TAK 0891

DE BEERS

A DIAMOND IS FOREVER

07 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: Potential Effects of Total Dissolved Solids on the Aquatic Communities in Snap Lake

Please accept the attached technical memo titled "Potential Effects of Increased Total Dissolved Solids on Aquatic Communities in 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

Robin Johnstone
Senior Environmental Manager

DE BEERS CANADA MINING INC.

#300 – 5102 50th AVENUE
YELLOWKNIFE NT X1A 3S8 CANADA
TEL (867) 766-7300 FAX (867) 766-7347

REPORT ON

POTENTIAL EFFECTS OF INCREASED TOTAL DISSOLVED SOLIDS ON AQUATIC COMMUNITES IN 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
2 Copies - Golder Associates Ltd., Saskatoon, Saskatchewan

February 2003
022-6659-5300

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

The concentration of total dissolved solids (TDS) will increase in Snap Lake during mine construction and operation (Environmental Assessment Report [EAR] Section 9.4). Concerns were raised during the Mackenzie Valley Environmental Impact Review Board Technical Sessions in November regarding the impact of elevated TDS on aquatic communities and particularly on the population of lake trout (*Salvelinus namaycush*). Questions were also raised regarding the level of conservatism used to model future TDS concentrations in Snap Lake. This technical memorandum was prepared to address those concerns and elaborates on the potential for effects of high TDS on aquatic communities in Snap Lake. Items presented include the following: a) predicted TDS levels in Snap Lake, b) regulatory TDS guidelines and relevant definitions in the scientific literature, c) a review of relevant literature, and d) conclusions regarding potential effects of predicted elevated TDS concentrations in Snap Lake.

TDS is an expression of salinity and a measure of the sum of all dissolved ionic constituents in water. There is no Canadian TDS guideline for the protection of aquatic life, nor is there a site specific criterion.

The toxicity of TDS is related to several factors and depends on the specific ions in question (*e.g.*, calcium, magnesium, sodium, potassium, chloride, sulphate, carbonate, bicarbonate). An increase in TDS may also alter the osmotic stress on aquatic biota. Concentrations of solutes in organism cells are higher than in lake water, and as a result, water tends to move into cells by osmosis. Organisms in softwater lakes are well adapted to high osmotic stress and a change in osmotic conditions could cause a shift in the composition of aquatic communities towards other species. Changes in community composition resulting from increased TDS could potentially impact higher trophic levels by altering their food supply.

An extensive literature review was conducted to document potential ecosystem changes that could occur in Snap Lake. Information was collected from scientific journals and technical reports on the toxicity of TDS and the predicted major constituents of TDS in Snap Lake (*i.e.*, chloride and calcium), and the response of aquatic organisms to increases in TDS. The literature review showed that little is known about the effects of increases in TDS, calcium and chloride on zooplankton, phytoplankton, benthic invertebrate, and fish communities, especially those in arctic and subarctic lakes. Much of the available information comes from laboratory toxicity tests where test concentrations often exceed environmentally relevant concentrations, test species are unacclimated, and test species are not common to arctic waters. Therefore, the literature also was examined to identify the concentration range where aquatic biota such as lake trout are found.

2.0 SCOPE AND OBJECTIVES

The objective of this technical memorandum was to elaborate on the potential impacts of increased TDS on aquatic communities in Snap Lake. 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 TDS, calcium and chloride loading, using the GoldSim model, conducted for the EAR (De Beers 2002);
- scientific literature on acute and chronic toxicity thresholds for key aquatic organisms; and,
- scientific literature on aquatic biota, particularly lake trout, that exist in lakes with TDS levels similar to those predicted for Snap Lake.

Effects of increased TDS were examined for phytoplankton, zooplankton, benthic invertebrates, and fish in Snap Lake. Expected changes in Snap Lake are addressed for the period of mine construction and operation as well as for post-closure.

Chloride and calcium are the principal constituent ions that will increase TDS in Snap Lake during mine operation and construction. There are no Canadian Council of Ministers of the Environment (CCME) water quality guidelines or site-specific water quality benchmarks established for TDS, calcium and chloride (CCME 2002). However, there is a United States Environmental Protection Agency (EPA) criterion for chloride as well as one for the province of Quebec.

The maximum predicted concentration of chloride in Snap Lake is below the EPA and Quebec water quality criterion of 230 mg/L (U.S. EPA 1988). This criterion is intended to prevent significant toxic effects in chronic exposures when chloride is associated with sodium. This criterion may not be adequately protective when the chloride is associated with potassium, calcium, or magnesium (U.S. EPA 1988). Further elaborations with regard to the degree of potential chloride toxic and paired cations is provided in Section 4.1.

3.0 INCREASE IN TOTAL DISSOLVED SOLIDS IN SNAP LAKE DURING MINE CONSTRUCTION AND OPERATIONS

3.1 Baseline Total Dissolved Solids

TDS, an expression of salinity, is a measure of the sum of all dissolved ionic constituents in water. The primary ions in freshwater lakes that make up the TDS measurement include:

- cations: Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}; and,
- anions: HCO_3^-, CO_3^{2-}, SO_4^{2-}, and Cl^-.

Median baseline TDS is low in Snap Lake at 15 mg/L (Table 3.1). However, baseline TDS concentrations in Snap Lake have been observed as high as 70 mg/L. Calcium is the primary cation in Snap Lake water with a median concentration of 1.34 mg/L. The median chloride concentration is less than 0.2 mg/L. Both calcium and chloride are at concentrations similar to other arctic lakes (Table 3.2).

3.2 Predicted Increase in Total Dissolved Solids

TDS concentrations were predicted to increase in Snap Lake from the median baseline concentration of about 15 mg/L to a maximum average whole-lake concentration in Snap Lake of approximately 350 mg/L during winter ice cover. During the summer months the TDS concentration in 1% of Snap Lake (*i.e.*, 250 m from the diffuser) is expected to reach 444 mg/L. The ions responsible for the increase in TDS concentrations will be primarily chloride and calcium. These ions originate from groundwater. The predicted change in TDS concentration in Snap Lake over time is shown in Figure 3.1. Concentrations representing average lake concentrations in Figure 3.1 are shown at 250 m (444 mg/L) and at 2000 m (350 mg/L) from the diffuser. The predicted spatial distribution of TDS concentrations in Snap Lake for a typical period during year 19 of operations is shown in Figure 3.2. Maximum simulated TDS concentrations in Snap Lake occur during year 19 of operations; therefore, this year represents worst-case conditions for TDS.

Table 3.1 Summary of Baseline Water Quality in Snap Lake from 1998-2001

Parameter	Units	Snap Lake												Water Quality Guidelines[a]	
		1998 (n = 5 to 8)[b]			1999 (n = 6 to 16)			2001 (n = 3 to 9)			Summary (1998-2001) (n = 3 to 33)			Drinking Water	Aquatic Life
		min	median	max	min	median	max	min	median	max	min	median	max		
Total Dissolved Solids	mg/L	< 10	13	25	<10	15	19	<10	30	70	<10	15	70	≤500 [c]	-
Bicarbonate	$mgCO_3/L$	-	-	-	5	6	7	7	10	12	5	7	12	-	-
Carbonate	mg/L	-	-	-	-	-	-	<5	<5	<5	<5	<5	<5		
Calcium	mg/L	0.93	0.99	1.81	1.06	1.34	1.76	1.26	1.38	2.43	0.93	1.34	2.43	-	-
Chloride	mg/L	0.2	0.5	0.81	<0.2	<0.2	0.2	<1	<1	<1	<0.2	<0.2	<1	≤250[c]	230
Fluoride	mg/L	-	-	-	0.04	0.04	0.04	<0.05	<0.05	0.06	0.04	<0.05	0.06	1.5	-
Hydroxide	mg/L	-	-	-	-	-	-	<5	<5	<5	<5	<5	<5		
Magnesium	mg/L	0.48	0.52	0.94	0.56	0.63	0.78	0.54	0.58	1.01	0.48	0.61	1.01	-	-
Potassium	mg/L	0.40	0.41	0.78	0.32	0.47	0.58	0.41	0.43	0.77	0.32	0.44	0.78	-	-
Silica	mg/L	-	-	-	-	-	-	0.4	0.4	0.6	0.4	0.4	0.6	-	-
Sodium	mg/L	0.44	0.47	0.94	0.44	0.53	0.7	0.5	0.6	1	0.44	0.57	1	≤200[c]	-
Sulphate	mg/L	3	3.5	6	<3	<3	36	1.3	1.5	2.7	1.3	3	36	≤500[c]	-

[a] All guidelines are from CCME (2002), with the exception of the aquatic life guideline for chloride, which is from United States EPA (1999).

[b] The parameters analyzed vary between sampling events. Refer to the EAR Appendix IX.6 for detailed results.

[c] Aesthetic objective.

Notes: < = less than detection limit

Statistics (*i.e.*, minimum, median, and maximum) were calculated using the method outlined in the EAR Appendix IX.5.

