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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: Potential Effects of Phosphorus Enrichment on the Productivity of Snap Lake

Please accept the attached technical memo titled "Potential Effects of Phosphorus Enrichment on the Productivity of Snap Lake" for submission to the Public Registry. This memo was compiled in response to issues raised 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

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REPORT ON

POTENTIAL EFFECTS OF PHOSPHORUS ENRICHMENT ON THE PRODUCTIVITY OF SNAP LAKE

Submitted to:

Department of Fisheries and Oceans
Mackenzie Valley Environmental Review Board
as supplemental information to the Snap Lake
Diamond Project Environmental Assessment

DISTRIBUTION:

2 Copies - De Beers Canada Mining Inc., Yellowknife Northwest Territories
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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

The environmental assessment report (EAR) for the De Beers Snap Lake Diamond Project predicts that phosphorus loading from treated mine water discharge will increase the chlorophyll *a* levels of Snap Lake (De Beers 2002). During the Mackenzie Valley Environmental Impact Review Board (MVEIRB) Technical Sessions on the EAR conducted in November and December 2002, issues were raised regarding the amount and type of expected changes to biological communities that may occur. In response to these concerns, this technical memorandum was prepared to more clearly describe potential changes to the productivity in Snap Lake.

Mine water discharge will enrich Snap Lake with biologically-available phosphorus during construction and operation phases of the mine. The potential impact of phosphorus is different than most other water chemistry parameters because phosphorus is not toxic to aquatic life; however, it is a nutrient that plays a major role in biological metabolism (Wetzel 1983). Furthermore, in comparison to the natural supply of other major nutritional and structural components of the biota (*e.g.*, carbon, hydrogen, nitrogen, oxygen, sulphur), phosphorus is least abundant and commonly limits biological productivity (Wetzel 1983, Carpenter *et al.* 2001). Phosphorus enrichment will likely increase the productivity of Snap Lake by stimulating algal growth, which in turn, will provide more food resources for aquatic organisms at higher trophic (feeding relationships among organisms in an ecosystem and is related to productivity in lakes [Wetzel 1983]) levels.

Should phosphorus concentrations increase considerably, the physical and chemical characteristics of a lake can change. An increase in phytoplankton productivity can reduce water transparency, and increase the deposition of organic matter to the lake bottom. Greater rates of organic matter decomposition can potentially reduce dissolved oxygen (DO) concentrations (Wetzel 1983).

Phosphorus enrichment also can lead to changes in the biomass and species composition of aquatic communities. Algal biomass increases and species composition may change with increasing nutrient levels. This shift can alter zooplankton and benthic invertebrate communities, which graze on algae, and in turn, may affect the supply of food to fish.

A literature review was conducted to document potential ecosystem changes that could occur in Snap Lake due to phosphorus enrichment. Information was collected from scientific journals and technical reports on the effect of phosphorus concentration on phytoplankton and the response of aquatic organisms to an increase in primary production. Case studies of fertilized arctic and subarctic lakes were also referenced to provide context to the predicted increase in lake productivity.

2.0 SCOPE AND OBJECTIVES

The objective of this technical memorandum was to describe the predicted effects of mine-related phosphorus enrichment on the productivity of Snap Lake. Currently, it is difficult to definitively predict changes that will occur at an ecosystem level. No Canadian Council of Ministers of the Environment (CCME) water quality guideline exits for phosphorus nor are there accepted benchmarks for assessing the impact of changes in lake productivity. As a result, a combination of information sources was used to provide an overall picture of expected changes and place these changes in context with other lakes. The following resources were used:

- baseline information from the EAR (De Beers 2002) on the physical, chemical and biological characteristics of Snap Lake;
- quantitative predictions of phosphorus loading, phytoplankton biomass and DO concentrations obtained from modeling conducted for the EAR (De Beers 2002);
- case studies of lake fertilization, particularly in the arctic; and,
- relevant scientific literature on lake eutrophication.

Effects of phosphorus enrichment on the physical and chemical characteristics of Snap Lake (water transparency, pH, DO) were evaluated as well as corresponding potential influences to the phytoplankton, zooplankton, benthic invertebrate, and fish communities. Potential changes to these communities within Snap Lake were addressed for periods of mine construction, operation, and post-closure.

3.0 CLASSIFICATION OF LAKE PRODUCTIVITY

3.1 Background

Lake productivity refers to the amount of growth of aquatic organisms inhabiting a lake. Lakes can be classified into one of several broad categories based on their productivity (*e.g.*, OECD 1982, Wetzel 1983). Lakes with low productivity are termed "oligotrophic", while those with intermediate and high productivity are termed "mesotrophic" and "eutrophic", respectively. Extremely unproductive and extremely productive lakes are sometimes further subdivided into "ultra-oligotrophic" and "hyper-eutrophic" categories, respectively. The categories are often combined (*e.g.*, oligo-mesotrophic) when a lake displays characteristics of two categories).

Because phosphorus generally limits the growth of phytoplankton and phytoplankton is a dominant source of energy for many other aquatic organisms, phosphorus concentration and phytoplankton biomass are commonly used as criteria to define categories of lake productivity. Water transparency also is commonly used as a classification criterion.

Total phosphorus (TP) concentration, chlorophyll *a* concentration (an important photosynthesizing pigment found in all living plants, which is commonly used as a biomass estimate for phytoplankton), and water transparency (measured as Secchi disk depth) typically observed for each lake productivity-type are presented in Table 3.1. This system of classification is to some degree arbitrary. In reality, lake productivity varies as a gradient or continuum and the boundaries for each category should not be interpreted in a rigid manner. Nevertheless, categories of lake productivity provide a useful tool for assessing the degree of change in productivity (or eutrophication) of a lake. The classification system presented in Table 3.1 is based on internationally cited endpoints established by the Organization for Economic Co-operation and Development (OECD 1982).

Table 3.1 OECD Categories of Lake Productivity Based on Total Phosphorus Concentration, Phytoplankton Chlorophyll *a* and Water-column Secchi Depth

Productivity Category	Total Phosphorus	Phytoplankton Chlorophyll *a*		Secchi Depth	
	Mean (µg/L)	Mean (µg/L)	Maximum (µg/L)	Mean (m)	Minimum (m)
Ultra-oligotrophic	<4	<1	<2.5	>12	>6
Oligotrophic	<10	<2.5	<8	>6	>3
Mesotrophic	10-35	2.5-8	8-25	6-3	3-1.5
Eutrophic	35-100	8-25	25-75	3-1.5	1.5-0.7
Hypereutrophic	>100	>25	>75	<1.5	<0.7

Source: OECD (1982).

