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MACKENZIE VALLEY ENVIRONMENTAL IMPACT REVIEW BOARD

28 February 2003

Mackenzie Valley Environmental Impact Review Board (MVEIRB)
Box 938, 5102 – 50th Avenue
Yellowknife, NT X1A 2N7

Attention: Glenda Fratton, Environmental Assessment Coordinator

Dear: Glenda

SUBJECT: Algal Modeling Update

Please accept the attached technical memo titled "Snap Lake Diamond Project – Algal Modeling Update" for submission to the Public Registry. This memorandum was compiled in response to issues raised by intervenors during the MVEIRB Technical Sessions.

Additionally, information contained within this memo should address the outstanding concerns identified by Indian and Northern Affairs Canada in their Request for Ruling to the Board dated 22 January 2003.

Should you have any questions, please feel free to contact the undersigned.

Sincerely,
SNAP LAKE DIAMOND PROJECT

ORIGINAL SIGNED BY

Robin Johnstone
Senior Environmental Manager

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TECHNICAL MEMORANDUM

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TO:	Robin Johnstone De Beers Canada Mining Inc.	**DATE:**	February 28, 2003
FROM:	Dawn Kelly and Rick Schryer	**JOB NO:**	03-1322-017/5405
Prepared By:	Mark Digel, Julia Tarnowski, Robert Mugo		
RE:	**SNAP LAKE DIAMOND PROJECT ALGAL MODELLING UPDATE**		

1.0 INTRODUCTION

Phosphorus concentrations in the treated mine-water discharge and their effect on primary productivity (algal concentrations) in Snap Lake received considerable attention at the Mackenzie Valley Environmental Impact Review Board (MVEIRB) Technical Sessions for the Snap Lake Diamond Project environmental assessment (EA). A breakout meeting at these sessions was held on the evening of November 28, 2002 to discuss this specific topic. The primary concern raised by intervenors was that the algal modelling in the environmental assessment report (EAR) might have underestimated total available phosphorus loadings to Snap Lake by only using orthophosphate concentrations and not including the remaining fraction of total dissolved phosphorus.

In response to these concerns, De Beers undertook a review of phosphorus in the mine water and prepared a technical memorandum providing an update of phosphorus loading to Snap Lake that included total and dissolved forms in addition to orthophosphate (Golder 2003), a copy of which is provided as Attachment 1. A follow-up meeting was held in Yellowknife with interested intervenors on February 10, 2003 to present the results of the phosphorus loading update and to agree on a path forward for resolving concerns over the effects of phosphorus loading on algal concentrations in Snap Lake. The results of a re-calibration of the Snap Lake algal model and sensitivity analyses were also presented and discussed. The February 10th meeting was advertised through the MVEIRB and all interested parties were invited to attend. Participants at the February 10th meeting included: De Beers- Colleen English; Golder Associates- Mark Digel; Dogrib Treaty 11 - Steve Wilbur; Gartner Lee Limited for the MVEIRB- Neil Hutchinson; Environment Canada- Anne Wilson; Fisheries and Oceans Canada- Dave Balint, Julie Dahl, and Marc Lange; Government of the Northwest Territories- Gavin More; Indian and Northern Affairs Canada - Sevn Bohnet, Francis Jackson, Don MacDonald, Kenn Raven; Mackenzie Valley Land and Water Board- Laurie Cordell; North Slave Metis Association- Bob Schelast; Yellowknives Dene First Nation- Tim Byers. Meeting notes have been provided to the MVEIRB for inclusion on the public record for the Snap Lake Diamond Project and have been included in this document as Attachment 2.

Phosphorus is the limiting nutrient in Snap Lake. Therefore, increases in phosphorus loading and specifically orthophosphate, which is the bioavailable form that algae can utilize as a nutrient, will result in increased algal concentrations. Because of the high level of solids removal that will be achieved in the water treatment plant, the discharge to Snap Lake will consist primarily of total dissolved phosphorus. Total dissolved phosphorus consists of orthophosphate, as well as other dissolved and colloidal forms. These other dissolved and colloidal forms of phosphorus may be refractory (non-reactive) and not contribute to algal growth in Snap Lake, or they may be labile, meaning they will react (mineralize) to form orthophosphate within Snap Lake. The main discussion at the February 10th meeting centred on the effect that dissolved phosphorus in the mine water discharge would have on algal productivity in Snap Lake. A number of discharge scenarios for re-modelling were mutually agreed upon at the February 10th meeting to evaluate the potential effect of different assumptions regarding the reactivity of dissolved phosphorus in the treated water discharge on algal concentrations in Snap Lake.

This technical memorandum presents the results of a recalibration of the Snap Lake algal model (Section 2) and a sensitivity study of key model parameters affecting predicted algal concentrations (Section 3). Predicted algal concentrations for potential discharge scenarios mutually agreed upon at the February 10th meeting are provided in Section 4. Conclusions of this algal modelling update are presented in Section 5 and reference citations are provided in Section 6.

The following abbreviations and definitions are used in this technical memorandum.

Chl a	Chlorophyll a, which is an indicator of algal biomass
d	day
DP	Dissolved phosphorus, which is calculated as the difference between TDP and OrthoP.
g	gram
L	litre
mg	milligram
orgP	Organic phosphorus, which is a measure of phosphorus adsorbed to or incorporated into organic molecules.
orthoP	Orthophosphate, which is the form of phosphorus that algae can utilize as a nutrient. The orthoP concentration is derived from a colorimetric analysis of an unfiltered and unpreserved sample.
PP	Particulate phosphorus, which is calculated as the difference between TP and TDP.
TDP	Total dissolved phosphorus. The concentration of phosphorus derived from a colorimetric analysis of a sample that has been filtered through a 0.45 micron filter and digested in a strong acid. TDP includes orthoP, as well as other dissolved and colloidal forms.
TP	Total phosphorus, which represents the total concentration of all dissolved, colloidal and particulate forms of phosphorus. The TP concentration is derived from a colorimetric analysis of an unfiltered sample that has been digested in a strong acid.
µg	microgram

2.0 RE-CALIBRATION OF NUTRIENT MODEL

The potential impact of treated water discharge on the nutrient and algal concentrations in Snap Lake was assessed during the EA using the RMA suite of models (De Beers 2002). The Snap Lake algal model was calibrated to baseline nutrient and chlorophyll a data measured in the lake during the 1999 baseline water quality program (De Beers 2002).

Following comments and issues arising out of the EA Technical Sessions in November of 2002, further review of the modelling exercise was initiated to evaluate key parameters responsible for model predictions. As part of this exercise, the eutrophication model was re-calibrated using a new set of values for the key parameters responsible for nutrient-algal interactions. This recalibration used lower settling and benthic release terms, which are more representative of expected conditions in arctic lakes.

2.1 Methods

A literature search was performed to review and refine the ranges of the key model parameters influencing nutrient-algae interactions in Snap Lake. There is a paucity of data in the literature with respect to water quality modelling studies for arctic lakes. Although the scientific literature contains various studies documenting limnological and trophic status studies of lakes in the NWT, very few of these studies provide the kind of information necessary for the simulation of algal dynamics in Snap Lake. Values for the key modelling parameters were determined based on the available literature for temperate lakes with trophic status similar to that of Snap Lake (i.e., oligo-mesotrophic), supplemented by best professional judgment, as necessary. The following key parameters were adjusted during the re-calibration exercise:

- conversion factor from g of chlorophyll a to mg of algae;
- maximum algae growth rate;
- algal settling rate;
- orgP decay (mineralization) rate;
- benthos source rate for orthoP release; and
- orthoP loss rate, which accounts for adsorption and settling.

The original and updated values for the model parameters can be found in Table 1. The rationale for the recalibrated model rates and coefficients is provided below.

The conversion factor from g of chlorophyll a to mg of algae has a widely accepted range of values from 20 to 50 (Bowie et al. 1985). This value tends to increase with greater clarity of water because there is a better penetration of sunlight into the water column. The re-calibration adjusted this conversion factor from 15 to 30. Higher values are more representative of oligotrophic arctic lakes; however, baseline water clarity in Snap Lake is lower than in more oligotrophic lakes (e.g., Lac de Gras).

Table 1 Original and Re-calibrated Model Parameters

Parameters					
Algae	**Original EA Value**	**Re-calibrated Value**	**Units**	**Range of Values**	**Source[a]**
Conversion factor ug Chla to mg Algae	15	**30**		20-50	USEPA
Fraction of algal biomass that is N	0.085	0.085			USEPA
Fraction of algal biomass that is Org-P	0.012	0.012			USEPA
O2 production rate per unit of algal photosynthesis	1.6	1.6	mgO/mgA		model
O2 uptake rate per unit of algae respired	2	2	mgO/mgA		model
Algal growth rate temperature factor	1.03	1.03			**calibrated**
Algal respiration rate temperature factor	1.03	1.03			**calibrated**
Algal settling rate temperature factor	1.03	1.03			**calibrated**
Preference for NH3-N	0.9	0.9			model
Light half-saturation coefficient	0.0168	0.0168	kJ/m2/sec		USEPA
N half-saturation coefficient	0.2	0.2	mg/L		USEPA
Phosphate half-saturation coefficient	0.02	0.02	mg/L		USEPA
Non-algal portion of light extinction coefficient	0.38	0.38	1/m		model
Linear algal self-shading coefficient	0.0088	0.0088			model
Non-linear algal self-shading coefficient	0.054	0.054			model
Maximum algal growth rate	1.87	**1.75**	1/day	1.0-3.0	**calibrated**
Algal respiration rate	0.08	0.08	1/day		**calibrated**
Algal settling rate	0.08	**0.01**	m/day	0.01-0.6	**calibrated**
Nitrogen					
O2 uptake rate per unit of NH3-N oxidation	3.5	3.5	mgO/mgN		model
O2 uptake rate per unit of NO2-N oxidation	1.2	1.2	mgO/mgN		model
Temperature coefficient for Org-N decay	1.12	1.12			**calibrated**
Temperature coefficient for Org-N settling	1.12	1.12			**calibrated**
Temperature coefficient for NH3-N decay	1.11	1.11			**calibrated**
Temperature coefficient for NH3-N benthic sources	1.11	1.11			**calibrated**
Temperature coefficient for NO2-N decay	1.11	1.11			**calibrated**
First order nitrification inhibition	0.6	0.6	(mg/L)-1		model
Org-N					
Org-N to NH3-N conversion rate	0.0025	0.0025	1/day		**calibrated**
Org-N settling rate	0	0	1/day		**calibrated**
NH3					
NH3-N to NO2-N conversion rate	0.03	0.03	1/day		**calibrated**
Benthos source rate for NH3-N	0.7	0.7	mg/m^2 day		**calibrated**
NO2					
NO2-N to NO3-N conversion rate	3	3	1/day		**calibrated**
Phosphorus					
Temperature coefficient for Org-P decay	1.06	1.06			**calibrated**
Temperature coefficient for Org-P settling	1.06	1.06			**calibrated**
Temperature coefficient for PO4 benthic sources	1.06	1.06			**calibrated**
Org-P					
Org-P decay rate	0.0072	**0.003**	1/day	0.001-0.14	**calibrated**
Org-P settling rate	0	0	1/day		**calibrated**
PO4					
Benthos source rate for PO4-P	0.48	0	mg/m^2 day	0.1-1.2	**calibrated**
PO4-P decay rate	0.012	0	1/day	0.01-0.12	**calibrated**
Reaeration					
Use Churchill Formula					
DO-BOD					
Temperature coefficient for BOD decay	1.04	1.04			**calibrated**
Temperature coefficient for BOD settling	1.04	1.04			**calibrated**
Temperature coefficient for DO benthic demand	1.04	1.04			**calibrated**
Temperature coefficient for DO reaeration rate	1.04	1.04			**calibrated**
BOD					
Decay rate for BOD	0.3	0.3	1/day		**calibrated**
BOD settling rate	0	0	m/day		**calibrated**
DO					
Oxygen demand rate for sediment	200	200	mg/m^2 day		**calibrated**

Maximum algal growth rates reported in literature vary between 1.0-3.0 d^{-1} (Bowie et al. 1985). During the original calibration, the maximum growth rate (obtained by calibration) was 1.87 d^{-1}. Through the re-calibration of other parameters, this value was adjusted to 1.75 d^{-1}, which falls within the standard range of the values reported in literature.

