WABAMUN LAKE WATER QUALITY 1982 TO 2001

Alberta Environment

WABAMUN LAKE WATER QUALITY
1982 TO 2001

Prepared by:

Richard Casey, M.Sc.
Limnologist

Science and Standards
Alberta Environment

September 2003

W0309

Pub. No: T/695
ISBN: 0-7785-2503-1 (Printed Edition)
ISBN: 0-7785-2504-X (On-Line Edition)
Web Site: http://www3.gov.ab.ca/env/info/infocentre/publist.cfm

Any comments, questions, or suggestions regarding the content of this document may be directed to:

Environmental Monitoring and Evaluation Branch
Alberta Environment
10th Floor, Oxbridge Place
9820 – 106th Street
Edmonton, Alberta T5K 2J6
Phone: (780) 427-6278
Fax: (780) 422-6712

Additional copies of this document may be obtained by contacting:

Information Centre
Alberta Environment
Main Floor, Great West Life Building
9920 – 108th Street
Edmonton, Alberta T5K 2M4
Phone: (780) 944-0313
Fax: (780) 427-4407
Email: env.infocent@gov.ab.ca

SUMMARY

Wabamun Lake, approximately 60 km west of Edmonton, is large, shallow, and generally well mixed. Sport fish in the lake include northern pike, yellow perch, and lake whitefish. There are a unique mix of land uses in the lake watershed, which include undisturbed bush and forest, agriculture, two coal mines with active and reclaimed areas, three coal-fired power plants, major transportation (road and rail) corridors, residences, and recreation. The mines supply fuel for the power plants, operated by the TransAlta Utilities Corporation (TAU). Industrial wastewaters, runoff and cooling water from the Whitewood mine and Wabamun power plant are discharged to the lake. Over time, TAU operations associated with the mines and power plants in the watershed have caused cumulative and ongoing impacts on the lake level. In order to eliminate these effects on the lake water balance, TAU built the Wabamun Lake Water Treatment Plant (WL-WTP) to treat water from the Sundance cooling pond and pump it to the lake. The cooling pond contains water pumped from the North Saskatchewan River (NSR), local runoff, and various wastewaters from the Highvale mine and Sundance power plant. The WL-WTP uses chlorination and ozonation treatments to eliminate the potential transfer of fish parasites (including zooplankton hosts) and larval fish from the NSR to the lake. The WL-WTP began pumping treated water to the lake in late 1997, but relatively large volumes were not pumped until after 1998. In 2001, TAU submitted an application to Alberta Environment to build a second WTP that would pump more treated water to the lake (total capacity = 23 x 10^6 m^3 of treated water per year).

In the early 1980s, Alberta Environment established a formal water quality monitoring program at Wabamun Lake. The program was designed to determine long-term patterns in the overall water quality of the lake. It was not designed to evaluate the effects of specific activities (e.g., point and non-point source inputs) in the watershed. The objectives of this report are:

1. To summarise patterns in the water quality of Wabamun Lake using data collected by Alberta Environment from 1982 to 2001

2. To evaluate the main changes of lake water quality as they relate to aquatic biota, lake level, lake water balance, and effects of the WL-WTP inflow to the lake.

The water quality of Wabamun Lake from 1982 to 2001 was similar to other freshwater lakes of central Alberta. However, various temporal trends in the water quality of the lake were found over the 20-year period. The main change in the overall water quality of the lake was an increase of total dissolved solids (TDS) by about 30%. Some major ions (i.e., components of TDS) showed greater annual concentration increases in the lake after 1992. This trend was probably due to the absence of flushing of major ions from the lake by more dilute surface inflows (e.g., precipitation and runoff) after 1992, when lake outflow (via Wabamun Creek) ceased. The overall pattern of increasing TDS in Wabamun Lake was also found in regional lakes with similar basin characteristics (small basin area : lake area) and limited or no hydraulic flushing of the lakes over the same 20-year period. The overriding cause of the TDS increases in these lakes was likely due to the prevailing climate conditions. The trophic state (or fertility) of Wabamun Lake was moderately to highly productive (i.e., meso-eutrophic) from 1982 to 2001, which was similar to previous assessments using 1970s data.

Metal samples in Wabamun Lake were mostly restricted to the 1999 to 2001 period, except for one sample taken in 1996. Overall the data showed no pronounced spatial differences in metal concentrations among the three sites sampled from 1996 to 2001. Temporal patterns were evident for some metals in the lake. Concentrations of four metals declined in the lake, while one showed a small increase from 1999 to 2001. Some metal concentrations also showed consistent increases or decreases in the lake in each of the three years. These patterns may be due to temporal influences of metal loads in natural streams, which generally occur in the open-water period, compared to more atypical inflows (i.e., WL-WTP treated water and ash lagoon discharge) occur throughout the year. All metal concentrations in the lake were less than water quality guidelines for the protection of freshwater aquatic life and livestock watering. All boron and some manganese concentrations in the lake were greater than guidelines for irrigation uses.

Two commonly used herbicides (2,4-D and MCPA) were found at low concentrations in the lake in 1995 (the only year when pesticides were sampled). The concentrations were below water quality guidelines for the protection of freshwater aquatic life.

Preliminary analysis of plankton sampled in Wabamun Lake from 1990 to 2001 showed no overall changes in the phytoplankton and zooplankton communities during this period.

Changes in the lake water quality that were likely associated with effects of the WL-WTP inflow to the lake, from 1999 to 2001, were: (1) step increases of TDS and some major ion (notably sulphate) concentrations in the lake; (2) a step decrease or declining concentrations of calcium and carbonate in the lake; and (3) small decreases of phosphorus and chlorophyll-*a* (equivalent to algal biomass) concentrations in the lake, which generally remained at lower levels in the three-year period. Lower phosphorus concentrations (often a limiting nutrient in Alberta lakes) probably caused the concurrent reductions of chlorophyll-*a* in the lake.

Sulphate and TDS increases in the lake were likely related to the influences of higher concentrations of these variables in the treated water (compared to the lake). Sulphate and calcium made up the highest annual loads of major ions in the treated water, compared to the individual masses of these ions in the lake. The water quality of the WL-WTP treated water could be affected by: the quality of the raw water (Sundance cooling pond); treatment chemicals used and efficacy of the WL-WTP; and seasonal conditions in the cooling pond.

The small declines of phosphorus in the lake were probably related to phosphorus co-precipitating with calcium carbonate (calcite) onto the lake bottom. This process occurs naturally in hardwater lakes, such as Wabamun Lake. Various water quality data indicate that calcite precipitation in the lake was likely enhanced from 1999 to 2001, due to the new WL-WTP inflow to the lake.

Other potential inputs from the WL-WTP to the lake include disinfection by-products (DBPs), which were present at low levels in the final treated water. Alberta Environment initiated a sampling program in 2002 to determine the spatial and temporal variability of DBPs in the vicinity of the treated water discharge and in the lake.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ACKNOWLEDGEMENTS

I would like to thank Dave Trew for initiating this project and providing insight and discussion at various stages in the analysis of the data. I am also grateful to several Alberta Environment staff who provided assistance in preparing the report. They include: Bridgette Halbig for technical support (compiling data, preparation of graphics, and formatting the report); Roderick Hazewinkel for preparing the box and whisker graphs; Doreen LeClair for obtaining data and resolving some data issues; Anne-Marie Anderson, Pat Mitchell, Leigh Noton, and Dave Trew for helpful comments on the report; Michael Seneka who supplied data and analysis on the lake level and water balance and reviewed those portions of the report; and Rick Phaneuf for assistance in obtaining data associated with Approvals.

Pat Mitchell designed the original monitoring program and managed the program throughout the 20-year period, which is the basis of data in the report. Over the years, many technical staff from the current Monitoring Branch, Alberta Environment, were involved in the collection of the monitoring data. These staff (in alphabetical order) included: Dave Allan, Trina Ball, Mike Bilyk, Morna Hussey, Brian Jackson, Don Jones, Doreen LeClair, Shelley Manchur, Marianne McCutcheon, Treva Piekema, Monica Polutranko, Chris Rickard, Chris Ware, and John Willis. Michael Agbeti of Bio-Limno Research & Consulting, Inc. analysed the plankton samples.

1.0 INTRODUCTION

Wabamun Lake is located approximately 60 km west of Edmonton in the transition zone between the parkland and boreal forest natural regions. Mitchell and Prepas (1990) presented a detailed overview of the physical, chemical, and biological characteristics of the lake in the *Atlas of Alberta Lakes*. The lake is large (area = 82 km^2), shallow (mean depth = 6.3; maximum depth = 11 m), and generally well mixed, usually with well oxygenated conditions in the entire water column during the open-water period (Mitchell and Prepas 1990; Alberta Environment, unpublished data). The lake is moderately to highly enriched with nutrients (Mitchell and Prepas 1990). Sport fish in the lake include northern pike, yellow perch, and there is an important commercial fishery of lake whitefish. Walleye were re-introduced to the lake by annual stocking of fry from 1983 to 1986. However, they are not known to have reproduced successfully in the lake (Stephen Spencer, Alberta Sustainable Resources, personal communication).

There are a unique diversity of land uses in the Wabamun Lake watershed compared to other Alberta lakes. Land uses include undisturbed bush and forest, agriculture, two coal mines with active and reclaimed areas, three coal-fired power plants, residences, and recreation (Figure 1). The coal mines supply fuel for the power plants which are entirely or partially within the lake and adjoining North Saskatchewan River watersheds (Figure 1). The power plants are operated by the TransAlta Utilities Corporation (TAU). Mitchell and Prepas (1990) provided a general chronology of the establishment of power plants, mining and other major activities in the watershed. Cooling water for the Wabamun power plant is extracted and returned back to the lake. Industrial wastewaters and runoff from the Whitewood mine and Wabamun power plant are discharged to Wabamun Lake, via the ash lagoon system of ponds on the north shore of the lake (Figure 1). Cooling water for the Sundance and Keephills power plants originates from separate cooling ponds, which contain water pumped from the North Saskatchewan River (Figure 1). The Sundance cooling pond also contains local runoff and various wastewaters from the Highvale mine and Sundance power plant. Wastewaters (blowdown) from the Sundance and Keephills cooling ponds are discharged periodically to the North Saskatchewan River.

Over time, TAU operations associated with the coal mines and power plants within the Wabamun Lake watershed have caused cumulative and ongoing impacts on the lake level. These impacts include water losses caused by enhanced evaporation (due to cooling waters discharged to the lake), consumption of lake water by the Wabamun and Sundance power plants (for potable water and plant processes), and diversion of runoff and groundwater out of the lake watershed, due to mining activities. Other users of the lake water are for domestic uses by the village of Wabamun and irrigation by a golf course, located on the east shore of the lake. The estimated cumulative impact (also known as the "historical debt") on the lake level (volume) due to TAU activities within the lake watershed is estimated as 47.2 x 10^6 m^3 from 1992 to the end of 2000 (Appendix A). The historical debt was estimated beginning in 1992 when lake outflow (via Wabamun Creek) ceased, i.e., from about mid-1992 to the present. Direct effects of TAU activities on the lake level are of most concern when the lake level drops below the outlet level. Estimates of the annual impact of TAU activities in the lake watershed range from about 6.3 to 12.0 x 10^6 m^3 per year from 1996 to 2001 (TAU 2001a). In order to eliminate the cumulative and ongoing impacts on the lake water balance, TAU built the Wabamun Lake Water Treatment Plant (WL-WTP) to treat water from the Sundance cooling pond and pump it to the lake (Figure 1). The difference in

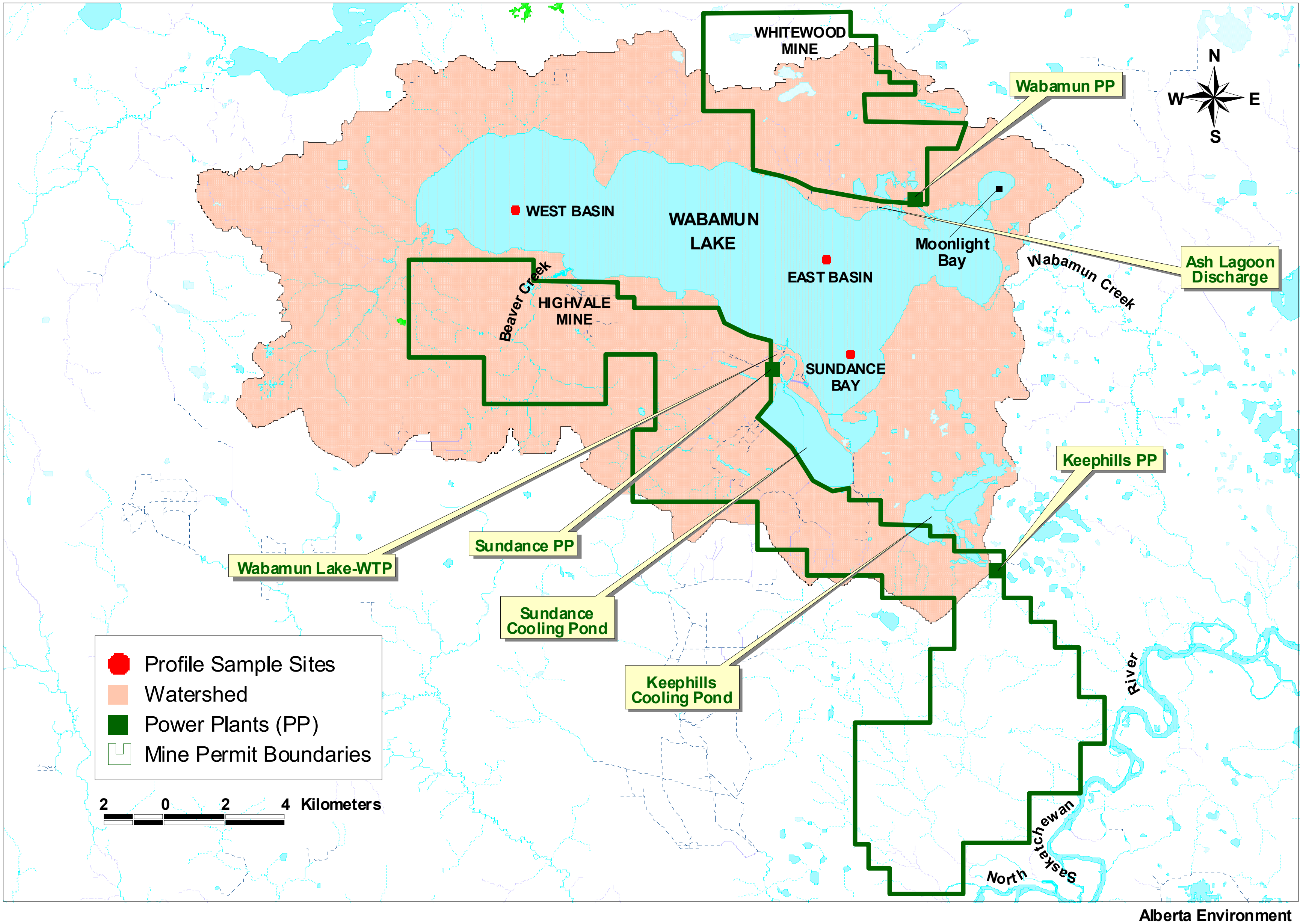


Figure 1 Features in the Wabamun Lake watershed and surrounding area

temperatures between the WL-WTP treated water and lake water is maintained at less than 3°C (TAU 2001a, 2001b). The WL-WTP was designed to produce up to 15 x 10^6 m^3 of treated water (equivalent to drinking water quality) per year. It was also designed to eliminate the potential transfer of fish parasites (including zooplankton hosts) and larval fish from the North Saskatchewan River to the lake. The WL-WTP began pumping treated water to the lake in late 1997, but only small volumes of treated water were pumped to the lake in 1997 and 1998 (total volume for both years = 2.3 x 10^6 m^3), compared to the 1999 to 2001 period (range = 10.2 to 13.1 x 10^6 m^3 per year) (TAU 2001a).

In 2001, TAU submitted an application to Alberta Environment to build a second WTP to treat and pump additional water from the Sundance cooling pond to the lake (TAU 2001a). The total capacity of the current and proposed WTPs is 23 x 10^6 m^3 of treated water per year. The original and new WTPs together are referred to as the WL-WTP throughout this report, unless noted as otherwise. Following commissioning of the expanded WL-WTP in 2002, the total volume of treated water pumped to the lake is expected to be $\geq$20 x 10^6 m^3 per year from 2003 to 2006 inclusive (Appendix A). It is anticipated that the historical debt due to TAU activities on the lake volume (as cited above) will be eliminated by the end of 2006 (Appendix A).

The lake level and water balance are also influenced by other inflows and outflows including precipitation, runoff, evaporation, and groundwater exchange within the watershed. In turn, these water balance components and their respective chemical loads may affect the water quality of Wabamun Lake. In addition, air emissions from industrial and transportation sources (e.g., power plants, Highway 16, trans-Alberta railway link, and mine vehicles) have the potential to affect the lake water quality.

Previous studies on the water quality of Wabamun Lake have included the effects of various natural and anthropogenic activities in the lake watershed. For example, Gallup and Hickman (1975) examined the effects of thermal discharges from the Wabamun power plant on water chemistry of the lake. In another study, Schwartz and Gallup (1978) described effects of groundwater, surface runoff, and snow on major ions in the lake. Habgood (1983) reviewed published scientific literature and some unpublished information on the lake water quality and biotic studies up to the early 1980s. In 1980 to early 1982, Alberta Environment conducted an intensive study to determine a nutrient budget for the lake, based on phosphorus and nitrogen loads from various sources in the water- and air-sheds (Mitchell 1985). The focus of this latter study and related studies on groundwater (e.g., Crowe and Schwartz 1982) were to evaluate concerns related to nutrient enrichment (eutrophication) of the lake ecosystem. A comprehensive summary of the water quality of Wabamun Lake (including selected data from the 1980s) was prepared by Mitchell and Prepas (1990). Other more recent reports included reviews of information on the water quality of the lake (e.g., Golder 1999).

In the early 1980s, Alberta Environment established a formal water quality monitoring program at Wabamun Lake. The program was designed to determine long-term patterns in the overall water quality of the lake. It was not designed to evaluate the effects of specific activities (e.g., point and non-point source inputs) in the watershed. The most current and comparable field sampling and analytical methods were used to collect data at the same sites in the program.

Comparisons of these data to other Wabamun Lake data before the early 1980s often are difficult, or may not be valid, because of differences in the sampling and analytical methods used.

The objectives of this report are:

1. To summarise patterns in the water quality of Wabamun Lake using data collected by Alberta Environment from 1982 to 2001

2. To evaluate the main changes of lake water quality over the 20 years as they relate to aquatic biota, lake level, lake water balance, and effects of the WL-WTP treated water pumped to the lake.

2.0 METHODS

2.1 Monitoring Program Design, 1982 to 2001

The Alberta Environment monitoring program included monthly sampling in the East and West Basins or the entire lake (identified as the "Main Basin") during the open-water period (Table 1; Figure 1). Treated water from the Wabamun Lake Water Treatment Plant (WL-WTP) was sampled three or four times per year from 1999 to 2001 (Table 1). The treated water was also sampled (monthly) by TAU throughout this period (as per Approval requirements). The results in the report are those collected by Alberta Environment.

Other limnological data collected from 1982 to 2001 include vertical profiles of temperature, pH, dissolved oxygen, and conductivity at profile sites and water samples from Moonlight Bay (1991 to 1993 and 1995 to 1997) (Figure 1). These results are not presented in the report because the focus is on patterns in the overall water quality of the lake.

Samples of zooplankton and phytoplankton, were collected monthly during the open-water period of most years from 1982 to 2001. These results can be used to determine long-term patterns in aquatic biota (plankton) which may be related to changes in lake water quality.

2.2 Field and Laboratory Measurements

Methods and materials used in the sampling program followed the field and laboratory protocols outlined in *Water Quality Sampling Methods* (Alberta Environment 2002a).

2.2.1 General Characteristics, Major Ions, Nutrients, and Trophic State

Vertically integrated samples of the euphotic zone were taken monthly during the open-water period of each year from 1982 to 2001 (Table 1; Figure 1). The euphotic zone is generally defined as the portion of the water column with enough light for photosynthesis. It is measured as the depth equivalent to 1% of the light reading just below the water surface. A composite sample of each basin was made up of individual subsamples of the euphotic zone taken at 10 sites throughout the basin.

Each euphotic composite sample was analysed for the following variables:

- General physical and chemical characteristics - alkalinity, pH, conductivity, total dissolved solids (TDS; calculated), hardness, and non-filterable residue (NFR).

- Major ions – calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulphate, chloride, and fluoride (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, CO_3^{2-}, SO_4^{2-}, Cl^{-}, and F^{-}, respectively).

Table 1 Summary of the water quality sampling program at Wabamun Lake, 1982 to 2001

Water Quality Variables	Site	Sample Type: Composite of Euphotic Zone or Discrete Sample (Water Depth, metres)	Range of Dates	Number of Samples
	East Basin	Composite	May to Sept. 1982	6
			May to Nov. 1999	6
Physical & Chemical Characteristics (temperature, dissolved oxygen, alkalinity, pH, conductivity, TDS, hardness, NFR)			May to Oct. 2000	6
			May to Oct. 2001	6
	Main Basin	Composite	May to Oct. 1983	7
			April to Sept. 1984	7
			May to Oct. 1985	8
			May to Oct. 1986	6
			May to Oct. 1987	7
Major Ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, CO_3^{2-}, SO_4^{2-}, Cl^{-}, F^{-})			May to Oct. 1988	8
			May to Oct. 1989	6
			May to Oct. 1990	7
			May to Sept. 1991	6
			April to Oct. 1992	7
			May to Oct. 1993	7
Nutrients and Related Variables (TP, DP, TKN, NH_3-N, $[NO_3+NO_2]$-N, DOC, Chlorophyll *a*)			April to Oct. 1994	8
			May to Oct. 1995	8
			May to Oct. 1996	10
			May to Oct. 1997	8
			May to Aug, 1998	5
	West Basin	Composite	May to Nov. 1999	6
			May to Oct. 2000	6
			May to Oct. 2001	6
	East Basin Profile	Discrete (6 m)	21-Feb-96	1
		Discrete (7 m)	25-Feb-99	1
		Discrete (6 m)	26-Jul-99	1
		Discrete (6 m)	10-Feb-00	1
		Discrete (6 m)	22-Aug-00	1
Metals: 28 elements (Al, Sb, As, Ba, Be, Bi, B, Cd, Cr, Co, Cu, Fe, Pb, Li, Mn, Hg, Mo, Ni, Se, Ag, Sn, Sr, Th, Ti, Tl, U, V, Zn; additional Hg samples were taken at some sites on other dates from 1996 to 2001, see Table 5)		Discrete (6 m)	26-Feb-01	1
		Discrete (6 m)	18-Jul-01	1
	West Basin Profile	Discrete (9 m)	25-Feb-99	1
		Discrete (9 m)	10-Feb-00	1
		Discrete (9 m)	22-Aug-00	1
		Discrete (9 m)	26-Feb-01	1
		Discrete (9 m)	18-Jul-01	1
	Sundance Bay Profile	Discrete (1 m, 4.5 m)	25-Feb-99	2
		Discrete (1 m, 4 m)	10-Feb-00	2
		Discrete (1 m, 3 m)	26-Feb-01	2
Pesticides: 31 compounds	East Basin Profile	Discrete (1 m, 6 m)	19-Jul-95	2
(see Table 6 for list)		Discrete (1 m, 6 m)	10-Aug-95	2

- Nutrients and indicators of trophic state – total phosphorus (TP), dissolved phosphorus (DP), total Kjeldahl nitrogen (TKN), total ammonia (sum of NH_3 and NH_4^+), nitrite plus nitrate ($[NO_2 + NO_3]$-N), dissolved organic carbon (DOC), and chlorophyll-*a.*

Samples were analysed for general characteristics including pH, major ions, and nutrients (excluding phosphorus) primarily by Chemex Ltd., now Maxxam Analytical Ltd. Some samples were analysed by the Alberta Research Council (Water Laboratory), Vegreville. Chlorophyll-*a,* TP, and DP were analysed by the Monitoring Branch Water Laboratory, Alberta Environment.

Transparency of the lake water (equivalent to the depth of visible light penetration) was measured using a Secchi disk, a circular plate with four quadrants of alternating black and white colour. The Secchi depth (or visibility) is the water depth where the disk is no longer visible from the water surface. The Secchi depths were taken at the East Basin profile site from 1983 to 2001; additional readings were taken at the West Basin profile site from 1999 to 2001.

2.2.2 Metals

Metals were analysed less frequently than other water quality variables (Table 1). Results presented in the report only include samples that were collected at the routine monitoring sites and analysed using the same multi-element analytical scan. Discrete samples were taken 0.5 to 1.0 m above the lake bottom at the East Basin, West Basin, and Sundance Bay profile sites (Table 1; Figure 1). Other local names for Sundance Bay or portions of the bay are Indian and Goosequill Bay. In winter (February) of 1999 to 2001, additional metal samples were taken (concurrently with the bottom samples) at about 0.5 m below the water surface at the Sundance Bay site (Table 1).

All samples (total number of samples =18) were analysed for 27 elements: aluminum, antimony, arsenic, barium, beryllium, bismuth, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, molybdenum, nickel, selenium, silver, tin, strontium, thorium, titanium, thallium, uranium, vanadium, and zinc (Table 1). The samples were analysed using total recoverable or extractable analytical methods and an inductively coupled plasma mass spectrometer (ICP-MS) method with low analytical detection limits, usually <0.001 mg/L or 1 µg/L (1 mg = 1 g x 10^{-3}; 1 µg = 1 g x 10^{-6}).

An additional metal, mercury was sampled more frequently than other metals in the lake (total number of mercury samples = 39) from 1996 to 2001. About half of the mercury samples (18 samples) were taken at the East Basin profile site, that is about 2 km south-west of the Wabamun power plant and about 4 km north-east of the Sundance power plant (Figure 1). The samples were collected and transported to the analytical laboratory using ultra-clean procedures (following protocols provided by the Alberta Research Council). The samples were analysed for total mercury by a cold vapour atomic absorption spectrometer (CV-AAS) method, using an ultra-trace method detection limit of 1.2 ng/L (1 ng = 1 g x 10^{-9}). All metal samples were analysed at the Water Laboratory of the Alberta Research Council, Vegreville.

2.2.3 *Pesticides*

A total of four samples were taken near the surface and bottom of the East Basin profile site in July and August of 1995 (Table 1; Figure 1). The samples were analysed for 31 compounds (including herbicides and insecticides) by the Trace Organics Laboratory of the Alberta Research Council, Vegreville. Analytical detection limits ranged from 0.1 to 0.005 µg/L.

2.2.4 *Quality Assurance*

Quality assurance (QA) data were collected as part of the Wabamun Lake monitoring program. The samples included splits of the same field sample, true replicate field samples, and field blank samples which were submitted to the same or different analytical laboratories. The field blank samples were collected by pouring ultra-clean water (supplied by the analytical laboratory) into an appropriate sample bottle in the field. The sample was usually labelled with a false sample site and submitted to the analytical laboratory for analysis with the regular field samples. The QA results were routinely reviewed to identify any concerns with the analytical results. Only the QA data for mercury samples are included in the report, because of some concern with these results. Quality assurance for the mercury sampling included one or more field blank samples taken on the same day as the mercury field samples.

2.2.5 *Plankton*

Plankton samples were taken monthly in the open-water period of most years, using the same schedule as the water samples (Table 1). Phytoplankton (number of taxa and biomass) were analysed in a sub-sample of the euphotic water sample taken in the lake basin(s). Zooplankton (number of taxa and abundance) samples were taken using a plankton net. On each sample date, a vertical sample of the euphotic zone was taken at one or two profile sites (East and West Basins). Zooplankton was usually sampled at the East Basin site if the "Main Basin" (Section 2.1) was sampled in the water sampling program (Table 1).

2.3 Data Analysis

All water quality data for Wabamun Lake including those in the report (1982 to 2001) are stored in the Water Data System (WDS) computer database maintained by Alberta Environment. The electronic data can be obtained from Alberta Environment (Environmental Assurance, Environmental Monitoring and Evaluation Branch).

Before calculating summary statistics and conducting statistical analyses of the data, any variables with concentrations (or other measurement values) less than their respective analytical detection limits were replaced by values equal to half of the analytical detection limit for that variable. Water quality variables with concentrations less than their respective analytical detection limits are labelled as "L" in WDS (e.g., see raw data in Appendices; Section 3.0). The term "analytical detection limit" used in the report, is equivalent to the method detection limit (MDL) for most variables (except for metals) as reported by the analytical laboratories and stored in WDS. Metals analysed by the Alberta Research Council (i.e., metal scans by ICP-MS and ultra-trace mercury by CV-AAS) are reported in WDS as the minimum reported value

(MRV), which is equivalent to the instrument detection limit. This concentration is usually lower than the MDL.

Temporal trends in the water quality data (excluding metals and pesticides) from 1982 to 2001 were examined using box and whisker plots. These graphs show the maximum, minimum, median, and other percentile concentrations (10, 25, 75, and 90%) of individual variables during the open-water period of each year. Common statistical tests were also used to analyse temporal and other patterns in the data (e.g., Zar 1984). Simple linear regression analysis was used to assess the functional relationship of changes in water quality variables over the 20-year period. Products of this analysis provided in the report are the r^2 value and an associated probability level. The r^2 value is equivalent to the strength of the linear relationship, which can vary from no relationship ($r^2 = 0$; i.e., concentrations show no change over time) to an exact straight-line relationship ($r^2 = 1$). The probability level (P) (based on a one-way analysis of variance test) indicates whether the slope of the regression line is significantly different from a slope of zero. The t-test (two tailed) was used to test the statistical significance of changes in water quality variables between different periods. Correlation analysis was used to assess the strength of linear relationships between the concentrations of pairs of water quality variables. The correlation coefficient can vary from an exact positive relationship ($r = 1$), no relationship ($r = 0$), to a negative relationship ($r = -1$). For all statistical tests, $P \leq 0.05$ was used to indicate statistically significant differences. All water quality data (excluding pH) used in the statistical tests were transformed ($\log_{10}[x+1]$) to reduce dependence of the mean on variance and to obtain more equal variances in the data (Zar 1984).

Water quality guidelines for the protection of freshwater aquatic life (Alberta Surface Water Quality Guidelines; Canadian Council of Ministers of Environment: CCME; and U.S.A. Environmental Protection Agency: US-EPA) were used to evaluate potential effects on aquatic biota in Wabamun Lake (Alberta Environment 1999; CCME 2000; CCME 2002). Water quality guidelines for agricultural uses (i.e., for irrigation and livestock watering) were also used because some lake water is used for irrigation (Alberta Environment 1999).

Long-term data for TDS in lakes within a radius of about 100 km from Wabamun Lake (i.e., in the North Saskatchewan River and Athabasca River basins) were reviewed to determine if similar patterns of TDS concentrations occurred in these lakes from 1982 to 2001. Lakes with a span of at least 15 years of TDS data within the 20-year period were chosen from the Alberta Environment WDS database, although data were sparse for some lakes.

The potential influence of the observed changes in lake level (or volume) of Wabamun Lake on major ions in the lake was examined using a simple formula. The following formula was used to estimate the effect of the lake level changes on the concentrations of major ions and related variables in the lake from 1982 to 2001:

Predicted Conc. in Year X = [Observed Conc. in Yr. 1] x [Vol. in Yr. 1] / [Vol. in Yr. of Prediction]

where,

Year X	=	each year beginning in 1983 or 1984[1] to 2001
Observed Conc. In Yr. 1	=	median concentration measured in 1982 or 1983[1]
Vol. in Yr. 1	=	lake volume in 1982 or 1983[1]
Vol. in Yr. of Prediction	=	lake volume in the year evaluated, beginning in 1983 or 1984[1] to 2001

[1] = no data were collected for bicarbonate and carbonate in 1982

The mean annual lake volumes used in these calculations were based on measured lake water levels, and area and capacity (lake volume) curves for the lake (Appendix B). In the assessment, it was assumed that (1) there were no influences of major inflows and outflows (excluding evaporation) to the lake (i.e., the mass of each major ion (or related variables) in the lake did not change from the first year of the assessment, Year 1 = 1982 or 1983) and (2) all major ions behaved conservatively (i.e., they were not affected by biochemical processes) in the lake over the 20 years.

3.0 RESULTS AND DISCUSSION

Section 3.1 includes a description of the water quality of Wabamun Lake in the open-water period from 1982 to 2001. Section 3.2 includes an analysis of plankton samples from Wabamun Lake. Discussion of the potential influences of the lake level and water balance components on the water quality of the lake is provided in Section 3.3. Finally, Section 3.4 includes an overview of the quality and quantity of the Wabamun Lake Water Treatment Plant (WL-WTP) treated water from 1999 to 2001 and discussion of effects of the treated water on the lake water quality. Comparisons of the Wabamun Lake data to those from other lakes and published literature is provided where appropriate data are available. Summaries or raw water quality data for the lake and WL-WTP treated water are presented in Section 3.1 and Appendices C, D, and E.

3.1 Physical and Chemical Characteristics of Wabamun Lake, 1982 to 2001

3.1.1 Alkalinity and pH

Alkalinity of water is generally defined as the capacity to neutralise strong acid. In most inland waters, alkalinity is primarily caused by the concentrations and chemical equilibrium between bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}). This chemical equilibrium is the major buffering mechanism in freshwater and it is strongly influenced by pH (Wetzel 1983). High alkalinity (>100 mg/L [$CaCO_3$]) causes high buffering capacity which is typical of Wabamun Lake. Median alkalinity in the lake increased by about 16% from 187 mg/L ($CaCO_3$) in 1982 to a maximum of 216 mg/L ($CaCO_3$) in 1999 (Figure 2). There was a strong pattern of increasing alkalinity in the lake over the 20 years ($r^2 = 0.821$, $P < 0.001$, $n = 148$).

Hydrogen ion concentration (pH) is a measure of the acidity of a solution. Values of pH <7 are acidic, those equal to 7 are neutral, and values >7 indicate alkaline conditions. Wabamun Lake is alkaline, with a narrow range of median pH from 8.4 to 8.8 throughout 1982 to 2001 (Figure 2). Overall, there was a small decline of pH over the 20 years ($r^2 = 0.094$, $P < 0.001$, $n = 148$), which was likely due to trend of decreasing pH during the 1990s up to 2000 (Figure 2).

3.1.2 Specific Conductance and Total Dissolved Solids

Specific conductance (or conductivity) is a measure of the electrical conductivity of a solution, caused by the quantity of charged ions in the solution. Higher levels of dissolved solids generally result in greater conductivity. In Wabamun Lake, median conductivity increased by 24% from 404 µS/cm in 1982 to 499 µS/cm in 2000 ($r^2 = 0.872$, $P < 0.001$, $n = 148$) (Figure 3). The overall rates of annual increases were generally greater in the 1990s compared to 1980s (Figure 3).

Conductivity is often correlated or shows a similar pattern to total dissolved solids (TDS) in a water solution because they both measure quantities of dissolved ions. However, the strength of this relationship is influenced by the ionic composition of the solution. Total dissolved solids are primarily made up of calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulphate, and chloride which are usually referred to as major ions in freshwaters. Similar to many water

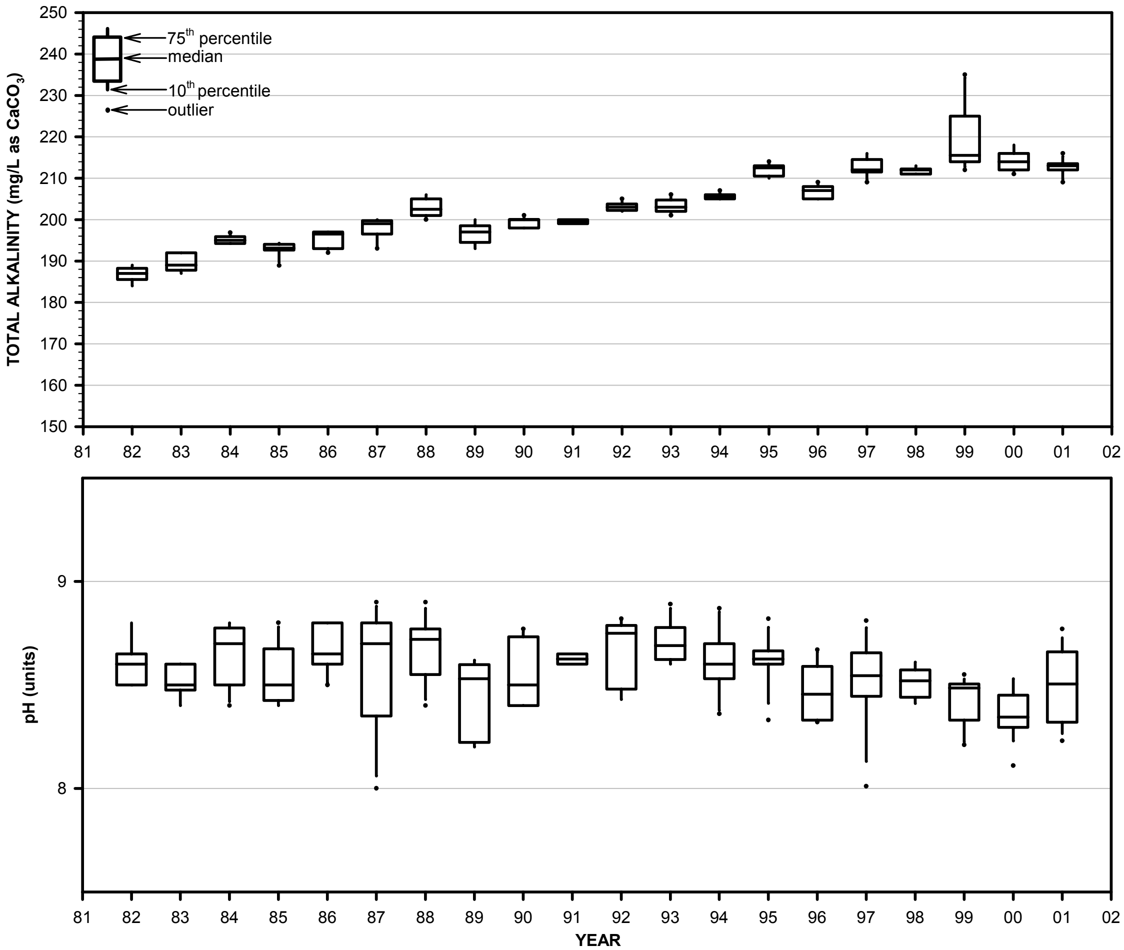


Figure 2   Total alkalinity and pH in Wabamun Lake, 1982 to 2001

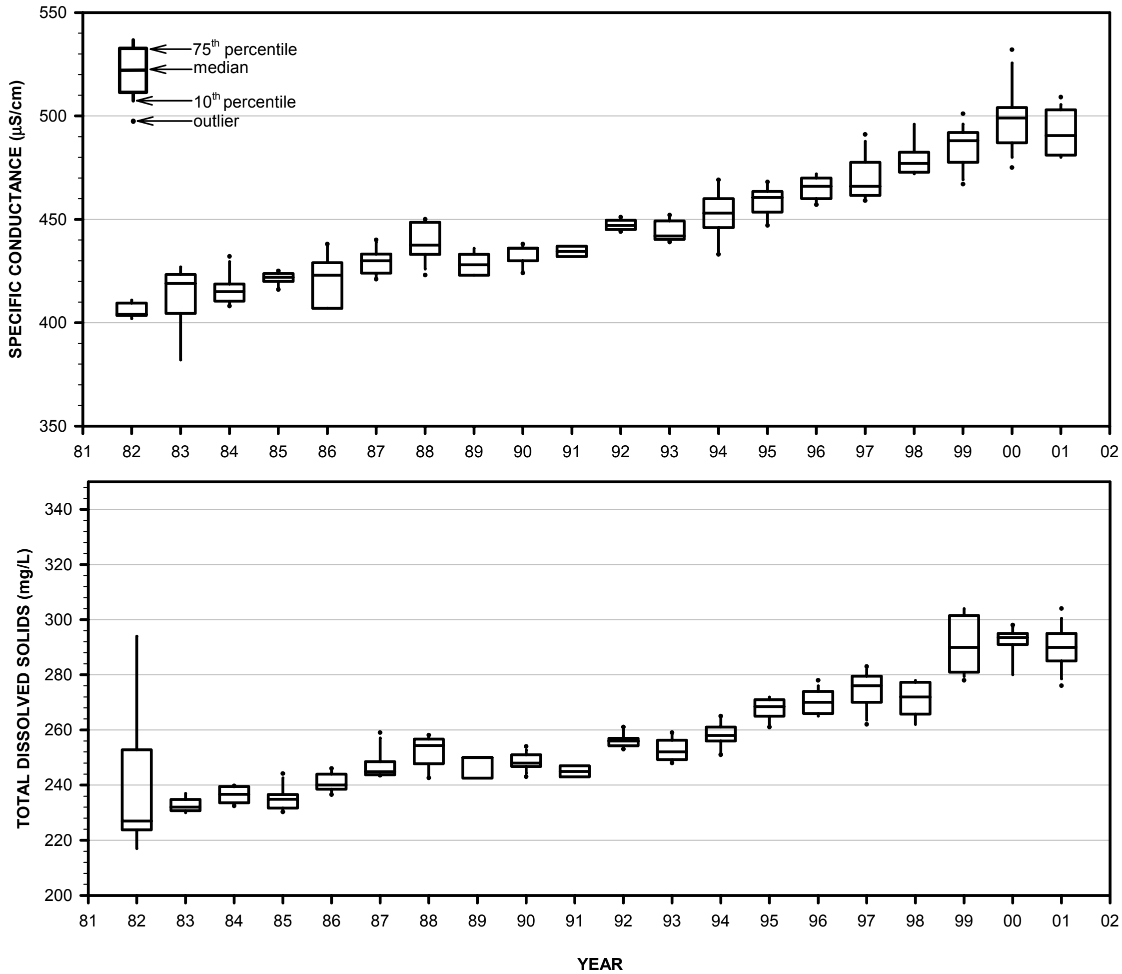


Figure 3 Specific conductance and total dissolved solids in Wabamun Lake, 1982 to 2001

quality studies, the TDS measurement used in the Wabamun Lake study was the sum of these major ions. Other constituents such as fluoride, nitrate, phosphorus, and organic compounds (e.g., dissolved organic carbon) may also contribute to TDS. Total dissolved solids are often used as a general measure of the salinity of surface waters. Lakes with TDS concentrations <500 mg/L are usually considered as freshwater lakes (e.g., Mitchell and Prepas 1990). Sources of TDS in surface waters include the weathering of rocks and soils, runoff, groundwater, precipitation, and dry deposition.

In Wabamun Lake, median TDS concentrations increased by 30% from 227 mg/L in 1982 to 294 mg/L in 2000 ($r^2 = 0.813$, $P < 0.001$, $n = 143$) (Figure 3). Similar to conductivity, there was a greater rate of annual concentrations increases in the 1990s than in the 1980s (Figure 3). In addition, there was a noticeable step increase of TDS concentrations from 1998 to highest TDS concentrations during the 1999 to 2001 period (Figure 3). This latter three-year period coincided with the time when the WL-WTP was pumping large volumes of treated water to the lake (Section 1.0). Total dissolved solids concentrations in the lake were statistically greater from 1999 to 2001 compared to the previous 3 year period (t-test critical value = 2.01, $P < 0.001$, df = 53).

<u>Total Dissolved Solids in Wabamun Lake Compared to Surrounding Lakes</u>

Total dissolved solids data for other lakes surrounding Wabamun Lake (within about 100 km radius of Wabamun Lake) were reviewed to determine if the same general pattern of increasing TDS over the 20-year study was occurring in these lakes. A total of six lakes (Isle, Lac Ste. Anne, Nakamun, Pigeon, Thunder, and Sandy) with long-term (≥15 years) TDS data were selected from the Alberta Environment WDS database (Figure 4). An overview of the physical, chemical, and biological characteristics of these lakes is provided in the *Atlas of Alberta Lakes* (Mitchell and Prepas 1990).

Two main trends of TDS concentrations over the 20-year period were found in all lakes examined, including Wabamun Lake. In four lakes (Isle, Lac Ste. Anne, Nakamun, and Pigeon), TDS concentrations remained stable throughout the period of record (1983 to 1998), and they were about one-third lower than those in Wabamun Lake (approximate difference = 80 mg TDS/L) (Figure 5). In the remaining lakes (Thunder, Sandy, and Wabamun), TDS concentrations generally increased from the early 1980s to 2001 (Figure 5). The TDS pattern in Thunder Lake was very similar to that in Wabamun Lake, with overlapping concentrations for most of the record (Figure 5)($r = 0.779$, $P < 0.001$, $n = 17$; based on annual medians). Total dissolved solid concentrations were also highly correlated in Sandy and Wabamun lakes ($r = 0.808$, $P < 0.05$, $n = 5$), although TDS levels in Sandy Lake were even higher than those in Thunder Lake compared to Wabamun Lake (approximate difference between Sandy and Wabamun lakes = 100 mg TDS/L) (Figure 5). The greatest overall increase of TDS concentrations occurred in Sandy Lake over the 20 years, compared to those in the other lakes (Figure 5).