$mgCO_3/L$ = milligram carbonate per litre; mg/L = milligram per litre

Table 3.2 Comparison of Cation Data for Snap Lake and Other Forested Tundra Lakes

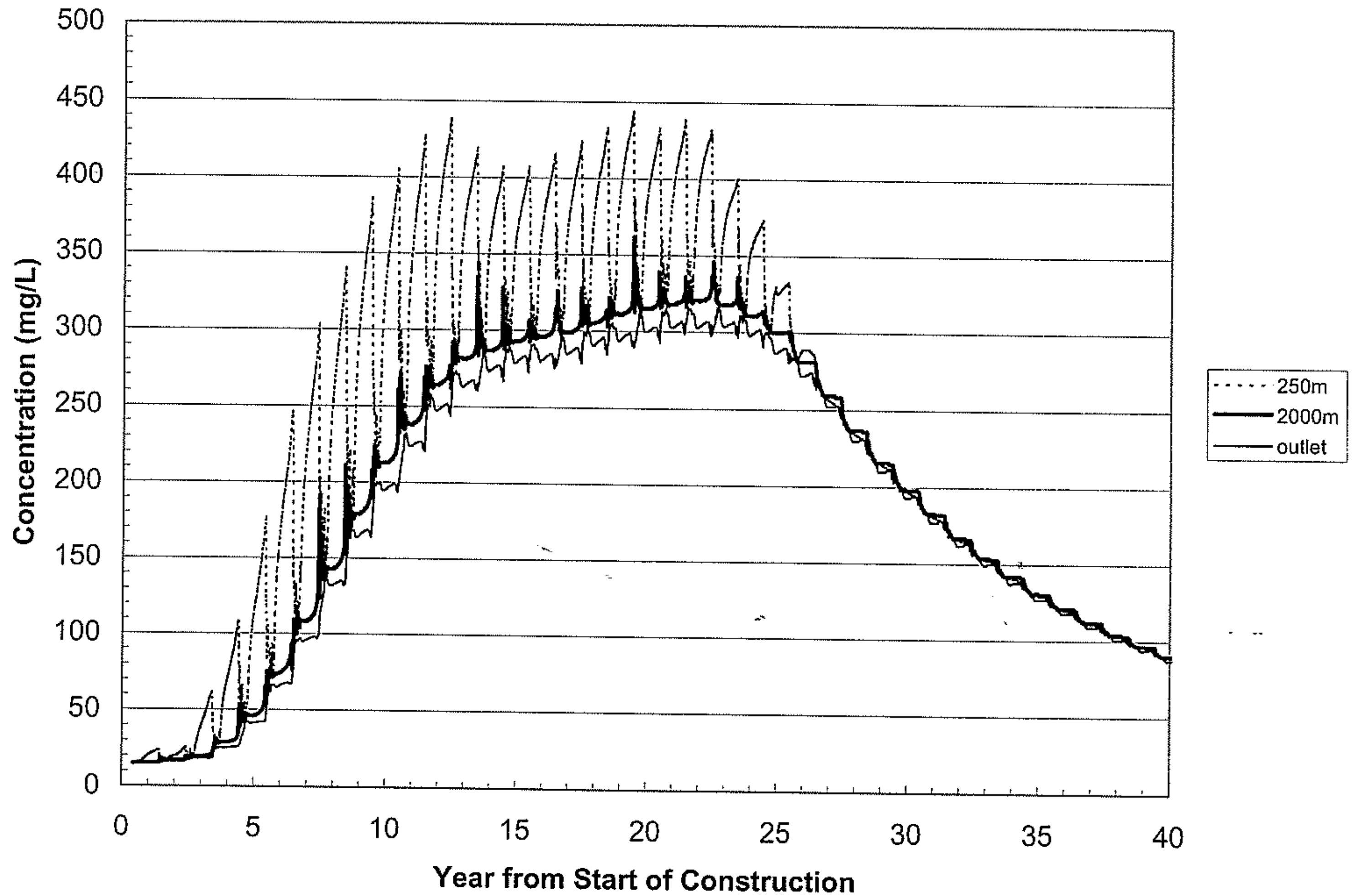
Forest Tundra Lakes			Snap Lake		
Cations	Average (mg/L)	Percent	Cations	Average (mg/L)	Percent
Ca^{2+}	2.01	54%	Ca^{2+}	1.34	49%
Na^{+}	0.78	21%	Na^{+}	0.57	21%
K^{+}	0.59	16%	K^{+}	0.44	16%
SiO_2	0.32	9%	SiO_2	0.4	14%
Cl^{-}	0.69		Cl^{-}	<0.2	

Adapted from Pienitz *et al.* 1997.
mg/L = milligrams per litre.

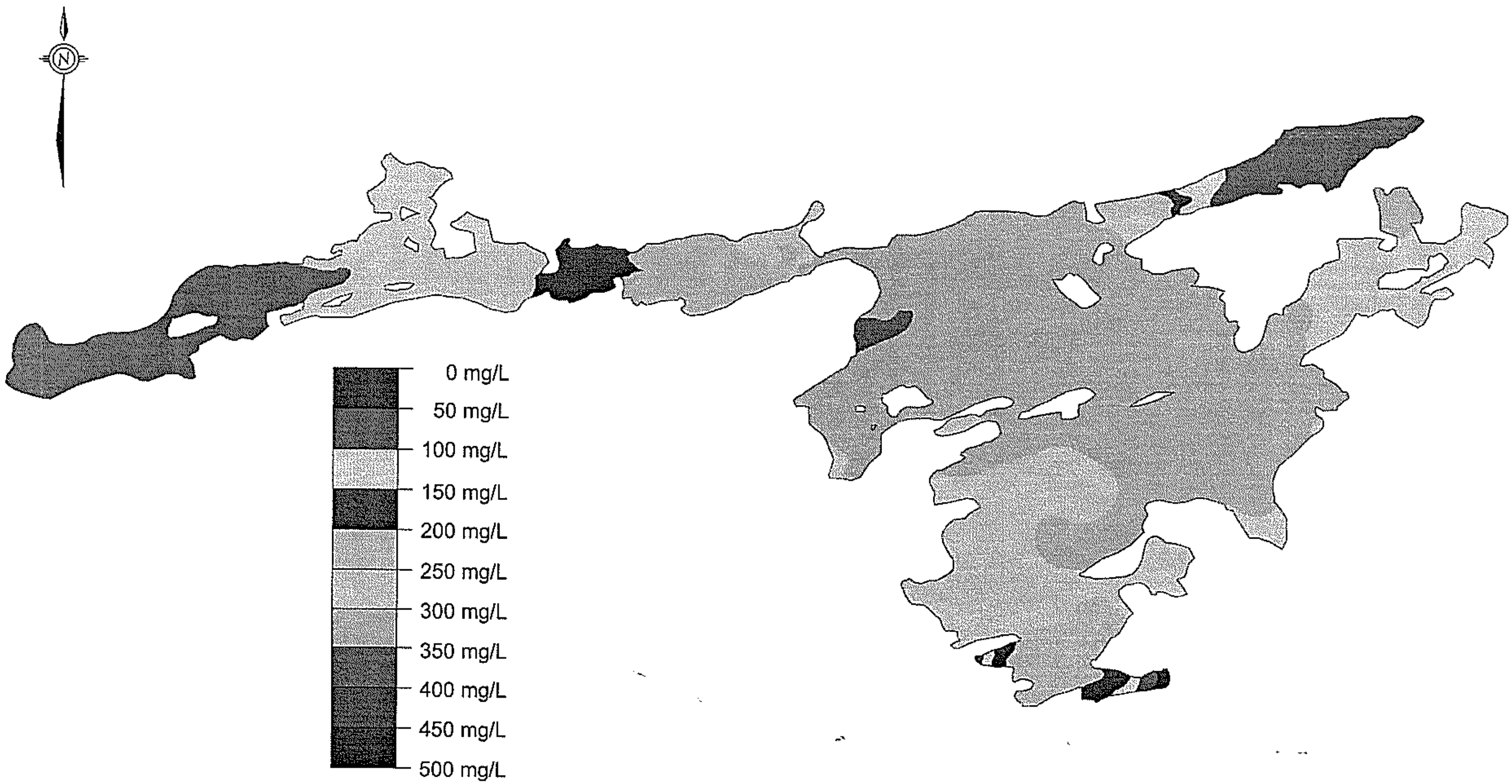
3.3 Predicted Increases in Calcium and Chloride

The average baseline concentrations for calcium and chloride are very low at 1.34 mg/L and <0.2 mg/L, respectively. The proposed Snap Lake Diamond Project is expected to raise lake-wide water-column calcium concentrations to a maximum of 88 mg/L in Snap Lake during winter ice cover. The maximum concentration of calcium is expected to be 113 mg/L in 1% (*i.e.*, within 250 m of the diffuser) of the lake area during the summer. The 113 mg/L maximum concentration is a product of effluent concentration and wind dynamics in operation years 15-25. The maximum lake-wide chloride concentration is expected to reach 137 mg/L in Snap Lake during the winter. Chloride concentration in 1% (*i.e.*, within 250 m of the diffuser) of Snap Lake during the summer months is expected to reach 177 mg/L.

Figure 3.1 **Time Series of Simulated Total Dissolved Solids Concentrations in Snap Lake, during Construction, Operations, and Post-closure**



N:\Active\6600\022-6659 De Beers EA Support\cad\5300\ Drawing file: 6659-5300-TDS-FIG3-2.dwg Feb 04, 2003 - 4:26pm



PROJECT	DE BEERS			
TITLE	SPATIAL PATTERN OF TOTAL DISSOLVED SOLIDS CONCENTRATIONS IN SNAP LAKE DURING OPERATIONS (YEAR 19)			
Golder Associates, Saskatoon, Saskatchewan	PROJECT No. 022-6659.5300			FILE No.
	DESIGN			SCALE AS SHOWN REV. 0
	CADD	SIB	04/02/03	FIGURE: 3.2
	CHECK			
	REVIEW			

4.0 PREDICTED RESPONSE OF AQUATIC COMMUNITIES TO THE INCREASE IN TOTAL DISSOLVED SOLIDS IN SNAP LAKE

4.1 Water Quality Guidelines for Total Dissolved Solids, Calcium and Chloride

There are no CCME water quality guidelines or site-specific water quality benchmarks established for TDS, calcium and chloride to protect aquatic life (CCME 2002). Lakes are considered to be saline when TDS concentrations at or greater than 3,000 mg/L (Hammer *et al.* 1975, Timms *et al.* 1986, Mandaville 2002). At TDS concentrations greater than 3,000 mg/L, freshwater biota begins to disappear (Hammer *et al.* 1975). This threshold is almost ten times higher than the maximum TDS concentration predicted for Snap Lake during mine construction and operation.

