SCIENCE & INFORMATION BRANCH
WATER STEWARDSHIP DIVISION
MINISTRY OF ENVIRONMENT

Water Quality Assessment and Objectives for Shawnigan Lake

Technical Appendix

Prepared pursuant to Section 5(e) of the
Environmental Management Act, 2003

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January 23, 2007

Library and Archives Canada Cataloguing in Publication Data
Rieberger, Kevin.
Water quality assessment and objectives for Shawnigan Lake [electronic resource] : technical appendix

Author: Kevin Rieberger. Cf. Acknowledgements.
"Prepared pursuant to Section 5(e) of the Environment Management Act, 2003."
Includes bibliographical references: p.
Available on the Internet.
ISBN 978-0-7726-5844-9

1. Water quality - British Columbia – Shawnigan Lake (Lake). 2. Environmental monitoring - British Columbia - Shawnigan Lake (Lake). 3. Shawnigan Lake (B.C : Lake) – Environmental conditions. I. British Columbia. Ministry of Environment. Water Stewardship Division. Science and Information Branch. II. Title.

TD227.B7R53 2007 363.739'42097112 C2007-960193-6

SUMMARY

This document presents a summary of the ambient water quality of Shawnigan Lake, British Columbia, and proposes water quality objectives designed to protect existing and future water uses. The water quality assessment for the lake and an evaluation of the watershed form the basis for the objectives.

There are numerous water licences within the Shawnigan Lake watershed authorizing withdrawals for domestic purposes. The main source is Shawnigan Lake itself, with other licences on tributaries to the lake. There has been increasing dependency on groundwater in recent years. Shawnigan Lake is home to numerous permanent residences and also provides significant recreational opportunities and fish and wildlife habitat.

Non-point sources of waste are the only major input of pollutants to the lake. These are potentially derived from urban runoff, land development, on-site sewage systems, agriculture and logging.

The data collected over the past 30 years indicate the lake is oligotrophic and the overall state of water quality is very good. There was no evidence of overall lake deterioration, despite concerns expressed by the public. All chemical, physical and biological parameters indicate good water quality; however microbiological indicators exceeded drinking water guidelines at most sites during 2003. Results from additional sampling in 2004 were below water quality guideline levels. While the water quality remains good, that fact that its primary use for residents is as a domestic water supply should not be overlooked. Continuing growth and development within the watershed, in addition to a high level of recreational use, will present challenges in protecting water quality in the future.

Ambient water quality objectives were set for dissolved oxygen, water clarity (Secchi depth), total phosphorus, total nitrogen, N:P ratio, turbidity, total organic carbon, *E. coli*, enterococci and fecal coliforms. Some of these objectives are based on provisional objectives proposed by Nordin and McKean (1984) which were never formalized.

Future monitoring recommendations include continuation of annual spring overturn sampling including microbiological indicators measured near domestic intakes, and a survey of aquatic plants in Shawnigan Lake.

A glossary of technical terms is included as an appendix to this report.

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AKNOWLEDGEMENTS

The author would like to thank the following individuals for their assistance in the preparation of this report: Deborah Epps, Ministry of Environment Regional Operations (Nanaimo), John Deniseger, Ministry of Environment Regional Operations (Nanaimo), Les Swain, Ministry of Environment, Narender Nagpal, Ministry of Environment and Patrick Shaw, Environment Canada.

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1.0 INTRODUCTION

1.1 Background

Shawnigan Lake has long been a popular recreational destination on southern Vancouver Island. Since the early 1970's, the surrounding land-use has gradually changed from seasonal to permanent residential. The lake provides the primary source of domestic drinking water in this watershed through individual points of diversion and therefore protection of the water quality is a primary concern for residents, purveyors and resource managers.

A comprehensive water quality assessment for Shawnigan Lake was prepared by Nordin and McKean in 1984. That assessment noted that the general water quality was good and recommended that controls be implemented to minimize sediment, phosphorus and bacteria inputs from land development and on-site sewage disposal systems. Provisional water quality objectives were proposed for phosphorus, turbidity, suspended solids and fecal coliforms, but never formalized. In recent years, there have been many concerns from local residents about the water quality of Shawnigan Lake and the potential impacts of increasing development and other activities within the watershed. Based on these concerns, Regional Operations staff of the Ministry of Environment (formerly Water, Land and Air Protection) in Nanaimo made this waterbody a priority for the Vancouver Island region and a second water quality assessment was completed (Rieberger *et al.*, 2004).

These two reports provide the basis for the water quality objectives recommended for Shawnigan Lake in this report. These objectives will help ensure that the future water quality is protected for the designated water uses.

1.2 Water Quality Objectives

Water quality objectives are prepared for specific bodies of fresh, estuarine and coastal marine surface waters of British Columbia as part of the Ministry of Environment's mandate to manage water quality. Objectives are prepared only for those waterbodies and water quality characteristics that may be affected by human activity now or in the future.

Water quality objectives are based on scientific guidelines that are safe limits of the physical, chemical or biological characteristics of water, biota (plant and animal life) or sediment which protect water use. Objectives are established in British Columbia for waterbodies on a site-specific basis. They are derived from the guidelines by considering local water quality, water uses, water movement, waste discharges and socio-economic factors.

Water quality objectives are set to protect the most sensitive designated water use at a specific location. A designated water use is one that is protected in a given location and is one of the following:

- Raw drinking water, public water supply and food processing;
- Aquatic life and wildlife;
- Agriculture (livestock watering and irrigation)
- Recreation and aesthetics;
- Industrial water supplies.

Each objective for a location may be based on the protection of a different water use, depending on the uses that are the most sensitive to the physical, chemical or biological characteristics affecting that water body.

Water quality objectives have no legal standing at this time and are not directly enforced. However, they do provide policy direction for resource managers for the protection of water uses in specific waterbodies. Objectives guide the evaluation of water quality, the issuing of permits, licences and orders, and the management of fisheries and the province's land base. They also provide a reference against which the state of water quality in a particular water body can be checked, and help determine whether basin-wide water quality studies should be initiated. Water quality objectives are also a standard for assessing the Ministry's performance in protecting water uses.

Water quality objectives are established to protect all water uses which may take place in a water body. Monitoring is undertaken to determine if all the designated water uses are being protected. The monitoring usually takes place at a critical time when it has been determined that the water quality objectives may not be met. It is assumed that if all the designated water uses are protected at the critical time, then they also will be protected at other times when the threat is less. The monitoring usually takes place during a five week period, which allows the specialists to measure the worst, as well as the average condition in the water. For some waterbodies, the monitoring period and frequency may vary, depending on the nature of the problem, severity of threats to designated water uses, and the way the objectives are expressed (i.e., mean value, 95th percentile, etc.).

2.0 SITE DESCRIPTION

2.1 Watershed Description and Hydrology

Shawnigan Lake is located on southern Vancouver Island in the Shawnigan Community Watershed with a watershed size of approximately 69 km^2 (Figure 1). The Shawnigan Community Watershed is larger at 110 km^2 and includes the land draining to Shawnigan Creek below the lake outlet to Mill Bay. The watershed has a maximum elevation of 610 m GSC (Geodetic Survey of Canada) and a minimum elevation of approximately 116 m GSC at the lake level (Bryden and Barr, 2002).

Shawnigan Lake empties from south to north. There are three main inflows to the lake: Shawnigan Creek at the south end of the lake, McGee Creek on the west shore and the West Arm inflow in the northwest corner of the lake. Shawnigan Lake has a relatively short water residence time of approximately one year (Nordin and McKean, 1984).

Water levels are controlled on Shawnigan Lake by a dam on Shawnigan Creek located 450 m downstream from the lake outlet. In 1983, there was general agreement that the lake level should be maintained at elevations between 116.3 m GSC and 115.75 GSC between March 15 and October 1 to provide storage and prevent flooding (Bryden and Barr, 2002).

2.2 Lake Morphometry

Shawnigan Lake is a medium-sized lake with a surface area of 537 ha, a volume of over 64 Mm^3, a mean depth of 12 m and a maximum depth of 52 m. It is approximately 7.2 km long and 1.4 km across at its widest point. The narrowest point is approximately 150 m wide in the West Arm; this part of the lake is quite distinct in that it is a long, narrow, shallow arm isolated from the main body of the lake. The lake has one main deep basin in the northern half of the lake and several smaller basins to depths of 28 m in the southern half (Figure 2).

3.0 WATER USES

3.1 Domestic

There are three major waterbodies licensed for water withdrawal in the Shawnigan Lake watershed: Shawnigan Lake, Shawnigan Creek and McGee Creek. In total, these areas have 225 active water withdrawal licenses that are permitted to extract over 7,000 m^3/d

(Table 1) (Land and Water BC, 2001). In addition, there is approximately 5,500 m^3/d of water licensed for storage in Shawnigan Lake.

The largest withdrawals for Shawnigan Lake are located near the northeastern portion of the lake, servicing the Village and Shawnigan Lake Estates (Table 2). These are treated water supplies with chlorine disinfection. They account for about 3.5% of all licences for Shawnigan Lake and approximately 38% of all water withdrawn from the lake itself.

The number of licenses issued for the Shawnigan Lake watershed increased steadily during the 1940's to 1970's (Table 3). Since the 1970's, this trend has slowed considerably.

There are also withdrawals from Shawnigan Creek downstream from the lake, including the Mill Bay Waterworks District, and changes in water quality in Shawnigan Lake could potentially impact these users.

3.2 Recreational

Shawnigan Lake provides a number of recreational opportunities including swimming, water skiing, boating, and fishing. Although the majority of the residences are now occupied year round, there are number of campgrounds and resorts that receive the heaviest use in the summer months.

3.3 Fisheries

Shawnigan Lake provides a good recreational fishery that has been supported by rainbow (*Onchorhynchus mykiss*) and cutthroat trout (*O. clarki*) stockings since 1903. In 2004, Shawnigan Lake was stocked with 26,000 rainbows and 15,000 cutthroat. There is also a native population of kokanee salmon (*O. nerka*) present in Shawnigan Lake.

Shawnigan Lake has also received several unauthorized introductions of non-native species including brown bullhead (*Ictalurus nebulosus*), pumpkinseed sunfish (*Lepomis gibbosus*), yellow perch (*Perca flavescens*) and smallmouth bass (*Micropteus dolomieui*). Although these species provide anglers with additional opportunities, there is concern of the impact these introductions have had on populations of juvenile salmonids and non-fish species like crayfish (Best, 2001).

3.4 Ground Water

Groundwater is a valuable drinking water resource in Shawnigan Lake and there are eight aquifers located within the watershed (Table 4). The aquifers are classified to provide information of their level of development, vulnerability to contaminants and water quality, but do not consider the existing type of land use, nature of potential contaminants or other risks (Bernardinucci and Ronneseth, 2002). Vulnerability is defined as the potential for an aquifer to be degraded by contaminants, based on the aquifer's hydrogeological characteristics.

Two aquifers within the Shawnigan Lake watershed, one immediately surrounding Shawnigan Lake and one in Mill Bay, have a classification of II A indicating moderate development and high vulnerability. Aquifers with this classification usually require particular care and attention regarding land use activities that could affect water quality (Bernardinucci and Ronneseth, 2002).

The remaining six aquifers are classified II B (moderate development, moderate aquifer vulnerability) or II C (moderate development, low aquifer vulnerability). All may be able to support additional withdrawals; however, until site specific studies are undertaken, aquifers with either classification require care and attention for development activities that could affect water quality of quantity (Bernardinucci and Ronneseth, 2002).

The number of wells constructed in the Shawnigan Lake watershed has risen dramatically since 1970 to accommodate population growth; currently there are approximately 860 wells within the watershed. The bulk of the wells constructed are in the north-east quadrant of the watershed, where the village area is located. The number of new wells constructed will likely continue to rise since there are no immediate plans to implement central water and sewer services in these areas.

4.0 LAND USE

Shawnigan Lake is located within the Cowichan Valley Regional District (CVRD) Electoral Area B. Shawnigan Lake's current population is over 7,000 people and has experienced considerable growth over the past 15 years. From 1986 to 2001, the population of Shawnigan Lake increased by 190%, compared to 136% for the rest of B.C. during this time (Statistics Canada, 2004). The majority of development has been concentrated around the north end of the lake around the Shawnigan Lake Village and Shawnigan Lake Estates communities.

Forestry is the dominant land use in this watershed with urban development and agriculture using the majority of the remaining land base. Approximately 9.5% of the land base is under the Agricultural Land Reserve (ALR).

Historically, Shawnigan Lake was a rural community with predominately seasonal residences but its close proximity to Victoria makes it ideal for commuting workers and permanent residences have become more prevalent. At one time, Shawnigan Lake was considered to be the most reliable source of water for future development in that watershed (CVRD, 1976). However, as of 1979, it was determined that any further water withdrawals, except for individual residential water use, would require storage (Bryden and Barr, 2002). This has created an increasing reliance on groundwater as a domestic water source.

The majority of Shawnigan Lake waterfront is developed and zoned as either Suburban Residential or Urban Residential. The only waterfront area that is not zoned this way is approximately one kilometre of the lake's most southern shoreline, which is included in the ALR. As of 1996, there were approximately 616 subdivision lots bordering directly on Shawnigan Lake with a further 2,000+ lots bordering these, but not directly adjacent to the lake. A "flood construction level" was established at 119.2 m GSC (Bryden and Barr, 2002).

Within the Shawnigan Lake watershed there are five waste management permits for point discharges (Table 5), all of which are to ground and at distances of 400 m to 4,100 m from the lake edge. The total maximum permitted discharge is approximately 800 m^3/d.

There are also numerous smaller residential septic and onsite disposal systems (discharges less than 22.7 m^3/d) which are regulated by the B.C. Ministry of Health. Septic systems are the dominant means of disposing of domestic effluent in the Shawnigan Lake watershed and are effective at treating household sewage if designed properly and maintained regularly. In typical on-site sewage systems, the wastewaters from toilets and other drains flow from the residence to a holding tank where the solids and liquids are separated. Bacteria in the tank help break down the solids into sludge and the liquid flows from the tank to a network of pipes in the drainfield. From here, the liquid is released to the ground where naturally occurring bacteria cleanse the wastewater. If the system is improperly located, constructed, serviced or poorly maintained, it can fail, discharging untreated wastewater to nearby waterbodies. This can impact the suitability of the water for drinking, recreational activities and aquatic life.

The CVRD Stage Three South Sector Liquid Waste Management Plan has outlined an initiative which would provide sewer services to the densest areas of Shawnigan Lake.