The species composition of phytoplankton communities differ among oligotrophic, mesotrophic and eutrophic lakes (Table 3.2). Golden algae (Chrysophyta) and cryptomonads (Cryptophyta) commonly dominate in oligotrophic lakes and decrease in importance with increasing productivity. In lakes of moderately low productivity (oligo-mesotrophic), diatoms (Bacillariophyta) and dinoflagellates (Pyrrophyta) are often the dominant algal groups. Diatoms typically represent the greatest biomass in mesotrophic lakes and are replaced by cyanobacteria (a.k.a., blue-green algae [Cyanophyta]) and green algae (Chlorophyta) in eutrophic and hypereutrophic lakes.

Table 3.2 Dominant Phytoplankton Groups Commonly Found in Lakes of Different Productivity

Productivity Category	Dominant Phytoplankton Groups
Oligotrophic	Cryptomonads (Cryptophyta) Golden algae (Chrysophyta)
Oligo-mesotrophic	Diatoms (Bacillariophyta) Dinoflagellates (Pyrrophyta)
Mesotrophic	Diatoms
Eutrophic	Diatoms Cyanobactera (Cyanophyta)
Hypereutrophic	Green algae (Chlorophyta) Cyanobacteria Euglenoids (Euglenophyta)

Sources: Wetzel (1983), Watson *et al.* (1997), Kalff (2002).

3.2 Snap Lake Baseline Trophic Conditions

The use of biological communities of higher trophic levels to categorize lake productivity becomes more tenuous and general in nature primarily because of indirect relationships between nutrient levels and mechanisms/efficiencies of energy assimilation among higher trophic levels (*e.g.*, zooplankton, benthic invertebrates, and fish). For example, a generally positive correlation exists between the rates of production of phytoplankton and zooplankton. However, zooplankton utilize other sources of food (*e.g.*, bacteria, detritus) and the feeding efficiency of herbivorous zooplankton is inefficient. Thus, the relationships between phytoplankton and zooplankton often result in variable descriptions of lake productivity and definitive resolution of corresponding zooplankton community structures (Wetzel 1983). The relationship becomes more tenuous with benthic invertebrate and fish communities. However, some generalizations between lake productivity and the general abundance and composition among zooplankton, benthic invertebrates, and fish communities in Snap Lake can be inferred from the scientific literature. These relationships are presented below.

Depending on the criteria or biological community used to rate productivity, Snap Lake can be classified as oligotrophic to mesotrophic (Table 3.3). Using OECD (1982) criteria would result in a rating of Snap Lake from ultra-oligotrophic to mesotrophic. The biological communities also tended to be representative of a lake that is oligotrophic to mesotrophic in productivity.

The aquatic community in Snap Lake displays characteristics of both oligotrophic and mesotrophic lakes. Phytoplankton and zooplankton communities are most commonly used to classify the trophic status of lakes. Consequently, for the purposes of this document, Snap Lake will be classified as an oligo-mesotrophic lake.

Table 3.3 Summary of Snap Lake Baseline Conditions and Productivity Classification

Parameter	Baseline Conditions	Productivity Classification	Comments
Total Phosphorus (µg/L)	Mean = 8 Median = 8 Range = <1 to 26	upper oligotrophic to lower mesotrophic (OECD1982)	
Phytoplankton Chlorophyll *a* (µg/L)	Overall Mean Summer = 0.85 Range = 0.2 to 1.8	Ultra-oligotrophic to Oligotrophic (OECD1982)	
Secchi Depth (m)	Median = 3.5 Range = 1.25 to 4.5	mesotrophic (OECD1982)	
Phytoplankton Community	Diatoms & Dinoflagellates Dominated (By Biomass)	oligo-mesotrophic (Wetzel 1983, Watson *et al.* 1997, Kalff 2002, Holmgren 1985)	overall mean summer density low (285 cells/mL)
Zooplankton Community	Copepods Dominated (by Biomass): Calanoids (74.5 to 90.0%) Cyclopods (7.0 to 22.1%) Water fleas low (by Biomass): Cladocera (0.1 to 0.5%)	mesotrophic (Wetzel 1983, Gemza 1995)	overall mean summer density low (52,428 animals/m^3). numerically, shallow water areas dominated by Rotifiera (65 to 83% of total numbers).
Benthic Invertebrate Community	Numerically Dominated by Chironomidae (midge larvae) and Nematoda (roundworms)	indicative of low productive systems (Wetzel 1983, Resh and Rosenberg 1984, Merritt and Cummins 1996)	mean total numbers low (5,000 to 7,400 organisms/m^2)
Fish Community	lake trout Arctic grayling burbot round whitefish longnose sucker lake chub slimy sculpin	low numbers in catch (App. IX-11 of EAR) suggests productivity is low	lake chub, lake trout, and round whitefish most abundant in the catch

4.0 PHOSPHORUS ENRICHMENT IN SNAP LAKE DURING MINE CONSTRUCTION AND OPERATION

4.1 Baseline Water-Column Phosphorus and Nitrogen

The concentration of phosphorus is moderately low in Snap Lake water and within the range typically observed in other lakes in the region (Table 4.1, Puznicki 1996, Pienitz *et al.* 1997). Mean TP concentrations of Snap Lake ranged from 4 to 12 micrograms per litre (µg/L) among three years of baseline study. The trophic status of Snap Lake is in the upper oligotrophic to lower mesotrophic (low to moderate nutrient inputs) range based on the TP criterion established by OECD (Table 3.1). This indicates that the lake would be expected to have a moderately low biological productivity.

Table 4.1 Baseline Total Phosphorus and Total Nitrogen Concentrations in the Water Column of Snap Lake

Year	Total Phosphorus (µg/L)					Total Nitrogen[a] (µg/L)				
	n	Min	Max	Mean[b]	Median	n	Min	Max	Mean[b]	Median
1998	7	<2	10	5	4	0	---	---	---	---
1999	16	8	26	12	11	6	174	244	209	204
2001	9	<1	9	4	3	9	<d.l.	703	252	253
2001 AS [c]	8	<1	9	5	6	9	197	616	343	285
Summary	40	<1	26	8	8	24	<d.l.	703	275	254

(a) Total nitrogen was calculated as the sum of total Kjeldahl nitrogen and nitrate + nitrite.
(b) To calculate the mean, half the detection limit was used for values below analytical detection.
(c) AS = additional Snap Lake stations.
<d.l. = below detection limit, min = minimum, max = maximum, n = sample size.