According to the United States EPA, the chloride ion is considered to have chronic effects on aquatic organisms above concentrations of 372.1 mg/L (U.S. EPA 1988). The EPA and Quebec water quality chloride criterion for the protection of aquatic life is 230 mg/L. The predicted Snap Lake peak concentrations of 177 mg/L (summer) and 137 mg/L (winter) are below the EPA and Quebec chloride guideline.

Current scientific literature and a modeling approach to assessing toxicity of TDS do not consider calcium ions because it has no correlation with toxicity (Gulley *et al.* 1992, Mount *et al.* 1997, Tietge *et al.* 1997). For example, Mount *et al.* (1997) conducted a suite of almost 3,000 laboratory tests to identify the toxicity of various salt solutions on *Ceriodaphnia dubia*, *Daphnia magna* and the fathead minnow (*Pimephales promelas*). They then used this extensive database to develop statistical models that predict the toxicity of major ions. Calcium was not included in the statistical models to predict toxicity of a mixed salt solution because it did not provide any explanatory power. Mount *et al.* (1997) concluded that the toxicity of calcium salts such as calcium chloride is primarily attributable to the corresponding anion, in this case, chloride. According to these results, chloride is the TDS constituent of potential concern in Snap Lake mine water effluent.

The degree to which chloride is toxic may depend on its corresponding cation(s). The U.S. EPA document for the chloride guideline suggests that chloride is more toxic in combination with calcium than it is in combination with sodium and cautions that the criterion of 230 mg/L only applies to sodium chloride (U.S. EPA 1988). Because the corresponding cation in Snap Lake is predominately calcium, it is not known whether or not predicted chloride concentrations in Snap Lake would be toxic to aquatic life. However, the predicted concentration of chloride in Snap Lake is considerably lower than the EPA criterion and TDS concentrations will increase over a long period (*i.e.*, biological communities may adapt to TDS increases). To be conservative, a thorough literature review focusing on the potential effects of calcium and chloride on each of the biological communities in Snap Lake was conducted.

4.2 Phytoplankton Community

4.2.1 Baseline

Phytoplankton abundance in Snap Lake is low (Table 4.1), which is typical of Arctic and subarctic lakes (*e.g.*, Welch *et al.* 1989, Holmgren 1985). In 1999, summer averages of chlorophyll *a* ranged from 0.82 to 0.99 µg/L among sampling stations, while those for density and biomass ranged from 258 to 329 per mL and from 223 to 423 mg/m^3, respectively. The phytoplankton biomass in Snap Lake is typical of low productivity lakes in the region (Pienitz *et al.* 1997). Detailed phytoplankton sampling results are presented in Table 9.5-2, Appendix IX.10 of the Snap Lake EAR.

Table 4.1 Phytoplankton Chlorophyll *a*, Density and Biomass in Snap Lake in 1999

Sampling Station	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

Units: µg/L = microgram per litre; number/mL = number per millilitre; mg/m^3 = milligrams per cubic metre.
Water Quality (WQ) stations 1, 3, and 7 (see EAR Figure 9.4-2).
Note: Values represent the summer average.

In spite of the low biomass, the composition of the phytoplankton community in Snap Lake is characteristic of a moderately-low productive (*i.e.*, oligo-mesotrophic [trophic definitions can be found in Wetzel 1983]) lake rather than an oligotrophic (*i.e.*, unproductive) lake (Table 4.2). Oligotrophic lakes are typically dominated by golden algae and cryptophytes (Wetzel 1983, Watson *et al.* 1997), but in Snap Lake, phytoplankton biomass is comprised predominately of diatoms and dinoflagellates. Diatoms and dinoflagellates, particularly diatoms, tend to dominate in slightly more productive waters. Cyanobacteria also contribute to a lesser extent to community biomass in Snap Lake (7.8% to 18.8%), an algal group that is rare in oligotrophic lakes and increases in importance with lake productivity. Green algae, cryptophytes, and euglenophytes have very low biomass in Snap Lake compared with other algal groups. Species of *Gymnodinium* (dinoflagellate), *Cyclotella* (diatom) and *Tabellaria* (diatom) were dominant contributors to total phytoplankton biomass in Snap Lake.

Table 4.2 Composition of Phytoplankton Groups in Snap Lake in 1999

Phytoplankton Group	Mean Percent Biomass (%)		
	WQ1	WQ3	WQ7
Cyanobacteria	11.5	18.8	7.8
Green algae	3.2	3.0	5.5
Cryptophytes	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
Euglenophytes	2.1	2.4	0

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

4.2.2 Predicted Response to Increase in Total Dissolved Solids

Predicted TDS concentrations in Snap Lake are less than upper optima for relevant phytoplankton species. Wilson *et al.* (1994, 1996) determined a salinity optimum and, lower and upper limits for selected diatom species (Table 4.3). The predicted maximum TDS concentration is much less than the upper limits and slightly higher or similar to salinity optima for diatom species that are dominant in Snap Lake. In addition, the changes in TDS will be gradual (see Figure 4.1) and would allow phytoplankton to adapt over time.

Table 4.3 Salinity Optima for Selected Diatom Phytoplankton Species Found in Snap Lake

Taxon	Salinity Optimum (mg/L)	Lower Limit (mg/L)	Upper limit (mg/L)
Tabellaria flocculosa	180	0	10,090
Cyclotella bodanica	240	30	1,820
Fragilaria tenera	320	10	807

Adapted from Wilson *et al.* (1994, 1996).
Units: mg/L = milligrams per litre.

Phytoplankton appear to be tolerant to a wide range of calcium concentrations. Vyverman *et al.* (1996) found limited differences in phytoplankton assemblages attributable to calcium concentrations. Species richness was not affected until concentrations were very high. Diatom richness was not substantially affected in calcium concentrations ranging from 8-203 ueq/L (160-4,060 mg/L). Vyverman *et al.* (1996) concluded that the mean calcium effect concentration for *Tabellaria flocculosa* (a dominant diatom species in Snap Lake) is 44.26 meq/L (885 mg/L) and the lower tolerance threshold is 32.12 meq/L (642 mg/L). These thresholds are far above predicted calcium concentrations. Patrick *et al.* (1968) observed that another diatom, *Nitzschi* *linearis*, had an LC_{50} (lethal concentration where 50% of organism die) of 3,130 mg/L when exposed to calcium chloride.

Based on the scientific literature available, the predicted TDS concentrations in Snap Lake will be well below any potential thresholds for an effect. Therefore, the magnitude of impact on the phytoplankton community is predicted to be negligible.

4.3 Zooplankton Community

4.3.1 Baseline

Zooplankton abundance in Snap Lake (Table 4.4) is low, which is typical for Arctic and subarctic lakes (*e.g.*, Kettle and O'Brien 1978). 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 $\mu g/m^3$. Zooplankton density and biomass were higher at shallow habitat sites with densities ranging from 29,844 to 102,459 individuals/m^3 and biomass ranging from 76,368 to 152,300 $\mu g/m^3$. 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 4.4 Zooplankton Density and Biomass in Snap Lake in 1999

Sampling Station	Density (individuals/m^3)	Biomass ($\mu g/m^3$)
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.

Units: individuals per cubic metre (individuals/m^3), micrograms per cubic metre ($\mu g/m^3$)

The zooplankton community in Snap Lake is dominated by calanoid copepods and, to a lesser extent, cyclopoid copepods (Table 4.5). 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%. The dominant species of calanoid copepods were *Heterocope septentrionalis, Leptodiaptomus sicilis, Leptodiaptomus minutus,* calanoid copepodids (copepod early life history stage). 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). Rotifers and cladocerans have very low biomass in Snap Lake.

Table 4.5 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.

4.3.2 Predicted Response to Increase in Total Dissolved Solids

Laboratory toxicity tests for calcium and chloride are generally conducted using simple solutions composed primarily of the chemical of concern. However, mixtures of ions are found to be less toxic than individual ions Mount *et al.* (1997). Mount *et al.* (1997) found that toxicity to zooplankton was reduced in solutions enriched with more than one cation. For example, chloride was less toxic to *Daphnia magna* and *Cerodaphnia dubia* in a mixture with sodium and calcium than in single solutions of sodium chloride or calcium chloride. These results suggest that concentrations of calcium chloride that are toxic in the laboratory are not necessarily toxic in Snap Lake due to a mixture of cations present in the lake.

A thorough review of the literature indicates that effects of TDS on zooplankton are observed generally above 600 mg/L and often above 1,000 mg/L for cladoceran and copepod species (Table 4.6). For example, the sodium chloride (NaCl) LC_{50}'s for *Daphnia magna* (6,034 mg/L) and *Ceriodaphnia dubia* (2,019 mg/L) are very high (Cowgill and Milazzo 1990). Hammer *et al.* (1975) determined that the rotifer *Keratella quadrata* (present in Snap Lake) thrives in highly saline environments of 2,000-3,000 mg/L. Cowgill and Milazzo (1990) determined that a conservative "no observable effect level" to avoid reproductive limitation would be ~1,200 mg/L NaCl. This is much higher than the predicted TDS concentration of 350 mg/L for Snap Lake. Based on the above, predicted TDS concentrations in Snap Lake will likely not affect the zooplankton community.

