.5
1
1.5
km
0
0.5
1
1.5
2
2.5
3

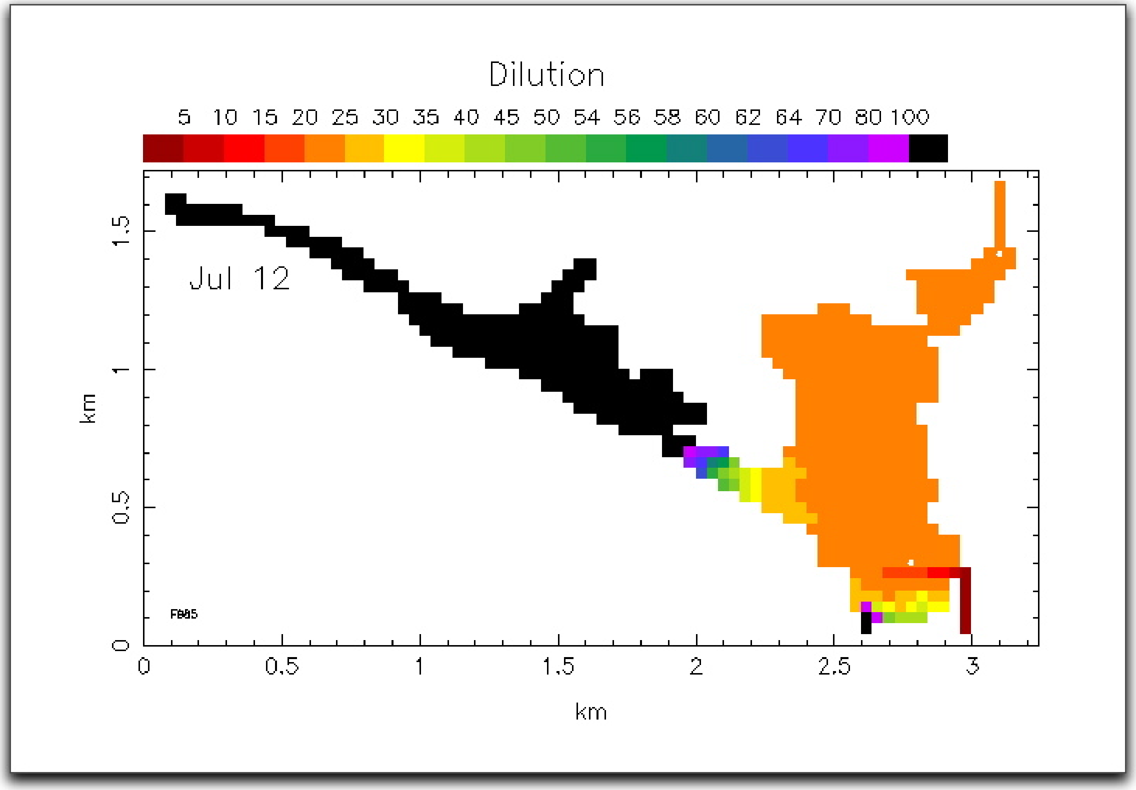
ATTACHMENT N3B

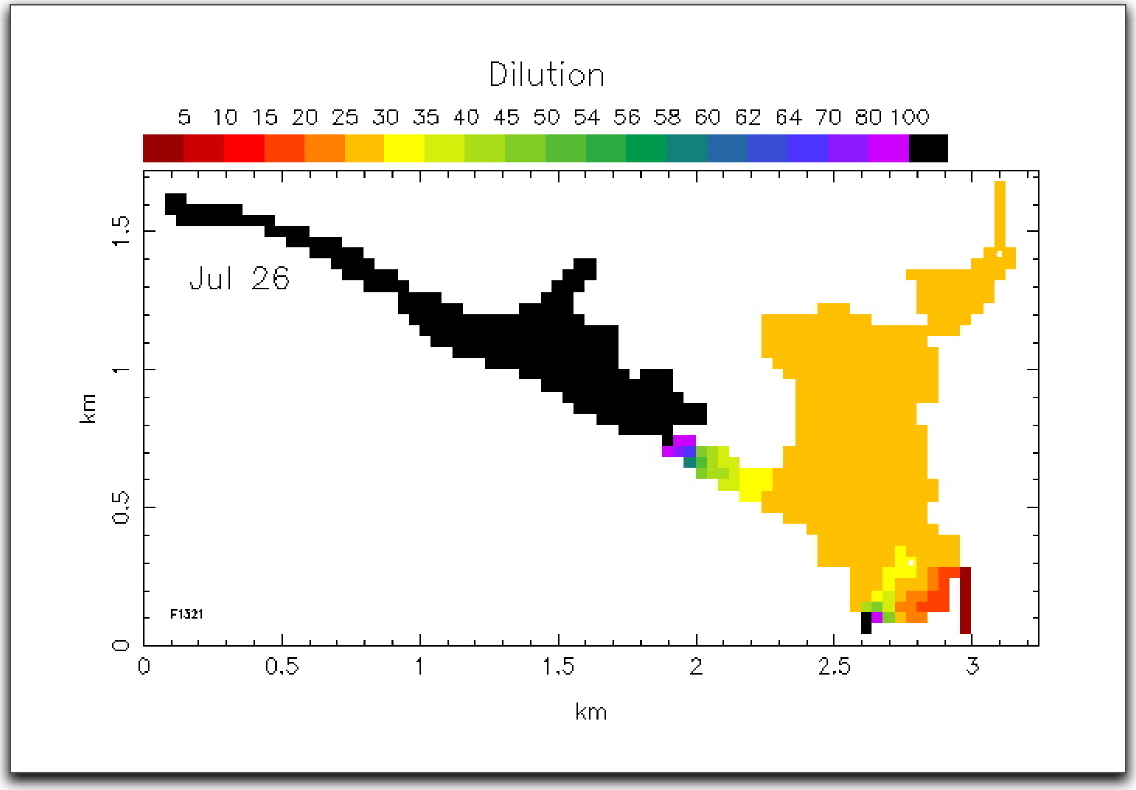
Contingency Release of Stored Flows

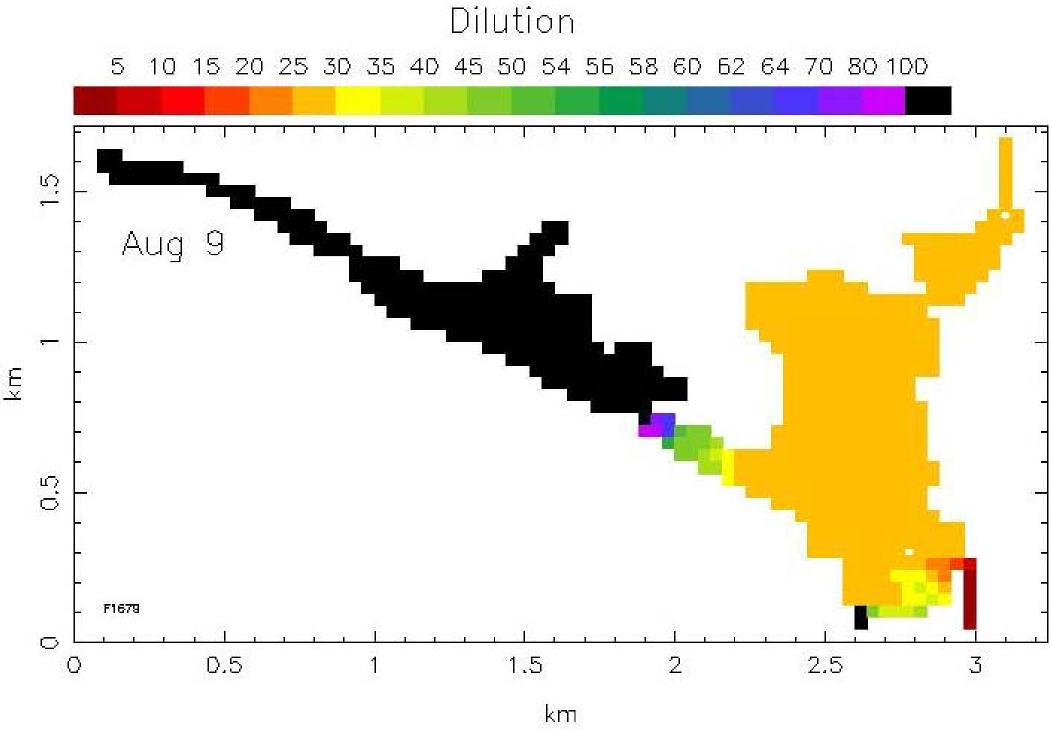

sim2a
180 m from outfall
Outlet of Lake C3
Whole lake dilution
Dilution
0
20
40
60
80
Elapsed time (d)
0
20
40
60
80