The two distinct patterns of TDS concentrations in the lakes over the 20 years may be due to differences in the drainage basin characteristics and hydraulic flushing of each lake. Hydraulic flushing is a term used to describe the replacement of high TDS concentrations in the lake by

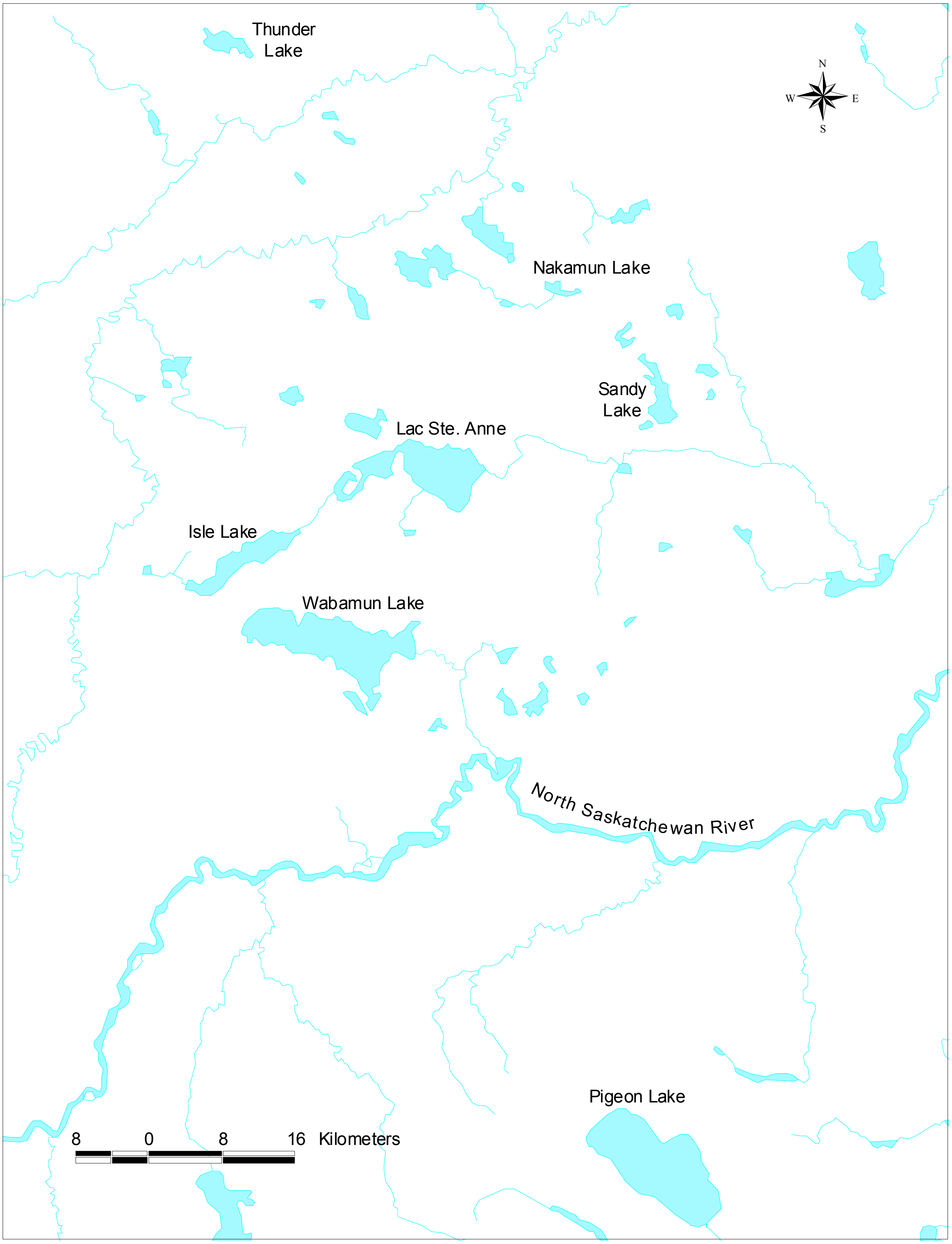


Figure 4 Lakes surrounding Wabamun Lake which have long-term total dissolved solids data (≥15 years), 1982 to 2001

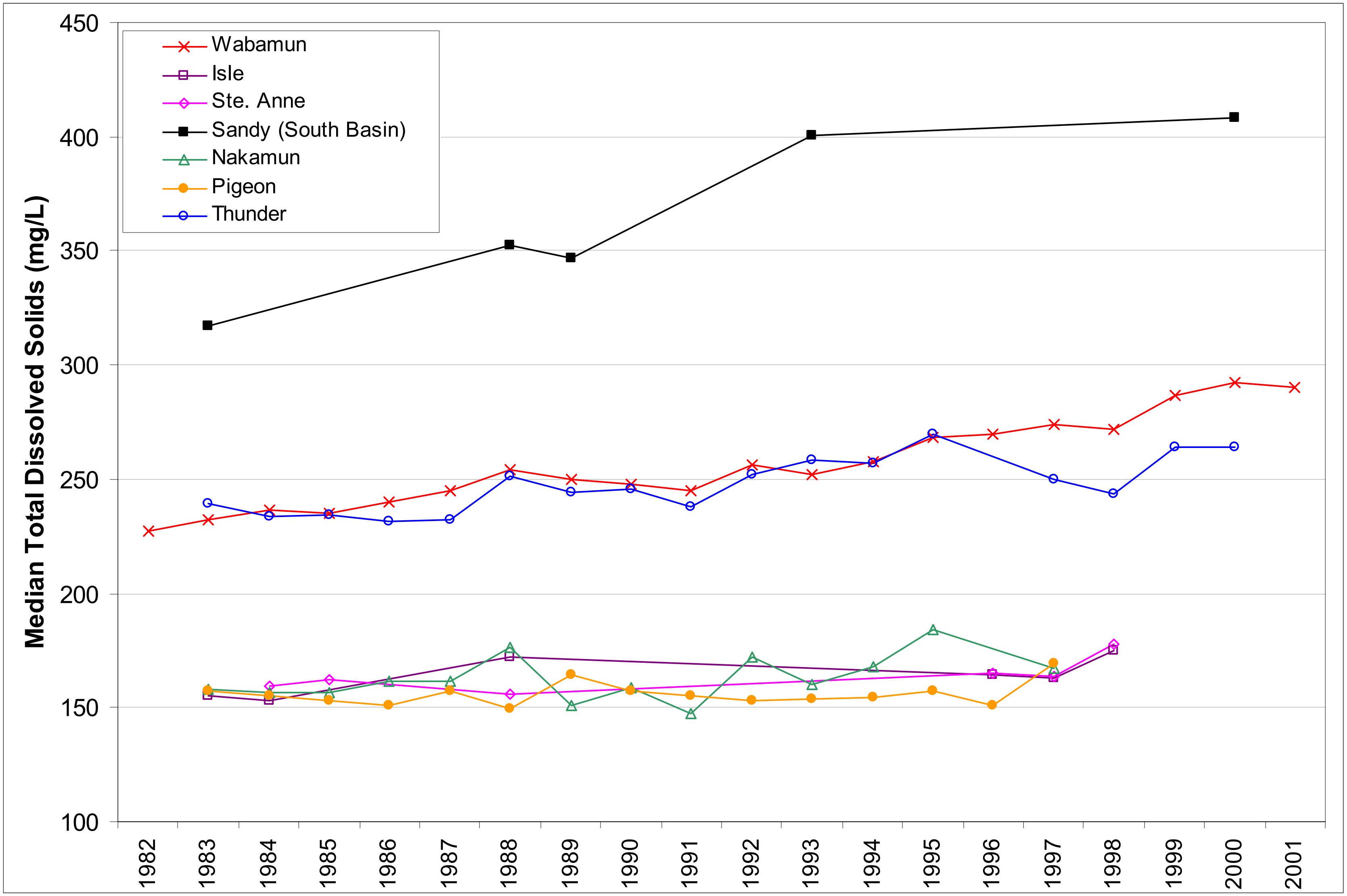


Figure 5 Total dissolved solids in Wabamun Lake and other regional lakes, 1982 to 2001

Table 2 Basin characteristics and total dissolved solids concentrations in Wabamun Lake and other regional lakes, 1982 to 2001

Lake	Area (km^2)		Basin Area/ Lake Area	Mean Residence Time (yr)	Range of TDS Monthly Median Concentrations (mg/L)		TDS Temporal Pattern
	Basin (excluding lake)	Lake			1982 to 1991	1992 to 2001	1982 to 2001
Isle	246.0	23.0	10.7	9.5	141-178	159-181	Stable
Ste. Anne	619.0	54.5	11.4	12	149-173	156-178	Stable
Nakamun	44.9	3.5	12.7	21	142-180	150-187	Stable
Pigeon	187.0	96.7	1.9	>100	146-168	147-169	Stable
Thunder	20.7	7.0	2.9	>100	225-256	242-279	Increasing
Wabamun	259.0	81.8	3.2	>100	217-294	248-302	Increasing
Sandy	48.4	11.4	4.2	>100	317-357	394-411	Increasing

Notes:
Basin characteristics from the *Atlas of Alberta Lakes* (Mitchell and Prepas 1990)
Source of TDS data: Alberta Environment WDS database
Sandy Lake TDS data taken in the south basin of the lake

more dilute inflows (e.g., precipitation and streams). This dilution effect will depend on the relative TDS load (volume x TDS concentration per unit time) in the inflows, compared to the TDS mass already present in the lake. The four lakes with stable TDS concentrations had relatively large basin area : lake area ratios and short residence times (compared to the other lakes), with the exception of Pigeon Lake (Table 2). Residence time is defined as the average time required to replace the volume of the lake with inflows, less total evaporation losses (e.g., Mitchell and Prepas 1990). A large basin area : lake area typically results in greater annual volumes of runoff and stream flow to the lake, compared to lakes with smaller ratios. Combined with greater surface inflows, shorter residence times could potentially result in greater flushing of TDS in the lakes. In Pigeon Lake (that had a small basin area : lake area), the stable TDS concentrations throughout the 15-year record (Table 2) may be related to the strong likelihood that hydraulic flushing was occurring through most of 1982 to 2001. This assessment was based on the observed lake levels over the 20 years, which were often higher than the sill elevation at Pigeon Lake outlet (Alberta Environment, unpublished data; Mitchell and Prepas 1990).

The overall effect of hydraulic flushing in a lake will be enhanced by the occurrence and magnitude of surface outflow from the lake. Hydraulic flushing may also be affected by groundwater exchange, such as chemical loads in the groundwater inflow and outflow to the lake. The effect of groundwater on the water quality of Alberta lakes, however, is not well defined, partly because accurate measurements of groundwater exchange in lakes are difficult and expensive to obtain.

An accurate assessment of hydraulic flushing in each of the selected lakes (and most Alberta lakes) is difficult, because the occurrence and quantity of all inflows and outflows to the lakes are not routinely measured. Based on the available information for the three lakes with highest TDS concentrations (Thunder, Sandy, and Wabamun), each lake had long periods (>10 years) of no surface outflow from 1982 to 2001 (Mitchell and Prepas 1990; Alberta Environment 1997, 2002b). It is likely that these circumstances led to reduced hydraulic flushing and overall increases of TDS in the lakes over the 20-year period. In Sandy Lake, there was no surface outflow during the entire period of record (Mitchell and Prepas 1990; Alberta Environment, unpublished data), which would eliminate or reduce hydraulic flushing of the lake (depending on the influence of groundwater exchange).

Evaporation, which occurs in all lakes, may also have influenced TDS concentrations differently in the two groups of lakes. Evaporation losses (equivalent to relatively pure water) can lead to more concentrated solutes (e.g., major ions or TDS) remaining in a lake. This effect may have been enhanced in the three lakes with long periods of no surface outflow. In these lakes, TDS may become increasingly concentrated as the lake level drops further below the outflow elevation. The highest TDS concentrations and greatest overall change of TDS in Sandy Lake over the 20 years may have been due to a combination of no lake outflow and an enhanced evaporation effect over this period.

Overall, the main cause of lake level changes in the selected lakes was likely to be due to the prevailing climate conditions over the 20-year period. The regulation of adjustable weir structures at lake outlets also may have influenced the water levels in some lakes (e.g., Pigeon Lake) (Mitchell and Prepas 1990).

3.1.3 Major Cations and Anions

Concentrations of major ions in lakes are affected by changes in the composition and chemical load of major inflows and outflows, which include precipitation, dry deposition, runoff, groundwater, evaporation, and lake outflow. Concentrations of some major ions notably sodium, potassium, magnesium, and chloride are often defined as “conservative”, because they are not substantially affected by biochemical processes in freshwater systems. Fluoride is also sometimes considered as a conservative ion and in lakes. In contrast, inorganic carbon (CO_2, HCO_3^- and CO_3^{2-}) and other major ions (calcium and sulphate) are classified as “non-conservative”, because they are often strongly influenced by various biological processes (e.g., microbial metabolism and photosynthesis) in lakes.

Calcium is abundant and widely distributed in freshwaters. Calcium carbonate minerals in sedimentary rocks are a common source of calcium. Calcium is important to the growth and population dynamics of freshwater flora and fauna. In Wabamun Lake, median calcium concentrations remained fairly stable (range of medians = 20 to 26 mg/L) during 1982 to 2001 (Figure 6). However, there was a statistically significant decline of calcium concentrations over the 20 years ($r^2 = 0.174$, $P < 0.001$, $n = 148$); this statistical pattern in the regression analysis was probably influenced by the lowest concentrations occurring in 2001 (Figure 6). The lack of a consistent increase of calcium concentrations compared to TDS and most other major ions over the 20-year period (see results below for the other major ions) may be due to a naturally occurring equilibrium of calcium carbonate ($CaCO_3$) in the lake water. In hardwater lakes, such as Wabamun Lake, calcium carbonate is often supersaturated in the upper layer of warmer water, present under summer stratification (i.e., epilimnion). In Wabamun Lake, the entire water column is typically well mixed from May to October and strong thermal stratification is unusual in this period (with the exception of calm and warm conditions) (Mitchell and Prepas 1990; Alberta Environment, unpublished data). Under these conditions, calcium carbonate can precipitate out of solution as calcite onto the lake bottom and aquatic plants (often visible as marl deposits). This process is mediated by photosynthesis, associated with the uptake of carbon dioxide, leading to increased pH in lake waters.

The saturation of calcium carbonate in Wabamun Lake was calculated, using a Saturation Index based on annual medians of relevant water quality variables (calcium, alkalinity, TDS, conductivity, and pH) sampled in the euphotic zone (APHA 1995). Saturation Index (SI) values >1 indicated calcium carbonate was supersaturated in the lake for all years (Figure 7). The SI data also showed a trend of declining values in the 1990s, with the lowest SI values in 2000 (Figure 7). The SI values were strongly influenced by pH in the lake (e.g., $r^2 = 0.958$, $P < 0.001$, $n = 20$; using SI values based on median TDS concentrations and 20^oC). Schwartz and Gallup (1978) also found calcium carbonate was supersaturated in Wabamun Lake in 1971 and 1972 (based on a Saturation Index). Overall these results support the likelihood that calcite precipitation occurred annually in Wabamun Lake. See Section 3.4.4 for further discussion of calcite precipitation and effects on the water quality of Wabamun Lake.

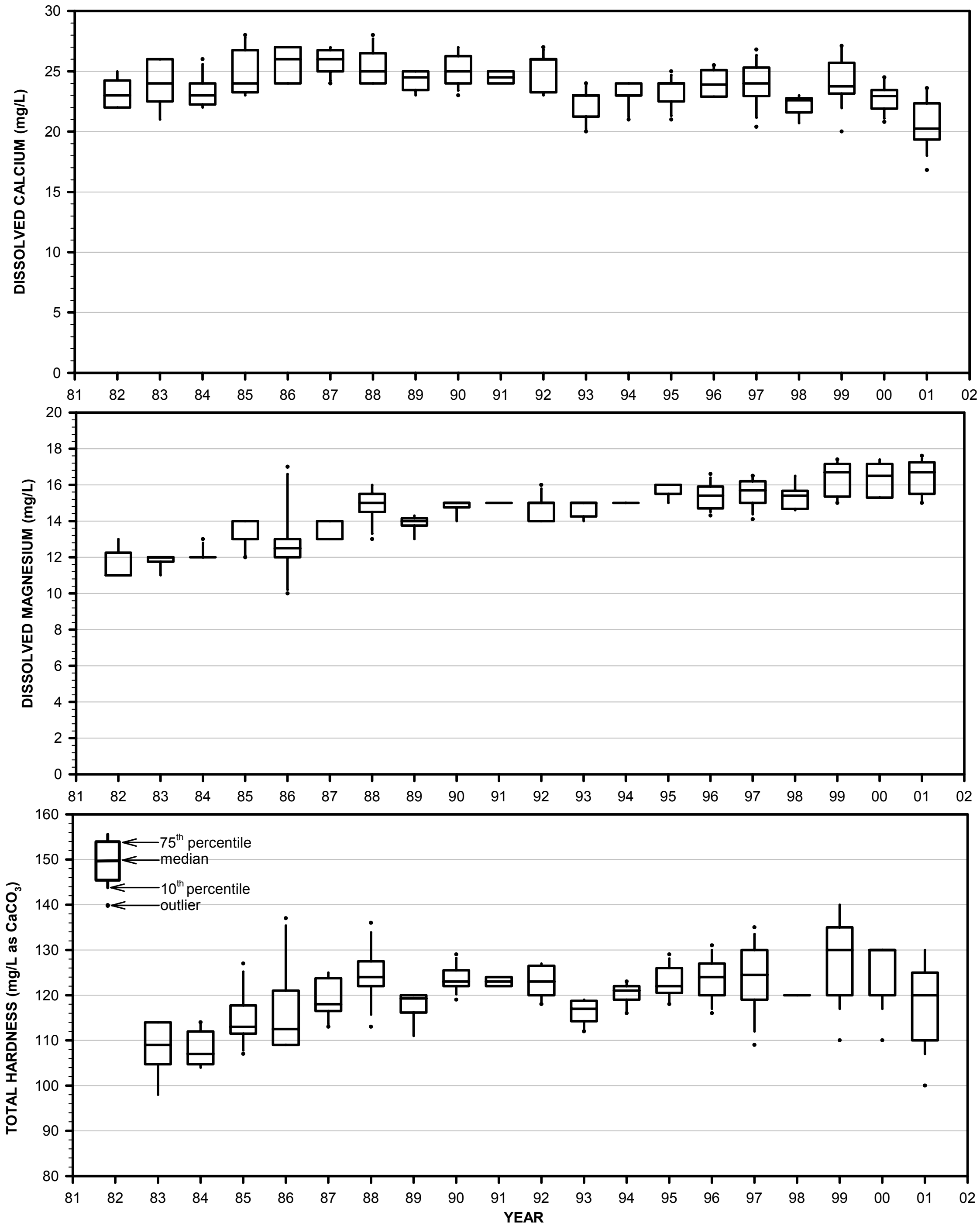


Figure 6 Calcium, magnesium, and hardness in Wabamun Lake, 1982 to 2001

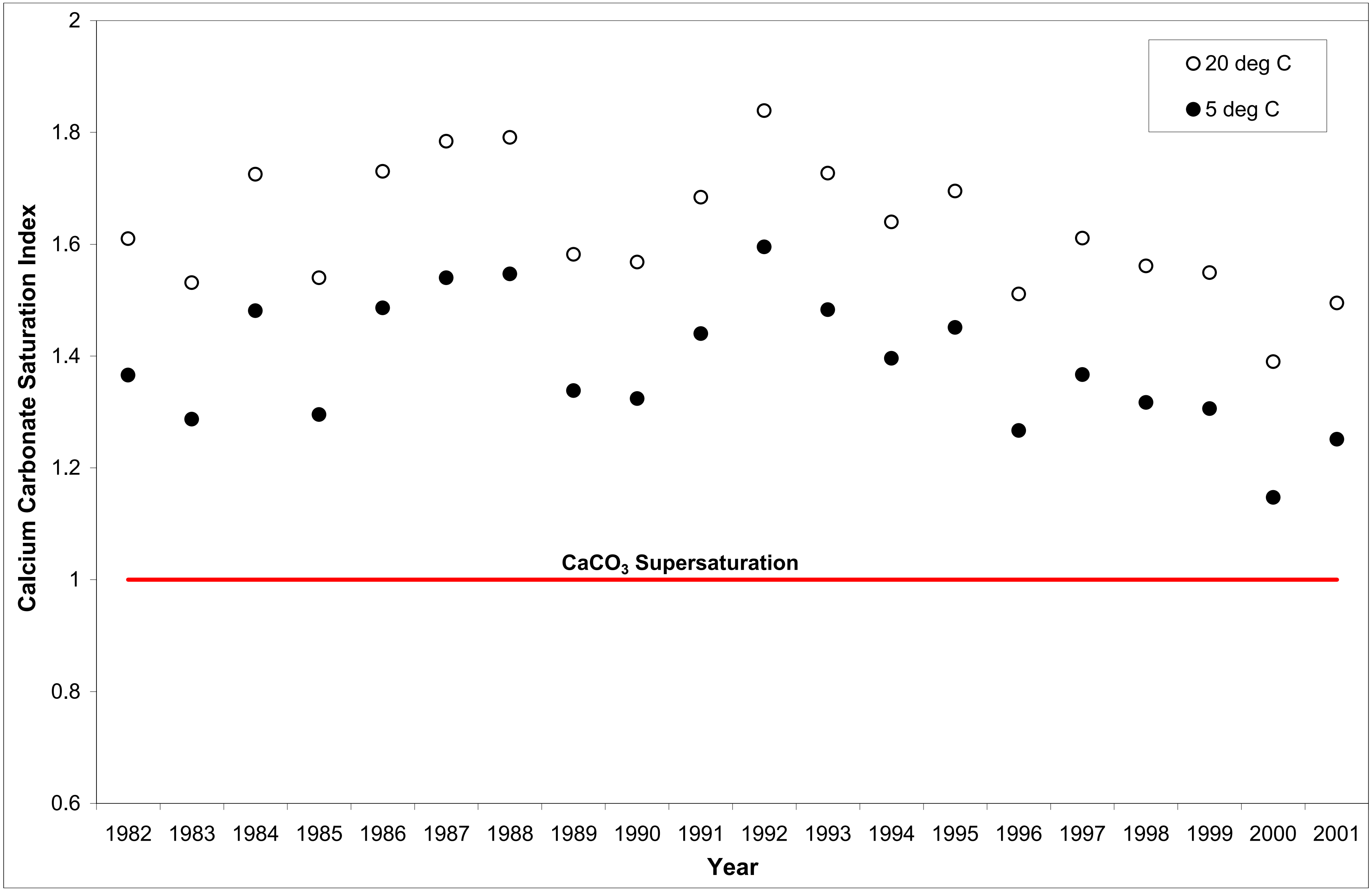


Figure 7 Annual calcium carbonate ($CaCO_3$) Saturation Index (SI) values in Wabamun Lake, 1982 to 2001

Magnesium is required by aquatic plants containing chlorophyll and it is used as a micronutrient by algae, fungi, and bacteria. Sources of magnesium include igneous and sedimentary rocks (Hem 1989). Typically, magnesium is very abundant relative to the needs of aquatic biota and it is more soluble than calcium in freshwaters (Wetzel 1983). Median concentrations of magnesium in Wabamun Lake increased by 55% from 11 mg/L in 1982 to a maximum of 17 mg/L in the 1999 to 2001 period (r^2 = 0.692, P <0.001, n = 147) (Figure 6). Magnesium concentrations showed a small step increase to stable levels after 1998. Magnesium concentrations were statistically greater in the 1999 to 2001 period, compared to the previous three years (t-test critical value = 2.01, P <0.001, df = 52).

Calcium and magnesium salts, often derived from calcareous sediments and rock, are the main components of hardness in water. Hardness refers to the ability of water to produce a lather with soap, thus it is often used as a measure of the quality of a water supply. Hardness (expressed as $CaCO_3$) ranges from moderately hard (61 to 120 mg/L), to hard (121 to 180 mg/L) and very hard (>180 mg/L) (Hem 1989). Hardness in Wabamun Lake increased by 22% from the lowest median concentrations of 107 mg/L ($CaCO_3$) in 1984 to the highest concentration of 130 mg/L ($CaCO^3$) in 1999 (r^2 = 0.158, P <0.001, n = 142) (Figure 6). Overall hardness in the lake increased from moderately hard (<121 mg/L) to hard in the mid-1980s; although there was a declining trend of hardness from maximum concentrations in 1999 to lower levels in 2001 (Figure 6). This trend of declining hardness in recent years is probably related to lower calcium concentrations during the same years (Figure 6).

Sodium originates from many sources, such as igneous and sedimentary rocks, soils, groundwater, and road salt, and it is a common in freshwaters (Hem 1989). Sodium is important to physiological processes (ion transport and exchange) in aquatic biota (Wetzel 1983). Median sodium concentrations in Wabamun Lake increased by 51% from 43 mg/L in 1982 to 65 mg/L in 2001 (r^2 = 0.844, P <0.001, n = 148) (Figure 8). Median sodium concentrations increased in the lake at a greater annual rate in the 1990s, compared to 1980s (Figure 8).

Potassium occurs widely in freshwaters; sources include silicate rocks, sediments, plant material, and ash (Hem 1989). Similar to sodium, potassium is important in physiological processes of aquatic biota (Wetzel 1983). Median potassium concentrations in Wabamun Lake increased by 38% from lowest concentrations of 7.2 mg/L in 1982 to 9.9 mg/L in 1999 (r^2 = 0.575, P <0.001, n = 148); although median concentrations showed a decline from 2000 to 2001 (Figure 8). The decrease in potassium in the lake may be due to an effect from the WL-WTP treated water (Section 3.4.4).

A major source of carbonates (HCO_3^- and CO_3^{2-}) is the weathering of carbonate minerals, such as limestone ($CaCO_3$). Although the equilibrium of bicarbonate and carbonate ion concentrations in a solution is strongly influenced by pH, the two ions are presented separately in the report because changes in carbonate concentrations may reflect the occurrence of calcite precipitation in Wabamun Lake. Median bicarbonate concentrations in the lake gradually increased by 17% from 217 mg/L in 1983 to 254 mg/L in 2000 (r^2 = 0.545, P <0.001, n = 143) (Figure 9). Highest bicarbonate concentrations occurred from 1999 to 2001, which corresponded to the highest alkalinity in the same period (Figures 2 and 9). Median carbonate concentrations varied from 2.5 (in 2000) to 12.2 (in 1998) mg/L, with a tendency for declining concentrations

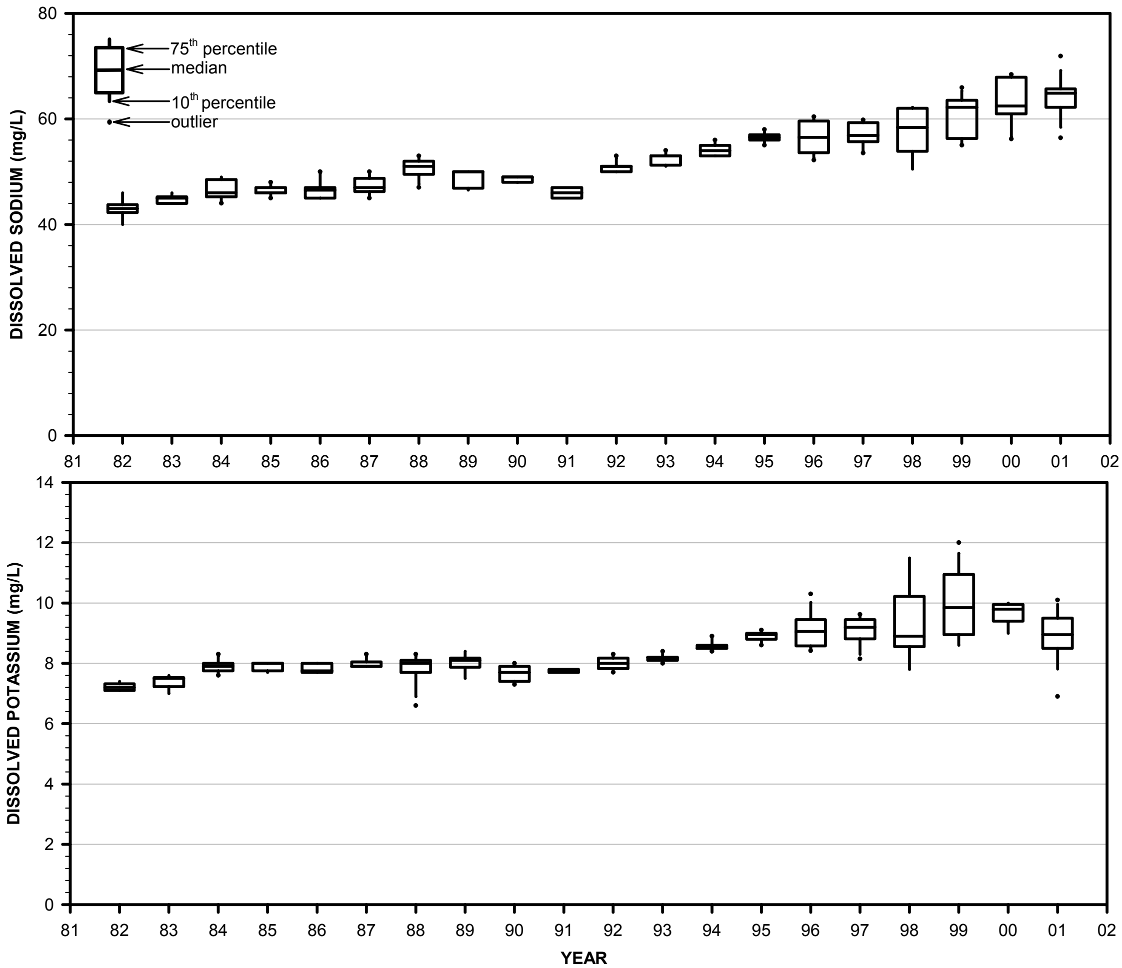


Figure 8 Sodium and potassium in Wabamun Lake, 1982 to 2001

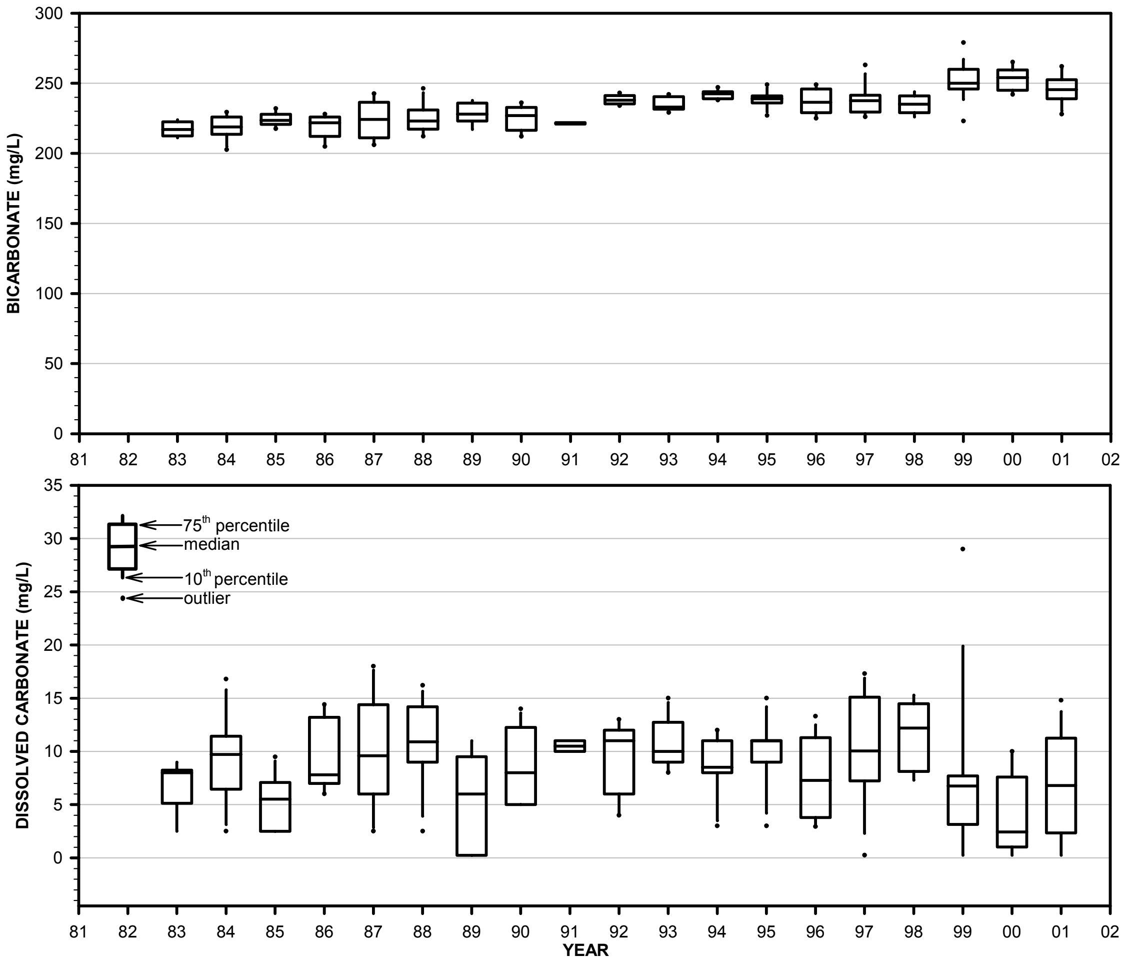


Figure 9 Bicarbonate and carbonate in Wabamun Lake, 1982 to 2001

over the 20 years (Figure 9)(r^2 = 0.029, P = 043, n = 141). Lowest carbonate concentrations occurred from 1999 to 2001 compared to most other years (Figure 9). The lower carbonate concentrations from 1999 to 2001 (which showed a step decrease after 1998) may indicate increased calcite precipitation on the lake bottom during this period (Figure 9).

Sulphate is a common and important component of the sulphur cycle that is complex in freshwater systems. The decomposition of organic matter containing sulphur (e.g., proteins) and anaerobic reduction of sulphate in anoxic sediments and water can affect ecosystem productivity, cycling of other nutrients, and distribution of aquatic biota (e.g., Wetzel 1983; Holmer and Storkholm 2001). Sources of sulphate include reduced forms in rocks that are oxidised by weathering, combustion of fossil fuels, marine or saline derived sediments, groundwater, volcanic activity, and precipitation (Hem 1989). In Wabamun Lake, median sulphate concentrations increased by 76% from 25 mg/L in 1982 to 44 mg/L in 2001 (r^2 = 0.576, P <0.001, n = 148) (Figure 10). Median concentrations of sulphate ranged from 25 to 33 mg/L throughout 1982 to 1998, after which there was a notable step increase and consistent annual increases of concentrations up to 2001 (Figure 10). Sulphate concentrations in the lake were statistically higher in the 1999 to 2001 period, compared to the previous three years (1996 to 1998) (t test critical value = -16.03, P <0.001, df = 57). Section 3.4 contains discussion of sulphate levels in the WL-WTP treated water and potential effects in Wabamun Lake.

Chloride is important to physiological processes of aquatic biota. Sources of chloride include igneous rock, sedimentary rocks and groundwater of marine origin, precipitation affected by seawater, and road salt (Hem 1989; Wetzel 1983). Median chloride concentrations in Wabamun Lake increased by 163% from 3.0 mg/L in 1982 to 7.9 mg/L in 2001 (r^2 = 0.785, P <0.001, n = 148) (Figure 10). The rate of annual chloride concentration increases was greater in the 1990s than in 1980s (Figure 10).

The fluoride ion has low solubility and is generally found at low concentrations (<1 mg/L) in natural waters (Hem 1989). Sources of fluoride include igneous and sedimentary rocks, groundwater, volcanic gases, and ash (Hem 1989). Median fluoride concentrations in Wabamun Lake increased by 41% from 0.27 mg/L in 1982 to 0.38 mg/L in 1998 (r^2 = 0.588, P <0.001, n = 110), and annual increases of median concentrations were often greater in the 1990s compared to 1980s (Figure 10). No fluoride data were collected from 1999 to 2001.

Percent Composition of Major Cations and Anions

Percent composition of individual major cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+) and anions (HCO_3^-, CO_3^{2-}, SO_4^{2-}, and Cl^-) in Wabamun Lake were estimated (based on milliequivalents) to evaluate any major changes in the relative composition of individual ions in the lake over the 20 years. In general, all major ions showed similar percent proportions from year to year (Table 3). However, there was a tendency for some major ions to be at higher (sulphate, sodium, and chloride) or lower (calcium and carbonate) proportions throughout the 1990s, or from 1999 to 2001 (Table 3). In most years, the dominant cations or anions in decreasing order of percent proportions were: bicarbonate, sodium, magnesium, calcium, sulphate, carbonate, potassium, and chloride (Table 3). The dominant anion and cation, bicarbonate and sodium (respectively), in Wabamun Lake are similar to those in many freshwater lakes of Alberta (Mitchell and Prepas 1990).

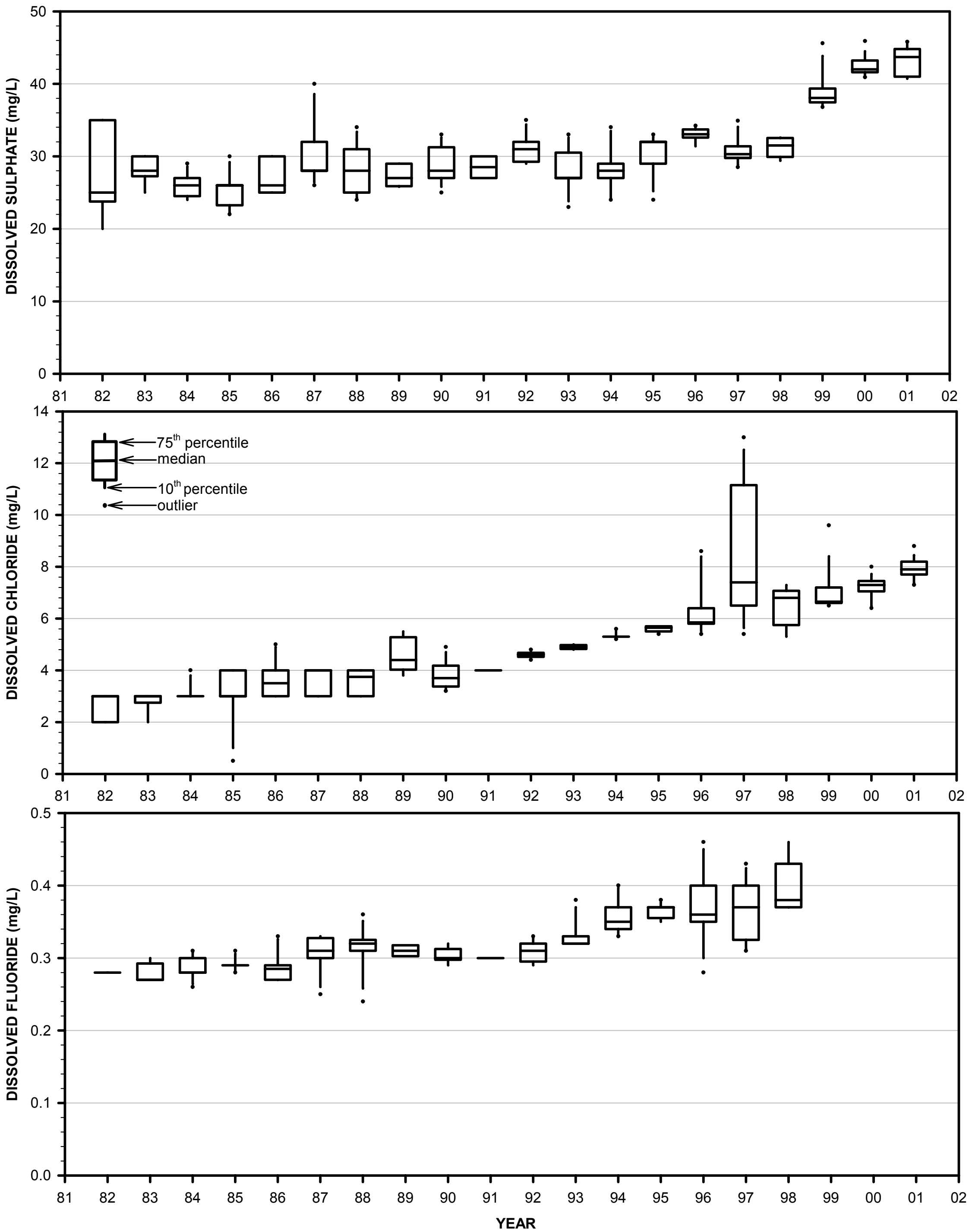


Figure 10 Sulphate, chloride, and fluoride in Wabamun Lake, 1982 to 2001

Table 3 Major ion concentrations in Wabamun Lake, expressed as milliequivalents/L and percent composition, 1982 to 2001

Year:	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Calcium (mg/L)											
Observed (me/L)	1.148	1.198	1.148	1.198	1.297	1.297	1.248	1.223	1.248	1.223	1.297
Percent		**14**	**13**	**13**	**14**	**14**	**13**	**13**	**13**	**13**	**13**
Magnesium (mg/L)											
Observed (me/L)	0.905	0.987	0.987	1.070	1.029	1.070	1.234	1.152	1.234	1.234	1.234
Percent		**11**	**11**	**12**	**11**	**11**	**13**	**12**	**13**	**13**	**12**
Sodium (mg/L)											
Observed (me/L)	1.871	1.958	2.001	2.001	2.023	2.045	2.219	2.175	2.132	2.001	2.219
Percent		**22**	**23**	**22**	**22**	**22**	**23**	**23**	**22**	**21**	**22**
Potassium (mg/L)											
Observed (me/L)	0.184	0.192	0.202	0.205	0.198	0.202	0.205	0.207	0.197	0.198	0.205
Percent		**2.2**	**2.3**	**2.3**	**2.2**	**2.2**	**2.1**	**2.2**	**2.1**	**2.1**	**2.0**
Bicarbonate (mg/L)											
Observed (me/L)	nd	3.557	3.588	3.664	3.636	3.676	3.656	3.737	3.721	3.630	3.901
Percent		**40**	**40**	**41**	**40**	**40**	**38**	**40**	**39**	**39**	**39**
Carbonate (mg/L)											
Observed (me/L)	nd	0.267	0.324	0.184	0.260	0.320	0.363	0.200	0.267	0.350	0.367
Percent		**3.0**	**3.6**	**2.1**	**2.9**	**3.4**	**3.8**	**2.1**	**2.8**	**3.7**	**3.7**
Sulphate (mg/L)											
Observed (me/L)	0.521	0.583	0.541	0.541	0.541	0.583	0.583	0.562	0.583	0.593	0.645
Percent		**6.6**	**6.1**	**6.1**	**6.0**	**6.3**	**6.1**	**6.0**	**6.1**	**6.4**	**6.5**
Chloride (mg/L)											
Observed (me/L)	0.085	0.085	0.085	0.085	0.099	0.113	0.106	0.124	0.104	0.113	0.130
Percent		**1.0**	**1.0**	**0.9**	**1.1**	**1.2**	**1.1**	**1.3**	**1.1**	**1.2**	**1.3**
TOTAL (me/L)		**8.825**	**8.876**	**8.947**	**9.083**	**9.306**	**9.613**	**9.380**	**9.485**	**9.343**	**9.998**
TOTAL CATIONS	nd	4.334	4.338	4.473	4.547	4.614	4.905	4.757	4.810	4.656	4.955
TOTAL ANIONS	nd	4.491	4.538	4.474	4.536	4.692	4.708	4.623	4.675	4.687	5.043
TOTAL (Percent)		**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
TOTAL CATIONS	nd	49	49	50	50	50	51	51	51	50	50
TOTAL ANIONS	nd	51	51	50	50	50	49	49	49	50	50

Note: nd = no data or incomplete data for calculation

Table 3 Major ion concentrations in Wabamun Lake, expressed as milliequivalents/L and percent composition, 1982 to 2001 (continued)

Year:	1993	1994	1995	1996	1997	1998	1999	2000	2001
Calcium (mg/L)									
Observed (me/L)	1.148	1.148	1.198	1.193	1.198	1.128	1.185	1.145	1.010
Percent	**12**	**12**	**12**	**12**	**12**	**11**	**11**	**11**	**9**
Magnesium (mg/L)									
Observed (me/L)	1.234	1.234	1.317	1.267	1.292	1.267	1.374	1.358	1.374
Percent	**13**	**12**	**13**	**13**	**13**	**12**	**13**	**13**	**13**
Sodium (mg/L)									
Observed (me/L)	2.306	2.349	2.458	2.458	2.475	2.540	2.706	2.717	2.828
Percent	**24**	**24**	**24**	**24**	**24**	**25**	**25**	**25**	**26**
Potassium (mg/L)									
Observed (me/L)	0.210	0.217	0.229	0.232	0.235	0.228	0.252	0.251	0.229
Percent	**2.2**	**2.2**	**2.2**	**2.3**	**2.3**	**2.2**	**2.3**	**2.3**	**2.1**
Bicarbonate (mg/L)									
Observed (me/L)	3.819	3.975	3.917	3.876	3.893	3.852	4.098	4.163	4.032
Percent	**39**	**40**	**38**	**38**	**38**	**38**	**38**	**39**	**37**
Carbonate (mg/L)									
Observed (me/L)	0.333	0.283	0.367	0.243	0.335	0.407	0.225	0.082	0.227
Percent	**3.4**	**2.9**	**3.6**	**2.4**	**3.3**	**4.0**	**2.1**	**0.8**	**2.1**
Sulphate (mg/L)									
Observed (me/L)	0.562	0.583	0.666	0.688	0.631	0.656	0.792	0.874	0.910
Percent	**5.8**	**5.9**	**6.5**	**6.8**	**6.1**	**6.4**	**7.3**	**8.1**	**8.4**
Chloride (mg/L)									
Observed (me/L)	0.138	0.150	0.159	0.165	0.209	0.192	0.188	0.206	0.223
Percent	**1.4**	**1.5**	**1.5**	**1.6**	**2.0**	**1.9**	**1.7**	**1.9**	**2.1**
TOTAL (me/L)	**9.750**	**9.939**	**10.310**	**10.122**	**10.267**	**10.269**	**10.819**	**10.795**	**10.832**
TOTAL CATIONS	4.897	4.948	5.201	5.149	5.200	5.163	5.517	5.470	5.441
TOTAL ANIONS	4.853	4.990	5.109	4.972	5.067	5.106	5.302	5.325	5.391
TOTAL (Percent)	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
TOTAL CATIONS	50	50	50	51	51	50	51	51	50
TOTAL ANIONS	50	50	50	49	49	50	49	49	50

Note: nd = no data or incomplete data for calculation

Summary of Major Ions and TDS

The concentrations of most major ions (excluding calcium and carbonate) and related variables (TDS, conductivity, and alkalinity) generally increased in Wabamun Lake from 1982 to 2001. Similar patterns of increasing TDS concentrations over the 20 years were also found in other regional lakes with comparable lake characteristics. The overriding cause of this general pattern of increasing TDS concentrations in these lakes was likely related to the effects of climate conditions on major components of the lake water balance inflows (precipitation and runoff) and outflow (evaporation) over the 20-year period. Higher concentration increases of some major ions (sodium, chloride and fluoride) and TDS in Wabamun Lake during the 1990s, up to 2001, was probably due to no or limited hydraulic flushing of the lake after 1992, when there was no surface outflow from the lake.