Shawnigan Lake Beach Estates, near the Village is the only area serviced by a centralized sewage collection system. Presently, there are approximately 275 sewer connections in this area which receive secondary wastewater treatment and in-ground disposal by the CVRD.

5.0 STUDY DETAILS

The sites used in this assessment are listed in Table 6 and illustrated in Figure 3.

Water chemistry was sampled at four lake basin sites (sites 1 – 4), four inflow sites (sites (5 – 8), one outflow site (site 9) and four lake perimeter sites (sites 10 – 13) (Figure 3 and Table 1). All samples were collected according to Ministry approved sampling procedures (B.C. Ministry of Water, Land and Air Protection, 2003a).

Samples were collected from the basin sites in February 2003 (while the water column was mixed), and then monthly from May to November 2003. Follow-up sampling took place in February 2004 and March 2005, again while the water column was well mixed.

Field measurements were taken using a Hydrolab Surveyor 4 at one metre intervals up to 15 m, and at five metre intervals beyond that. The parameters measured included temperature, dissolved oxygen, pH and specific conductance. Water clarity was measured on each sampling day using a Secchi disc. Results were entered into the Ministry of Environment's Environmental Monitoring System (EMS) database. Grab samples were taken throughout at three depths in the water column (surface, 5 m and 20 m) for the deep stations (1199901 and 1199902) and at the surface and bottom of the water column for the other basin sites (1199903 and 1199904). Water column samples were collected using a Van Dorn bottle and analyzed for the following parameters:

- Physical: pH, colour true, turbidity, hardness
- General inorganics: alkalinity
- Nitrogen: total Kjeldahl N, total N, total organic N, ammonia, nitrate + nitrite
- Phosphorus: ortho-P, total P

Total metals were also analyzed at the beginning of the monitoring program and during the 2004 and 2005 spring overturn monitoring for each lake basin site.

The lake perimeter, inflow and outflow sites were sampled four times over the period of study: February, May, August and November, 2003. Surface grab samples were analyzed for the following parameters:

- Physical: pH, colour true, specific conductance, turbidity
- Carbon: total inorganic carbon, total organic carbon

- Nitrogen: total Kjeldahl N, total N, total organic N, ammonia, nitrate + nitrite
- Phosphorus: total P

Total metals were also analyzed once in the period of study for each perimeter, inflow and outflow site.

Phytoplankton samples were collected by taking one litre grab samples at the surface. Chlorophyll *a* samples were collected using a hand-operated vacuum pump to filter 500 mL of surface water through a 0.45 micron membrane filter; the filter paper was then analyzed for chlorophyll *a*. Zooplankton were collected using a 10 m vertical tow in a Wisconsin-style net with a mouth area of 0.07 m^2, a net opening diameter of 0.5 m and a mesh size of 80 μm. All samples were collected following the Ministry of Environment approved methods (Ministry of Water, Land and Air Protection, 2003a).

Surface water grab samples were collected according to Ministry approved sampling procedures (Ministry of Water, Land and Air Protection, 2003a) and tested for *E. coli*, enterococci, fecal coliforms and fecal streptococci at nine sites: four inflow sites (sites 5 – 8), one outflow site (site 9) and four lake perimeter sites (sites 10 – 13). Results are reported in colony forming units (CFU)/100 mL. The lake basin sites (1199901, 1199902, 1199903, 1199904) were not tested for bacteriological parameters because of the distance from domestic intakes. There were two distinct sampling periods for this assessment in which five samples were collected for each site in a 30-day period: August/September (summer flow-flow) and October/November (fall freshet). Ninetieth (90th) percentile concentrations and geometric mean concentrations were calculated to determine whether concentrations exceeded provincial water quality guidelines for raw drinking water with disinfection and recreational primary contact, respectively. Follow-up sampling was conducted in November and December 2004 at two lake perimeter sites (sites 14 and 15) within 10 m of domestic intakes to determine the bacteriological water quality at those sites.

6.0 WATER QUALITY

6.1 Limnological Characteristics

6.1.1 Lake Temperature Stratification

Water temperature was measured at each lake site from February 2003 to February 2004 and time/depth temperature profiles for each site are illustrated in Figures 4 through 7. The water temperature ranged from a minimum of 4°C - 6°C in the winter months to a maximum surface water temperature of 20°C - 22°C in July and August for all sites. The north basin (1199901) and the south basin (1199902) showed similar patterns of thermal stratification with a strong thermocline forming by June. Deterioration of the thermocline and vertical mixing for both sites took place in mid-November which is consistent with earlier assessments (Nordin and McKean, 1984). The water in the north basin was warmer than the south basin and corresponding isotherms were generally deeper at 1199901.

The West Arm (1199903) was interesting in that it did not show a strong pattern of stratification and vertical mixing of the water column occurred relatively early compared to the other sites. This is likely related to the morphometry of the west arm; it is a long, slender and relatively shallow body of water and may be easily mixed by the increased inflow at the head of the arm, which increases with the fall freshet.

The north beach site (1199904) showed an earlier pattern of stratification and breakdown of the thermocline. This is likely due to the location of the sampling site in shallower waters which are more easily cooled and mixed in the fall.

6.1.2 Dissolved Oxygen

Dissolved oxygen (DO) profiles were measured at each lake site on each sampling date and percent DO saturation was calculated and plotted (Figures 8 to 11).

The north basin (1199901) site showed a similar pattern of DO saturation to those reported by Nordin and McKean (1984) from 1977 and 1978. The 2003 data did show a more extensive period of DO supersaturation (>100%) in the epilimnion and higher DO concentrations in the hypolimnion.

The south basin (1199902) also showed a similar pattern to that previously reported (Nordin and McKean, 1984) with greater DO levels in both the epilimnion and the hypolimnion. The 2003 results showed a much greater hypolimnetic oxygen depression in the south basin, compared to the north basin, as was previously reported. Nordin and McKean (1984) attributed this difference between the two main basins to the relatively shallow hypolimnion of the south basin and to the morphometry of the main basin.

The DO profiles for the West Arm (1199903) and north beach site (1199904) showed fairly well oxygenated waters throughout the year.

The B.C. water quality guideline for dissolved oxygen in the water column is 5 mg/L (instantaneous minimum for the protection of aquatic life). This guideline was met throughout the water column at all lake sites in 2003 except 1199902. At the south basin site, the DO guideline was met throughout the water column up until June. A DO profile was not taken in July and in August the guideline was not met at 15 m (2.7 mg/L). In September, the guideline was not met at nine metres (4.8 mg/L) and in October it was not met at 14 m (2.9 mg/L). In November, the guideline was again met throughout the water column at 1199902 indicating that vertical mixing of the water column had begun to take place. It is not uncommon to have depressed hypolimnetic DO levels in lakes and the fact that Shawnigan Lake meets the guideline level throughout the water column most of the time indicates the lake has a well oxygenated hypolimnion.

The proposed water quality objective for dissolved oxygen in Shawnigan Lake is an instantaneous minimum of 5 mg/L at any depth. The level represents the minimum concentration required to minimize stress in salmonids and will also protect other species present which are more tolerant of lower DO concentrations (e.g. smallmouth bass).

6.1.3 Water Clarity

Water clarity was measured using a standard 20 cm Secchi disc, lowered in the water column until it was no longer visible from the surface. This is a standard, yet simple, measure of water clarity or transparency and can be used to indicate changes in water quality, as transparency decreases with increasing colour, suspended sediments or algal abundance.

The average Secchi depths for the four Shawnigan Lake basin sites are listed in Table 7. Overall, the average was approximately 6 m which is consistent with that reported by Nordin and McKean (1984) (6.2 m at 1199901 and 5.8 m at 1199902).

Secchi depth readings over time for the north and south basins are illustrated in Figures 12 and 13, respectively. These diagrams show that, although there is some seasonal variability, water clarity has remained fairly consistent since 1976. Some of the highest transparencies measured over the period of record were in the summer of 2003 at both the north and south basins.

The proposed water quality objective for Secchi depth in Shawnigan Lake is an annual mean of ≥ 5 m. This objective set as an indicator of water quality; however results must be interpreted with caution as there are several influencing factors which must be considered. For example, phytoplankton concentrations, zooplankton grazing and temporal hydrology can affect water clarity. Results can also be influenced by weather and water conditions as well as the individual recording the measurement. Attainment of this objective should be based on monthly readings taken throughout the year. Secchi depths should be recorded on the shady side of the boat and taken sometime between two hours after dawn to two hours before dusk. During winter months, Secchi depths should only be recorded between 10:00 am and 2:00 pm. Sunglasses should not be worn when taking the measurement. The Canadian Environmental Quality Guideline for water clarity is 1.2 m to ensure there is negligible risk to the health and safety of recreational users and the results reported here easily meet that guideline.

A second measure of water clarity is turbidity, which is a measurement of the suspended particulate matter in a water body which interferes with the passage of a beam of light through the water. Materials that contribute to turbidity are silt, clay, organic material or micro-organisms. Turbidity values are generally reported in Nephelometric Turbidity Units (NTU). High levels of turbidity increase the total surface area of solids in suspension which bacteria can grow. Turbidity also interferes with the disinfection of drinking water and is unpleasing aesthetically (B.C. Ministry of Environment, Lands and Parks, 1997). The water quality guideline (maximum) for turbidity for raw treated water is 5 NTU. The turbidity results of this study were well within the guideline and most were less than one NTU.

The proposed water quality guideline for turbidity in Shawnigan Lake is a mean monthly value that does not exceed 1 NTU with no individual sample to exceed 5 NTU. This objective is set to protect the quality of source drinking water and reflects the current conditions of Shawnigan Lake. It applies to sites 1199903 and 1199904 which are more likely to be representative of conditions near domestic intakes.

6.1.4 Limnological Interpretation

Water temperature, thermal stratification patterns and water clarity were similar to previous observations (Nordin and McKean, 1984). The deepest Secchi depth measurements were generally seen during summer months and may have partially resulted from brighter, sunnier conditions when the disc would have been more visible in the water and higher zooplankton grazing rates. Dissolved oxygen concentrations appear to be higher than those previously reported with greater periods of epilimnetic oxygen supersaturation in the summer months and greater hypolimnetic oxygen concentrations. Nordin and McKean (1984) reported an oxygen depletion rate of 276 $mg/m^2/d$ for the years 1976-1980 suggesting mesotrophic conditions. They indicated that the high oxygen deficit seen in Shawnigan Lake was likely due to the long-term decomposition of wood waste material in the lake. We were unable to calculate oxygen depletion rates because of incomplete oxygen profiles for the entire water column; however, a comparison of the time/depth DO profiles with those from Nordin and McKean's work suggests that the oxygen depletion rate may not be as extreme as previously measured. This observation is supported by a decrease in chlorophyll *a* concentrations (Section 5.4.3), which would result in a lower oxygen demand in bottom waters from decomposing organic material.

6.2 Water Chemistry

6.2.1 Lake basin sites

The results of all water chemistry monitoring are summarized in Appendices 1 through 13. The data are organized by decade to illustrate any changes in water quality over time. The north basin site (1199901) had the most data over the period of record and provides the best representation of water quality in Shawnigan Lake.

6.2.1.1 General Parameters

All general parameters showed low levels and no significant trends were identified over the period of record. The water is of neutral pH (mean = 7.1 – 7.2) with low turbidity (<5 NTU) and low dissolved solids (mean specific conductivity = 48 µS/cm – 64 µS/cm). Current average alkalinity ranged between 15.1 mg/L (1199902) and 20.9 mg/L (1199903) indicating a moderate sensitivity to acidic inputs.

6.2.1.2 Nutrients

Nutrients are any material assimilated by organisms for growth and maintenance. In freshwater ecosystems the primary nutrients for algal growth are phosphorus (P) and nitrogen (N) although there are a number of others required in lesser amounts (e.g. sodium, manganese, silica, potassium, calcium, magnesium, iron, cobalt, copper, zinc and molybdenum). Nutrients required for metabolic processes are available through natural pathways and processes and, along with light, limit primary production in aquatic environments (NRC, 2000). Dissolved nutrients are metabolized by primary producers and provide primary consumers (zooplankton for example) with a nutrient source. The primary consumers are food for organisms higher in the food web and in this way nutrients are transferred to other organisms, both aquatic and terrestrial.

Nitrogen and phosphorus occur naturally before human development, were in limited supply. However, their availability has increased in the past several decades because of the increased use of fertilizers, burning of fossil fuels, urban development, land clearing and deforestation. The influx of nutrients has disrupted the natural N and P cycles, greatly increasing the bioavailability of these elements. The environmental consequences of the increased bioavailability of N and P include accelerated eutrophication of waterbodies, contamination of groundwater, fish kills due to ammonia toxicity, increased toxic algal blooms, contamination of water supplies and increased economic burdens as a result of the need for monitoring, treatment and remediation of contaminated water (Environment Canada, 2001).

Although there are several analytical measures of the various forms of N and P in the aquatic environment, total N and total P are the most widely measured variables for predicting eutrophication responses. While these summary measures tend to overestimate the actual amount of bioavailable N and P, they are considered the most reliable indicators because of the dynamic nature of nutrients in the aquatic environments in terms of cycling (US Environmental Protection Agency, 2000).

6.2.1.2.1 Phosphorus

Phosphorus plays a major role in nearly all phases of algal metabolism, particularly in photosynthesis. It is required in the synthesis of nucleotides, phospholipids, sugar phosphates and other compounds and is bonded in a number of essential low molecular weight enzymes and vitamins (Wetzel, 1983).

Phosphorus is least abundant in relation to other required nutrients, and therefore usually limits primary productivity in lakes (Brönmark and Hansson, 1998), however to raise algal biomass, additions of both P and N are usually required (Kallf, 2002). The most available fraction of P for direct uptake by aquatic primary producers is the dissolved inorganic form orthophosphate (PO_4^-), which is also referred to as soluble reactive phosphorus (Nordin, 1985). More than 90% of P occurs as biologically unavailable organic phosphates and cellular constituents within the biota (Wetzel, 1983) while PO_4^- is usually less than 5% of all P. Other fractions include organic P and particulate P which are transformed to more available forms at rates dependent on microbial action, environmental conditions, origin of material, kinetics and water residence time. In lakes with short water residence there is a higher rate of flushing which limits the amount of organic P that is transformed to inorganic P (Nordin, 1985).

Phosphorus is measured as total P (TP), PO_4^- and total dissolved P (TDP). Total P consists of PO_4^-, total dissolved P and particulate P (>0.45 μm in diameter), which can be both organic and mineral in origin. The TDP fraction consists of PO_4^- and a fraction of dissolved organic P from the breakdown of biotic material and polyphosphates (Nordin, 1985). Total P is the best measure because dissolved orthophosphate in eutrophic waters is often turning over every few minutes.