100
120

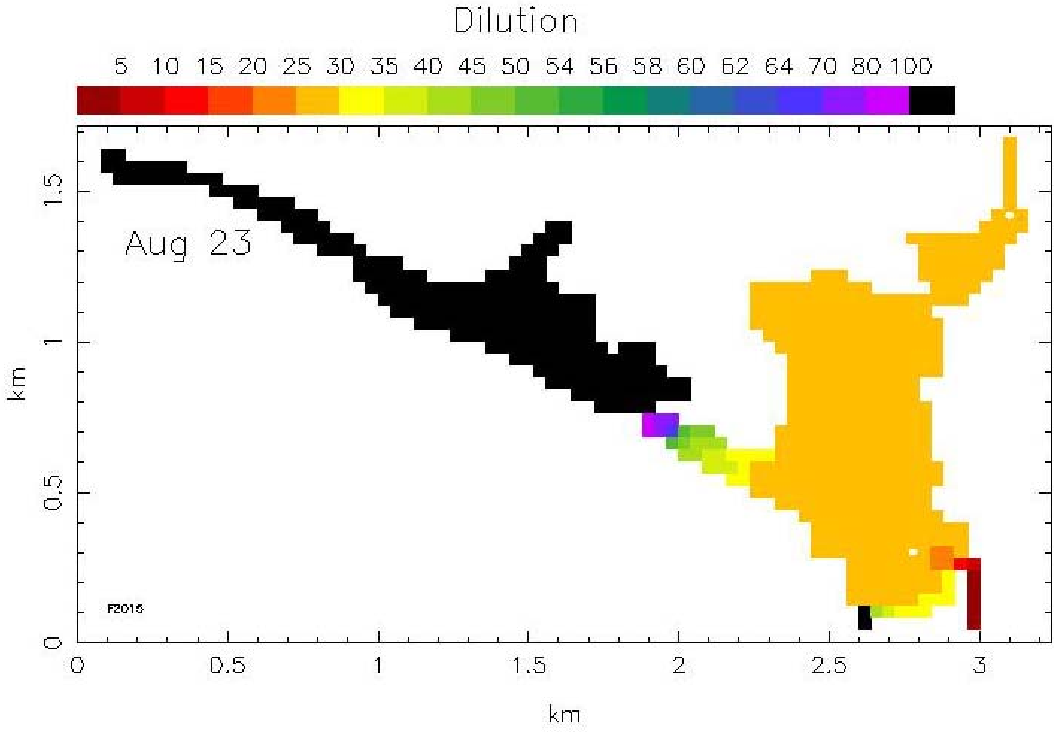

Dilution
5 10 15 20 25 30 35 40 45 50 54 56 58 60 62 64 70 80 100
Jun 14
F313
km
0
0.5
1
1.5
km
0
0.5
1
1.5
2
2.5
3

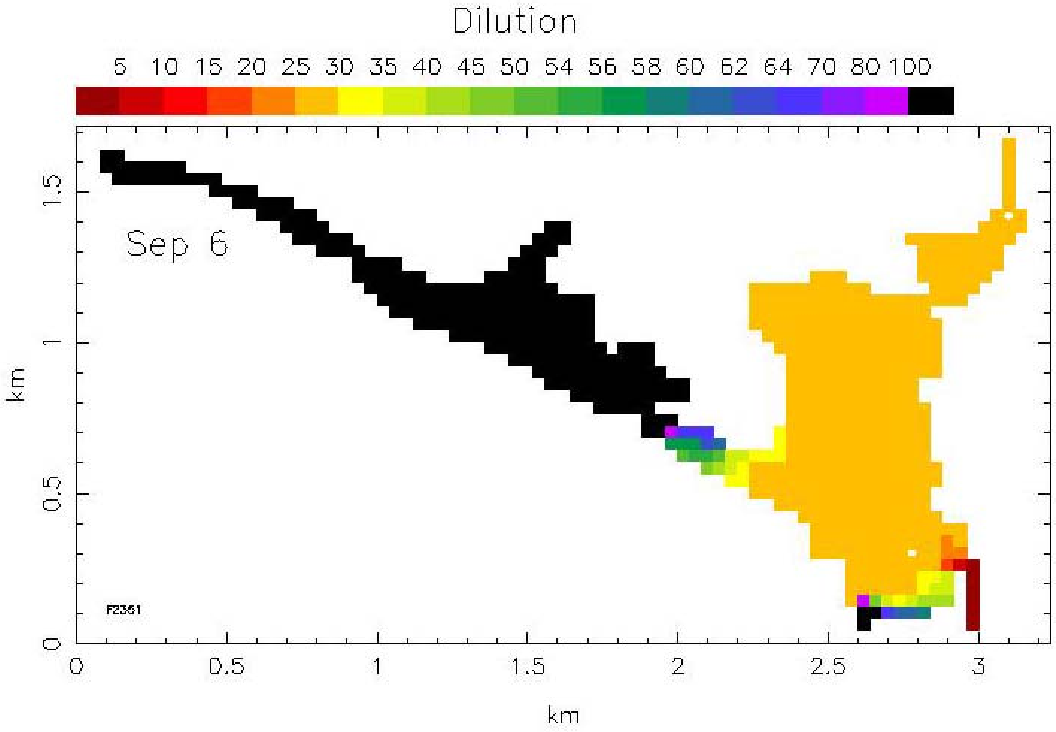

Dilution
5
10
15
20
25
30
35
40
45
50
54
56
58
60
62
64
70
80
100
Jun 28
F640
km
0
0.5
1
1.5
km
0
0.5
1
1.5
2
2.5
3