The algal settling rate tends to range from 0.01 to 0.6 m/d (Bowie et al. 1985). The original calibrated value for this parameter was 0.08 m/d. The low end of the range, 0.01 m/d, was chosen for the re-calibration. By so doing, the majority of the algae is retained in the water column. This conservative assumption increases the amount of biomass available to undergo decay (and thus nutrient release and cycling) in the water column.

The rate of decay of orgP to orthoP, or the rate of mineralization of orgP, was originally set to 0.0072 d^{-1}. Through the re-calibration process, this value was reduced to 0.003 d^{-1}. No values for orgP decay in oligotrophic arctic lakes were available; however, the value selected for the re-calibration is within the range used for other lakes (0.001-0.14 d^{-1}; Bowie et al. 1985).

The benthic source rate for orthoP release was originally set at 0.48 mg/m^2 day. Benthic release rates vary by several orders of magnitude, depending on the trophic status of the lake (and also depending on whether *in-situ* or laboratory studies were used to obtain values). Significant phosphorus release from sediments is usually associated with bottom water anoxia in oligotrophic lakes, which results in reductive dissolution of Fe and Mn oxyhydroxides, with subsequent release of sorbed orthoP. The trophic status of Snap Lake is oligotrophic to lower mesotrophic and anoxic conditions are not expected to occur extensively under baseline or EA conditions. Under these conditions, it is expected that sediments are a *sink* of phosphorus from the water column and not a source of phosphorus to the water column. Therefore, the benthic release term in the re-calibrated model was set at 0.

The orthoP loss rate, or adsorption of orthoP to sediments, was set at 0, in order to conservatively maintain all the bioavailable phosphorus in the water column. A reported range for the rate of adsorption of orthoP is 0.01 to 0.12 d^{-1} (Chapra 1997). Laboratory studies have shown that there is no detectable adsorption of orthoP below a pH of 8.5 and a water column phosphorus concentration of approximately 10 mg/L (typical conditions in Snap Lake) (Olila and Reddy 1995). An orthoP loss rate of 0.012 d^{-1} was used during the original baseline calibration.

2.2 Results

Observed baseline conditions, original baseline model results and re-calibrated baseline results are summarized in Table 2. The results of the original and re-calibrated EA runs are summarized in Table 3.

Table 2 Comparison of Original Baseline and Re-calibrated Baseline Results

Parameter	Units	Observed Values (1999)			Original Baseline Calibration			Alternate Baseline Calibration		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Total Phosphorus	μg/L	8	9	26	7	10	13	9	9	9
Organic P	μg/L	6	7	24	6	8	10	6	7	8
Orthophosphate	μg/L	2	2	2	1	2	3	1	2	3
Chlorophyll a	μg/L	0.4	0.8	1.2	0.2	0.9	1.8	0.1	0.8	1.5

Table 3 Comparison of Original EA Run and Re-calibrated EA Run

Parameter	Units	Original Calibration EA Run[a]			Alternate Calibration EA Run[a]		
		Min	Mean	Max	Min	Mean	Max
Total Phosphorus	μg/L	3	5	7	12	12	13
Orthophosphate	μg/L	2	2	2	1	2	3
Chlorophyll a	μg/L	0.6	1.3	2.6	0.6	1.5	2.3

[a] Years 17-19 were used to represent the maximum effect of the Snap Lake Diamond Project on nutrients and chlorophyll a in Snap Lake.

The algal model was successfully calibrated with two different sets of model parameters, which indicates that there is no unique combination of parameters for the baseline calibration. In the original EA calibration, the relatively high benthic source rate for orthoP release had to be balanced by a relatively high orthoP loss rate. In the alternate calibration, both of these rates were lowered; however, they are still in balance.

The reduction of the orthoP loss rate in the alternate calibration results in most phosphorus being retained in the water column. Consequently, the treated water discharge results in an increase in TP concentrations (orgP + orthoP) in Snap Lake in contrast to the EA calibration, which predicted decreased TP concentrations in Snap Lake. The predicted algal concentrations in Snap Lake under EA conditions are comparable for the original and alternate calibrations (Table 3). Predicted orthoP concentrations remained consistently low, indicating that phosphorus limited conditions occurred with both calibrations. These results indicate that, while the total phosphorus concentrations are sensitive to different calibrations, the orthoP and chlorophyll a concentrations are not sensitive.

3.0 SENSITIVITY ANALYSIS

A number of simulations were run to assess the sensitivity of model simulations to changes in parameter values. For each of these runs, a single model reaction rate or model coefficient was increased or decreased. The sensitivity of the model simulations to the five parameters discussed in Section 2 (parameters primarily associated with phosphorus and chlorophyll a concentrations in the lake) was assessed to provide a better understanding of the impact of changing parameter values on model predictions. The values of the parameters tested in the sensitivity analysis were determined based on the ranges obtained from literature as discussed in Section 2.

Predicted phosphorus and algal concentrations are quite sensitive to the rate of benthic release of orthoP (Table 4) and the orthoP loss (adsorption) rate (Table 5). The results of the model recalibration (Section 2) showed that the calibration requires a balance between these two sensitive parameters. Predicted phosphorus and algal concentrations are less sensitive to changes in the algal settling rate (Table 6), the orgP mineralization rate (Table 7) and the maximum algal growth rate (Table 8).

Table 4 Sensitivity of EA Results to PO_4 Benthic Source Rate (Calibration Rate 0.0 mg/m^2/d)

Parameter	Units	Re-Calibrated EA			PO_4 Benthic Source – 0.1			PO_4 Benthic Source – 0.4		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
TP	µg/L	12	12	13	24	24	25	56	59	63
PO_4	µg/L	1	2	3	1	1	2	1	2	3
Chl a	µg/L	0.6	1.5	2.3	1.1	2.1	3.8	4.1	4.8	5.7

Table 5 Sensitivity of EA Results to PO_4 Loss (Adsorption) Rate (Calibration Rate 0.0/d)

Parameter	Units	Re-Calibrated EA			PO_4 Adsorption – 0.01			PO_4 Adsorption – 0.1		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
TP	µg/L	12	12	13	3	3	4	2	3	3
PO_4	µg/L	1	2	3	0	1	1	0	0	0
Chl a	µg/L	0.6	1.5	2.3	0.0	0.1	0.1	0.0	0.0	0.0

Table 6 Sensitivity of EA Results to Algal Settling Rate (Calibration Rate 0.01 m/d)

Parameter	Units	Re-Calibrated EA			Algal Settling – 0.1			Algal Settling – 0.6		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
TP	µg/L	12	12	13	9	10	10	7	8	8
PO_4	µg/L	1	2	3	1	2	3	3	4	4
Chl a	µg/L	0.6	1.5	2.3	0.5	1.0	1.5	0.1	0.4	0.6

Table 7 Sensitivity of EA Results to Organic Phosphorus Mineralization Rate (Calibration rate 0.003/d)

Parameter	Units	Re-Calibrated EA			Org-P min. Rate – 0.001			Org-P min. Rate – 0.01		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
TP	µg/L	12	12	13	12	13	13	10	11	11
PO_4	µg/L	1	2	3	1	2	2	1	1	2
Chl a	µg/L	0.6	1.5	2.3	0.2	0.7	1.2	1.3	2.2	3.9

Table 8 Sensitivity of EA Results to Maximum Algae Growth Rate (Calibration rate 1.75/d)

Parameter	Units	Re-Calibrated EA			Max. Algae Growth – 1.0			Max. Algae Growth – 3.0		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
TP	µg/L	12	12	13	12	12	13	12	12	12
PO_4	µg/L	1	2	3	3	4	5	1	1	1
Chl a	µg/L	0.6	1.5	2.3	0.2	1.2	1.8	0.5	1.0	1.9

4.0 POTENTIAL DISCHARGE SCENARIOS

4.1 Methods

The algal modelling results presented in the EA report were based on orthoP being the only form of phosphorus in the treated water discharge that would contribute to increased algal concentrations in Snap Lake. The remaining forms of phosphorus (PP and DP) in the treated water discharge would consist primarily of particulate, colloidal and dissolved mineral phosphates, which were assumed to be non-reactive (i.e., would not mineralize to orthoP) within Snap Lake. The reactivity (bioavailability) of particulate and colloidal mineral phosphates is known to be very low (Grobbelaar and House 1995); however, there does not appear to be any information on the reactivity of dissolved mineral phosphates in groundwater.

To evaluate the response of algae (total phytoplankton) in Snap Lake to different levels of reactivity of DP in the treated water discharge to Snap Lake, a number of different discharge scenarios were mutually agreed upon at the February 10th meeting. These scenarios included DP as either orthoP (immediately available) or as orgP (labile). To address concerns that expected concentrations in the EA may have underestimated orthoP and DP in the treated water discharge, additional scenarios were mutually agreed upon based on increasing concentrations by one standard deviation above expected concentrations.

The five different scenarios and a total of nine model runs mutually agreed upon by intervenors and De Beers at the February 10th meeting, are as follows:

1. **EA Case.** orthoP is the only bioavailable form of phosphorus in the treated water discharge. (EA Case).

2. **EA Case plus a percentage of DP as orthoP.** Three percentages were modelled, 25%, 50% and 100%. All concentrations were based on expected concentrations from the EA. (EA Case + 0.25 DP as orthoP, EA Case + 0.5 DP as orthoP and EA Case + 1.0 DP as orthoP)
3. **EA Case plus a percentage of DP as orgP.** Three percentages were modelled, 25%, 50% and 100%. All concentrations were based on expected concentrations from the EA. (EA Case + 0.25 DP as orgP, EA Case + 0.5 DP as orgP and EA Case + 1.0 DP as orgP)
4. **EA Case, but run at +1 standard deviation above expected concentrations.** (EA Case with +1SD on concentrations)
5. **EA Case plus 50% of DP as OrthoP, with all site water concentrations at +1 standard deviation above expected concentrations.** (EA Case + 0.5 DP as orthoP with + 1SD on concentrations)

It was further agreed that all simulations would be run using the revised (alternate) calibration, because model rates and coefficients, and simulation results for the revised calibration, are more representative of conditions expected in Snap Lake.

4.2 Results

For each simulation, the Snap Lake algal model was run for the entire period of construction and operations. Results are summarized for years 17 through 19 to be consistent with the EA report and because these years are representative of maximum predicted algal concentrations in Snap Lake. Average discharge concentrations for each simulation run are summarized in Table 9. The phosphorus loading that was modelled in the EA was based on the concentration of orthoP in the treated mine water, but also included an assumed orgP concentration of 7 μg/L (based on the baseline orgP concentration in Snap Lake). This assumed orgP loading was included to ensure that potential recharge of orgP into the minewaters would not be underestimated. Because the majority of orgP is expected to be in a particulate or surface reactive form, the assumed orgP concentration resulted in conservatively high phosphorus loadings. For consistency with the EA Case, this assumed orgP concentration was used for all scenarios where DP was assumed to be OrthoP.

Table 9 Mean Phosphorus Discharge Concentrations and Loadings to Snap Lake, Years 17-19

Scenario	Discharge Concentration (ug/L)		Discharge Loading (kg/d)	
	OrgP[(a)]	OrthoP	OrgP	OrthoP
EA Case	7.0	9.6	0.17	0.24
EA Case + 0.25 DP as OrthoP	7.0	14.5	0.17	0.36
EA Case + 0.5 DP as OrthoP	7.0	19.3	0.17	0.48
EA Case + 1.0 DP as OrthoP	7.0	29	0.17	0.71
EA Case + 0.25 DP as OrgP	4.8	9.6	0.12	0.24
EA Case + 0.5 DP as OrgP	9.7	9.6	0.24	0.24
EA Case + 1.0 DP as OrgP	19.3	9.6	0.48	0.24
EA Case with +1SD Conc.	7.0	18	0.17	0.44
EA Case + 0.5 DP as OrthoP with +1SD Conc.	7.0	27.6	0.17	0.68

(a) In all cases, except 0.25DP, 0.5DP and 1.0DP as OrgP, the concentration of orgP in the discharge is equal to the Snap Lake background concentration of 7 µg/L. For all other cases, the concentration of DP predicted from GoldSim was used.