Phosphorus is generally non-volatile and atmospheric transport of P is limited to movement as a dust or aerosol. Surface waters receive P mainly through surface flows rather than groundwater because soils tend to bind P unless the soil is saturated and anoxic. In soils, PO_4^- in solution reacts quickly with ions to become unavailable to plants and decreases the potential for leaching of P to lakes. Transport of P in soils to lakes is more likely to occur as a result of erosion rather than leaching. Once delivered to a lake, P is usually retained fairly efficiently by a combination of biological assimilation and the deposition of sediments and biota to the bottom sediments. Phosphorus becomes bound with bottom sediments and binding with aluminium and ferric hydroxides is particularly strong. In anoxic conditions the ferric ions are reduced and the binding is weakened allowing the phosphate to diffuse more freely to the water column (Correll, 1998).

Total phosphorus (TP) results are summarized temporally and spatially in Table 8. Site 1199901 has the most extensive data set and provides the best indication of water quality. Overall, average total phosphorus concentrations (for all available data) are low for this site and present values ($\bar{x} = 6$ μg/L) are not noticeably different from the 1970's data. The 2005 spring overturn results for 1199901 showed a very low average TP concentration of 1 μg/L.

Total phosphorus results for the south basin (1199902) showed a higher average value for results collected in 1980 – 1989 ($\bar{x} = 9$ μg/L). This higher result is due to a smaller number of samples, the majority of which were taken during periods of water column stratification. Under these conditions, internal loading processes and reduced flushing typically result in higher total P concentrations deeper in the water column.

The spring overturn total P concentration for 1199902 in 2005 was low at about 2.5 μg/L.

Average TP concentrations were low for the other two lake sites and have not changed significantly since the 1970's. The West Arm site (1199903) had an average concentration of 5 μg/L in the 1970's and 5 μg/L in 2000 – present. The spring overturn average TP concentration in 2005 was 3.5 μg/L. The north end site (1199904) had an average concentration of 5 μg/L in the 1970's and 4 μg/L in 2000 – present. The spring overturn average TP concentration in 2005 was also 3.5 μg/L.

Average total phosphorus concentrations at the north basin were calculated for all spring overturn data and these results are illustrated in Figure 14. Spring overturn phosphorus concentrations are generally correlated with summer algal biomass (Nordin, 1985) and therefore provide a good indicator of nutrient status of the lake. Spring overturn phosphorus values for coastal lakes should be obtained in February before the biological uptake of P begins (Nordin and McKean, 1984). The proposed objective value for TP at overturn (8 μg/L) has been exceeded only once in the past 28 years (9 μg/L in 1980). In 1979, 1984 and 2001 the spring overturn concentrations equalled the objective level; for all other years the overturn TP concentration was below the objective level with most values being less than 6 μg/L.

Average total dissolved phosphorus and average dissolved ortho-phosphate values (a measure of the biologically available form of P) were also low for all lake sites (Appendices 1 - 4).

The proposed water quality objective for total phosphorus in Shawnigan Lake is an average concentration of 8 μg/L at spring overturn. This is the objective originally proposed by Nordin and McKean (1984) to protect the existing oligotrophic conditions of the lake and reflects the high quality of water in Shawnigan Lake. It is lower than the provincial water quality guideline of 10 μg/L for lakes used for drinking water and recreational purposes. This objective applies to the average of at least three samples taken throughout the water column (surface, mid depth and one metre above the bottom) at the two deep stations (1199901 and 1199902). This objective also applies to the average of at least two samples taken at the surface and one metre above bottom at sites 1199903 and 1199904.

6.2.1.2.2 Nitrogen

Nitrogen is one of the major constituents of the cellular protoplasm of organisms and plays a key role in the productivity of freshwaters (Wetzel, 1983). Nitrogen limitation in lakes is less common than P limitation because of the potential for fixation of atmospheric N by cyanobacteria (Nordin, 1985). Based on the N:P ratios discussed in section 6.2.1.2.3, Shawnigan Lake is P-limited.

The aquatic nitrogen cycle is a balance of N inputs and N losses from an aquatic environment. Nitrogen inputs to aquatic systems include atmospheric (particulate fallout and precipitation), N fixation in both water and the sediments, and inputs from both groundwater and surface water. Nitrogen losses occur through outflows from the basin, reduction of nitrate (NO_3^-) to nitrogen gas (N_2) by bacterial denitrification followed by its loss to the atmosphere, and sedimentation of inorganic and organic N-containing compounds (Wetzel, 1983).

The forms of nitrogen monitored in the lake sites include total nitrogen (TN), ammonia (dissolved) and nitrate + nitrite (dissolved). Kjeldahl nitrogen, total organic nitrogen and total nitrate were not consistently measured and are not discussed here. All data are summarized in Appendices 1 - 4.

The deep station (1199901) provided the most complete data set, while there were less data from the south basin (1199902) and minimal results available from the West Arm (1199903) and the north end site (1199904).

Nitrogen in all forms was low at all sites throughout all sampling periods. At 1199901, average TN values increased from the 1970's (182 μg/L) to the 1980's (240 μg/L) but have decreased since that time to 213 μg/L in (2000 – present). A similar pattern was seen in the 1199902 data. The West Arm and north end sites showed increases from 182 μg/L and 165 μg/L to 270 μg/L and 230 μg/L, respectively.

The average ammonia concentrations showed overall decreases for all sites, while nitrite + nitrate concentrations have shown overall increases since the 1970's.

Although the measured values are low, changes in average concentrations over time were noted for all forms of N. To determine if these represented a significant change over time, the data were plotted and fitted with least-squares regression lines. These results are listed in Table 9 and showed no significant trends of parameter concentration over time.

Total N concentrations at spring overturn for the four lake sites are listed in Table 10. Of the four sites, the north basin deep station (1199901) has the most complete data set and shows that TN concentrations are generally below 250 μg/L. The near-shore sites (1199903 and 1199904) showed higher TN concentrations as might be expected in areas under more direct influence from land use in the watershed (e.g. onsite sewage disposal, fertilizers).

The proposed water quality objective for total nitrogen in Shawnigan Lake is an average concentration of 250 μg/L at spring overturn. This objective reflects the current conditions and is set to protect the existing oligotrophic conditions of the lake. It applies to the average of at least three samples taken throughout the water column (surface, mid depth and one metre above the bottom) at the two deep stations (1199901 and 1199902). This objective also applies to the average of at least two samples taken at the surface and one metre above bottom at sites 1199903 and 1199904.

6.2.1.2.3 Nitrogen:Phosphorus Ratio

The nitrogen:phosphorus (N:P) ratio is a useful indicator of lake trophic status and whether primary production is limited by phosphorus or nitrogen concentrations. Algae require N and P in particular ratios and comparing these values to what is actually available in the water can be a valuable diagnostic tool (Nordin, 1985). The N:P ratio is derived from the Redfield Ratio (Redfield, 1958) which describes the general requirements of carbon, nitrogen and phosphorus for freshwater primary producers. The ratio is 106 C: 16 N: 1 P (by atoms) or 40 C: 7 N: 1 P (by weight); because our analytical results, and much of that in the literature, are reported by weight we will use the latter ratio in this discussion.

Most lakes, including Shawnigan, are P-limited and N:P ratios tend to decrease with increasing eutrophication, either natural or anthropogenically mediated. Therefore, decreasing N:P ratios would indicate deteriorating water quality. As a general guideline, lakes with N:P ratios greater than 7:1 are P-limited and those less than 7:1 are N-limited although there is considerable variation around this "ideal" ratio.

Nordin (1985) proposed the following range of total N: total P ratios to describe nutrient limitation:

- <5:1 is indicative of N limitation;
- 5:1 – 15:1 indicates no limitation or co-limitation, and;
- >15:1 indicated P limitation.

Slightly different levels were reported by the OECD (1982) as follows:

- <10:1 = N limitation;
- 10:1 – 17:1 = no limitation or co-limitation, and;
- >17:1 = N limitation.

The observed variation in the limiting nutrient ratios is due to a number of factors. One contributing factor could be the luxury uptake of both N and P, whereby primary producers are able to take up and store more of the nutrients than are immediately required for optimal growth (Forsberg, 1975). Inter-specific differences in nutrient requirements among different phytoplankton species used, as well as environmental conditions such as water residence time (Meakin Consultants in draft, 2002) could also account for variation. Finally, the varying experimental conditions and uncertainties in the bioavailable fractions of the nutrients among the reported experiments (OECD, 1982) will also contribute to variation in reported results.

This variation demonstrates that there is a range of requirements by primary producers in aquatic environments and various conditions will provide certain species with an advantage over their competitors. Watershed characteristics play a role in the N:P ratio of a lake – generally oligotrophic lakes receive runoff from undisturbed areas with high N:P ratios while eutrophic lakes often receive runoff with low N:P ratios originating from feedlots, stormwater drainage, sewage and other inputs (Meakin Consultants in draft, 2002). Although in many areas, soil-borne P can result in naturally high P levels in lakes and streams as well. In Meakin Consultants' review of N:P ratios (in draft, 2002) they conclude that there is no distinct N:P ratio at which to expect changes in phytoplankton species composition in surface waters, especially in regards to predicting timing of potentially harmful cyanobacterial blooms. Instead they suggest that N:P ratios be used as one of several tools available to ecosystem managers in an integrated lake management strategy. For example, N:P ratios could be used to help assess the general trophic status of a lake i.e. high N:P ratios are associated with oligotrophic conditions (low algal biomass dominated by green algae) and low N:P ratios are associated with eutrophic conditions (higher algal biomass dominated by cyanobacteria), providing an approximation of potential nutrient limitation in a system. They could also serve as indicators of potential change in phytoplankton community structure or watershed changes in nutrient supplies in long-term monitoring programs.

In this study, N:P ratios were calculated by dividing the average spring overturn total N concentration by the average spring overturn total P concentration. Where total N data were not available, it was calculated by summing the Kjeldahl nitrogen (ammonia and organic N) and nitrate + nitrite values. The N:P ratios over time for 1199901 are illustrated in Figure 14. The N:P ratio for this site has increased over the period of study, from 26:1 in 1976 to 160:1 in 2005. This corresponds with a low in total phosphorus concentrations at spring overturn of 1 μg/L, as illustrated in Figure 15.

N:P ratios were also calculated by site using the average values by decade and these are listed in Table 11. These are all comparable to the N:P ratio reported by Nordin and McKean (1984) of 35:1 which was based on all of the lake data available at that time.

The proposed water quality objective for N:P ratios in Shawnigan Lake is 30:1. This objective is set to protect the existing oligotrophic conditions of the lake and reflects current conditions. Calculation of N:P ratios will be based on average total nitrogen and total phosphorus concentrations measured at spring overturn. If the objectives for total N (250 μg/L) and total P (8 μg/L) are met, the N:P ratio objective will also be attained.

6.2.1.2.4 Total Organic Carbon

Organic carbon is an important water quality parameter to consider with respect to drinking water sources. The B.C. provincial water quality guideline for total organic carbon (TOC) in source water with chlorination is 4 mg/L to prevent the production of disinfection by-products (e.g., trihalomethanes) during treatment with chlorine (B.C. Ministry of Environment, Lands and Parks, 1998). Although the TOC guideline has been exceeded in Shawnigan Lake in past, it was met during the most recent sampling efforts and the overall average concentrations were below the guideline level.

The proposed total organic carbon water quality objective for Shawnigan Lake is a maximum of 4 mg/L at anytime. This objective reflects current conditions and is set to minimize the formation of disinfection by-products resulting from chlorination of domestic water and applies to sites 1199901, 1199902, 1199903 and 1199904.

6.2.1.3 Halides

Dissolved bromide, chloride and fluoride were measured at sites 1199901 and 1199902. Average concentrations for dissolved bromide were below analytical detection limits. Dissolved chloride concentrations were well below the guidelines for raw drinking water and aquatic life (250 mg/L and 600 mg/L, respectively) (B.C. Ministry of Water, Land and Air Protection, 2003b) as were the dissolved fluoride concentrations (1.5 mg/L and 0.2 mg/L, respectively) (B.C. Ministry of Environment, Lands and Parks, 1990) for both sites. No objectives were set for these parameters.

6.2.1.4 Metals

The majority of the total metals results were collected from the north basin (1199901) and the south basin (1199902) and most of these results were below analytical detection limits. For those parameters where concentrations were above detection, the average values were below B.C.'s approved or working guidelines, or there were no guidelines available. For parameters without approved or working guidelines, levels measured were low and likely do not present any cause for concern at this time.

6.2.2 Lake perimeter sites

Data from the four lake perimeter sites were collected from 2001 to 2004 (Appendices 5 - 8). The results were low for all parameters and consistent with concentrations from the basin sites.

6.2.3 Inflow Sites

The Shawnigan Lake inflow sites were last sampled in 2004. The West Arm inflow (1199911) showed the highest average concentrations of the inflow sites for hardness ($\bar{x} = 51.8$ mg/L), conductivity ($\bar{x} = 111$ µS/cm) and turbidity ($\bar{x} = 0.97$ NTU). All forms of nitrogen were low at this site but were highest (average TN = 341 µg/L) among the inflow sites (sites 5 – 8). Average TP among inflows was also highest at this site (10 µg/L); however, recent average total and dissolved phosphorus concentrations were similar to those measured in the 1970's. The concentrations measured at 1199911 were also higher than those for the nearest basin site in the West Arm (1199903) (see Appendix 3).

The Shawnigan Creek inflow site (1199906) showed average colour, hardness, conductivity and turbidity values that were consistent with those measured for the south basin site (1199902). Nitrogen and phosphorus concentrations were also comparable to concentrations for 1199902 and were similar to values measured in the 1970's. Total metals concentrations were low and were below guideline levels or analytical detection limits.

McGee Creek (1199909) showed higher average colour, hardness and conductivity values than those measured at the north basin site (1199901). However, turbidity, nitrogen and phosphorus concentrations were comparable to those at 1199901 and historical data. Total metals results were below guideline levels or analytical detection limits.

Data for site 1199916 (Inflow at East Shawnigan Road) are limited, although available results show low levels for all parameters measured.

6.2.4 Outflow

The Shawnigan Creek outflow (1199912) was last sampled in 2004 and monitoring results were consistent with those from the lake basin sites. A higher average concentration was noted for turbidity ($\bar{x} = 1.33$ NTU) but this was influenced by one high measurement of 12 NTU taken in October, 2003 after a period of extremely high rainfall.