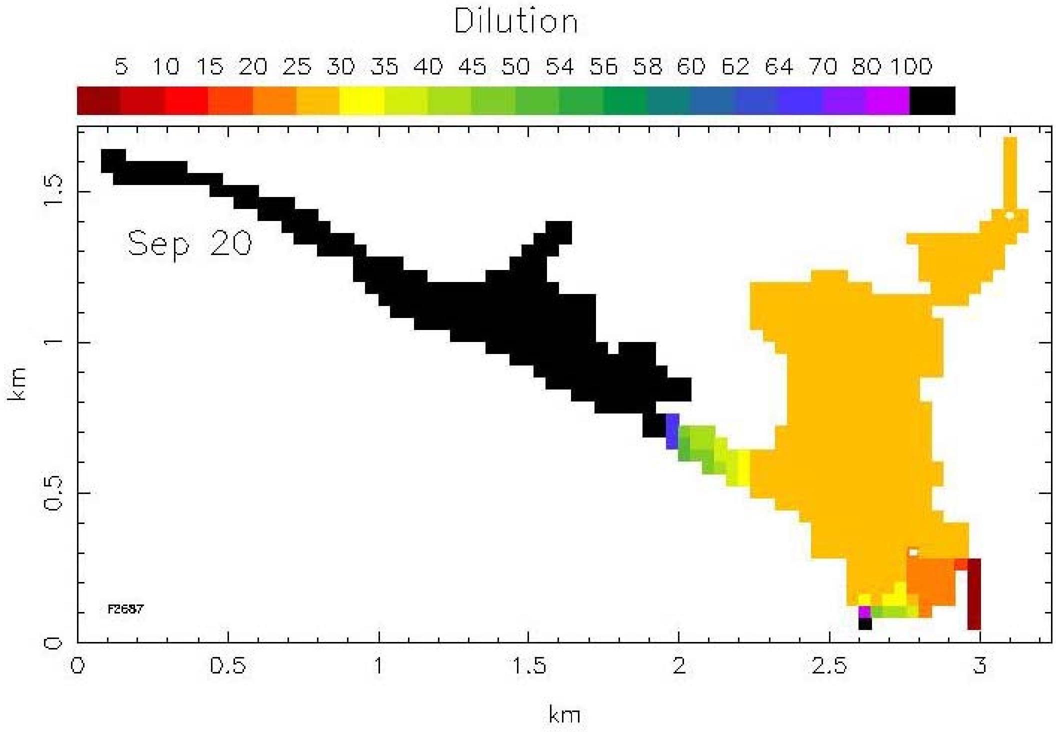

Dilution
5
10
15
20
25
30
35
40
45
50
54
56
58
60
62
64
70
80
100
Jul 12
F805
km
0
0.5
1
1.5
km
0
0.5
1
1.5
2
2.5
3


Dilution
5
10
15
20
25
30
35
40
45
50
54
56
58
60
62
64
70
80
100
Jul 26
F1321
km
0
0.5
1
1.5
km
0
0.5
1
1.5
2
2.5
3


Dilution
5
10
15
20
25
30
35
40
45
50
54
56
58
60
62
64
70
80
100
Aug 9
F1679
km
0
0.5
1
1.5
km
0
0.5
1
1.5
2
2.5
3


Dilution
5 10 15 20 25 30 35 40 45 50 54 56 58 60 62 64 70 80 100
Aug 23
F2015
km
0 0.5 1 1.5
0 0.5 1 1.5 2 2.5 3
km

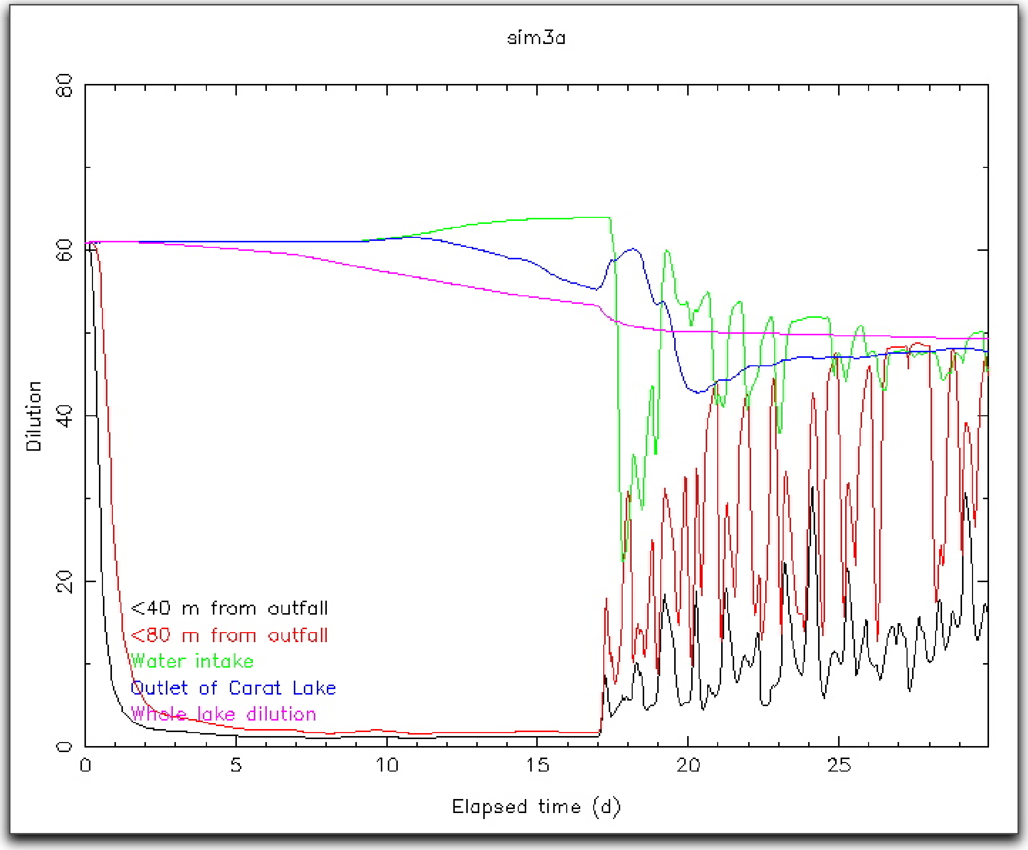

Dilution
5 10 15 20 25 30 35 40 45 50 54 56 58 60 62 64 70 80 100
Sep 6
F2361
km
0 0.5 1 1.5
0 0.5 1 1.5 2 2.5 3
km