The predicted mean open-water concentrations of phosphorus and chlorophyll a in Snap Lake for years 17 through 19 are summarized in Table 10. The mean open-water chlorophyll a concentration is highly correlated with the total loading of phosphorus (Figure 1). The predicted chlorophyll a concentrations in Snap Lake appear to be highly dependent on the total loading of phosphorus ($r^2 = 0.97$), with no apparent distinction on whether the phosphorus is included as orthoP or orgP. The form of DP could affect the predicted algal concentration if the DP was labile but mineralized significantly more slowly than orgP.

Table 10 Mean Open Water Simulation Results, Years 17-19

Scenario	Mean Concentration (ug/L)		
	Total Phosphorus	Ortho-phosphate	Chlorophyll a
Baseline	9	2	0.8
EA Case	13	1	1.6
EA Case + 0.25 DP as OrthoP	16	1	1.8
EA Case + 0.5 DP as OrthoP	18	1	2.0
EA Case + 1.0 DP as OrthoP	23	1	2.3
EA Case + 0.25 DP as OrgP	12	2	1.5
EA Case + 0.5 DP as OrgP	15	1	1.7
EA Case + 1.0 DP as OrgP	19	1	2.0
EA Case with +1SD Conc.	17	1	2.0
EA Case + 0.5 DP as OrthoP with +1SD Conc.	22	1	2.2

Minimum, mean and maximum open water concentrations of total phosphorus and chlorophyll a in Snap Lake are compared for the different simulation runs in Figures 2 and 3, respectively. Time-series plots of phosphorus and chlorophyll a concentrations for years 17 through 19 are provided for each simulation run in Figures 4 through 12. The pattern of phosphorus concentrations is the same in each scenario regardless of whether the loading is as orthoP or orgP. Predicted total bioavailable phosphorus (orgP + orthoP) concentrations remain relatively constant and the majority of the phosphorus pool is orgP. OrthoP is lowest during the open water period when algal growth is highest and highest in the winter when algal growth is lowest. OrgP follows an opposite pattern to orthoP.

Conservative assumptions were incorporated into all of the discharge scenarios, including the original EA scenario. These assumptions are listed below:

- All of the discharge scenarios incorporated a conservative calculation of groundwater recharge of phosphorus from Snap Lake. The site water quality model uses a simple mixing calculation without accounting for algal uptake, which overestimates the DP and orthoP concentrations in groundwater recharge from Snap Lake to the underground mine workings. Algal uptake will substantially lower the concentrations of DP and orthoP in Snap Lake, converting it to orgP. OrgP in Snap Lake will be largely particulate or surface reactive (i.e., will adsorb to particles) which will be retained in the lake bottom sediments, and will be effectively filtered out of the groundwater recharge from Snap Lake.
- DP in the underground mine water will consist of dissolved and colloidal mineral phosphates, some fraction of which will not be bioavailable (i.e., will not be reactive in Snap Lake).
- All of the cases where DP was assumed to be orthoP, include an assumed orgP concentration of 7 µg/L. For the reasons stated above, groundwater recharge from Snap Lake is not expected contain any substantive concentrations of orgP.

The selection of a representative discharge scenario is complicated by the uncertainty in the bioavailability of DP in the treated water discharge. While the available soil science literature indicates that the reactivity (bioavailability) of particulate and colloidal mineral phosphates is very low (Grobbelaar and House 1995), there is no information on the reactivity of dissolved mineral phosphates in groundwater.

The bioavailable phosphorus loading from the highest loading case (EA Case + 1.0 DP as orthoP) is higher than what could occur (i.e., is overly conservative) because it assumes that every one of the conservative assumptions listed above actually occurs. By assuming no phosphorus uptake or retention in Snap Lake, that all TDP (DP + orthoP) is bioavailable, and an incremental increase of 7 µg/L of orgP in the discharge, the scenario "EA Case + 1.0 DP as orthoP" results in a greater loading of bioavailable P than the total amount of TDP that is available in the system.

The loading scenario "EA Case + 1.0 DP as orgP" is a more representative upper estimate of bioavailable phosphorus loading in the treated water discharge. The bioavailable phosphorus loading from this scenario is the same as for the highest loading scenario (EA Case + 1.0 DP as orthoP), but without the incremental addition of 7 µg/L of orgP to the discharge. Consequently, the scenario "EA Case + 1.0 DP as orgP" represents the maximum loading of bioavailable phosphorus. This case is still conservative because it does not account for any uptake and retention of phosphorus in Snap Lake, and it assumes all TDP is bioavailable.

The phosphorus loading and predicted chlorophyll a concentrations for the scenario "EA Case + 0.5 DP as orthoP" is similar to the scenario "EA Case + 1.0 DP as orgP". The loadings are similar because the 50% reduction in DP for scenario "EA Case + 1.0 DP as orgP" is offset by the 7 µg/L of orgP that was added to the discharge. The scenario "EA Case + 0.5 DP as orthoP", therefore, has bioavailable phosphorus loadings that are similar to scenario "EA Case + 1.0 DP as orgP", but with a lower proportion of orthoP and a higher proportion of orgP. Both cases provide representative upper estimates of bioavailable phosphorus loading in the treated water discharge.

The phosphorus loading and predicted chlorophyll a concentrations for the scenario "EA Case with + 1SD on concentrations" are comparable to the scenarios "EA Case + 0.5 DP as orthoP" and the "EA Case + 1.0 DP as orgP". This scenario (EA Case with + 1SD on concentrations) illustrates that increasing orthoP concentrations in the discharge by one standard deviation is approximately equivalent to assuming that all DP is bioavailable and that there is no reduction in orgP concentrations in groundwater recharge from Snap Lake.

The scenario "EA Case with 0.5 DP as orthoP with +1SD concentrations" represents the maximum potential estimate of bioavailable phosphorus loading from the treated water discharge. This case is similar to the upper estimate cases, except that it incorporates an additional level of conservatism by assuming that all concentrations are one standard deviation higher than expected values.

The EA Case does not include DP in the treated discharge on the basis that DP will consist of dissolved and colloidal mineral phosphates that will not be bioavailable in Snap Lake. This makes this scenario less conservative than the other scenarios that were modelled. The EA Case scenario does, however, include the other conservative assumptions that are common to the discharge scenarios (i.e., increase of 7 µg/L of orgP, and no reduction of orthoP resulting from algal uptake in Snap Lake). On balance, the EA Case provides a good estimate of the expected loading of bioavailable phosphorus from the treated water discharge. The remaining scenarios (EA Case + 0.25 DP as OrthoP, EA Case + 0.5 DP as OrthoP, EA Case + 0.25 DP as OrgP, EA Case + 0.5 DP as OrgP) are intermediate between the original EA Case and the upper estimate cases.

Predicted mean, open water phosphorus concentrations (years 17 to 19) increase from 13 µg/L for the EA Case to 16 to 18 µg/L for the upper estimate loading cases and to 22 µg/L for the maximum potential loading case. These concentrations fall within the lower to middle range of the mesotrophic conditions (11 to 30 µg/L). Predicted mean, open water chlorophyll a concentrations (years 17 to 19) increase from 1.6 µg/L for the EA Case to 2.0 µg/L for the upper estimate loading cases and to 2.2 µg/L for the maximum potential loading case. These concentrations fall within the range of the oligotrophic conditions (<2.5 µg/L).

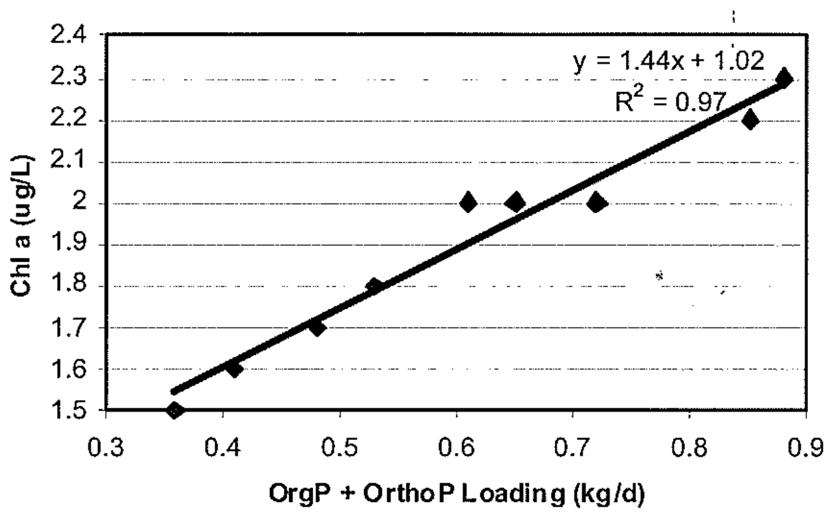

Figure 1 Correlation of total loading of orgP and orthoP from treated water discharge with predicted mean, open water concentration of chlorophyll a in Snap Lake

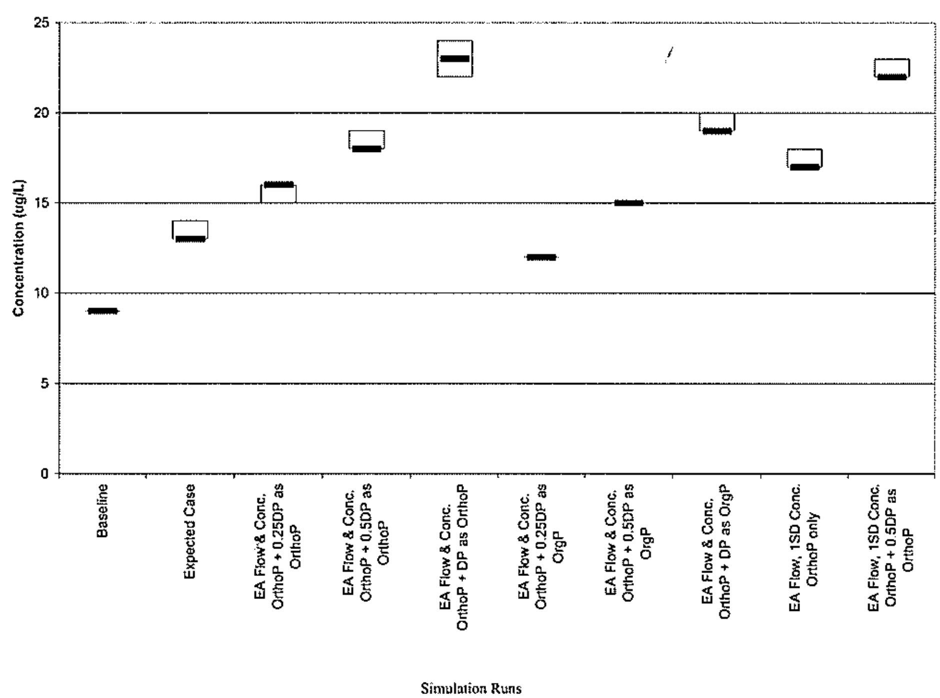

Figure 2 Minimum, mean and maximum simulated total phosphorus (orthoP + orgP) concentrations in Snap Lake for each simulation run