Table 4.6 Effect Concentrations of Calcium Chloride and Other Salts for Zooplankton Species

Species	Effect Concentration (mg/L)	TDS Components	Effect Unit	Reference
Ceriodaphnia dubia (Cladoceran)	2,260 1,830	$CaCl_2$	LC_{50} – 24 hr LC_{50} – 48 hr	Mount *et al.* (1997)
	1,031	$CaCO_3$	LC_{50} – 48 hr	Cowgill and Milazzo (1990)
	630 630	KCl	LC_{50} – 24 hr LC_{50} – 48 hr	Mount *et al.* (1997)
	3,380 1,960	NaCl	LC_{50} – 24 hr LC_{50} – 48 hr	Mount *et al.* (1997)
	2,019	NaCl	LC_{50} – 48 hr	Cowgill and Milazzo (1990)
	735-835	NaCl	LC_{50} – 48 hr	Hoke *et al.* (1992), cited in Scannell and Jacob (2001)
Daphnia magna (Cladoceran)	116 464	Ca^{+2}	LOEC – 3 week (reproductive impairment) LC_{50} – 48 hr	Biesinger and Christensen (1972)
	3,250 2,770	$CaCl_2$	LC_{50} – 24 hr LC_{50} – 48 hr	Mount *et al.* (1997)
	1,516	$CaCO_3$	LC_{50} – 48 hr	Cowgill and Milazzo (1990)
	740 660	KCl	LC_{50} – 24 hr LC_{50} – 48 hr	Mount *et al.* (1997)
	2,019	NaCl	LC_{50} – 48 hr	Cowgill and Milazzo (1990)
	4,746	NaCl	LC_{50} – 48 hr	Arambasic *et al.* (1995), cited in Evans and Frick (2001)
	680 1,820	Na^{+2}	LOEC – 3 week (reproductive impairment) LC_{50} – 48 hr	Biesinger and Christensen (1972)
Daphnia hyalina (Cladoceran)	3,000	$CaCl_2$	LC_{50} – 48 hr	Baudouin and Scoppa (1974)
Eudiaptomus padanus (Copepod)	4,000	$CaCl_2$	LC_{50} – 48 hr	Baudouin and Scoppa (1974)
Cyclops abyssorum (Copepod)	7,000	$CaCl_2$	LC_{50} – 48 hr	Baudouin and Scoppa (1974)

Units: milligram per litre (mg/L), 50 percent lethal concentration (LC_{50}), hour (hr), lowest observed effects concentration (LOEC).

Toxicity effects of calcium solutions on zooplankton are typically observed at concentrations above 1,000 mg/L. Mount *et al.* (1997) found that 48 hour LC_{50}s for calcium chloride were 1,830 mg/L and 2,770 mg/L on *Cerodaphnia dubia* and *Daphnia magna*, respectively. The lowest threshold documented for calcium is the lowest observed effects concentration (LOEC) of 116 mg/L for *Daphnia magna* (Table 4.6, Biesinger and Christensen 1972). The LOEC documented in 1972 by Biesinger and Christensen is considered a highly uncertain threshold because the results are dated and have not been repeated elsewhere in the literature since then.

Maximum predicted calcium concentrations of 113 mg/L in Snap Lake will be approximately equivalent to this published LOEC. This maximum concentration would occur in only 1% of the lake area in the summer months. Furthermore, the average predicted calcium concentration for the whole lake (88 mg/L) would be well below the LOEC for *Daphnia magna*.

Based on the above information, the potential impact of TDS due to direct toxicity on zooplankton species is expected to be negligible. Maximum predicted concentrations of TDS and calcium solutions are far below toxicity thresholds documented in the most current literature for sensitive cladoceran species. The cladocerans *Daphnia* spp. and *Ceriodaphnia* spp. are more sensitive than copepods to high calcium concentrations (Baudouin and Scoppa 1972) and high salinity (Galat and Robinson 1983). However, zooplankton in Snap Lake are dominated by copepods and not by cladocerans who contribute less than 1% to total biomass. Cladocerans are most commonly used for zooplankton toxicity testing and therefore, the use of cladoceran toxicity data provides an additional level of conservatism to the assessment of effects in Snap Lake.

The distribution of *Daphnia* species is related to the calcium concentration of lakes (Waevagen *et al.* 2002). Calcium is an essential element for zooplankton growth and the development of their carapace. *Daphnia* have greater calcium requirements than copepods and other cladocerans, which may explain their low presence in soft water lakes (Alstad *et al.* 1999, Waevagen *et al.* 2002).

Zooplankton community structure may change because the growth and egg production of *Daphnia* species may be sub-optimal at calcium levels found in Snap Lake (<10 mg Ca/L; Hessen *et al.* 2000). Higher concentrations of calcium in Snap Lake may stimulate the growth of *Daphnia* species and potentially cause a shift in community structure towards larger-sized zooplankton. Calcium limitation may explain the observation that high TDS lakes are associated with higher zooplankton productivity (Shuter *et al.* 1998). Large zooplankton are more susceptible to predation by planktiverous fish (Kettle and O'Brien 1978). Fish predation may control the abundance of *Daphnia* and prevent an observable shift in community structure. A minor shift to larger body size for cladocerans or higher zooplankton biomass would not be detrimental to the food supply for fish because *Daphnia* species are considered to be a preferential zooplankton prey (O'Brien *et al.* 1992).

A minor change in zooplankton community structure may result from an increase in TDS because of stimulated growth of calcium-limited cladoceran species. However, given that the cladocerans are a minor component of the zooplankton community in Snap Lake, the overall change will be negligible. TDS concentrations in Snap Lake will be insufficient to have toxic effects on zooplankton.

4.4 Benthic Invertebrate Community

4.4.1 Baseline

Benthic invertebrates were collected at four sites in Snap Lake during the fall sampling program in 1999. Mean total benthic invertebrate abundance varied between 5,000 and 7,400 organisms/m^2 in Snap Lake (see Table 4.7). Benthic invertebrate abundance is higher in Snap Lake in comparison to other arctic lakes (Moore 1978). Moore (1978) found benthic invertebrate abundance ranged from 4,100 to 4,300 organisms/m^2 in small northern lakes and was less than 2,000 organisms/m^2 in large, deep lakes. 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 to 30. These taxa are commonly found in other arctic lakes (Moore 1978). Chironomid midge larvae (predominantly tribes Chironomini and Tanytarsini) and nematode worms dominated the benthic community, accounting for 71% and 24%, respectively, of the total invertebrates collected in Snap Lake. Detailed benthic invertebrate sampling results are presented in Appendix IX.10, Tables IX.10-11 through IX.10-15.

Table 4.7 Benthic Invertebrate Data Collected in Snap Lake, Fall 1999

Variable	Snap Lake			
	SH1[(a)]	SH2	SH3	WQ3
Abundance and Taxonomic Richness (site mean ± standard error)				
Total abundance (no./m^2)[(b)]	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[(c)]	2.4	1.1	0.9	0.9

(a) Shallow habitat (SH) locations 1, 2, and 3; water quality (WQ) location 3 (see EAR Figure 9.4-2).

(b) no./m^2 = number per square metre.

(c) Includes Oligochaeta, Hirudinea, Amphipoda, Hydracarina, Collembola, Ephemeroptera, Hemiptera, and Trichoptera.

4.4.2 Predicted Response to Increase in Total Dissolved Solids

Benthic invertebrate toxicity thresholds for salts are much higher than predicted TDS concentrations in Snap Lake (Table 4.8). Generally, effects concentrations are above 1,000 mg/L for various benthic invertebrate species. The United States EPA (1999) reported that growth in *Chironomus tentans* (Chironomidae) was inhibited at a concentration of 1,598 mg/L when exposed to $CaSO_4$. Only one published study examining the direct effects of calcium on a benthic invertebrate, *Tubifex tubifex* (Oligochaeta) was found in the literature (Khangarot 1991). The 96-hour EC_{50} for this test was 281 mg/L of calcium. Because the maximum predicted calcium concentration in Snap Lake is expected to reach only 113 mg/L, the toxicological effects of elevated calcium on the benthic invertebrates are expected to be negligible.

Observational data from field studies indicate that effects on benthic invertebrates from salinity do not occur until TDS concentrations are much higher than the predicted 350 mg/L for Snap Lake. Hynes (1990) describes no effects on the benthic invertebrate community of a lake in northern Saskatchewan receiving treated uranium mill effluent with elevated TDS. In the Hynes study, the increase in TDS from baseline conditions was from 76 mg/L to 2,700 mg/L. The major ions primarily responsible for this increase were calcium, sodium, chloride, and sulphate. There were no statistically significant decreases in abundance or species diversity. Species richness declined, with fewer oligochaetes, Hirudinea, and amphipods, but considerably more *Tanytarsus* (Chironomidae).