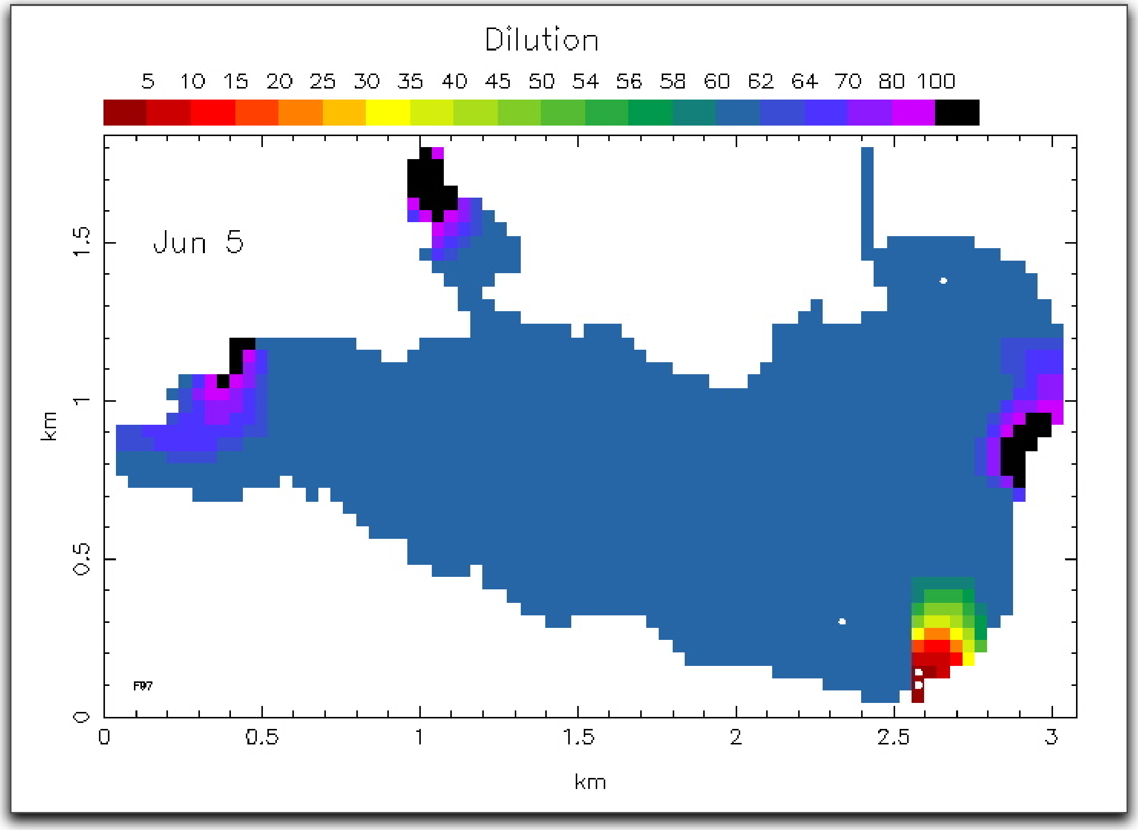

Dilution
5
10
15
20
25
30
35
40
45
50
54
56
58
60
62
64
70
80
100
Sep 20
F2687
km
0
0.5
1
1.5
km
0
0.5
1
1.5
2
2.5
3

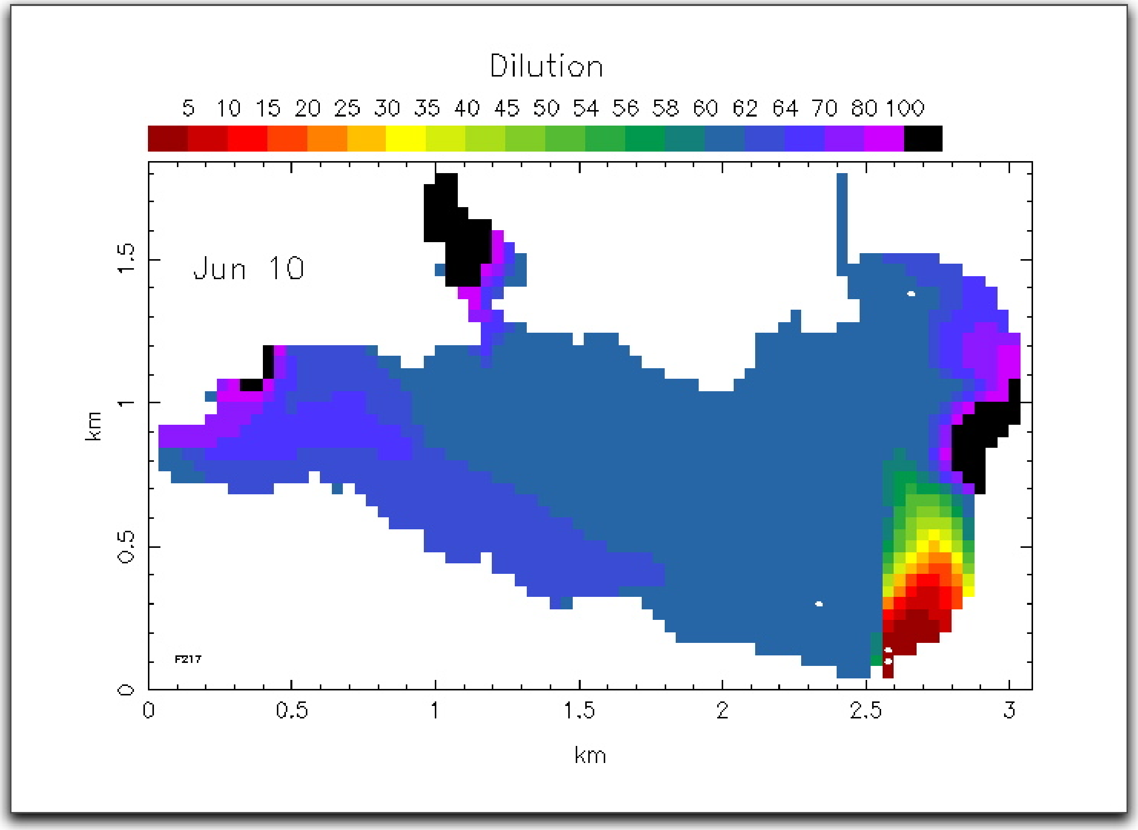
ATTACHMENT N4

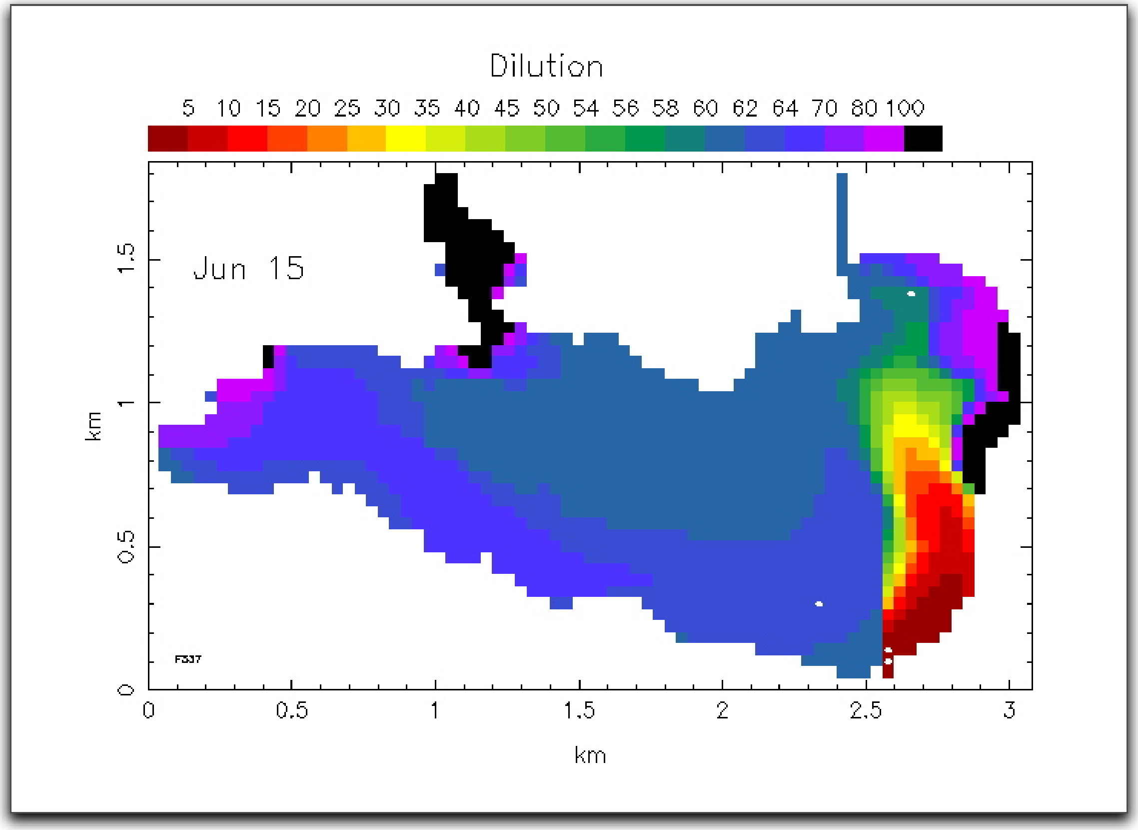
Dilution Modelling Results – Post Closure Discharge, Shoreline of Carat Lake