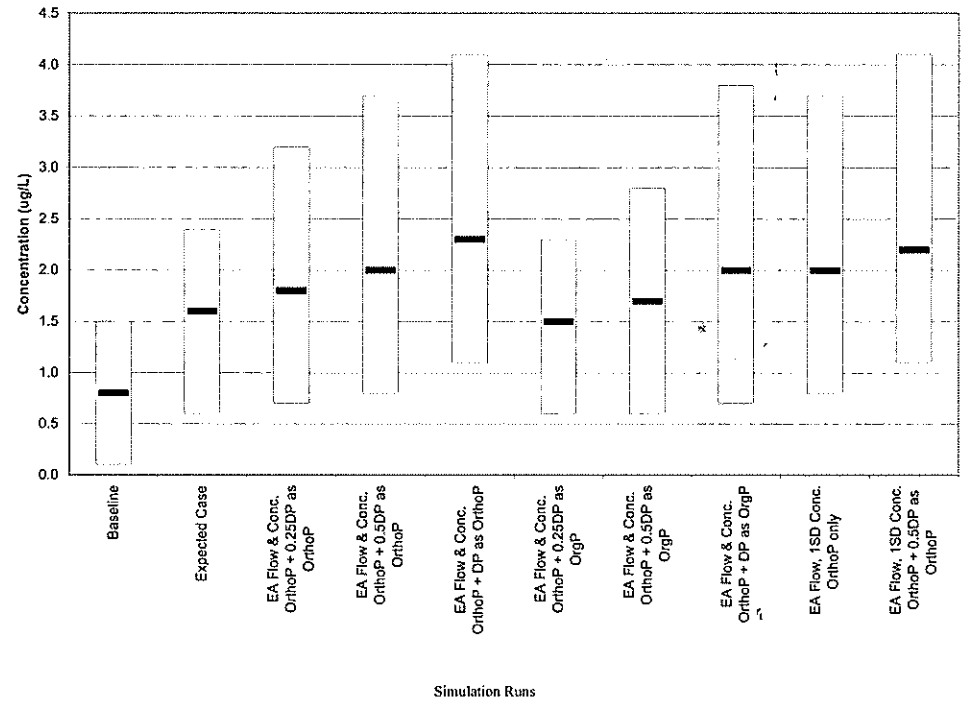

Figure 3 Minimum, mean and maximum simulated chlorophyll a concentrations in Snap Lake for each simulation run

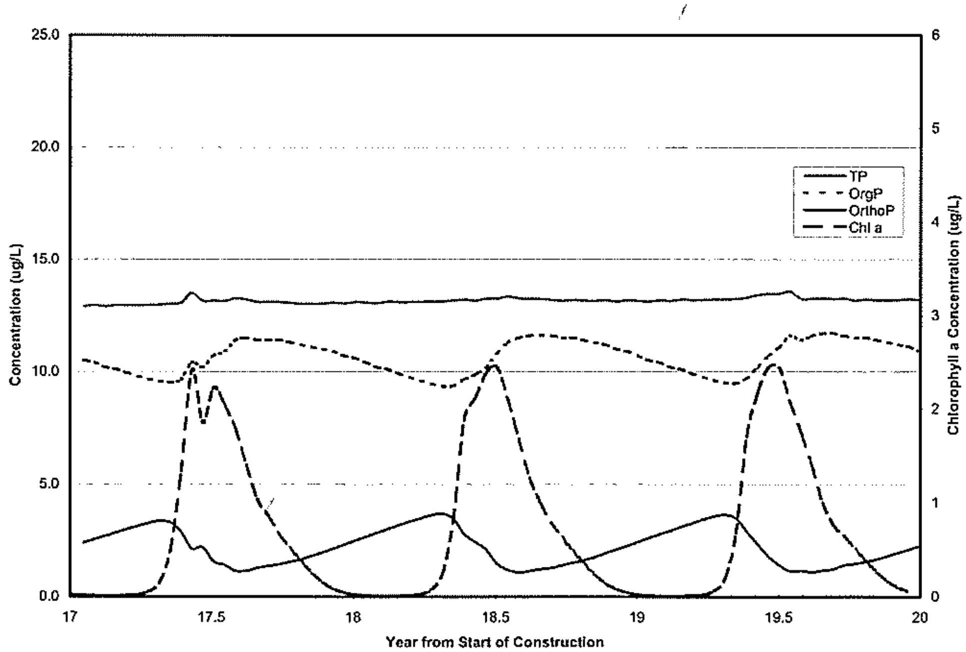

Figure 4 Simulated Phosphorus and Chlorophyll a Concentrations for Year 17-20 – EA Case

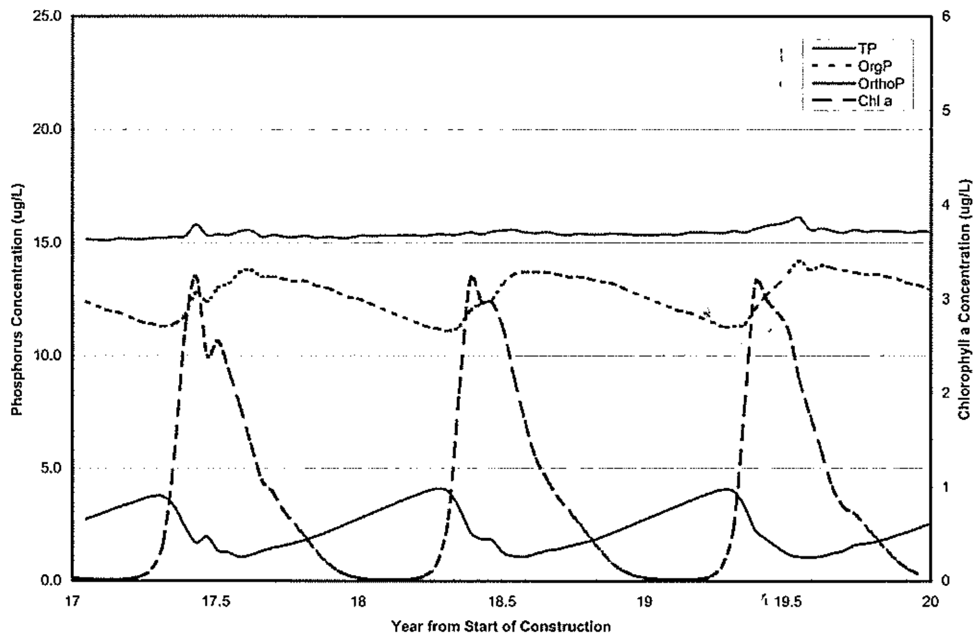

Figure 5 Simulated Phosphorus and Chlorophyll a Concentrations for Year 17-20 – EA Case + 0.25 DP as OrthoP

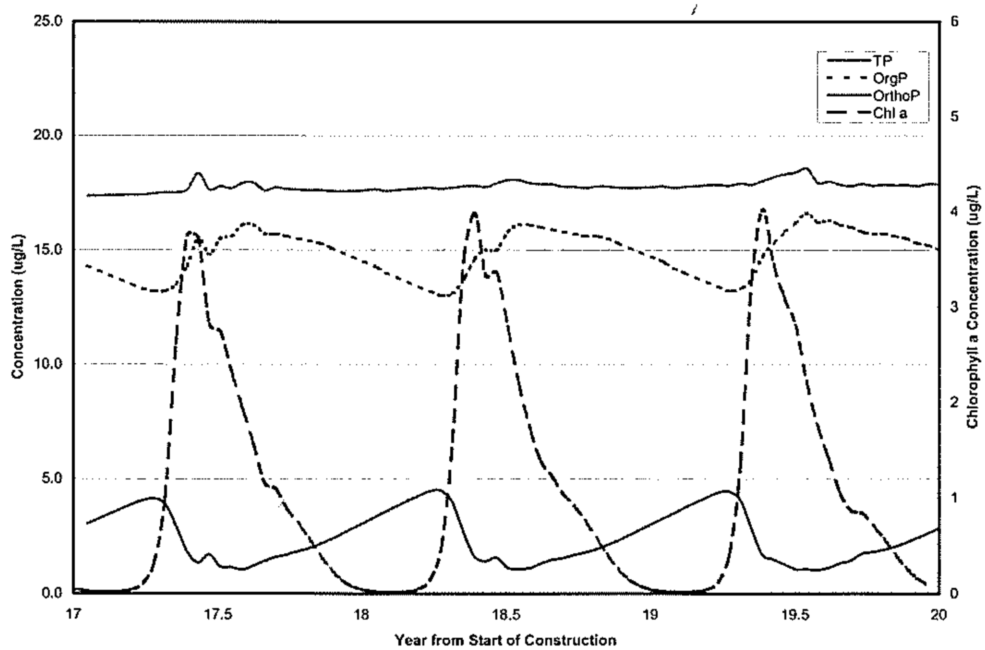

Figure 6 Simulated Phosphorus and Chlorophyll a Concentrations for Year 17-20 – EA Case + 0.5 DP as OrthoP

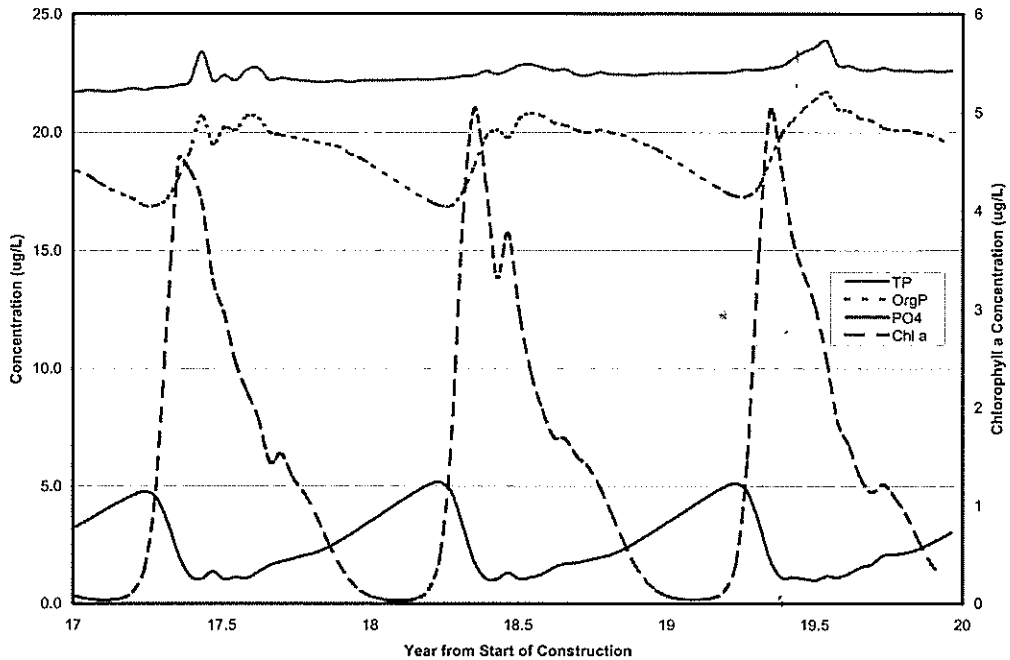

Figure 7 Simulated Phosphorus and Chlorophyll a Concentrations for Year 17-20 – EA Case + 1.0 DP as OrthoP