6.2.5 Water Chemistry Interpretation

The monitoring results for Shawnigan Lake show that water quality has been consistently good over the period of study, despite significant changes within the watershed. No parameters measured showed levels or trends which would cause concern at this time.

Phosphorus is probably the most influential parameter with respect to water quality and aquatic ecosystems. The productivity of most lakes is limited by phosphorus and very small increases in P can have significant effects to both the chemical and biological aspects of water quality. Nordin and McKean (1984) proposed an objective of 8 μg/L at spring overturn to control an uncharacteristically high dissolved oxygen depletion rate and protect the level of water quality for domestic purposes. Even though the population within the watershed has doubled since that time and significant development and logging has taken place, the total phosphorus concentration remains low at all sites.

Nordin and McKean (1984) described four factors which contribute to the relatively good water quality in Shawnigan Lake:

- A short lake water residence time (approximately one year) which was estimated to flush out half the phosphorus inputs for a given year.
- A favourable hydrologic regime that is common to many coastal lakes whereby nutrients from the watershed are supplied to the lake during fall freshet when algal growth is light-limited and nutrients are lost either through sedimentation or outflow.
- Localized nutrient loadings from the Village area so that the highest loadings affect a limited area and, being close to the outlet, are partially removed from the lake system.
- Low P loadings because the soils in the watershed have a very high affinity for P and bind much of what originates from natural and manmade sources.

It is possible that each of these factors, and others (e.g. improved waste management practices on new developments) could be contributing to the low total P concentrations measured in recent years.

The low P levels in Shawnigan Lake are also reflected in the ratio of total nitrogen to total phosphorus (N:P). The N:P ratio is useful for confirming the limiting nutrient for a given lake and its trophic status, as well as tracking changes in nutrient inputs into the system (Chiaudani and Vighi, 1974). N:P ratios greater than 27:1 (by mass) indicate oligotrophic conditions (Kalff, 2002) and, from a eutrophication perspective, very good water quality. A decreasing trend in N:P ratios would indicate an increasing input of nutrients, especially P, and values less than 10:1 generally indicate nitrogen limiting conditions. The shift towards N limitation favours the phytoplanktonic cyanobacteria (blue-green algae), which are capable of fixing atmospheric nitrogen, but are also associated with water quality concerns (generally taste and odour problems, but in extreme cases, hepatotoxins and neurotoxins can be produced). Spring overturn N:P ratios for Shawnigan Lake are showing an overall increasing trend which appears to be the result of lower phosphorus concentrations rather than higher nitrogen levels. The N:P ratios indicate that Shawnigan Lake is oligotrophic and very phosphorus-limited.

Although total organic carbon concentrations were below guideline levels, this parameter is still of concern because of the potential health concerns associated with it. The reasons for reducing organic carbon in drinking water are not related to the toxicity of the organic carbon compounds, but the desire to reduce the formation of disinfection by-products following chlorination (B.C. Ministry of Environment, Lands and Parks, 1998). The major purveyors of domestic water on Shawnigan Lake all provide disinfection with chlorine and because of anthropogenic activities within the watershed (e.g., forestry, urban runoff) there is the potential for increases in TOC concentrations over time and consequently, increases in disinfection by-product formation.

The one area of concern would be the West Arm which has always had the highest inputs of nutrients and sediments. Because this area is relatively shallow and isolated from the main basins, the potential for mixing and flushing may be less than other areas of the lake and it could be more susceptible to the effects of increasing nutrient inputs in the future.

6.3 Biological Analysis

Biological sampling is an important component of water quality monitoring. Organisms respond to a range of environmental conditions and can provide a clearer understanding of the functional relationships within an aquatic ecosystem. In this study, phytoplankton and zooplankton were collected to determine their abundance and dominance and help identify any linkages between water quality and anthropogenic activities.

Chlorophyll *a* is a measure of phytoplankton biomass and relates to the productivity of a waterbody. Agriculture, sewage effluent, forest harvesting, urban development, and recreational activities can add nutrients to a lake, increasing chlorophyll *a* concentrations (Cavanaugh *et al*., 1998). Chlorophyll *a* is an ideal measurement because it is simple and universally applied (Nordin and McKean, 1984). There are no provincial guidelines for chlorophyll *a* in lakes, but phosphorus guidelines are designed to limit algal growth.

Changes in phytoplankton community composition may signal changes in water chemistry and nutrient concentration. Nutrient enrichment affects phytoplankton density and diversity (Palmer, 1977). Water quality impacts associated with phytoplankton blooms include taste and odour problems, filter and screen clogging, corrosion, increased turbidity (Palmer, 1977, Nordin and McKean, 1984), reduced water clarity, reduced hypolimnetic oxygen levels and the risk of toxins produced by blue-green algae.

Zooplankton hold an important intermediate position in the aquatic food web. Although they do not cause problems with water quality or aesthetics directly, they are sensitive to changes in water quality and are used as indicators. Specifically, zooplankton respond to dissolved oxygen concentrations, contaminants, and changes in food quality/abundance.

6.3.1 Methods

Phytoplankton samples were collected by taking one litre grab samples at the surface. Chlorophyll *a* samples were collected using a hand-operated vacuum pump to filter 500 mL of surface water through a 0.45 micron membrane filter; the filter paper was then analyzed for chlorophyll *a*. Zooplankton were collected using a 10 m vertical tow in a Wisconsin-style net with a mouth area of 0.07 m^2, a net opening diameter of 0.5 m and a mesh size of 80 μm. All samples were collected following the Ministry of Water, Land

and Air Protection approved methods (B.C. Ministry of Water, Land and Air Protection, 2003a).

6.3.2 Chlorophyll *a*

Chlorophyll *a* results are presented in Table 13. The chlorophyll *a* concentrations from all sites were low suggesting good water quality. The majority of samples were below 3 µg/L, which is the upper threshold for oligotrophic conditions (Kalff, 2002). There was an overall decrease in mean chlorophyll *a* concentrations for 1977 to 2005, suggesting a difference in primary productivity. The two deep sites (1199901 and 1199902) showed chlorophyll *a* concentrations ranging from <0.5 µg/L to 1.5 µg/L and 1.6 µg/L, respectively. Both the West Arm (1199903) and the north beach (1199904) sites showed higher concentrations in May (2.6 µg/L and 2.3 µg/L, respectively) with concentrations below the detection limits (<0.5 µg/L) in other months.

The proposed water quality objective for chlorophyll *a* in Shawnigan Lake is a maximum concentration of 2 µg/L. This objective is set to protect the existing oligotrophic conditions of the lake. Values are to be summer (April – October) averages for epilimnetic water in the main basin of the lake.

6.3.3 Phytoplankton

Phytoplankton results were summarized and the dominant species are presented in Table 12.

These results show differences in dominant species to those reported by Nordin and McKean (1984). The only dominant species occurring in the same month as previously reported were the diatoms *Asterionella formosa* and *Cyclotella bodanica* and the golden-brown *Dinobryon divergens* in May, and the golden-browns *D. divergens* and *D. bavaricum* in June. Two genera of blue-greens, *Anacystis* and *Gomphosphaeria*, were common to both studies in May, June, July and August.

Several of the genera present are characteristic of oligotrophic conditions including the diatoms *Asterionella*, *Cyclotella*, and *Melosira*; the green *Botryococcus*; and the golden-browns *Dinobryon* and *Peridinium*.

The diatoms were dominant in February and May 2003 (76% and 41%, respectively) although in May the diversity of the phytoplankton assemblage had increased. In June, the dominance of the blue-greens became evident (55%) and peaked in August at 77%. This dominance began to decrease in the fall and the greens and cryptophytes became more significant. The cryptophytes were dominant in the winter 2004/2005 and the diatoms became dominant in the spring (86% in March 2005). This interpretation of the results should be taken with caution because of the wide range in size of the individual species. An equal amount of cells of one species may be much more significant than another based on the larger size of one of the species. The fact that chlorophyll *a* concentrations did not increase dramatically during the sampling period suggests that, although there were shifts in phytoplankton community composition through the year, the overall biomass did not reach problem levels.

6.3.4 Zooplankton

Zooplankton results are summarized in Table 14. This list includes only the dominant species, although several other species are present (see Rieberger *et al*., 2004). Overall concentrations were typical of systems with low levels of nutrients. Rotifers were dominant throughout in terms of total numbers and peaked in June 2003. *Keratella cochlearis* was the most common rotifer species; it was the dominant species in seven out of the 10 months sampled. *Ptygura libera* was the dominant species in July, *Kellicotia longispina* in September and *Polyarthra* sp. in November 2003.

Zooplankton species diversity increased during the winter and autumn. Cyclopoid copepods concentration, especially nauplii, peaked in November, 2003, representing 10% of all zooplankton present. The other orders of copepods, Calanoida and Cladocera, had low abundance throughout the study period and comprised little of the overall species assemblage.

Overall, the zooplankton abundance showed two peaks throughout the 2003-2004 sampling period in June/July and November (Figure 16). The high summer concentrations may be a consequence of increased food quality and quantity, while the November peak could be the result of nutrient inputs associated with fall freshet. Spring overturn sampling in 2005 showed higher zooplankton concentrations than previously noted which were dominated by *K. cochlearis*.

Carl's (1940) and Nordin and McKean's (1984) reports were used as benchmarks to compare crustacean zooplankton species assemblages for Shawnigan Lake over time (Table 15). Carl's report focussed entirely on crustacean zooplankton, so comparisons using other phyla could not be made. In addition, Carl did not include species concentrations, so only absence/presence assessments could be performed. Rare species, in this report, were defined as species whose total abundance was less than 1% of the total number of organisms collected. Carl (1940) found six cladoceran species in Shawnigan Lake, compared to eight (two of which are rare) for Nordin and McKean's

(1984) and 15 (14 of which are rare) in this study. *Daphnia rosea*, *Sida crystallina* and *Leptodora kindtii* are the only species appearing in all three assessments, however *S. crytallina* and *L. kindtii* were rare in this study. For copepods, Carl found two species, compared to three for Nordin and McKean's and eight (six of which are rare) for this study. *Epischura nevadensis* was the only copepod found in all three assessments; however it was rare in this study.

An overall increase in zooplankton abundance for sites 1199901 and 1199902 was observed since 1977 and 1978 (Tables 16 and 17). *Keratella cochlearis* was the species that showed the greatest increase in abundance; this species has been shown to be associated with P- limited oligotrophic lake conditions (Ramos-Rodriguez and Conde-Porcuna, 2003). *Daphnia rosea* increased in abundance in May and June at 1199901 and June and July at 1199902 but decreased in abundance later in the season. Also contributing to the large overall increases in zooplankton abundance were the large increases in copepod nauplii (i.e. larva) present in most samples.

6.3.5 Biological Interpretation

Phytoplankton and zooplankton populations are seasonally variable and are regulated by both chemical (nutrients and other essential elements) and physical factors (e.g., light, temperature, pH).

Phytoplankton concentrations for Shawnigan Lake did not depart from natural or acceptable levels during the sampling period, as indicated by lower chlorophyll *a* concentrations than measured in earlier assessments.

Blue-green algae dominated the phytoplankton community in the summer months, with peaks following nitrate+nitrite trends in the surface water (epilimnion). Blue-green dominance was the greatest in the summer months (June – September) when nitrate+nitrite concentrations were lowest (2 μg/L), diminishing in the fall and winter months with increasing epilimnetic nitrate+nitrite concentrations. Epilimnetic total phosphorus concentrations were low throughout the summer and did not create nitrogen limiting conditions which would favour the blue-green algal growth. In addition, the chlorophyll *a* concentrations measured did not indicate an increase in primary productivity which would be associated with problematic levels of blue-green algae. Finally, the dominant blue-greens found did not include species that are typically associated with eutrophic conditions (e.g. *Anacystis aeruginosa*, *Aphanizomenon* and *Anabaena*).

There is likely considerable interannual variability in phytoplankton community composition as demonstrated in comparisons between sampling periods. For example, the diatom *Tabellaria fenestrata*, the chlorophyte *Spondylosium planum* and the blue-green *Rhabdoderma gorskii*, were dominant in 1984 (Nordin and McKean, 1984) but generally absent in this study. The dominant groups for each time period, however, were similar. Diatoms, for example, were dominant in May in both studies.

Mean chlorophyll *a* concentrations in Shawnigan Lake indicate oligotrophic conditions and the decrease in mean concentrations since the 1970's suggests that primary productivity may have also declined. A large decrease in average chlorophyll *a* concentrations was noted over the period of study and is consistent with the low total P concentrations measured. Zooplankton grazing may have also contributed to the decrease in chlorophyll *a* concentrations.

There were differences in zooplankton assemblages noted between this study and with Nordin and McKean's (1984) and Carl's (1940) assessments which concentrated on the cladocerans and copepods. In comparing our results with the earlier assessments we observed a more diverse zooplankton community in Shawnigan Lake than previously reported because of the greater occurrence of rare zooplankton species (Table 15). Neither of the previous assessments included rotifers in their examination of species diversity which is problematic as they were a major constituent of the contemporary species assemblage. One reason for this may be the sample collection methods used. We used a net with an 80 μm mesh size. If the others used nets with a larger mesh size, this could account for the small-sized species (like rotifers) being absent from earlier results. Changes in species names, classifications and identification keys may also account for some of the increase in rare species presence.

An increase in zooplankton abundance was also noted despite the fact that Shawnigan Lake has remained in an oligotrophic condition throughout both sampling periods. The rotifer *Keratella cochlearis* was a dominant species and has been shown to have high growth rates when algae are under phosphorus limitation (Ramos-Rodriguez and Conde-Porcuna, 2003). The ability of *K. cochlearis* to excel under low P conditions may help explain this dramatic rise in zooplankton abundance.

Generally, healthy lakes are comprised of small cell-size phytoplankton, large body-size zooplankton, high zooplankton and macrozooplankton biomass, low microzooplankton concentration and a high ratio of zooplankton to phytoplankton biomass (Xu *et al*., 1999). With respect to zooplankton body size, this is not the case in Shawnigan Lake where the majority of zooplankton have small body sizes. The zooplankton species composition may be influenced by planktivorous fish like kokanee (*O. nerka*) and juvenile rainbow trout (*O. mykiss*) and possibly the introduced bass (*M. dolomieui*) and perch (*P. flavescens*). This is illustrated by the disproportionate number of copepod nauplii compared to copepod adults (Table 14).