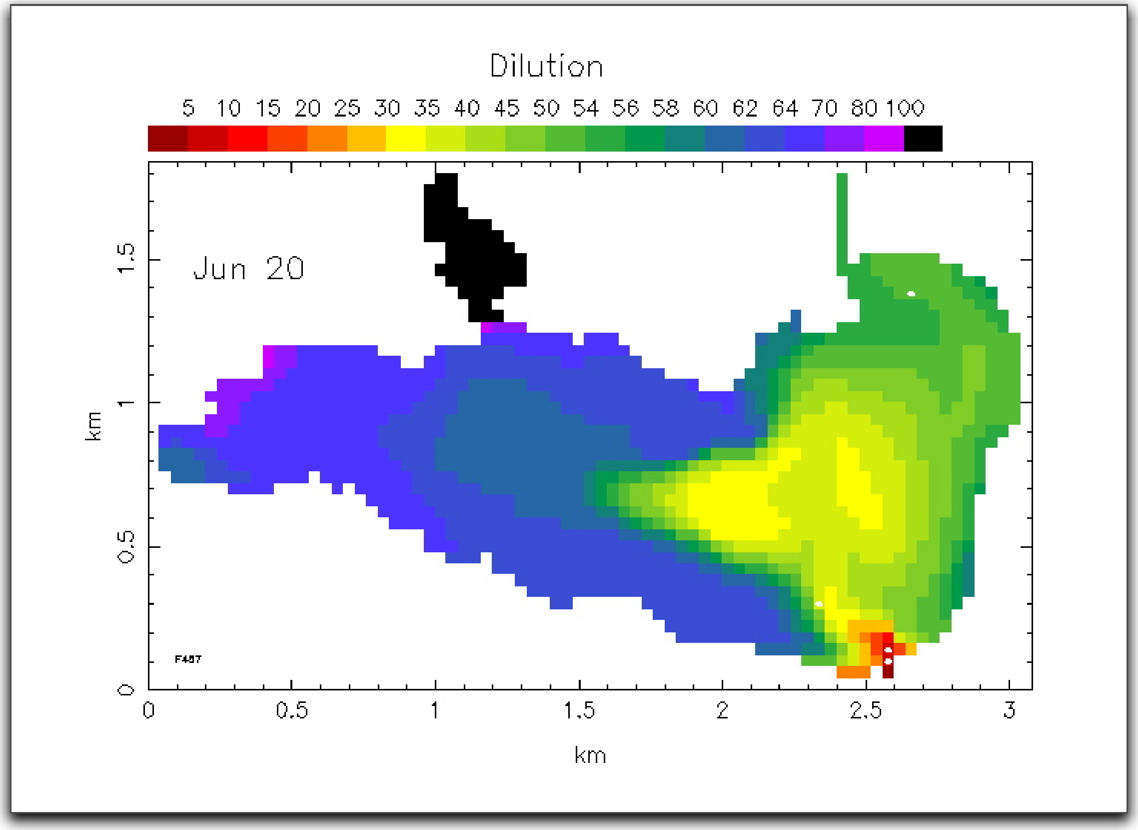
(Results provided by Lorax)

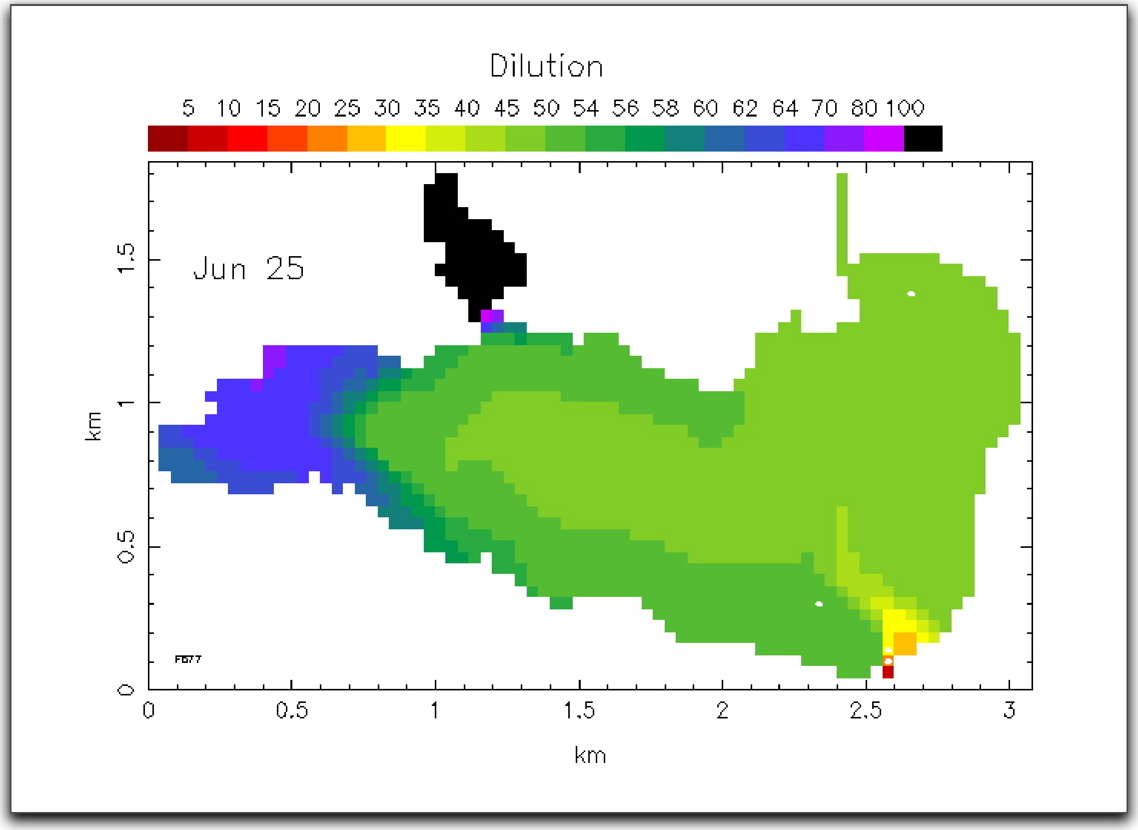

sim3a
Dilution
0
20
40
60
80
0
5
10
15
20
25
Elapsed time (d)
<40 m from outfall
<80 m from outfall
Water intake
Outlet of Carat Lake
Whole lake dilution