From 1999 to 2001, median concentrations of TDS and some major ions, especially sulphate, showed step increases in the lake (after 1998), while some major ions (notably calcium and carbonate) showed a trend of lower or declining median concentrations during the same years. These patterns coincided with the same years when the WL-WTP was pumping large volumes of treated water to the lake. Thus these changes in the lake water quality may be due to effects of the WL-WTP treated water inflow to the lake.

Major Ion Concentrations compared to Water Quality Guidelines

For most major ions and TDS, there are no water quality guidelines used to protect freshwater aquatic life in Alberta, with the exception of chloride and fluoride (Alberta Environment 1999; CCME 2002). The chloride concentrations in Wabamun Lake from 1982 to 2001 were one to two orders of magnitude less than the chloride guidelines (US-EPA chronic and acute guidelines = 230 and 830 mg/L, respectively; Alberta Environment 1999).

Unlike chloride, all fluoride concentrations in Wabamun Lake over the 20 years (range = 0.24 to 0.46 mg/L; Figure 10) were greater than the inorganic fluorides water quality guideline for the protection of freshwater aquatic life (interim guideline = 0.12 mg/L; CCME 2002). This finding must be placed in the context of the basis of the recent Canadian guideline. Firstly, the CCME guideline is an “interim” concentration, because there are incomplete toxicity data, which are required to develop a “final” CCME guideline. Following the CCME protocol to develop guidelines, the interim concentration was derived from the lowest adverse effect level reported in an acceptable toxicity study (i.e., 144-h LC_{50} of 11.5 mg F^-/L for the larvae of a caddisfly species) (CCME 2002). Because this toxicity study was an acute test rather than a chronic test, a more conservative safety factor of 0.01 (instead of 0.1) was used to obtain the interim guideline (CCME 2002). (The interim concentration is the product of 11.5 mg/L x 0.01, i.e., 0.12 mg/L.) Secondly, the toxicity studies available also indicated that high hardness concentrations, such as those found in Wabamun Lake, reduced the toxicity of inorganic fluorides to aquatic biota (CCME 2002). Finally, the fluoride concentrations found in central and southern Alberta lakes (mean = 0.21 mg/L, range = 0.02 to 2.00 mg/L from 1982 to 2001, n = 2,034; Alberta Environment, unpublished data) are generally greater than those in other Canadian surface waters (mean = 0.05 mg/L, range = 0.01 to 11.0 mg/L, n = 51,299; CCME 2002). Based on the information above, the fluoride concentrations in Wabamun Lake are unlikely to have adverse effects on aquatic biota in the lake.

Other water quality guidelines for major ions and related variables used in Alberta are for various uses by humans (drinking water) and agriculture (irrigation and livestock watering) (Alberta Environment 1999). Untreated Wabamun Lake water is not used for human consumption, however, some lake water is used for irrigation (Klohn Crippen 2000: license volume for irrigation = 229,436 m^3 per year) (Section 1.0). Concentrations of all relevant water variables in the lake during 1982 to 2001 were less than water quality guidelines for agricultural uses (i.e., guidelines for calcium, sulphate, chloride, fluoride, and TDS; Alberta Environment 1999).

3.1.4 Nutrients

The trophic state (i.e., fertility or productivity) of a lake is often based on the phosphorus and chlorophyll-*a* concentrations in the euphotic zone (upper water column) during the summer months. Alberta lakes with several years of data have been grouped into four major categories of lake fertility: oligotrophic (low nutrients), mesotrophic, eutrophic, and hyper-eutrophic (very high in nutrients) (Table 4).

Phosphorus

Phosphorus is an important nutrient for plant growth, but the supply of phosphorus in freshwater systems (including most Alberta lakes) is often limited, compared to other nutrients required by plants (e.g., nitrogen and carbon). If phosphorus is limited in the water column, additions of phosphorus can lead to substantial increases of plant biomass, such as algal blooms (which can contain toxic cyanobacteria) in lakes. Sources of phosphorus include igneous rocks, soils, phosphate fertilisers, atmospheric deposition, manure, and sewage (Hem 1989). Phosphorus occurs in lake water as particulate and dissolved forms. The latter fraction is equivalent to the portion that passes through a 0.45 µm filter.

Median total phosphorus (TP) concentrations in Wabamun Lake showed no overall change from 1982 to 1998 (range of medians = 0.030 mg/L to 0.038 mg/L) (Figure 11). After 1998, there was a marked, although small, decline of median TP concentrations in 1999 to 2001 (range of medians = 0.028 to 0.031 mg/L) (Figure 11). Overall, TP concentrations showed no statistical change in the lake from 1982 to 2001 ($r^2 = 0.012$, $P = 0.198$, $n = 143$).

Dissolved phosphorus (DP) made up about 30% of TP in the euphotic zone of Wabamun Lake (Figure 11). Median DP concentrations in the lake ranged from 0.009 mg/L to 0.012 mg/L during 1982 to 1998 (Figure 11). After 1998, median DP concentrations showed a step reduction to lowest concentrations in the 1999 to 2001 period (range of medians = 0.008 to 0.009 mg/L) (Figure 11). Concentrations of DP showed a weak relationship with time, although there was an overall statistically significant decline of DP over the 20-year period ($r^2 = 0.088$, $P < 0.001$, $n = 141$).

In each year from 1999 to 2001, the concentrations of both TP and DP in Wabamun Lake showed less statistical variation (e.g., difference between 25 and 75% percentiles or maximum and

Table 4 Trophic state of Alberta lakes (n=140) based on total phosphorus and chlorophyll-*a* concentrations during summer months

Trophic Status (Productivity)	Mean (May to September) Concentrations (mg/L)*			
	Total Phosphorus		Chlorophyll *a*	
	Range	Number of Lakes	Range	Number of Lakes
Oligotrophic (low)	<0.010	10	<0.0025	18
Mesotrophic (moderate)	0.010-0.035	50	0.0025-0.008	32
Eutrophic (high)	0.035-0.100	47	0.008-0.025	47
Hypereutrophic (very high)	>0.100	33	>0.025	43

*Data source: Alberta Environment WDS database

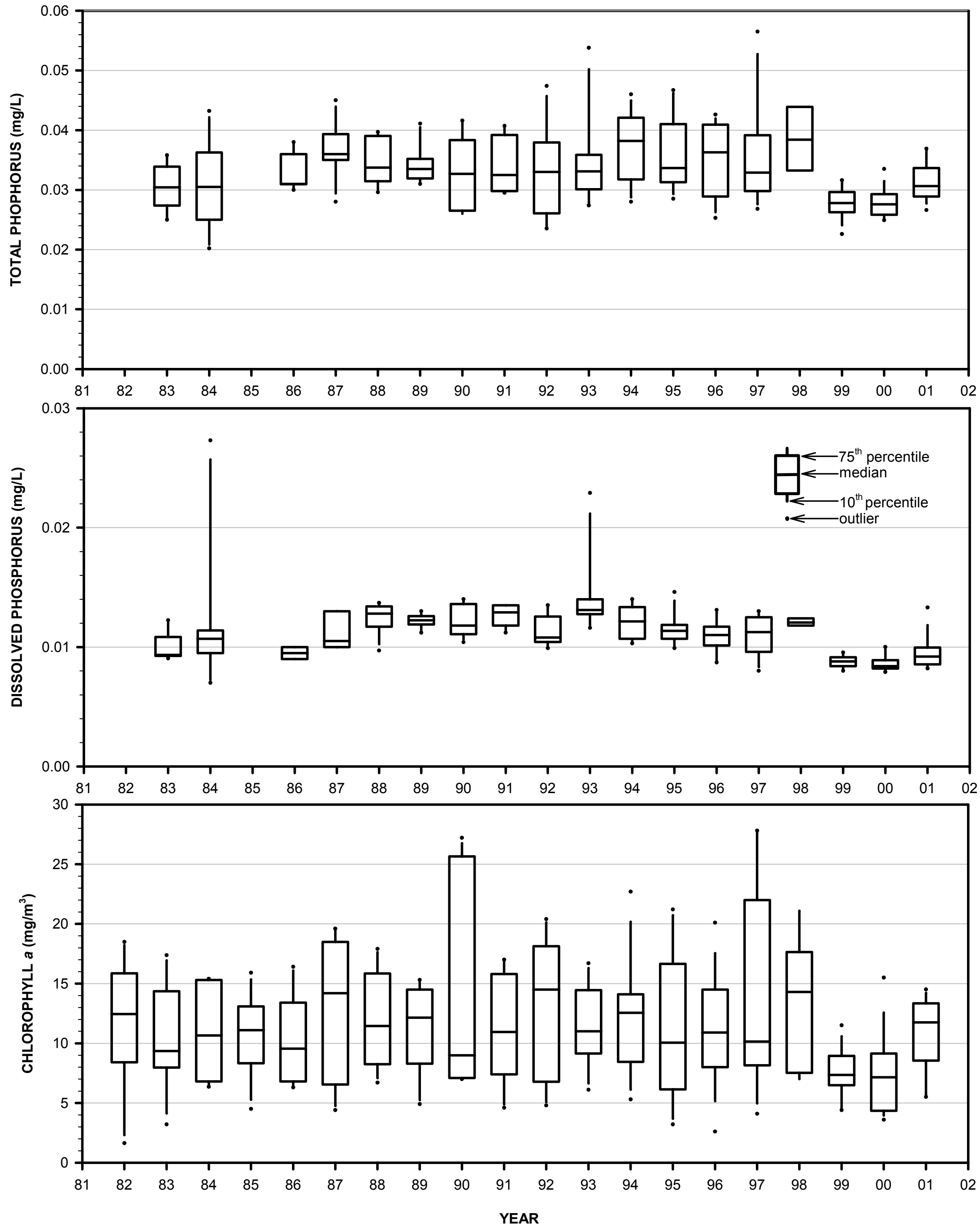


Figure 11 Total phosphorus, dissolved phosphorus, and chlorophyll-*a* in Wabamun Lake, 1982 to 2001

minimum concentrations), compared to most earlier years (Figure 11). In addition, statistical comparisons of phosphorus data in the two three-year periods before and after the WL-WTP was fully commissioned (Section 1.0) showed the TP and DP concentrations were significantly lower in 1999 to 2001 compared to 1996 to 1998 (TP: t-test critical value = 4.97, P <0.001, df = 55; DP: t-test critical value = 6.51, P <0.001, df = 55) (see below for further discussion).

Chlorophyll-*a*

Chlorophyll-*a* concentrations are often used as a measure of phytoplankton (algal) biomass in lakes. In many freshwater lakes of central Alberta (<500 mg TDS/L), there is a strong positive linear relationship between TP and chlorophyll-*a* concentrations, likely due to phosphorus supply limiting algal growth in the lakes (Prepas and Trew 1983; Alberta Environment, unpublished data). Median chlorophyll-*a* concentrations in Wabamun Lake were generally stable from 1982 to 1998, ranging from 0.009 to 0.014 mg/L (Figure 11). Similar to the patterns for TP and DP, median chlorophyll-*a* concentrations were lowest in the lake after 1998 (0.007 mg/L in 1999 and 2000), although concentrations recovered in 2001 (median = 0.012 mg/L) (Figure 11). Overall there was no statistical change of chlorophyll-*a* concentrations from 1982 to 2001 (r^2 = 0.009, P = 0.238, n = 157).

Similar to the pattern for TP and DP, chlorophyll-*a* concentrations were less variable in 1999 to 2001 compared to most earlier years (Figure 11). Also, chlorophyll-*a* concentrations in the lake were lower from 1999 to 2001, compared to the previous 3-year period (t-test critical value = 2.52, P= 0.014, df = 57); although this difference was close to the level of statistical significance (P $\leq$0.05) (see below for further discussion). Strong correlations for phosphorus and chlorophyll-*a* concentrations in Wabamun Lake throughout 1982 to 2001 (correlations of chlorophyll-*a* with TP: r = 0.613, P <0.001, n = 141; and DP: r = 0.347, P<0.001, n = 141) indicated phytoplankton biomass was probably limited by phosphorus supply in the euphotic zone of the lake.

Phosphorus and Chlorophyll-*a*, 1999 to 2001

The small reductions of median TP, DP, and chlorophyll-*a* concentrations in Wabamun Lake from 1999 to 2001 (compared to earlier years 1982 to 1998) may be related to an effect(s) of the WL-WTP treated water pumped to the lake. Quality assurance (QA) data associated with the phosphorus and chlorophyll-*a* samples were reviewed to determine the reliability of the results. The QA data indicated the observed concentration changes in the lake were unlikely to be due to errors in the sampling or analytical procedures used. The QA samples included three replicate sub-samples for each TP, DP, and chlorophyll-*a* concentration reported and additional analysis of split samples, which were taken occasionally and sent to another analytical laboratory. Data from other comparable lakes were also reviewed to determine if similar concentration changes were found in these lakes during the same period. Sosiak (2002) reviewed phosphorus and chlorophyll-*a* data from central Alberta lakes during 1982 to 2000. Of the 10 lakes examined, only one or two lakes (depending on the variable measured) showed lower median phosphorus and chlorophyll-*a* concentrations in 1999 and 2000, compared to 1998 (Sosiak 2002). Thus, the phosphorus and chlorophyll-*a* patterns observed in Wabamun Lake appeared to be unusual compared to other regional lakes.

Additional evidence of a unique pattern for TP, DP, and chlorophyll-*a* concentrations in Wabamun Lake during 1999 to 2001 is based on the narrower concentration ranges of these variables in this period, compared to earlier years. Narrower concentration ranges could indicate a mechanism(s) which may have controlled phosphorus concentrations and subsequently chlorophyll-*a* in the lake. Potential control of phosphorus concentrations in Wabamun Lake could include the effect of the new and relatively large annual load of some major ions (e.g., calcium) in the WL-WTP treated water (pumped to the lake) interacting with natural processes (e.g., nutrient cycles) in the lake (see Section 3.4.4 for further discussion).

Nitrogen

Nitrogen is an important nutrient that can affect the productivity of lakes. However, it is usually present at sufficient quantities for aquatic plants in Alberta lakes (Mitchell and Prepas 1990). Sources of nitrogen include atmospheric deposition, decomposing organic material, sediments, groundwater, and wastewaters. The nitrogen cycle in aquatic systems is complex and includes various biologically mediated processes (nitrogen fixation, assimilation, and denitrification). Different chemical species of nitrogen measured in surface waters include: nitrate, nitrite, ammonia, and organic nitrogen. These fractions together make up total nitrogen (TN). Concentrations of nitrate are usually much higher than nitrite in oxygenated water, which is typical of the euphotic zone of Wabamun Lake (Mitchell and Prepas 1990; Alberta Environment, unpublished data). Sources of nitrate include groundwater, precipitation, nitrogen-based explosives, and fertilisers. Ammonia is produced by bacterial decomposition of nitrogenous organic matter in aquatic habitats. Thus, high ammonia concentrations can be due to manure, sewage, fertilisers, and some industrial wastes. Total Kjeldahl nitrogen (TKN) is an analytical procedure that measures ammonia and organic nitrogen together. Organic nitrogen often forms the greatest proportion of TN in unpolluted surface waters.

Median nitrite+nitrate-N concentrations were generally at low levels in Wabamun Lake ($\leq$0.04 mg/L) and there was no overall change from 1982 to 2001 (Figure 12) (r^2 = 0.0002, P = 0.850, n = 150). Median total ammonia-N concentrations in the lake ranged from 0.005 to 0.028 mg/L and they showed no overall change in the 20-year period (Figure 12) (r^2 = 0.019, P = 0.092, n = 151). Median TKN concentrations ranged from 0.77 to 0.995 mg/L and they were generally stable throughout the study (Figure 12) (r^2 = 0.0008, P = 0.736, n = 149).

All total ammonia concentrations in Wabamun Lake were less than water quality guidelines for the protection of freshwater aquatic life (total ammonia = 0.600 to 0.100 mg/L for temperatures of 0 to 25°C, respectively, and pH = 8.5; CCME 2000), with the exception of one sample in 1996 (Figure 12). Nitrite+nitrate-N concentrations in the lake (except for one sample in 1999) were also less than the nitrite guideline for the protection of freshwater aquatic life (CCME: nitrite = 0.06 mg/L; Alberta Environment 1999) (Figure 12). Currently there is no nitrate water quality guideline for the protection of freshwater aquatic life (Alberta Environment 1999).

Dissolved Organic Carbon

Carbon is an important nutrient in freshwater systems because it is a significant structural component of aquatic biota. Organic carbon in surface waters is made up of particulate and

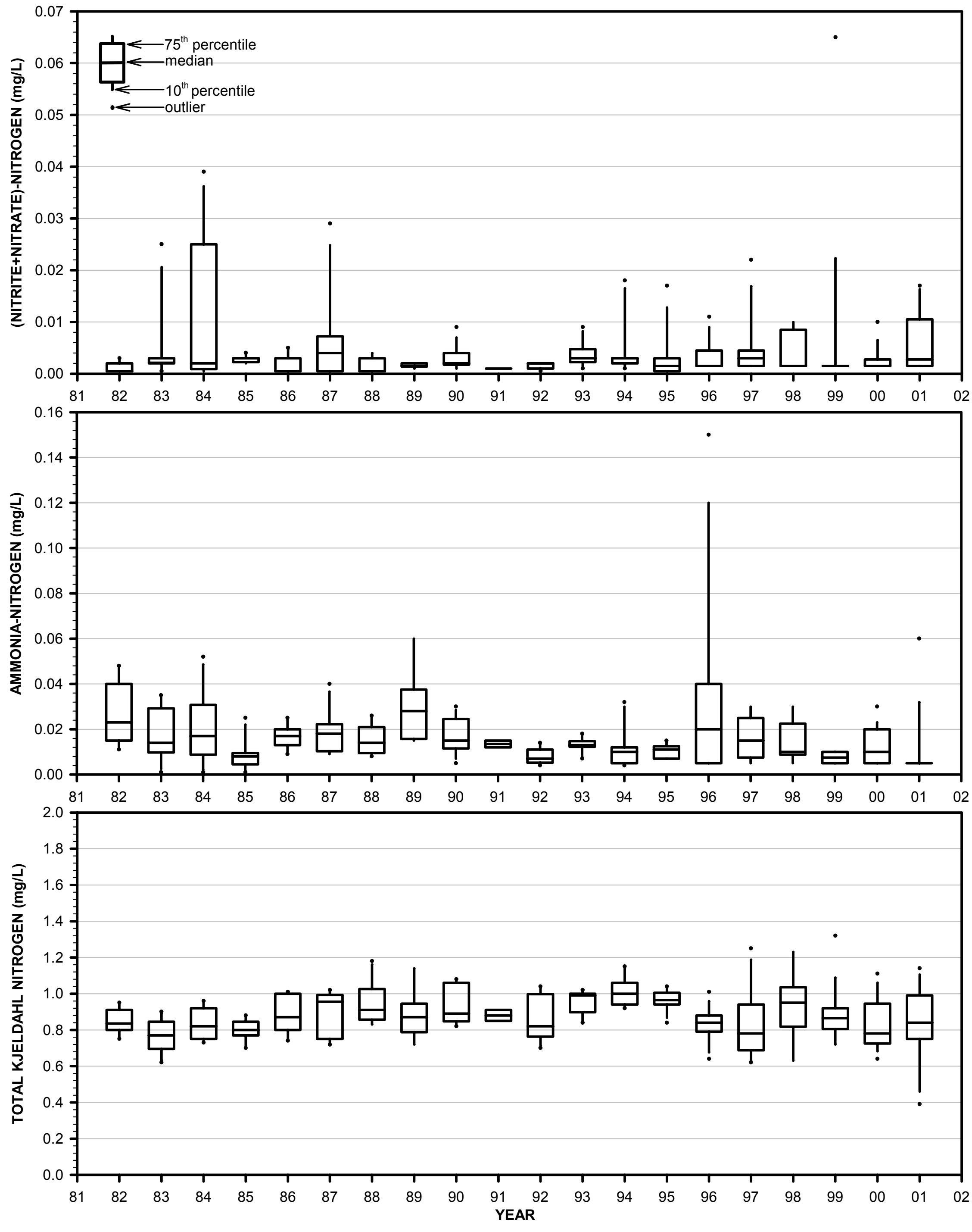


Figure 12 Nitrite+nitrate-nitrogen, ammonia-nitrogen, and total Kjeldahl nitrogen in Wabamun Lake, 1982 to 2001

dissolved forms. The dissolved fraction (which passes through a 0.45 µm filter) is usually the dominant form in lakes (e.g., Wetzel 1983), including Alberta lakes, although concentrations can be quite variable (Alberta Environment, unpublished data). Some aquatic ecosystems, such as wetlands, bogs and eutrophic lakes, have higher DOC concentrations compared to rivers and oligotrophic lakes (Wetzel 1983).

Median DOC concentrations in Wabamun Lake showed a fairly consistent trend of gradually increasing levels over the 20 years, ranging from 10.2 mg/L in 1983 to 12.9 mg/L in 1999 (Figure 13) ($r^2 = 0.159$, $P < 0.001$, $n = 145$). The cause of this small increase is unclear. Levels of DOC in a lake may be influenced by various internal lake processes, such as the decomposition of detritus or biota, and secretions (e.g., carbohydrates and amino acids) from living phytoplankton and macrophytes. External influences on DOC levels could include major activities or changes in land use within the lake watershed (e.g., mining and drainage of wetlands), which potentially could alter DOC loads in runoff and stream inflows to the lake. Other external factors related to warmer climate conditions may lead to lower DOC levels in runoff to lakes (e.g., due to dryer soils, lower water tables, and reduced stream flow) (Schindler 2001). In the case of Wabamun Lake, comprehensive data on DOC levels related to various internal and external influences on DOC over the 20 years are limited or not available.

Secchi Disk Visibility

The Secchi disk visibility (or Secchi depth) provides a general measure of lake transparency (Section 2.2.1). Transparency is generally affected by dissolved and suspended material (e.g., colour and phytoplankton) in the water column. Secchi depth may also be used as a crude measure of lake fertility, because it is often directly related to the phytoplankton biomass (chlorophyll-*a*) in the water column. In Alberta lakes, Secchi depths range from about 6 m in low productivity (oligotrophic) lakes to 0.4 m in very high productivity (hyper-eutrophic) lakes (Mitchell and Prepas 1990). In Wabamun Lake, median Secchi depths did not vary substantially in most years (range of medians = 1.7 to 2.5 m), except for 1987 and 1988 when the greatest Secchi depths occurred (medians = 3.0 and 2.8 m, respectively) (Figure 13). Overall, Secchi depths did not show a major change over the 20 years, although there was a statistical trend towards lower Secchi depths in more recent years ($r^2 = 0.053$, $P = 0.005$, $n = 149$). As expected, Secchi depths showed a strong negative correlation with chlorophyll-*a* concentrations ($r = -0.532$, $P < 0.001$, $n = 148$).

Trophic State of Wabamun Lake

Based on TP (annual medians = 0.028 to 0.038 mg/L) and chlorophyll-*a* (annual medians = 0.007 to 0.014 mg/L) concentrations in the euphotic zone of Wabamun Lake, the trophic state of the lake was moderate to highly productive (i.e., meso-eutrophic) from 1992 to 2001 (Table 4). This trophic classification was consistent with earlier assessments using chlorophyll-*a* data from the early-1970s to 1980s (Noton 1975; Habgood 1983; Mitchell and Prepas 1990).

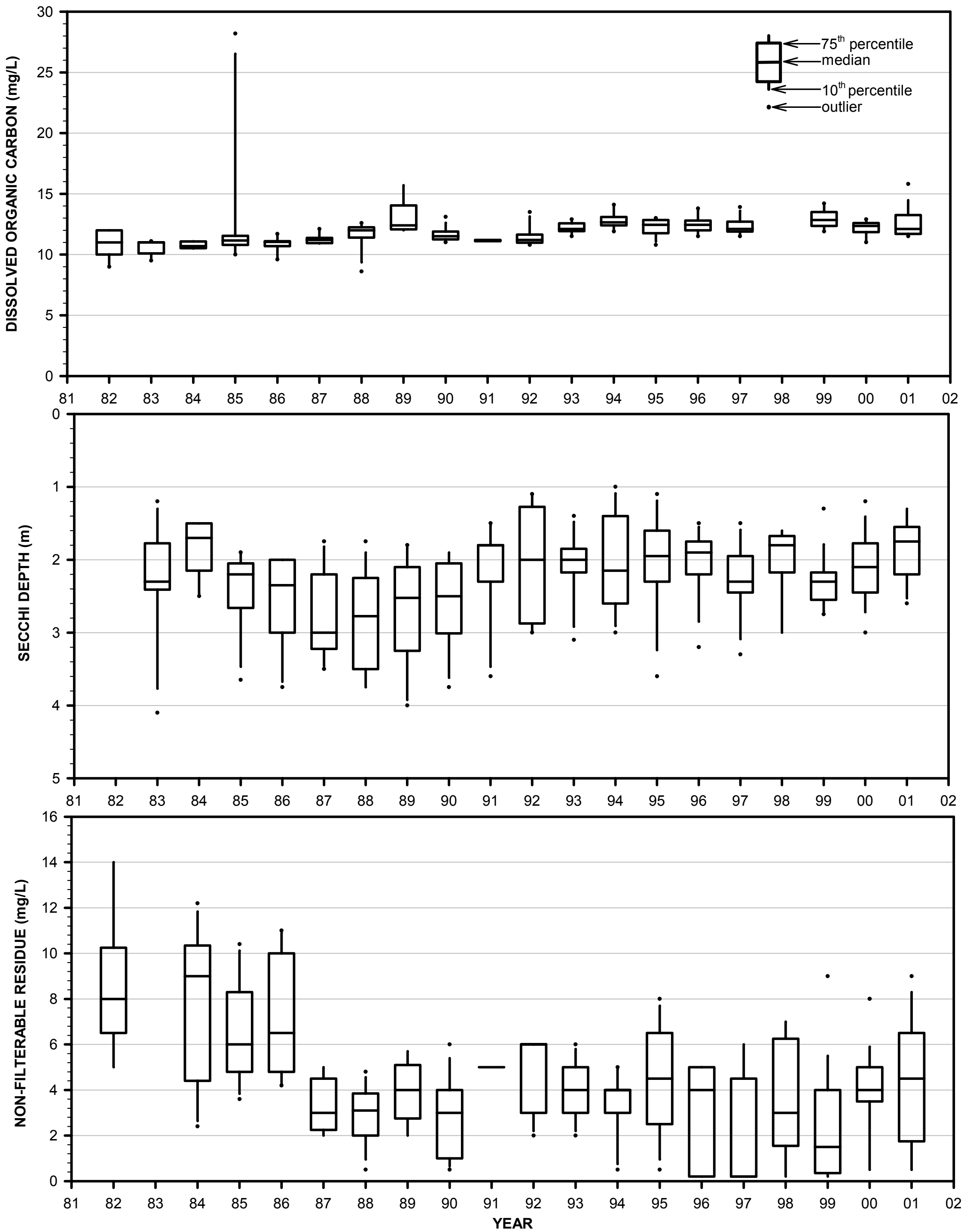


Figure 13 Dissolved organic carbon, Secchi depth, and non-filterable residue in Wabamun Lake, 1982 to 2001

3.1.5 Non-filterable Residue

Non-filterable residue (NFR) is generally equivalent to total suspended solids (TSS) in urface water samples (depending on the analytical methods used). Sources of NFR in lakes include soil, runoff (especially following heavy precipitation), algae, wastewaters, and re-suspension of bottom sediments (e.g., caused by wind action in lakes). Nutrients (notably phosphorus) and some metals are often associated with suspended particles. Therefore, high NFR concentrations in lakes can lead to corresponding increases of nutrients and metals in the water column. Elevated NFR in lakes can also reduce photosynthesis (due to reduced light), affect fish (e.g., irritation of gills and reduced dissolved oxygen transport across gills), and impact benthic habitat and associated biota (e.g., due to siltation). Suspended solids in the water column may also be taken up by aquatic biota (e.g., filter feeders). In Wabamun Lake, NFR concentrations generally declined from 1982 to 2001 ($r^2 = 0.123$, $P = 0.001$, $n = 141$)(Figure 13). Highest median NFR concentrations (6 to 9 mg/L) occurred in the lake from 1982 to 1986, compared to lower levels (1 to 5 mg/L) after 1986 (Figure 13). The NFR concentrations from 1982 to 1986 were statistically higher than those in the following 5-year period (1987 to 1991) (t-test critical value = 2.01, $P < 0.001$, df = 53). These slightly higher NFR concentrations in the early to mid-1980s may have been related to direct discharges of Highvale mine wastewaters to Wabamun Lake during this period. Diversion of the mine wastewaters (which may be high in suspended solids), away from the Beaver Creek sub-basin to the Sundance cooling pond (Figure 1), was completed in 1986 (Reid Crowther 1995). As expected, NFR concentrations showed a negative correlation with Secchi depths (water transparency)($r = -0.346$, $P < 0.001$, $n = 131$; based on available data, i.e., paired data from 1984 to 2001).

3.1.6 Metals

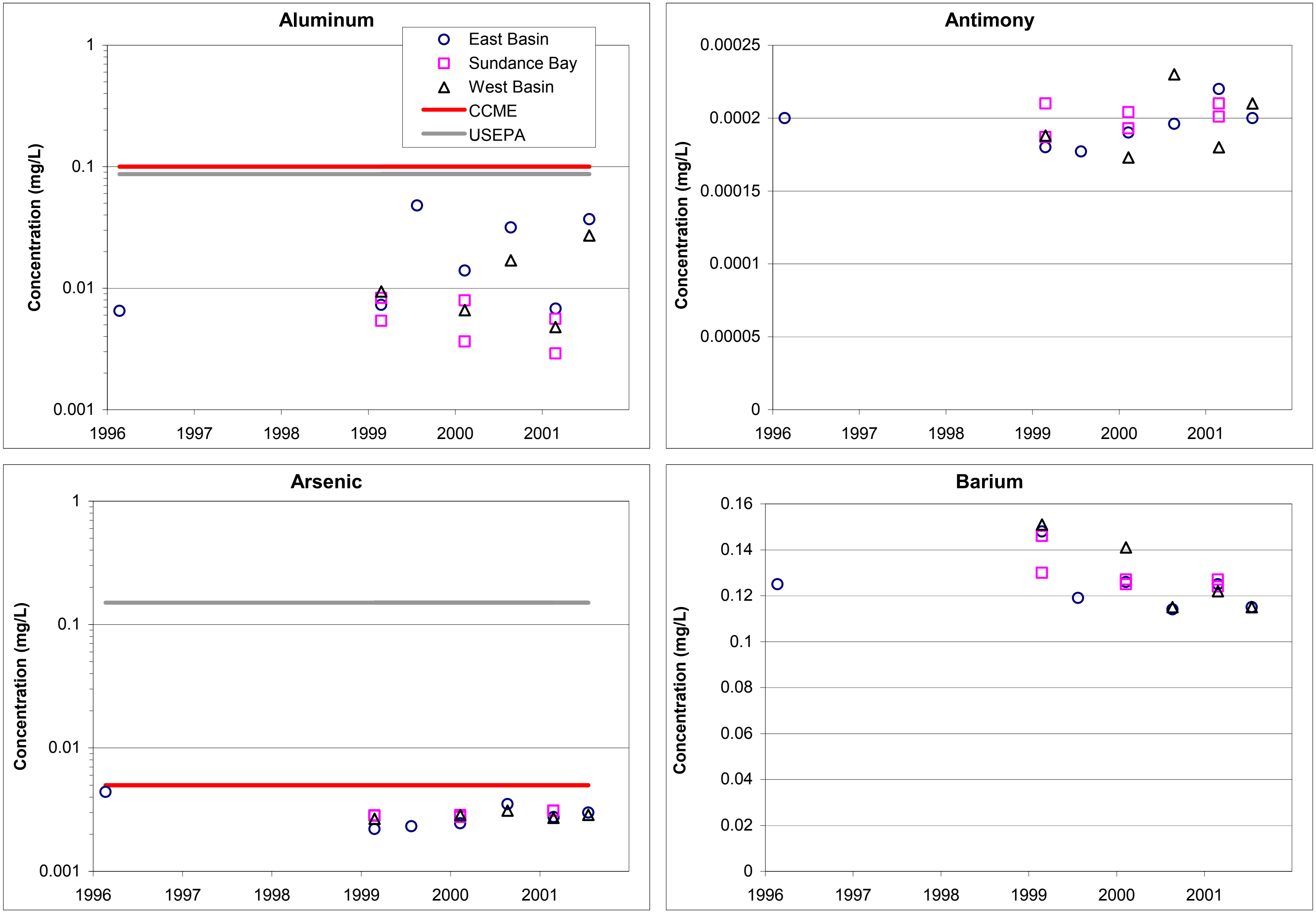
The sampling of metals (excluding mercury) in Wabamun Lake were mostly limited to the 1999 to 2001 period; only one comparable sample was taken in 1996 (Table 1; Figure 14). In total, 18 samples were collected and analysed for 27 elements using total recoverable and extractable methods (Section 2.2.2). Patterns in the metal dataset (Figure 14) are outlined in the following sections.

<u>General Patterns</u>

1. During 1999 to 2001, about 59% of the metals analysed (16 of 27 elements: aluminum, beryllium, bismuth, chromium, cobalt, copper, iron, lead, manganese, nickel, thallium, thorium, tin, titanium, vanadium, and zinc) in the lake samples were at concentrations which varied by at least one-order of magnitude.

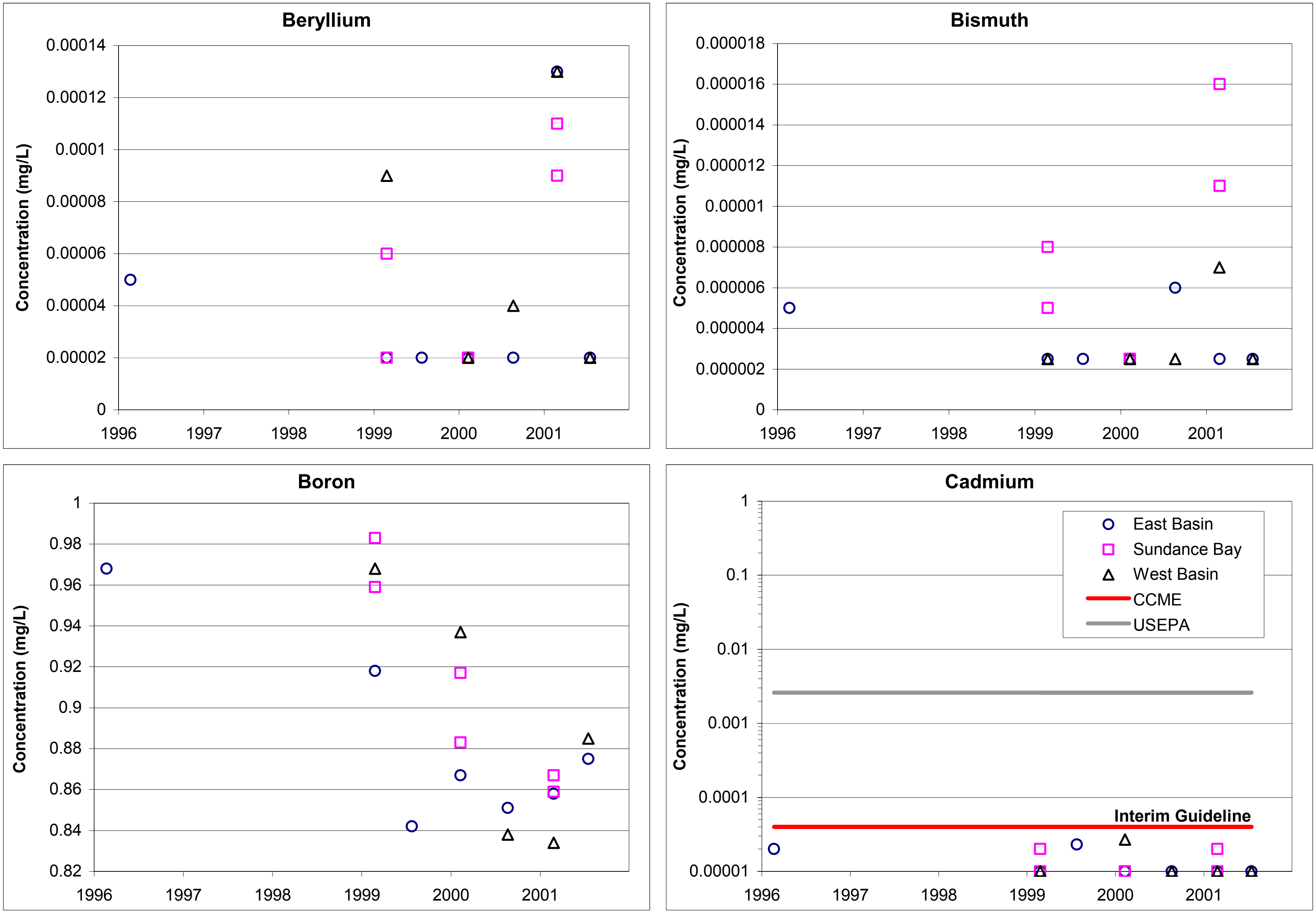
2. All metal concentrations in the lake (i.e., from 1996 to 2001) were less than water quality guidelines for the protection of freshwater aquatic life; guidelines exist for 13 of the metals analysed (Alberta Environment 1999).