The concentration of nitrogen is low in Snap Lake (Table 4.1) and typical of other lakes in the region (Pienitz *et al.* 1997). Mean total nitrogen (TN) concentrations of Snap Lake ranged from 209 to 343 µg/L among three years of baseline study.

4.2 Predicted Phosphorus Enrichment

Predicted phosphorus concentrations in the combined discharge during operations (range 4 to 110 µg/L, median 10 µg/L) are similar to concentrations in baseline streamwater inflows to Snap Lake (range 6 to 20 µg/L, median 10 µg/L; see EAR Table 9.4-6). Mine water discharge concentrations are expected to be higher during construction, when underground mine water flows are low and the discharge concentration would be dominated by effluent from the sewage treatment plant.

Nutrients were simulated by the eutrophication model, a component of the RMA suite of models (see EAR Appendix IX.7) in Snap Lake during construction and operation. The maximum potential changes in nutrients are summarized in Table 4.2. Continuous simulation results at two selected locations in Snap Lake are shown for total phosphorous in Figure 4.1. Concentrations at 250 m represent conditions in an area less than 1% of Snap Lake located around the discharge and concentrations at 2000 m represent average conditions in Snap Lake.

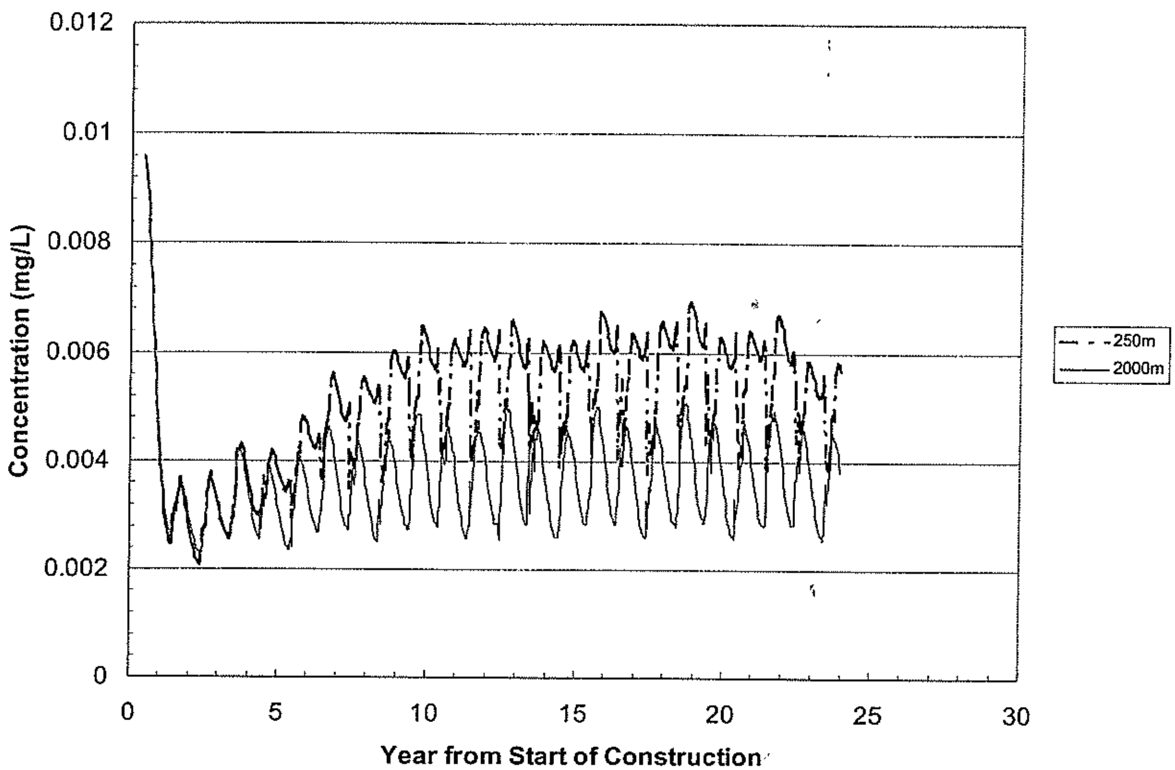
Table 4.2 Simulated Average Summer Nutrient Concentrations in Snap Lake, Baseline, and Operations

Parameter	Units	Simulated Baseline			Simulated Maximum Operations [a]		
		min	mean	max	min	mean	max
Ammonia	mg/L	0.001	0.001	0.017	0.11	0.39	1.23
Nitrate	mg/L	0.011	0.024	0.031	3.38	5.28	5.87
Total Phosphorus	µg/L	7	10	13	3	5	7
Phosphate	µg/L	1	2	3	2	2	2

[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 predicted concentrations of TP (Figure 4.1) were based on the model calibrated to simulate the maximum potential change in chlorophyll *a* concentrations within Snap Lake. The eutrophication model is sensitive to the rate of mineralization of organic phosphorus. A low value was selected for calibration, to provide an upper estimate of the utilization of phosphate released from the combined discharge during construction and operations. The predicted TP concentration decreases because of the low proportion of organic phosphorus in the discharge. The use of higher rates of mineralization of organic phosphorous in the model would result in smaller increases in simulated chlorophyll *a* concentrations during operations.

Figure 4.1 Simulated Total Phosphorus Concentrations in Snap Lake during Construction and Operations (250 and 2000 m from the discharge)



5.0 INCREASED PRODUCTIVITY IN SNAP LAKE DURING MINE CONSTRUCTION AND OPERATION

5.1 Water Transparency

5.1.1 Baseline Conditions

Water in Snap Lake is moderately transparent. Secchi depths measured in June and July of 1999 ranged from 1.25 to 4.5 m, with a median of 3.5 m. Observed water transparencies in the Snap Lake area is typical of a mesotrophic lake, based on the Secchi depth criterion established by the OECD (Table 3.1).