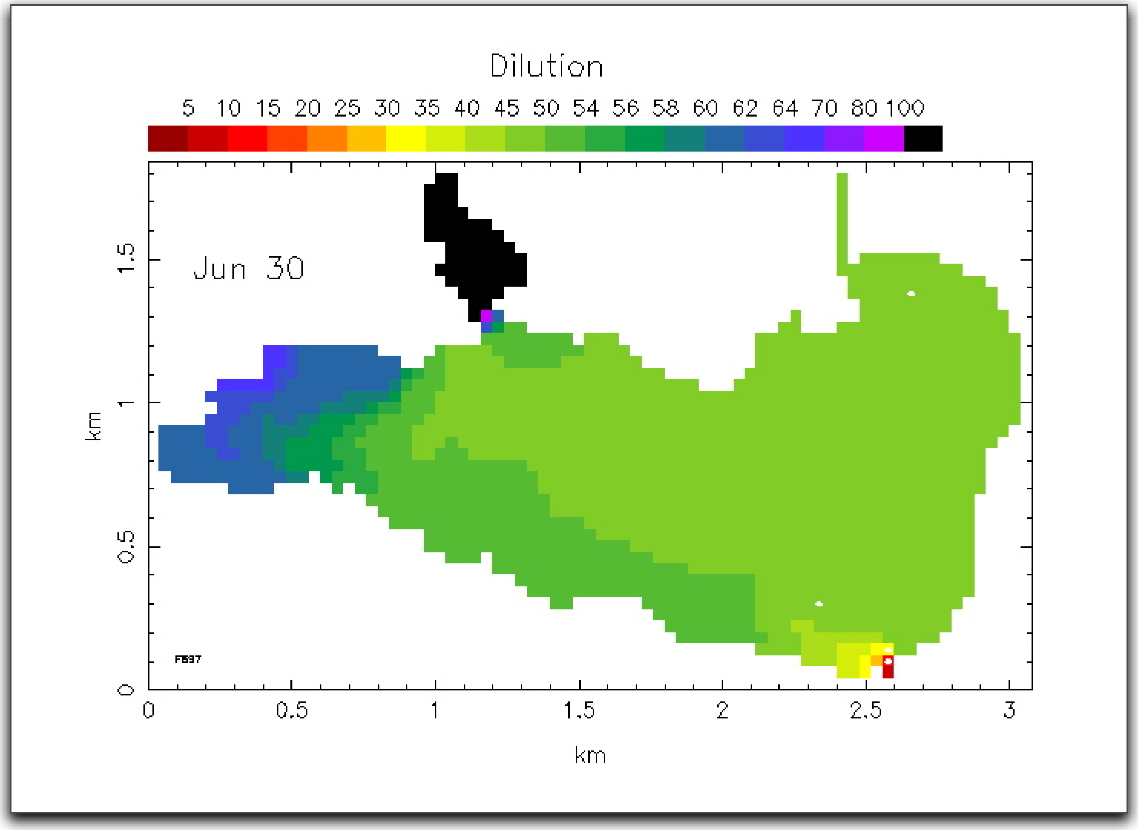

Dilution
5
10
15
20
25
30
35
40
45
50
54
56
58
60
62
64
70
80
100
Jun 5
km
0
0.5
1
1.5
0
0.5
1
1.5
2
2.5
3
km
F07


Dilution
5 10 15 20 25 30 35 40 45 50 54 56 58 60 62 64 70 80 100
Jun 10
F217
km
0
0.5
1
1.5
0
0.5
1
1.5
2
2.5
3
km


Dilution
5 10 15 20 25 30 35 40 45 50 54 56 58 60 62 64 70 80 100
Jun 15
F337
km
0
0.5
1
1.5
0
0.5
1
1.5
2
2.5
3
km


Dilution
5
10
15
20
25
30
35
40
45
50
54
56
58
60
62
64
70
80
100
Jun 20
F487
km
0
0.5
1
1.5
km
0
0.5
1
1.5
2
2.5
3


Dilution
5
10
15
20
25
30
35
40
45
50
54
56
58
60
62
64
70
80
100
Jun 25
F577
km
0
0.5
1
1.5
km
0
0.5
1
1.5
2
2.5
3


Dilution
5
10
15
20
25
30
35
40
45
50
54
56
58
60
62
64
70
80
100
Jun 30
km
km
0
0.5
1
1.5
2
2.5
3
0
0.5
1
1.5
FB37

ATTACHMENT N5

Review of Total Dissolved Solids in Proposed Discharge from the Jericho Diamond Project, Nunavut (AMEC 2004)

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Review of Total Dissolved Solids in Proposed Discharge from the Jericho Diamond Project

West Kitikmeot
Nunavvt

Submitted to:

Tahera Corporation
Toronto, Ontario

Submitted by:

AMEC Earth & Environmental,
a division of AMEC Americas Limited

Burnaby, BC

June 2004

AMEC File: VE51295

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IMPORTANT NOTICE

This report was prepared exclusively for Tahera Corporation by AMEC Earth & Environmental Limited. The quality of information, conclusions and estimates contained herein is consistent with the level of effort involved in AMEC services and based on: i) information available at the time of preparation, ii) data supplied by outside sources, and iii) the assumptions, conditions and qualifications set forth in this report. This report is intended to be used by Tahera Corporation only, subject to the terms and conditions of its contract with AMEC. Any other use of, or reliance on, this report by any third party is at that party's sole risk.

1.0 INTRODUCTION

Tahera Corporation is in the process of applying for a water license to discharge water from the proposed Jericho Diamond Mine. Discharge from the mine will contain elevated concentrations of total dissolved solids (TDS) relative to the receiving environment and, consequently, this review was conducted to evaluate whether the concentrations that are likely to be observed in the receiving environment are of toxicological significance.

TDS reflects the sum of materials that are dissolved in a solution. These materials are primarily comprised of four cations (calcium, magnesium, sodium and potassium) and three anions (sulphate, chloride, and bicarbonate/carbonate), all of which are important in biological structures and functions. A significant number of other trace materials can also contribute to TDS; however, for the sake of this assessment, we will only be considering the major ions.

Toxicity associated with elevated concentrations of TDS generally results from one of three mechanisms:

- The overall ionic strength associated with the combination of ions comprising the TDS can result in toxicity as a result of the inability of organisms to osmoregulate.

- Adverse effects can occur as a result of one or more of the ions which make-up TDS reaching toxicologically significant concentrations.

- An imbalance in the ratio between particular ions can result in toxicity because of disruption of biological mechanisms.

Toxicity test data for cationic components of TDS are always derived from tests with solutions containing an associated anionic component, and vice versa. These ions are present as salts, such as calcium carbonate, calcium sulphate, potassium chloride, etc, which are introduced into the test solutions. Consequently, the degree to which one or other of the co-ions comprising each salt, or any interactions associated with their combined presence, is responsible for toxicity is not entirely known.

Ions which comprise TDS each exhibit a differing degree of toxicological effect. A study on acute toxicity to larval fathead minnows and two species of cladocerans demonstrated that the order of relative ion toxicity is $K^+ > HCO_3^- \approx Mg^{2+} > Cl^- > SO_4^{2-}$. Sodium and calcium ions were generally unrelated to toxicity; toxicity associated with salts containing these two cations was generally caused by the corresponding anions (Mount et al., 1997).

2.0 EFFLUENT DESCRIPTION

Water from mining operations will be contained in the PKCA pond and will be discharged each year while weather conditions permit. Discharge from the PKCA is expected to contain elevated concentrations of TDS. In particular, under average precipitation conditions, average and maximum TDS concentrations are projected to be 1074 and 1635 mg/L, respectively (SRK, 2004). The projected composition of TDS in the effluent under these scenarios is provided in Table 1.

The anionic composition of the effluent is dominated by chloride, which comprises 40 to 45% of the total TDS by weight. Sulphate also contributes substantially to the total TDS (17 to 23%). Cationic components of the effluent collectively contribute approximately 30% of the TDS.

Table 1. Projected average and maximum contributions of major ions to TDS in water in the PKCA under conditions of average rainfall (from SRK, 2004).

	Average concentration (mg/L)	**Maximum concentration (mg/L)**	**Average Composition (%)**	**Maximum Composition (%)**
Calcium	101	202	9%	12%
Magnesium	175	206	16%	13%
Sodium	21	36	2%	2%
Potassium	36	64	3%	4%
Alkalinity	42	70	4%	4%
Chloride	487	647	45%	40%
Sulphate	184	380	17%	23%
TDS	1074	1635	--	--

3.0 RECEIVING ENVIRONMENT DESCRIPTION

Effluent from the PKCA will be discharged through a small stream into Lake C3, which subsequently drains into Carat Lake. These lakes are oligotrophic and very low in TDS (typically less than 20 mg/L). Dilution rates provided by Lake C3 and Carat Lake are estimated to be 50- and 58-fold, although higher concentrations of effluent would be expected to occur proximate to the discharge point.