3. Two metals in the lake were at concentrations greater than water quality guidelines for agricultural uses (i.e., for irrigation and livestock watering). These guidelines exist for 19 of the metals analysed in the samples (Alberta Environment 1999). All



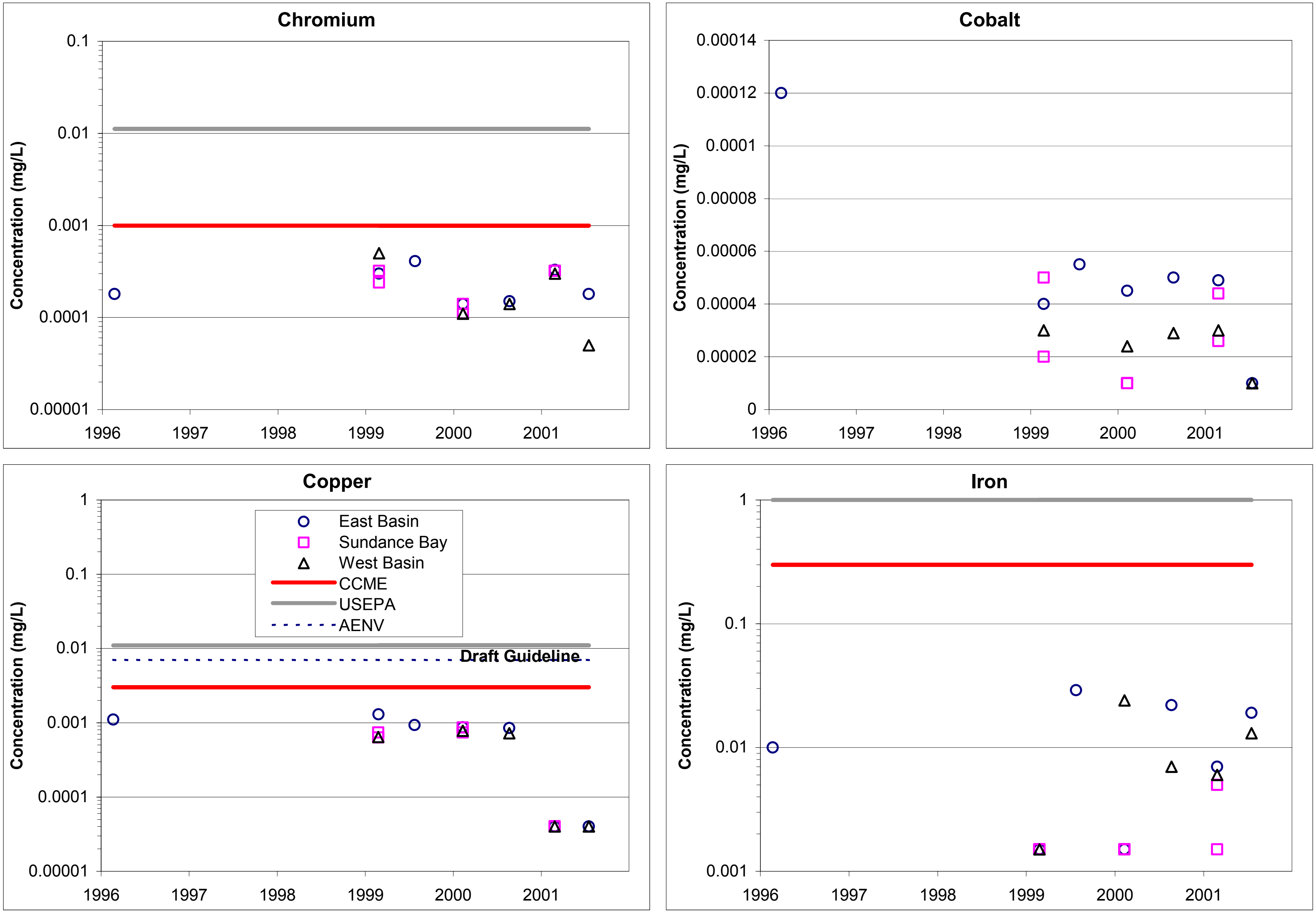
Note: y-axis for aluminum and arsenic is shown as log scale

Figure 14 Total metal concentrations at three sites in Wabamun Lake, (February) 1996 to (July/August) 2001



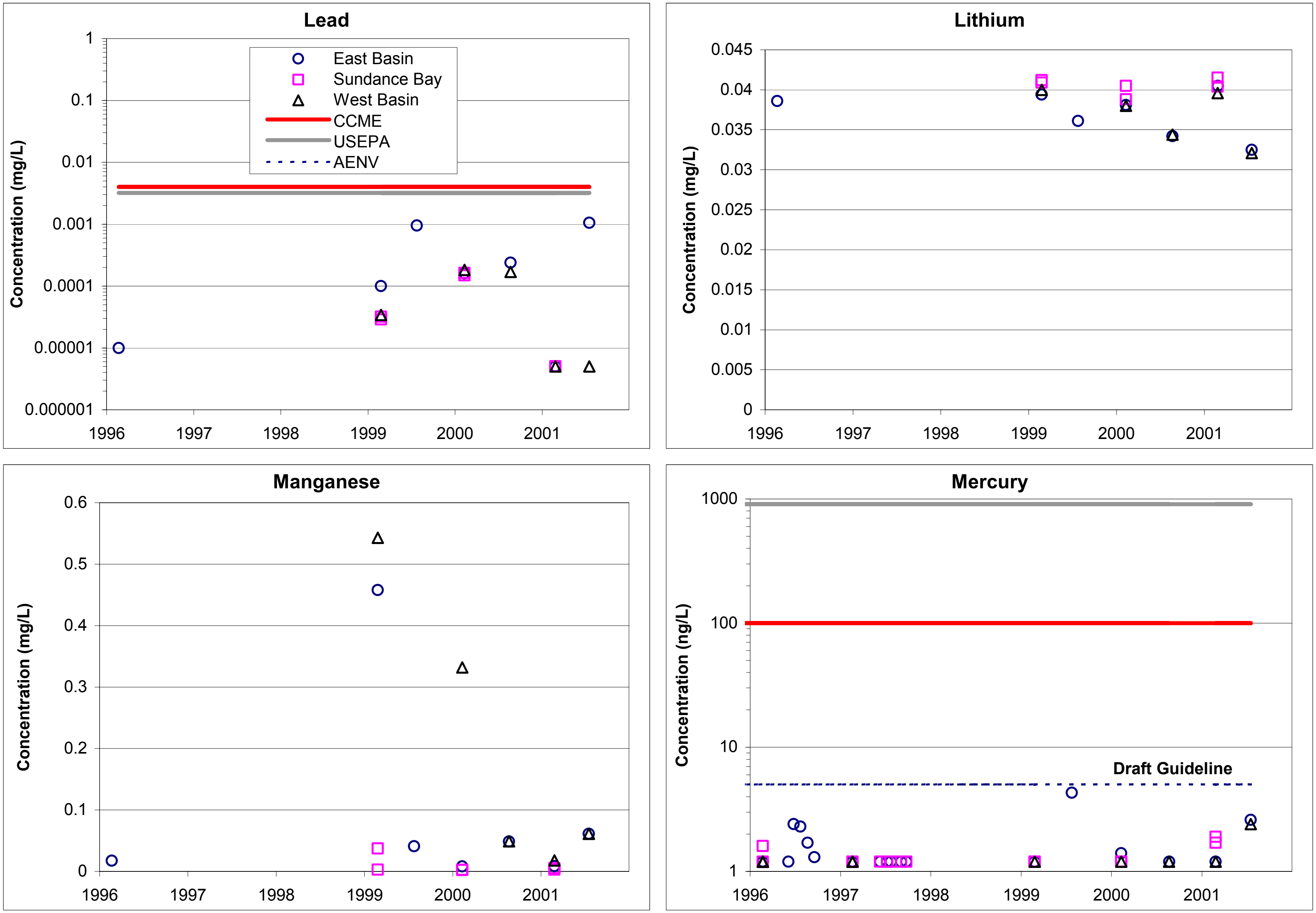
Note: y-axis for cadmium is shown as log scale

Figure 14 Total metal concentrations at three sites in Wabamun Lake, (February) 1996 to (July/August) 2001 (continued)



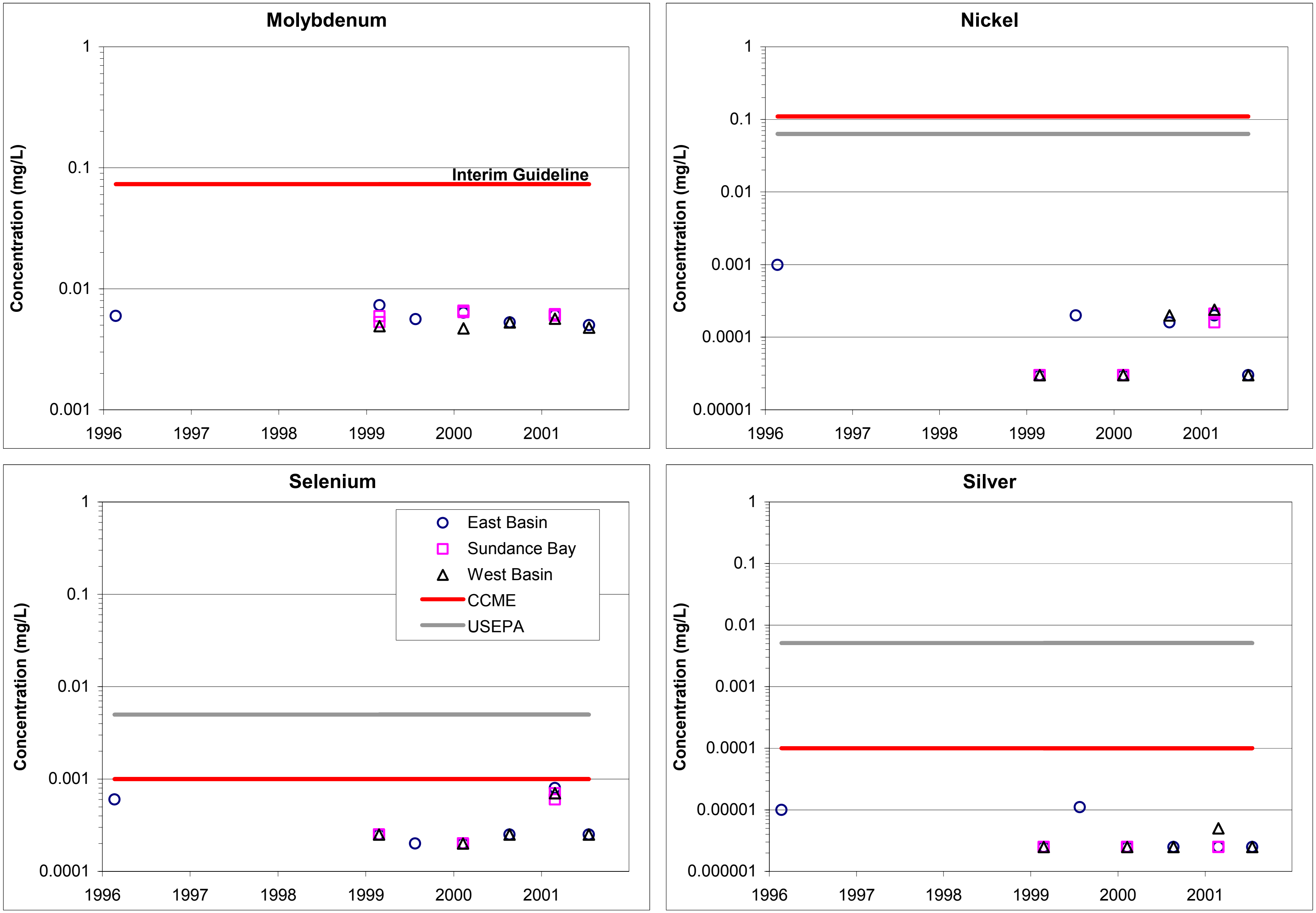
Note: y-axis for Cr, Cu, Fe is shown as log scale

Figure 14 Total metal concentrations at three sites in Wabamun Lake, (February) 1996 to (July/August) 2001 (continued)



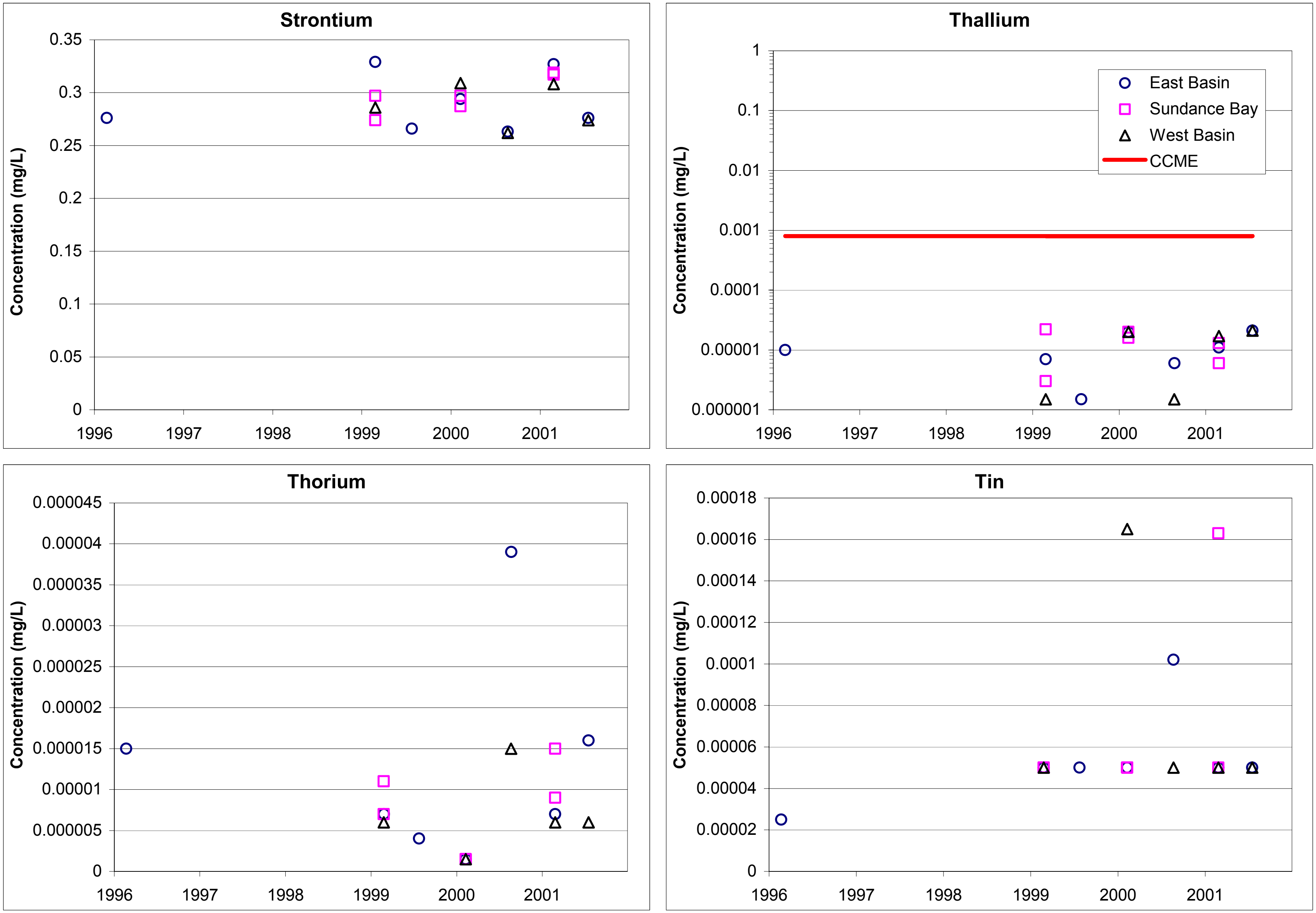
Note: y-axis for lead and mercury is shown as log scale

Figure 14 Total metal concentrations at three sites in Wabamun Lake, (February) 1996 to (July/August) 2001 (continued)



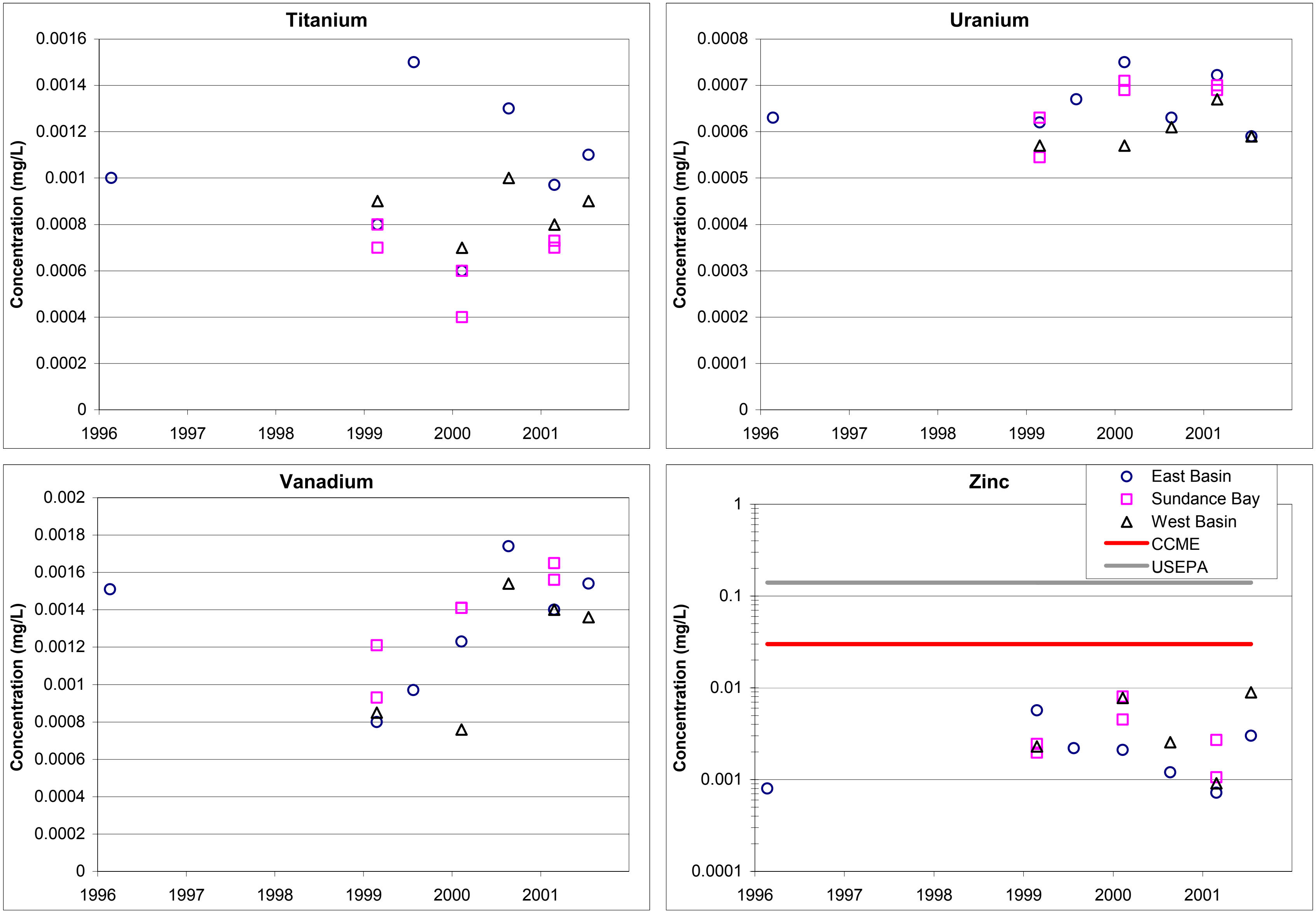
Note: y-axis is shown as log scale

Figure 14 Total metal concentrations at three sites in Wabamun Lake, (February) 1996 to (July/August) 2001 (continued)



Note: y-axis for thallium is shown as log scale

Figure 14 Total metal concentrations at three sites in Wabamun Lake, (February) 1996 to (July/August) 2001 (continued)



Note: y-axis for zinc is shown as log scale

Figure 14 Total metal concentrations at three sites in Wabamun Lake, (February) 1996 to (July/August) 2001 (continued)

boron concentrations in the lake (range = 0.834 to 0.983 mg/L) were greater than the lowest guideline for irrigation. The boron guideline concentrations can vary from 0.5 to 6.0 mg/L, depending on the crops irrigated (Alberta Environment 1999). Some manganese concentrations in the lake, during the winters of 1999 and 2000 (range = 0.002 to 0.543 mg/L), were greater than the water quality guideline for irrigation (0.2 mg/L; Alberta Environment 1999).

Spatial and Temporal Patterns

1. Overall there were no pronounced spatial differences in the concentrations of most metals among the three sites sampled (East and West basins and Sundance Bay; Figure 1).

2. Temporal patterns for some metal concentrations in the lake were evident from 1999 to 2001, when most samples were collected. For example, concentrations of boron, chromium, copper, and manganese declined, while vanadium showed a trend of increasing concentrations over the three-year period.

3. Within individual years, from 1999 to 2001, consistent changes in the concentrations of some metals in the lake were found. Higher or lower concentrations were found in the open-water period (July or August) compared to winter. For example, aluminum and titanium concentrations were lower in the winter (February), compared to those in the open-water period of each year. The opposite pattern was found for barium, lithium, and strontium which were at higher concentrations in the lake during winter. These patterns may be related to temporal influences of various metal loads in natural inflows (e.g., streams), which primarily occur in the open-water period, compared to other atypical (or artificial) inflows to the lake watershed. Atypical inflows (i.e., the ash lagoon discharge and WL-WTP treated water) occur throughout the year, including winter. The influence of metal loads in these artificial inflows on the overall water quality of the lake may have a more pronounced effect in winter, when natural inflows to the lake (i.e., streams and precipitation) are more restricted.

Mercury

Total mercury is usually found at very low concentrations (1 to 20 ng/L) in uncontaminated (background) surface waters (e.g., Morel and Kraepiel 1998; US-Dept. of Interior 1998a). Thus ultra-trace sampling and analytical detection limits (e.g., <1 ng/L) are needed to determine meaningful mercury concentrations in surface waters. Caution, however, should be used when evaluating ultra-trace mercury in surface waters, because it is very difficult to avoid contamination of the samples by atmospheric mercury (e.g., dissolved, volatile, and particulate forms), especially under field conditions.

For the Wabamun Lake program, the analytical laboratory (Alberta Research Council) may be able to achieve the method detection limit of 1.2 ng/L under controlled laboratory conditions. However, the realities of field conditions make the elimination of mercury contamination, even using ultra-trace collection and handling protocols, difficult to achieve. This concern was confirmed by the quality assurance data associated with the Wabamun Lake samples, which indicated mercury contamination occurred in the sampling program. Total mercury ($\geq$ 1.2 ng/L) was found in about 39% of the field blank samples (15 of 39 samples) that were taken concurrently (on the same dates) with the lake samples. The total mercury concentrations in the blanks (range = $\leq$1.2 to 3.9 ng/L; Appendix E) were similar to those in the lake samples (range = $\leq$1.2 to 4.3 ng/L; Table 5). There was no statistical difference between total mercury concentrations in the lake and blank samples (t-test critical value = 1.99, P = 0.219, df = 72).

These data illustrate the difficulty of obtaining accurate measurements of mercury using ultra-trace methods under field conditions. However, the results also show that total mercury concentrations were at very low levels in Wabamun Lake. In addition, there was no overall change of total mercury concentrations in the lake from 1996 to 2001 (Figure 14). All total mercury concentrations in the lake were less than water quality guidelines for the protection of freshwater aquatic life (CCME = 100 ng/L and US-EPA = 906 ng/L), including the lowest (draft Alberta) guideline of 5 ng/L (Alberta Environment 1999). The Canadian (CCME) total and methyl-mercury guidelines are currently under review. All total mercury concentrations were well below the water quality guidelines for agricultural uses (livestock watering = 3 µg/L; Alberta Environment 1999).

Discussion of Wabamun Lake Metal Data and Comparisons to Other Lakes

The metal dataset for Wabamun Lake was somewhat limited in scope, compared to other water quality variables sampled in the lake. Samples analysed for 27 elements were only taken once or twice per year, at up to three sites in the lake. Thus continuing and possibly more detailed sampling are required to confirm the spatial and temporal patterns observed in the lake, including any long-term changes which may occur in the future.

For some elements, such as mercury, more focussed sampling of surface waters may be necessary to establish the chemical forms (e.g., methyl-mercury) and concentrations in the lake under different seasonal conditions. Sampling of metals (and possibly metal species) may be warranted for some elements which can bioconcentrate or accumulate to levels of concern in sediment and aquatic biota.

There were few comparable metal data (e.g., 27-element scans) from other regional lakes in the Alberta Environment WDS database, to compare to the Wabamun Lake dataset. However, the limited ultra-trace mercury data from other central and southern Alberta lakes (Big Lake, near St. Albert, Buffalo Lake, and Oldman Reservoir) showed that the total mercury concentrations (range = $\geq$1.2 ng/L to 3.4 ng/L, n = 11; Alberta Environment, unpublished data) were similar to those in Wabamun Lake.

3.1.7 Pesticides

Two commonly used herbicides, 2,4-D and MCPA (2,4-dichlorophenoxyacetic acid and 4-chloro-2-methyl phenoxy acetic acid, respectively) were found at low concentrations in Wabamun Lake (at the East Basin site) in 1995, the only year pesticides were sampled (Table 6).

Table 5 Total mercury concentrations in Wabamun Lake, (February) 1996 to (July) 2001

SAMPLE SITE								
EAST BASIN PROFILE (AB05DE0590)			WEST BASIN PROFILE (AB05DE0580)			SUNDANCE BAY PROFILE (AB05DE0610)		
Date	Depth (m)	Mercury (ng/L)	Date	Depth (m)	Mercury (ng/L)	Date	Depth (m)	Mercury (ng/L)
21-Feb-96		0.6	21-Feb-96	1	0.6	21-Feb-96	1	0.6
21-Feb-96	1	0.6	21-Feb-96	3	0.6	21-Feb-96	4	1.6
21-Feb-96	3	0.6	21-Feb-96	5	0.6			
21-Feb-96	6	0.6	21-Feb-96	7	0.6			
4-Jun-96	6	0.6	21-Feb-96	9	1.2			
26-Jun-96	6	2.4						
23-Jul-96	6	2.3						
21-Aug-96	6	1.7						
17-Sep-96	6	1.3						
18-Feb-97	1	0.6	18-Feb-97	1	0.6	18-Feb-97	1	0.6
18-Feb-97	3	0.6	18-Feb-97	4	0.6	18-Feb-97	4	0.6
18-Feb-97	6	0.6	18-Feb-97	9	0.6	10-Jun-97	2	0.6
10-Jun-97	6.5	0.6				8-Jul-97	2	0.6
8-Jul-97	6	0.6				24-Jul-97	2	0.6
24-Jul-97	6	0.6				3-Sep-97	2	0.6
3-Sep-97	0.025	0.6				24-Sep-97	2	0.6
24-Sep-97	6	0.6						
25-Feb-99	7	0.6	25-Feb-99	9	0.6	25-Feb-99	1	0.6
26-Jul-99	6	4.3				25-Feb-99	4.5	0.6
10-Feb-00	6	1.4	10-Feb-00	9	0.6	10-Feb-00	1	0.6
22-Aug-00	6	0.6	22-Aug-00	9	0.6	10-Feb-00	4	0.6
26-Feb-01	6	1.2	26-Feb-01	9	0.6	26-Feb-01	1	1.9
18-Jul-01	6	2.6	18-Jul-01	9	2.4	26-Feb-01	3	1.7

Notes:
Shaded cells are 1/2 the analytical detection limit

Table 6 Pesticide concentrations at the East Basin profile site in Wabamun Lake, 1995

Variable:	Depth (metre)	2,4-D	2,4-DB	Dichlorprop	Alpha-Benzenehexa chloride	Alpha-Endosulfan	Gamma-Benzenehexa chloride (Lindane)	Methoxychlor (P,P'-Methoxychlor)	Atrazine
19-Jul-95	1	**0.005**	L0.005	L0.005	L0.005	L0.005	L0.005	L0.03	L0.005
19-Jul-95	6	L0.005	L0.005	L0.005	L0.005	L0.005	L0.005	L0.03	L0.005
10-Aug-95	1	L0.005	L0.005	L0.005	L0.005	L0.005	L0.005	L0.03	L0.005
10-Aug-95	6	**0.014**	L0.005	L0.005	L0.005	L0.005	L0.005	L0.03	L0.005

Variable:	Depth (metre)	Bromacil	Bromoxynil	Carbathiin (Carboxin)	Cyanazine	Diazinon	Dicamba (Banvel)	Diclofop-Methyl	Disulfoton (Di-Syston)
19-Jul-95	1	L0.03	L0.005	L0.1	L0.05	L0.005	L0.02	L0.02	L0.2
19-Jul-95	6	L0.03	L0.005	L0.1	L0.05	L0.005	L0.02	L0.02	L0.2
10-Aug-95	1	L0.03	L0.005	L0.1	L0.05	L0.005	L0.02	L0.02	L0.2
10-Aug-95	6	L0.03	L0.005	L0.1	L0.05	L0.005	L0.02	L0.02	L0.2

Variable:	Depth (metre)	Diuron	Chlorpyrifos (Dursban)	Ethalfluralin (Edge)	Ethion	Guthion	Clopyralid (Lontrel)	MCPB	MCPP (Mecoprop)
19-Jul-95	1	L0.2	L0.005	L0.005	L0.1	L0.2	L0.02	L0.02	L0.005
19-Jul-95	6	L0.2	L0.005	L0.005	L0.1	L0.2	L0.02	L0.02	L0.005
10-Aug-95	1	L0.2	L0.005	L0.005	L0.1	L0.2	L0.02	L0.02	L0.005
10-Aug-95	6	L0.2	L0.005	L0.005	L0.1	L0.2	L0.02	L0.02	L0.005

Variable:	Depth (metre)	Terbufos	Triallate (AvadexBW)	Trifluralin (Treflan)	Picloram (Tordon)	Malathion	Phorate (Thimet)	MCPA	
19-Jul-95	1	L0.03	L0.005	L0.005	L0.005	L0.05	L0.005	L0.005	
19-Jul-95	6	L0.03	L0.005	L0.005	L0.005	L0.05	L0.005	**0.0065**	
10-Aug-95	1	L0.03	L0.005	L0.005	L0.005	L0.05	L0.005	L0.005	
10-Aug-95	6	L0.03	L0.005	L0.005	L0.005	L0.05	L0.005	L0.005	

Notes:
All concentrations are µg/L
Detections are shown as bold font
"L" = concentrations which are less than the analytical detection limit

Concentrations of 2,4-D and MCPA in the lake were well below water quality guidelines for the protection of freshwater aquatic life (CCME: MCPA interim guideline = 2.6 µg/L and chlorophenoxy herbicides guideline, which includes 2,4-D, = 4.0 µg/L; Alberta Environment 1999).

These two herbicides were the most common ones found in other lakes and smaller waterbodies in central and southern Alberta and they were generally present at similar concentrations to those in Wabamun Lake (Alberta Environment, unpublished data; Anderson 1998). For example, 2,4-D and MCPA were found in about 40% and 27% of samples, respectively (total of 62 samples), taken in 23 lakes, with varying levels of pesticide use and runoff volume (Anderson 1998).

3.2 Water Quality Changes Related to Aquatic Biota in Wabamun Lake

Changes in the composition and abundance of various aquatic communities (e.g., plankton, benthic and free-swimming macroinvertebrates, and fish) in Wabamun Lake could occur due to changes in lake water quality. The main water quality changes observed in the lake were increasing concentrations of most major ions and TDS over the 20-year study period. Increases of individual major ions and possibly interactive effects of these ions may have direct short-term effects on aquatic biota (e.g., physiological responses by individuals or populations) and/or more long-term effects on aquatic communities (e.g., changes in the species diversity of communities).

Evaluating the potential effects of increasing major ion or TDS concentrations on aquatic biota in Wabamun Lake, however, is limited by information available in scientific literature. This is because there is a paucity of published studies on the effects of TDS on freshwater biota at concentrations similar to those found in Wabamun Lake. Most studies on the responses of aquatic biota to TDS (equivalent to salinity) in inland waters focuses on observations of community composition in lakes with relatively high salinity, often well above 1,000 TDS mg/L (e.g., Hammer 1983; Williams *et al.* 1990; Williams 1993; US-Dept. of Interior 1998b). Studies on Alberta lakes have shown reduced levels of phytoplankton biomass at TDS concentrations much higher than those observed in Wabamun Lake (Prepas and Trew, 1983: >500 mg TDS/L; Bierhuizen and Prepas, 1985: >1,000 mg TDS/L).

In addition to few relevant studies in the literature, at present there are no detailed studies on long-term patterns in the diversity and abundance of aquatic fauna in Wabamun Lake (excluding commercial fishery data). However, a preliminary analysis of plankton samples from Wabamun Lake (taken by Alberta Environment) showed no major changes in the phytoplankton and zooplankton communities during the 1990s to 2001 (Alberta Environment, unpublished data). Measures of diversity (number of taxa) and abundance of the phytoplankton and zooplankton communities (using biomass and density, respectively) showed variability among years (Figures 15 and 16).

But overall, there were no consistent trends (of increasing or decreasing levels) in these community measures from the early-1990s to 2001 (Figures 15 and 16). Statistical analysis of the data between the two three-year periods before and after the WL-WTP was fully commissioned showed no statistically significant differences for the number of phytoplankton taxa (t-test critical value = -1.70, P = 0.100, df = 28), total phytoplankton biomass (t-test critical value = -0.36, P = 0.722, df = 28), and total zooplankton density (t-test critical value = -1.36, P =

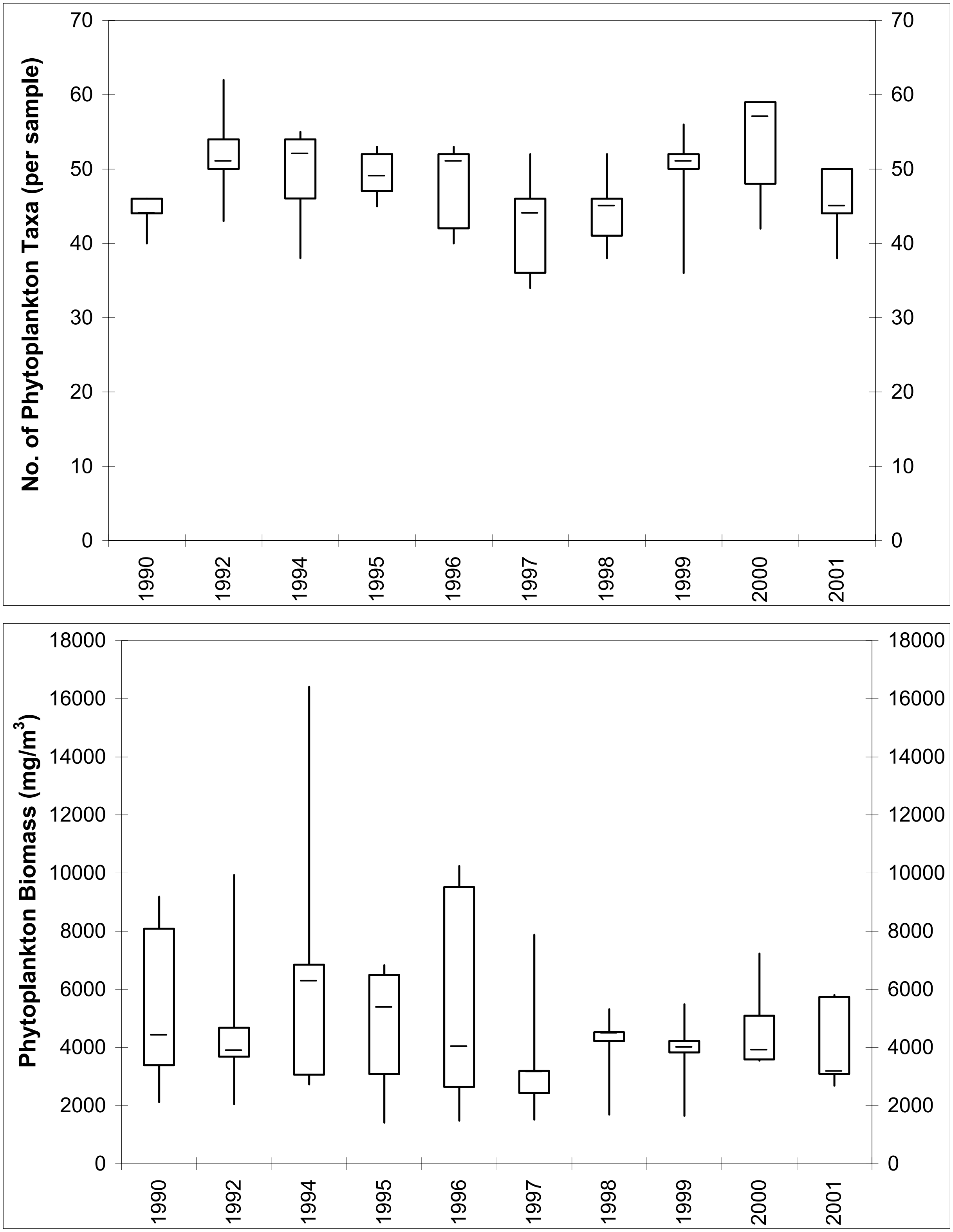
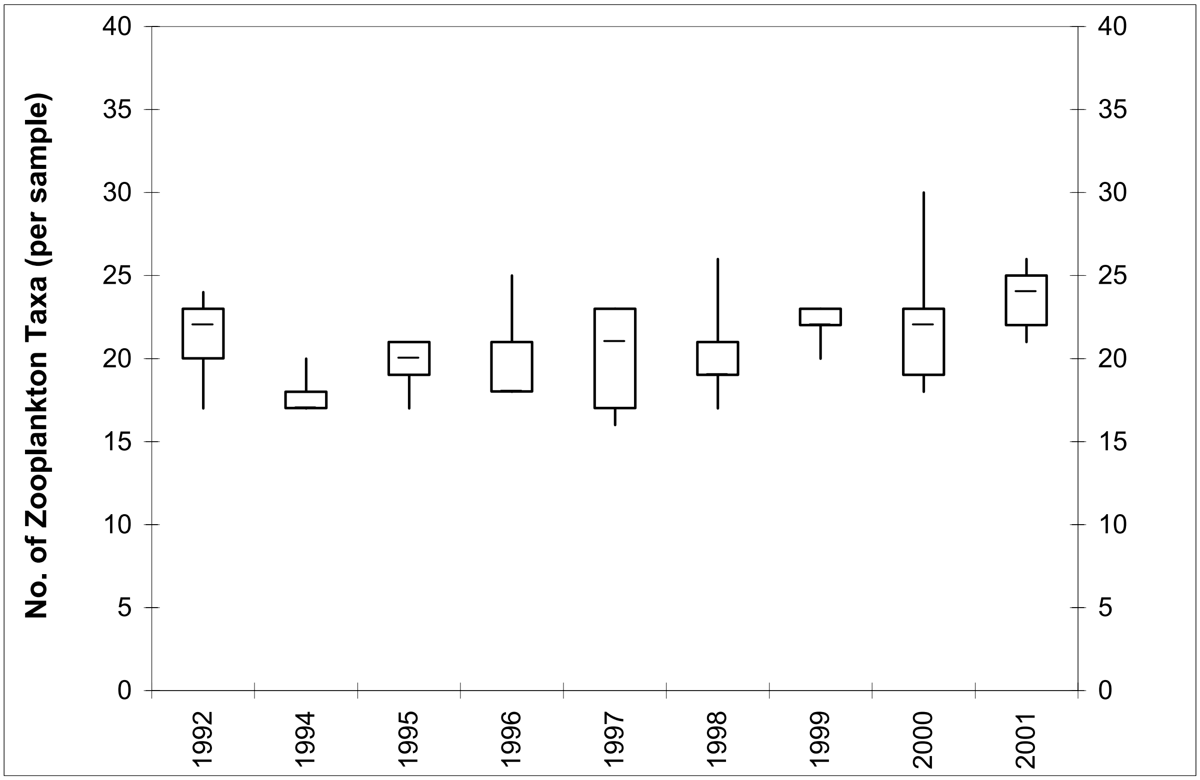


Figure 15 Total number of phytoplankton taxa and biomass in Wabamun Lake, 1990 to 2001



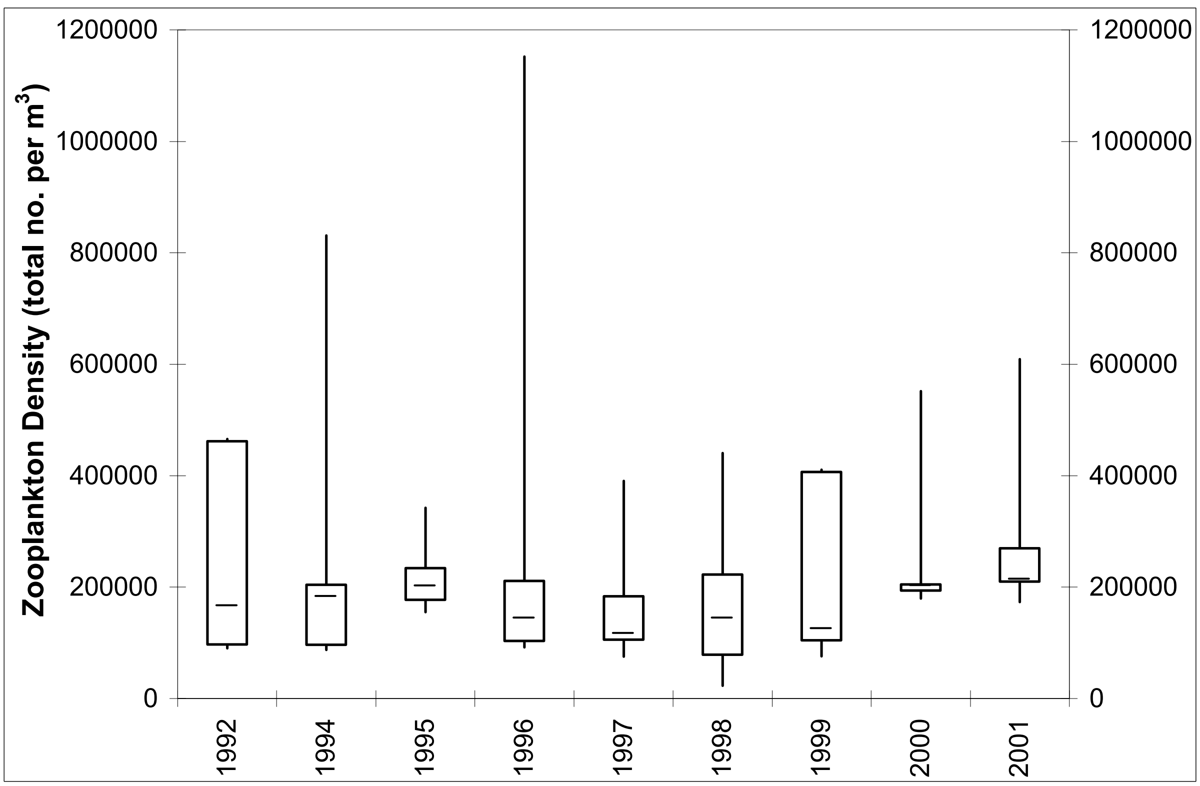


Figure 16 Total number of zooplankton taxa and density in Wabamun Lake, 1992 to 2001

0.184, df = 28) between the two periods. The only exception was for zooplankton taxa where there was a tendency for a greater number of taxa from 1999 to 2001, compared to the three-year period before 1999 (t-test critical value = -2.43, P = 0.022, df = 28); the probability level of the statistical test was close to the level of significance. Note the phytoplankton biomass reported here showed a different statistical result from those reported in Section 3.1.4. This was because two different measures of algal biomass were used, i.e., cell volume (converted to weight in mg) compared to chlorophyll-*a* content. Although the two measures are usually strongly correlated, some variability is expected.

In summary, this basic analysis of the plankton data indicated no overall change in the plankton communities in Wabamun Lake form the early 1990s to 2001. This period coincided with the higher observed increases of most major ions and TDS concentrations in the lake, including the period when the WL-WTP treated water was pumped to the lake. A more detailed analysis of the plankton data, together with similar samples collected during the 1980s, would provide a more complete analysis of trends relative to changes in the lake water quality over the 20 years.

3.3 Effects of Lake Level and Water Balance on Water Quality, 1982 to 2001

As noted above (Section 3.1.2), the basin characteristics (basin area : lake area), hydraulic flushing (occurrence and magnitude), and evaporation likely had important effects on the concentrations of major ions and related variables in Wabamun Lake. Associated with these effects, climate conditions have an overall influence on the level and water balance of the lake. In the following Sections, specific data and analysis of the Wabamun Lake level and water balance from 1982 to 2001 provide insight on the role and importance of these factors on the lake water quality.

Previous studies have evaluated changes in the Wabamun Lake level and basic water balance for the lake (Reid Crowther 1995; Klohn Crippen 2001). These studies used various assumptions and data available at the time. More recently, Alberta Environment (Environmental Assurance, Monitoring and Evaluation Branch) reconstructed a basic water balance simulation using consistent methods and assumptions for all years from 1982 to 2001 and based on information in the Reid Crowther (1995) and Klohn Crippen (2001) studies (Alberta Environment 2002b).

3.3.1 Lake Level

Over the 20-year study, Wabamun Lake water levels were higher from 1982 to the early-1990s, compared to more recent years (Figure 17). Surface outflow from the lake (via Wabamun Creek) occurred from 1982 to 1987 and from 1990 to mid-1992; no outflow was assumed in 1988 and 1989, although records for these years are incomplete (Figure 17)(Alberta Environment 2002b). After June 1992, there was no surface outflow from the lake to the end of 2001 (Figure 17) (Alberta Environment 2002b). The period of no lake outflow corresponded to the approximate time (beginning about 1992 to 1993) when TDS and some conservative major ion (sodium, chloride, and fluoride) concentrations increased at greater annual rates in the lake (compared to the earlier years) (Section 3.1). These higher annual rates were likely related to reduced or no flushing (depending on the influence of groundwater; Section 3.3.2) of major ions in the lake during the 1990s to the present.

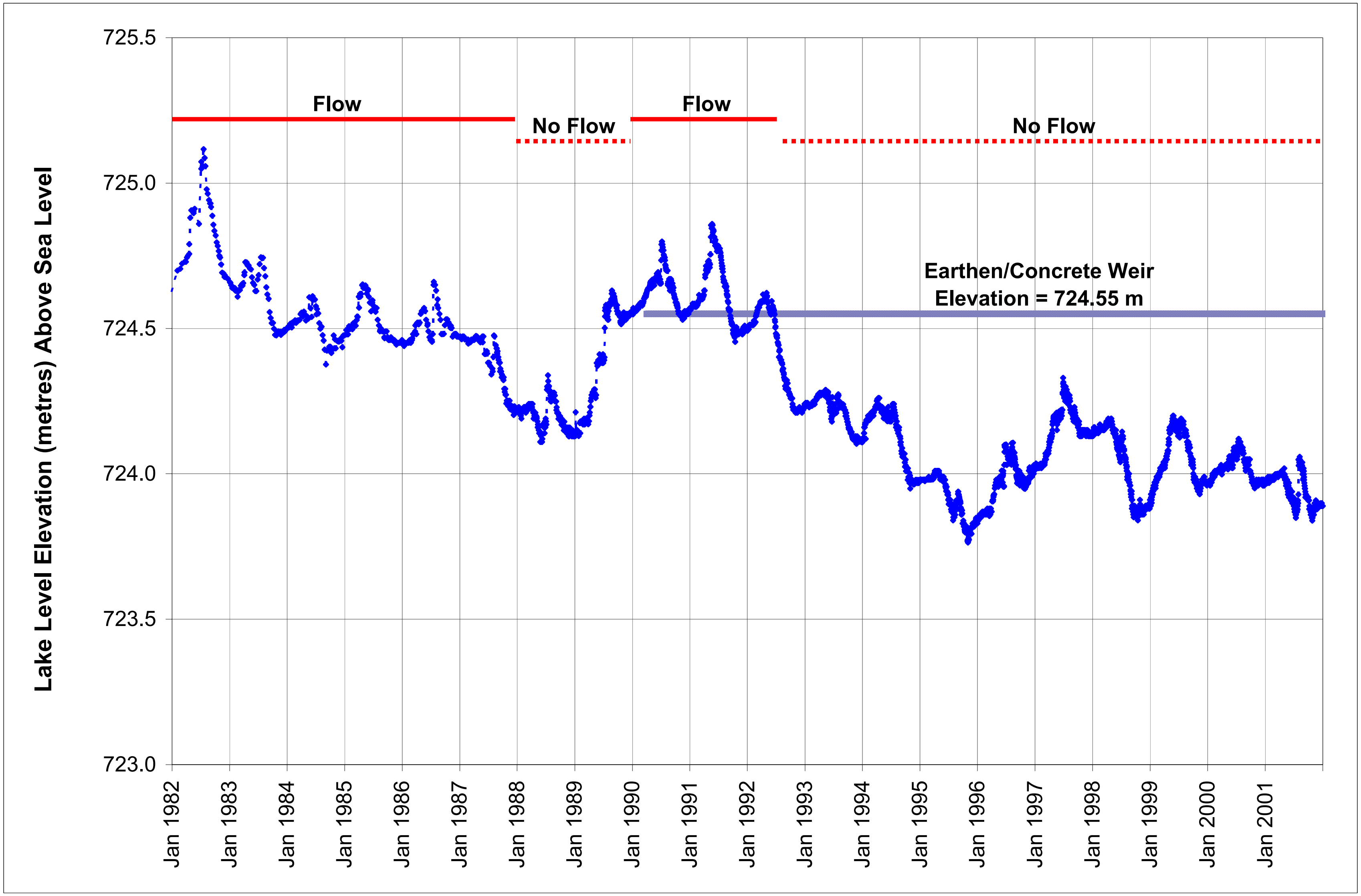


Figure 17 Lake level and approximate timing of surface outflow from Wabamun Lake (via Wabamun Creek), 1982 to 2001

The effect of lake level changes on major ion concentrations in Wabamun Lake was examined further using a simple formula to estimate the effect of lake level (or volume) changes on the concentrations of major ions and related variables in the lake (Section 2.3). Some caution, however, is necessary when interpreting the results of this analysis (Figure 18), because basic assumptions were used in the calculations. The assumptions were that there were no influences of inflows and outflows (excluding evaporation) to the lake and all major ions behaved conservatively. Reductions in the lake volume were likely to be mostly due to evaporation, which was the main outflow in the lake water balance (evaporation was about 82% of losses in the lake water balance; Section 3.3.2).