Table 4.8 Effect Concentrations of Calcium Chloride and Other Salts for Benthic Invertebrate Species

Species	Effects Concentration (mg/L)	TDS Components	Effect Unit	Reference
Chironomus tentans (Diptera larvae)	1,100	TDS	NOEC – 10 day	Chapman *et al.* (2000)
	1,598 2,035	$CaSO_4$	NOEC – 10 day LC_{50} – 10 day	United States EPA (1999), cited in Scannell and Jacobs (2001)
Cricotopus trifascia (Diptera larvae)	1,406	Cl^-	LC_{50}	Hamilton (1975), cited in Scannell and Jacobs (2001)
Culex sp. (mosquito larvae)	10,254	NaCl	LC_{50} – 48 hr	Dowden and Bennett (1965), cited in Evans and Frick (2001)
Dugesia gonocephala (Flatworm)	1,230	Cl^-	Mortality	Palladina (1980), cited in Scannell and Jacobs (2001)
Gammarus pseudolimnaeus (Amphipod)	4,121	NaCl	LC_{20} – 24 hr	Crowther and Hynes (1977), cited in Evans and Frick (2001)
Hdroptila angusta (Caddisfly)	2,077	Cl^-	LC_{50}	Hamilton (1975), cited in Scannell and Jacobs (2001)
Hydropsyche betteni (Caddisfly)	1,319	NaCl	Survival and pupate - 10 day	Kersey (1981), cited in Evans and Frick (2001)
Nais variabilis (Oligochaete)	3,735	NaCl	LC_{100} – 48 hr	Hamilton *et al.* (1975), cited in Evans and Frick, 2001
Physa gyrina (Snail)	2,540	Cl^-	LC_{50} – 96 hr	Birge *et al.* (1985), cited in Evans and Frick (2001)
Tubifex tubifex (Oligochaete)	814 389 281	$CaCl_2$	EC_{50} – 24 hr EC_{50} – 48 hr EC_{50} – 96 hr	Khangarot (1991)

Units: milligram per litre (mg/L), 50 percent lethal concentration (LC_{50}), hour (hr), No observed effects concentration (NOEC), 50 percent effective concentration (EC_{50})

Chironomids, the dominant group of benthic invertebrates in Snap Lake, inhabit freshwaters with high TDS. Moore (1978) found that the distribution of chironomids showed little relation to salinity in his examination of 22 saline lakes in Saskatchewan. Leland and Fend (1997) found that many chironomid species in rivers have high TDS optima between 130 and 1300 mg/L. Table 4.9 presents TDS optima for chironomid species sampled by Leland and Fend (1997). The species in this table belong to the same genera as those found in Snap Lake. Although physiological optima can differ considerably between species in the same genus, the TDS optima of these chironomids suggests that elevated TDS will not effect the benthic invertebrate community. In addition to being within expected optimal condition ranges, the TDS concentration in Snap Lake will gradually increase over an extended period of time which will allow the benthic invertebrate community to adapt.

Table 4.9 Dissolved Solids Optima for Selected Benthic Invertebrates Species

Chironomid Taxon	Dissolved Solids Optimum [a] (mg/L)
Tanytarsus sp. 1	160 ± 21
Polypedilum cf. *halterale*	170 ± 30
Ablabesmyia mallochi	240 ± 31
Cladotanytarsus vanderwulpi	280 ± 50
Paratanytarsus sp.	560 ± 95
Parachironomus arcuatas	630 ± 83
Parachironomus frequens	670 ± 70
Tanytarsus sp. 2	890 ± 25
Cladotanytarsus mancus	1300 ± 53

[a] Dissolved solids optima are presented plus or minus one standard deviation
Units: milligrams per litre (mg/L)
Source: Leland and Fend (1997)

TDS concentrations in Snap Lake will not exceed any known toxicity thresholds for benthic invertebrates. Conditions within Snap Lake will likely fall within the optimal TDS range for many species. Changes in TDS will occur slowly over time in Snap Lake allowing for adaption to new conditions. All these lines of evidence indicate that TDS will have a negligible effect on the benthic invertebrate community.

4.5 Fish Community

4.5.1 Baseline

Fish species richness is relatively low in Snap Lake but typical for a medium-sized headwater arctic lake. During the 1998 and 1999 baseline studies at Snap Lake, a total of seven species of fish were captured: longnose sucker (*Catostomus catostomus*), burbot

(*Lota lota*), lake trout, round whitefish (*Prosopium cylindraceum*), Arctic grayling (*Thymallus arcticus*), lake chub (*Couesius plumbeus*) and slimy sculpin (*Cottus cognatus*). Examination of gut contents of adult lake trout captured in Snap Lake during baseline studies revealed that adult lake trout feed primarily on aquatic invertebrates (*e.g.*, mayfly and chironomid larvae) and forage fish such as round whitefish.

4.5.2 Predicted Response to Increase in Total Dissolved Solids

There are two principal concerns regarding effects of elevated TDS on the fish community in Snap Lake. First, elevated TDS could potentially have toxicological effects on fish resulting from the increased concentration of calcium and chloride or the change in water osmolarity. Second, increased TDS could potentially impact the supply and type of food available for fish in Snap Lake. The assessment in this section will focus on impacts to lake trout as this species was identified as the major species of concern during the November/December technical hearings. Salmonids are generally regarded as the most sensitive fish family. Lake trout is an important species culturally and economically in the region. In cases where data gaps exist on the toxic effects of elevated TDS on lake trout, discussions will include data on other salmonids and other fish species.

Toxicological effects of high TDS on salmonids and other fish species occur at much higher concentrations than those predicted for Snap Lake (Table 4.10). Waller *et al.* (1996) reported lake trout experienced 0% mortality when exposed for 24-hours (acute lethality test) at 12°C to 10,000 mg/L $CaCl_2$ water. Scannell and Jacobs (2001) provided a detailed literature review of the toxic effects of TDS to aquatic species, including fish. Based on their review, they made the following generalizations:

- TDS concentrations in the range of 750 mg/L significantly reduced fertilization and hatching rates in coho and chum salmon, and extended the development time to epiboly and the eyed egg stage; and,
- After egg hardening, fish do not appear to be affected by elevated concentrations of TDS up to 2000 mg/L.

In general, when the main TDS cation is calcium, effects on sex cells and early life stages of some salmonids begin at 520 mg/L (Table 4.10). Stoss *et al.* (1977), as summarized by Scannell and Jacobs (2001), reported inhibition of rainbow trout spermatozoa at $CaCl_2$ concentration of 15,229 mg/L. Ketola *et al.* (1988) investigated the effects of water chemistry during water hardening on survival of Atlantic salmon, rainbow trout, and brook trout. They found low survival (approximately 38%) when fertilized eggs were exposed to hard water containing high concentrations of calcium (520 mg Ca/L).

Table 4.10 Effect Concentrations of Calcium Chloride and Other Salts for Fish Species

Species	Effect Concentration (mg/L)	TDS Components	Observed Effect	Comments	References
Coregonus artedi (Cisco)	1,200 >1,200	Mg^{2+}, Na^{+}	Reproduction successful Reproduction impaired	Average for 12 lakes	Rawson and Moore (1944)
Lota Lota (Burbot)	11,500 >11,500	Mg^{2+}, Na^{+}	Reproduction successful Reproduction impaired	Average for 12 Lakes	Rawson and Moore (1944)
Oncorhynchus mykiss (Rainbow Trout)	>2000	TDS	NOEC – 7 day	Tested on embryos and developing fry	Chapman *et al.* (2000)
	4,500 20,000	TDS	Reproduction Successful Reproduction Impaired		Atton (1986)
	10,000	$CaCl_2$	16% mortality	Exposure time 24 hr, water temperature 12°C	Waller *et al.* (1996), cited in Evans and Frick 2001
	600	Primarily $CaSO_4$	IC_{25} – 15 day	Life Stage – fertilization and development to eye stage	EVS (1998), cited in Scannell and Jacob 2001
	520 1750	Ca^{+2} $CaSO_4$	38% survival	Life stage – hardening	Ketola *et al.* (1988), cited in Scannell and Jacob (2001)
	16,010 15,229	NaCl $CaCl_2$	Activity was inhibited	Life stage – spermatozoa	Stoss *et al.* (1977), cited in Scannel and Jacob (2001)
Oncorhynchus nerka (Coho Salmon)	750	$CaSO_4$	LOEC (Reduced survival at epiboly)	Life stage - fertilization	Stekoll *et al.* (2001) cited in Scannell and Jacob (2001)
Oncorhynchus keta (Chum Salmon)	750	$CaSO_4$	Reduced fertilization	Life stage - fertilization	Stekoll *et al.* (2001), cited in Scannell and Jacob (2001)
Salmo trutta (Brown Trout)	10,000	$CaCl_2$	20% mortality	Exposure time 24 hr, water temperature 12°C	Waller *et al.* (1996), cited in Evans and Frick (2001)
Salvelinus namaycush (Lake Trout)	10,000	$CaCl_2$	0% mortality	Exposure time 24 hr, water temperature 12°C	Waller *et al.* (1996), cited in Evans and Frick (2001)

Units: milligram per litre (mg/L), hour (hr), No observed effects concentration (NOEC), 25 percent inhibition concentration (IC_{25}), Lowest observed effects concentration (LOEC)

The predicted concentrations of TDS in Snap Lake are much lower than those found to cause an effect in laboratory toxicity tests; therefore direct toxicological effects of elevated TDS are not predicted to occur.

Lake trout inhabit lakes with a wide range of TDS concentrations. A number of lakes with TDS concentrations in excess of 200 mg/L support lake trout populations (Table 4.11). Lake trout are found to occur in waters ranging from less than 20 mg/L to as high as 612 mg/L. Clearwater Lake in Ontario has a TDS concentration measuring 364 mg/L and contains a natural, healthy lake trout population; in fact, lake trout from this lake have been used successively to stock other inland lakes in Ontario (Evans and Olver 1995). Lake trout lakes are not limited to Eastern Canada; numerous lakes in Western Canada contain lake trout populations. For many of these lakes, TDS concentrations exceed the 350 mg/L concentration predicted for Snap Lake (Table 4.11). The presence of lake trout in lakes with TDS levels similar to those predicted for Snap Lake supports the prediction that lake trout will adapt to the increase in dissolved solids over the lifetime of the mine.

Studies show that factors other than TDS are important to determining the success of lake trout. The success of lake trout is, at least in part, influenced by the complexity of the trophic structure, amount of available food (Donald and Alger 1993), lake area, angling-effort (Goddard *et al.* 1987), size of littoral zones and other abiotic conditions such as temperature, and dissolved oxygen levels (Evans and Olver 1995). Shuter *et al.* (1998) found that lake trout populations from small, low-TDS lakes are more sensitive to overexploitation than populations from large, high-TDS lakes. Martin and Olver (1976) found in their survey of inland lakes of Ontario, that lake trout lakes were generally deeper, colder, and higher in dissolved oxygen than non-lake trout lakes. They also recognized the importance of TDS, but found lake trout inhabiting a wide range of TDS values, including lake trout lakes with TDS concentrations in excess of 150 mg/L. Christie and Reiger (1988) found that the amount of thermally available habitat was an important factor influencing lake trout distribution.