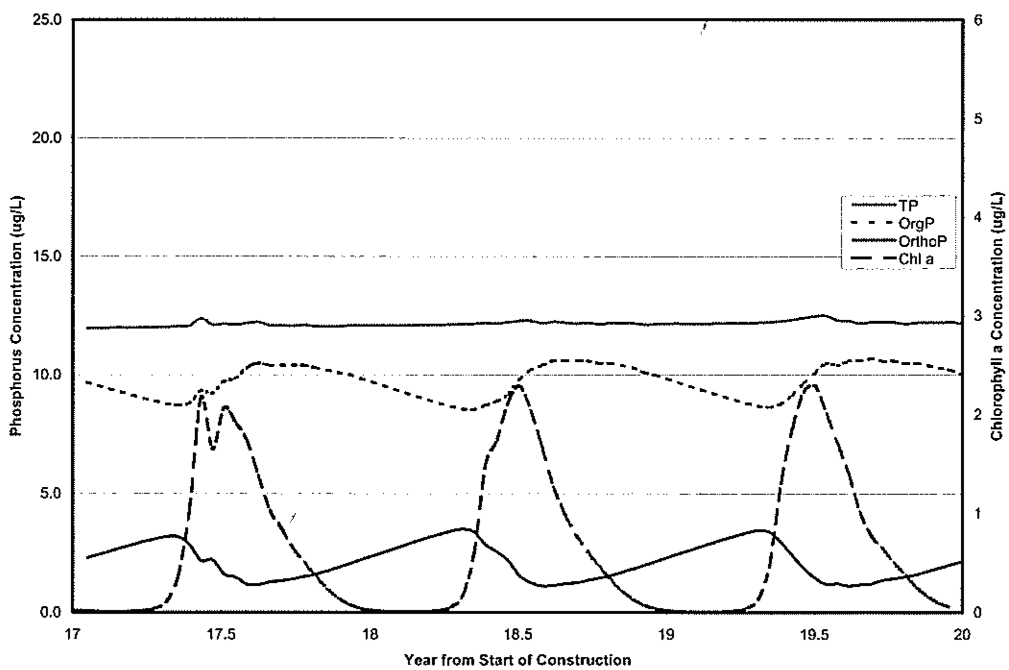

Figure 8 Simulated Phosphorus and Chlorophyll a Concentrations for Year 17-20 – EA Case + 0.25 DP as OrgP

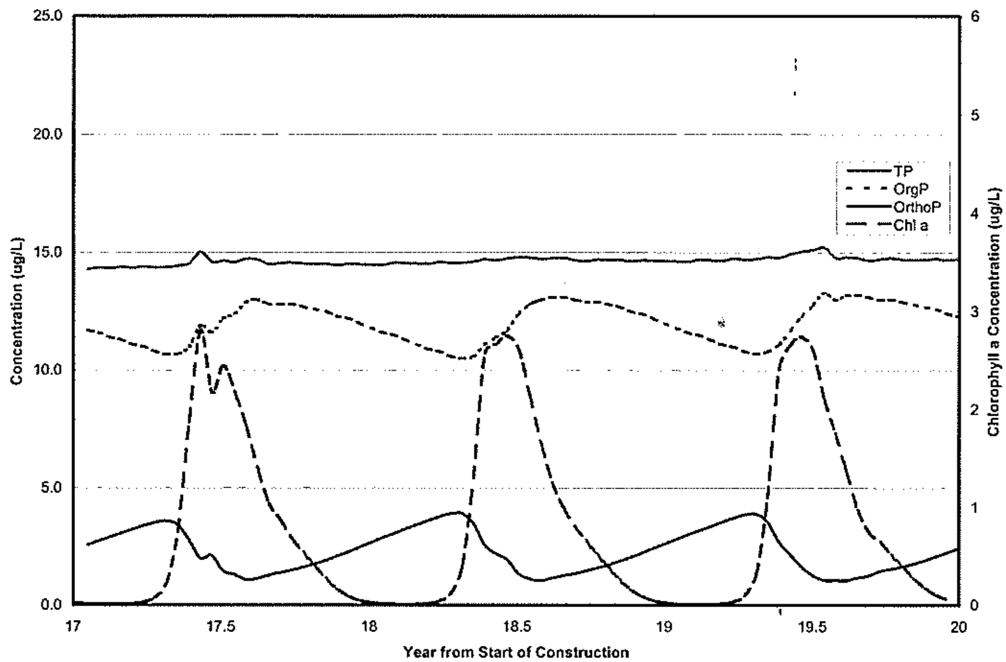

Figure 9 Simulated Phosphorus and Chlorophyll a Concentrations for Year 17-20 – EA Case + 0.5 DP as OrgP

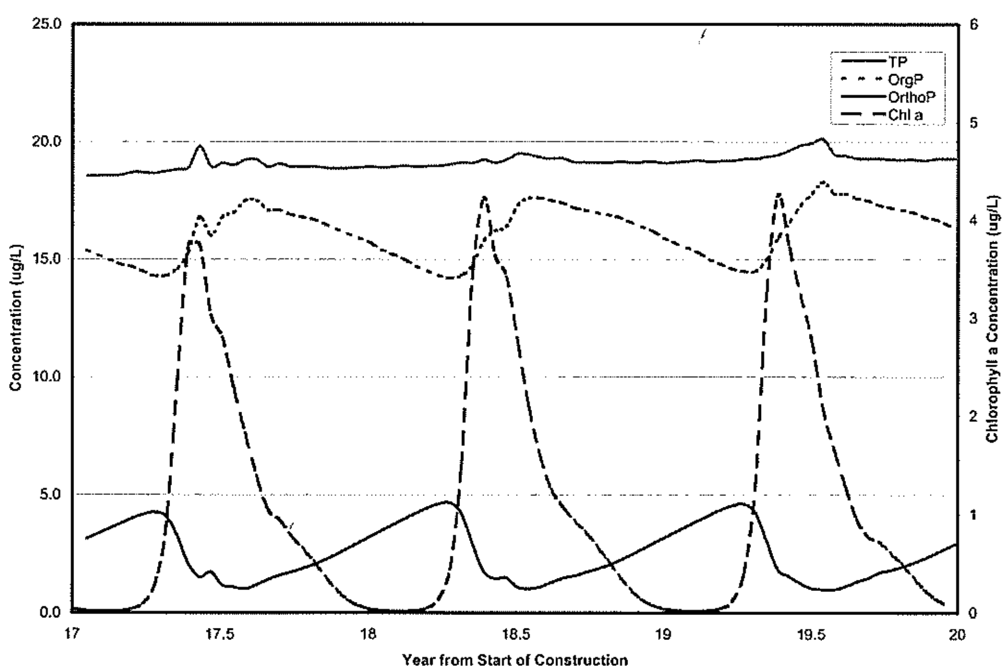

Figure 10 Simulated Phosphorus and Chlorophyll a Concentrations for Year 17-20 – EA Case + 1.0 DP as OrgP

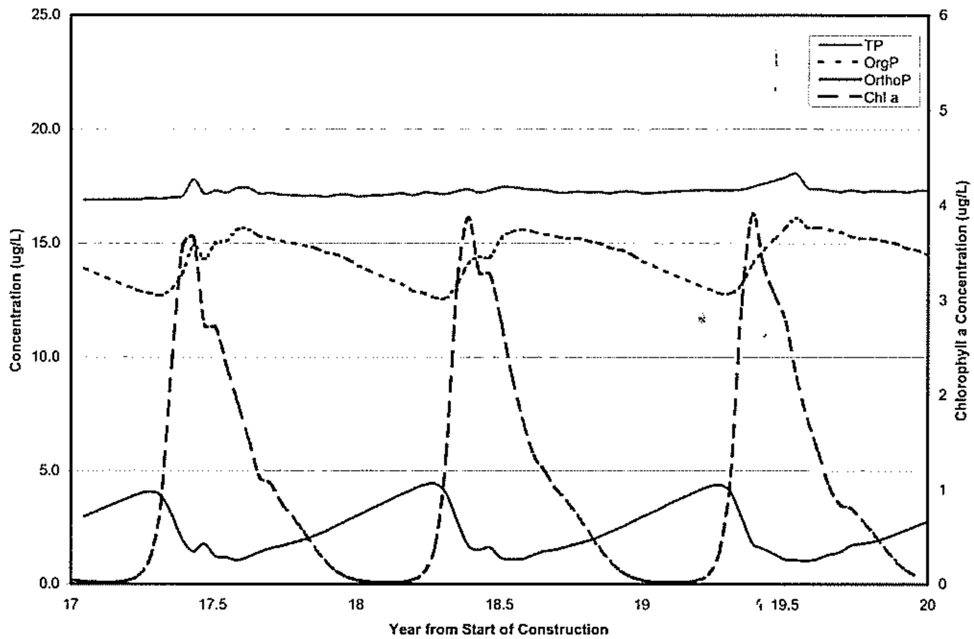

Figure 11 Simulated Phosphorus and Chlorophyll a Concentrations for Year 17-20 – EA Case with +1 SD Increase in Concentrations

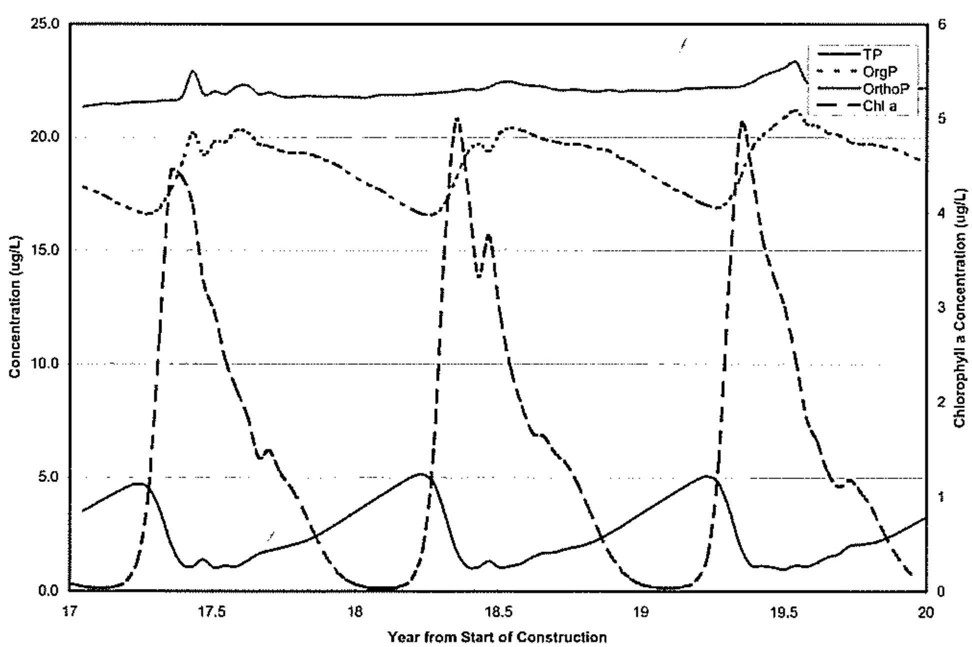

Figure 12 Simulated Phosphorus and Chlorophyll a Concentrations for Year 17-20 – EA Case + 0.5 DP as OrthoP with +1 SD Increase in Concentrations

5.0 SUMMARY AND DISCUSSION

The model recalibration demonstrated that there is no unique combination of model parameter values for the baseline calibration. The original and alternate calibrations differ in the simulated response of total phosphorus concentrations in Snap Lake to the treated water discharge. The original model calibration predicted a decrease in simulated total phosphorus concentration under EA conditions resulting from the relatively high orthoP loss (adsorption) rate and to a lesser extent on the higher algal settling rate. The alternate calibration predicted an increase in total phosphorus concentrations because the lower orthoP loss rate and algal settling rate maintains more of the phosphorus in the water column. Both calibrations predicted a similar response of orthoP and chlorophyll a indicating that the model predictions for these parameters are relatively robust.

The sensitivity analysis indicated that the predicted phosphorus and algal concentrations were most sensitive to changes in the benthic source rate for orthoP release and the orthoP loss rate. A balance of these two rates was required to successfully calibrate the model; however, the model could be calibrated for a high or a low range of these two rates. The original calibration represents the high range of these rates and the alternate (new) calibration represents the low range of these rates.

A range of discharge scenarios was simulated where varying portions of DP (TDP minus orthoP) in the treated water discharge were included as either orthoP or orgP. Two scenarios were also run with phosphorus concentrations in the treated water discharge increased by one standard deviation. The simulation results show a very high correlation ($r^2 = 0.97$) between the TP (orthoP plus OrgP) loading and the predicted chlorophyll a concentration, regardless of the ratio of orthoP to orgP in the discharge. The form of DP could affect the predicted algal concentration if the DP was labile but mineralized significantly more slowly than orgP.