Two biological indicators that were not addressed in this report, but could be considered in the future, are macrophytes (aquatic plants) and fish. Excessive weed growth in the littoral zones (shallow, shoreline areas) is an issue with lakeshore residents and attempts by individuals to remove macrophytes may in fact promote their growth because many are able to propagate from small fragments of plants that are broken off. With fish, the relatively recent introductions of bass and perch into Shawnigan Lake may have an impact on the salmonid species, and other organisms, that might not be immediately apparent.

Biological indicators can have significant amounts of incidental or unexplained variability which can affect results and therefore caution must be exercised when using phytoplankton or zooplankton to indicate anthropogenic disturbances. Biological indicators are complex and may contain many elements capable of corresponding differently and in unpredictable ways to a range of physical and biological factors (Stemberger *et al.*, 2001). Recognizing these limitations, it appears that the current phytoplankton assemblages in Shawnigan Lake are similar to those observed in the late 1970’s at a high level (i.e., diatoms dominant in the spring and blue-greens dominant in the summer) but there appears to be considerable change at the genus and species level. Nordin and McKean (1984) only reported on dominant phytoplankton from May to August 1977 which limits comparisons over time. Increasing phosphorus limitation, as suggested by lower chlorophyll *a* concentrations, may have resulted in an increased abundance of smaller bodied zooplankton species like rotifers or this observed increase could be the result of different sampling methods from previous collections (e.g. smaller plankton net mesh size). Despite these cautions, the overall biology of Shawnigan Lake appears healthy and indicates no impairment to water quality.

6.4 Microbiology

The fecal microbiota of warm blooded animals is potentially pathogenic and fecal contamination of water can cause many illnesses including scarlet fever, diarrhoea, pneumonia and meningitis. Potential fecal contamination sources for Shawnigan Lake are: livestock, waterfowl, failing septic systems, inadequate locations of sewage disposal fields, and stormwater runoff (Nordin and McKean, 1984; Webber, 1996).

The human health risks of fecal contamination in Shawnigan Lake were assessed using the presence of the microbiological indicator species *Escherichia coli* and enterococci.

Escherichia coli was the primary microbiological indicator, while enterococci were supplementary. Fecal coliform and streptococci concentrations were also measured but not relied on to indicate human enteric health risks because of concerns about their value as indicators.

The presence of *E. coli* in water is a strong indication of human sewage or animal waste contamination because it rarely multiplies in the environment (Leclerc *et al*., 2001) and has been statistically associated with an increase in the relative risk of gastrointestinal illness in freshwater studies (Wade *et al*., 2003; Pruss, 1998). Currently, *E. coli* is considered to be the superior freshwater fecal bacterial contamination indicator.

There has been debate on whether enterococci should be used as an indicator of freshwater enteric illness (Atherholt *et al*., 2003; Kinzelman *et al*., 2003). Enterococci have been considered by the US Environmental Protection Agency (EPA) to be a better indicator of human fecal contamination than fecal coliforms (Griffin *et al*., 2001), although supplementary to *E. coli*. Therefore, enterococci were used as an additional bacteriological indicator in this assessment.

Fecal coliforms are included to provide comparison to earlier assessments of Shawnigan Lake (Nordin and McKean, 1984, Webber, 1996), although no statistically significant association between the risk of illness and the concentration of fecal coliforms has been found (Wade *et al*., 2003) and the US EPA has recommended that fecal coliforms no longer be used as an indicator for recreational freshwater quality (Wade *et al*., 2003; US Environmental Protection Agency, 1986;).

Fecal streptococci were measured but not used to assess contamination. Fecal streptococci are known to have environmental origins, compromising their ability as indicators of fecal contamination. Currently, the associations between gastrointestinal illness and fecal streptococci are contradictory (Pruss, 1998) and not generally supported as an indicator of health risk (Wade *et al*., 2003; Godfree *et al*., 1997).

6.4.1 Methods

Surface-water grab samples were collected according to Ministry approved sampling procedures (B.C. Ministry of Water, Land and Air Protection, 2003a) and tested for *E. coli*, enterococci, fecal coliforms and fecal streptococci at nine sites: four inflow sites (sites 5 – 8), one outflow site (site 9) and four lake perimeter sites (sites 10 – 13). Results are reported in colony forming units (CFU)/100 mL. The lake basin sites (sites 1 - 4) were not tested for bacteriological parameters because of the distance from domestic intakes. There were two distinct sampling periods for this assessment in which five samples were collected for each site in a 30-day period: August/September 2003 (summer flow-flow) and October/November 2003 (fall freshet). Ninetieth (90th) percentile concentrations and geometric mean concentrations were calculated to determine whether concentrations exceeded provincial water quality guidelines for raw drinking water with disinfection and recreational primary contact, respectively.

Additional sampling was conducted in November/December 2004 in close proximity to two domestic water intakes to determine the bacteriological quality of this water. The two intakes sampled were: Lidstech Holdings on the east shore (E257436) and Cowichan Valley Regional District on the north shore (E257437). Samples were taken at the surface and near the bottom at a depth of six metres.

6.4.2 Results

Indicator bacteria concentrations are summarized in Tables 18 to 20. During the 2003 summer low flow period, 90th percentile concentrations exceeded drinking water guideline levels at only one lake site, West Shawnigan Lake Park (E222055). Enterococci and fecal coliform guidelines were exceeded and the *E. coli* concentration was at the guideline level of 10 CFU/100 mL. All the inflow sites (1199906, 1199909 and 1199911) and the outflow site (1199912) exceeded the drinking water guidelines.

During the 2003 fall freshet period, 90th percentile values at all sites exceeded the drinking water guidelines. However, subsequent samples taken near domestic intakes during the 2004 fall freshet were all within the drinking water guidelines.

The primary recreational contact guidelines were met much more consistently and during the summer low flow period guidelines were only exceeded at the inflow and outflow sites. The *E. coli* and enterococci guidelines were exceeded at Shawnigan Creek inflow site (1199906); the enterococci guideline was also exceeded at McGee Creek (1199909), the west arm inflow (1199911) and the Shawnigan Creek outflow (1199912).

During the 2003 fall freshet, only the enterococci recreational guideline was exceeded at West Shawnigan Lake Park (E222055) and Shawnigan Lake Resort (E246900). The 2004 fall freshet monitoring results showed all results to be within the recreational guidelines (Table 20).

6.4.3 Microbiology Interpretation

Nordin and McKean (1984) observed higher levels of fecal contamination in near shore areas compared to the deep water sites and the inflows showed the highest levels of contamination. Webber (1996) found all sites sampled to meet the primary recreational contact guidelines; however, three lake sites exceeded the guidelines for raw drinking water with disinfection. The Vancouver Island Health Authority (Central Island Unit) performs tests at three Shawnigan Lake sites (West Shawnigan Lake Provincial Park beach, Easter Seal camp beach and Mason's beach) for fecal and total coliforms to determine the surface water's suitability for recreational use and their results for 2002 and 2003 were all within guideline levels.

With respect to drinking water, the lake sites are probably of more significance because the largest licenced withdrawals are all from the lake itself; however, there are 28 licenced withdrawals on Shawnigan and McGee creeks with a total authorized withdrawal of over 1,300 m^3/d. Although most of the lake sites met the drinking water guidelines (disinfection only), with the exception of the West Shawnigan Lake Park site, during the 2003 summer low flow, all of the lake sites exceeded the guidelines during the 2003 fall freshet. That all the inflow sites exceeded the drinking water guidelines during both sampling periods should be of concern; this also suggests that, because the lake sites were predominantly exceeded only during fall freshet, there may be other contributing sources of contamination to the lake other than the inflow streams. The most obvious source would be surface runoff containing surfacing septic effluent and animal wastes (pets, livestock, wildlife) and the very heavy rain storms that were experienced in this area during the 2003 fall freshet sampling period could have contributed to increased fecal contamination in Shawnigan Lake.

The follow-up monitoring during the 2004 fall freshet was conducted to determine if there was a risk to the water quality near the major domestic water intakes. The results of this sampling suggest that the water quality is good having met the guidelines for all three parameters measured. The 2003 summer low flow and fall freshet samples were taken from the beach in shallow water while the 2004 fall freshet samples were taken from a boat. This may account for the discrepancy between results as the beach areas may be more susceptible to contamination from wildlife, people and pets. It may be worthwhile to repeat the bacteriological sampling at the intakes during the summer low flow and fall freshet periods to confirm the guidelines are being met.

There are many single home intakes in Shawnigan Lake, most of which are likely not treating the water prior to use. Although the guidelines for raw water with disinfection were mostly met at the lake sites during the summer low flow, the guideline for raw water without treatment for all parameters is 0 CFU/100 mL and emphasizes the importance of treating raw water prior to consumption to avoid health risks.

The bacteriological guidelines for recreational primary contact were exceeded for *E. coli* (1 exceedance) and enterococci (4 exceedances) at the inflow and outflow sites during the 2003 summer low flow period. The enterococci guidelines were exceeded at two of the lake perimeter sites during the 2003 fall freshet period, while the fecal coliform concentrations were always within the guidelines. It is interesting to note that the recreational *E. coli* and enterococci guidelines in the inflows were only exceeded during the summer low flow period and were generally lower during the fall freshet suggesting that the source may be seasonal (e.g. wildlife, recreational use, livestock) or that the loadings are diluted with the increasing flows of the fall freshet.

The proposed water quality objective for microbiological indicators in Shawnigan Lake are as follows:

- ***E. coli*: maximum concentration of 10 CFU/100 mL (90th percentile)**
- **Enterococci: maximum concentrations of 3 CFU/100 mL (90th percentile)**
- **Fecal coliform: maxuimum concentrations of 10 CFU/100 mL (90th percentile).**

These objectives are set to protect the quality of source drinking water in Shawnigan Lake. The objectives are based on guidelines established for drinking water that is subject to disinfection and applies to all areas where drinking water is withdrawn. Calculation of 90th percentile values is based on a minimum of five samples collected within a 30-day period. If any of these objectives are exceeded, further sampling should be conducted during the summer low flow and fall freshet periods.

7.0 WATER QUALITY OBJECTIVES

In British Columbia, water quality objectives are mainly based on approved or working water quality guidelines (Nagpal and Pommen, 1994). These guidelines were established to prevent specified detrimental effects from occurring with respect to a designated water use. Identified water uses for Shawnigan Lake that are sensitive and should be protected are drinking water, primary contact recreation and aquatic life. The water quality objectives recommended here are based on those proposed by Nordin and McKean in 1984 with some additions. The fact that the original proposed objectives have been met over the past 20 years and the continuing state of good water quality indicates that these objectives are both appropriate and effective at protecting the designated water uses and preventing eutrophication. The objectives are summarized in Table 21.

8.0 MONITORING RECOMMENDATIONS

The recommended water quality monitoring program for Shawnigan Lake is summarized in Table 22. Annual spring overturn monitoring should continue on Shawnigan Lake to determine if the water quality objectives recommended here are being attained. This monitoring should consist of full water chemistry sampling at three depths (surface, mid depth and bottom) at the deep stations 1199901 and 1199902 and include measurement of physical parameters such as dissolved oxygen, temperature and extinction depth.

Spring overturn sampling should also be conducted at two additional lake basin sites, 1199903 (West Arm) and 1199904 (north beach), with samples taken at the surface and one metre above the bottom.

If any of objectives are exceeded, a more extensive monitoring program should be developed to determine the cause of the problem. This may include sampling inflow streams.

In addition, microbiological indicators should be sampled at 1199903 and 1199904, and near domestic water intakes (E256436 and E257437) at both the surface and near the bottom. If the results exceed the objectives stated above for any of the indicators follow up monitoring consisting of at least 5 samples within 30 consecutive days should be conducted during the summer dry period and the fall freshet period.

Finally, a survey of aquatic macrophytes in Shawnigan Lake should be conducted. Aquatic plant growth patterns can provide useful information for water quality trends and are of particular interest to lakeshore residents in terms of nuisance species and excessive growth.

9.0 CONCLUSIONS

Shawnigan Lake continues to provide a desirable community in a natural, rural setting close to Victoria. Growth and development has been considerable in recent years; associated with this are the risks to water quality, like runoff from impervious surfaces, sewage disposal and increased recreational use of power boats on the lake itself. Other land uses in the watershed, like forestry and agriculture, create additional risks to water quality. In addition to quality is the issue of water quantity. The growing domestic demand on Shawnigan Lake has been offset by an increased dependency on groundwater, however the lake remains the main source of domestic water in this watershed and the impacts of human land-use must be considered to prevent human health risks and other water quality problems.

Despite the increased development and changes to human land use within the watershed, the overall water quality of Shawnigan Lake, from both chemical and biological perspectives, remains remarkably good at the present time. Spring overturn phosphorus concentrations have met the provisional water quality objectives for phosphorus (i.e., 8 μg/L) since proposed in 1984 and appear to be decreasing; however, there's no obvious explanation for this trend at this time. This same observation was made in the 2000 report Water Quality Trends in Selected British Columbia Waterbodies (B.C. Ministry of Environment, Lands and Parks and Environment Canada, 2000). All forms of nitrogen measured showed no obvious trends in concentration since the late 1970's. This, in conjunction with lower phosphorus concentrations, has resulted in a trend of higher N:P ratios over the period of study. Based on these observations, it can be said that Shawnigan Lake continues to be oligotrophic (low productivity). Total organic carbon concentrations were below guideline levels; this is important because the domestic water systems on Shawnigan Lake treat the water with chlorine disinfection and meeting the TOC guidelines will minimize the risk of disinfection by-product formation.

The results of this assessment showed other water chemistry parameters to be low and do not suggest any problems at this time. The turbidity levels measured at all sites met the provisional water quality objectives (5 NTU). Dissolved oxygen concentrations were higher than previously reported with greater periods of oxygen supersaturation in surface waters and greater hypolimnetic oxygen concentrations, while other limnological characteristics (water temperature, thermal stratification patterns and clarity) remained the same.

The biological parameters measured also suggest good water quality in Shawnigan Lake. Chlorophyll *a* concentrations were lower than measured in earlier assessments which is to be expected given the lower concentrations of nutrients measured in recent years. Several species of phytoplankton common to oligotrophic conditions were observed and although dominance by blue-green algae was noted throughout the summer this appears to be related to nitrogen-limited conditions created by a decrease in nitrogen concentrations in the summer months rather than an increase in phosphorus. Results of zooplankton sampling are consistent with these observations in that species typical of oligotrophic conditions (e.g., *Keratella cochlearis*) have become more prevalent.