TDS concentrations will gradually increase during operations; this extended period of time (maximum TDS concentration expected during year 19 of operations) is more than adequate time for a salmonid, such as lake trout, to acclimate to their environment. Dickerson and Vinyard (1999) found that survival of stocked cutthroat trout increased in Walker Lake, Nevada (TDS of 13,180 mg/L in 1995), when acclimated at TDS concentrations near 3,600 mg/L for three days.

Table 4.11 Lakes with High Total Dissolved Solids Concentrations that Support Lake Trout Populations

Lake	Province	Size (ha)	Mean Depth (m)	TDS (mg/L)	Reference
Till Lake	BC	79	7.8	612	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Helena Lake	BC	238	3.4	482	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Hathaway Lake	BC	20	19.7	480	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Birches Lake	BC	302	14.5	392	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Sulphurous Lake	BC	381	15.4	386	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Drewry Lake	BC	567	12.9	385	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Lac La Hache	BC	2301	14.6	365	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Clearwater Lake	MB	na	13.2	364	Evans and Olver (1995)
Good Hope Lake	BC	150	15.2	360	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Delta Lake	BC	1154	21.6	338	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Deka Lake	BC	1154	21.6	329	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Boreal Lake	BC	77	6.3	294	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Solitary Lake	BC	512	5.8	280	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Captain Lake	BC	189	17.4	266	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Greenlee Lake	BC	29	9	265	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Big Lake	BC	571	13.2	260	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Bosk Lake	BC	507	19.4	240	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Rock Lake	AB	202	Na	236	Donald and Alger (1993)
Deadwood Lake	BC	1280	na	232	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Horneline Lake	BC	203	5	230	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Fishing Lake	BC	346	20	222	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Rainbow Lake	BC	75.5	7.1	218	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Canim Lake	BC	5611	84.1	215	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Fishpot Lake	BC	87	5	214	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Abbot Lake	BC	24	11.1	210	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Lake Simcoe	ON	na	13.2	200	Evans and Olver (1995)

Table 5.11 Lakes With High Total Dissolved Solids Concentrations That Support Lake Trout Populations (Continued)

Lake	Province	Size (ha)	Mean Depth (m)	TDS (mg/L)	Reference
Horse Lake	BC	1162	15.2	200	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Pinetree Lake	BC	110	9.9	200	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Horse Lake	BC	1162	15.2	198	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Muncho Lake	BC	1489	52	195	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Dease Lake	BC	na	na	195	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Lac la Ronge (Main Lake)	SK	na	na	180	Sawchyn (1987)
Lake Manitou	ON	na	15.1	180	Shuter *et al.* (1998)
Jack of Clubs Lake	BC	95	19.1	180	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Loon cry Lake	BC	694	25.6	176	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Portage Lake	BC	50	na	175	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Crean Lake	SK	na	na	175	HydroQual Consultants Inc. 1986. Water Quality Assessment of Crean, Kingsmere and Waskesiu Lakes
Tatsameni Lake	BC	1595	63.4	164	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Wollaston Lake	ON	na	na	162	Shuter *et al.* (1998)
McDame Lake	BC	30	8	160	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Morley Lake	BC	na	na	160	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Carbon Lake	BC	70	13	157	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Pacific Lake	BC	57	na	155	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Waskesiu	SK	na	na	154	HydroQual Consultants Inc. (1986)
Sutton	ON	na	na	154	Shuter *et al.* (1998)
Kingsmere	SK	na	na	150	HydroQual Consultants Inc. (1986)
Gwilliam Lake	BC	1121	30.9	136	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Bridge Lake	BC	1371	17.4	134	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Fox Lake	BC	114	10.5	134	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Bridge Lake	BC	na	na	134	http://www.bcadventure.com/adventure/explore/caribou/scaribou/bridge.html
Anahim Lake	BC	595	1.7	130	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Horsefly Lake	BC	5868	66.1	130	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html

Table 5.11 Lakes With High Total Dissolved Solids Concentrations That Support Lake Trout Populations (Continued)

Lake	Province	Size (ha)	Mean Depth (m)	TDS (mg/L)	Reference
Morfee Lake	BC	279	12.6	129	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Bednesti Lake	BC	261	8.3	128	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Lac la Ronge (Hunter Bay)	SK	na	na	125	W.W. Sawchyn 1987. Fisheries Technical Report 87-1. Evaluation of lake trout and lake whitefish resources in Lac la Ronge
Berman Lake	BC	44	2.6	124	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Cuningham Lake	BC	2996	25.3	124	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Chrismaina Lake	BC	641	9.1	118	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Bertzi Lake	BC	182	13.1	116	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Pinchi Lake	BC	5554	23.9	116	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Swinton Lake	BC	na	na	116	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Long Mountain Lake	BC	120	9	112	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Cariboo Lake	BC	na	na	108	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
McKinely Lake	BC	479	26.1	108	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Maeford Lake	BC	51	18.1	102	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Fraser Lake	BC	5463	13.4	100	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Lac la Plonge	SK	na	na	100	Sawchyn (1987)
Quesnel Lake	BC	27195	158.5	94	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Airline Lake	BC	446	6.3	94	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Wolverine Lake	BC	25	3.38	88	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Kazchek Lake	BC	1325	20.7	86	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Mahood Lake	BC	3311	94.2	83	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Carina Lake	BC	233	4.5	82	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Beaverpond Lakes	BC	na	na	80	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Hallett Lake	BC	560	17.3	80	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Spanish Lake	BC	454	29	78	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Oone Lake	BC	338	7.8	75	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Abuntlet Lake	BC	230	0.7	74	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html

Table 5.11 Lakes With High Total Dissolved Solids Concentrations That Support Lake Trout Populations (Continued)

Lake	Province	Size (ha)	Mean Depth (m)	TDS (mg/L)	Reference
Binta Lake	BC	789	21.3	74	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Manson Lakes	BC	223	13.8	70	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Cold Fish Lake	BC	788	21	68	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Tzenzcicut Lake	BC	761	7.7	65	http://www.bcadventure.com/adventure/explore/cariboo/lakes/index.html
Chapman Lake	BC	1019	12.8	63	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
East Hautete Lake	BC	270	5.1	62	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Hautete Lake	BC	230	6.7	61	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Humphrey Lake	BC	194	na	56	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Nakinleak Lake	BC	734	10.8	56	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Purvis Lake	BC	294	19.6	56	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Rond Lake	BC	28	2.1	56	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Black Fox Lake	BC	na	na	56	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Dall Lake	BC	1813	9.7	54	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Stephan Lake	BC	110	9.4	54	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Redfern Lake	BC	539	43.5	52	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Silver Lake	BC	133	na	52	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
McNeil Lake	BC	253	23.2	52	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Electra Lake	BC	68	14.3	50	http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp
Cree Lake	SK	na	14.9	27	Christie and Regier (1988)
Mishibishu Lake	ON	na	20.3	22	Evans and Olver (1995)
Bone Lake	ON	123	8.5	17	Goddard *et al.* (1987)
Rawlinson Lake	ON	234	11.1	13.3	Goddard *et al.* (1987)

na = not available, AB = Alberta, BC = British Columbia, MB = Manitoba, ON = Ontario, SK = Saskatchewan
Units: hectares (ha), milligrams per litre (mg/L), metre (m)

Lake trout populations in lakes with TDS concentrations ranging from 15 mg/L to 180 mg/L exhibit higher growth rates in early life, lower ages at first maturity, larger sizes at first maturity, and higher natural mortality rates (Shuter *et al.* 1998). The effects of TDS and lake area on growth probably reflect differences in associated biota rather than differences in abiotic conditions. Higher TDS concentrations have been associated with higher zooplankton productivity (Shuter *et al.* 1998).

Adult lake trout are recognized as "opportunistic" feeders, consuming a wide range of organisms including zooplankton, benthic invertebrates, forage fish, ciscos, whitefish, sucker species, and sometimes shrews and mice (Scott and Crossman 1973, Shuter *et al.* 1998). If suitable forage fish such as lake whitefish and sculpins are not available, the lake trout will feed on alternate prey, including benthic invertebrates, smaller fish, and plankton (Burr 1997). Examination of gut contents of adult lake trout captured in Snap Lake during baseline studies revealed that adult lake trout were feeding primarily on aquatic invertebrates (*e.g.*, mayfly and chironomid larvae) and forage fish such as round whitefish. Although not examined in Snap Lake, younger lake trout are known to feed primarily on plankton and benthic invertebrates (Kettle and O'Brian 1978, Adams 1997). Kettle and O'Brien (1978) found that juvenile lake trout in Toolik Lake, Alaska, fed on the zooplankton *Daphnia longiremis, Holopedium gibberum, Bosmina longirostri,* and *Hetercope septentrionalis*. These zooplankton species are all found in Snap Lake. However, young lake trout are not limited to eating only cladoceran zooplankton. McDonald *et al.* (1992) found that young-of-the-year lake trout ate copepods such as *Cyclops scutifer* and some benthic invertebrates when the density of the preferred copepod (*Diaptomis progbilofensis*) was low. This study demonstrates that juvenile lake trout will switch prey choices and, in this case, to a species which is 70% smaller, if the preferred prey is not available. Given the low abundance of zooplankton biomass in Snap Lake and their low density in arctic waters overall, benthic invertebrates, such as chironomid midge larvae, may already make up a significant proportion of a young lake trout's diet. It is possible the increase in TDS, and more specifically Ca, may have indirect effects on the juvenile lake trout population in Snap Lake by increasing the amount of food supply available to juvenile lake trout.