5.1.2 Effect of Phosphorus Enrichment

An increase in phytoplankton biomass due to phosphorus enrichment in Snap Lake could potentially reduce water transparency. The maximum phytoplankton chlorophyll *a* concentration predicted for Snap Lake during operation is 2.6 µg/L (see Section 5.4.2). Based on a study of 32 subarctic lakes near Yellowknife, Northwest Territories, dramatic decreases in water clarity usually begin to occur at chlorophyll *a* concentrations of 5-10 µg/L (Ostrofsky and Rigler 1987). The predicted maximum chlorophyll *a* concentrations for Snap Lake during mine operations are considerably lower than those reported to have a notable effect on water transparency. Thus, the effect on water transparency would be negligible, given the relatively small increase in phytoplankton biomass that is predicted to occur in Snap Lake during mine construction and operation.

5.2 Dissolved Oxygen

5.2.1 Baseline Conditions

Some lakes will stratify into two non-mixing layers in the summer: a layer of warmer, less dense water lying on a cooler, denser layer with a thin transitional layer in between. The reverse can happen in the winter with very cold (*i.e.*, less than 4°C), less dense water overlying warmer, denser water (approximately 4°C). When a parcel of water becomes isolated from the atmosphere by stratification or ice cover, anoxic conditions can occur if the store of DO in the water is depleted (Wetzel 1983).

Based on baseline data discussed in the EAR, Snap Lake does not exhibit thermal stratification in summer or winter. In summer, the lake is well mixed with no vertical gradients of DO concentrations. Snap Lake is relatively shallow (mean depth 5.2 m) and is well mixed from wind-driven circulation of bottom and surface waters. During winter, DO concentrations can decrease with depth (EAR Appendix IX.6, Tables IX.6-1 and 2).

In March 1999, DO concentrations were near saturation at the surface and declined with depth in the lower half of the water column at three of six sites where DO profiles were recorded. The minimum measured DO concentrations at the bottom of the water-column profiles ranged from 4.8 to 7.6 mg/L, whereas near-surface concentrations ranged from 16.6 to 17.8 mg/L.

The decline in winter DO concentrations with depth is likely due to the consumption of oxygen by bacterial decomposition of lake-bottom organic matter. Surface DO concentrations remain above the CCME (2002) water quality guideline of 6.5 and 9.5 mg/L for the protection of aquatic life (early life stages and other life stages, respectively), indicating adequate oxygen levels. In March 1999, DO concentrations were slightly below the CCME guideline for the protection of aquatic life at the lowest depth at site WQ2. Low DO concentrations are common in natural lakes subjected to winter ice cover due to oxygen consumption by bacterial mediated decomposition and lack of mixing. Studies have shown that mortality and/or loss of equilibrium occurred between 1.0 and 3.0 mg/L (Doudoroff and Shumway 1970, EIFAC 1973, USEPA 1986, CCME 1999).

5.2.2 Effect of Phosphorus Enrichment

An increase in the deposition of organic matter with greater lake productivity could further reduce winter DO concentrations in Snap Lake. Based on potential changes in oxygen consumption due to increased productivity, predicted winter DO concentrations in Snap Lake were obtained from modeling reported during the November/December Technical Sessions. Minimum DO concentrations at the bottom of Snap Lake could decline by a maximum of 1.0 to 2.2 mg/L. The maximum decrease in near-surface DO concentrations are anticipated to range between near zero to 1.0 mg/L. Given this preliminary scenario and based on the aforementioned March 1999 data, DO concentrations recorded at the bottom of some basins of Snap Lake could range between 2.6 and 5.4 mg/L. Similarly, DO concentrations near the surface of Snap Lake could range between 15.6 and 16.8 mg/L.

With these preliminary maximum predicted decreases, dissolved oxygen concentrations in the majority of Snap Lake (by volume and area), including all spawning shoals, would remain at levels that would not impact aquatic life. The area of bottom sediments, and consequently benthic invertebrates, exposed to reduce DO concentrations would increase. However, the area is expected to be small, and would certainly be less than 10% of the surface area of Snap Lake. Because of the limited extent of impacts affecting a small proportion of the aquatic community, the predicted impact would be negligible. For a more in-depth assessment of potential effects of DO decline on Snap Lake, see the technical memorandum on late-winter dissolved oxygen (De Beers in preparation).

5.3 Phytoplankton Community

5.3.1 Baseline Conditions

Phytoplankton chlorophyll *a*, density, and biomass concentrations in Snap Lake are low (Table 5.1). In 1999, summer averages of chlorophyll *a* ranged from 0.82 to 0.99 µg/L among three sampling stations, whereas those for density and biomass ranged from 258 to 329 organisms/mL and from 223 to 423 mg/m^3, respectively. The low phytoplankton biomass in Snap Lake is indicative of an ultra-oligotrophic to oligotrophic lake, based on the chlorophyll *a* criterion established by the OECD (Table 3.1). Detailed phytoplankton sampling results are presented in Table 9.5-2, Appendix IX.10 of the Snap Lake EAR.

Table 5.1 Phytoplankton Chlorophyll *a*, Density and Biomass in Snap Lake in 1999

Sampling Station [a]	Chlorophyll a (µg/L)	Density (number/mL)	Biomass (mg/m^3)
WQ1	0.82	258	423
WQ3	0.73	267	223
WQ7	0.99	329	328
Average	0.85	285	325

[a] Water Quality (WQ) stations 1, 3, and 7 (see EAR Figure 9.4-2).
Note: Concentrations represent summer average.

Despite of the overall low biomass, the composition of the phytoplankton community in Snap Lake is characteristic of an oligo-mesotrophic lake rather than an oligotrophic lake (Table 5.2). The phytoplankton communities of low-productivity lakes are typically dominated by golden algae and cryptophytes (Table 3.2). The phytoplankton community of Snap Lake, however, is comprised predominately of diatoms and dinoflagellates. Diatoms in particular, and dinoflagellates to a lesser extent, tend to dominate in slightly more productive waters. Cyanobacteria also contributed a moderate proportion towards the biomass of the phytoplankton community in Snap Lake (7.8-18.8%); this algal group is rare in oligotrophic lakes and increases in importance with lake productivity (Watson *et al.* 1997). Green algae, cryptomonads, and euglenoids had very low biomass in Snap Lake compared with other algal groups. Species of *Gymnodinium* (dinoflagellate), *Cyclotella* (diatom) and *Tabellaria* (diatom) were the dominant contributors to total phytoplankton biomass in Snap Lake.