The most recent microbiological results show that the guidelines were met near the domestic intakes. The guidelines may still be exceeded for individual intakes and so all withdrawals for domestic purposes should be treated to prevent health risks.

Earlier assessments (Nordin and McKean, 1984) recognized several factors which help protect the water quality of Shawnigan Lake. The lake has a high flushing rate which removes a significant portion of the phosphorus from the system. The hydrologic regime is also favourable in that most of the nutrient inputs come with the fall freshet at a time when primary productivity is limited by decreasing daylight. Finally, the most intense development has been at the north end of the lake close to the outflow which removes most of the nutrients from these areas. The current trend of development (logging and residential) in other areas of the watershed may result in an increase of nutrients to other areas of the lake potentially impacting water quality.

While the chemical water quality of Shawnigan Lake remains good, the fact that its primary use for residents is as a domestic water supply should not be overlooked. Continuing growth and development within the watershed in addition to a high level of recreational boating will present challenges to protecting water quality in the future. Efforts to protect the existing chemical water quality of Shawnigan Lake and address the problems with bacteriological contamination must be driven at the local level. Local government agencies, water purveyors and lake stewards should be encouraged to take action to protect the water quality for current and future uses. Activities include public outreach and awareness to promote maintenance of on-site sewage systems, environmentally sound development practices to limit the impact on water quality and responsible land use practices to prevent contamination from other sources like forestry and agriculture.

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TABLE 1
LICENCED DOMESTIC WATER WITHDRAWALS AND STORAGE VOLUMES FOR SHAWNIGAN LAKE

Site	Number of licences	Quantity of Withdrawal (m^3/day)	Quantity of Storage (m^3/day)
McGee Creek	2	38	
Shawnigan Creek	26	1,354	2,002
Shawnigan Lake	197	5,646	3,489
Sum	225	7,038	5,491

TABLE 2
MAJOR WATER PURVEYORS LICENCED TO WITHDRAW WATER FROM SHAHNIGAN LAKE

Licencee	Licence Number	Quantity
Cowichan Valley Regional District	C057107	209,115 m^3/year
Lidstech Holdings	C116151	165,932 m^3/year
Cowichan Valley Regional District	C106569	141,884 m^3/year
Shawnigan Lake School	C117969	273 m^3/day
Cowichan Valley Regional District	C040373	61, 395 m^3/year
Lidstech Holdings	C045744	58,076 m^3/year
Cowichan Valley Regional District	C041661	53,928 m^3/year

TABLE 3
LICENCED WATER WITHDRAWALS, BY DECADE, FOR SHAWNIGAN LAKE

	Decade						
	1940	1950	1960	1970	1980	1990	2000
Cumulative number of licenses	5	24	40	142	184	216	225
Cumulative total quanitity (m^3/day)	61	210	3,886	6,003	6,104	6,177	7,038

TABLE 4
AQUIFERS AND THEIR CLASSIFICATIONS WITHIN THE SHAWNIGAN LAKE WATERSHED

Aquifer Number	Descriptive Location	Classification	Size (km^2)	Productivity	Vulnerability	Domestic Well Density (wells/km^2)	Use
197	Cobble Hill, Cowichan Bay	IIC	39	Moderate	Low	16.6	Multiple
201	Cobble Hill	IIC	1.7	Moderatel to high	Low	8.2	Domestic
202	Shawnigan Lake, Cowichan Bay	IIB	20	Low	Moderate	5.5	Multiple
203	Shawnigan Lake, Cobble Hill	IIA	30.5	Low	High	8	Multiple
204	Cobble Hill, Mill Bay	IIB	16.2	Moderate	Moderate	16.6	Multiple
205	Shawnigan Lake, Cobble Hill	IIC	2.6	Moderate	Low	17.7	Multiple
206	Mill Bay	IIA	2.7	Moderate	High	11	Multiple
207	Shawnigan Lake, Mill Bay	IIB	27	Low to moderate	Moderate	7.3	Multiple

TABLE 5
PERMITTED WASTE DISCHARGES WITHIN THE SHAWNIGAN LAKE WATERSHED

Permit number	Name	Type description	Maximum discharge (m^3/day)	Maximum average discharge (m^3/day)	Approximate distance to surface waters (m)
RE 06580	Cobblestone Inn Ltd.	Tile field	37.1		4,100
PE 04320	Shawnigan School STP Effluent	Discharge to ground	182		1,000
PE 05290	Shawnigan Beach Estates	Discharge to ground	485		500
PE 07938	Shawngian Lake Baha'I School	Tile field		38.5	400
PE 08121	Simard Pit	Discharge to ground	90		1,000

TABLE 6
SHAWNIGAN LAKE WATER QUALITY SAMPLING SITES

Site Location	Site Number	EMS Number	Site Description
Lake	1	1199901	Deepest point of main (north) basin, approximate depth is 45 m
Lake	2	1199902	Deepest point in south basin midway between Memory Island and the west shore of the lake, approximate depth is 20 m
Lake	3	1199903	West Arm, mid-channel, halfway up the arm, approximate depth is 9 m
Lake	4	1199904	North end of the lake near Mason's Beach, approximate depth is 15 m
Inflow	5	1199906	Shawnigan Creek inflow at south end of lake
Inflow	6	1199909	McGee Creek inflow on west side of lake
Inflow	7	1199911	West Arm inflow
Inflow	8	1199916	Shawnigan Lake inflow at East Shawnigan Road
Outflow	9	1199912	Shawnigan Creek outflow at north end of lake
Perimeter	10	E222045	Galley Restaurant, marina dock on east side of lake
Perimeter	11	E222048	Easter Seal Camp beach, camp float on east side of lake
Perimeter	12	E222055	West Shawnigan Lake Park, beach on west side of lake
Perimeter	13	E246900	Shawnigan Lake Resort, resort dock on northwest end of lake
Perimeter	14	E257436	Shawnigan Lake domestic intake – east shore
Perimeter	15	E257437	Shawnigan Lake north domestic intake

TABLE 7
MEAN SECCHI DEPTHS (METRES) FOR SHAWNIGAN LAKE BASIN SITES

	1199901			**1199902**			**1199903**			**1199904**		
Year	**Mean**	**std. dev**	**n**	**Mean**	**std. dev**	**n**	**Mean**	**std. dev**	**n**	**Mean**	**std. dev**	**n**
1976-1979	6.1	1.0	26	5.8	1.15	23						
1980-1987	5.4	2.6	5	7.0		1						
1994	6.0		1									
2003-2005	5.6	2.0	9	5.9	2.1	8	5.9	1.0	9	6.3	1.5	7

TABLE 8
AVERAGE TOTAL PHOSPHORUS CONCENTRATIONS (μg/L) FOR SHAWNIGAN LAKE BASIN SITES

	1976-79			**1980-89**			**1990-99**			**2000-present**		
Site	**Mean**	**SD**	**n**	**Mean**	**SD**	**n**	**Mean**	**SD**	**n =**	**Mean**	**SD**	**n =**
1199901	6	2	81	7	2	39	4	1	20	6	3	92
1199902	6	2	67	9	3	7				7	4	51
1199903	5	2	24							5	5	20
1199904	5	2	14							4	2	21

TABLE 9
RESULTS OF LEAST SQUARES REGRESSION ON NITROGEN PARAMETERS VERSUS TIME ON SHAWNIGAN LAKE

Site	**Total Nitrogen**			**Ammonia**			**Nitrate + Nitrite**		
	R^2	**Slope**	**n**	**R^2**	**Slope**	**n**	**R^2**	**Slope**	**n**
1199901	0.0954	+	50	0.3286	-	60	0.3665	+	62
1199902	0.0374	+	36	0.0597	-	36	0.3883	+	37
1199903	0.1693	+	36	0.0003	0	36	0.1724	+	36
1199904	0.1867	+	24	0.1636	-	26	0.0645	+	26

TABLE 10
AVERAGE SPRING OVERTURN TOTAL NITROGEN CONCENTRATIONS (mg/L) FOR SHAWNIGAN LAKE

Date	1199901	1199902	1199903	1199904
11-May-77	230	257	200	
17-Apr-78	245	275	300	230
8-Mar-79	257	235		
21-Feb-80	253			
10-Mar-83	227			
4-Mar-84	223			
26-Mar-97	225			
8-Apr-99	235			
22-Mar-00	260			
7-Feb-01	263	283		
21-Mar-01	195	247		
11-Feb-03	250		290	265
12-Feb-04	270	313	460	340
10-Mar-05	234	226	307	290

TABLE 11
N:P RATIOS BY SITE FOR SHAWNIGAN LAKE

Year	**1199901**	**1199902**	**1199903**	**1199904**
1976 – 1979	30:1	34:1	36:1	33:1
1980 – 1989	34:1	26:1		
1990 – 1999	58:1			
2000 - present	36:1	32:1	54:1	58:1

TABLE 12
DOMINANT PHYTOPLANKTON SPECIES FOR SHAWNIGAN LAKE
(average cells/100 mL for sites 1199901, 1199902, 1199903, 1199904)

Group	Species	11-Feb-03	13-May-03	25-Jun-03	23-Jul-03	13-Aug-03	23-Sep-03	21-Oct-03	18-Nov-03	12-Feb-04	10-Mar-05
Diatoms	*Asterionella formosa*	35	147		32		64			26	639
	Cyclotella bodanica	17	180	20							11
	Melosira italica	259	67	49	46	11		11	28	77	56
	Tabellaria fenestrata										26
	Percent of total	76%	41%	5%	10%	3%	9%	1%	8%	36%	86%
Blue-green	*Anacystis elachista*		71	305	250	194	182	193	77		
	Anacystis limneticus		39	371	61	26	14	58			
	Gomphosphaeria aponina				79	40	67	174	45		
	Percent of total		9%	55%	63%	77%	46%	46%	15%		
Green	*Botryococcus braunii*			134	45	16		78	22	34	
	Gloeocystis ampla		92	234	85	30	37	139	26	17	
	Quadrigula closterioides		17		11	17	23	34	34		
	Sphaerocystis schroeteri		41	126							
	Percent of total		14%	32%	19%	10%	9%	22%	10%	7%	
Cryptophyte	*Chroomonas acuta*	86	90	43	26	12	58	160	171	132	14
	Cryptomonas ovata		86	16	17		11	66	32	17	4
	Percent of total	23%	18%	4%	5%	1%	12%	27%	59%	55%	2%
Golden-brown	*Dinobryon bavaricum*		50	15	13	14	14	30			22
	Dinobryon divergens	14	134	36		95	124	25	26	11	72
	Percent of total	1%	18%	3%	2%	9%	24%	4%	8%	2%	12%

TABLE 13
SHAWNIGAN LAKE AVERAGE CHLOROPHYLL *A* CONCENTRATIONS (μg/L)

	1977 - 1979			2003 - 2004		
Site	**Mean**	**SD**	**n**	**Mean**	**SD.**	**n**
1199901	3.04	1.72	12	0.78	0.36	8
1199902	2.95	1.63	10	0.94	0.42	8
1199903	2.24	0.74	8	1.24	0.86	7
1199904	0.30	0	3	0.78	0.53	8

TABLE 14
DOMINANT ZOOPLANKTON SPECIES FOR SHAWNIGAN LAKE,
FEBRUARY 2003 – FEBRUARY 2004 (ORGANISMS/SAMPLE)

Order	Species	11-Feb-03	13-May-03	25-Jun-03	23-Jul-03	13-Aug-03	23-Sep-03	21-Oct-03	18-Nov-03	12-Feb-04	10-Mar-05
Cyclopoida	Nauplii	18,193	19,083	4,000	7,483	10,133	14,533	6,117	19,467	10,467	8,835
	Diacyclops thomasi	5,724	1,025					1,492	9,740	2,740	11,787
	Percent of Total	38%	37%	4%	8%	15%	19%	26%	30%	39%	15%
Calanoida	*Diaptomus sp.*				1,140					480	714
	Percent of Total				1%					1%	1%
Cladocera	*Daphnia rosea*	2,270	3,500	2,967	1,167		1,167			560	1,031
	Percent of Total	4%	6%	3%	1%		2%			2%	1%
	Kellicotia longispina	4,024	4,717	8,233	5,133	4,000	20,867	2,425	8,733	1,600	4,345
	Keratella cochlearis	32,567	20,367	35,867	14,733	27,067	17,467	9,258	25,267	15,167	110,117
	Polyarthra sp.		5,750	15,050	14,817	20,400	17,200	4,242	33,733	3,067	5,342
	Ptygura sp.			25,733	49,433	6,133	4,200				
	Percent of Total	58%	57%	93%	90%	85%	79%	74%	70%	58%	84%

TABLE 15
COMPARISON OF SHAWNIGAN LAKE CRUSTACEAN ZOOPLANKTON SPECIES COLLECTED IN THE 1930's (Carl, 1940), 1970's (Nordin and McKean, 1984) AND 2003

Cladocera	**1930's**	**1970's**	**2003**
Acroperus harpae			Yes (rare)
Bosmina longirostris		Yes	Yes (rare)
Bosmina obtusirostris	Yes		
Ceriodaphnia reticulata		Yes	
Ceriodaphnia sp.			Yes (rare)
Chydorus sp.			Yes (rare)
Chydorus sphaericus		Yes (rare)	
Daphnia cf ambigua			Yes (rare)
Daphnia longiremus		Yes	Yes (rare)
Daphnia pulex			Yes (rare)
Daphnia pulicaria			Yes (rare)
Daphnia rosea	Yes	Yes	Yes
Daphnia sp.			Yes (rare)
Diaphanosoma leuchtenbergionum		Yes	
Holopedium gibberum			Yes (rare)
Holopedium sp.			Yes (rare)
Leptodora kindtii	Yes	Yes	Yes (rare)
Polyphemus pediculus	Yes		Yes (rare)
Scapholeberis mucronata	Yes		
Sida crystallina	Yes	Yes (rare)	Yes (rare)
Copepoda			
Diacyclops sp.			Yes (rare)
Diacyclops thomasi			Yes
(Cyclops bicuspidatus)	Yes	Yes	
Diaptomus franciscanus			Yes (rare)
Diaptomus sp.			Yes
Epischura nevadensis	Yes	Yes	Yes (rare)
Macrocyclops sp.			Yes (rare)
Skistodiaptomus oregonensis			Yes (rare)
(Diaptomus oregonensis)		Yes	

Note: For the 2003 study, rare species were defined as those whose abundance was less than 1% of the total number of organisms collected.