5.0 TOTAL DISSOLVED SOLIDS AND AQUATIC COMMUNITY POST-CLOSURE

Snap Lake is a headwater lake and therefore, is a groundwater recharge area, not a groundwater discharge area (see EAR Section 9.2.1.4.2). Consequently, the response of Snap Lake after mining will be controlled by the amount and quality of post-closure discharge and the residence time of water in Snap Lake. The return of TDS levels in Snap Lake to near baseline conditions will take place in less than 100 years. The predicted response in the first 15 years of post-closure is from approximately 300 mg/L at year 26 to approximately 90 mg/L at year 40. The declining TDS levels will continue at a decreasing rate as the lake concentration approaches the baseline concentration. Community structure is also expected to return to baseline conditions over time.

Discharge of non-toxic ions in arctic and subarctic lakes results in ecosystem changes that are reversible. For example, 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 (BHP 2001). Meretta Lake in the high arctic is also returning to near-baseline conditions following extensive nutrient loading over several decades (Schindler *et al.* 1974, Douglas and Smol 2000). Although major shifts in taxonomic composition are not expected in Snap Lake during mine construction and operation, it is expected that there will be a shift back to conditions similar to baseline following reductions in TDS. The phytoplankton of Meretta Lake has returned to a golden algae and cryptophyte dominated community typical of an oligotrophic lake (Douglas and Smol 2000). In an arctic fertilization experiment, Bettez *et al.* (2002) also found that the structure of the microzooplankton community returned to baseline characteristics when fertilization stopped. These documented cases exemplify the resiliency of arctic and subarctic lakes to ecosystem perturbation.

6.0 SUMMARY

Increased TDS in Snap Lake during mine construction and operations is expected to have a negligible impact on resident aquatic communities. Based on a review of the literature, phytoplankton and benthic invertebrates are tolerant of the TDS levels expected in Snap Lake and no toxicity impacts are predicted to occur. Salinity ranges and optima of dominant genera and species indicate that major shifts in community composition would not occur, although the relative abundance of phytoplankton and benthic invertebrate species may change slightly. Increased TDS concentrations may cause a minor change in zooplankton community structure due to the stimulation of growth of calcium-limited species or the inhibitory effects of TDS constituents on some species; however, the increase in TDS will be gradual enough to allow ample opportunity for communities to adapt.

Laboratory toxicological studies on salmonids indicate lake trout will not be adversely affected by increased TDS concentrations. These laboratory results are supported by field observations of lake trout populations in high TDS lakes (>300 mg/L). Salmonids are able to acclimate to higher TDS and the slow increase in TDS in Snap Lake will provide sufficient time to allow lake trout to acclimate. No major changes in diet are expected, although higher TDS may result in greater abundance of zooplankton, providing more food for plankton feeding fish and juvenile lake trout. Juvenile and adult lake trout have flexible diets and are able to opportunistically prey on a wide range of organisms.

The major conclusion regarding predicted increase of TDS concentrations in Snap Lake during operations and its effects on the aquatic community in the lake are:

- Major shifts in the aquatic community biomass or diversity in Snap Lake are not predicted. Gradual, subtle changes in the relative abundance and dominance of some zooplankton species may be seen if some species are better able to utilize the available calcium.

- The expected increase in TDS is well within ranges seen in other Canadian lakes with lake trout populations. No toxicological effects to fish in Snap Lake are predicted. Available food is predicted to remain diverse and may slightly increase in abundance.

7.0 LITERATURE CITED

Adams F.J. 1997. Relative Abundance and Maturity of Lake Trout from Walker Lake, Gates of the Arctic National Park and Reserve, Alaska, 1997-1988. Pages 104-108 *in* J. B. Reynolds, *editor. Fish Ecology in Arctic North America.* American Fisheries Society Symposium 19.

Arambasic M. B., D. C. Bjelicand, G. Subakov. 1995. Acute Toxicity of Heavy Metals (Copper, Lead and Zinc), Phenols and Sodium*Alliumcepa* L., *Lepidium sativum* L. *and Daphnia magna* St.: Comparative Investigations and The Practical Applications. Water Research 29 :497-503.

Atton F. M. 1986. Fish in Saskatchewan Endorheic Systems and Saline Waters. In D.T. Waite (ed). Evaluating Saline Waters in a Plains Environment. University of Regina, Canadian Plains Research Center. Canadian Plains Proceedings 17.

Alstad N. E. W., L. Skardal, and D. O. Hessen. 1999. The Effect of Calcium Concentrate on the Calcification of *Daphnia Magna*. Limnol. Oceanogr. 44(8): 2001-2017.

Baudouin M. F. and P. Scoppa. 1974. Acute Toxicity of Various Metals to Freshwater Zooplankton. Bulletin of Environmental Contamination and Toxicology. 1296) 745-751.

Bettez N.D., P.A. Rublee, J. O;Brien and M.C. Miller. 2002. Changes in Abundance, Composition and Controls within the Plankton of a Fertilised Arctic Lake. Freshwater Biology. 47: 303-311.

BHP. 2001. Kodiak Lake Sewage Effects Study Technical Report. Prepared by Rescan Environmental Services Ltd. for BHP Billiton Diamonds Inc.

Biesinger K. E. and G. M. Christensen. 1972. Effects of Various Metals on Survival, Growth, Reproduction, and Metabolism of *Daphnia magna*. Journal of Fisheries Research Boards of Canada. 29(12) 1691-1700.

Birge W. J., J. A. Black, A. G. Westerman, T.M. Short, S. B. Taylor, D. M. Bruser and E. D. Wallingford. 1985. Recommendations on Numerical Values for Regulating Iron and Chloride Concentrations for the Purpose of Protecting Warm Water Species of Aquatic Life in the Commonwealth of Kentucky. Memorandum of Agreement No, 5429. Kentucky Natural Resources and Environmental Protection Cabinet.

Burr, J. M. 1997. Growth, density, and biomass of lake trout in Arctic and subarctic Alaska. Pages 109-118 *in* J. B. Reynolds, *editor*. *Fish Ecology in Arctic North America*. American Fisheries Society Symposium 19.

CCME (Canadian Council of Ministers of the Environment). 2002. Canadian Environmental Quality Guidelines, Summary Table. Canadian Council of Ministers of the Environment. Winnipeg, MN.

Chapman P. M., H. Bailey and E Canaria. 2000. Toxicity of Total Dissolved Solids Associated with Two Mine Effluent to Chironomid Larvae and early Life Stages of Rainbow Trout. Environmental Toxicology and Chemistry. 19(1): 210-214.

Christie, G.C., and J.A. Regier. 1988. Optimal Therma Habitat and Their Relationship to Yields for Four Commercial Fish Species. Can. J. Fish. Aquat. Sci. 45: 301-314.

Cowgill U. M. and D. P. Milazzo. 1990. The Sensitivity of Two Cladocerans to Water Quality Variables: Salinity and Hardness. Arch. Hydrobiol. 120(2): 185-196.

Crowther R. A. and H. B. Hynes. 1977. The Effects of Road Deicing Salt on the Drift of Stream Benthos. Environ. Pollut. 14: 113-126.

De Beers. 2002. De Beers Snap Lake Diamond Project Environmental Assessment Report. Presented to the Mackenzie Valley Environmental Impact Review Board by De Beers Canada Mining Inc.

Dickerson B. R. and G. L. Vinyard. 1999. Effects of High Levels of Total Dissolved Solids in Walker Lake, Nevada, on survival and Growth of Lahontan Cutthrouat Trout. Transactions of the American Fisheries Society. 128: 507-515.

Donald, D.B., and D.J. Alger. 1993. Geographic distribution, species, displacement, and niche overlap foor lake trout and bull trout in mountain lakes. Can. J. Zool. 71: 238-247.

Douglas M. S. V. and J. P. Smol. 2000. Eutrophication and Recovery in the High Arctic: Meretta Lake (Cornwallis Island, Nunavut, Canada) revisited. Hydrobiologia. 431: 193-204.

Dowden B. F. and H. J. Bennett. 1965. Toxicity of Selected Chemicals to Certain Animals. J. Water Pollut. Control Fed. 37: 1308-1316. (in U.S. EPA 1988).

Evans M.S. and C. Frick. 2001. The Effects of Road Salt on Aquatic Ecosystems. N.W.R.I. Contributiona Series No. 02-308.

Evans O. and C. H. Olver. 1995. Introduction of Lake Trout (*Salvelinus namycush*) to Inland Lakes of Ontario, Canada: Factors Contributing to Successful Colonization. J. Great Lakes Res. 21(Supplement 1): 30-53.

EVS Environmental Consultants. 1998. Effects of Total Dissolved Solids (TDS) on Fertilization and Viability of Rainbow Trout and Chum Salmon Embryos. Revised Final Draft. EVS Project No. 9/203-28. Prepared for Cominco Alaska Inc.

Galat D.L. and R. Robinson. 1983. Predicted Effects of Increasing Salinity on the Crustacean Zooplankton Community in Pyramid Lake, Nevada. Hydrobiol. 105: 115-131.

Goddard, C.I. D. H. Loftus, J.A. MacLean, C.H. Olver, and B.J. Shuter. 1987. Evaluation of the Effects of Fish Community Structure on Observed Yields of Lake Trout (Salvelinus namaycush). Can. J. Fish. Aquat. Sci. 22(Suppl.2): 239-248.