The biological community in the lakes that will receive input from the mine is limited by the low productivity of the lakes. Periphyton and phytoplankton are dominated by Bacillariophyta (diatoms), Cyanophyta (cyanobacteria), Chrysophyta (golden-brown algae) and Chlorophyta (green algae). Zooplankton are comprised of cladocerans (52 to 86% of biomass), copepods and rotifers, and benthic invertebrates are predominantly comprised of benthic copepods and chironomid larvae. Smaller numbers of hydracarina, nematodes, oligochaetes, ostracods, pelecypods and turbellarians are also observed. Fish populations present in Lake C3 and Carat Lake are comprised mainly of lake trout, round whitefish and Arctic char (data from a 1999 survey [RL&L, 2000]).

4.0 POTENTIAL FOR TOXICOLOGICAL EFFECTS ASSOCIATED WITH TDS

Evaluations of TDS with respect to potential for toxicological effects are complicated by the fact that they generally rely on laboratory data from toxicity tests with individual ion pairs (i.e., salts). Data from each of these tests must be considered in the context of the possibility that the toxicity was caused by one or other of the pair of ions, or some combination of the two. Furthermore, extrapolation of these effects data to mixtures of all seven of the major ions is complicated by the potential for interaction of the ions with one another. In some cases, the combined presence of multiple ions can reduce the toxicity of individual ions (Mount et al, 1997); however, the combined presence of multiple ions increases the overall ionic strength of the water, and may result in toxicity in cases where the individual ions would not have, if tested alone.

4.1 Anionic contributors to TDS

Sulphate

There are currently no Canadian or USEPA guidelines for the protection of aquatic life for sulphate; however, the BC Ministry of Water Land and Air Protection has established a water quality criterion for this parameter of 100 mg/L (BCMELP, 2000). This guideline is primarily based on sensitivity data for *Hyalella azteca*, a freshwater amphipod, and aquatic mosses.

The BC criteria document for sulphate contains a significant amount of toxicity data that are not published elsewhere; these data were generated in support of the guideline derivation. A subset of these results which are of particular relevance to Jericho have been summarized in Table 2. Although amphipods such as *H. azteca* would not be expected to occur in these lakes, the data for this species have also been included in Table 2 because of the reliance of the guideline on data from this species.

Adverse effects on the cladocerans *Ceriodaphnia dubia* and *Daphnia magna*, the chironomid *Chironomus tentans*, the salmonid *Oncorhynchus mykiss* and the unicellular alga *Selenastrum capricornutum* occurred at substantially higher concentrations than the maximum sulphate concentrations projected in the PKCA of 380 mg/L (i.e., not allowing for any dilution by lakes downstream of the discharge point). Concentrations of sulphate in the PKCA are expected to exceed the lowest effect value presented for *H. azteca*; however, it should be noted that the sensitivity of this species to sulphate is highly hardness dependant, and the toxicity of sulfate is more than an order of magnitude lower at a hardness of 100 mg/L than it is at a hardness of 25 mg/L. Moreover, elevated sulphate concentrations in discharges from the Jericho mine will co-occur with higher hardnesses: for example, at a sulphate concentration of 205 mg/L (the LC50 for *H azteca* in 25 mg/L hardness water), we would anticipate that the discharge would have a hardness of more than 700 mg/L. Thus, even if *Hyalella* were present, we would not anticipate observing adverse effects on survival, and it would appear that the BC criterion for this parameter is overly protective in this instance.

The only other adverse effect data reported in the BC criteria document that were reported at concentrations below the maximum sulphate concentration predicted in the PKCA under average precipitation conditions (380 mg/L) were for larval striped bass (*Morone saxatilus*) which exhibited a 96-hr LC50 of 250 mg/L SO_4; this species does not occur in the receiving environment at the Jericho mine. In addition, evidence has been reported of adverse effects on aquatic mosses, in particular *Fontinalis antipyretica*, at concentrations of sulphate as low as 100 mg/L (Frahm, 1975, cited by BCMELP, 2000); however, these tests were apparently conducted using potassium sulphate rather than sodium sulphate, and it is likely that any observed effect was related to the potassium co-ion rather than to sulphate.

Thus, on the basis of a "worst case" analysis, it would appear that adverse effects associated with elevated concentrations of sulphate would not be likely to occur, even within the PKCA. Furthermore, given the 50-fold dilution available in Lake C3, projected sulphate concentrations in the receiving environment should be well under any known thresholds for toxicity.

Table 2. Effects concentrations for sulphate for selected data generated as part of derivation of the BC criteria for this parameter.

	Species	Endpoint	Hardness (mg/L)	Effect concentration (mg/L SO_4)
Cladoceran	*C. dubia*	7-d reproduction IC25	100	1267
	D. magna	21-day reproduction IC25	100	883
		48 hr survival LC50	25	537
		48 hr survival LC50	100	6281
Amphipod	*H. azteca*	96-hr survival LC50	25	205
		96-hr survival LC50	100	3711
		96-hr survival LC50	250	6787
Chironomid	*C. tentans*	96-hr survival LC50	25	6667
Salmonid	*O. mykiss*	96-hr survival LC50	25	5000
		7-day embryo EC25	100	1280
Alga	*S. capricornutum*	72-hr IC25	NR	2210

NR = Not reported

Chloride

The USEPA has established an ambient water quality criterion for chloride of 230 mg/L (USEPA, 1988). This value is based on laboratory toxicity tests using sodium chloride (NaCl). Chlorides of other co-ions (e.g., potassium, magnesium) are expected to exhibit a greater degree of toxicity; however, mixtures of ions are expected to exhibit lower overall toxicity than solutions of individual salts. Invertebrates were generally more sensitive to chloride than vertebrates, and *Daphnia* (a cladoceran) was the most sensitive genus evaluated.

There is currently no Canadian water quality guideline for chloride; however, Environment Canada have produced a report on use of road de-icing salts in which an HC_5 (the concentration that would be expected to protect 95% of the potentially exposed taxonomic groups) value of 212.6 mg/L chloride was reported (Environment Canada, 2001).

The BC water quality criterion for chloride is 150 mg/L (BCMWLAP, 2003). This was derived based on dividing data for the most sensitive species for which data were available (*C. dubia*) by a safety factor of five. The AMEC toxicity laboratory in Fife, Washington, uses sodium chloride as a reference toxicant in chronic tests with this cladocerans species. Based on the last twenty tests, a 50% reduction in reproductive output of *C. dubia* was observed at 1083 ± 329 mg/L NaCl (657 ± 200 mg/L Cl^-). Bailey et al. (2000) reported results for reference toxicant tests for the same species using potassium chloride (KCl) of 192 ± 23 mg/L (92 ± 11 mg/L Cl^-). The higher toxicity observed with the use of KCl, rather than NaCl, suggests that toxicity in the KCl tests was related primarily to the presence of potassium rather than chloride.

A risk assessment has recently been conducted for the Ekati mine in which a site-specific species sensitivity distribution was calculated for chloride for organisms that occur in the receiving environment (EVS, 2004). This approach involved calculating a threshold value designed to protect 95 percent of the species by extrapolation of the distribution of toxicity data for taxonomic groups (or reasonable surrogates) that occur in the community. It should be noted that this derivation relied largely on acute toxicity data, and used the acute to chronic ratio published in the EPA criteria document for this parameter to determine the chronic HC_5 from the acute HC_5. The acute and chronic values were 1369 and 180 mg/L chloride, respectively.