Table 5.2 Composition of Phytoplankton Groups in Snap Lake in 1999

Phytoplankton Group	Mean Percent of Biomass [a]		
	WQ1	WQ3	WQ7
Cyanobacteria	11.5	18.8	7.8
Green algae	3.2	3.0	5.5
Cryptomonads	2.7	4.2	4.3
Golden algae	6.0	12.2	10.0
Dinoflagellates	19.2	17.1	15.8
Diatoms	55.3	42.3	56.6
Euglenoids	2.1	2.4	0

[a] Water Quality (WQ) stations 1, 3, and 7 (see EAR Figure 9.4-2).
Note: Values represent the summer average.

5.3.2 Effect of Phosphorus Enrichment

Phytoplankton biomass, measured as chlorophyll *a* concentration, was simulated with the eutrophication model a component of the RMA suite of models (see EAR Appendix IX.7) in Snap Lake during construction and operations using worst case assumptions that maximized the uptake of phosphate. The maximum potential changes in chlorophyll *a* are summarized in Table 5.3. Continuous simulation results at two selected locations in Snap Lake are shown for chlorophyll *a* in Figure 5.1.

Table 5.3 Simulated Average Summer Chlorophyll *a* Concentrations in Snap Lake, Baseline, and Operations

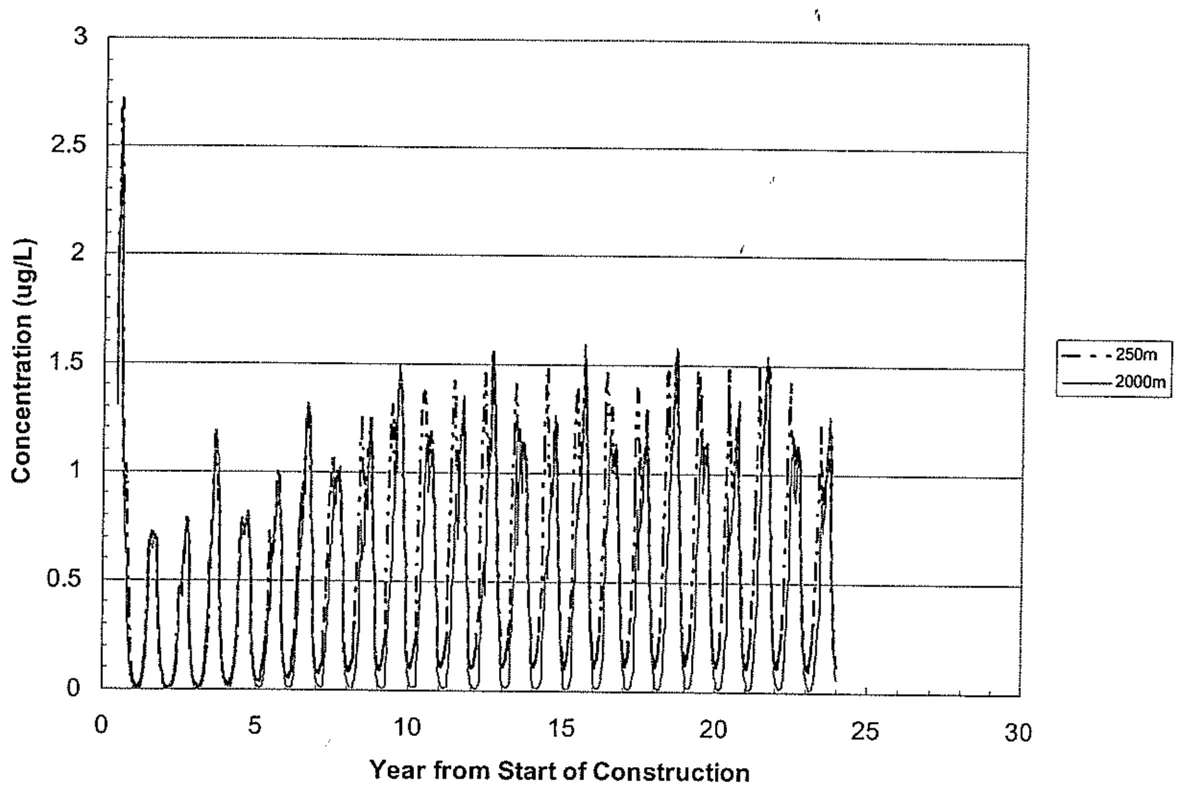
Baseline Chlorophyll *a* (µg/L)			Maximum Chlorophyll *a* during Operations [a] (µg/L)		
Min	Mean	Max	Min	Mean	Max
0.2	0.9	1.8	0.6	1.3	2.6

[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.

Phytoplankton biomass is predicted to increase slightly during mine construction and operation. Expected chlorophyll *a* concentrations are anticipated to reach a mean of 1.3 µg/L and a maximum of 2.6 µg/L. These concentrations remain within the range observed in oligotrophic lakes, as defined by the OECD chlorophyll *a* criterion (Table 3.1), and are only slightly above baseline levels typical of arctic and subarctic lakes (Pienitz *et al.* 1997). It should also be noted that the increase in phytoplankton biomass will be gradual, with peak concentrations occurring approximately in years 17 to 19 of operations.

Phosphorus enrichment is not expected to cause a shift in phytoplankton community composition in Snap Lake. Although there may be subtle changes in the relative abundance of species, considerable shifts in community structure are not anticipated as a result of the small increase in nutrient availability. The support for this position is that presently, the phytoplankton community in Snap Lake (dominated by diatoms and dinoflagellates) is characteristic of a lake with moderate-low productivity (*i.e.*, oligo-mesotrophic) (Section 3.2). Diatoms typically are the dominant phytoplankton taxonomic group in mesotrophic lakes (Watson *et al.* 1997, Wetzel 1983). Therefore, the dominant phytoplankton (*i.e.*, diatoms) of Snap Lake would very likely be tolerant to the minor nutrient increase caused by mine water release. Even with the predicted increases of TP (*e.g.*, from baseline mean of 8.0 μg/L to predicted mean of 10 μg/L) Snap Lake would still be classified as oligo-mesotrophic. It should also be noted that the composition and biomass of phytoplankton in undisturbed lakes fluctuates naturally; the relative abundance of species varies among seasons and from year to year (Wetzel 1983).