During most years from 1982 to 2001, changes in Wabamun Lake volume appeared to account for the observed concentrations of the general chemical characteristics (TDS, conductivity, and alkalinity) and four major ions (calcium, potassium, bicarbonate, and sulphate) in the lake (Figure 18; Appendix F). This pattern was characterised by the observed : predicted concentrations of these variables in the lake, which were less than $\pm$10% of 100% in most years (Figure 18). An observed : predicted concentration ratio of 1 : 1 was equal to 100%.

Changes of lake volume were less reliable in accounting for the observed concentrations of the other major ions (magnesium, sodium, carbonate, chloride, and fluoride) over the 20 years; i.e., when the observed : predicted concentrations were greater than $\pm$10% of 100% (Figure 18). Three conservative ions (sodium, chloride, and fluoride) showed a pattern of increasingly higher observed : predicted concentrations in the lake during the 1990s. This pattern supported the hypothesis of reduced flushing of major ions in the lake during the 10-year period up to 2001 (compared to the 1980s). Other factors notably evaporation and possibly groundwater inflow (another potential source of major ion loads) also may have contributed to this pattern.

From 1999 to 2001 (compared to earlier years), consistent patterns in the observed : predicted concentrations of some water quality variables in the lake were found. Large differences in the observed : predicted concentrations of sulphate occurred from 1999 to 2001 (range = 135 to 152%; Appendix F) (Figure 18). Higher observed : predicted concentrations of sodium and TDS in the lake were also found in the three-year period (range = 128 to 132% and 111 to 114%, respectively; Appendix F), although these differences were smaller than those for sulphate (Figure 18). Finally, calcium and carbonate, showed lower observed : predicted concentrations in the lake from 1999 to 2001 (range = 77 to 91% and 28 to 77%, respectively; Appendix F) (Figure 18). Overall, these results appear to support the potential influences of specific major ions in the WL-WTP inflow on lake water quality (Sections 3.1.3 and 3.4).

3.3.2 Lake Water Balance

A detailed analysis of the effects of chemical loads in individual components of the Wabamun Lake water balance on the lake water quality from 1982 to 2001 is not possible. This is because appropriate data, such as the annual chemical loads for all major inflows and outflows within the lake watershed, are not available for all years of the study. However, an overview of the major components of the Wabamun Lake water balance (Alberta Environment 2002b), as they relate to the changes in the lake water quality over the 20 years, is provided below.

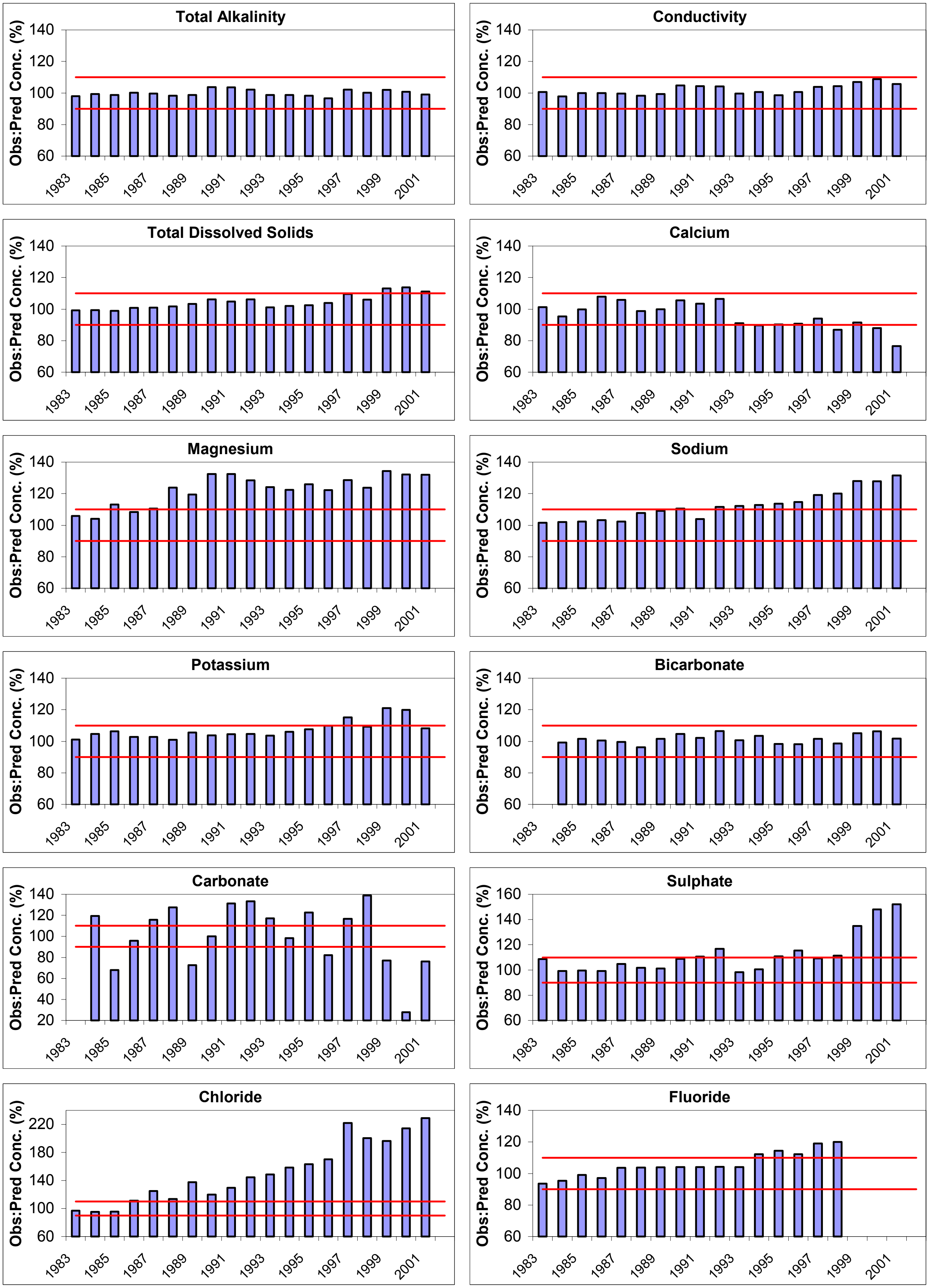


Figure 18 Ratio of observed:predicted concentrations (percent difference) of major ions and related variables in Wabamun Lake, 1983 to 2001

Cumulatively over the 20-year study, the lake water balance simulation (using consistent analysis methods; Alberta Environment 2002b) showed that direct precipitation onto the lake and net surface runoff (to the lake) made up about 92% (or 67 and 25%, respectively) of the total annual inflows to the lake (Table 7). Total evaporation made up 82% of the total annual outflows from the lake over the same period; enhanced evaporation, due to thermal discharge of cooling water to the lake, was estimated to be 6% of that amount (Table 7). Lake outflow, that ceased in 1992, accounted for a relatively small proportion, 5%, of the total annual losses from the lake over the 20 years (Table 7). Groundwater exchange was estimated to be equal to 4% of total inflow and 10% of total outflow in the lake water balance; thus there was a net loss of groundwater volume in the lake water balance (Table 7).

Comparing the total annual inflows and outflows in the lake water balance, there was a net loss of water from the lake in most years (13 of the 20 years; Table 7). During the two decades, the total of annual net losses from the lake was 141.970 x 10^6 m^3, compared to the total net gain of 86.631 x 10^6 m^3 (Table 7). These lower inflows to the lake reflect the combination of effects due to the small basin area : lake area of Wabamun Lake and climatic factors (e.g., reduced precipitation and runoff) over the 20 years.

Evaporation played an important role (82% loss) in total losses of the lake water balance over the 20 years, which in turn would have contributed to the increases of major ion concentrations observed in the lake. The evaporation effect, causing increases of major ion concentrations in the lake, may have been enhanced after mid-1992 (to 2001), when the lake level dropped below the lake outlet elevation. This is supported by the annual estimates of total evaporation losses from the lake, which made up higher proportions of annual losses from 1993 to 2001 (mean = 86%), compared to the earlier years (mean from 1982 to 1992 = 80%) (Table 7).

From the analysis of the lake level and water balance, above, it is evident that no or reduced hydraulic flushing and evaporation played important roles in increasing most major ions and TDS concentrations in Wabamun Lake. But groundwater may also have influenced individual major ions and overall TDS in the lake. For example, previous studies have indicated that groundwater could play an important role in maintaining TDS concentrations in Wabamun Lake (Fritz and Krouse 1973; Schwartz and Gallup 1978; Crowe and Schwartz 1982), however, clear cause and effect relationships in these studies were inconclusive. Based on the simple analysis of the Wabamun Lake water quality data relative to water level changes from 1982 to 2001, the much higher observed : predicted concentrations of some conservative ions (sodium, chloride, and fluoride) in the lake after 1992 may indicate an influence of groundwater on the overall lake water quality. These major ions can be high in groundwater, including samples in the Wabamun Lake watershed (e.g., Schwartz and Gallup 1978; Crowe and Schwartz 1982). However, the dynamics of groundwater exchange (quantity and quality) in the lake are poorly understood. Thus the absolute effects of groundwater flux on the lake water quality can not be fully assessed at this time.

Table 7 Results of the Wabamun Lake water balance simulation (Alberta Environment 2002b)

Year	Inflows										Total Inflows
	Direct Precipitation (On Lake)		Net Surface Runoff (To Lake)		Groundwater Inflow (To Lake)		Other Inflows		WL-WTP		
	dam^3	Relative Proportion of Total Inflow (%)	dam^3	Relative Proportion of Total Inflow (%)	dam^3	Relative Proportion of Total Inflow (%)	dam^3	Relative Proportion of Total Inflow (%)	dam^3	Relative Proportion of Total Inflow (%)	
1982	51,716	58	34,575	39	3,300	4	114	0.1	0		**89,705**
1983	42,748	69	15,049	24	3,300	5	435	0.7	0		**61,532**
1984	46,976	75	12,962	21	2,652	4	0	0	0		**62,591**
1985	47,108	67	20,588	29	2,652	4	0	0	0		**70,347**
1986	53,863	65	26,866	32	1,920	2	90	0.1	0		**82,739**
1987	41,408	71	15,011	26	1,420	2	181	0.3	0		**58,020**
1988	42,155	74	12,192	21	2,412	4	452	0.8	0		**57,210**
1989	56,944	61	33,395	36	1,740	2	542	0.6	0		**92,622**
1990	46,661	65	22,575	31	1,950	3	627	0.9	0		**71,813**
1991	49,859	71	16,844	24	2,546	4	1,193	1.7	0		**70,441**
1992	30,793	77	5,924	15	2,432	6	995	2.5	0		**40,145**
1993	35,415	82	4,884	11	2,300	5	729	1.7	0		**43,328**
1994	44,165	69	16,043	25	3,023	5	509	0.8	0		**63,740**
1995	34,054	80	5,771	14	2,878	7	0	0	0		**42,703**
1996	48,989	65	23,654	31	2,965	4	0	0	0		**75,608**
1997	48,444	62	27,323	35	2,768	4	0	0	38	0.05	**78,573**
1998	34,698	78	4,729	11	2,881	6	0	0	2,259	5	**44,566**
1999	42,279	56	18,142	24	2,881	4	0	0	12,873	17	**76,175**
2000	43,496	70	5,696	9	2,793	4	0	0	10,156	16	**62,141**
2001	37,157	60	8,361	14	2,883	5	0	0	13,078	21	**61,479**
1982-1992	46,385	68	19,635	27	2,393	4	421	0.7	0		**68,833**
1993-2001	40,966	69	12,734	19	2,819	5	137	0.3	4,267	12	**60,924**
Total	**878,927**	**67**	**330,584**	**25**	**51,696**	**4**	**5,866**	**0.4**	**38,404**	**3**	**1,305,478**

Note: 1 dam^3 = 1000 m^3

Table 7 Results of the Wabamun Lake water balance simulation (Alberta Environment 2002b) (continued)

	Losses										
Year	Natural Evapor-ation	Enhanced Evapor-ation	Total Evapor-ation	Groundwater Outflow		Licenses		Channel Outflow		Total Losses	Net Change: [Total Inflows] - [Total Losses]
	dam^3	dam^3	Relative Proportion of Total Inflow (%)	dam^3	Relative Proportion of Total Inflow (%)	dam^3	Relative Proportion of Total Inflow (%)	dam^3	Relative Proportion of Total Inflow (%)	dam^3	dam^3
1982	-53,186	-2,786	64	-7,000	8	-1,409	2	-23,732	27	**-88,112**	**1,592**
1983	-49,591	-2,541	74	-7,000	10	-1,485	2	-9,403	13	**-70,021**	**-8,488**
1984	-51,962	-2,471	84	-7,000	11	-1,655	3	-1,406	2	**-64,494**	**-1,903**
1985	-55,451	-2,934	84	-7,000	10	-1,537	2	-2,422	3	**-69,345**	**1,002**
1986	-51,148	-2,956	76	-7,000	10	-1,394	2	-8,643	12	**-71,141**	**11,598**
1987	-54,835	-2,768	81	-7,000	10	-1,338	2	-4,986	7	**-70,926**	**-12,906**
1988	-55,922	-3,970	88	-7,000	10	-1,464	2	0	0	**-68,357**	**-11,147**
1989	-52,633	-3,842	87	-7,000	11	-1,523	2	0	0	**-64,998**	**27,623**
1990	-55,354	-3,709	79	-7,000	9	-1,856	2	-6,670	9	**-74,588**	**-2,775**
1991	-55,162	-3,988	74	-7,000	9	-1,930	2	-11,618	15	**-79,698**	**-9,256**
1992	-52,007	-3,234	85	-7,000	11	-1,882	3	-677	1	**-64,799**	**-24,654**
1993	-50,109	-3,976	86	-7,000	11	-1,822	3	0	0	**-62,907**	**-19,579**
1994	-52,020	-3,615	86	-7,000	11	-1,805	3	0	0	**-64,440**	**-700**
1995	-51,518	-4,431	86	-7,000	11	-2,005	3	0	0	**-64,954**	**-22,251**
1996	-46,372	-3,543	85	-7,000	12	-1,992	3	0	0	**-58,907**	**16,701**
1997	-49,522	-3,704	86	-7,000	11	-1,997	3	0	0	**-62,223**	**16,350**
1998	-52,884	-3,533	86	-7,000	11	-1,998	3	0	0	**-65,415**	**-20,848**
1999	-52,473	-3,043	86	-7,000	11	-1,893	3	0	0	**-64,410**	**11,765**
2000	-52,278	-2,828	86	-7,000	11	-1,780	3	0	0	**-63,886**	**-1,745**
2001	-55,158	-3,028	87	-7,000	10	-2,009	3	0	0	**-67,195**	**-5,716**
1982-1992	-53,386	-3,200	79	-7,000	10	-1,589	2	-6,323	8	**-71,498**	**-29,314**
1993-2001	-51,371	-3,522	86	-7,000	11	-1,922	3	0	0	**-63,815**	**-26,024**
Total	**-1,049,585**	**-66,899**	**82**	**-140,000**	**10**	**-34,774**	**3**	**-69,557**	**5**	**-1,360,816**	**-55338**

Note: 1 dam^3 = 1000 m^3

3.4 Wabamun Lake Water Treatment Plant and Effects on Lake Water Quality

Changes in water quality of Wabamun Lake from 1999 to 2001 (notably higher sulphate and TDS concentrations, and lower concentrations of phosphorus, chlorophyll-*a*, calcium, and carbonate in the lake) indicated that the WL-WTP inflow may be influencing the lake water quality. These changes are supported by the importance of the annual WL-WTP inflow volumes, which made up 16 to 21% of total inflows to the lake water balance, in each of the three years (Table 7).

The following Sections include an overview of the treatment chemicals and some processes used in the WL-WTP, quantity and quality of the treated water pumped to the lake, and discussion of some observed and potential effects of the treated water on the lake water quality.

3.4.1 Treatment Chemicals and Processes used in WL-WTP

Various chemicals are used in the WL-WTP. Some of these chemicals or breakdown products may be found in the final treated water pumped to the lake. The chemical type and mass used to produce the projected maximum volume of treated water per year from the expanded WL-WTP (total capacity = 23 x 10^6 m^3 of treated water; Section 1.0) are (TAU 2001a):

- Alum ($Al_2(SO_4)_3.14H_2O$) – 3,587,253 kg/yr
- Sulphuric acid (H_2SO_4) – 182,146 kg/yr
- Sodium hypochlorite (NaOCl) – 1,048,137 kg/yr
- Sodium thiosulphate ($Na_2S_2O_3$) – 603,727 kg/yr
- Polymers (Percol LT 22 S® and Liquipam C 452 PG®) – 12,578 kg/yr

The treatment polymers proposed for use in the WL-WTP were replaced by another commercial polymer, Magnafloc LT-22S® (Rick Phaneuf, Alberta Environment, personal communication). Magnafloc LT-22S® is a high molecular weight polyacrylamide that is used as a flocculating agent in drinking water treatment plants (Material Safety Data Sheet supplied by Ciba Specialty Chemical Canada Ltd.). Ozonation and chlorination disinfection treatments are used in the WL-WTP to control algae and zooplankton in the two plants and final treated water. Chlorination was added to the original WTP processes in 1998 (TAU 1998).

3.4.2 Volume of WL-WTP Treated Water Pumped to Wabamun Lake

The WL-WTP treated water was pumped monthly to Wabamun Lake throughout the year (with few exceptions), although smaller volumes were usually pumped in winter (Figure 19). On an annual basis, the total volume of treated water was considerably greater in 1999, 2000, and 2001 (12.9, 10.2 and 13.1 x 10^6 m^3, respectively), compared to the first years of operation, 1997 and 1998 (total volume = 2.3 x 10^6 m^3) (Figure 19) (TAU 2001a).

3.4.3 Water Quality Characteristics of the WL-WTP Treated Water, 1999 to 2001

The following description of the WL-WTP treated water quality is based on samples collected by Alberta Environment from 1999 to 2001. Comparisons of these data to samples taken by TAU

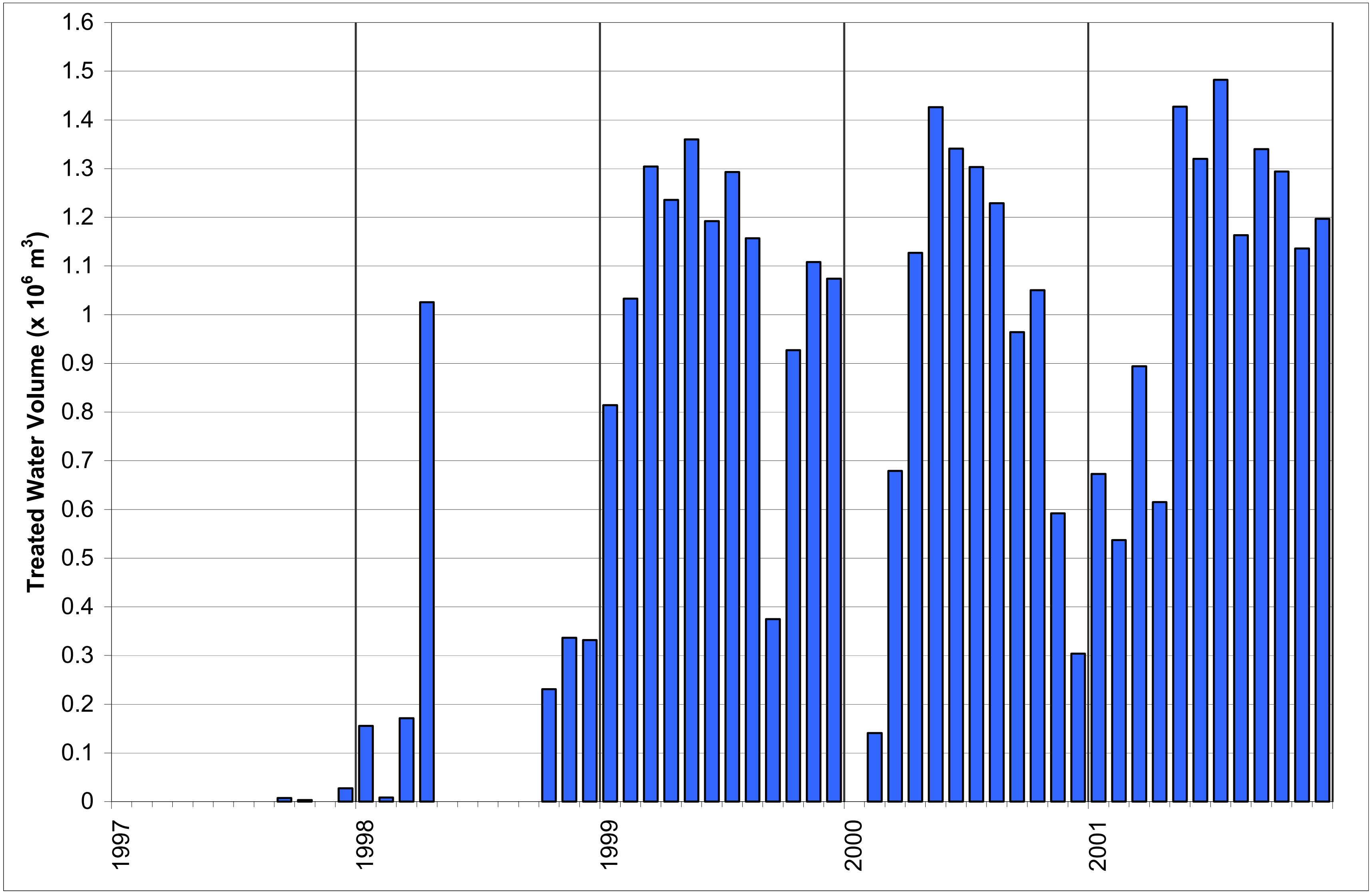


Figure 19 Monthly volumes of Wabamun Lake Water Treatment Plant treated water pumped to Wabamun Lake, 1997 to 2001

during the same period (Section 2.1) showed similar levels of the general chemical characteristics, major ions, and nutrients in the treated water. The metal data, however, were not directly comparable, because the analytical detection limits of several metals in the TAU data were higher than those used by Alberta Environment. Lower detection limits allow a more precise assessment of actual metal concentrations in the treated water.

Overall, the general chemical characteristics of the treated water remained relatively stable or improved from 1999 to 2001. Median concentrations of major ions and related variables in the treated water showed overall decreases (total alkalinity, conductivity, TDS, sodium, potassium, sulphate, bicarbonate, silica, and DOC), similar levels among years (pH, hardness, calcium, and magnesium), or concentrations which were generally less than analytical detection limits (carbonate, manganese, iron, hydroxide) from 1999 to 2001 (Table 8). Chloride was the only major ion that showed an increase of concentrations in the treated water over the 3 years (range of medians = 7.4 to 8.4 mg/L; Table 8).

Nutrients (phosphorus and nitrogen) were at low concentrations in the treated water and they showed no marked difference in median concentrations from 1999 to 2001 (although nitrate was at highest concentrations in 1999) (Table 8). Chlorophyll-*a* and non-filterable residue (NFR) concentrations were below the analytical detection limits, with the exception of NFR (3 mg/L) in the sample taken on 31 July 2000 (Table 8). This sample may reflect atypical conditions for the quality of the treated water, because the WL-WTP stopped pumping treated water to the lake one half-hour before the sample was taken (Alberta Environment, unpublished field notes).

Generally, most metals showed no major change of median concentrations in the treated water from 1999 to 2001 (Table 8). Exceptions were for the median concentrations of thallium which increased and copper which decreased by one order of magnitude each; and median lead concentrations which declined by two orders of magnitude over the three-year period (Table 8). Total mercury concentrations in the treated water ranged from <1.2 to 3.4 ng/L, with the exception of the atypical sample of 31 July 2000, when total mercury was 17 ng/L (Table 8). Total mercury concentrations in the treated water were generally similar to those in the lake (Tables 5 and 8). Similar to the mercury samples taken in the lake, there was no statistical difference between total mercury concentrations in the treated water and blank samples taken on the same dates (t-test critical value = 2.16, $P = 0.378$, $df = 13$).

The observed temporal changes in the quality of the WL-WTP treated water may be due to several factors. These include the quality of the raw water (Sundance cooling pond), types and quantities of treatment chemicals used in the WL-WTP, and efficacy of the plant at the time of sampling. Quality of the raw water, for example, may be affected by the proportions (quantity and quality) of North Saskatchewan River water pumped to the Sundance cooling pond and runoff or wastewaters (from the mine and power plant) entering the pond, and seasonal conditions in the pond (e.g., temperature and the physical and biochemical processing of chemicals).

Table 8 Quality of treated water from the Wabamun Lake Treatment Plant, 1999 to 2001

Variable:	pH	Total Alkalinity	Phenol-phthalein Alkalinity	Specific Conductance	Total Dissolved Solids	Total Hardness	Calcium, diss. filtered	Magnesium, diss. filtered	Sodium, diss. filtered	Potassium, diss. filtered
Units:	pH Units	CaCO3, mg/L	mg/L	uS/cm	mg/L	CaCO3, mg/L	mg/L	mg/L	mg/L	mg/L
17-Mar-99	8.13	165	0.5	739	473	235	56.4	23.0	68.0	3.9
20-May-99	8.21	142	0.05	730	447	220	49.7	22.1	66.9	3.8
26-Jul-99	8.06	159	0.05	705	420	220	50.6	22.5	68.9	4.2
3-Nov-99	8.01	153	0.05	648	412	210	48.5	22.4	65.5	4.9
27-Jun-00	6.93	120	0.05	662	405	210	44.7	24.3	55.4	3.6
31-Jul-00	7.91	128	0.05	647	368	200	44.7	20.6	51.3	3.3
22-Aug-00	7.96	124	0.05	632	398	210	49.3	22	51.8	3.4
13-Jun-01	7.88	156	0.05	611	388	250	60.3	24.1	48.3	2.9
18-Jul-01	8.17	145	0.05	640	383	210	50.4	21.4	43.6	2.7
21-Aug-01	8.31	132	0.4	592	376	210	48.6	21.6	53.5	2.5
Median 1999:	8.10	156	0.05	718	434	220	50.2	22.5	67.5	4.1
Median 2000:	7.91	124	0.05	647	398	210	44.7	22.0	51.8	3.4
Median 2001:	8.17	145	0.05	611	383	210	50.4	21.6	48.3	2.7
Median 1999-01:	8.04	144	0.05	648	402	210	49.5	22.3	54.5	3.5

Variable:	Manganese, diss.	Iron, diss.	Sulphate, diss.	Bicarbonate, calc.	Carbonate, calc.	Chloride, diss.	Silica, Reactive	Hydroxide, calc.	Ionic Balance, calc.
Units:	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	meq/L
17-Mar-99			216			6.9	6		
20-May-99	0.001	0.005	206	173	0.25	8	5	0.25	0.98
26-Jul-99	0.0005	0.005	164	194	0.25	7.8	5.9	0.25	1.07
3-Nov-99	0.0005	0.005	165	187	0.25	6.3	6.78	0.25	1.05
27-Jun-00	0.002	0.005	191	146	0.25	7.7	5.6	0.25	1
31-Jul-00	0.002	0.005	156	156	0.25	9	5.5	0.25	1.01
22-Aug-00	0.002	0.005	186	152	0.25	5.4	6	0.25	0.99
13-Jun-01	0.002	0.005	149	190	0.25	8.4	1.76	0.25	1.11
18-Jul-01	0.002	0.005	169	177	0.25	7.4	1.91	0.25	0.94
21-Aug-01	0.002	0.005	158	160	0.25	9.9	2.73	0.25	1.05
Median 1999:	0.001	0.005	186	187	0.25	7.4	6.0	0.25	1.05
Median 2000:	0.002	0.005	186	152	0.25	7.7	5.6	0.25	1.00
Median 2001:	0.002	0.005	158	177	0.25	8.4	1.9	0.25	1.05
Median 1999-01:	0.002	0.005	167	173	0.25	7.8	5.6	0.25	1.01

Table 8 Quality of treated water from the Wabamun Lake Treatment Plant, 1999 to 2001 (continued)

Variable:	Total Phosphorus	Total Dissolved Phosphorus	Total Kjeldahl Nitrogen	Total Ammonia	Nitrate-Nitrogen	Nitrite-Nitrogen	[Nitrite+ Nitrate]-Nitrogen	Chlorophyll *a*	Dissolved Organic Carbon	Nonfilterable Residue
Units:	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	µg/L	mg/L	mg/L
17-Mar-99	0.002	0.001		0.019						0.5
20-May-99	0.0026	0.0019	0.23	0.02	0.003	0.0015	0.003	0.05	4.8	0.2
26-Jul-99	0.0029	0.0028	0.38	0.02	0.016	0.0015	0.016	0.05	4.1	0.2
3-Nov-99	0.004	0.0029	0.3	0.01	0.021	0.0015	0.021	0.05	4.4	0.5
27-Jun-00	0.002	0.002	0.29	0.02	0.0015	0.0015	0.0015	0.05	3.3	0.5
31-Jul-00	0.0018	0.0014	0.64	0.04	0.011	0.0015	0.011	0.05	4.1	3
22-Aug-00	0.0041	0.0018	0.025	0.005	0.0015	0.0015	0.0015	0.05	3.7	0.5
13-Jun-01	0.003	0.0027	0.14	0.04	0.006	0.0015	0.006	0.05	3.4	0.5
18-Jul-01	0.0046	0.0044	0.31	0.005	0.0015	0.0015	0.0015	0.05	2.4	0.5
21-Aug-01	0.0024	0.002	0.26	0.01			0.013	0.05	3	0.5
Median 1999:	0.0028	0.0024	0.30	0.02	0.016	0.0015	0.016	0.05	4.4	0.4
Median 2000:	0.0020	0.0018	0.29	0.02	0.002	0.0015	0.002	0.05	3.7	0.5
Median 2001:	0.0030	0.0027	0.26	0.01	0.004	0.0015	0.006	0.05	3.0	0.5
Median 1999-01:	0.0028	0.0020	0.29	0.02	0.005	0.0015	0.006	0.05	3.7	0.5

Variable:	Aluminum, tot.	Antimony, tot.	Arsenic, tot.	Barium, tot.	Beryllium, tot.	Bismuth, tot.	Boron, tot.	Cadmium, tot.	Chromium, tot.	Cobalt, tot.
Units:	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
17-Mar-99	65.6	0.48	0.65	189	0.02	0.0025	449	**13.6**	0.43	0.11
20-May-99	64.5	0.47	0.49	178	0.02	0.0025	409	0.01	0.2	0.134
26-Jul-99	64.9	0.36	0.4	164	0.02	0.0025	377	0.03	0.04	0.13
3-Nov-99	48.4	0.31	0.45	153	0.02	0.0025	362	0.04	0.04	0.302
27-Jun-00	37.5	0.37	0.56	157	0.02	0.0025	302	0.01	0.18	0.24
31-Jul-00	53.9	0.35	0.63	158	0.02	0.0025	276	0.01	0.04	0.2
22-Aug-00	38	0.37	0.81	156	0.02	0.0025	308	0.02	0.15	0.26
13-Jun-01	92	0.39	0.55	173	0.02	0.006	277	0.04	0.33	0.29
18-Jul-01	67.4	0.39	0.44	170	0.02	0.0025	256	0.01	0.16	0.24
21-Aug-01	**103**	0.41	0.6	172	0.06	0.0025	264	0.01	0.3	0.47
Median 1999:	64.7	0.42	0.47	171	0.02	0.0025	393	0.035	0.12	0.13
Median 2000:	38.0	0.37	0.63	157	0.02	0.0025	302	0.010	0.15	0.24
Median 2001:	92.0	0.39	0.55	172	0.02	0.0025	264	0.010	0.30	0.29
Median 1999-01:	64.7	0.38	0.56	167	0.02	0.0025	305	0.015	0.17	0.24
CCME:	100		5					0.04	1	
USEPA:	87		150					2.6	11.2	

Table 8 Quality of treated water from the Wabamun Lake Treatment Plant, 1999 to 2001 (continued)

Variable:	Copper, tot.	Iron, tot.	Lead, tot.	Lithium, tot.	Manganese, tot.	Mercury, tot.	Molybdenum, tot.	Nickel, tot.	Selenium, tot.	Silver, tot.
Units:	µg/L	µg/L	µg/L	µg/L	µg/L	ng/L	µg/L	µg/L	µg/L	µg/L
17-Mar-99	1.11	15	0.032	19.9	2.32	1.2	18.8	0.7	0.8	0.008
20-May-99	1.29	1.5	0.045	18.2	0.55	3.4	18.3	0.4	**1.1**	0.007
26-Jul-99	1.49	1.5	0.58	16.7	3.02	3.2	15.6	0.59	0.5	0.0025
3-Nov-99	1.35	63	0.205	17.6	0.75	2.0	14.4	2.1	0.25	0.012
27-Jun-00	0.57	19	0.043	13.8	0.47	0.6	13.3	1.3	0.5	0.0025
31-Jul-00	0.71	1.5	0.027	20	0.44	17.0	13	1.33	0.25	0.0025
22-Aug-00	0.83	1.5	0.17	14	0.87	0.6	12.6	1.23	0.25	0.0025
13-Jun-01	0.2	33	0.005	12.5	0.78	0.6	13.6	2.1	0.25	0.0025
18-Jul-01	0.04	4	0.005	10.8	2.06	2.3	11.6	0.69	0.8	0.0025
21-Aug-01	2.48	5	0.07	12.2	1.53	1.2	12.3	0.03	**1.2**	0.011
Median 1999:	1.32	8.3	0.125	17.9	1.54	2.6	17.0	0.65	0.65	0.0075
Median 2000:	0.71	1.5	0.043	14.0	0.47	0.6	13.0	1.30	0.25	0.0025
Median 2001:	0.20	5.0	0.005	12.2	1.53	1.2	12.3	0.69	0.80	0.0025
Median 1999-01:	0.97	4.5	0.044	15.4	0.83	1.6	13.5	0.97	0.50	0.0025
CCME:	3	300	4			100	73	110	1	0.1
USEPA:	11	1000	3.2			906		63	5	5.1

Variable:	Tin, tot.	Strontium, tot.	Thorium, tot.	Titanium, tot.	Thalllium, tot.	Uranium, tot.	Vanadium, tot.	Zinc, tot.
Units:	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
17-Mar-99	0.05	793	0.0015	1.8	0.0041	1.55	1.68	1.33
20-May-99	0.05	818	0.009	1	0.009	0.54	1.44	1.71
26-Jul-99	0.05	727	0.0015	3.2	0.0015	0.519	0.43	2.7
3-Nov-99	0.05	717	0.0015	1	0.083	0.67	1.16	1.41
27-Jun-00	0.05	719	0.004	0.5	0.018	0.18	0.89	1.6
31-Jul-00	0.05	687	0.006	0.42	0.0015	0.222	0.93	1.14
22-Aug-00	0.05	697	0.007	0.6	0.003	0.138	1.09	1.68
13-Jun-01	0.05	827	0.005	1.2	0.028	0.52	1.2	2
18-Jul-01	0.05	779	0.0015	0.4	0.018	0.24	0.96	3.25
21-Aug-01	0.05	700	0.024	0.5	0.035	0.279	1.24	3.51
Median 1999:	0.05	760	0.002	1.4	0.007	0.605	1.30	1.56
Median 2000:	0.05	697	0.006	0.5	0.003	0.180	0.93	1.60
Median 2001:	0.05	779	0.005	0.5	0.028	0.279	1.20	3.25
Median 1999-01:	0.05	723	0.005	0.8	0.014	0.399	1.13	1.70
CCME:					0.8			30
USEPA:								140

Notes:
Shaded cells are half the analytical detection limit
Bold value = concentration greater than water quality guidelines for protection of freshwater life
Alberta Surface Water Quality Guidelines, chronic guidelines (draft): total mercury = 5 ng/L, total copper = 7 µg/L
Interim CCME Water Quality Guidelines are outlined

3.4.4 Potential Effects of Treated Water on Wabamun Lake Water Quality

Comparison of water quality data for the WL-WTP treated water and Wabamun Lake during the 1999 to 2001 period provide a basic evaluation of potential effects of the treated water on the lake water quality. A more complete assessment, could include comparisons of the chemical loads in all major inflows and outflows within the lake watershed. However, recent data for these water balance components were not available for this study.

General Characteristics and Major Ions

Comparing the quality of the WL-WTP treated water and Wabamun Lake (from 1999 to 2001), median concentrations of four major ions and related variables (calcium, magnesium, sulphate, chloride, conductivity, TDS, and hardness) were higher in the treated water compared to those in the lake (Table 9). Median concentrations of the other major ions and alkalinity were lower in the treated water than in the lake (Table 9). These results indicate that some major ions, especially conservative ions, and related variables may increase or decrease in the lake in response to their respective loads pumped to the lake. Based on the major ion data, sulphate and calcium had the highest median concentrations in the treated water compared to those in the lake (about 4- and 2-fold higher in the treated water, respectively)(Table 9). Estimates of the annual loads of major ions in the treated water also showed sulphate and calcium made up the largest loads in the treated water, compared to their respective masses already present in the lake (Table 10). In contrast, potassium (a conservative ion) was the only major ion to show much lower median concentration in the treated water (2.7-fold lower) compared to the lake (Table 9). Potassium also had the smallest annual load of all major ions in the treated water, compared to the mass of potassium in the lake (Table 10). The potassium concentrations observed in Wabamun Lake (i.e., a recent decline of potassium, noted in Section 3.1.3) appeared to indicate the potential of future reductions of potassium concentrations in the lake, possibly due to dilution by the treated water.

With respect to sulphate, it is evident that the concentrations increased in Wabamun Lake during the 1999 to 2001 period compared to earlier years. These step increases were likely related to the influence of sulphate loads from the WL-WTP treated water. The effects of increasing sulphate levels in the lake, however, are somewhat uncertain, based on the scientific literature and water quality changes observed in the lake. In general, the sulphur cycle in lakes is complex and there is a limited understanding of interactions between the sulphur cycle and eutrophication in lakes (e.g., Wetzel 1983; Holmer and Storkholm 2001). Several studies have shown that increased sulphate input to lakes can affect iron and phosphorus cycles, especially under anoxic conditions, which potentially can cause phosphorus release from bottom sediments and subsequent increases of lake productivity (e.g., Schindler 1985; Caraco *et al.* 1993). In one Alberta study, Mitchell (1987) found some evidence that such mechanisms may be occurring in Lac St. Cyr. The addition of untreated North Saskatchewan River water (pumped to the lake in order to restore the lake level) caused increases of sulphate concentrations in the lake that corresponded to the years of much higher concentrations of phosphorus in the anoxic waters of a deep basin in the lake (Mitchell 1987).

Table 9 General characteristics, major ions, and nutrients in the Wabamun Lake Water Treatment Plant (WL-WTP) treated water and Wabamun Lake, 1999 to 2001

Water Quality Variable	Water Treatment Plant March-November				Wabamun Lake May-November			
	Median	Maximum	Minimum	No. of Samples	Median	Maximum	Minimum	No. of Samples
General Characteristics								
pH (units)	8.0	8.3	6.9	10	8.4	8.8	8.1	36
Total Alkalinity	143.5	165	120	10	214	235	209	36
Conductivity (uS/cm)	**648**	**739**	**592**	10	492	532	467	36
Total Dissolved Solids	**402**	**473**	**368**	10	292	304	276	34
Hardness	**210**	**250**	**200**	10	120	140	100	36
Major Ions								
Calcium	**49.5**	**60.3**	**44.7**	10	23.0	27.1	16.8	36
Magnesium	**22.3**	**24.3**	**20.6**	10	16.7	17.6	15.0	36
Sodium	54.5	68.9	43.6	10	62.8	71.9	55.0	36
Potassium	3.5	4.9	2.5	10	9.5	12.0	6.9	36
Bicarbonate	175.0	201.0	146.0	10	250.0	279.0	223.0	36
Sulphate	**167.0**	**216.0**	**149.0**	10	41.8	45.9	36.8	36
Chloride	**7.75**	**9.90**	5.40	10	7.35	9.60	6.40	36
Nutrients & Related Variables								
Total Phosphorus	0.0028	0.0046	0.0018	10	0.0288	0.0369	0.0226	36
Dissolved Phosphorus	0.0020	0.0044	0.0010	10	0.0088	0.0133	0.0079	36
Total Kjeldahl Nitrogen	0.275	0.640	0.025	10	0.835	1.320	0.390	36
Total Ammonia	**0.020**	0.040	0.005	10	0.005	0.060	0.005	36
[Nitrite+Nitrate]-Nitrogen	**0.0085**	**0.1210**	0.0015	10	0.0015	0.0650	0.0015	36
Dissolved Organic Carbon	3.6	4.8	2.4	10	12.4	15.8	11.0	36

Notes:
Units are mg/L unless noted as otherwise
Shaded cells are half the analytical detection limit
Wabamun Lake data includes samples from the East, West and Main basins
WL-WTP concentrations which exceed those in Wabamun Lake are shown as bold font

Table 10 Annual loads of major ions and related variables in the Wabamun Lake Water Treatment Plant (WL-WTP) treated water and Wabamun Lake

Variable	WL-WTP Treated Water		Wabamun Lake (2000)		WL-WTP
	Median Concentration in 2000 mg/L	Annual Load kg	Median Concentration mg/L	Mass kg	Annual Load/ Mass in Lake Percent
Total Alkalinity	124	1,352,592	214	98,418,600	1.4
TDS	398	4,341,384	294	134,980,650	3.2
Calcium	44.7	487,588	23	10,554,705	4.6
Magnesium	22	239,976	16.5	7,588,350	3.2
Sodium	51.8	565,034	62.5	28,720,755	2.0
Potassium	3.4	37,087	9.8	4,507,020	0.8
Bicarbonate	152	1,658,016	254	116,814,600	1.4
Sulphate	186	2,028,888	42	19,315,800	10.5
Chloride	7.7	83,992	7.3	3,357,270	2.5

Notes:
WL-WTP loads are based on a volume of 10.908 x 10^6 m^3 treated water pumped to the lake from July 2000 to June 2001
Chemical masses in Wabamun lake are based on a lake volume of 459.9 x 10^6 m^3 in 2000

In Wabamun Lake, there was no evidence that phosphorus was increasing in response to higher levels of sulphate in the lake. In fact the opposite pattern occurred, where phosphorus concentrations decreased concurrently with sulphate increases during the 1999 to 2001 period. These different findings in the two lakes may be related to weak or no stratification which normally occurred in Wabamun Lake, resulting in well oxygenated conditions in the water column, compared Lac St. Cyr (Mitchell 1987; Mitchell and Prepas 1990; Alberta Environment unpublished data). Thermal stratification in Lac St. Cyr may have lead to suitable anoxic conditions for the release of phosphorus from bottom sediments.

Other Alberta studies have shown that relatively high sulphate or TDS concentrations may lead to reductions of phytoplankton communities in saline lakes. In one study, Bierhuizen and Prepas (1985) found reduced levels of algal biomass (chlorophyll-*a*) in some lakes with very high salinity; sulphate ($\geq$216 mg/L) and TDS (>1 g/L) concentrations in these lakes were much greater than those observed in Wabamun Lake. In another study, Evans and Prepas (1996) also found evidence of lower chlorophyll-*a* concentrations with increases of conductivity (which were directly correlated with sulphate) in saline lakes (>1 g TDS/L).

Longer-term monitoring of the water quality and aquatic biota of Wabamun Lake when the WL-WTP is operating will provide a better understanding of the potential effects of sulphate on the lake ecosystem. More detailed studies of potential processes and interactions of increased sulphate with nutrient cycles in Wabamun Lake may be necessary.

<u>Nutrients</u>

Median concentrations of phosphorus (especially TP) were lower in the WL-WTP treated water compared to those in Wabamun Lake (Table 9). Total ammonia and nitrite+nitrate-N were at higher concentrations in the treated water than in the lake (Table 9).