Conservative assumptions were incorporated into the discharge scenarios, including the original EA scenario. These assumptions include the following:

- The original EA Case, and all of the scenarios where DP was assumed to be orthoP, include an assumed orgP concentration of 7 µg/L. OrgP in Snap Lake will be largely particulate or surface reactive (i.e., will adsorb to particles), which will be retained in the lake bottom sediments, and will be effectively filtered out of the groundwater recharge from Snap Lake.
- None of the discharge scenarios account for algal uptake in Snap Lake, which results in substantially lower concentrations of bioavailable phosphorus in groundwater recharge from Snap Lake to the underground mine workings.
- DP in the underground mine water will consist of dissolved and colloidal mineral phosphates, some fraction of which will not be bioavailable (i.e., will not be reactive in Snap Lake).

The EA Case is less conservative than the other scenarios modelled because it does not include DP in the treated discharge on the basis that DP will not be bioavailable in Snap Lake. The EA Case scenario does, however, include the other conservative assumptions that are common to the discharge scenarios (i.e., increase of 7 µg/L of orgP, and no reduction of orthoP resulting from algal uptake in Snap Lake). Of all the discharge scenarios considered, the EA Case provides the most representative estimate of expected bioavailable phosphorus loadings in the mine water discharge.

The discharge scenario "EA Case + 1.0 DP as orgP" provides a representative upper estimate of bioavailable phosphorus loading from the treated water discharge. This scenario incorporates the maximum loading of bioavailable phosphorus, based on the conservative assumption that all DP is bioavailable. Two other discharge scenarios (EA Case + 0.5 DP as orthoP and EA Case + 0.5 DP as orthoP with +1SD on concentrations) have bioavailable phosphorus loadings and predicted chlorophyll a concentrations that are comparable to the scenario "EA Case + 1.0 DP as orgP", and are substantively different only in the relative proportions of orthoP and orgP.

The scenario "EA Case + 0.5 DP as orthoP with +1SD on concentrations" represents an estimate of the maximum potential bioavailable phosphorus loading from the treated water discharge. This case is similar to the upper estimate cases, except that it incorporates an additional level of conservatism by assuming that all concentrations are one standard deviation higher than expected values.

Predicted mean, open water phosphorus concentrations for the EA Case, the upper loading scenarios and the maximum potential loading scenarios for years 17 to 19 (13 to 22 μg/L) fall within the lower to middle range of the mesotrophic conditions. Predicted mean, open water chlorophyll a concentrations for all cases in years 17 through 19 (1.5 to 2.2 μg/L) fall within the range of oligotrophic conditions. Years 17 through 19 were selected because they are representative of the period of maximum concentrations in Snap Lake. These concentrations are within the accepted range for oligo-mesotrophic lakes. The baseline phytoplankton community in Snap Lake is characteristic of an oligo-mesotrophic lake. Therefore, a major shift in community structure is unlikely to occur because the predicted primary productivity remains within the same trophic range. Zooplankton biomass may increase due to the change in primary productivity but overall community structure should not be affected because of the level of change to primary productivity anticipated and the inefficiency of energy transfers among trophic levels. Benthic invertebrates may or may not respond to the increase in primary productivity, although any changes that may occur would be minor.

No major changes in food availability to fish inhabiting Snap Lake are anticipated. In general, all of the fish species in Snap Lake feed upon benthic invertebrates and/or zooplankton. Lake trout, burbot, and Arctic grayling become generalized "opportunistic" feeders as they grow/age, such that they include fish in their diet (i.e., become more piscivorous with size). An increase in the biomass of either zooplankton or benthic invertebrates may occur which would increase foraging opportunities for fish. However, the community structure of both zooplankton or benthic invertebrates will not likely be altered.

Overall, it is expected that the integrity and function of the aquatic ecosystem in Snap Lake will remain intact for the range of phosphorus loadings evaluated (the EA Case, the upper loading scenarios and the maximum potential loading scenarios). The most likely effect will be an increase in algal biomass and, to a lesser extent, zooplankton and benthic invertebrate biomass, with no loss of species richness in Snap Lake, and no changes to the overall oligo-mesotrophic status of the lake.

There are monitoring and mitigation actions that can be implemented to manage the effects of the Snap Lake Diamond Project on primary productivity in Snap Lake. These include:

- De Beers will undertake a site water quality and flow monitoring program and a water quality and primary productivity (chlorophyll a) monitoring program in Snap Lake. The site monitoring program will measure nutrient loading (including phosphorus) to Snap Lake. The Snap Lake monitoring program will measure nutrient and chlorophyll a concentrations within Snap Lake. The monitoring results will be used to validate and refine the Snap Lake algal model predictions on an annual basis. The algal model will be used as a forecasting tool to provide an earlier warning indicator of whether mitigation will be required.
- The water treatment plant will effectively reduce particulate phosphorus to very low concentrations because the basis of treatment is a high level of total suspended solids removal (to a TSS of less than 5 mg/L). The water treatment plant will also include the contingency of using ferric sulfate to precipitate phosphorus. The use of ferric iron in water treatment plants to precipitate insoluble ferric phosphate and coagulate colloidal phosphorous, coupled with filtration represents proven best available practical technology to achieve the low phosphorus levels.
- Areas of high groundwater inflow and high bioavailable phosphorus concentrations, especially those in ramps and drift development, can be grouted to minimize the overall bioavailable phosphorus loading to the mine over the long-term.

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ATTACHMENT 1

TECHNICAL MEMO ON THE POTENTIAL EFFECTS OF PHOSPHORUS ENRICHMENT ON THE PRODUCTIVITY OF SNAP LAKE

TECHNICAL MEMORANDUM

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TO:	Robin Johnstone	**DATE:**	February 4, 2003
FROM:	Dawn Kelly and Rick Schryer	**JOB NO:**	022-6659-5300
Prepared By:	Mark Digel and Ken DeVos		
RE:	Snap Lake Diamond Project Environmental Assessment Phosphorus Loading Update – Draft Technical Memorandum		

1.0 INTRODUCTION

Phosphorus concentrations in the treated mine-water discharge and their effect on primary productivity (algal concentrations) in Snap Lake received considerable attention at the MVEIRB Technical Sessions for the Snap Lake Diamond Project Environmental Assessment and were the subject of a breakout meeting on the evening of November 28, 2002. The primary concern raised by intervenors was that the algal modelling in the environmental assessment (EA) might have underestimated total available phosphorus loadings to Snap Lake by only using orthophosphate concentrations and not including dissolved phosphorus. The rationale for using orthophosphate in the assessment of potential changes in algal concentrations in Snap Lake was based on the following points:

- Particulate phosphorus in groundwater is not bioavailable and dissolved phosphorus is not biovailable or will have a very low bioavailability.
- Treatment is expected to effectively remove most particulate and dissolved phosphorus.

There was a consensus amongst the intervenors present at the breakout session that additional model runs of the Snap Lake algal model that included dissolved phosphorus in addition to orthophosphate could resolve concerns over the forms of phosphorus used in the algal modelling. The intervenors felt that a cooperative approach between De Beers and the intervenors was the preferred approach to resolve phosphorus issues. De Beers' intention is to pursue further discussion about phosphorous loading with intervenors as part of their objective of resolving as many outstanding technical issues prior to public hearings as possible.

The purpose of this technical memorandum is to provide an update on phosphorus loadings to Snap Lake that accounts for total phosphorus, dissolved phosphorus and orthophosphate. The memo provides an explanation of how concentrations were derived and how phosphorus reductions in the water treatment plant were derived. The memo will provide a basis for a discussion of additional modelling to assess the potential influence of dissolved phosphorus on algal concentrations in Snap Lake.

2.0 SOURCES OF PHOSPHORUS

The water management system for the Snap Lake Diamond Project will collect and treat water collected in underground mine workings, and runoff and seepage from disturbed areas, prior to discharging it to Snap Lake. These "site" waters account for almost all (over 99%) of the water affected by the project. The sources of site water include the following:

- connate groundwater inflow to the mine;
- Snap Lake water contribution to the mine;
- runoff and seepage from the North Pile; and
- site runoff from developed and undeveloped areas.

Flows and concentrations have been predicted for each of these waters on a weekly basis for the duration of construction and operations, and at post-closure. In addition to the mass loading (flow multiplied by concentration) associated with water from each source, the groundwater inflow to the underground mine workings will also receive a mass loading due to additional sources:

- rock-water interactions at the active mine face; and
- water released due to consolidation of paste backfill placed in mined out workings.

The water discharged to Snap Lake will also include tertiary effluent from the sewage treatment plant.

Connate Groundwater – The groundwater in the bedrock prior to development of the mine is referred to as connate groundwater. Groundwater flow is very slow and, therefore, this water has had a very long residence time in the bedrock. During initial mining, the majority of groundwater inflow to the mine workings will be connate groundwater. Phosphorus concentrations (total, dissolved and orthophosphate) in connate groundwater were based on measured values from nine borehole samples from the granitic unit, which is the source of the majority of groundwater inflow to the mine.

Lake water contribution to mine – As connate groundwater seeps into the mine workings, this water will be replaced by recharge from Snap Lake, which overlies much of the mine workings. This groundwater recharge from Snap Lake will have a very short residence time (weeks to months) compared to connate groundwater (centuries). The contribution of lake water to mine inflows will increase over time, to a maximum contribution of 70% near the end of operations. Lake water inflow phosphorus was based on modelled concentrations in Snap Lake. Concentrations were assumed not to change along the flow pathway between Snap Lake and the mine workings because of the very short residence time and the low reactivity of phosphorus in groundwater.

In the Environmental Assessment Report (EAR) for the Snap Lake Diamond Project, lake water inflow concentrations were based on total phosphorus. This represented a conservatively high estimate of lake water contribution to the mine because particulate phosphorus would be removed in the lake bed sediments or along the groundwater flow pathway. In the source-water calculations presented in this technical memorandum, only dissolved phosphorus was included in the lake water contribution to the mine.

To account for the feedback between the lake water contribution to the mine and the effect of the treated water discharge on lake concentrations, a simple, yet conservative mixing model was incorporated into the Site Water Quality Model (i.e., the GoldSim based model used to predict flows and concentrations of all site waters). The term conservative is used to indicate assumptions that will bias an assessment result towards higher environmental impacts. The model assumes that the treated water discharge and watershed runoff from areas upstream of the discharge (96% of the total watershed runoff) mixes in 10% of the volume of Snap Lake (8.7 Mm^3). The mixed concentrations are then allowed to recharge the mine workings. The Site Water Quality Model is conservative for two reasons:

- the inherent assumption of mixing 10% of the volume of Snap Lake will overestimate concentrations compared to the expected concentrations (i.e., those predicted by the Snap Lake algal model results); and
- the Site Water Quality Model does not account for reductions in dissolved phosphorus that occur in Snap Lake due to a net uptake (reduction) of dissolved phosphorus by phytoplankton (algae) that results in a loss of dissolved phosphorus in Snap Lake.

North Pile and Site Runoff –North Pile runoff and seepage, and site runoff from developed areas are combined in this technical memorandum because their contribution is very small relative to mine-waters (2.2% of total flow and 0.9% of dissolved phosphorus load, see Table 1). Runoff and seepage from the North Pile will be collected in a settling pond, prior to discharge to the water treatment plant. Runoff from developed and undeveloped areas of the mine footprint will be collected in the Water Management Pond (WMP) prior to being discharged to the water treatment plant. Phosphorus concentrations in North Pile runoff and seepage were based on average results from laboratory kinetic tests (EAR Appendix III.2 and IX.1). Phosphorus concentrations in site runoff concentrations were based on measured values of runoff from areas developed during the advanced exploration program (AEP) (EAR Appendix IX.1). Only total phosphorus was measured in the kinetic tests and in site runoff samples, which were assigned as dissolved phosphorus in the Site Water Quality Model to be conservative.

Working Area Contribution – Groundwater inflow at working areas (areas being actively mined) is expected to receive an incremental increase in concentrations of phosphorus (and other parameters) due to interactions of mine-water with fine rock material, explosives, grout and cement. The resulting water is referred to as "mine-water". The effects of explosives, grout and cement were considered separately and are discussed below. The increase in concentrations due to interactions of mine-water with fine rock material in active working areas was based on the difference observed between the inflow values and discharge values during the AEP at Snap Lake in 2001. For example, if the measure inflow chemistry for a parameter during the AEP was 0.2 mg/L and the measured mine-water discharge chemistry was 1 mg/L, then the difference between these two values (0.8 mg) would be added per L of groundwater to working areas of the mine.