Gulley D.D., D.R. Mount, J.R. Hockett and H.L. Bergman. 1992. A Statistical Model to Predict Toxicity of Saline Produced Waters To Freshwater Organisms. *In* J.P. Ray and F.R. Engelhart (eds.). Produced Water. Plenum Press, New York.

Hamilton R. W., J. K. Buttner and R. G. Brunetti. 1975. Lethal Levels of Sodium Chloride and Potassium Chloride for and Oligochete, a chironomid midge and a caddisfly of Lake Michigan. Environmental Entomology. 4: 1003-1006.

Hammer U. T., R. C. Haynes, J. M. Heseltine and S. Swanson. 1975. The Saline Lakes of Saskatchewan. – Verh. Internat. Verein. Limnology. 19: 589-598.

Hesssen D. O., N, E. W. Alstan and L. Skardal. 2000. Calcium Limitation in *Daphnia magna*. Journal of Plankton Research. 22(3) 553-568.

Hoke R. A., W. R. Gala, J. B. Drake, J. P Geisy, and S. Fleger. 1992. Bicarbonate as a Potential Confounding Factor in Caldoceran Toxicity Assessments of Pore Water from Contaminated Sediments. Canadian Journal of Fisheries and Aquatic Sciences. 49: 1633-1640.

Holmgren S. 1985. Phytoplankton in a Polluted Subarctic Lake Before and After Nutrient Reduction. Water Res. 1: 63-71.

HydroQual Consultants Inc. 1986. Water Quality Assessment of Crean, Kingsmere and Waskesiu Lakes

Hynes, T.P. 1990. The Impacts of the Cluff Lake Uranium Mine and Mill Effluent on the Aquatic Environment of Northern Saskatchewan. M.Sc. Thesis, University of Saskatchewan, department of Biology, Saskatoon, Sk. 215 pp.

Khangarot B. S. 1991. Toxicity of Metals to a Freshwater Tubrificid Worm, *Tubifex tubifex* (Muller). Bull. Environ. Contam, Toxicol. 46: 906-912.

Kersey K. 1981. Laboratory and Field Studies on the Effects of Road Deicing Salt on Stream Invertebrates SIC -9. R. J. Mackay, ed. University of Toronto. Toronto.

Ketola H. G., D. Longacre, A. Greulich, L. Phetterplace and R. Lashomb. 1988. High Calcium Concentration in Water Increases Mortality of Salmon and Trout Eggs. Progressive Fish-Culturist. 50(3): 129-135.

Kettle D. and W. J. O'Brien. 1978. Vulnerability of Arctic Zooplankton Species to Predation by Small Lake Trout (*Salvelinus namaycush*). J. Fish. Res. Board Can. 35: 1495-1500.

Leland H.V. and S. V. Fend. 1997. Benthic Invertebrate Distributions in the San Joaquin River, California, in Relation to Physical and Chemical Factors. Can. J. Fish. Aquat.Sci. 55(1051-1067).

Mandaville, S.M. 2002. Saline Lakes. Chebucto, Nova Scotia, Canada. http://www.chebucto.ns.ca/Science/SWCS/saline1.html.

Martin, N.V., and C.H. Olver. 1976. The Distribution and Characteristics of Ontario Lake Trout Lakes. Ministry of Natural Resources. 30p.

McDonald M. E., A. E. Hershey and W. J. O'Brien. 1992. Cost of Predation Avoidance in Young-of-year Lake Trout (*Salvelinus namaycush*): Growth Differential in Sub-optimal Habitats. Hydrobiol. 240: 213-218.

Moore J. W. 1978. Some Factors Influencing the Diversity and Species Composition of Benthic Invertebrate Communities in Twenty Arctic and Subarctic Lakes. Int. Revue ges. Hydrobiol. 63: 757-771.

Mount D.R., D.D. Gullry, J.R. Hockett, T.D. Garrison and J.M. Evans. 1997. Statistical Models to Predict the Toxicity of Major Ions to *Ceriodaphnia dubia, Daphnia magna and Pimephales promelas* (Fathead Minnows). Environmental Toxicology and Chemistry. 16(10)2009-2019.

Neubert M.G. and H. Caswell. 1996. Alternatives to Resilience fro Measuring the Responses of Ecosystems to Perturbations. Ecology. 78(3): 653-665.

O'Brien W.J., A.E. Hershey, J.E. Hobbie, M.A. Huller, G.W. Kipphut, M.C. Miller, B. Moller and J.R. Vestal. 1992. Control Mechanisms of Arctic Lake Ecosystems: A Limnocorral Experiment. Hydrobiologia 240: 143-188.

Palladina G., V. Margotta, A. Carolei and M.C. Hernandez. 1980. Dopamine Agonist Performance in *Planaria* after Manganese Treatment. Experientia. 36: 449-450.

Patrick R. J., J. J. Cairns and A. Scheier. 1968. The Relative Sensitivity of Diatoms, Snails and Fish to Twenty Common Constituents of Industrial Wastes. The Progressive Fish-Culturist. 30: 137-140.

Pienitz R., J. P, Smol and D. R. S. Lean. 1997. Physical and Chemical Limnology of 24 Lakes Located Between Yellowknife and Contwoyto Lake, Northwest Territories (Canada). Can. J. Fish. Aquat. Sci. 54: 347-358.

Rawson D. S. and J. E. Moore. 1944. The Saline Lakes of Saskatchewan. Can. J. Res. 22: 141-201.

Raufflet E. 2000. Berkes, F. and C. Folke, editors. 1998. Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience. Cambridge University Press, New York. Conservation Ecology 4(2):5. [online] URL:<http://www.consecol.org/vol4/iss2/art5>.

Sawchyn, W.W. 1987. Evaluation of lake trout and lake whitefish resources in Lac la Plonge. Fisheries Technical Report 87-1.

Scannell P. W. and L. L. Jacobs. 2001. Effects of Total Dissolved Solids on Aquatic Organisms: A Literature Review. Alaska Department of Fish and Game, Division of Habitat and Restorations. Technical Report No. 01-06.

Schindler D. W., J. Kalff, H. E. Welcj, G. J. Brinskill, H. Kling and N Kritsch. 1974. Eutrophication in the High Arctic – Meretta Laek, Cornwallis Island (75° N Lat.). J. Fish. Res. Board Can. 31: 647-662.

Scott W. B. and E. J. Crossman. 1973. Freshwater Fishes of Canada. Fisheries Research Board of Canada. Bulletin 184.

Shuter B. J., M.L. Jones, R.M. Korver and N.P. Lester. 1998. A General, Life History Based Model for Regional Management of Fish Stocks: the Inland Lake Trout (*Salvelinus namycush*) fisheries on Ontario. Can. J. Fish. Aquat.Sci. 55: 2161-2177.

Stekoll M., W. Smoker, I. Wang and B. Failor. 2001. Fourth Quarter 2000 Report for ASTF Grant #98-012, Project: Salmon as a Bioassay Model of Effects of Total Dissolved Solids. 17 January 2001.

Stoss J., S. Buyujhatopoglu and W. Holtz. 1977. The Influence of Certain Electrolytes on the Induction of Sperm Motility in Rainbow Trout (*Salmo gairdneri*). Zuchthg 12 (1977): 178-184 (Abstract and summary translated).

Tietge, J. E., J.R. Hochettand J. M. Evans. 1997. Major Ion Toxicity of Six Produced

Waters to Three Freshwater Species: application of ion toxicity models and tie procedures. Environmental Toxicology and Chemistry, 16(10): 2002–2008.

Timms B. V., U. T. Hammer and J. W. Sheard. 1986. A Study of Benthic communities in Some Saline lakes in Saskatchewan and Alberta, Canada. Int. Revue ges. Hydrobiol. 71(6) 759-777.

United States EPA. 1988. Ambient Water Quality Criteria for Chloride. United States Environmental Protection Agency. EPA 440/5-88-001.

United States EPA. 1999. National Recommended Water Quality Criteria – Correction. Environmental Protection Agency, Office of Water. EPA 822-Z-99-001. April 1999.

Vyverman, W., R. Vyverman, V. S. Rajendran, and P. Tyler. 1996. Distribution of Benthic Diatom Assemblages in Tasmanian Highland Lakes and Their Possible use as Indicators of Environmental Changes. Can. J. Aquat. Sci. 53: 493-508.

Waevagen S. B., N. A. Rukke and D. O. Hessen. 2002. Calcium Content of Crustacean Zooplankton and its Potential role in Species Distribution. Freshwater Biology 47: 1866-1878.

Waller D. L., S. W. Fisher and H. Drabrowska. 1996. Prevention of Zebra Mussel Infestation and Dispersal During Aquaculture Operations. The Progressive Fish-Culturalist. 58(2): 77-84.

Watson S.B., E. McCauley and J.A. Downing. 1997. Patterns in Phytoplankton Taxonimic Composition Across Temperate Lakes of Nutrient Status . Limnol. Oceanogr. 42: 487-495.

Welch H.E., J. A. Legault and H.J. Kling. 1989. Phytoplankton, Nutrients, and Primary Productivity in Fertilized and Natural Lakes at Saqvaqjuac, N.W.T. Can. J. Fish. Aquat. Sci. 46:90-107.

Wetzel R.G. 1983. Limnology. Second Edition. Saunders College Publishing. Philadelphia.

Wilson, S.E., B. F. Cumming and J. P. Smol. 1994. Diatom Salinity Relationships in 111 Lakes from the Interior Plateau of British Columbia, Canada: the Development of Diatom-based Models for Paleosalinity Reconstructions. Journal of Paleolimnology 12: 197-221.

Wilson, S. E., B. F. Cumming and J. P. Smol. 1996. Assessing the Reliability of Salinity Inference Models from Diatom Assemblages: an examination of a 219-lake data set from western North America. Can. J. Fish. Aquat. Sci. 53: 1580-1594.