The unique patterns of small declines of phosphorus and chlorophyll-*a* concentrations in Wabamun Lake from 1999 to 2001 are probably related to the precipitation of calcium carbonate (calcite) on the lake bottom. Various studies have shown much evidence that phosphorus can co-precipitate with calcite in hardwater lakes of western Canada (e.g., Murphy *et al.* 1983; Prepas *et al.* 1990, 2001). In these lakes, lower phosphorus levels typically resulted in corresponding reductions of chlorophyll-*a* in the water column. In Wabamun Lake, several factors indicate that greater levels of calcite precipitation, along with co-precipitation of phosphorus, may have occurred when large volumes of WL-WTP treated water were pumped to the lake. These factors which occurred from 1999 to 2001 compared to earlier years (1982 to 1998) include: (1) the introduction of the new and relatively large calcium load in the WL-WTP treated water to the lake watershed; (2) lowest or decreasing concentrations, and lower proportions of calcium and carbonate ions (compared to other major ions) in the lake; and (3) lowest or lower concentrations, and less (statistically) variable concentrations of phosphorus and chlorophyll-*a* in the lake. Lower calcium carbonate Saturation Index (SI) values (i.e., lower levels of calcium carbonate supersaturation) in the lake from 1999 to 2001 may also indicate higher calcite precipitation on the lake bottom at this time.

In conclusion, phosphorus and subsequently chlorophyll-*a* levels in Wabamun Lake (from 1999 to 2001) appear to be controlled to some degree by the rate of calcite precipitation which occurred in the lake. The rate of calcite precipitation may have been enhanced by the new and overall increase of calcium loads in the WL-WTP inflow pumped to the lake. A more complete understanding of all potential mechanisms affecting phosphorus dynamics in the lake (e.g., sediment-water flux of phosphorus and interactions with the sulphur cycle) may be necessary in order to make accurate predictions of phosphorus and chlorophyll-*a* levels in the lake in the future. There is also some uncertainty on how the small change in algal biomass may affect higher trophic levels (e.g., zooplankton and fish populations) in the lake ecosystem. Future monitoring may be used to further evaluate the current pattern for phosphorus and chlorophyll-*a* in the lake and to determine any unforeseen changes which may occur as the annual volumes of WL-WTP treated water pumped to the lake are increased (Section 1.0).

Metals

Median concentrations of 12 of the 28 elements analysed in the samples were at greater concentrations in the WL-WTP treated water compared to those in Wabamun Lake (Table 11). Some of these metal concentrations (aluminum, cobalt, molybdenum, nickel) were an order of magnitude higher in the treated water than in the lake (Table 11). Median concentrations of individual metals in the treated water were less than water quality guidelines for the protection of freshwater aquatic life. Perspective on the potential contribution of metal loads in the WL-WTP inflow to the lake cannot be assessed at this time, because there are limited data on metal loads in other major inflows in the watershed.

Metals of particular interest at Wabamun Lake are aluminum, a component of alum used in the WL-WTP, and mercury associated with air emissions from coal-fired power plants in the Wabamun Lake area. Aluminum is common in various rock types and clays, and it is toxic to aquatic biota at high concentrations, especially under certain environmental conditions (e.g., low pH). Based on available data, total aluminum concentrations in the lake were higher in the summer compared to winter. Lower aluminum concentrations in the winter may be due to adsorption and/or settling of suspended particles onto the lake bottom, following spring and summer inflows (which may have high suspended materials) to the lake. Overall, there was no change of aluminum concentrations in the lake from 1996 to 2001 (Figure 14). Mercury is a concern because it is toxic to aquatic life and humans. It can bioaccumulate and biomagnify from very low levels in surface waters to toxic levels in sediments and aquatic biota. Based on the Wabamun Lake data, total mercury was found at very low concentrations in the lake water and there was no overall change in concentrations from 1996 to 2001 (Section 3.1.6). Future monitoring of metals in the lake ecosystem can be used to verify patterns in the data and to determine any unforeseen changes that may occur.

Disinfection By-Products

Chlorination and ozonation treatment processes, used in the original and expanded WL-WTP, can produce various halogenated and non-halogenated compounds in the final treated water pumped to Wabamun Lake. These compounds, known as disinfection by-products (DBPs), may include trihalomethanes (THMs), other halogenated volatile organic compounds, haloacetic

Table 11 Total metal concentrations in the Wabamun Lake Water Treatment Plant (WL-WTP) treated water and Wabamun Lake, 1999 to 2001

Water Quality Variable	WL-WTP Treated Water (March-November)				Wabamun Lake (February-August)			
	Median	Maximum	Minimum	No. of Samples	Median	Maximum	Minimum	No. of Samples
Silver	0.0000025	**0.000012**	0.0000025	10	0.0000025	0.000011	0.0000025	17
Aluminum	**0.0647**	**0.103**	**0.0375**	10	0.00794	0.048	0.0029	17
Arsenic	0.000555	0.00081	0.0004	10	0.00284	0.0035	0.0022	17
Barium	**0.167**	**0.189**	**0.153**	10	0.125	0.151	0.114	17
Boron	0.305	0.449	0.256	10	0.875	0.983	0.834	17
Beryllium	0.00002	0.00006	0.00002	10	0.00002	0.00013	0.00002	17
Cadmium	**0.000015**	**0.0136**	0.00001	10	0.00001	0.000027	0.00001	17
Cobalt	**0.00024**	**0.00047**	**0.00011**	10	0.00003	0.000055	0.00001	17
Chromium	0.00017	0.00043	0.00004	10	0.00024	0.0005	0.00005	17
Copper	**0.00097**	**0.00248**	0.00004	10	0.00072	0.0013	0.00004	17
Iron	0.0045	**0.063**	0.0015	10	0.005	0.029	0.0015	17
Mercury	**0.0000016**	**0.000017**	0.0000006	10	0.0000006	0.0000043	0.0000006	17
Lithium	0.01535	0.02	0.0108	10	0.0394	0.0415	0.0321	17
Manganese	0.000825	0.00302	0.00044	10	0.0374	0.543	0.00244	17
Molybdenum	**0.01345**	**0.0188**	**0.0116**	10	0.00567	0.0073	0.0047	17
Nickel	**0.000965**	**0.0021**	0.00003	10	0.00003	0.00024	0.00003	17
Lead	0.000044	0.00058	0.000005	10	0.0001	0.00105	0.000005	17
Selenium	**0.0005**	**0.0012**	**0.00025**	10	0.00025	0.0008	0.0002	17
Antimony	**0.00038**	**0.00048**	**0.00031**	10	0.000196	0.00023	0.000173	17
Strontium	**0.723**	**0.827**	**0.687**	10	0.294	0.329	0.262	17
Titanium	0.0008	**0.0032**	0.0004	10	0.0008	0.0015	0.0004	17
Thallium	**0.0000135**	**0.000083**	0.0000015	10	0.000013	0.000022	0.0000015	17
Vanadium	0.001125	0.00168	0.00043	10	0.0014	0.00174	0.00076	17
Zinc	0.001695	0.00351	**0.00114**	10	0.00244	0.00889	0.00072	17
Uranium	0.000399	**0.00155**	0.000138	10	0.00063	0.00075	0.000545	17
Bismuth	0.0000025	0.000006	0.0000025	10	0.0000025	0.000016	0.0000025	17
Tin	0.00005	0.00005	0.00005	10	0.00005	0.000165	0.00005	17
Thorium	0.0000045	0.000024	0.0000015	10	0.000007	0.000039	0.0000015	17

Notes:
Units are mg/L
Shaded cells are half the analytical detection limit
Wabamun Lake data includes samples from the East, West and Main basins
WL-WTP concentrations which exceed those in Wabamun Lake are shown as bold font

acids, haloacetonitriles, haloketones, chlorinated phenols, aldehydes, chloral hydrate, chloropicrin, total residual chlorine (TRC), bromate, chlorate, and chlorite.

Determining the levels and potential effects of some DBPs in surface waters are somewhat limited by the development or availability of analytical methods in some cases and incomplete published information on the effects of all DBPs on freshwater biota. Concern with impacts of DBPs is often based on human health concerns, because they are typically produced in treated drinking water. Thus drinking water quality guidelines are used to evaluate potential effects of these compounds on humans. The circumstances at Wabamun Lake are unique where large volumes of treated water are pumped directly to the lake rather than into a drinking water distribution system.

Various DBPs were present in the final treated water pumped to the lake (Table 12). However, the fate and effects of these compounds in Wabamun Lake are not known. Disinfection by-products are not typically measured in the lake. Evaluating the potential effects of DBPs on aquatic life is hindered because there are few water quality guidelines available to evaluate the potential effects of DBPs on freshwater aquatic life in Alberta. Currently, there are only three guidelines for chloromethane compounds, including one THM (i.e., trichloromethane or chloroform), which are used in Alberta (Alberta Environment 1999). These CCME guidelines are interim concentrations because there is insufficient toxicity data to develop full guidelines. In the final treated water pumped to Wabamun Lake, the median THM concentration (8.4 µg/L) during 1999 to 2001 (Table 12) exceeded the CCME interim guideline for chloroform (1.8 µg/L) (Alberta Environment 1999).

Alberta Environment initiated a sampling program in 2002 to determine the occurrence and temporal and spatial variability of DBP concentrations in the WL-WTP treated water and at sites further out in the lake. Results of this study are contained in a separate Alberta Environment report (Casey 2003).

Table 12 Summary of disinfection by-products in WL-WTP treated water, (October) 1998 to (December) 2001

	WL-WTP Treated Water: 1998 to 2001 (µg/L)		
	Maximum	Median	Minimum
Total haloacetic acids	124.1	47.8	0.3
Total haloacetonitriles	5.1	1.3	0.25
Total haloketones	3.4	1.9	0.25
Total trihalomethanes	50.6	8.4	2.1
Chloral hydrate	14.5	4.8	0.3

Data sources: Annual Reports for the WL-WTP (TAU 1998 to 2001)

4.0 CONCLUSIONS

4.1 Water Quality of Wabamun Lake, 1982 to 2001

The overall water quality of Wabamun Lake from 1982 to 2001 was similar to other freshwater lakes of central Alberta.

The following temporal trends in the water quality of the lake were found in the 20-year period:

1. Most major ions (excluding calcium and carbonate) and related variables (total dissolved solids, conductivity, and alkalinity) generally increased in the lake over the 20 years. Some major ions (sodium, chloride, and fluoride) and total dissolved solids (TDS) showed greater annual increases of concentrations in the lake after about 1992 to 2001. This pattern was probably due to the lack of flushing of major ions (or TDS) in the lake by more dilute inflows (e.g., precipitation and runoff) after 1992, when lake outflow (via Wabamun Creek) ceased.

2. The overall pattern of increasing TDS in Wabamun Lake from 1982 to 2001 was also found in regional lakes (Thunder Lake and Sandy Lake) with similar basin characteristics (small basin area : lake area) and low or no hydraulic flushing of the lakes (depending on the influences of surface and ground waters), over the same period. The overriding cause of the general increases of major ions in these lakes was likely due to the prevailing climate conditions.

3. From 1999 to 2001, median concentrations of TDS and some major ions (notably sulphate) showed step increases in the lake, while calcium and carbonate showed a step decrease or trend of declining concentrations in the 3-year period. These changes coincided with the same years when the Wabamun Lake Water Treatment Plant (WL-WTP) was pumping large volumes of treated water to the lake.

4. The trophic state (or fertility) of Wabamun Lake was moderately to highly productive (i.e., meso-eutrophic) from 1982 to 2001, which was similar to previous assessments based on 1970s data. After 1998, there were small decreases of phosphorus and chlorophyll-*a* (equivalent to algal biomass) concentrations in the lake, which generally remained at lower levels from 1999 to 2001. Lower phosphorus concentrations (often a limiting nutrient in Alberta lakes) probably caused the concurrent reductions of chlorophyll-*a* in the lake.

5. Metal samples in Wabamun Lake were mostly restricted to the 1999 to 2001 period, except for one sample taken in 1996. Overall the data showed no pronounced spatial differences in metal concentrations among the three sites sampled from 1996 to 2001. Temporal patterns were evident for some metals in the lake. Concentrations of boron, chromium, copper, and manganese declined while one metal (vanadium) increased in the lake from 1999 to 2001. Some metals (e.g., aluminum, barium, lithium, strontium, and titanium) also showed consistent increases or decreases of concentrations in the lake in each year, from 1999 to 2001. These latter patterns may

be due to temporal influences of metal loads in natural streams, which typically occur in the open-water period, compared to atypical inflows to the lake (WL-WTP treated water and ash lagoon discharge) which occur throughout the year, including winter.

6. All metal concentrations (including mercury) in the lake (from 1996 to 2001) were less than water quality guidelines for the protection of freshwater aquatic life and livestock watering. All boron concentrations and some manganese concentrations in the lake were greater than some water quality guidelines for irrigation uses.

7. Two commonly used herbicides (2,4-D and MCPA) were found at low concentrations in the lake in 1995, the only year when pesticides were sampled. The concentrations were below water quality guidelines for the protection of freshwater aquatic life.

8. Preliminary analysis of plankton samples from the lake showed no overall changes in the diversity and abundance of the phytoplankton and zooplankton communities from 1990 to 2001.

4.2 Wabamun Lake-WTP Inflow and Effects on Lake Water Quality

Effects of the WL-WTP treated water on the lake water qaulity were evident, based on the changes observed in the lake and information on the (quantity and quality of the) Wabamun Lake Water Treatment Plant (WL-WTP) treated water pumped to the lake.

Changes in the lake water quality that were likely related to effects of the WL-WTP inflow (from 1999 to 2001) include:

1. Step increases of TDS and some major ion (notably sulphate) concentrations

2. Step decrease or declining concentrations of calcium and carbonate

3. Small decreases of phosphorus and chlorophyll-*a* concentrations in the lake.

Increased TDS and sulphate concentrations in the lake from 1999 to 2001 were likely related to the overall higher salinity of the WL-WTP treated water, compared to the lake. Potential sources of sulphate and TDS in the treated water may be due to several factors including the quality of the raw water (Sundance cooling pond); treatment chemicals used and efficacy of the WL-WTP; and seasonal conditions in the cooling pond.

The small declines of phosphorus and chlorophyll-*a* concentrations in Wabamun Lake (from 1999 to 2001) were likely caused by increased precipitation of calcium carbonate (as calcite) on the lake bottom. The new and relatively large calcium load in the treated water probably enhanced calcite precipitation during this period. Calcite precipitation, which occurs naturally in hardwater lakes, can co-precipitate phosphorus. These processes in turn probably caused the reduction of chlorophyll-*a* concentrations in the lake. The changes of phytoplankton biomass in the lake were small, however, it is not known if the observed change will affect higher trophic levels in the lake ecosystem.

Other potential inputs from the WL-WTP treated water to the lake include disinfection by-products (DBPs) and related compounds, which were present at low levels in the final treated water. These compounds were produced by chlorination and ozonation treatments used in the WL-WTP. Alberta Environment initiated a sampling program in 2002 to determine the spatial and temporal variability of DBPs in the vicinity of the WL-WTP discharge and in the lake.

5.0 LITERATURE CITED

Alberta Environment. 1997. Thunder Lake Water Balance Study. Internal Report. Water Sciences Branch, Water Management Division, Edmonton, Alberta.

Alberta Environment. 1999. Surface Water Quality Guidelines for Use in Alberta. November 1999. Environmental Sciences Division and Water Management Division, Edmonton, Alberta. http://www.gov.ab.ca/env/protenf/publications/SurfWtrQual-Nov99.pdf

Alberta Environment. 2002a. Water Quality Sampling Methods for Surface Waters. Prepared by Water Monitoring Group, Compliance Branch, Northern and Southern Regions, Regional Services, Edmonton, Alberta.

Alberta Environment. 2002b. Wabamun Lake Water Balance 1982-2001. Prepared by Hydrology Branch, Environmental Assurance, Edmonton, Alberta.

Anderson, A.-M. 1998. Water Quality Monitoring of Agricultural Streams and Lakes. Prepared for the Alberta Environmentally Sustainable Agriculture Water Quality Monitoring Program, 1997 Annual Technical Report. Alberta Agriculture, Food and Rural Development, Edmonton, Alberta.

APHA. 1995. Standard Methods for the Examination of Water and Wastewater. Prepared and published jointly by the American Public Health Association and American Water Works Association, and Water Environment Federation.

Bierhuizen, J.F.H. and E.E. Prepas. 1985. Relationship Between Nutrients, Dominant Ions, and Phytoplankton Standing Crop in Prairie Saline Lakes. Can. J. Fish. Aquat. Sci. 42: 1588-1594.

Caraco, N.F., J.J. Cole and G.E. Likens. 1993. Sulfate Control of Phosphorus Availability in Lakes. Hydrobiologia. 253: 275-280.

Casey, R. 2003. Disinfection By-products in the Wabamun Lake Water Treatment Plant-Treated Water and Wabamun Lake, July 2002 to March 2003. Environmental Monitoring and Evaluation Branch, Environmental Assurance, Edmonton, Alberta. Publication available at the Alberta Government Information Centre: http://www3.gov.ab.ca/env/info/infocentre/publist.cfm

CCME. 2000. Canadian Water Quality Guidelines of the Protection of Aquatic Life: Ammonia. Published in Canadian Environmental Quality Guidelines, by Canadian Council of Ministers of the Environment, Winnipeg, Manitoba.

CCME. 2002. Canadian Water Quality Guidelines of the Protection of Aquatic Life: Inorganic fluorides. Published in Canadian Environmental Quality Guidelines, by Canadian Council of Ministers of the Environment, Winnipeg, Manitoba.

Crowe, A.S. and F.W. Schwartz. 1982. The Groundwater Component of the Wabamun Lake Eutrophication Study. Prepared by SIMCO Groundwater Research Ltd. for Water Quality Control Branch, Alberta Environment, Edmonton, Alberta.

Evans, J.C. and E.E. Prepas. 1996. Potential Effects of Climate Change on Ion Chemistry and Phytoplankton Communities in Prairie Saline Lakes. Limnology and Oceanography 41: 1063 – 1076.

Frtiz, P. and H.R. Krouse. 1973. Wabamun Lake Past and Present, an Isotopic Study of the Water Budget. In Proceedings of the Symposium on the Lakes of Western Canada, p. 244 - 258. University of Alberta Water Research Centre, Edmonton.

Gallup, D.N. and M. Hickman. 1975. Effects of Discharge of Thermal Effluent from a Power Station on Lake Wabamun, Alberta, Canada – Limnological Features. Hydrobiologia 4: 45-69.

Golder Associates Ltd. 1999. Water Quality in the Lake Wabamun Watershed. Prepared for TransAlta Utilities Corporation, Calgary, Alberta.

Habgood, H. 1983. Lake Wabamun Literature Review. Prepared for the Lake Wabamun Watershed Advisory Committee.

Hammer, U.T. 1983. Proceedings of the 2nd International Symposium on Athalassic (Inland) Saline Lakes, held in Saskatchewan, Canada, June 1982. Hydrobiologia 105. Dr. W. Junk Publishers, The Hague, Netherlands.

Hem, J.D. 1989. Study and Interpretation of the Chemical Characteristics of Natural Water. United States Geological Survey Water-Supply Paper 2254.

Holmer, M. and P. Storkholm. 2001. Sulphate Reduction and Sulphur Cycling in Lake Sediments: A Review. Freshwater Biology. 46: 431-451.

Klohn Crippen. 2000. Wabamun Lake Water Balance Model Review and Upgrade Report. Prepared for Trans Alta Utilities Corporation.

Mitchell, P. 1985. Preservation of Water Quality in Lake Wabamun. Lake Wabamun Eutrophication Study. Water Quality Control Branch, Pollution Control Division, Alberta Environment. 26 pages.

Mitchell, P. 1987. Lac St Cyr: the Impact of River Diversion on Water Quality. Water Quality Control Branch, Pollution Control Division, Alberta Environment. 50 pages.

Mitchell, P. and Prepas, E. 1990. Atlas of Alberta Lakes. University of Alberta Press, Edmonton, Alberta.

Morel, F.M.M. and A.M.L. Kraepiel. 1998. The Chemical Cycle and Bioaccumulation of Mercury. Annual Review of Ecology and Systematics 29: 543-566.

Murphy, T.P., K.J. Hall and I. Yesaki. 1983. Coprecipitation of Phosphate with Calcite in a Naturally Eutrophic Lake. Limnol. Oceanogr. 28: 58-69.

Noton, L.R. 1975. The Effect of Thermal Effluent on Phytoplankton Productivity in Lake Wabamun, Alberta. Verh. Internat. Verein. Limnol. 19: 542-551.

Phaneuf, P. Approvals Engineer, Alberta Environment, Stony Plain. Personal communication.

Prepas, E.E. and D.O. Trew. 1983. Evaluation of the Phosphorus-Chlorophyll Relationship for Lakes off the Precambrian Shield in Western Canada. Can. J. Fish. Aquat. Sci. 40: 27-35.

Prepas, E.E., T.P. Murphy, J.M. Crosby, D.T. Walty, J.T. Lim, J. Babin and P.A. Chambers. 1990. Reduction of Phosphorus and Chlorophyll *a* Concentrations Following $CaCO_3$ and $Ca(OH)_2$ Additions to Hypereutrophic Figure Eight Lake, Alberta. Environ. Sci. Technol. 24: 1252:-1258.

Prepas, E.E., B. Pinel-Alloul, P.A. Chambers, T.P. Murphy, S. Reedyk, G. Sandland and M. Serediak. 2001. Lime Treatment and its Effects on the Chemistry and Biota of Hardwater Eutrophication Lakes. Freshwater Biology. 46: 1049-1060

Reid Crowther and Partners Ltd. 1995. Wabamun Lake Water Level Study. Draft (November 1995). Prepared by Reid Crowther and Partners Ltd., Calgary, Alberta.

Schindler, D.W. 1985. The Coupling of Elemental Cycles by Organisms: Evidence from Whole-Lake Chemical Perturbations. Pages 225 to 250 in *Chemical Processes in Lakes.* Edited by W. Stumm. John Wiley and Sons, New York, New York.

Schindler, D.W. 2001. The Cumulative Effects of Climate Warming and other Human Stresses on Canadian Freshwaters in the New Millennium. Canadian Journal of Fisheries and Aquatic Sciences 58: 18-29.

Schwartz, F.W. and D.N. Gallup. 1978. Some Factors Controlling the Major Ion Chemistry of Small Lakes: Examples from the Prairie Parkland of Canada. Hydrobiologia. 58: 65-81.

Sosiak, A. 2002. Initial Results of the Pine Lake Restoration Program. Science and Standards, Alberta Environment. 99 pages.

Spencer, Stephen. Fisheries Biologist, Alberta Sustainable Resources, Stony Plain. Personal communication.

TAU. 1998. Sundance Generating Plant Water Use Return. 1998. Annual Report (License No. 12086-00-03). Submitted to Alberta Environment.

TAU. 1998 to 2001. Four Separate Annual Reports entitled: Wabamun Lake Water Treatment Plant [Year of report] Annual Waterworks Report Approval No. 18528-00-01. Submitted to Alberta Environment.

TAU. 2001a. Application to Build an Addition to the Wabamun Lake Water Treatment Plant (WLWTP). TransAlta Responses to Supplemental Questions. Submitted to Alberta Environment (June 7 2001).

TAU. 2001b. Wabamun Lake Water Treatment Plant Addition. Operating Approval Amendment. Submitted to Alberta Environment.

U.S. Dept. of Interior. 1998a. Guidelines for Interpretation of the Biological Effects of Selected Constituents in Biota, Water, and Sediment: Mercury. National Irrigation Water Quality Program Information Report No. 3. Pages 91 – 113. Web address: http://www.usbr.gov/niwqp/MERCURY.PDF

U.S. Dept. of Interior. 1998b. Guidelines for Interpretation of the Biological Effects of Selected Constituents in Biota, Water, and Sediment: Salinity. United States Department of the Interior, National Irrigation Water Quality Program Information Report No. 3. Pages 129-137. Web address: http://www.usbr.gov/niwqp/SALINITY.PDF

Wetzel, R.G. 1983. Limnology. Saunders College Publishing, Philadelphia.

Williams, W.D. 1993. The Worldwide Occurrence and Limnological Significance of Falling Water Levels in Large, Permanent Saline Lakes. Verh. Internat. Verein. Limnol. 25: 980-983.

Williams, W.D., A.J. Boulton and R.G. Taaffe. 1990. Salinity as a Determinant of Salt Lake Fauna: A Question of Scale. Hydrobiologia. 197: 257-266.

Zar, J.H.. 1984. Biostatistical Analysis. Second Edition. Prentice-Hall, New Jersey, U.S.A.

Appendix A Licence Amendment (dated 31 March 2002) to the Water Act Licence for the Wabamun Lake Water Treatment Plant

LICENCE AMENDMENT

PURSUANT TO THE PROVISIONS OF THE *WATER ACT*

LICENCE No.	Dated 1984 01 26
FILE No.	12245-A
PRIORITY No.	1973-11-19-001
AMENDMENT No.	00037698-00-02

TransAlta Utilities Corporation
Box 1900, Station M
Calgary, Alberta
T2P 2M1

The licence is amended as follows:

1. Change Section B. on the cover page of Interim Licence No. 12086, as amended by the May 31, 1996 Addendum, to read as follows:

   a) PURPOSE: Industrial and Water Management

   b) GROSS DIVERSION: Up to 33,000 acre-feet annually consisting of:

1. Estimated Consumptive Use (net evaporative losses):	17,500 acre-feet ($21\ 585\ dam^3$)
2. Estimated Water Treatment Plant and Cooling Tower losses:	900 acre-feet ($1\ 110\ dam^3$)
3. Estimated Return Flow to the North Saskatchewan River:	10,300 acre-feet ($12\ 705\ dam^3$)
4. Estimated Maximum Discharge to Wabamun Lake:	23,300 acre-feet ($28\ 740\ dam^3$)
c) RESERVOIR CAPACITY:	22,163 acre-feet ($17\ 338\ dam^3$)

2. Add the following conditions after condition 1:

   1.1 All definitions from the Act and the regulations apply except where expressly defined in this approval.

   1.2 (a) "Act" means the *Water Act,* S.A. 1996, c.W-3.5, as amended;

AMENDMENT

(b) "annual ongoing impact" means the impact to the level of Wabamun Lake for a particular year from the following facilities with volumes to be determined from running the Wabamun Lake Water Balance Model:
   (i) Wabamun Power Plant;
   (ii) Sundance Power Plant;
   (iii) Keephills Power Plant;
   (iv) Highvale coal mine; and
   (v) Whitewood coal mine,

   as licensed under the Act or approved under the Environmental Protection and Enhancement Act.

(c) "Director" means the Director responsible for this licence unless otherwise specified;

(d) "historical debt" means the accumulated impact to Wabamun Lake level caused by TransAlta Utilities' combined operations incurred from June 1992 to December 31, 2000, which was 47.2 million cubic metres as of December 31, 2000;

(e) "treated water" means the water produced by the Wabamun Lake Water Treatment Facility and discharged to Wabamun Lake;

(f) "Wabamun Lake Water Balance Model" means the model described in Report No.12245-R006, entitled, "Wabamun Lake Water Balance Model Review and Upgrade", prepared for the licensee by Klohn-Crippen Consultants Ltd., September 2000, as amended;

(g) "WLWTF" means the Wabamun Lake water treatment facility which consists of the physical components such as buildings, structures, process equipment, vessels, storage facilities, material handling facilities, roadways, pipelines, and other installations and including the land of the facility constructed on the Sundance power plant site at the following legal description: N ½ Sec 20-052-04-W5, that are used to produce potable water and treated water, and includes components associated with the management of any wastes generated during treatment;

(h) "WLWTP1" means Wabamun Lake water treatment plant 1 which uses conventional water treatment;

(i) "WLWTP2" means Wabamun Lake water treatment plant 2 which uses ballasted flocculation; and

(j) "year" means calendar year.

3. Revise condition 3 of the licence to read as follows:

3.1 The licensee shall

(a) annually run the Wabamun Lake Water Balance Model and determine the annual ongoing impact;

(b) obtain written authorization from the Director prior to any change to the Wabamun Lake Water Balance Model; and

(c) review or amend the Wabamun Lake Water Balance Model upon request by the Director.

AMENDMENT

3.2 The licensee shall submit an annual water use return to the Director on or before March 31 of the year following the year in which the information on which the return was based was collected.

3.3 The annual water return shall contain, at a minimum, all of the following information:

(a) periods and rates of water diversion from the North Saskatchewan River;

(b) total monthly quantity of water diverted from the North Saskatchewan River under this licence;

(c) total monthly quantity of water returned to the North Saskatchewan River under this licence;

(d) total monthly quantity of treated water discharged to Wabamun Lake under this licence;

(e) total annual quantity of water diverted from the North Saskatchewan River under this licence;

(f) total annual quantity of water returned to the North Saskatchewan River under this licence;

(g) total annual quantity of treated water discharged to Wabamun Lake under this licence;

(h) the total annual ongoing impact from the licensee's operations for that year;

(i) the status of the historical debt;

(j) actual mean weekly water surface elevations of Wabamun Lake;

(k) estimated mean weekly water surface elevations of Wabamun Lake as calculated by the Wabamun Lake Water Balance Model;

(l) an electronic copy of the Excel Workbook containing the Wabamun Lake Water Balance Model run(s) for the year; and

(m) any other information requested in writing by the Director.

4. Revise condition 9 of the licence to read as follows:

9.1 By no later than December 31, 2006 the licensee shall have discharged sufficient treated water into Wabamun Lake to satisfy the historical debt**,** unless the actual mean weekly water surface elevation of Wabamun Lake rises to an elevation of 724.55 metres or greater above sea level. If the actual mean weekly water surface elevation of Wabamun Lake meets or surpasses the elevation of 724.55m, then the historical debt is considered satisfied.

9.2 Beginning January 1, 2003, and until the historical debt is satisfied as required by condition 9.1, the licensee shall discharge a minimum of:

(a) 20 million cubic metres of treated water into Wabamun Lake for the period from January 1, 2003 to December 31, 2003;

AMENDMENT

(b) 40 million cubic metres of treated water into Wabamun Lake for the period from January 1, 2003 to December 31, 2004;

(c) 60 million cubic metres of treated water into Wabamun Lake for the period from January 1, 2003 to December 31, 2005; and

(d) 80 million cubic metres of treated water into Wabamun Lake for the period January 1, 2003 to December 31, 2006.

9.3 The minimum discharge volumes in 9.2 include the annual ongoing impact.

9.4 The licensee shall participate as an active stakeholder in any process initiated by Alberta Environment to establish an appropriate level for Wabamun Lake.

5. Revise condition 10 of the licence to read as follows:

10.1 By September 15, 2002, the licensee shall submit to the Director a proposal to develop an operational plan, regarding offsetting ongoing impacts on Wabamun Lake after the historical debt is satisfied.

10.2 The proposal shall contain, at a minimum, all of the following:

(a) the development of an operational water balance model, demonstrating how, through the use of the WLWTF, the licensee will offset the impacts of its operations on Wabamun Lake;

(b) use of the operational water balance model to assess the feasibility of the following scenarios, at a minimum:

(i) a maximum of 15% reduction in the percent of time each year, that the mean water level of Wabamun Lake would have equalled or exceeded 724.55 metres above sea level without the licensee's influences on the water system of Wabamun Lake, on a weekly, monthly and quarterly basis;

(ii) a maximum of 0.05 metre reduction in the mean water level of Wabamun Lake as compared to the mean water level that would have occurred without the licensee's influences on the water system of Wabamun Lake, whenever the water level would have been less than 724.55 metres above sea level, on a weekly, monthly and quarterly basis; and

(iii) analyses under (i) and (ii) shall consider operation of the WLWTF at the range of available capacities, and under different weather conditions;

(c) parameters for the operation of the WLWTF after the requirements in conditions 9.1, 9.2 and 9.3 have been met, based on the analysis from (b); and

(d) any other information requested in writing by the Director.

10.3 Within one year after the Director authorizes the proposal, the licensee shall develop the operational plan and submit a copy of the operational water balance model and operational plan to the Director.

AMENDMENT

10.4 The licensee shall implement the operational plan and operational water balance model as authorized in writing by the Director.

10.5 The Director may amend this licence to address the results of conditions 10.1 through 10.4 inclusive.

6. Delete Condition 11 and 12 in their entirety.

7. Include the following plan and reports filed in departmental records:

NUMBER	TITLE
12245-P026	Site Development – Overall Site Plan
12245-R004	Wabamun Lake Water Treatment Plant Addition – Operating Approval Amendment, by TransAlta Utilities.
12245-R005	TransAlta Responses to Supplemental Questions, by TransAlta Utilities, June 2001.
12245-R006	Wabamun Lake – Water Balance Model – Review and Upgrade, by Klohn Crippen, September 2000.

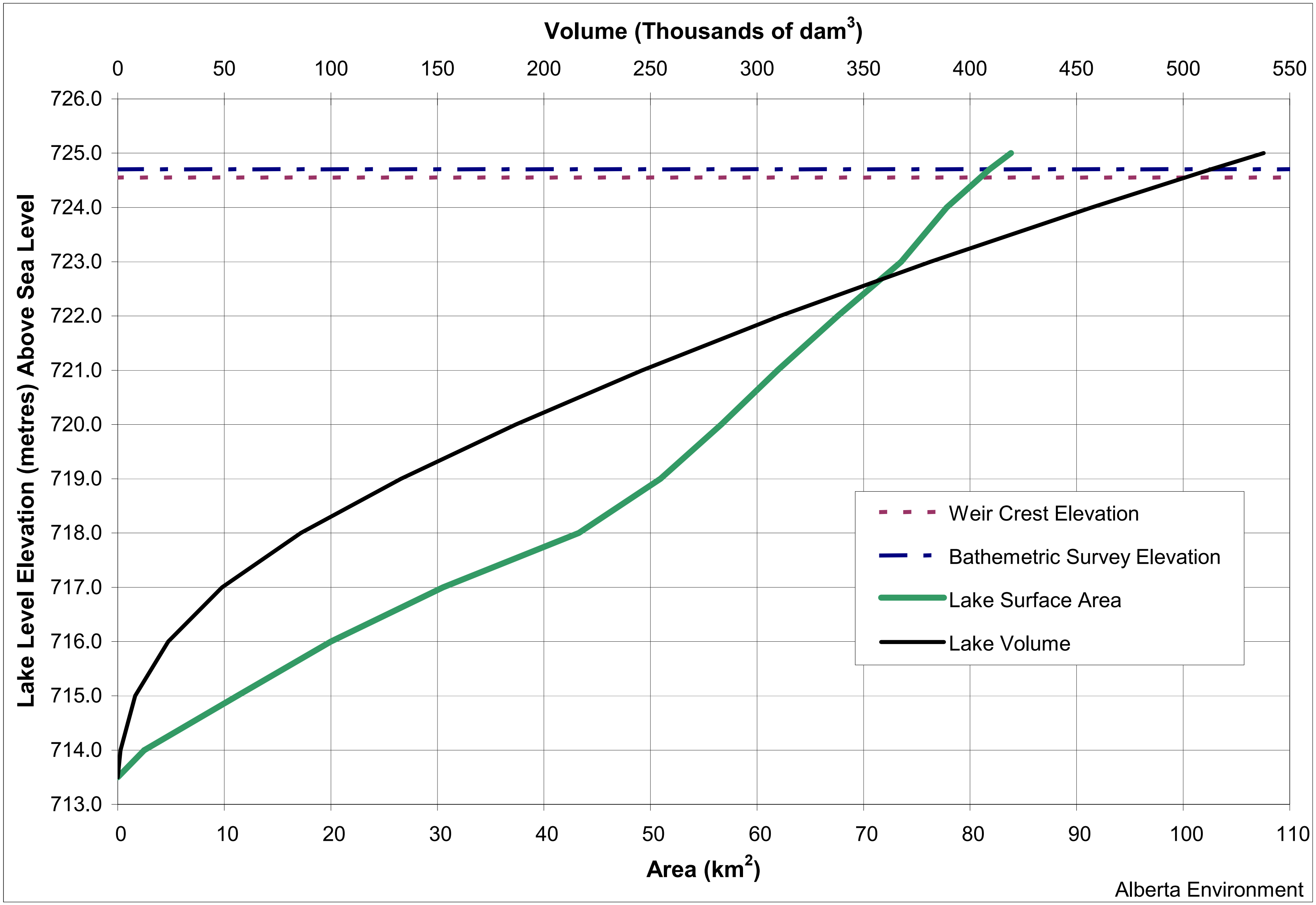
____

Designated Director Under the Act

2002 03 31

Dated (Y/M/D)

Appendix B Area and capacity (lake volume) curves for Wabamun Lake



Appendix C General physical and chemical characteristics, major ions, and nutrients in samples from Wabamun Lake, 1982 to 2001

Sample No.	Valid Method Variable Code: / Sample Date/Time / Variable: / Units:	2041 Specific Conductance (uSie/cm)	10301 pH (pH units)	2078 Secchi Depth (metre)	2021/24 True Colour (rel.units)	10101/11/65 Total Alkalinity (CaCO3, mg/L)	10151 Phenol-phthalein Alkalinity (CaCO3, mg/L)	10602/04/05 Total Hardness (CaCO3, mg/L)	102455, 10401/07 Non-filterable Residue (mg/L)	10474 Total Residue (mg/L)	100536, 201/3/5 Total Dissolved Solids, calc. (mg/L)	10451/53 Filterable Residue (mg/L)	111 Ionic Balance (meq/L)	20103/07/10/11, 360 Calcium, diss.filt. (mg/L)
Wabamun Lake East Basin (AB05DE0630)														
82AB000981	26-May-82 12:00													
82AB000982	16-Jun-82 12:00	411	8.5			186	L4.17		5	395	294	390		22
82AB000983	06-Jul-82 12:00	404	8.5			184	L4.17		9	439	217	430		24
82AB000984	10-Aug-82 12:00	404	8.8			187	9.17		8	328	227	320		25
82AB000985	31-Aug-82 12:00	402	8.6			188	5.8		7	387	239	380		23
82AB000986	21-Sep-82 12:00	409	8.6			189	6.7		14	464	226	450		22
99SWE02190	20-May-99 10:05	485	8.5	2.6		214	6.2	120	4		284		0.94	23.1
99SWE02568	17-Jun-99 09:30	479	8.21	2.7		215	L0.1	140	1		291		1.08	27
99SWE03844	26-Jul-99 08:00	491	8.51	2		231	24.1	130	1		303		1	25.2
99SWE04532	25-Aug-99 07:45	467	8.47	2.25		212	5.1	120	9		278		0.96	22.8
99SWE04995	22-Sep-99 08:00	492	8.52	2.5		216	5.8	110	L1.0		280		0.91	20
99SWE05631	03-Nov-99 09:20	492	8.33	2.3		217	2.7	130	4		300		1.05	24
00SWE01460	25-May-00 09:45	486	8.28	2.6		214	L0.1	130	4		295		1.01	24.5
00SWE01981	27-Jun-00 08:30	523	8.28	2.1		216	L0.1	130	L1.0		291		0.99	22.6
00SWE02820	31-Jul-00 12:00	503	8.46	2.3		211	6.6	120	4		280		0.94	21.2
00SWE03039	22-Aug-00 13:30	502	8.53	1.2		215	8.1	120	5		291		1.01	22.9
00SWE03292	14-Sep-00 09:15	475	8.4	1.5		212	2.9	110	8		293		1.03	20.8
00SWE03710	24-Oct-00 10:00	496	8.32	1.8		212	1.5	130	4		297		1.07	23
01SWE00692	10-May-01 09:30	497	8.28	2.5		213	L0.1	120	L1.0				1	22
01SWE01349	13-Jun-01 10:00	480	8.32	2.1		210	2	130	L1.0		290		1.07	23.5
01SWE01892	18-Jul-01 11:30	504	8.56	1.7		212	6.5	110	5		276		0.9	18.5
01SWE02655	21-Aug-01 11:00	481	8.77	1.3		209	11	120	9		288		1.02	19.7
01SWE03238	24-Sep-01 11:20	480	8.63	1.7		213	9.6	120	5		304		1.07	20.8
01SWE03450	24-Oct-01 11:00	503	8.44	1.6		213	4.1	100	4		285	282	0.91	16.8
Wabamun Lake Main Basin (AB05DE0650)														
83AB001692	03-May-83 11:00	419	8.4	2.3		188	L4.2	109			231			24
83AB001693	31-May-83 09:00	427	8.5	4.1		192	6.7	114			234			26
83AB001694	28-Jun-83 09:00	422	8.5	2.3		192	5	114			237			26
83AB001695	27-Jul-83 10:00			1.2										
83AB001696	24-Aug-83 09:00	412	8.6	2		187	6.7	107			230			23
83AB001697	20-Sep-83 09:30	382	8.6	1.7		189	7.5	98			232			21
83AB001698	17-Oct-83 09:00			2.45			0							
84AB002148	24-Apr-84 08:00													
84AB002149	24-Apr-84 12:00	432	8.4			195	L4.2	113	6.8		236.49			24
84AB002150	09-May-84 09:00			2.5										
84AB002151	09-May-84 12:00	415	8.5			195.8	8.4	109	3.6		239.52			24
84AB002152	05-Jun-84 09:00	420	8.5	1.75		196.8	7.5	114	10.4		239.69			26
84AB002153	04-Jul-84 09:00	412	8.7	1.5		194.4	10	107	12.2		233.57			23
84AB002154	30-Jul-84 09:00	408	8.8	1.65		194.2	14.2	104	2.4		236.73			22
84AB002155	28-Aug-84 10:00	410	8.7	1.5		194.2	8.3	104	10.2		232.43			22

Appendix C General physical and chemical characteristics (cont'd)

Sample No.	Sample Date/Time (Valid Method Variable Code: / Vari-ble: / Units:)	Specific Conductance (2041) uSie/cm	pH (10301) pH units	Secchi Depth (2078) metre	True Colour (2021/24) rel.units	Total Alkalinity (10101/11/65) CaCO3, mg/L	Phenolphthalein Alkalinity (10151) CaCO3, mg/L	Total Hardness (10602/04/05) CaCO3, mg/L	Non-filterable Residue (102455, 10401/07) mg/L	Total Residue (10474) mg/L	Total Dissolved Solids, calc. (100536, 201/3/5) mg/L	Filterable Residue (10451/53) mg/L	Ionic Balance (111) meq/L	Calcium, diss.filt. (20103/07/10/11, 360) mg/L
Wabamun Lake Main Basin (AB05DE0650)														
84AB002156	25-Sep-84 10:00	415	8.8	2.15		195.9	5	107	9					23
85AB001812	14-May-85 09:00	422	8.5	2.4		188.9		111	9		230.27			23
85AB001813	03-Jun-85 09:00			3.65										
85AB001814	05-Jun-85 09:00	425	8.4			193.1		107	3.6		232.89			23
85AB001815	26-Jun-85 09:00	416	8.5	2.2		192.6		113	10.4		236.62			27
85AB001816	23-Jul-85 09:00	420	8.8	2.2		194.3		118	4.8		231.26			26
85AB001817	20-Aug-85 09:00	424	8.7	2		193.2		113	4.8		234.81			24
85AB001818	19-Sep-85 09:00	420	8.6	1.9		192.8		127	6		236.44			28
85AB001819	21-Oct-85 09:00	423	8.4	2.75		194.3		117	6.2		244.14			24
86AB000989	20-May-86 09:00	428	8.5	3		197		137	11		244			27
86AB000990	17-Jun-86 09:00	407	8.6	2.7		197		121	4.2		241.01			27
86AB000991	28-Jul-86 14:30	407	8.8	2		192		109	10		238.99			27
86AB000992	12-Aug-86 08:30	429	8.6	2		193		116	4.8		238.51			25
86AB000993	09-Sep-86 09:00	438	8.8	2		196		109	7		236.51			24
86AB000994	15-Oct-86 09:00	418	8.7	3.75		197		109	6		246			24
87AB000929	05-May-87 10:00	431	8.5	3.5		198		125	2		243.68			27
87AB000930	04-Jun-87 10:00	434	8	3		200		125	3		258.97			27
87AB000931	30-Jun-87 10:00	422	8.7	3		200		118	2		244.79			26
87AB000932	28-Jul-87 07:00	430	8.9	2.1		199		116	3		245.31			25
87AB000933	27-Aug-87 10:00	421	8.8	1.75		196		120	5		243.48			25
87AB000934	23-Sep-87 10:00	430	8.8	2.5		193		113	5		243.79			24
87AB000935	27-Oct-87 09:00	440	8.3	3.3		199		118	3		249.59			26
88AB001580	03-May-88 11:00	448	8.4	3.75		206		129	2.6		256.24			27
88AB001581	06-Jun-88 14:00	450	8.5	3.25		206		122	3.7		258.06			26
88AB001582	27-Jun-88 11:30	449	8.6	2.8		203		136	L1.0		252.45			28
88AB001583	26-Jul-88 11:00	440	8.8	2.75		204		124	2		256.35			25
88AB001584	15-Aug-88 10:30	435	8.7	1.75		201		124	3.6		242.55			25
88AB001585	25-Aug-88 10:00	433	8.9	2.25		201		122	4.8		244.47			24
88AB001586	20-Sep-88 14:00	423	8.74	2.25		200		126	4		251			24
88AB001587	18-Oct-88 11:00	433	8.74	3.75		202		113	2		257			24
89AB001735	15-May-89 11:00	436	8.59	3.25		200		120	3		250			25
89AB001736	08-Jun-89 11:00	432	8.53	4		198		120	2		250			25
89AB001737	04-Jul-89 11:30			1.8										
89AB001738	01-Aug-89 11:00	423	8.62	2.1		197		111	4		240			23
89AB001739	14-Sep-89 12:00	423	8.23	2.25		193	L0.1	119.29	5.7			241		24.5
89AB001740	19-Oct-89 12:00	428	8.2	2.8		195	L0.1	117.86	4.9			246		23.6
90AB000822	03-May-90 11:00	436	8.4	3.75		201		123	1		247			26
90AB000823	03-May-90 11:05	436	8.4			200		129	1		248			27
90AB000824	03-May-90 11:10	436	8.4			200		125	L1.0		247			27
90AB000825	31-May-90 10:00	436	8.5	3.1		200		124	3		248			25
90AB000826	26-Jun-90 10:30	433	8.64	2.5		200		122	3		251			24
90AB000827	24-Jul-90 11:00	424	8.77	1.9		198		122	4		246			24