Figure 5.1 Simulated Chlorophyll *a* Concentrations in Snap Lake during Construction and Operations (250 and 2000 m from the discharge)



5.4 Zooplankton Community

5.4.1 Baseline Conditions

Zooplankton densities in Snap Lake are low (Table 5.4). In 1999, summer averages of zooplankton density at deep water sites (WQ1, WQ3, and WQ7) ranged from 24,927 to 35,979 individuals/m^3 while biomass ranged from 91,795 to 115,520 µg/m^3. Zooplankton density and biomass were higher at shallow habitat sites (SH1, SH2, SH3) with densities ranging from 29,844 to 102,459 individuals/m^3 and biomass ranging from 76,368 to 152,300 µg/m^3. The complete listing of zooplankton results can be found in the EAR in Appendix IX.10, Tables IX.10-5 through IX.10-7.

Table 5.4 Zooplankton Density and Biomass in Snap Lake in 1999

Sampling Station	Density (individuals/m^3)	Biomass (µg/m^3)
SH1 [(a)]	29,844	76,368
SH2 [(a)]	88,114	186,462
SH3 [(a)]	102,459	152,300
WQ1 [(b)]	33,243	115,520
WQ3 [(b)]	24,927	91,795
WQ7 [(b)]	35,979	109,774
Average	52,428	122,037

[(a)] Shallow habitat (SH) locations 1, 2, and 3 (see EAR Figure 9.4-2). Sampling station only sampled in July, 1999.

[(b)] Water quality (WQ) sites 1, 3, and 7 (see EAR Figure 9.4-2). Values represent the summer average.

The zooplankton community in Snap Lake is dominated by calanoid copepods and to a lesser extent cyclopoid copepods (Table 5.5). In 1999, calanoid copepods accounted for 74.5 to 90.0 % of zooplankton total biomass while cyclopoid copepods accounted for 7.0 to 22.1 %. Rotifers and cladocerans had very low biomass in Snap Lake. The dominant species of calanoid copepods were *Heterocope septentrionalis, Leptodiaptomus sicilis, Leptodiaptomus minutus,* and copepodids (immature life-history stage of copepods). In July, *Laptodiaptomus minutus* accounted for 41% to 60% of the zooplankton biomass at the open water sites. In August and September, *Leptodiaptomus sicilis* dominated the open water sites (46 to 80%, by biomass).

Table 5.5 Composition of Zooplankton Groups in Snap Lake in 1999

Zooplankton Group	Percent Biomass					
	SH1[(a)]	SH2[(a)]	SH3[(a)]	WQ1[(b)]	WQ3[(b)]	WQ7[(b)]
Rotifers	2.8	3.3	6.0	1.1	1.4	1.6
Calanoid copepods	90.0	74.5	76.3	79.0	84.8	78.5
Cyclopoid copepods	7.0	22.1	17.3	19.8	13.6	19.3
Cladocerans	0.5	0.1	0.4	0.1	0.2	0.5

[(a)] Shallow habitat (SH) locations 1, 2, and 3 (see EAR Figure 9.4-2). Sampling station only sampled in July, 1999.
[(b)] Water quality (WQ) sites 1, 3, and 7 (see EAR Figure 9.4-2). Values represent the summer average.

5.4.2 Effect of Phosphorus Enrichment

The stimulation of phytoplankton growth from phosphorus enrichment will increase the food supply available for zooplankton in Snap Lake. As a result, phosphorus enrichment may also indirectly increase zooplankton biomass (Hanson and Peters 1984, Shortreed and Stockner 1986). However, given the low maximum predicted increase in primary productivity in Snap Lake, the increase in zooplankton biomass would be minimal. Energy transfer between trophic levels is inefficient and therefore zooplankton biomass would increase proportionally less than phytoplankton biomass (McCauley and Kalff 1981, Kalff 2002). Typical transfer efficiencies between phytoplankton and zooplankton usually average less than 10% (Wetzel 1983).

A study of lakes in the Yukon and Northwest Territories indicated that zooplankton community composition was not related to nutrient status (Swadling *et al.* 2000). Zooplankton community structure is likely controlled more by predation pressure (*i.e.*, a top-down force) than food availability (*i.e.*, a bottom-up force) (McQueen *et al.* 1986, Carpenter 1989, Carpenter *et al.* 2001). Predation pressure from carnivorous zooplankton such as *Heterocope septentrionalis* (a dominant species in Snap Lake) and from planktivorous fish have a major impact on the size structure and species composition of zooplankton (O'Brien *et al.* 1992, O'Brien 2001). Brett and Goldman (1997) conducted a statistical analysis of numerous trophic studies to identify generalizations on the relative importance of resource control and predation on aquatic communities. They found that while phytoplankton biomass was strongly controlled by nutrient availability, zooplankton biomass was more strongly controlled by fish predation. As with the phytoplankton community (Section 5.3 above), the composition and biomass of zooplankton in undisturbed lakes fluctuates naturally; the relative abundance of species varies among seasons and from year to year (Wetzel 1983).

A shift in zooplankton community structure is not predicted as a result of phosphorus loading in Snap Lake. There may be subtle changes in the relative abundance of some zooplankton species; however, although changes in relative abundance of zooplankton species is also a natural occurrence, a shift in the dominance of zooplankton groups would not occur with the low increase in primary productivity that is predicted.

5.5 Benthic Invertebrate Community

5.5.1 Baseline Conditions

Benthic invertebrates were collected at four sites in Snap Lake during the fall 1999 sampling program. Mean total benthic invertebrate abundance varied between 5,000 and 7,400 organisms/m^2 (Table 5.6). Total taxonomic richness (the number of taxa at the lowest level of identification) varied little among sites. The total number of taxa found (calculated by pooling all the replicate samples at a site) was between 27 and 30. Chironomid larvae (midges), predominantly represented by the Tribes Chironomini and Tanytarsini, and nematode worms dominated the benthic community; these two groups accounted for 71% and 24%, respectively, of the total invertebrates collected in Snap Lake. Detailed benthic invertebrate sampling results are presented in the EAR in Appendix IX.10, Tables IX.10-11 through IX.10-15.