TABLE 16
COMPARISON OF NORTH BASIN (1199901) ZOOPLANKTON SPECIES (ORGANISMS/SAMPLE) BETWEEN 1977/78 AND 2003

Date	***Epischura nevadensis***	***Bosmina longirostris***	***Daphnia rosea***	**Nauplii and Copepodites**	***Kellicotia longispina***	***Keratella cochlearis***	***Keratella quadrata***	**Sum of all species reported**
11-May-77	32	56	136	328	640	1,104	120	3,256
16-May-77		16	136	8	640	2,152	240	4,016
25-May-77	32	8	152	32	400	760	96	2,168
8-May-78	16	240	112	224	1,808	304	176	4,592
29-May-78	24		56	216	1,392	152	16	2,888
13-May-03	10	21	1,800	6,540	1,667	5,400	2,133	12,273
14-Jun-77	12		112	84	184	40		676
27-Jun-77	24		176	416	208	72		1,504
25-Jun-03	5	240	1,100	4,000	4,300	15,200		29,800
18-Jul-77	96		104	664	64	68		1,556
25-Jul-78	20	12	40	1,376	140	52		2,132
23-Jul-03		38		2,750	1,600		7,600	46,390
16-Aug-77	132		320	376	116	52		1,532
28-Aug-78		16	356	832	268	148	12	3,044
13-Aug-03	3	50		2,533	733	5,200		46,713
29-Sep-77	8	24	656	88	72	32	8	2,672
23-Sep-03	23	60		4,933	2,467	5,800		22,933

TABLE 17
COMPARISON OF SOUTH BASIN (1199902) ZOOPLANKTON SPECIES (ORGANISMS/SAMPLE) BETWEEN 1977/78 AND 2003

Date	***Epischura nevadensis***	***Bosmina longirostris***	***Daphnia rosea***	**Nauplii and Copepodites**	***Kellicotia longispina***	***Keratella cochlearis***	***Keratella quadrata***	**Sum of all species reported**
11-May-77	16	92	136	48	568	452	40	2,120
25-May-77	40		168	16	640	632		2,168
8-May-78	8	56	8	24	1,016	216	208	2,368
29-May-78	12		116	108	608	276	8	2,292
13-May-03		9		7,800		7,733	3,467	64,021
14-Jun-77	16		244	64	240	152	8	760
27-Jun-77	60		60	228	76	28		680
25-Jun-03			1,867		1,067	12,667		22,600
25-Jul-78	60	28	28	856	76	16	8	1,720
23-Jul-03	1	2	1,167	2,533		1,000		47,592
16-Aug-77	60		136	480	12		12	1,088
28-Aug-78	4	64	624	648	320	164	8	3,332
13-Aug-03	2	5		2,133	733	5,200		52,646
03-Nov-77		24	324	12	32	16	4	908
18-Nov-03	6	367		7,733	3,067	10,733		77,010

TABLE 18
90TH PERCENTILE CONCENTRATIONS (CFU/100 mL) FOR BACTERIOLOGICAL INDICATORS FOR SHAWNIGAN LAKE, 2003

(Guideline levels (CFU/100 mL) for raw drinking water with disinfection only are provided in parentheses)

		Summer Low Flow			Fall Freshet		
Site Name	**Site #**	***E. coli*** (10)	**Enterococci** (3)	**Fecal coliforms** (10)	***E. coli*** (10)	**Enterococci** (3)	**Fecal coliforms** (10)
Lake sites:							
Galley Restaurant Area	E222045	2	2	2	58	123	110
Easter Seal Camp Beach	E222048	1	0	3	27	121	107
West Shawnigan Lake Park	E222055	10	8	32	857	388	1,185
Shawnigan Lake Resort	E246900	1	1	1	20	225	138
Inflow/Outflow sites:							
Shawnigan Creek Inflow	1199906	820	54	1,432	54	13	373
McGee Creek	1199909	64	58	93	74	76	131
West Arm Inflow	1199911	19	62	35	65	74	77
Shawnigan Creek Outflow	1199912	150	120	200	35	70	86
Inflow on East Shawnigan Rd.	1199916				20	34	89

TABLE 19
GEOMETRIC MEAN CONCENTRATIONS (CFU/100 mL) FOR BACTERIOLOGICAL INDICATORS FOR SHAWNIGAN LAKE, 2003

(Guideline levels (CFU/100 mL) for recreational primary contact are provided in parentheses)

		Summer Low Flow			Fall Freshet		
Site Name	**Site #**	***E. coli*** (77)	**Enterococci** (20)	**Fecal coliforms** (200)	***E. coli*** (77)	**Enterococci** (20)	**Fecal coliforms** (200)
Lake sites:							
Galley Restaurant Area	E222045	1	1	1	7	10	15
Easter Seal Camp Beach	E222048	1	1	2	4	12	7
West Shawnigan Lake Park	E222055	2	3	5	28	51	44
Shawnigan Lake Resort	E246900	1	1	1	6	25	27
Inflow/Outflow sites:							
Shawnigan Creek Inflow	1199906	99	24	161	8	4	19
McGee Creek	1199909	27	34	47	15	11	28
West Arm Inflow	1199911	8	22	14	10	11	17
Shawnigan Creek Outflow	1199912	68	55	100	10	16	17
Inflow on East Shawnigan Rd.	1199916				7	7	19

TABLE 20
SHAWNIGAN LAKE BACTERIOLOGICAL INDICATOR RESULTS (CFU/100 mL)
NOVEMBER 9, 2004 – DECEMBER 6, 2004

(Guideline levels (CFU/100 mL) for raw drinking water with disinfection only (90th percentiles) and recreational primary contact (geometric means) are provided in parentheses)

Site	Depth (m)	*E. coli* (CFU/100 mL)		Enterococci (CFU/100 mL)		Fecal Coliform (CFU/100 mL)	
		90th Percentile (10)	Geometric Mean (77)	90th Percentile (3)	Geometric Mean (20)	90th Percentile (10)	Geometric Mean (200)
East Shore Intake - Lidstech Holdings E257436	0.1	1	1	1	1	2	1
	6	3	1	2	1	4	2
North Shore Intake - CVRD E257437	0.1	3	1	1	1	2	1
	6	1	1	2	1	3	2

TABLE 21
WATER QUALITY OBJECTIVES FOR SHAWNIGAN LAKE

Site	1199901	1199902	1199903	1199904	E257436	E257437
Designated Water Uses	Drinking water, recreation (primary contact), aquatic life					
Characteristics						
Dissolved Oxygen[1]	≥ 5 mg/L					
Secchi Depth[2]	≥ 5 m					
Total Phosphorus[3]	≤ 8 µg/L at spring overturn					
Total Nitrogen[4]	≤ 250 µg/L					
N:P Ratio[5]	≥ 30:1					
Turbidity[6]			≤ 1 NTU			
Total Organic Carbon	≤ 4 mg/L					
Chlorophyll *a*[7]	≤ 2 µg/L					
Escherichia coli[8]			≤ 10 CFU/100 mL (90th percentile)			
Enterococci[8]			≤ 3 CFU/100 mL (90th percentile)			
Fecal coliforms[8]			≤ 10 CFU/100 mL (90th percentile)			

[1] This objective applies to any depth of the water column throughout the year.

[2] Annual mean.

[3] This objective applies to the average of at least three samples taken throughout the water column (surface, mid depth, one metre above bottom) for sites 1199901 and 1199902 and to the average of at least two samples (surface and one metre above bottom) for sites 1199903 and 1199904.

[4] This objective applies to the average of at least three samples taken throughout the water column (surface, mid depth, one metre above bottom) for sites 1199901 and 1199902, at spring overturn.

[5] The N:P ratio is calculated using average total nitrogen and total phophorus concentrations.

[6] This objective applies to any grab sample taken within 10 m of a domestic water intake (E257436 and E257437). It also applies to sites 1199903 and 1199904 which likely reflect conditions near domestic intakes on the lake.

[7] Values are to be growing season averages for epilimnetic water in the main basin of the lake.

[8] The 90th percentiles are calculated from at least five weekly samples collected in a period of 30 days. For values recorded as <1, a value of 0 should be used to calculate the statistic. If any of the objectives are exceeded, further sampling should be conducted during the summer low flow and fall freshet periods, consisting of at least 5 weekly samples in a 30 day period.

TABLE 22
RECOMMENDED WATER QUALITY MONITORING FOR SHAWNIGAN LAKE

Site	Timing	Depth	Parameters
1199901	Spring overturn (preferably before February 28)	Surface, mid-depth, bottom (1 m above bottom)	**Nutrients:** total P, dissolved P, total N, NO_3+NO_2, NO_2, total organic N, ammonia, total organic C, total inorganic C, chlorophyll *a* **Total metals** **Anions:** dissolved chloride **Physical properties:** conductivity, pH, total solids, total dissolved solids, turbidity **Miscellaneous:** alkalinity, true colour **Field measurements:** DO (profile), temperature (profile), Secchi depth **Biological:** phytoplankton (1), zooplankton (2), chlorophyll *a*
1199902			
1199903		Surface, bottom (1 m above bottom)	
1199904			
E257436		Surface, bottom (1 m above bottom)	*E. coli*, enterococci, fecal coliforms (3)
E257437			

1. Surface (0.5m) unconcentrated 1 L sample preserved with Lugol's solution.
2. Vertical haul from 10 m to surface. Preserved in 5% formalin. Mouth size of net must be recorded.
3. If any of these results exceed objective levels, further sampling should be conducted during the summer low flow period and the fall freshet, consisting of at least 5 weekly samples in a 30 day period.

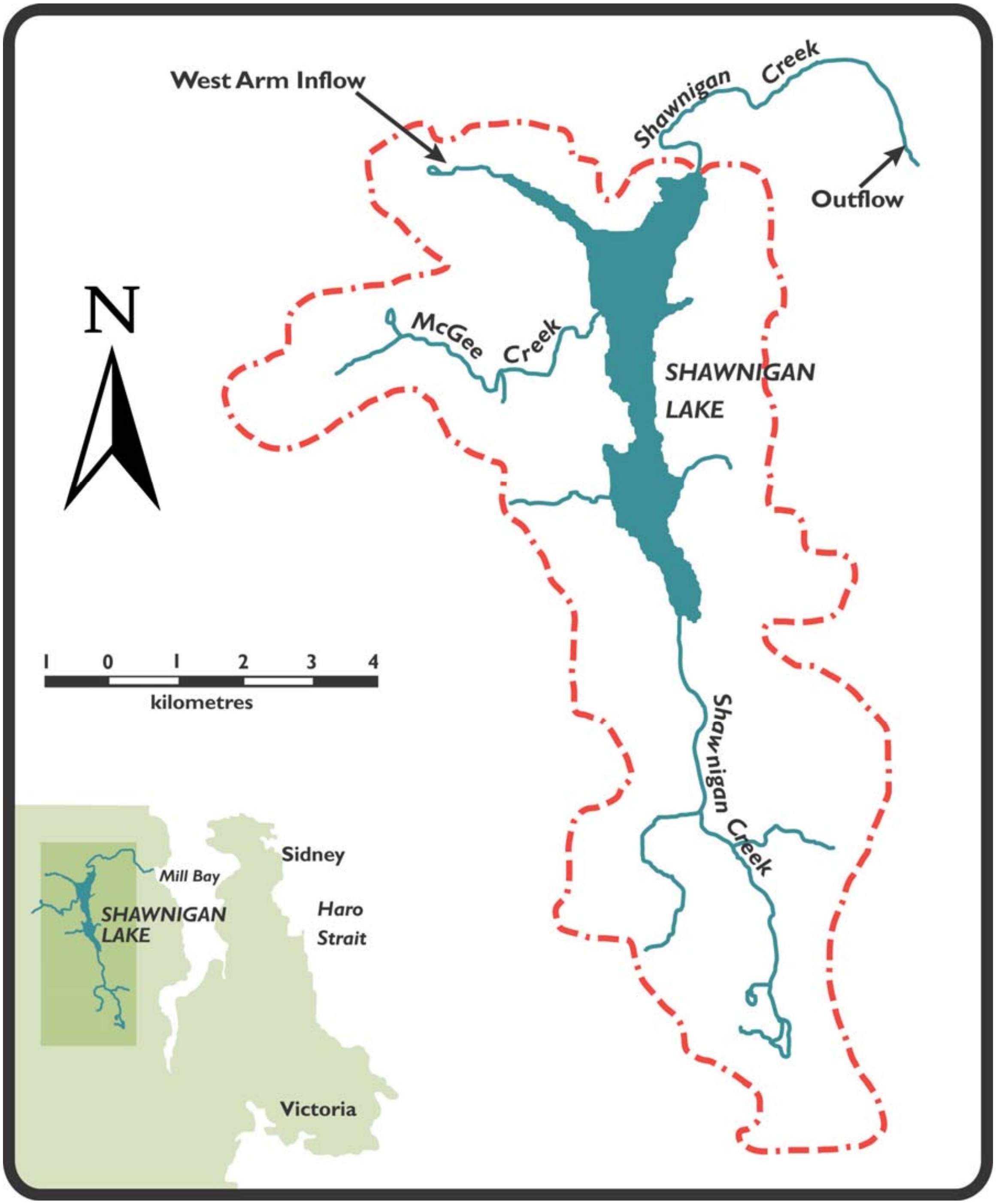

Figure 1: Location of Shawnigan Lake with watershed boundaries (adapted from Nordin and McKean, 1984).