Appendix C General physical and chemical characteristics (cont'd)

Sample No.	Sample Date/Time	Specific Conductance (uSie/cm)	pH (pH units)	Secchi Depth (metre)	True Colour (rel.units)	Total Alkalinity (CaCO3, mg/L)	Phenolphthalein Alkalinity (CaCO3, mg/L)	Total Hardness (CaCO3, mg/L)	Non-filterable Residue (mg/L)	Total Residue (mg/L)	Total Dissolved Solids, calc. (mg/L)	Filterable Residue (mg/L)	Ionic Balance (meq/L)	Calcium, diss.filt. (mg/L)
	Valid Method Variable Code:	2041	10301	2078	2021/24	10101/11/65	10151	10602/04/05	102455, 10401/07	10474	100536, 201/3/5	10451/53	111	20103/07/10/11, 360
Wabamun Lake Main Basin (AB05DE0650)														
90AB000828	21-Aug-90 10:00	427	8.73	1.9		198		119			243			23
90AB000829	24-Sep-90 10:30	431	8.74	2.5		198		122	6		251			24
90AB000837	18-Oct-90 11:00	438	8.48	2.75		198		127	4		254			26
91AB001366	07-May-91 11:30			2.3										
91AB001367	06-Jun-91 09:00			3.6										
91AB001368	03-Jul-91 08:30			1.8										
91AB001369	23-Jul-91 10:30			1.8										
91AB001370	22-Aug-91 11:00	432	8.6	1.5		199		124	5		243			25
91AB001371	24-Sep-91 09:00	437	8.65	1.8		200		122	5		247			24
92AB001156	30-Apr-92 11:30	447	8.43	2.9		202		127	3		254			26
92AB001157	26-May-92 13:00	450	8.43	3		203		127	2		257			26
92AB001158	23-Jun-92 09:00	448	8.63	2.8		202		125	3		256			27
92AB001159	16-Jul-92 10:30	451	8.75	2		205		123	6		261			26
92AB001160	10-Aug-92 15:00	445	8.82	1.5		204		118	6		257			24
92AB001161	11-Sep-92 08:00	444	8.78	1.1		203		123	6		255			23
92AB001162	05-Oct-92 12:00	445	8.79	1.2		203		119	6		253			23
93AB001296	11-May-93 10:00	451	8.6	3.1		205		119	2		257			23
93AB001306	01-Jun-93 09:30	444	8.69	2.2		206		115	3		254			23
93AB001307	28-Jun-93 11:00	452	8.69	1.8		204		118	5		259			24
93AB001308	27-Jul-93 09:30	440	8.79	1.4		202		119	5		250			23
93AB001309	19-Aug-93 09:00	442	8.89	2		202		117	4		248			22
93AB001310	14-Sep-93 10:00	441	8.74	2		201		112	6		249			20
93AB001311	12-Oct-93 11:00	439	8.6	2.1		203		114	3		252			21
94AB000826	28-Apr-94 11:30	455	8.36	3		205		123	L1.0		265			24
94AB000827	25-May-94 10:00	460	8.59	2.7		206		121	3		256			23
94AB000828	21-Jun-94 09:30	451	8.61	2.5		206		122	4		258			24
94AB000829	12-Jul-94 13:30	446	8.87	1.5		205		121	5		258			23
94AB000830	03-Aug-94 10:30			1.3										
94AB000831	24-Aug-94 10:00	433	8.7	1		205		116	4		251			21
94AB000832	20-Sep-94 10:00			2										
94AB000833	18-Oct-94 11:00	469	8.53	2.3		207		119	4		261			23
95AB002313	03-May-95 11:20	468	8.33	2.4		210		122	2		266			24
95AB002314	30-May-95 10:00	460	8.6	3.6		212		126	L1.0		272			24
95AB002315	27-Jun-95 09:45	466	8.61	1.9		213		126	3		270			24
95AB002316	19-Jul-95 09:20	461	8.65	1.8		214		129	8		272			25
95AB002317	10-Aug-95 09:00	461	8.64	1.1		213		122	5		269			23
95AB002318	30-Aug-95 08:45	459	8.68	1.4		210		122	7		268			24
95AB002319	27-Sep-95 10:00	448	8.82	2		211		118	6		264			21
95AB002320	20-Oct-95 10:00	447	8.6	2.2		213		119	4		261			22
96AB000730	13-May-96 11:00	469	8.33	3.2	10	209	2.5	120	L0.4		270		1	23
96AB000731	04-Jun-96 10:00	472	8.32	2.5	10	208	3.2	129			274	298	1.06	25.3

Appendix C General physical and chemical characteristics (cont'd)

Sample No.	Valid Method Variable Code:	2041	10301	2078	2021/24	10101/11/65	10151	10602/04/05	102455, 10401/07	10474	100536, 201/3/5	10451/53	111	20103/07/10/11, 360
	Sample Date/Time / Variable:	**Specific Conductance**	**pH**	**Secchi Depth**	True Colour	**Total Alkalinity**	Phenol-phthalein Alkalinity	**Total Hardness**	**Non-filterable Residue**	Total Residue	**Total Dissolved Solids, calc.**	Filterable Residue	Ionic Balance	**Calcium, diss.filt.**
	Units:	uSie/cm	pH units	metre	rel.units	CaCO3, mg/L	CaCO3, mg/L	CaCO3, mg/L	mg/L	mg/L	mg/L	mg/L	meq/L	mg/L
Wabamun Lake Main Basin (AB05DE0650)														
96SWE00253	26-Jun-96 09:00	457	8.33	1.8	2.5	205	4	126	0.2		274		1.09	23.7
96SWE00374	09-Jul-96 12:10	465	8.41	2.2	10	205	5.8	123	2		265		0.99	25.1
96SWE00796	23-Jul-96 10:00	465	8.5	1.75	10	208	8	116	5		266		0.96	22.9
96SWE01090	07-Aug-96 09:00	460	8.59	1.6	10	205	9.42	121	4.5		270		1.04	22.9
96SWE01305	21-Aug-96 10:15	467	8.67	1.5	10	207	11.1	127	5		267		1.02	25.5
96SWE01686	05-Sep-96 10:00	472	8.54	1.8	10	207	6.32	118	5		265		1	22.9
96SWE01890	17-Sep-96 10:30	470	8.65	2	10	207	9.74	131	4		278		1.09	25
96SWE02202	08-Oct-96 10:00	458	8.33	2.2	10	207	2.45	125	L0.4		274		1.07	24.1
97SWE01247	14-May-97 08:45	480	8.41	2.6	10	209	5.9	135	L0.4		283		1.07	26.8
97SWE01712	10-Jun-97 12:15	467	8.5	3.3	10	211	6.12	130	L0.4		280		1.05	25.3
97SWE02059	08-Jul-97 10:45	475	8.01	2.3		216	L0.1	119	6		279		0.96	23
97SWE02296	24-Jul-97 10:00	460	8.48	1.8		212	7.17	130	3		277		1.08	25.3
97SWE02492	05-Aug-97 13:00	459	8.61	2.3		213	12	120	L0.4		275		0.99	22.9
97SWE03145	03-Sep-97 08:50	491	8.7	1.5		216	14.5	129	L0.4		273		1.03	25
97SWE03586	24-Sep-97 09:20	463	8.81	2.3		212	13.2	109	L0.4		262		0.93	20.4
97SWE03921	15-Oct-97 10:30	465	8.59	2.1		212	9.59	119	6		267		0.99	23
98SWE00656	11-May-98 10:15	496	8.45	3		211	7	120	2		267		0.96	21.9
98SWE00881	10-Jun-98 09:00	472	8.52	1.9		212	6.1	120	7		272		1.01	23
98SWE01239	07-Jul-98 10:00	477	8.41	1.8		213	10.2	120	6		262		0.92	22.7
98SWE01619	04-Aug-98 09:15	478	8.56	1.7		211	12.8	120	L0.4		277		1.06	22.6
98SWE02112	31-Aug-98 11:30	473	8.61	1.6		212	11.8	120	3		278		1.03	20.7
Wabamun Lake West Basin (AB05DE0620)														
99SWE02208	20-May-99 11:05	480	8.5	2.25		213	6.2	120	L0.4		282		0.96	23.2
99SWE02555	17-Jun-99 10:00	476	8.23	2.1		215	L0.1	140	L0.4		289		1.08	27.1
99SWE03679	26-Jul-99 09:30	501	8.38	2.4		235	13.3	140	L0.4		304		0.99	26.2
99SWE04550	25-Aug-99 08:30	470	8.5	2.3		214	5.4	120	2		280		0.95	23.3
99SWE04980	22-Sep-99 09:00	491	8.55	1.3		219	6.6	130	2		294		1.03	23.8
99SWE05617	03-Nov-99 10:05	494	8.33	2.75		234	2.5	130	4		304		0.99	23.7
00SWE01470	25-May-00 11:30	488	8.31	3		216	2.2	130	5		294		1	24.4
00SWE01967	27-Jun-00 10:00	532	8.11	2.6		218	L0.1	130	L1.0		295		1.01	23.3
00SWE02837	31-Jul-00 10:00	503	8.44	2.25		213	6.1	120	4		280		0.94	22.3
00SWE03052	22-Aug-00 10:45	505	8.53	1.75		218	8.4	130	3		294		1	23.6
00SWE03279	14-Sep-00 08:15	482	8.35	2.1		212	2	120	4		293		1.03	21.5
00SWE03721	24-Oct-00 09:00	495	8.34	2.1		214	1.9	130	5		298		1.07	23.2
01SWE00669	10-May-01 11:00	498	8.23	2.6		215	L0.1	130	6				1.02	22.7
01SWE01335	13-Jun-01 11:00	481	8.32	2.3		212	1.9	130	L1.0		292		1.07	23.6
01SWE01899	18-Jul-01 13:00	509	8.54	1.8		213	6.9	110	3		281		0.94	19.6
01SWE02674	21-Aug-01 12:00	482	8.71	1.5		216	9.2	120	8		297		1.01	21.1
01SWE03255	24-Sep-01 12:00	484	8.69	1.8		214	12.3	120	4		295		0.99	19.4
01SWE03466	24-Oct-01 12:00	503	8.47	1.3		213	4.8	110	7		290	298	0.96	19.3

Notes: 'L' = concentrations are less than the analytical detection limit. **Bold Variable Names** show data presented in the report

Sample No.	Valid Method Variable Code: / Sample Date/Time / Variable: / Units:	Sodium, diss.filt.	Magnesium, diss.filt.	Potassium, diss.filt.	Sulphate, diss.	Chloride, diss.	Fluoride, diss.	Hydroxide, calc.	Bicarbon-ate, calc.	Carbon-ate, diss.	Dissolved Inorganic Carbon	Total Inorganic Carbon	Total Particulate Carbon	Dissolved Organic Carbon
	Valid Method Variable Code:	102085, 11103/11 /15	368, 12102/03 /05/11	366, 19103/11, 102086	16111, 16306/09	17203/ 06/09, 102087	9105/07	8501	6201/02	6301/02	6154	6052	6905	6101/04 /07
	Units:	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Wabamun Lake East Basin (AB05DE0630)														
82AB000981	26-May-82 12:00										49		1.76	9
82AB000982	16-Jun-82 12:00	40	11	7.1	35	3	0.28				58		1.25	11
82AB000983	06-Jul-82 12:00	43	11	7.1	20	2	0.28				46		1.47	10
82AB000984	10-Aug-82 12:00	43	11	7.3	25	3	0.28				51		2.51	12
82AB000985	31-Aug-82 12:00	46	12	7.2	35	3	0.28				48		3.14	12
82AB000986	21-Sep-82 12:00	43	13	7.4	25	2	0.28				48		3.34	11
99SWE02190	20-May-99 10:05	56.8	15.2	8.6	45.6	6.6		L0.5	246	7.5				12.4
99SWE02568	17-Jun-99 09:30	62.3	17.2	9.6	38.2	6.6		L0.5	262	L0.5				13
99SWE03844	26-Jul-99 08:00	63.8	17	10.1	39.4	6.6		0.25	223	29				12
99SWE04532	25-Aug-99 07:45	55.8	15.7	8.9	37.9	6.7		L0.5	246	6.1				14.2
99SWE04995	22-Sep-99 08:00	55	15	12	37.3	7.9		L0.5	249	7				13.2
99SWE05631	03-Nov-99 09:20	65.9	17.4	10.9	39.3	9.6		L0.5	258	3.3				12.7
00SWE01460	25-May-00 09:45	61.7	16.9	9.5	45.9	7.6		L0.5	261	L0.5				11.1
00SWE01981	27-Jun-00 08:30	60.8	17	9.5	43	7		L0.5	264	L0.5				12.6
00SWE02820	31-Jul-00 12:00	56.7	15.3	9	42.6	6.5		L0.5	242	7.9				12.2
00SWE03039	22-Aug-00 13:30	62.5	16.3	9.9	40.9	7.5		L0.5	243	9.7				12.9
00SWE03292	14-Sep-00 09:15	68.4	15.3	10	41.5	7.4		L0.5	251	3.5				12.4
00SWE03710	24-Oct-00 10:00	67.9	17.4	10	42.1	7.3		L0.5	255	1.8				12.7
01SWE00692	10-May-01 09:30	63.6	16.7	8.4	44.3	7.9		L0.5	260	L0.5				11.9
01SWE01349	13-Jun-01 10:00	64.8	17.4	9.2	40.7	7.9		L0.5	251	2.4				11.6
01SWE01892	18-Jul-01 11:30	56.4	15	8.2	41.3	8.3		L0.5	243	7.8				11.6
01SWE02655	21-Aug-01 11:00	65	16.7	9.9	41.8	8.1		L0.5	228	13.3				12.4
01SWE03238	24-Sep-01 11:20	71.9	17.6	10.1	45.7	8		L0.5	237	11.5				13.9
01SWE03450	24-Oct-01 11:00	61.4	15.2	8.7	45	7.4		L0.5	249	4.9				13.3
Wabamun Lake Main Basin (AB05DE0650)														
83AB001692	03-May-83 11:00	44	12	7.5	28	3	0.3		224	L5.0	49		0.98	11
83AB001693	31-May-83 09:00	45	12	7.6	25	3	0.27		217	8	49		0.45	11
83AB001694	28-Jun-83 09:00	45	12	7.5	30	2	0.27		222	6	43		2.85	10
83AB001695	27-Jul-83 10:00										44		2	11
83AB001696	24-Aug-83 09:00	44	12	7.3	28	3	0.29		211	8	42		1.17	9.5
83AB001697	20-Sep-83 09:30	46	11	7	30	3	0.27		213	9	50		1.24	11.1
83AB001698	17-Oct-83 09:00										44.7		L0.01	10.4
84AB002148	24-Apr-84 08:00													
84AB002149	24-Apr-84 12:00	45	13	7.6	27	3	0.26		229.41	L5.0	46.6		1.33	10.6
84AB002150	09-May-84 09:00													
84AB002151	09-May-84 12:00	46	12	7.9	29	3	0.28		218.93	9.72	47		0.92	10.5
84AB002152	05-Jun-84 09:00	46	12	7.7	27	3	0.28		221.85	8.88	48.1		1.77	10.7
84AB002153	04-Jul-84 09:00	44	12	7.9	26	4	0.3		213.08	11.76	45.2		3.68	10.5
84AB002154	30-Jul-84 09:00	49	12	8.3	26	3	0.28		202.59	16.8	46		2.06	11
84AB002155	28-Aug-84 10:00	47	12	8	24	3	0.3		215.51	10.44	44		1.85	11.1

Appendix C General physical and chemical characteristics (cont'd)

Sample No.	Valid Method Variable Code: / Sample Date/Time / Vari-ble: / Units:	Sodium, diss.filt. (102085, 11103/11/15) mg/L	Magnesium, diss.filt. (368, 12102/03/05/11) mg/L	Potassium, diss.filt. (366, 19103/11, 102086) mg/L	Sulphate, diss. (16111, 16306/09) mg/L	Chloride, diss. (17203/06/09, 102087) mg/L	Fluoride, diss. (9105/07) mg/L	Hydroxide, calc. (8501) mg/L	Bicarbon-ate, calc. (6201/02) mg/L	Carbon-ate, diss. (6301/02) mg/L	Dissolved Inorganic Carbon (6154) mg/L	Total Inorganic Carbon (6052) mg/L	Total Particulate Carbon (6905) mg/L	Dissolved Organic Carbon (6101/04/07) mg/L
Wabamun Lake Main Basin (AB05DE0650)														
84AB002156	25-Sep-84 10:00	49	12	8	24	3	0.31		227.34	5.64	44.6		1.97	11.1
85AB001812	14-May-85 09:00	46	13	7.7	23	4	0.28		221.97	L5.0	52.7		1.82	10
85AB001813	03-Jun-85 09:00													
85AB001814	05-Jun-85 09:00	47	12	8	26	L1.0	0.29		231.97	L5.0	57.1		1.13	10.8
85AB001815	26-Jun-85 09:00	46		8	26	3	0.29		223.56	5.52	60.1		1.32	28.2
85AB001816	23-Jul-85 09:00	46	13	8	26	3	0.29		217.59	9.48	56.7		22.07	10.9
85AB001817	20-Aug-85 09:00	47	13	8	24	3	0.29		220.15	7.56				
85AB001818	19-Sep-85 09:00	45	14	7.9	22	4	0.29		223.56	5.64	46.35		2.35	11.4
85AB001819	21-Oct-85 09:00	48	14	7.7	30	4	0.31		229.29	L5.0	45.75		0.96	11.55
86AB000989	20-May-86 09:00	45	17	7.7	26	3	0.29		228	6	48		0.79	10.7
86AB000990	17-Jun-86 09:00	46	13	7.8	26	3	0.33		223.07	8.4	47.3			11
86AB000991	28-Jul-86 14:30	45	10	7.7	30	4	0.29		204.79	14.4	46.6		1.8	11.1
86AB000992	12-Aug-86 08:30	47	13	7.7	25	5	0.27		220.63	7.2	48.3		1.42	9.6
86AB000993	09-Sep-86 09:00	47	12	8	25	3	0.28		212.1	13.2	47		1.88	11.7
86AB000994	15-Oct-86 09:00	50	12	8	30	4	0.27		226	7	46.4		0.93	11.1
87AB000929	05-May-87 10:00	45	14	7.9	28	3	0.3		229.17	6	49.1		1.07	10.9
87AB000930	04-Jun-87 10:00	46	14	7.9	40	4	0.33		238.92	L5.0			1.02	11.1
87AB000931	30-Jun-87 10:00	47	13	7.9	28	3	0.3		224.29	9.6			1.23	11.2
87AB000932	28-Jul-87 07:00	48	13	7.9	28	4	0.25		206.01	18			2.08	11.4
87AB000933	27-Aug-87 10:00	49	14	7.9	26	4	0.32		209.66	14.4			2.72	11.3
87AB000934	23-Sep-87 10:00	47	13	8.1	33	3	0.33		215.76	9.6			1.82	10.9
87AB000935	27-Oct-87 09:00	50	13	8.3	29	4	0.31		242.58				2.57	12.1
88AB001580	03-May-88 11:00	52	15	6.6	29	3	0.32		246.23	L5.0			0.77	12.1
88AB001581	06-Jun-88 14:00	53	14	7.6	30	4	0.32		236.48	7.2			1.05	8.6
88AB001582	27-Jun-88 11:30	50	16	8.1	25	3.5	0.36		225.51	10.8			1.13	11.7
88AB001583	26-Jul-88 11:00	50	15	8	32	4	0.3		219.42	14.4			1.46	12
88AB001584	15-Aug-88 10:30	47	15	8	24	3	0.33		223.07	10.8			2.16	11.1
88AB001585	25-Aug-88 10:00	49	15	7.8	25	3	0.24		212.1	16.2			2.33	12
88AB001586	20-Sep-88 14:00	52	16	8.1	27	4	0.32		215	14			1.33	12.6
88AB001587	18-Oct-88 11:00	52	13	8.3	34	4	0.32		223	11			0.98	12.4
89AB001735	15-May-89 11:00	50	14	8.1	29	4.1	0.31		225	9				12
89AB001736	08-Jun-89 11:00	50	14	8.1	29	5.5	0.32		228	6				12.4
89AB001737	04-Jul-89 11:30													
89AB001738	01-Aug-89 11:00	47	13	7.5	27	3.8	0.3		217	11				12.1
89AB001739	14-Sep-89 12:00	46.5	14.1	8	25.8	4.4			235.27	L0.5				13.5
89AB001740	19-Oct-89 12:00	50	14.3	8.4	25.9	5.2			237.71	L0.5		45		15.7
90AB000822	03-May-90 11:00	49	14	7.3	27	3.4	0.29		236	5	45.2		0.68	11.9
90AB000823	03-May-90 11:05	48	15	7.4	27	3.4	0.29		235	5	44.5		0.63	11.9
90AB000824	03-May-90 11:10	48	14	7.4	27	3.3	0.3		232	6	44.8		0.65	11.5
90AB000825	31-May-90 10:00	49	15	7.9	28	3.2	0.3		227	8	46.2		1.04	11
90AB000826	26-Jun-90 10:30	49	15	7.8	31	4.1	0.31		220	12			0.95	11.3
90AB000827	24-Jul-90 11:00	48	15	7.5	29	3.7	0.3		215	13	44.3		2.12	13.1

Appendix C General physical and chemical characteristics (cont'd)

Sample No.	Sample Date/Time	**Sodium, diss.filt.**	**Magnesium, diss.filt.**	**Potassium, diss.filt.**	**Sulphate, diss.**	**Chloride, diss.**	**Fluoride, diss.**	Hydroxide, calc.	**Bicarbon-ate, calc.**	**Carbon-ate, diss.**	Dissolved Inorganic Carbon	Total Inorganic Carbon	Total Particulate Carbon	**Dissolved Organic Carbon**
	Valid Method Variable Code:	102085, 11103/11 /15	368, 12102/03 /05/11	366, 19103/11, 102086	16111, 16306/09	17203/ 06/09, 102087	9105/07	8501	6201/02	6301/02	6154	6052	6905	6101/04 /07
	Units:	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Wabamun Lake Main Basin (AB05DE0650)														
90AB000828	21-Aug-90 10:00	49	15	7.7	25	4.4	0.31		217	12			1.81	11.1
90AB000829	24-Sep-90 10:30	48	15	7.9	32	4.9	0.32		212	14	44.7		1.93	11.5
90AB000837	18-Oct-90 11:00	49	15	8	33	4	0.32		232	5	45.3		1.31	11.8
91AB001366	07-May-91 11:30													
91AB001367	06-Jun-91 09:00													
91AB001368	03-Jul-91 08:30													
91AB001369	23-Jul-91 10:30													
91AB001370	22-Aug-91 11:00	45	15	7.8	27	4	0.3		222	10	43.7		1.67	11.1
91AB001371	24-Sep-91 09:00	47	15	7.7	30	4	0.3		221	11	46.9			11.2
92AB001156	30-Apr-92 11:30	50	15	7.8	30	4.4	0.29		242	5	48			11.2
92AB001157	26-May-92 13:00	50	15	7.7	32	4.6	0.31		243	4	49.2			10.8
92AB001158	23-Jun-92 09:00	50	14	8	31	4.5	0.29		238	9	46.4			11.2
92AB001159	16-Jul-92 10:30	51	14	7.9	35	4.6	0.31		239	11	44.2			10.9
92AB001160	10-Aug-92 15:00	51	14	8.2	32	4.6	0.32		236	13	48		2.44	13.5
92AB001161	11-Sep-92 08:00	53	16	8.3	29	4.7	0.33		234	12	46.8		2.49	11.7
92AB001162	05-Oct-92 12:00	51	15	8.1	29	4.8	0.32		235	12	45		2.19	11.5
93AB001296	11-May-93 10:00	51	15	8.1	31	4.8	0.32		242	8	45.2		1.19	11.5
93AB001306	01-Jun-93 09:30	52	14	8.2	29	4.9	0.32		241	10	47		2.02	12.1
93AB001307	28-Jun-93 11:00	53	14	8.1	33	5	0.38		239	9	44.3		2.23	12
93AB001308	27-Jul-93 09:30	51	15	8	27	4.8	0.32		233	13	46.5		2.04	12.9
93AB001309	19-Aug-93 09:00	53	15	8.4	23	4.9	0.33		231	15	42.8		1.48	12.5
93AB001310	14-Sep-93 10:00	53	15	8.2	27	4.9	0.33		233	12	43.2		3.39	12.6
93AB001311	12-Oct-93 11:00	54	15	8.2	27	5	0.32		229	9	45.1		1.46	11.9
94AB000826	28-Apr-94 11:30	55	15	8.5	34	5.3	0.4		247	3	47.6		0.89	11.9
94AB000827	25-May-94 10:00	53	15	8.4	27	5.3	0.34		243	8	45.4		1.34	12.8
94AB000828	21-Jun-94 09:30	54	15	8.5	28	5.3	0.33		242	9	48		1.59	14.1
94AB000829	12-Jul-94 13:30	53	15	8.6	29	5.3	0.34		238	12	46.9		2.68	12.5
94AB000830	03-Aug-94 10:30													
94AB000831	24-Aug-94 10:00	54	15	8.5	24	5.2	0.36		239	11	45.4		2.53	13.1
94AB000832	20-Sep-94 10:00													
94AB000833	18-Oct-94 11:00	56	15	8.9	28	5.6	0.37		244	8	46.1		1.84	12.4
95AB002313	03-May-95 11:20	55	15	8.6	32	5.5	0.35		249	3	49.6		1.47	11.7
95AB002314	30-May-95 10:00	57	16	9.1	33	5.7	0.36		240	9	47.9		0.61	12.5
95AB002315	27-Jun-95 09:45	56	16	8.8	32	5.4	0.35		242	9	47.2		1.54	12.9
95AB002316	19-Jul-95 09:20	58	16	9	30	5.5	0.37		239	11	49.3		2.83	12.8
95AB002317	10-Aug-95 09:00	56	16	8.9	32	5.6	0.37		237	11	49.3		2.57	12.4
95AB002318	30-Aug-95 08:45	56	15	9	32	5.7	0.37		235	11	47.7		2.08	11.8
95AB002319	27-Sep-95 10:00	57	16	9	28	5.7	0.38		227	15	47.6		2	13
95AB002320	20-Oct-95 10:00	57	16	8.8	24	5.7	0.37		239		45.6		1.64	10.8
96AB000730	13-May-96 11:00	55.8	15.2	8.87	33.8	5.8	0.32	L0.5	249	3				12.4
96AB000731	04-Jun-96 10:00	57.2	15.9	9.37	33.2	6	0.44	L0.5	246	3.8				12.5

Appendix C General physical and chemical characteristics (cont'd)

Sample No.	Valid Method Variable Code: / Sample Date/Time Variable: Units:	102085, 11103/11/15 Sodium, diss.filt. mg/L	368, 12102/03/05/11 Magnesium, diss.filt. mg/L	366, 19103/11, 102086 Potassium, diss.filt. mg/L	16111, 16306/09 Sulphate, diss. mg/L	17203/06/09, 102087 Chloride, diss. mg/L	9105/07 Fluoride, diss. mg/L	8501 Hydroxide, calc. mg/L	6201/02 Bicarbonate, calc. mg/L	6301/02 Carbonate, diss. mg/L	6154 Dissolved Inorganic Carbon mg/L	6052 Total Inorganic Carbon mg/L	6905 Total Particulate Carbon mg/L	6101/04/07 Dissolved Organic Carbon mg/L
Wabamun Lake Main Basin (AB05DE0650)														
96SWE00253	26-Jun-96 09:00	60.4	16.2	9.74	33.5	5.8	0.36	0.25	240	4.8				13.8
96SWE00374	09-Jul-96 12:10	52.2	14.7	8.42	33.7	6.4	0.36	L0.5	236	7				12.4
96SWE00796	23-Jul-96 10:00	53.1	14.3	8.52	34.2	5.9	0.37	L0.5	234	9.6				12.8
96SWE01090	07-Aug-96 09:00	58.2	15.5	9.24	31.4	8.2	0.28	L0.5	227	11.3				13.5
96SWE01305	21-Aug-96 10:15	53.6	15.3	8.68	32.7	5.6	0.46	L0.5	225	13.3				12.8
96SWE01686	05-Sep-96 10:00	55.1	14.7	8.58	32.6	5.4	0.4	L0.5	237	7.58				11.6
96SWE01890	17-Sep-96 10:30	60.3	16.6	10.3	31.4	8.6	0.35	L0.5	229	11.7				11.5
96SWE02202	08-Oct-96 10:00	59.6	15.7	9.45	32.9	5.8	0.36	L0.5	246	2.94				12
97SWE01247	14-May-97 08:45	59.5	16.5	9.41	32.1	11.4	0.33	L0.5	240	7.1				11.9
97SWE01712	10-Jun-97 12:15	59.1	16.1	9.28	34.9	6.8	0.32	L0.5	242	7.35				11.9
97SWE02059	08-Jul-97 10:45	56.4	15	9.62	30.6	13	0.37	L0.5	263	L0.5				12
97SWE02296	24-Jul-97 10:00	59.8	16.2	9.49	30.7	6.2	0.43	L0.5	241	8.6				11.5
97SWE02492	05-Aug-97 13:00	57.4	15.3	9.12	29.5	10.9	0.31	L0.5	231	14.3				12.2
97SWE03145	03-Sep-97 08:50	56.4	16.2	8.99	30	5.4	0.41	L0.5	228	17.3				12.9
97SWE03586	24-Sep-97 09:20	53.5	14.1	8.15	30	7.1	0.37	L0.5	226	15.9				12.5
97SWE03921	15-Oct-97 10:30	55	15	8.64	28.5	7.7	0.39	L0.5	235	11.5				13.9
98SWE00656	11-May-98 10:15	55	14.7	8.8	32.6	6.8	0.37	L0.5	240	8.4				
98SWE00881	10-Jun-98 09:00	58.4	15.4	8.9	30.1	7.3	0.42	L0.5	244	7.3				
98SWE01239	07-Jul-98 10:00	50.5	14.6	7.8	29.4	7	0.46	L0.5	235	12.2				
98SWE01619	04-Aug-98 09:15	62	16.5	9.8	31.5	5.9	0.37	L0.5	226	15.3				
98SWE02112	31-Aug-98 11:30	62.2	15.4	11.5	32.5	5.3	0.38	L0.5	230	14.2				
Wabamun Lake West Basin (AB05DE0620)														
99SWE02208	20-May-99 11:05	56.9	15.2	8.6	43.1	6.6		L0.5	245	7.5				12.7
99SWE02555	17-Jun-99 10:00	62.1	17.2	9.5	36.9	6.7		L0.5	262	L0.5				13.8
99SWE03679	26-Jul-99 09:30	63.2	16.9	10.1	37.6	6.5		L0.5	254	16				11.9
99SWE04550	25-Aug-99 08:30	55.2	15.5	9	38.7	6.6		L0.5	248	6.5				14.1
99SWE04980	22-Sep-99 09:00	63.3	16.5	11.5	37.7	7		L0.5	251	7.9				13
99SWE05617	03-Nov-99 10:05	65.1	17.1	11	36.8	7.4		L0.5	279	3				12.3
00SWE01470	25-May-00 11:30	61.1	16.7	9.3	43.9	8		L0.5	258	2.6				11
00SWE01967	27-Jun-00 10:00	62.5	17.4	9.8	43.4	7.1		L0.5	265	L0.5				11.5
00SWE02837	31-Jul-00 10:00	56.2	15.3	9	41.7	6.4		L0.5	245	7.3				12.6
00SWE03052	22-Aug-00 10:45	62.4	16.3	9.8	41	7.3		L0.5	245	10				12.2
00SWE03279	14-Sep-00 08:15	68.2	15.3	9.9	41.9	7.3		L0.5	253	2.3				12.4
00SWE03721	24-Oct-00 09:00	67.9	17.3	10	41.8	7.1		L0.5	256	2.3				12.3
01SWE00669	10-May-01 11:00	64.9	17.2	8.6	44.5	7.8		L0.5	262	L0.5				11.9
01SWE01335	13-Jun-01 11:00	65.2	17.3	9.3	40.7	7.6		L0.5	254	2.3				11.5
01SWE01899	18-Jul-01 13:00	59.3	15.5	8.6	40.7	8.3		L0.5	243	8.2				11.8
01SWE02674	21-Aug-01 12:00	66.2	17.1	9.5	43.1	8.8		L0.5	241	11				12.3
01SWE03255	24-Sep-01 12:00	68	16.5	6.9	45.8	7.9		L0.5	231	14.8				15.8
01SWE03466	24-Oct-01 12:00	63	15.5	9.5	44.6	7.3		L0.5	248	5.8				13.2

Notes: 'L' = concentrations are less than the analytical detection limit. **Bold Variable Names** show data presented in the report

Appendix C General physical and chemical characteristics (cont'd)

Sample No.	Valid Method Variable Code:	6005	6015	14102/05 /06/07, 10216	6715	15262	15256	15105/ 15423	15114	15901	15406/21	15422	102649, 7105/10 /11	102647	102648
	Sample Date/Time Vari-ble:	Total Organic Carbon	Total Carbon	Reactive Silica	**Chloro-phyll-*a***	Soluble Reactive Phosphorus	Dissolved Ortho Phosphate	Dissolved Phos-phorus	**Dissolved Phos-phorus**	Particulate Phosph-orus, calc.	Total Phos-phorus	**Total Phos-phorus**	**Nitrite+ Nitrate Nitrogen**	Nitrate Nitrogen	Nitrite Nitrogen
	Units:	mg/L	mg/L	mg/L	mg/m3	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Wabamun Lake East Basin (AB05DE0630)															
82AB000981	26-May-82 12:00				11.76		0.003	0.01			0.027		0.003		
82AB000982	16-Jun-82 12:00			0.8	1.63		0.003	0.01			0.025		0.002		
82AB000983	06-Jul-82 12:00			2	8.42		0.004	0.006			0.025		L0.001		
82AB000984	10-Aug-82 12:00			3.3	15.86		0.005	0.014			0.033		L0.001		
82AB000985	31-Aug-82 12:00			3.7	18.49		0.004	0.012			0.037		L0.001		
82AB000986	21-Sep-82 12:00			3.8	13.14		0.005	0.006			0.031		L0.001		
99SWE02190	20-May-99 10:05			L0.05	7.3				0.0094			0.0288	L0.003	L0.003	L0.003
99SWE02568	17-Jun-99 09:30			0.9	4.5				0.0084			0.0289	L0.003	L0.003	L0.003
99SWE03844	26-Jul-99 08:00			2.2	6.9				0.009			0.0247	0.0015	0.0015	0.0015
99SWE04532	25-Aug-99 07:45			2.95	10.2				0.0081			0.0263	L0.003	L0.003	L0.003
99SWE04995	22-Sep-99 08:00			3.45	6.2				0.0088			0.0262	L0.003	L0.003	L0.003
99SWE05631	03-Nov-99 09:20			2.9	6.8				0.0092			0.0316	0.065	L0.003	0.065
00SWE01460	25-May-00 09:45			0.98	3.6				0.0082			0.0306	L0.003	L0.003	L0.003
00SWE01981	27-Jun-00 08:30			1.05	4.2				0.0085			0.0255	L0.003	L0.003	L0.003
00SWE02820	31-Jul-00 12:00			1.7	6.7				0.0079			0.0267	L0.003	L0.003	L0.003
00SWE03039	22-Aug-00 13:30			2.2	11.3				0.0083			0.0288	L0.003	L0.003	L0.003
00SWE03292	14-Sep-00 09:15			2.15	9.3				0.0089			0.0298	0.004	L0.003	0.004
00SWE03710	24-Oct-00 10:00			2.5	5.2				0.0089			0.0249	0.01	L0.003	0.01
01SWE00692	10-May-01 09:30			1.68	7.8				0.0083			0.0296	0.004	0.004	L0.003
01SWE01349	13-Jun-01 10:00			0.79	5.5				0.0102			0.0342	L0.003	L0.003	L0.003
01SWE01892	18-Jul-01 11:30			1.16	14.1				0.0133			0.0365	0.004	0.004	L0.003
01SWE02655	21-Aug-01 11:00			1.6	12.5				0.0082			0.0295	L0.003		
01SWE03238	24-Sep-01 11:20			2.19	9.3				0.009			0.0317	L0.003	L0.003	L0.003
01SWE03450	24-Oct-01 11:00			2.79	12.8				0.0097			0.0331	0.011	0.007	0.004
Wabamun Lake Main Basin (AB05DE0650)															
83AB001692	03-May-83 11:00			1.9	7.86	0.0035	0.009	0.018	0.0093		0.02	0.025	0.025		
83AB001693	31-May-83 09:00			0.6	3.2	0.00204	0.006	0.018	0.00924		0.03	0.03149	0.002		
83AB001694	28-Jun-83 09:00			0.6	8.3	0.003	0.008	0.016	0.0112		0.046	0.0288	0.003		
83AB001695	27-Jul-83 10:00				17.37	0.00278	L0.002	0.1	0.00934		0.102	0.0358	L0.001		
83AB001696	24-Aug-83 09:00			1.9	11.63	0.00364	0.006	0.016	0.00977		0.032	0.02689	0.003		
83AB001697	20-Sep-83 09:30			1.4	15.27	0.00168	0.005	0.02	0.01224		0.032	0.03471	0.0021		
83AB001698	17-Oct-83 09:00				9.36	0.00131	0.003	0.006	0.00904		0.016	0.03042	0.002		
84AB002148	24-Apr-84 08:00				6.35	0.003			0.007			0.0202			
84AB002149	24-Apr-84 12:00			1									0.039		
84AB002150	09-May-84 09:00					0.0015						0.0234			
84AB002151	09-May-84 12:00			0.7									L0.05		
84AB002152	05-Jun-84 09:00			0.7	6.8	0.0015	0.0015		0.0104			0.0432	L0.001		
84AB002153	04-Jul-84 09:00			1.1	15.4	0.0023			0.0273			0.0308	0.002		
84AB002154	30-Jul-84 09:00			1.4	9.73	0.002	0.0024		0.0095			0.0298	L0.001		
84AB002155	28-Aug-84 10:00			2.3	15.3	0.0018			0.0114			0.0381	0.002		

Appendix C General physical and chemical characteristics (cont'd)

Sample No.	Valid Method Variable Code: / Sample Date/Time / Vari-ble: / Units:	6005 Total Organic Carbon mg/L	6015 Total Carbon mg/L	14102/05/06/07, 10216 Reactive Silica mg/L	6715 **Chloro-phyll-*a*** mg/m3	15262 Soluble Reactive Phosphorus mg/L	15256 Dissolved Ortho Phosphate mg/L	15105/15423 Dissolved Phos-phorus mg/L	15114 **Dissolved Phos-phorus** mg/L	15901 Particulate Phosph-orus, calc. mg/L	15406/21 Total Phos-phorus mg/L	15422 **Total Phos-phorus** mg/L	102649, 7105/10/11 **Nitrite+ Nitrate Nitrogen** mg/L	102647 Nitrate Nitrogen mg/L	102648 Nitrite Nitrogen mg/L
Wabamun Lake Main Basin (AB05DE0650)															
84AB002156	25-Sep-84 10:00			0.9	11.6	0.0024			0.011			0.0305	L0.05		
85AB001812	14-May-85 09:00			L0.5	8.3								0.002		
85AB001813	03-Jun-85 09:00				4.5										
85AB001814	05-Jun-85 09:00			0.7									0.003		
85AB001815	26-Jun-85 09:00			L0.5	13.1		L0.002	0.006			0.018		0.003		
85AB001816	23-Jul-85 09:00			L0.5	8.4		L0.002	0.005			0.015		0.002		
85AB001817	20-Aug-85 09:00			L0.5	13.1		L0.002	0.005			0.017		0.003		
85AB001818	19-Sep-85 09:00			0.9	15.9		0.004	0.008			0.02		0.003		
85AB001819	21-Oct-85 09:00			L0.5	11.1		L0.002	0.006			0.02		0.004		
86AB000989	20-May-86 09:00			L0.5	6.3				0.009			0.03	L0.001		
86AB000990	17-Jun-86 09:00			L0.5	6.8				0.01			0.031	L0.001		
86AB000991	28-Jul-86 14:30			L0.5	11.9				0.009			0.031	L0.001		
86AB000992	12-Aug-86 08:30			0.6	7.2				0.01			0.031	L0.001		
86AB000993	09-Sep-86 09:00			L0.5	16.4				0.009			0.038	0.005		
86AB000994	15-Oct-86 09:00			1	13.4				0.01			0.036	0.003		
87AB000929	05-May-87 10:00			L0.5	4.4				0.01			0.028	L0.001		
87AB000930	04-Jun-87 10:00			L0.5	6.2							0.0398	L0.001		
87AB000931	30-Jun-87 10:00			1.9	7.6				0.013			0.035	0.005		
87AB000932	28-Jul-87 07:00			2.4	15.8				0.01			0.038	0.004		
87AB000933	27-Aug-87 10:00			L0.5	19.6				0.01			0.036	L0.001		
87AB000934	23-Sep-87 10:00			0.9	19.4				0.011			0.045	0.008		
87AB000935	27-Oct-87 09:00			L0.5	14.2				0.013			0.035	0.029		
88AB001580	03-May-88 11:00			L0.5	9				0.0119			0.0346	L0.001		
88AB001581	06-Jun-88 14:00			L0.5	8.5				0.0115			0.0312	0.002		
88AB001582	27-Jun-88 11:30			1.3	6.7				0.0097			0.0296	L0.001		
88AB001583	26-Jul-88 11:00			1.4	8				0.0127			0.0317	L0.001		
88AB001584	15-Aug-88 10:30			2	17				0.0129			0.0388	L0.001		
88AB001585	25-Aug-88 10:00			0.9	14.7				0.0133			0.0397	L0.001		
88AB001586	20-Sep-88 14:00			0.2	17.9				0.0137			0.0329	0.004		
88AB001587	18-Oct-88 11:00			0.1	13.9				0.0135			0.0393	0.004		
89AB001735	15-May-89 11:00			0.6	15.3				0.013			0.0338	0.002		
89AB001736	08-Jun-89 11:00			0.2	4.9				0.0112			0.0411	0.002		
89AB001737	04-Jul-89 11:30				8.3				0.0126			0.0352			
89AB001738	01-Aug-89 11:00			2	11.9				0.0119		0.025	0.0332	0.001		
89AB001739	14-Sep-89 12:00	13.6	49.4	0.3	12.4				0.0126			0.0319	L0.003		
89AB001740	19-Oct-89 12:00	16.5	61.5	0.25	14.5				0.0119		0.03	0.031	L0.003		
90AB000822	03-May-90 11:00			0.6	7.1				0.0112			0.026	0.002		
90AB000823	03-May-90 11:05			0.7	7				0.0104			0.0267	0.002		
90AB000824	03-May-90 11:10			0.6	7.5				0.011			0.026	0.002		
90AB000825	31-May-90 10:00			0.3	7.1				0.0125			0.0327	0.004		
90AB000826	26-Jun-90 10:30			0.9	9				0.0118			0.0351	0.004		
90AB000827	24-Jul-90 11:00			1.9	26.1				0.0111			0.03	0.001		

Appendix C General physical and chemical characteristics (cont'd)