Table 5.6 Benthic Invertebrate Data Collected in Snap Lake, Fall 1999

Variable	Snap Lake			
	SH1 [(a)]	SH2	SH3	WQ3
Abundance and Taxonomic Richness (site mean ± one standard error)				
Total abundance (no./m^2)	7367 ± 2607	5010 ± 1230	5447 ± 919	6937 ± 1913
Mean richness/site	15.7 ± 1.6	14.5 ± 1.5	14.2 ± 1.3	11.8 ± 2.2
Total richness/site	30	27	28	27
Community Composition (site mean %)				
Chironomidae	53.1	81.3	82.7	66.7
Nematoda	40.1	14.8	12.8	30.0
Mollusca	4.4	2.9	3.5	2.5
Other groups [(b)]	2.4	1.1	0.9	0.9

(a) Shallow habitat (SH) locations 1, 2, and 3; water quality (WQ) location 3.
(b) Includes Oligochaeta, Hirudinea, Amphipoda, Hydracarina, Collembola, Ephemeroptera, Hemiptera, and Trichoptera.

5.5.2 Effect of Phosphorus Enrichment

It is difficult to predict whether benthic invertebrates in Snap Lake will respond to phosphorus enrichment during mine construction and operation. The response of benthic invertebrates to lake fertilization is less predictable than for planktonic communities (Hanson and Peters 1984). Benthic invertebrates feed on primary producers as well as detrital matter originating from the lake watershed. Phosphorus enrichment, in general, will increase primary production, which is only one component of the food supply for benthic invertebrates. The effects of altered primary productivity are variable; causing an increase in benthic invertebrate biomass in some lakes (*e.g.*, Rasmussen and Kalff 1987) and not in others (*e.g.*, Dinsmore *et al.* 1999).

Chironomids, the dominant group of benthic invertebrates encountered in Snap Lake, may or may not respond to an increase in primary productivity. For example, during experimental fertilization of an Alaskan Arctic lake, chironomids did not increase in biomass and were evidently not food limited (Hershey 1992). In contrast, chironomid abundance increased in fertilized lakes in Saqvaqjuac, Nunavut (Welch *et al.* 1989). Given the relatively low maximum predicted increase in primary productivity, it is anticipated that an increase in benthic invertebrate biomass or abundance would be minimal, at best. The small increase in food supply for benthic invertebrates would not cause a decline in the dominance of chironomids in Snap Lake because they have been documented to be adaptable to lake eutrophication processes (Johnson *et al.* 1989, Lods-Crozet and Lachavanne 1994).

In winter, depressed DO concentrations during mine construction and operation could impact the benthic invertebrate community. Preliminary data indicate that DO concentrations may be as low as 2.6 to 5.4 mg/L at the bottom of some basins within Snap Lake (see Section 5.3). Many benthic invertebrates are intolerant to low DO concentrations and may not survive in deep basins that feature considerably low DO concentrations (*i.e.*, generally accepted to be less than approximately 3.0 mg/L for most aquatic organisms [see Section 5.2.1]). Species richness would likely decline in basins with extremely low DO because only species adapted to those conditions would survive. However, given that there is only a potential for DO concentrations to reach 3.0 mg/L or less, the possibility for effects to be realized on the benthic invertebrate community would be low. Species inhabiting oxygen rich areas of the lake that are not adapted to low DO would reclaim the deep basins when DO conditions improve following mine closure.

Life-cycle adaptations or behaviours have evolved in many aquatic invertebrates that enable species to utilize favourable periods for growth or avoid extreme physical conditions. This may involve diapause or quiescent periods in a resistant life stage for avoiding excessively low oxygen. For example, populations of the midge genus *Chironomus* (this genus was encountered in samples collected from Snap Lake) are able to inhabit oxygen depleted sediments and low water DO concentrations by building U-shaped tubes with both openings at the mud-water interface. Body undulations cause a current of water, providing oxygen and particulate food to be drawn through the tube. Midges of the genus *Chironomus* also feature haemoglobin in their blood (Merritt and Cummins 1996).

The predicted increase in productivity is expected to have a negligible impact on benthic invertebrate biomass. Low DO concentrations may cause localized, short-term effects on species richness in small areas but the whole lake benthic invertebrate community is not expected to change. For a more in-depth assessment of potential effects of DO decline on Snap Lake, see the technical memorandum on winter dissolved oxygen (De Beers in preparation).

5.6 Fish Community

5.6.1 Baseline Conditions

A total of seven species of fish were captured in Snap Lake in 1998 and 1999 (Table 5.7). These included longnose sucker (*Catostomus catostomus*), burbot (*Lota lota*), lake trout (*Salvelinus namaycush*), round whitefish (*Prosopium cylindraceum*), Arctic grayling (*Thymallus arcticus*), lake chub (*Couesius plumbeus*), and slimy sculpin (*Cottus cognatus*). Lake trout are considered to be the top predator species of the fish community within Snap Lake.

Table 5.7 Summary of Fish Species Captured in Snap Lake in 1998 and 1999

Year	Fish Species Captured	Number Captured
1998 [a]	longnose sucker	17
	burbot	4
	lake trout	30
	round whitefish	52
	Arctic grayling	16
1999	round whitefish	46
	Arctic grayling	10
	burbot	1
	lake chub	193
	longnose sucker	6
	lake trout	119
	slimy sculpin	1

[a] Source: Hallam Knight Piesold Ltd. (1998).

Detailed data collected on fish captured or encountered in Snap Lake are provided in the EAR. The minimum, maximum, and mean fork length, weight, age, gonad weight, condition factor, liver somatic index, and gonadal somatic index from fish caught in gillnets or angled are summarized in Appendix IX.11, Table IX.11-3. Appendix IX.11, Table IX.11-2 includes data on fish that were captured and released, and fish that were retained for tissue analyses.

5.6.2 Effect of Phosphorus Enrichment

Phosphorus enrichment can potentially affect the fish community in a lake by changing their food supply (*i.e.*, increasing productivity and biomass of lower trophic levels) and altering habitat conditions (*e.g.*, altering DO concentrations). Phosphorus enrichment also increases the deposition of organic matter to the lake bottom and could potentially affect the quality of spawning habitats. Greater rates of organic matter decomposition can potentially reduce DO concentrations to the point where it becomes harmful to fish or other aquatic life (see Section 5.3 above and the detailed DO assessment technical memorandum on winter dissolved oxygen [De Beers in preparation]).