Explosives, Grout, and Cement – No phosphorus contribution was assigned to explosives, grout or cement use because the manufacturer's data sheets did not list phosphorus as a component of these products.

Paste Backfill – Paste backfill that is placed into inactive mine areas will consolidate over time, releasing water to the mine. It was assumed that consolidation would release 14% of the paste porewater to the mine workings. Concentrations of phosphorus in consolidation water from paste backfill were based on laboratory test measurements of short-term leachate concentrations from paste backfill samples obtained during the AEP. Only total phosphorus results were available, which were assigned as dissolved phosphorus in the Site Water Quality Model to be conservative.

Sewage Treatment Plant Effluent – Phosphorus from the sewage treatment plant (STP) was based on the design specifications, which include a phosphorus concentration of 0.2 mg/L and a flow rate of 200 m^3/day. All phosphorus in STP effluent was assumed to be orthophosphate.

3.0 FORMS OF PHOSPHORUS

Algal models generally consider two forms of phosphorus, organic and orthophosphate. Orthophosphate is the form of phosphorus that can be utilized by algae. Organic phosphorus may exist in a particulate or dissolved form, and mineralizes to orthophosphate according to a first order exponential reaction. Phosphorus in groundwater occurs as orthophosphate and as mineral phosphate (e.g., apatite) in particulate, colloidal and dissolved forms. Mineral phosphates are generally not considered to be biologically available and do not convert to orthophosphate or the reactions occur so slowly that they do not contribute an appreciable amount of orthophosphate. Phosphorus can also occur as condensed phosphates; however, these are generally not considered to be present in significant concentrations in connate groundwater from the Canadian Shield.

The site water (inflow to water treatment plant), which is dominated by groundwater, consists of inorganic forms of phosphorus and does not contain appreciable amounts of organic phosphorus. Inorganic phosphorus in the mine-water is analysed in three forms, total phosphorus, dissolved phosphorus and orthophosphate. All three forms of phosphorus are analysed by colorimetry, with the difference being in the treatment of the water prior to analysis. Colorimetry measures the concentration of orthophosphate in the water. Total phosphorus is measured by digesting the sample in a strong acid to convert all phosphorus to orthophosphate. Dissolved phosphorus is measured by filtering the sample prior to digestion in a strong acid. Orthophosphate is measured by analysing unfiltered samples without digestion, and is also referred to as total reactive phosphorus (Standard Methods for the Examination of Water and Wastewater, 1989).

4.0 CONCENTRATIONS IN TREATED WATER DISCHARGE TO SNAP LAKE

The relative proportions of flow, concentration and loading for each phosphorus source described in Section 2 are summarized in Table 1, which also includes the combined flow and concentrations for all sources (untreated site water), and treated water concentrations. Treatment was assumed to reduce phosphorus concentrations by removing dissolved phosphorus to a concentration of 0.02 mg/L and particulate phosphorus proportionately to the decrease in total suspended solids (TSS) concentrations. The water treatment plant will be designed to remove TSS from the site water to produce a discharge with an average TSS concentration of 5 mg/L. The feasibility of this level of treatment was verified by pilot testing of mine-waters collected as part of the AEP at Snap Lake in 2001.

Based on sampling and analyses conducted during the AEP in 2001, the mine-water, which accounts for greater than 95% of the site water, contains high concentrations of TSS as well as significant amounts of total and dissolved phosphorus. Unfortunately, the analysis of dissolved phosphorus does not provide a true measure of dissolved phosphorus, but rather provides a total phosphorus measure of whatever passes through a 0.45 μm filter. A major portion of the phosphorous that reports as "dissolved" in the analysis is colloidal in nature and will be removed by effective flocculation and filtration in the water treatment plant. This factor can be demonstrated by a statistical test involving construction of regression lines for total and dissolved phosphorus versus TSS. The results of this analysis, provided in Figure 1, show a very strong correlation between dissolved phosphorous and TSS for underground mine-water from the AEP at Snap Lake ($r^2 = 0.92$). If the fraction less than 0.45 μm in size was in true solution, the dissolved value should have been a relatively constant value over the full TSS range.

A conservative estimate of the reduction in dissolved phosphorus due to TSS removal in the water treatment plant can be generated using the regression equation of dissolved phosphorus as a function of TSS. At a TSS concentration of 5 mg/L, the predicted residual dissolved phosphorus concentration in the treated water discharge would be 0.020 mg/L. This may be close to the true dissolved phosphorus concentration, because the dissolved phosphorus-TSS relationship is exponential with the asymptote of the relationship occurring at a dissolved phosphorus concentration of just less than 0.02 mg/L. This is a conservative estimate for dissolved phosphorous in the treated water discharge because additional removal could be expected through flocculation of colloidal matter and filtration in the multi-media filter in the water treatment plant.

The residual dissolved phosphorus in the treated water discharge will consist of orthophosphate and dissolved/colloidal mineral phosphates. The average predicted orthophosphate concentration in the treated water discharge (site water and STP) during operations was 0.008 mg/L, resulting in a concentration of 0.011 mg/L for dissolved mineral phosphates, based on the predicted average residual dissolved phosphorus of 0.019 mg/L. Effluent from the sewage treatment plant will increase orthophosphate concentrations by 0.002 mg/L (to 0.010 mg/L) in the final treated discharge to Snap Lake (Table 1).

5.0 POTENTIAL DISCHARGE SCENARIOS

There are no clear guidelines in the literature on how dissolved phosphorus should be used in the Snap Lake algal model, because groundwater is generally not considered to be a significant source of bioavailable phosphorus, and there is very little literature available on the bioavailability of groundwater in the Canadian Shield. Potential discharge scenarios incorporating dissolved phosphorus include the following:

- The EA scenario assumed that orthophosphate was the only bioavailable or labile form of phosphorus in the discharge.
- The most conservative modelling scenario would be to assume that all of the 0.011 mg/L of dissolved phosphorus (total dissolved phosphorus minus orthophosphate) behaves like orthophosphate in Snap Lake, which would be an effective doubling of the loading from the project, compared to the EA scenario. This is an unrealistically conservative scenario, because the dissolved mineral phosphorus is not biologically available for algal uptake.
- A third scenario could be to assign a fraction of the dissolved phosphorus pool as orthophosphate.
- A fourth scenario could be to assume that part or all of the dissolved phosphorus is labile (a relatively stable but reactive species) and mineralizes to orthophosphate. Because the Snap Lake algal model and algal models generally, do not account for a fraction of dissolved phosphorus that is separate from orthophosphate, dissolved phosphorus in the discharge would have to be considered as part of the organic phosphorus pool.

Because dissolved phosphorus in Table 1, excludes orthophosphate, the third scenario is likely the most realistic; however, there is no clear basis in the literature on the fraction of dissolved phosphorus that would be labile or the rate of mineralization.

The potential phosphorus loading scenarios outlined above are intended to provide a basis for a follow-up meeting to resolve concerns regarding phosphorus loadings in water releases from the Snap Lake Diamond Project and their potential effect on algal concentrations in Snap Lake.

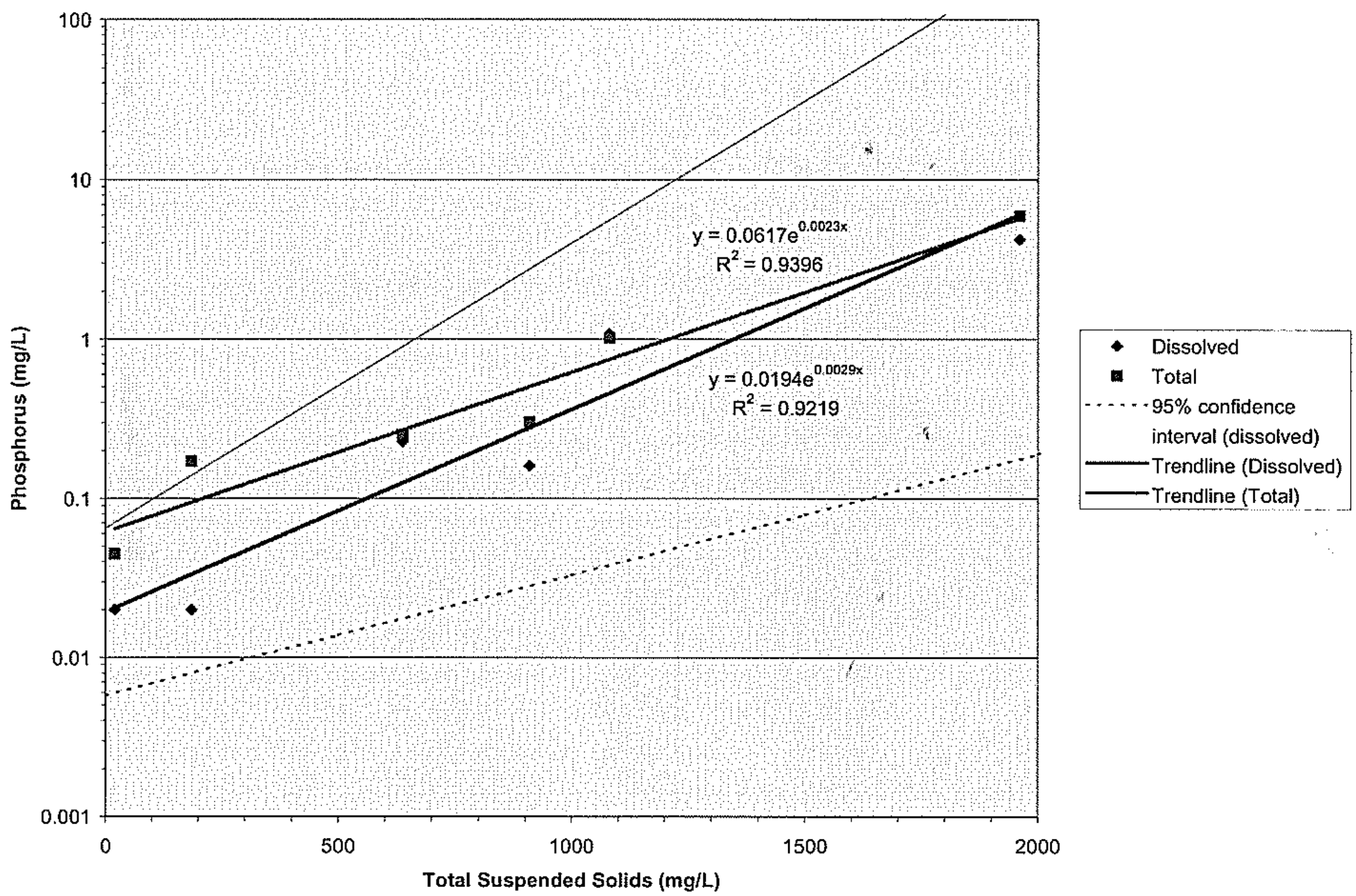

Figure 1 Correlation of total and dissolved phosphorus with total suspended solids in underground mine-water from the advanced exploration program at Snap Lake.