Sample No.	Valid Method Variable Code:	6005	6015	14102/05 /06/07, 10216	6715	15262	15256	15105/ 15423	15114	15901	15406/21	15422	102649, 7105/10 /11	102647	102648
	Sample Date/Time Vari-ble:	Total Organic Carbon	Total Carbon	Reactive Silica	**Chloro-phyll-*a***	Soluble Reactive Phosphorus	Dissolved Ortho Phosphate	Dissolved Phos-phorus	**Dissolved Phos-phorus**	Particulate Phosph-orus, calc.	Total Phos-phorus	**Total Phos-phorus**	**Nitrite+ Nitrate Nitrogen**	Nitrate Nitrogen	Nitrite Nitrogen
	Units:	mg/L	mg/L	mg/L	mg/m3	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Wabamun Lake Main Basin (AB05DE0650)															
90AB000828	21-Aug-90 10:00			2.7	25.5				0.0136			0.0416	0.003		
90AB000829	24-Sep-90 10:30			2.1	27.2				0.0136			0.0373	0.001		
90AB000837	18-Oct-90 11:00			1.7	18.1				0.014			0.0415	0.009		
91AB001366	07-May-91 11:30				10.7				0.0118			0.0347			
91AB001367	06-Jun-91 09:00				4.6				0.0112			0.0303			
91AB001368	03-Jul-91 08:30				7.4				0.0132			0.0298			
91AB001369	23-Jul-91 10:30				11.2				0.0135			0.0295			
91AB001370	22-Aug-91 11:00			3.7	17				0.0126			0.0392	0.001		
91AB001371	24-Sep-91 09:00			1.4	15.8				0.0135			0.0407	0.001		
92AB001156	30-Apr-92 11:30			0.9	8.5				0.0105			0.0252	0.002		
92AB001157	26-May-92 13:00			0.7	4.8				0.0108			0.0287	0.001		
92AB001158	23-Jun-92 09:00			0.9	6.2				0.0104			0.0235	L0.001		
92AB001159	16-Jul-92 10:30			2.3	14.5				0.0099			0.033	0.002		
92AB001160	10-Aug-92 15:00			3.5	19				0.0135			0.039	0.001		
92AB001161	11-Sep-92 08:00			4.8	20.4				0.0128			0.0474	0.002		
92AB001162	05-Oct-92 12:00			4.9	15.5				0.0118			0.0348	0.002		
93AB001296	11-May-93 10:00			4.7	8.8			0.006	0.0131			0.0274	0.003		
93AB001306	01-Jun-93 09:30			4	6.1			0.01	0.0229			0.0331	0.003		
93AB001307	28-Jun-93 11:00			3.4	14.7			0.019	0.0129		0.041	0.0538	0.009		
93AB001308	27-Jul-93 09:30			2.5	16.7			0.006	0.0116		0.024	0.0297	0.002		
93AB001309	19-Aug-93 09:00			1.6	11			0.01	0.0143		0.024	0.0359	0.005		
93AB001310	14-Sep-93 10:00			2	13.7			0.008	0.0127		0.027	0.0358	0.001		
93AB001311	12-Oct-93 11:00			2.1	10.2			0.012	0.0131		0.027	0.0313	0.004		
94AB000826	28-Apr-94 11:30			1.9	8.9			0.008	0.0104		0.024	0.028	0.018		
94AB000827	25-May-94 10:00			0.7	5.3			0.007	0.011		0.015	0.0305	0.001		
94AB000828	21-Jun-94 09:30			1.1	8			0.01	0.0116		0.03	0.033	0.003		
94AB000829	12-Jul-94 13:30			2.2	14.3			0.008	0.014		0.028	0.046	0.003		
94AB000830	03-Aug-94 10:30				13.9				0.0103			0.0399			
94AB000831	24-Aug-94 10:00			4.2	22.7			0.012	0.0127		0.033	0.0416	0.002		
94AB000832	20-Sep-94 10:00				12.6				0.0138			0.0426			
94AB000833	18-Oct-94 11:00			5.9	12.5			0.012	0.0129		0.031	0.0365	0.003		
95AB002313	03-May-95 11:20			5	10.4			0.007	0.0146		0.025	0.0314	0.003		
95AB002314	30-May-95 10:00			4.6	3.2			0.006	0.0109		0.022	0.0285	0.001		
95AB002315	27-Jun-95 09:45			4.3	7.5			0.01	0.0122		0.022	0.0321	L0.001		
95AB002316	19-Jul-95 09:20			5.3	4.8			0.006	0.0099		0.04	0.045	0.002		
95AB002317	10-Aug-95 09:00			5.9	21.2			0.009	0.0114		0.039	0.0467	0.003		
95AB002318	30-Aug-95 08:45			4.8	19.6			0.009	0.0105		0.03	0.037	L0.001		
95AB002319	27-Sep-95 10:00			2.9	13.7			0.009	0.0113		0.028	0.0312	0.017		
95AB002320	20-Oct-95 10:00			2.9	9.7			0.008	0.0115		0.028	0.0352	L0.001		
96AB000730	13-May-96 11:00	12.4		2.25	7.7				0.0131			0.0293	L0.003		
96AB000731	04-Jun-96 10:00	12.6		1.55	2.6				0.0087			0.0253	L0.003		

Appendix C General physical and chemical characteristics (cont'd)

Sample No.	Valid Method Variable Code:	6005	6015	14102/05 /06/07, 10216	6715	15262	15256	15105/ 15423	15114	15901	15406/21	15422	102649, 7105/10 /11	102647	102648
	Sample Date/Time Vari-ble:	Total Organic Carbon	Total Carbon	Reactive Silica	**Chloro-phyll-*a***	Soluble Reactive Phosphorus	Dissolved Ortho Phosphate	Dissolved Phos-phorus	**Dissolved Phos-phorus**	Particulate Phosph-orus, calc.	Total Phos-phorus	**Total Phos-phorus**	**Nitrite+ Nitrate Nitrogen**	Nitrate Nitrogen	Nitrite Nitrogen
	Units:	mg/L	mg/L	mg/L	mg/m3	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Wabamun Lake Main Basin (AB05DE0650)															
96SWE00253	26-Jun-96 09:00	13.9		1	8.3				0.011			0.0349	0.003		
96SWE00374	09-Jul-96 12:10	12.6		1.46	8				0.0114			0.0277			
96SWE00796	23-Jul-96 10:00	12.9		1.64	12				0.0105			0.041	L0.003		
96SWE01090	07-Aug-96 09:00	14.5		2.22	15				0.009			0.0409	L0.003		
96SWE01305	21-Aug-96 10:15	13.1		1.7	14.2				0.011			0.0384	0.006		
96SWE01686	05-Sep-96 10:00	12		1.45	20.1				0.0108			0.0426	0.004		
96SWE01890	17-Sep-96 10:30	11.9		L0.05	14.5				0.0126			0.0363	L0.003		
96SWE02202	08-Oct-96 10:00	12.4		0.2	9.8						0.025		0.011		
97SWE01247	14-May-97 08:45			0.5	9.4				0.008			0.0294	L0.003		
97SWE01712	10-Jun-97 12:15			3.65	4.1				0.0091			0.0268	L0.003		
97SWE02059	08-Jul-97 10:45			1.58	7				0.0101			0.0332	0.003		
97SWE02296	24-Jul-97 10:00			1.75	9.3				0.0115			0.0326	L0.003		
97SWE02492	05-Aug-97 13:00			1.7	10.9				0.011			0.0302	0.022		
97SWE03145	03-Sep-97 08:50			1.4	27.3				0.013			0.0565	0.003		
97SWE03586	24-Sep-97 09:20			L0.05	16.7				0.0123			0.0343	0.005		
97SWE03921	15-Oct-97 10:30			L0.05	27.8				0.0127			0.044	0.004		
98SWE00656	11-May-98 10:15	12.9		L0.05	7.7			0.006			0.027		0.01		
98SWE00881	10-Jun-98 09:00	13.8		1	7				0.0116			0.0334	L0.003		
98SWE01239	07-Jul-98 10:00	12.5		1.5	16.5				0.012			0.0434	L0.003		
98SWE01619	04-Aug-98 09:15	12.9		1.9	14.3				0.0121			0.0331	0.008		
98SWE02112	31-Aug-98 11:30	14		2.96	21.1				0.0127			0.0444	L0.003		
Wabamun Lake West Basin (AB05DE0620)															
99SWE02208	20-May-99 11:05			L0.05	9.4				0.00954			0.0304	L0.003	L0.003	L0.003
99SWE02555	17-Jun-99 10:00			0.75	4.4				0.008			0.0226	L0.003	L0.003	L0.003
99SWE03679	26-Jul-99 09:30			2.55	7.8				0.0088			0.0272	L0.003	L0.003	L0.003
99SWE04550	25-Aug-99 08:30			3.32	11.5				0.0084			0.0264	L0.003	L0.003	L0.003
99SWE04980	22-Sep-99 09:00			2.95	7.4				0.0087			0.0284	L0.003	L0.003	L0.003
99SWE05617	03-Nov-99 10:05			3	8.5				0.0091			0.0311	0.004	L0.003	0.004
00SWE01470	25-May-00 11:30			1.22	4.5				0.0082			0.0284	L0.003	L0.003	L0.003
00SWE01967	27-Jun-00 10:00			1.3	4.1				0.0083			0.0262	L0.003	L0.003	L0.003
00SWE02837	31-Jul-00 10:00			1.88	8.4				0.0081			0.0254	L0.003	L0.003	L0.003
00SWE03052	22-Aug-00 10:45			2.75	15.5				0.0086			0.0335	L0.003	L0.003	L0.003
00SWE03279	14-Sep-00 08:15			2.26	9				0.01			0.0287	0.005	L0.003	0.005
00SWE03721	24-Oct-00 09:00			2.8	7.6				0.0099			0.0268	L0.003	L0.003	L0.003
01SWE00669	10-May-01 11:00			2.36	12.9				0.0086			0.0325	0.016	0.016	L0.003
01SWE01335	13-Jun-01 11:00			1.01	5.7				0.0094			0.0282	L0.003	L0.003	L0.003
01SWE01899	18-Jul-01 13:00			1.49	13.8				0.0112			0.0285	L0.003	L0.003	L0.003
01SWE02674	21-Aug-01 12:00			1.82	11				0.0085			0.0266	L0.003		
01SWE03255	24-Sep-01 12:00			2.08	10.7				0.0087			0.0293	0.01	0.007	0.003
01SWE03466	24-Oct-01 12:00			2.87	14.5				0.0095			0.0369	0.017	0.013	0.004

Notes: 'L' = concentrations are less than the analytical detection limit. **Bold Variable Names** show data presented in the report

Appendix C General physical and chemical characteristics (cont'd)

Sample No.	Sample Date/Time	Dissolved Nitrite Nitrogen	**Ammonia Nitrogen**	**Total Kjeldahl Nitrogen**	Dissolved Kjeldahl Nitrogen	Total Particulate Nitrogen	Mangan-ese, diss.	Iron, diss.
	Valid Method Variable Code:	7205/06	7505/55/61/62	7015/21	7017	7906	102089	102090
	Units:	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Wabamun Lake East Basin (AB05DE0630)								
82AB000981	26-May-82 12:00	L0.001	0.029	0.8	0.55	0.14		
82AB000982	16-Jun-82 12:00	L0.001	0.015	0.75	0.625	0.07		
82AB000983	06-Jul-82 12:00	L0.001	0.04	0.8	0.675	0.16		
82AB000984	10-Aug-82 12:00	L0.001	0.017	0.95	0.71	0.28		
82AB000985	31-Aug-82 12:00	L0.001	0.048	0.91	0.69	0.33		
82AB000986	21-Sep-82 12:00	L0.001	0.011	0.87	0.7	0.13		
99SWE02190	20-May-99 10:05		0.01	0.72				
99SWE02568	17-Jun-99 09:30		0.01	0.88				
99SWE03844	26-Jul-99 08:00		0.005	0.92				
99SWE04532	25-Aug-99 07:45		L0.01	1.32				
99SWE04995	22-Sep-99 08:00		0.01	0.83				
99SWE05631	03-Nov-99 09:20		L0.01	0.92				
00SWE01460	25-May-00 09:45		L0.01	0.82				
00SWE01981	27-Jun-00 08:30		L0.01	0.79				
00SWE02820	31-Jul-00 12:00		0.02	1.02				
00SWE03039	22-Aug-00 13:30		L0.01	0.87				
00SWE03292	14-Sep-00 09:15		0.02	0.72				
00SWE03710	24-Oct-00 10:00		L0.01	0.73				
01SWE00692	10-May-01 09:30		L0.01	0.79			L0.004	L0.01
01SWE01349	13-Jun-01 10:00		L0.01	0.83			L0.004	L0.01
01SWE01892	18-Jul-01 11:30	L0.003	0.06	0.78			L0.004	L0.01
01SWE02655	21-Aug-01 11:00		L0.01	1.09			L0.004	0.02
01SWE03238	24-Sep-01 11:20		L0.01	0.49			L0.004	L0.01
01SWE03450	24-Oct-01 11:00		L0.01	0.93			L0.004	L0.01
Wabamun Lake Main Basin (AB05DE0650)								
83AB001692	03-May-83 11:00	0.002	0.014	0.68	0.57	0.67		
83AB001693	31-May-83 09:00	L0.001	L0.002	0.62	0.6	L0.01		
83AB001694	28-Jun-83 09:00	L0.001	0.034	0.77	0.6	L0.01		
83AB001695	27-Jul-83 10:00	L0.001	0.009	0.74	0.7	0.46		
83AB001696	24-Aug-83 09:00	L0.001	0.035	0.86	0.64	0.14		
83AB001697	20-Sep-83 09:30	0.002	0.015	0.9	0.7	0.11		
83AB001698	17-Oct-83 09:00	L0.001	0.012	0.8	0.7	0.17		
84AB002148	24-Apr-84 08:00							
84AB002149	24-Apr-84 12:00	L0.001	0.017	0.78	0.68	0.12		
84AB002150	09-May-84 09:00							
84AB002151	09-May-84 12:00	L0.001	0.006	0.74	0.68	0.23		
84AB002152	05-Jun-84 09:00	L0.001	L0.002	0.73	0.66	0.19		
84AB002153	04-Jul-84 09:00	0.002	0.017	0.82	0.8	0.25		
84AB002154	30-Jul-84 09:00	L0.001	0.018	0.96	0.74	0.22		
84AB002155	28-Aug-84 10:00	L0.001	0.052	0.94	0.68	0.38		

Appendix C General physical and chemical characteristics (cont'd)

Sample No.	Sample Date/Time	Valid Method Variable Code: / Variable: / Units:	Dissolved Nitrite Nitrogen (7205/06) mg/L	**Ammonia Nitrogen** (7505/55/61/62) mg/L	**Total Kjeldahl Nitrogen** (7015/21) mg/L	Dissolved Kjeldahl Nitrogen (7017) mg/L	Total Particulate Nitrogen (7906) mg/L	Mangan-ese, diss. (102089) mg/L	Iron, diss. (102090) mg/L
Wabamun Lake Main Basin (AB05DE0650)									
84AB002156	25-Sep-84 10:00			0.035	0.86	0.75	0.2		
85AB001812	14-May-85 09:00		L0.001	0.004	0.8	0.64	0.12		
85AB001813	03-Jun-85 09:00								
85AB001814	05-Jun-85 09:00		L0.001	0.006	0.8	0.76	0.12		
85AB001815	26-Jun-85 09:00		L0.001	L0.002	0.8	0.64	0.2		
85AB001816	23-Jul-85 09:00		0.002	0.008	0.76	0.7	2.43		
85AB001817	20-Aug-85 09:00		L0.001	0.01	0.7	0.7			
85AB001818	19-Sep-85 09:00		L0.001	0.025	0.86	0.64	0.26		
85AB001819	21-Oct-85 09:00		L0.001	0.008	0.88	0.7	0.13		
86AB000989	20-May-86 09:00		L0.001	0.018	0.8	0.64	0.1		
86AB000990	17-Jun-86 09:00		L0.001	0.009	0.74	0.61			
86AB000991	28-Jul-86 14:30		L0.001	0.025	1	0.67	0.22		
86AB000992	12-Aug-86 08:30		L0.001	0.013	0.9	0.66	0.13		
86AB000993	09-Sep-86 09:00		0.002	0.016	1.01	0.72	0.2		
86AB000994	15-Oct-86 09:00		L0.001	0.02	0.84	0.7	0.08		
87AB000929	05-May-87 10:00		L0.001	0.018	0.836				
87AB000930	04-Jun-87 10:00		L0.001	0.02	0.718				
87AB000931	30-Jun-87 10:00		L0.001	0.009	0.722	0.569			
87AB000932	28-Jul-87 07:00		L0.001	0.014	0.971				
87AB000933	27-Aug-87 10:00		L0.001	0.009	1.02				
87AB000934	23-Sep-87 10:00		L0.001	0.023	1				
87AB000935	27-Oct-87 09:00		L0.001	0.04	0.955				
88AB001580	03-May-88 11:00		L0.001	0.009	0.83				
88AB001581	06-Jun-88 14:00		L0.001	0.012	0.9				
88AB001582	27-Jun-88 11:30		L0.001	0.01	0.932				
88AB001583	26-Jul-88 11:00		L0.001	0.008	0.883				
88AB001584	15-Aug-88 10:30		L0.005	0.018	1.12				
88AB001585	25-Aug-88 10:00		L0.005	0.016	1.18				
88AB001586	20-Sep-88 14:00		0.002	0.024	0.92		0.14		
88AB001587	18-Oct-88 11:00		0.002	0.026	0.83		0.12		
89AB001735	15-May-89 11:00		0.001	0.016	0.88	0.72			
89AB001736	08-Jun-89 11:00		0.001	0.028	0.81				
89AB001737	04-Jul-89 11:30								
89AB001738	01-Aug-89 11:00		0.001	0.015	0.87				
89AB001739	14-Sep-89 12:00			0.03	0.72				
89AB001740	19-Oct-89 12:00			0.06	1.14				
90AB000822	03-May-90 11:00		0.001	0.024	0.86		0.11		
90AB000823	03-May-90 11:05		0.001	0.012	0.84		0.12		
90AB000824	03-May-90 11:10		0.001	0.026	0.85		0.12		
90AB000825	31-May-90 10:00		0.001	0.018	0.82		0.16		
90AB000826	26-Jun-90 10:30		0.001	0.005	0.89		0.12		
90AB000827	24-Jul-90 11:00		L0.001	0.012	1.08		0.33		

Appendix C General physical and chemical characteristics (cont'd)

Sample No.	Sample Date/Time	Valid Method Variable Code:	7205/06	7505/55/61/62	7015/21	7017	7906	102089	102090
		Vari-ble:	Dissolved Nitrite Nitrogen	**Ammonia Nitrogen**	**Total Kjeldahl Nitrogen**	Dissolved Kjeldahl Nitrogen	Total Particulate Nitrogen	Mangan-ese, diss.	Iron, diss.
		Units:	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Wabamun Lake Main Basin (AB05DE0650)									
90AB000828	21-Aug-90 10:00		0.001	0.015	1.06		0.21		
90AB000829	24-Sep-90 10:30		0.001	0.01	1.06		0.33		
90AB000837	18-Oct-90 11:00		L0.001	0.03	1.03		0.34		
91AB001366	07-May-91 11:30								
91AB001367	06-Jun-91 09:00								
91AB001368	03-Jul-91 08:30								
91AB001369	23-Jul-91 10:30								
91AB001370	22-Aug-91 11:00			0.012	0.85				
91AB001371	24-Sep-91 09:00		L0.001	0.015	0.91				
92AB001156	30-Apr-92 11:30		L0.001	0.005	0.76				
92AB001157	26-May-92 13:00		L0.001	0.011	0.82				
92AB001158	23-Jun-92 09:00		L0.001	0.007	0.77				
92AB001159	16-Jul-92 10:30		L0.001	0.006	0.7				
92AB001160	10-Aug-92 15:00		L0.001	0.014	1.04		0.32		
92AB001161	11-Sep-92 08:00		L0.001	0.004	0.99		0.3		
92AB001162	05-Oct-92 12:00		L0.001	0.011	1		0.26		
93AB001296	11-May-93 10:00		L0.001	0.018	0.87		0.15		
93AB001306	01-Jun-93 09:30		L0.001	0.012	0.84		0.25		
93AB001307	28-Jun-93 11:00		0.003	0.013	0.98		0.29		
93AB001308	27-Jul-93 09:30		0.002	0.007	1		0.31		
93AB001309	19-Aug-93 09:00		L0.001	0.015	1		0.2		
93AB001310	14-Sep-93 10:00		L0.001	0.013	0.99		0.49		
93AB001311	12-Oct-93 11:00		0.001	0.014	1.02		0.2		
94AB000826	28-Apr-94 11:30		L0.001	0.032	0.94		0.17		
94AB000827	25-May-94 10:00		L0.001	0.01	0.92		0.19		
94AB000828	21-Jun-94 09:30		L0.001	0.012	0.98		0.21		
94AB000829	12-Jul-94 13:30		L0.001	0.005	1.02		0.4		
94AB000830	03-Aug-94 10:30								
94AB000831	24-Aug-94 10:00		L0.001	0.004	1.15		0.38		
94AB000832	20-Sep-94 10:00								
94AB000833	18-Oct-94 11:00		0.001	0.01	1.06		0.26		
95AB002313	03-May-95 11:20		L0.001	0.012	0.97		0.15		
95AB002314	30-May-95 10:00		0.002	0.007	0.84		0.03		
95AB002315	27-Jun-95 09:45		L0.001	0.007	0.96		0.16		
95AB002316	19-Jul-95 09:20		L0.001	0.007	1.03		0.42		
95AB002317	10-Aug-95 09:00		L0.001	0.013	1.04		0.4		
95AB002318	30-Aug-95 08:45		L0.001	0.015	0.93		0.33		
95AB002319	27-Sep-95 10:00		0.002	0.012	0.98		0.28		
95AB002320	20-Oct-95 10:00		L0.001	0.01	0.95		0.25		
96AB000730	13-May-96 11:00			L0.01	0.84				
96AB000731	04-Jun-96 10:00			0.15	0.81				

Appendix C General physical and chemical characteristics (cont'd)

Sample No.	Sample Date/Time	Dissolved Nitrite Nitrogen	**Ammonia Nitrogen**	**Total Kjeldahl Nitrogen**	Dissolved Kjeldahl Nitrogen	Total Particulate Nitrogen	Manganese, diss.	Iron, diss.
	Valid Method Variable Code:	7205/06	7505/55/61/62	7015/21	7017	7906	102089	102090
	Units:	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Wabamun Lake Main Basin (AB05DE0650)								
96SWE00253	26-Jun-96 09:00		0.09	0.88				
96SWE00374	09-Jul-96 12:10		0.02	0.87				
96SWE00796	23-Jul-96 10:00		L0.01	0.88				
96SWE01090	07-Aug-96 09:00		0.03					
96SWE01305	21-Aug-96 10:15		L0.01	0.64				
96SWE01686	05-Sep-96 10:00		0.04	1.01				
96SWE01890	17-Sep-96 10:30		L0.01	0.73				
96SWE02202	08-Oct-96 10:00		0.02	0.81				
97SWE01247	14-May-97 08:45		0.03	0.67				
97SWE01712	10-Jun-97 12:15		0.03	0.94				
97SWE02059	08-Jul-97 10:45		L0.01	0.74				
97SWE02296	24-Jul-97 10:00		0.01					
97SWE02492	05-Aug-97 13:00		0.02	0.78				
97SWE03145	03-Sep-97 08:50		0.01	1.25				
97SWE03586	24-Sep-97 09:20		L0.01	0.94				
97SWE03921	15-Oct-97 10:30		0.02	0.62				
98SWE00656	11-May-98 10:15		0.01	0.63				
98SWE00881	10-Jun-98 09:00		L0.01	0.88				
98SWE01239	07-Jul-98 10:00		0.02	0.95				
98SWE01619	04-Aug-98 09:15		0.03	1.23				
98SWE02112	31-Aug-98 11:30		0.01	0.97				
Wabamun Lake West Basin (AB05DE0620)								
99SWE02208	20-May-99 11:05		0.01	0.78				
99SWE02555	17-Jun-99 10:00		0.01	0.85				
99SWE03679	26-Jul-99 09:30		L0.01	0.89				
99SWE04550	25-Aug-99 08:30		L0.01	0.99				
99SWE04980	22-Sep-99 09:00		0.01	0.84				
99SWE05617	03-Nov-99 10:05		L0.01	0.72				
00SWE01470	25-May-00 11:30		0.01	0.77				
00SWE01967	27-Jun-00 10:00		0.01	0.64				
00SWE02837	31-Jul-00 10:00		0.03	1.11				
00SWE03052	22-Aug-00 10:45		0.02	1.04				
00SWE03279	14-Sep-00 08:15		0.01	0.73				
00SWE03721	24-Oct-00 09:00		L0.01	0.7				
01SWE00669	10-May-01 11:00		L0.01	0.87			L0.004	L0.01
01SWE01335	13-Jun-01 11:00		L0.01	0.72			L0.004	L0.01
01SWE01899	18-Jul-01 13:00		0.02	1.14			L0.004	L0.01
01SWE02674	21-Aug-01 12:00		L0.01	1.05			L0.004	L0.01
01SWE03255	24-Sep-01 12:00		L0.01	0.39			L0.004	L0.01
01SWE03466	24-Oct-01 12:00		L0.01	0.85			L0.004	L0.01

Notes: 'L' = concentrations are less than the analytical detection limit. **Bold Variable Names** show data presented in the report

Appendix D Metal concentrations (mg/L) in Wabamun Lake, 1996 to 2001

Sample No.	Sample Date/Time	Depth (m)	Aluminum	Antimony	Arsenic	Barium	Beryllium	Bismuth	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead
Wabamun Lake East Basin (AB05DE0590)															
96AB000723	21-Feb-96 10:40	6	0.0065	0.0002	0.0044	0.125	L0.0001	L0.00001	0.968	L0.00004	0.00018	0.00012	0.0011	L0.02	L0.00002
99SWE00288	25-Feb-99 14:57	7	0.0073	0.00018	0.0022	0.148	L0.00004	L0.000005	0.918	L0.00002	0.0003	0.00004	0.0013	L0.003	0.0001
99SWE03858	26-Jul-99 09:00	6	0.048	0.000177	0.00232	0.119	L0.00004	L0.000005	0.842	0.000023	0.00041	0.000055	0.00093	0.029	0.00095
00SWE00183	10-Feb-00 15:20	6	0.014	0.00019	0.00245	0.126	L0.00004	L0.000005	0.867	L0.00002	0.00014	0.000045	0.00087	L0.003	0.00016
00SWE03048	22-Aug-00 13:22	6	0.0316	0.000196	0.0035	0.114	L0.00004	0.000006	0.851	L0.00002	0.00015	0.00005	0.00085	0.022	0.00024
01SWE00170	26-Feb-01 16:05	6	0.0068	0.00022	0.00275	0.125	0.00013	L0.000005	0.858	L0.00002	0.00033	0.000049	L0.00008	0.007	L0.00001
01SWE01890	18-Jul-01 11:00	6	0.037	0.0002	0.003	0.115	L0.00004	L0.000005	0.875	L0.00002	0.00018	L0.00002	L0.00008	0.019	0.00105
Wabamun Lake Indian Bay (AB05DE0610) (also known as Goosequill or Sundance Bay)															
99SWE00290	25-Feb-99 14:10	1	0.0054	0.00021	0.00284	0.13	0.00006	0.000008	0.959	L0.00002	0.00024	0.00005	0.00074	L0.003	0.000032
99SWE00294	25-Feb-99 14:17	4.5	0.0083	0.000187	0.00282	0.146	L0.00004	0.000005	0.983	0.00002	0.00032	0.00002	0.00063	L0.003	0.000029
00SWE00188	10-Feb-00 15:50	1	0.00365	0.000204	0.00286	0.127	L0.00004	L0.000005	0.917	L0.00002	0.00014	L0.00002	0.00074	L0.003	0.000149
00SWE00191	10-Feb-00 15:54	4	0.00794	0.000193	0.00275	0.125	L0.00004	L0.000005	0.883	L0.00002	0.00011	L0.00002	0.00086	L0.003	0.000163
01SWE00147	26-Feb-01 14:00	1	0.0056	0.00021	0.0031	0.124	0.00009	0.000016	0.859	0.00002	0.00032	0.000044	L0.00008	L0.003	L0.00001
01SWE00148	26-Feb-01 14:02	3	0.0029	0.000201	0.00309	0.127	0.00011	0.000011	0.867	L0.00002	0.00032	0.000026	L0.00008	0.005	L0.00001
Wabamun Lake West Basin (AB05DE0580)															
99SWE00305	25-Feb-99 11:52	9	0.0094	0.000188	0.00267	0.151	0.00009	L0.000005	0.968	L0.00002	0.0005	0.00003	0.00064	L0.003	0.000034
00SWE00175	10-Feb-00 11:36	9	0.0066	0.000173	0.00286	0.141	L0.00004	L0.000005	0.937	0.000027	0.00011	0.000024	0.00078	0.024	0.000182
00SWE03069	22-Aug-00 10:56	9	0.017	0.00023	0.0031	0.115	0.00004	L0.000005	0.838	L0.00002	0.00014	0.000029	0.00072	0.007	0.00017
01SWE00161	26-Feb-01 11:08	9	0.0048	0.00018	0.00272	0.122	0.00013	0.000007	0.834	L0.00002	0.0003	0.00003	L0.00008	0.006	L0.00001
01SWE01916	18-Jul-01 12:30	9	0.0272	0.00021	0.00287	0.115	L0.00004	L0.000005	0.885	L0.00002	L0.0001	L0.00002	L0.00008	0.013	L0.00001

Sample No.	Sample Date/Time	Depth (m)	Lithium	Manganese	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Thorium	Tin	Titanium	Uranium	Vanadium	Zinc
Wabamun Lake East Basin (AB05DE0590)																
96AB000723	21-Feb-96 10:40	6	0.0386	0.0176	0.00597	0.00099	0.0006	L0.00002	0.276	0.00001	L0.00003	L0.00005	0.001	0.00063	0.00151	0.0008
99SWE00288	25-Feb-99 14:57	7	0.0394	0.458	0.0073	L0.00006	L0.0005	L0.000005	0.329	0.000007	0.000007	L0.0001	0.0008	0.00062	0.0008	0.0057
99SWE03858	26-Jul-99 09:00	6	0.0361	0.041	0.00562	0.0002	L0.0004	0.000011	0.266	L0.000003	0.000004	L0.0001	0.0015	0.00067	0.00097	0.0022
00SWE00183	10-Feb-00 15:20	6	0.0381	0.0081	0.00636	L0.00006	L0.0004	L0.000005	0.294	0.00002	L0.000003	L0.0001	0.0006	0.00075	0.00123	0.0021
00SWE03048	22-Aug-00 13:22	6	0.0342	0.0487	0.00528	0.00016	L0.0005	L0.000005	0.263	0.000006	0.000039	0.000102	0.0013	0.00063	0.00174	0.0012
01SWE00170	26-Feb-01 16:05	6	0.0405	0.00846	0.00604	0.0002	0.0008	0.0000025	0.327	0.000011	0.000007	L0.0001	0.00097	0.000722	0.0014	0.00072
01SWE01890	18-Jul-01 11:00	6	0.0325	0.0613	0.005	L0.00006	L0.0005	0.0000025	0.276	0.000021	0.000016	L0.0001	0.0011	0.00059	0.00154	0.003
Wabamun Lake Indian Bay (AB05DE0610) (also known as Goosequill or Sundance Bay)																
99SWE00290	25-Feb-99 14:10	1	0.0409	0.00281	0.00594	L0.00006	L0.0005	L0.000005	0.274	0.000022	0.000011	L0.0001	0.0008	0.00063	0.00121	0.00244
99SWE00294	25-Feb-99 14:17	4.5	0.0412	0.0374	0.0053	L0.00006	L0.0005	L0.000005	0.297	0.000003	0.000007	L0.0001	0.0007	0.000545	0.00093	0.00197
00SWE00188	10-Feb-00 15:50	1	0.0405	0.00244	0.00658	L0.00006	L0.0004	L0.000005	0.297	0.00002	L0.000003	L0.0001	0.0006	0.00071	0.00141	0.0045
00SWE00191	10-Feb-00 15:54	4	0.0388	0.00258	0.0064	L0.00006	L0.0004	L0.000005	0.287	0.000016	L0.000003	L0.0001	0.0004	0.00069	0.00141	0.00802
01SWE00147	26-Feb-01 14:00	1	0.0415	0.00284	0.00618	0.00021	0.0006	0.0000025	0.319	0.000006	0.000015	L0.0001	0.00073	0.0007	0.00165	0.0027
01SWE00148	26-Feb-01 14:02	3	0.0404	0.0054	0.00599	0.00016	0.0007	0.0000025	0.317	0.000013	0.000009	0.000163	0.0007	0.00069	0.00156	0.00106
Wabamun Lake West Basin (AB05DE0580)																
99SWE00305	25-Feb-99 11:52	9	0.04	0.543	0.00491	L0.00006	L0.0005	L0.000005	0.286	L0.000003	0.000006	L0.0001	0.0009	0.00057	0.00085	0.0023
00SWE00175	10-Feb-00 11:36	9	0.038	0.332	0.0047	L0.00006	L0.0004	L0.000005	0.309	0.00002	L0.000003	0.000165	0.0007	0.00057	0.00076	0.00777
01SWE01916	18-Jul-01 12:30	9	0.0321	0.0612	0.00477	L0.00006	L0.0005	0.0000025	0.274	0.000021	0.000006	L0.0001	0.0009	0.00059	0.00136	0.00889
00SWE03069	22-Aug-00 10:56	9	0.0344	0.0491	0.00528	0.0002	L0.0005	L0.000005	0.262	L0.000003	0.000015	L0.0001	0.001	0.00061	0.00154	0.00255
01SWE00161	26-Feb-01 11:08	9	0.0396	0.0177	0.00567	0.00024	0.0007	0.000005	0.308	0.000017	0.000006	L0.0001	0.0008	0.00067	0.0014	0.00091

Notes: Metal concentrations include those analysed by total recoverable and extractable methods. 'L' = concentrations are less than the analytical detection limit.

Appendix E Field blank samples collected on dates when mercury was sampled in Wabamun Lake, 1996 to 2001

Sample No.	Sample Date/Time	101979 Mercury, Total (ng/L)
96SWE00265	26-Jun-96 10:00	0.8
96SWE00809	23-Jul-96 10:00	1.9
96SWE01320	21-Aug-96 11:00	1.9
96SWE01906	17-Sep-96 11:00	1.7
96SWE03156	17-Sep-96 11:05	1.3
97SWE00260	18-Feb-97 9:00	0.6
97SWE00261	18-Feb-97 9:30	0.6
97SWE00259	18-Feb-97 13:21	0.6
97SWE00253	18-Feb-97 15:00	0.6
97SWE00243	18-Feb-97 16:50	0.6
97SWE01714	10-Jun-97 11:35	0.6
97SWE04144	24-Jul-97 10:16	0.6
97SWE04145	24-Jul-97 10:17	0.7
97SWE03161	3-Sep-97 10:00	0.6
97SWE04507	3-Sep-97 10:30	0.6
97SWE03603	24-Sep-97 9:45	0.6
97SWE03606	24-Sep-97 11:00	0.6
99SWE00306	25-Feb-99 15:00	0.6
99SWE02059	20-May-99 14:00	2.9
99SWE03857	26-Jul-99 8:50	1.8
99SWE03862	26-Jul-99 13:30	3.6
99SWE05641	3-Nov-99 12:30	1.4
00SWE00176	10-Feb-00 11:38	0.6
00SWE00186	10-Feb-00 15:25	3.6
00SWE00193	10-Feb-00 15:57	3.9
00SWE00194	10-Feb-00 15:59	1
00SWE01991	27-Jun-00 14:30	0.6
00SWE02851	31-Jul-00 15:00	2.5
00SWE03068	22-Aug-00 10:40	0.6
00SWE03050	22-Aug-00 13:35	1.1
00SWE03072	22-Aug-00 15:40	0.6
01SWE00162	26-Feb-01 11:10	0.6
01SWE00149	26-Feb-01 14:05	0.8
01SWE00150	26-Feb-01 14:10	0.6
01SWE00171	26-Feb-01 16:10	0.6
01SWE01897	18-Jul-01 11:50	1.3
01SWE01919	18-Jul-01 13:30	1.5
01SWE01922	18-Jul-01 15:30	1.4
01SWE02639	21-Aug-01 14:00	1.3

Shaded cells are half the analytical detection limit

Appendix F Observed and predicted concentrations of major ions and related variables in Wabamun Lake, 1982 to 2001

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Lake Volume (dam^3) [1]:	522200	506700	497800	499500	498200	488700	474200	489800	507000	507000	491700	475300
Total Alkalinity (mg/L)												
Observed Concentration [2]	187	189	195	193	197	199	203	197	200	200	203	203
Predicted Concentration [3]		193	196	195	196	200	206	199	193	193	199	205
Observed:Predicted (%)		**98**	**99**	**99**	**100**	**100**	**98**	**99**	**104**	**104**	**102**	**99**
Conductivity (uS/cm)												
Observed Concentration [2]	404	419	415	422	423	430	438	428	436	435	447	442
Predicted Concentration [3]		416	424	422	423	432	445	431	416	416	429	444
Observed:Predicted (%)		**101**	**98**	**100**	**100**	**100**	**98**	**99**	**105**	**104**	**104**	**100**
TDS (mg/L)												
Observed Concentration [2]	227	232	237	235	240	245	254	250	248	245	256	252
Predicted Concentration [3]		234	238	237	238	243	250	242	234	234	241	249
Observed:Predicted (%)		**99**	**99**	**99**	**101**	**101**	**102**	**103**	**106**	**105**	**106**	**101**
Calcium (mg/L)												
Observed Concentration [2]	23	24	23	24	26	26	25	25	25	25	26	23
Predicted Concentration [3]		24	24	24	24	25	25	25	24	24	24	25
Observed:Predicted (%)		**101**	**95**	**100**	**108**	**106**	**99**	**100**	**106**	**103**	**106**	**91**
Magnesium (mg/L)												
Observed Concentration [2]	11	12	12	13	13	13	15	14	15	15	15	15
Predicted Concentration [3]		11	12	11	12	12	12	12	11	11	12	12
Observed:Predicted (%)		**106**	**104**	**113**	**108**	**111**	**124**	**119**	**132**	**132**	**128**	**124**
Sodium (mg/L)												
Observed Concentration [2]	43	45	46	46	47	47	51	50	49	46	51	53
Predicted Concentration [3]		44	45	45	45	46	47	46	44	44	46	47
Observed:Predicted (%)		**102**	**102**	**102**	**103**	**102**	**108**	**109**	**111**	**104**	**112**	**112**
Potassium (mg/L)												
Observed Concentration [2]	7.2	7.5	7.9	8.0	7.8	7.9	8.0	8.1	7.7	7.8	8.0	8.2
Predicted Concentration [3]		7.4	7.6	7.5	7.5	7.7	7.9	7.7	7.4	7.4	7.6	7.9
Observed:Predicted (%)		**101**	**105**	**106**	**103**	**103**	**101**	**106**	**104**	**105**	**105**	**104**
Bicarbonate (mg/L)												
Observed Concentration [2]	nd	217	219	224	222	224	223	228	227	222	238	233
Predicted Concentration [3]			221	220	221	225	232	224	217	217	224	231
Observed:Predicted (%)			**99**	**102**	**101**	**100**	**96**	**102**	**105**	**102**	**106**	**101**

Appendix F Observed and predicted concentrations of major ions and related variables in Wabamun Lake, 1982 to 2001 (cont'd)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Lake Volume (dam^3) [1]:	522200	506700	497800	499500	498200	488700	474200	489800	507000	507000	491700	475300
Carbonate (mg/L)												
Observed Concentration [2]	nd	8.0	9.7	5.5	7.8	9.6	10.9	6.0	8.0	10.5	11.0	10.0
Predicted Concentration [3]			8.1	8.1	8.1	8.3	8.5	8.3	8.0	8.0	8.2	8.5
Observed:Predicted (%)			**119**	**68**	**96**	**116**	**128**	**72**	**100**	**131**	**133**	**117**
Sulphate (mg/L)												
Observed Concentration [2]	25	28	26	26	26	28	28	27	28	29	31	27
Predicted Concentration [3]		26	26	26	26	27	28	27	26	26	27	27
Observed:Predicted (%)		**109**	**99**	**99**	**99**	**105**	**102**	**101**	**109**	**111**	**117**	**98**
Chloride (mg/L)												
Observed Concentration [2]	3.0	3.0	3.0	3.0	3.5	4.0	3.8	4.4	3.7	4.0	4.6	4.9
Predicted Concentration [3]		3.1	3.1	3.1	3.1	3.2	3.3	3.2	3.1	3.1	3.2	3.3
Observed:Predicted (%)		**97**	**95**	**96**	**111**	**125**	**114**	**138**	**120**	**129**	**144**	**149**
Fluoride (mg/L)												
Observed Concentration [2]	0.28	0.27	0.28	0.29	0.29	0.31	0.32	0.31	0.30	0.30	0.31	0.32
Predicted Concentration [3]		0.29	0.29	0.29	0.29	0.30	0.31	0.30	0.29	0.29	0.30	0.31
Observed:Predicted (%)		**94**	**95**	**99**	**97**	**104**	**104**	**104**	**104**	**104**	**104**	**104**

Notes: [1] Volume based on area & capacity curves for Wabamun Lake; 1 dam3 = 1000 m^3

[2] Median of concentrations in open-water period

[3] See Section 2.3 for details of calculations for Predicted Concentrations

nd = no data

Appendix F Observed and predicted concentrations of major ions and related variables in Wabamun Lake, 1982 to 2001 (cont'd)

	1994	1995	1996	1997	1998	1999	2000	2001
Lake Volume (dam^3) [1]:	468900	452000	456000	470400	461600	462400	459900	454300
Total Alkalinity (mg/L)								
Observed Concentration [2]	206	213	207	212	212	216	214	213
Predicted Concentration [3]	208	216	214	208	212	211	212	215
Observed:Predicted (%)	**99**	**98**	**97**	**102**	**100**	**102**	**101**	**99**
Conductivity (uS/cm)								
Observed Concentration [2]	453	461	466	466	477	488	499	491
Predicted Concentration [3]	450	467	463	448	457	456	459	464
Observed:Predicted (%)	**101**	**99**	**101**	**104**	**104**	**107**	**109**	**106**
TDS (mg/L)								
Observed Concentration [2]	258	269	270	276	272	290	294	290
Predicted Concentration [3]	253	262	260	252	257	256	258	261
Observed:Predicted (%)	**102**	**102**	**104**	**110**	**106**	**113**	**114**	**111**
Calcium (mg/L)								
Observed Concentration [2]	23	24	24	24	23	24	23	20
Predicted Concentration [3]	26	27	26	26	26	26	26	26
Observed:Predicted (%)	**90**	**90**	**91**	**94**	**87**	**91**	**88**	**77**
Magnesium (mg/L)								
Observed Concentration [2]	15	16	15	16	15	17	17	17
Predicted Concentration [3]	12	13	13	12	12	12	12	13
Observed:Predicted (%)	**122**	**126**	**122**	**129**	**124**	**134**	**132**	**132**
Sodium (mg/L)								
Observed Concentration [2]	54	57	57	57	58	62	62	65
Predicted Concentration [3]	48	50	49	48	49	49	49	49
Observed:Predicted (%)	**113**	**114**	**115**	**119**	**120**	**128**	**128**	**132**
Potassium (mg/L)								
Observed Concentration [2]	8.5	9.0	9.1	9.2	8.9	9.9	9.8	9.0
Predicted Concentration [3]	8.0	8.3	8.2	8.0	8.1	8.1	8.2	8.3
Observed:Predicted (%)	**106**	**108**	**110**	**115**	**109**	**121**	**120**	**108**
Bicarbonate (mg/L)								
Observed Concentration [2]	243	239	237	238	235	250	254	246
Predicted Concentration [3]	234	243	241	234	238	238	239	242
Observed:Predicted (%)	**103**	**98**	**98**	**102**	**99**	**105**	**106**	**102**

Appendix F Observed and predicted concentrations of major ions and related variables in Wabamun Lake, 1982 to 2001 (cont'd)

	1994	1995	1996	1997	1998	1999	2000	2001
Lake Volume (dam^3) [1]:	468900	452000	456000	470400	461600	462400	459900	454300
Carbonate (mg/L)								
Observed Concentration [2]	8.5	11.0	7.3	10.1	12.2	6.8	2.5	6.8
Predicted Concentration [3]	8.6	9.0	8.9	8.6	8.8	8.8	8.8	8.9
Observed:Predicted (%)	**98**	**123**	**82**	**117**	**139**	**77**	**28**	**76**
Sulphate (mg/L)								
Observed Concentration [2]	28	32	33	30	32	38	42	44
Predicted Concentration [3]	28	29	29	28	28	28	28	29
Observed:Predicted (%)	**101**	**111**	**115**	**109**	**111**	**135**	**148**	**152**
Chloride (mg/L)								
Observed Concentration [2]	5.3	5.7	5.9	7.4	6.8	6.7	7.3	7.9
Predicted Concentration [3]	3.3	3.5	3.4	3.3	3.4	3.4	3.4	3.4
Observed:Predicted (%)	**159**	**163**	**170**	**222**	**200**	**196**	**214**	**229**
Fluoride (mg/L)								
Observed Concentration [2]	0.35	0.37	0.36	0.37	0.38	nd	nd	nd
Predicted Concentration [3]	0.31	0.32	0.32	0.31	0.32			
Observed:Predicted (%)	**112**	**114**	**112**	**119**	**120**			

Notes: [1] Volume based on area & capacity curves for Wabamun Lake; 1 dam3 = 1000 m^3

[2] Median of concentrations in open-water period

[3] See Section 2.3 for details of calculations for Predicted Concentrations

nd = no data