The predicted increase in productivity in Snap Lake likely will not change the type of food available for lake trout and other fish species. Younger lake trout feed primarily on zooplankton and benthic invertebrates (Adams 1997). Adult lake trout are recognized as "opportunistic" feeders, consuming a wide range of organisms including zooplankton, benthic invertebrates, and fish. Examination of gut contents of adult lake trout captured in Snap Lake during baseline studies revealed that they feed primarily on aquatic invertebrates (*e.g.*, mayfly and chironomid larvae) and forage fish such as round whitefish. Round whitefish and lake chub commonly feed on benthic invertebrates and zooplankton (Scott and Crossman 1979). Slimy sculpin and longnose sucker primarily feed on benthic invertebrates (Scott and Crossman 1979). The remaining fish species inhabiting Snap Lake, including Arctic grayling, tend to feed on aquatic invertebrates and larger prey items (*i.e.*, fish) as they increase in size/age (Scott and Crossman 1979). Although the biomass of zooplankton and benthic invertebrates may increase slightly, some invertebrate species may be intolerant to anticipated lower DO concentrations in some of the basins. Because it is uncertain that predicted decreases in near-bottom DO will actually reach concentrations (*i.e.*, 1.0 to 3.0 mg.L) that are known to limit animals (Section 5.2; Doudoroff and Shumway 1970, EIFAC 1973, USEPA 1986, CCME 1999), potential increases in the production of these two communities will be small. Thus, the species composition and abundance of these invertebrate communities are not predicted to change (Sections 5.5, 5.2). Therefore, the type and amount of food items available for fish inhabiting Snap Lake, considered as a whole, is not expected to be altered considerably by phosphorus enrichment. In summary, no change in the food supply to fish is predicted as a result of phosphorus enrichment in Snap Lake.

6.0 PRODUCTIVITY OF SNAP LAKE FOLLOWING MINE CLOSURE

The productivity of Snap Lake is expected to return to baseline conditions following mine closure and the termination of mine water release. Eutrophication is a reversible process and lake productivity declines with reductions in nutrient loading (Holmgren 1985). Kodiak Lake, at the BHP Ekati™ Diamond Mine, increased in productivity after receiving treated sewage for two years and has subsequently shown signs of rapid recovery (Table 6.1). Meretta Lake in the high arctic is also returning to near-baseline conditions following extensive phosphorus loading over several decades. The examples provided in Table 6.1 demonstrate that northern lakes can recover from nutrient loading and increased productivity on a greater scale than would occur in Snap Lake.

Aquatic community composition typically return to baseline conditions following reductions in nutrient loading. The phytoplankton of Meretta Lake returned to a golden algae and cryptophyte dominated community typical of an oligotrophic lake (Douglas and Smol 2000) shortly following the termination of fertilization activities. In an arctic fertilization experiment, Bettez *et al.* (2002) also found that the structure of the microzooplankton community returned to baseline characteristics when fertilization ceased.

The time required for primary production to return to baseline conditions in Snap Lake following mine closure will depend, in part, on the total loading of phosphorus over the life of the mine. Most of the discussion in this document applies to the maximum effect nutrient addition could have on the biota of Snap Lake, which is expected to occur for less than the mine life. Considering that the total phosphorus loading to Snap Lake will be low and the associated increase in productivity will also be low, a reasonably rapid recovery is expected. It should also be noted that phytoplankton community composition was indicative of an oligo-mesotrophic lake.

Table 6.1 Examples of Recovery from Phosphorus Enrichment in Arctic and Subarctic Lakes

Lake	Baseline		Fertilization			Post-Fertilization		
	TP (µg/L)	Chl *a* (µg/L)	Time Period	TP (µg/L)	Chl *a* (µg/L)	Year	TP (µg/L)	Chl *a* (µg/L)
Kodiak Lake [a] (Northwest Territories)	10-14	0.5-1.1	1997 to 1999	12-25	2.2-8.0	2001	6	1.3
Lake Asvalltjarn [b] (Sweden)	---	---	1964 to 1974	168	---	1978 to 1980	74	---
Meretta Lake [c] (Nunavut)	4 [d]	0.1-0.7[d]	1949 to 1970s	Maximum >200	3-5	1990s	<10-23	<2

[a] BHP (2001).
[b] Holmgren (1985).
[c] Schindler *et al.* (1974), Douglas and Smol (2000).
[d] Baseline conditions are for a reference lake (Char Lake).

7.0 SUMMARY AND CONCLUSIONS

Elevated phosphorus in Snap Lake during mine construction and operations is expected to have a low or negligible impact on resident aquatic communities. Phytoplankton biomass will increase slightly but maximum concentrations of TP are expected to remain at levels typical of baseline conditions (*i.e.*, a oligo-mesotrophic lake). Dominant phytoplankton species in Snap Lake are characteristic of a mesotrophic lake and therefore a major shift in community structure is unlikely to occur. Zooplankton biomass may increase slightly but community structure should not be affected because of the minor changes to phytoplankton production anticipated and 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 fish species 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 deposition of organic matter in Snap Lake may reduce winter DO concentrations. DO concentrations low enough to limit habitat use may occur in a small portion of available fish and benthic invertebrate habitat in Snap Lake (*i.e.*, less than 10% of surface area). The species richness of benthic invertebrates would decrease in areas of low DO.

The major conclusions regarding the predicted increase of phosphorus concentration in Snap Lake during operations and its effects on the aquatic community in the lake are as follows:

- Only a slight increase in phytoplankton biomass is expected in Snap Lake in response to phosphorus enrichment. Zooplankton and benthic invertebrate biomass may also increase, albeit marginally, in response to greater food availability. Inefficiency in the transfer of energy between trophic levels will likely mean that the effect on high trophic levels will not be as distinct.

- Considerable shifts in the aquatic communities (phytoplankton, zooplankton, fish) are not anticipated. Loss of aquatic species presently inhabiting Snap Lake should not occur. Benthic invertebrate species richness may decline in a small portion of the lake because of potential low winter DO concentrations, but lake-wide changes in the invertebrate community are not expected.

- Although minor effects of phosphorus loading to lower trophic levels are possible, inefficiencies in energy transfers between trophic levels suggests that fish populations in Snap Lake likely will not be affected. Projected declines in late winter DO concentrations may limit the use of bottom habitats in some basins in the lake, however, this area is small, and potential for DO to reach harmful concentrations also is low.

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