Cladocerans, in particular, *C. dubia*, are the most sensitive taxonomic group for which data are available. A substantial amount of data from the AMEC toxicity laboratory for *C. dubia* (n=20) indicates that the IC50 occurs at or above 257 mg/L chloride (i.e., two standard deviations less than the mean response) in 97.5% of the tests. Thus, the EPA and BC criteria values (230 and 150 mg/L, respectively), and the site-specific species sensitivity distribution conducted for Ekati (180 mg/L) appear to be protective of effects to this species.

Based on the site-specific value for chloride of 180 mg/L prepared for Ekati, concentrations in the PKCA (up to 650 mg/L) exceed effects levels for chloride by nearly 4-fold. However, these concentrations will be rapidly diluted to levels well below toxicity thresholds once the discharge reaches Lake C3.

Alkalinity (bicarbonate/carbontate)

The alkalinity in the water associated with discharge from the PKCA is relatively low even under worst-case scenarios and well-within the range tolerated by freshwater organisms. Consequently, no adverse effects associated with alkalinity would be anticipated.

4.2 Cationic contributors to TDS

Data used for assessment of chloride toxicity have generally been obtained from tests using sodium chloride. The effect concentrations associated with the USEPA and BC water quality criteria for chloride (230 and 150 mg/L chloride, respectively) and the chronic value from the risk assessment conducted for Ekati for this parameter (180 mg/L chloride) correspond to sodium concentrations of 149, 97 and 115 mg/L, respectively. These values exceed the maximum sodium concentration in the PKCA, indicating that no toxicological effects would be associated with the concentrations of sodium in the discharge.

As described in the section above with regard to chloride, laboratory reference toxicant tests with potassium chloride (Bailey et al., 2000) were more sensitive than data for sodium chloride (AMEC laboratory, unpublished data) by a factor of seven when presented on the basis of chloride. This suggests that potassium is primarily responsible for toxicity in *C. dubia* tests with KCl; the 50% effect concentration in these tests calculated on the basis of potassium was 100 ± 12 mg/L.

The US EPA Ecotox database was reviewed for other toxicity data associated with exposure to potassium chloride. The lowest reported 50% effect value was 61 mg/L, which was obtained from a 21-d survival and reproduction test using *D. magna* (Biesinger and Christensen, 1972). Concentrations of potassium in the PKCA (36 – 64 mg/L) will approach this most sensitive value under worst-case conditions.

Biesinger and Christensen (1972) also reported 21-d EC50 estimates for calcium (220 mg/L Ca^{2+}) and magnesium (125 mg/L Mg^{2+}) for *D. magna*, which were also the most sensitive values reported in the US EPA Ecotox database for their corresponding chloride salts. Concentrations of calcium in the PKCA (101 – 202 mg/L) will approach this effect level for calcium; concentrations of magnesium in the PKCA (175 – 206 mg/L) will exceed the value for magnesium by a maximum factor of 1.6.

Collectively, these data indicate that cladocerans, such as *D. magna* and *C. dubia*, are among the most sensitive species to elevated concentrations of major cations, and that the concentrations of major cations in the PKCA may approach or exceed those associated with adverse effects under worst-case conditions. However, even under worst-case concentrations, a two- to three-fold dilution of the cationic components of TDS present in the PKCA should be sufficient to remove the risk of adverse toxicological effects in the receiving environment.

4.3 Ion ratios

The ratios of cations present in the discharge are somewhat unusual. In natural waters, calcium concentrations typically exceed magnesium, and sodium typically exceeds potassium. However, the reverse is true in the case of this discharge. Calcium to magnesium ratios in natural waters typically range from 1.6:1 to 8:1 (Naddy et al., 2002) on a mass-balance basis. Conversely, in this discharge the ratios will range from approximately 1:1 to 1:2. Potassium is generally present at low concentrations in surface waters and generally well below the concentration of sodium (Stumm and Morgan, 1981), whereas in the discharge from the PKCA, potassium concentrations exceed sodium by up to a factor of two.

It should be noted that the fact that ratios between specific ions are somewhat different than most natural waterbodies does not imply that adverse effects would result. For example, at the EC50 for KCl reported by Biesinger and Christensen (1972) for *D. magna*, the sodium to potassium ratio was 1:60. Thus, this species was able to survive and reproduce normally in waters with potassium concentrations exceeding sodium by a considerable margin.

In general, the ratios of calcium to magnesium and sodium to potassium do not exceed a factor of two and, therefore, it would be unlikely that adverse toxicological responses would occur as a result.

4.4 Other effects

The lake systems associated with the Jericho Diamond mining project are very low in productivity, largely as a result of cold temperatures and low concentrations of nutrients. Consequently, the types of species that can occur in these lakes and their abundances are limited. Increasing the concentration of dissolved solids may result in improved production of some species, which may result in a change in the balance of species that are present; however, these effects are not associated with toxicology but, rather, ecology. While data are available on the response of oligotrophic systems to nutrient enrichment, there is limited information that can be used to reliably predict changes to community structure that are likely to result in response to an increase in TDS. Regardless, the concentrations of TDS predicted in the receiving environment, while different from those currently present in these lakes, are well within those associated with water bodies supporting healthy aquatic ecosystems.

5.0 DIFFERENCES IN CLADOCERAN POPULATIONS OBSERVED IN THE LONG LAKE CONTAINMENT FACILITY, EKATI MINE

A study conducted at the Ekati mine in 2003 demonstrated that cladoceran populations tended to increase with distance from the discharge (Rescan, 2004). In particular, larger populations of cladocerans were observed in Cell E relative to Cell D within the Long Lake Containment Facility. Because cladocerans are relatively sensitive to elevated concentrations of TDS, it is worthwhile evaluating whether this difference could have been related to elevated concentrations of TDS.

Samples from Cell D collected in the summer of 2003 had mean values of approximately 40 mg/L sulphate and 123 mg/L TDS. While these values were higher than those observed in Cell E (approximately 25 mg/L sulphate and 65 mg/L TDS), they are well within the range of tolerance of cladocerans for these parameters. In fact, standardized laboratory reconstituted water for culturing *C. dubia* and *D. magna* is typically prepared to moderately hard standards of 80 – 100 mg/L as $CaCO_3$, and involves addition of more than 200 mg/L of various salts, incorporating more than 80 mg/L of sulphate (USEPA, 2002). Thus, standardized culture water for two sensitive cladoceran species contains higher concentrations of sulphate and overall TDS than that observed in Cell D in the Long Lake Containment Facility. Thus, it appears highly unlikely that differences in cladoceran populations observed between Cell D and Cell E in the 2003 monitoring program at Ekati were a result of toxicological responses to sulphate or TDS.

It should be noted that the differences in community composition observed between Cell D and Cell E in Long Lake at Ekati were only measured on one occasion in 2003. Thus, the differences observed on that occasion may be related to the patchiness or temporal variability inherent in zooplankton populations. Alternatively, they could also be related to the presence of a trace contaminant associated with the discharge or an ecological shift in the balance of the populations associated with nutrient enrichment.

6.0 SUMMARY

From the available toxicity data for TDS and the projected dilution rates available in Lake C3 and Carat Lake, it appears highly unlikely that TDS associated with discharge from the PKCA pond will result in toxicological effects on organisms in the receiving lakes. Conservatively, a three-fold dilution of the effluent under average discharge conditions and a four-fold dilution under worst-case discharge conditions should provide sufficient dilution to remove the risk of any toxicological effects associated with the major ions contributing to TDS, and result in a TDS values of approximately 400 mg/L.

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