Table 1 Flows, phosphorus and TSS concentrations and mass loadings in site waters

Flow/loading component		Flows (m^3/d)	Concentration (mg/L)					Load (kg/d)			
			DP	OrthoP	PP	TP	TSS	DP	OrthoP	PP	TotalP
Inflows to Mine	Connate groundwater inflow	6894	0.047	0.012	0.000	0.059	31	0.32	0.08	0.00	0.41
	Recharge from Snap Lake	15934	0.009	0.006	0.000	0.015	0	0.15	0.09	0.00	0.24
	Paste backfill consolidation	182	0.000	0.013	0.000	0.013	0	0.000	0.002	0.000	0.002
	Incremental Chemistry at Working Face	13965	0.591	0.000	1.750	2.341	2120	8.25	0.00	24.44	32.69
Inflows to Water Treatment	from the Mine	23010	0.379	0.008	1.076	1.463	1299	8.72	0.18	24.77	33.67
	North Pile runoff and seepage	533	0.142	0.030	0.172	0.344	2175	0.08	0.02	0.09	0.18
	Site runoff	185	0.010	0.004	0.000	0.013	28	0.002	0.001	0.000	0.00
	Treatment Feed [Total]	23728	0.371	0.008	1.045	1.424	1309	8.80	0.20	24.79	33.79
	Treated Sewage	200	0.000	0.200	0.000	0.200	25	0.000	0.04	0.00	0.04
	Treated Discharge to Snap Lake	23701	0.011	0.010	0.004	0.025	5	0.23	0.23	0.09	0.59

Notes: DP = total dissolved phosphorus - OrthoP, OrthoP = orthophosphate, PP = particulate phosphorus, TP = total phosphorus
TSS = total suspended solids

ATTACHMENT 2

MEETING MINUTES: PHOSPHORUS LOADING AND ALGAL MODELING FOR THE SNAP LAKE PROJECT

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File:

MINUTES OF MEETING

TIME: 9:00 am – 3:30 pm

DATE: 10 February 2003

LOCATION: De Beers Boardroom, 3rd Floor Scotia Center

SUBJECT: Phosphorus Loading and Algal Modeling for the Snap Lake Project

DESCRIPTION: The purpose of this meeting was to reach consensus on the modelling of additional phosphorus loading scenarios. The meeting was not intended to address the environment impact implications of changes in phosphorus concentrations, as this has been covered in a memo titled, "Potential Effects of Phosphorus Enrichment on the Productivity of Snap Lake". Discussion focused on the concentrations and bioavailability of different forms of phosphorus in the treated water discharge. The results of an algal model sensitivity analysis and recalibration were presented and discussed.

ATTENDEES: Neil Hutchinson (GLL/MVEIRB), Dave Balint (DFO), Marc Lange (DFO, morning only), Julie Dahl (DFO, morning only), Anne Wilson (EC), Gavin More (GNWT), Sevn Bohnet (INAC, morning only), Francis Jackson (INAC, morning only), Laurie Cordell (MVLWB), Mark Digel (Golder), Colleen English (DBCMI) Conference call: Tim Byers (BES for YDFN), Steve Wilbur (Entrix for Dogrib Treaty 11), Don McDonald (MESL for INAC), Kenn Raven (Intera for INAC, morning only), Bob Shelast (Stantec for NSMA, afternoon only)

DISTRIBUTION: Attendees plus: Public Registry

ITEM	DESCRIPTION	ACTION
1.0	**Where does the other 1/3 of the water collected go if not accounted for in the working face contribution?** The greatest concentration change is in the recent or active mining areas. Other water does not come in contact with the active face. **Is the water that runs back through the paste backfill not accounted for?** The paste is very tight and would actually be releasing water, so water would tend to flow around these areas. We didn't want to assume just clean groundwater coming in, so the groundwater inflow in contact with mining areas was assumed to have an increase in phosphorus concentrations.	De Beers to contact project geochemists and mining engineers in order to provide a rationale for how "Working Face Contributions" of groundwater were estimated.
2.0	**Are you using a representative average concentration, or changing concentrations?** The model does a week-by-week concentration, but for illustrative purposes today, I have used the average for Years 15-22, which is very representative of maximum loadings. Changes in concentration over time are included in the EA, and the model does account for total loading over time. **Will there be spikes in the phosphorus concentration that the water treatment**	See Item 10.0.

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ITEM	DESCRIPTION	ACTION
	plant (WTP) will have to handle over time, ie: how uniform is the phosphorus concentration in the groundwater? Groundwater inflow comes through the mine, so yes, there is variability is the WTP source water to a certain extent, but it is not a "spikey" process. Phosphorus loadings tend to gradually increase over time. There is a limit to what we can predict with models, with respect to short-term variability, so we have to focus on the intent of modeling, ,which is to predict the long-term response of Snap Lake to nutrient loadings, which was done in the EA using a very sophisticated approach. As an example of the long-term loading focus, Diavik has shifted to an annual loading limit versus a daily or monthly criteria. **Respecting the uncertainties with the model, perhaps we use Don McDonald's suggestion from the Technical Session Breakout Session of running a standard deviation?** This is a possibility, but it should be kept in mind that standard deviation (SD) is an approach usually taken for toxic substances and one SD is a very unlikely circumstance. SD's do not deal with variability, we would have to use an average and then a SD on top of that, so this addresses a different issue than short-term variability.	
3.0	**What is the specific concentration of orthophosphate (OP)?** The WTP does not remove orthophosphate so we assume no reduction and 10 ug/L is a blended concentration of all sources of water. Diavik OP concentrations in the groundwater are 95% of 300 ug/L. Snap is 10 ug/L, from a combination of sources. There is a decrease in this concentration over time due to lower amounts of connate water entering the mine. **So the depth of groundwater sampling is adequate to estimate the concentrations and you are not expecting an increase with depth?** Correct. If this is still a question, I can provide you with a more explicit explanation of how this was done. **What is the modeled OP concentration of groundwater recharge from Snap Lake in Year 15-22?** 6 ug/L, as stated in the last table of the presentation. This is a conservatively high estimate because it does not account for any algal uptake of OP.	De Beers to provide a memo that: 1) clarifies the distribution and concentration of phosphorus forms in connate water with depth, and 2) substantiates that phosphorus does not increase with depth.
4.0	**Table 1 provides minewater discharge concentrations for dissolved phosphorus (DP), but Appendix IX of the EA does not have concentrations that high. Are we to ignore the numbers is Appendix IX (DP = 10 ug/L)?** The EA did not look at DP because we did not think that it was in a form that contributed to algal growth in the lake, so we focused on OP. I would suspect that the concentration you speak of is OP, but I would have to re-visit Appendix IX before providing you with a response on this.	De Beers to confirm that the DP value in Appendix IX (Table IX.1-12) is mostly OP.
5.0	**Where does the DP originate from if there is no relation to PP?** Within a proportion of the groundwater and dissolution at the active mine face results in fine colloidals with no relation to TSS as there is no filtration. **If we extrapolate the graph of DP vs. TSS to 0 TSS, you would have 20 ug/L DP remaining. Is the other incremental level beyond 20ug/L colloidal?** Yes, it would be in some form that is adsorbed. **So you don't assume more of the very fine form is adsorbed into the water?** Correct.	De Beers to provide statistical significance (p-value) on DP-TSS relationship in underground mine water from AEP samples.
6.0	**There is a range of TSS values without treatment?** Correct. **If we assume DP is truly DP and eliminate the colloidal (11ug/L or 8%), this is most likely bioavailable?** It is most likely to be dissolved, but not necessarily bioavailable. **So only half of the total dissolved phosphorus (TDP) is bioavailable?** Correct. We did not address the other phosphorus in the EA, so the question is how do we treat this in the modeling scenarios being discussed today? We did a literature	

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ITEM	DESCRIPTION	ACTION
	review on phosphorus availability in groundwater but there was no information available. Groundwater is not normally considered a source of phosphorus contributing to the eutrophication of lakes. The key outcome of this meeting is agreement on what cases to look at and what they mean. **Considering what we know and what we don't know, might suggest performing a sensitivity analysis and then determining what is available from this.** This is what I was thinking. We don't know the percentage of DP not available so we run what you are comfortable with and then discuss what that means. **Sensitivity analysis is a good way to go. Run the 100% scenario. In Table 1, the recharge value for Snap is 6 ug/L – have you run the productivity model at that level, or is this the 10% zone?** The groundwater recharge from Snap Lake was calculated in the site water quality model assuming mixing in 10% of Snap Lake (this is the 10% zone).	
7.0	**What is the Diavik scenario?** 95% of the groundwater there is OP. They only considered OP as contributing to eutrophication. There was no consideration of the mining process; this is the first time this has been looked at.	
8.0	***(Suggestion of running the model using both labile and OP at 25, 50 and 100%)*** **What is the difference between running the model with labile or OP? Is one a slower process?** Yes, running the model with OP results in a more conservative approach because OP is immediately bioavailable, whereas labile phosphorus will result in a slower release of OP. In the model labile phosphorus would be included as organic phosphorus. This keeps the predictions conservative as organic phosphorus likely mineralizes more rapidly than labile phosphorus in the treated water discharge. **Could you clarify what you mean by organic phosphorus?** When algae dies, the phosphorus within it is unavailable until it is broken down to OP. It is a first order reaction that can be expressed as a half life. The decay rate in the model is 0.0072/day, so if you convert this it would take time to decay – it is a relatively slow process. This difference is what would make it worthwhile to run both scenarios.	The algal settling rate is to be run at zero sensitivity analysis for 'lower' and complete the 'higher' sensitivity analysis using the maximum algal growth rate.
9.0	**There is question surrounding the under ice pre-break up concentrations of phosphorus.** Wouldn't expect to see a seasonality with total phosphorus, and we certainly have not seen this to date. **Disagreement that De Beers has enough baseline data to make that assumption.** The model is not set up to try and account for all the variability. Trophic effects focus on average variability, which is minor when compared to the results of higher loading scenarios.	De Beers to distribute relevant sections of the RMA-11 model, showing technical details of algal production coefficients to those who wish to review them.
10.0	**If OP is low, why is the Chorophyll *a* (Chl a) so high? The net pool does not change?** Correct. OP would not stay low if we were not within a phosphorus-limited system. Within the algal model in general, there are a combination of rates that affect TP more than OP and Chl a. Settling terms and sediment release rate are the most sensitive in the model (see slide). **How is it that settling terms is the most sensitive?** Due to PO_4 adsorption and the benthic release rate. Sensitivity analysis (SA) simulations are not intended to represent reality, only changing individual parameters will affect model results. **How do the parameters of a SA affect the outcome?** We have a good range of model rates within two calibrations so we could run both calibrations. When modelling, we need to consider how changes to the lake could throw off the balance. We are not predicting a level of trophic change that would cause a shift in the net balance of phosphorus settling and release over the long-term. We can model at 1 SD; this would result in higher phosphorus concentrations, but would have to recognize this represents a low probability of occurrence. **After mine start up, at what point would you get better information by**	De Beers will run the following scenarios: 1. OrthoP + a percentage of DP as OrthoP. Three percentages will be run, 25%, 50% and 100%. All runs will be at expected concentrations from the EA. 2. OrthoP + a percentage of DP as OrgP. Three percentages will be run, 25%, 50% and 100%. All runs will be at expected concentrations from the EA. 3. OrthoP + 50 percent of DP as OrthoP, with all site water concentrations at +1 standard deviation above expected concentrations.

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ITEM	DESCRIPTION	ACTION
	continuing to calibrate the model? All the way along. **How did you represent gradual versus threshold effects in terms of community feedback?** We do not expect threshold affects in the communities, nor do we see substantial changes in the overall ecosystem – it is expected to be more of a gradual affect. ***General discussion on which model scenarios to run.** Consensus was reached on running the modelling scenarios listed in the action column using the revised (alternate) calibration.	4. OrthoP + 50 percent of DP as OrgP, with all site water concentrations at +1 standard deviation above expected concentrations. 5. OrthoP only, but run at +1 standard deviation above expected concentrations. - The four highest priority runs will be: 1. Scenario 5 2. Scenario 2 at 100% 3. Scenario 3 4. Scenario 2 at 50% - In all scenarios orthophosphate (OrthoP) will be included, plus a proportion of dissolved phosphorus (DP). The DP will be included as either OrthoP (immediately bioavailable) or as organic phosphorus (OrgP) (i.e., labile). - Note: All terminology is consistent with the Phosphorus Loading Update - Draft Technical Memorandum, dated February 4, 2003. - All simulations will be run using the revised (alternate) calibration.

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APPROVED BY:
R. Johnstone
Senior Environmental Manager