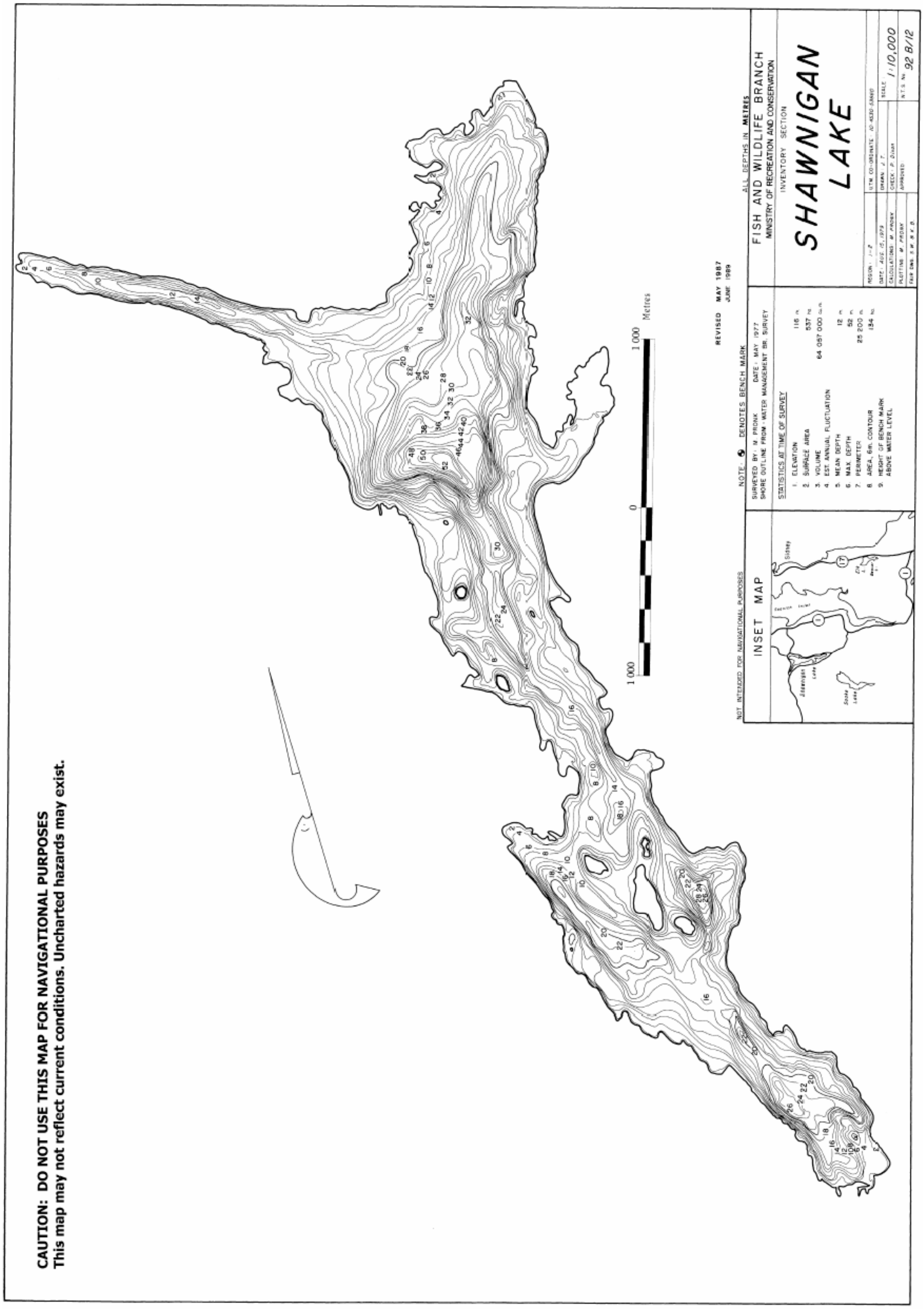

Figure 2: Bathymetric map of Shawnigan Lake (http://srmapps.gov.bc.ca/apps/fidq/).

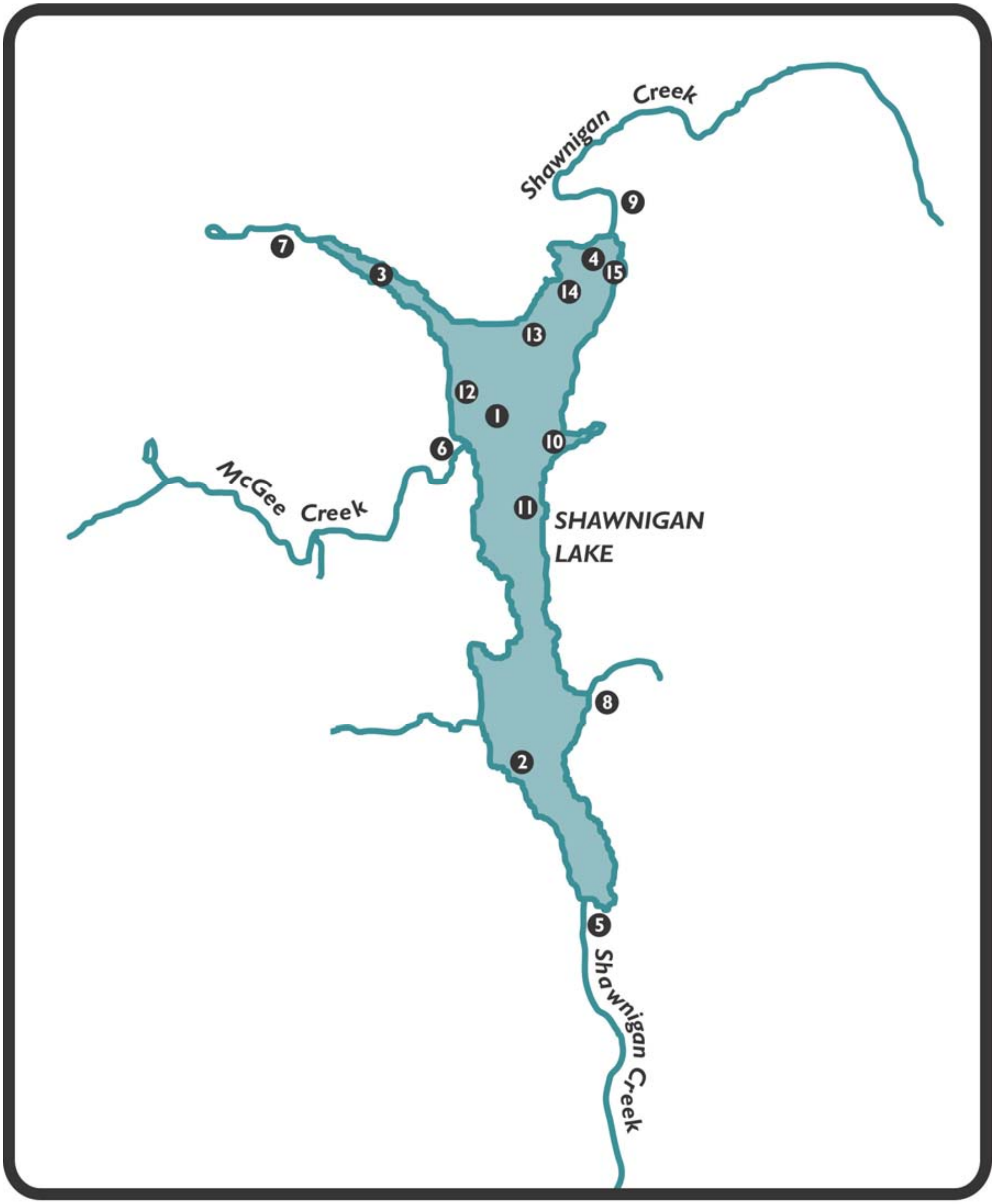

Figure 3: Location of Shawnigan Lake sampling sites. Sites are identified with site numbers corresponding to the EMS numbers and descriptions provided in Table 1.

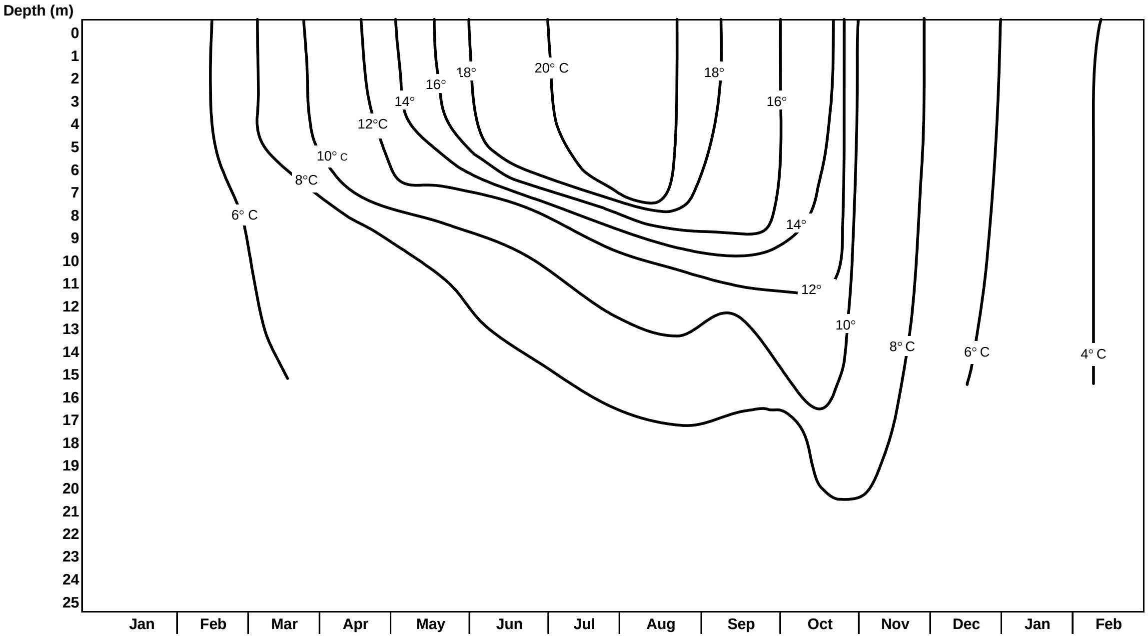

Figure 4: Time/depth temperature profile for Shawnigan Lake north basin site (1199901), February 2003 – February 2004.

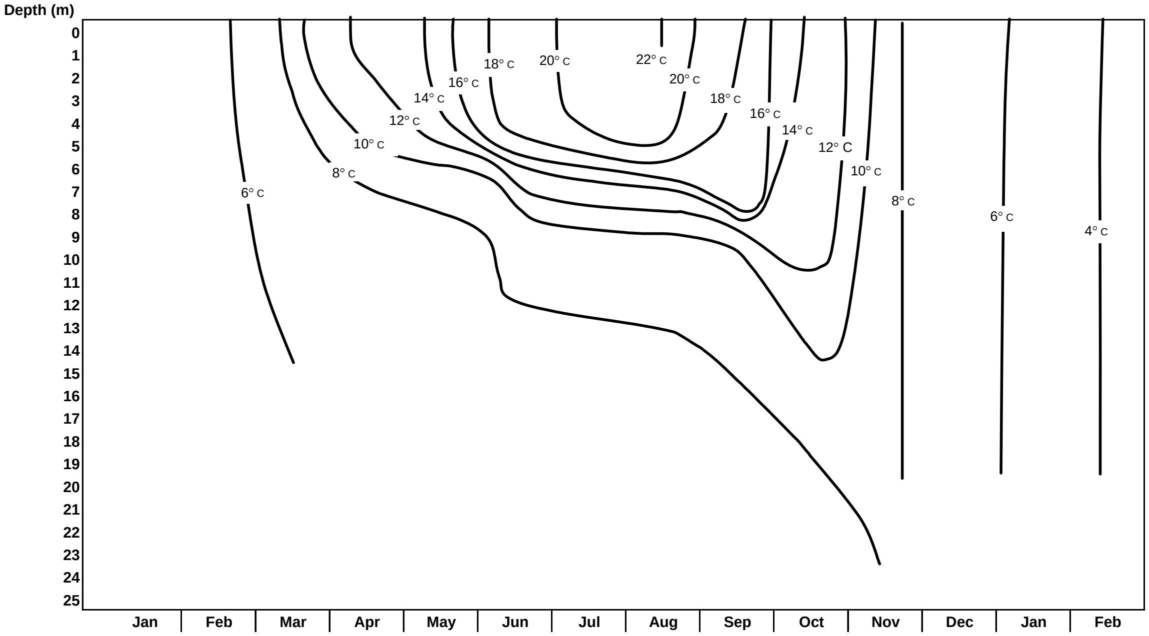

Figure 5: Time/depth temperature profile for Shawnigan Lake south basin site (1199902), February 2003 – February 2004.

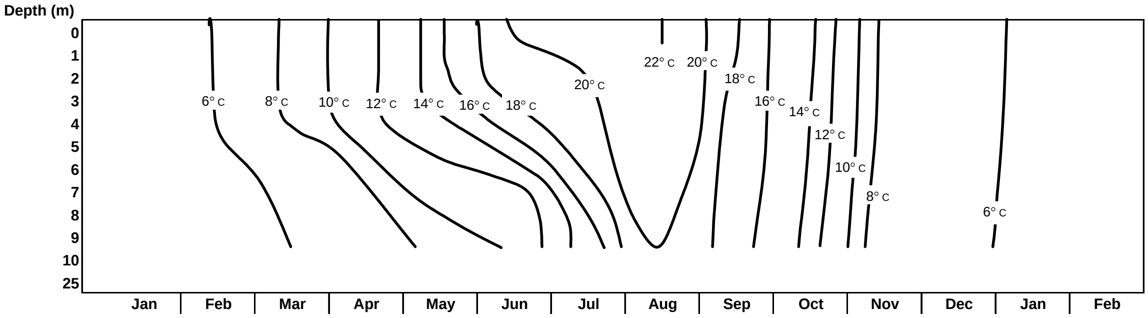

Figure 6: Time/depth temperature profile for Shawnigan Lake west arm site (1199903), February 2003 – February 2004.

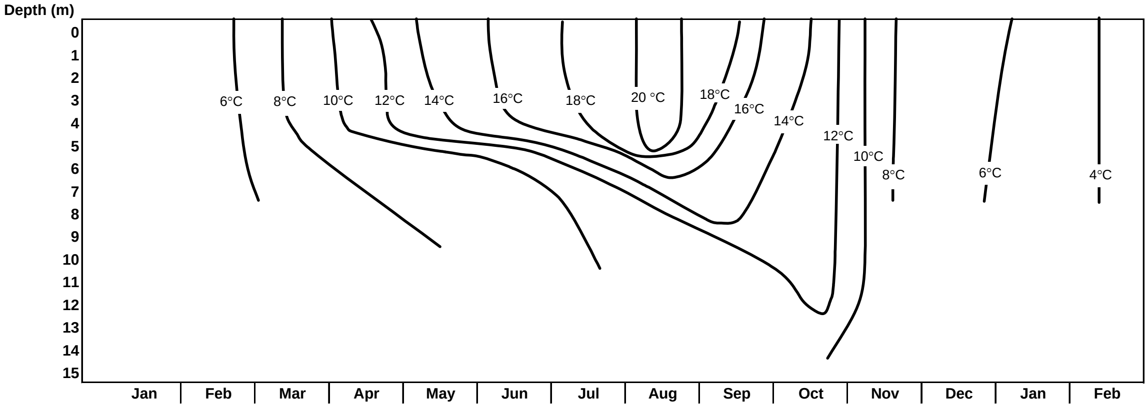

Figure 7: Time/depth temperature profile for Shawnigan Lake north beach site (1199904), February 2003 – February 2004.

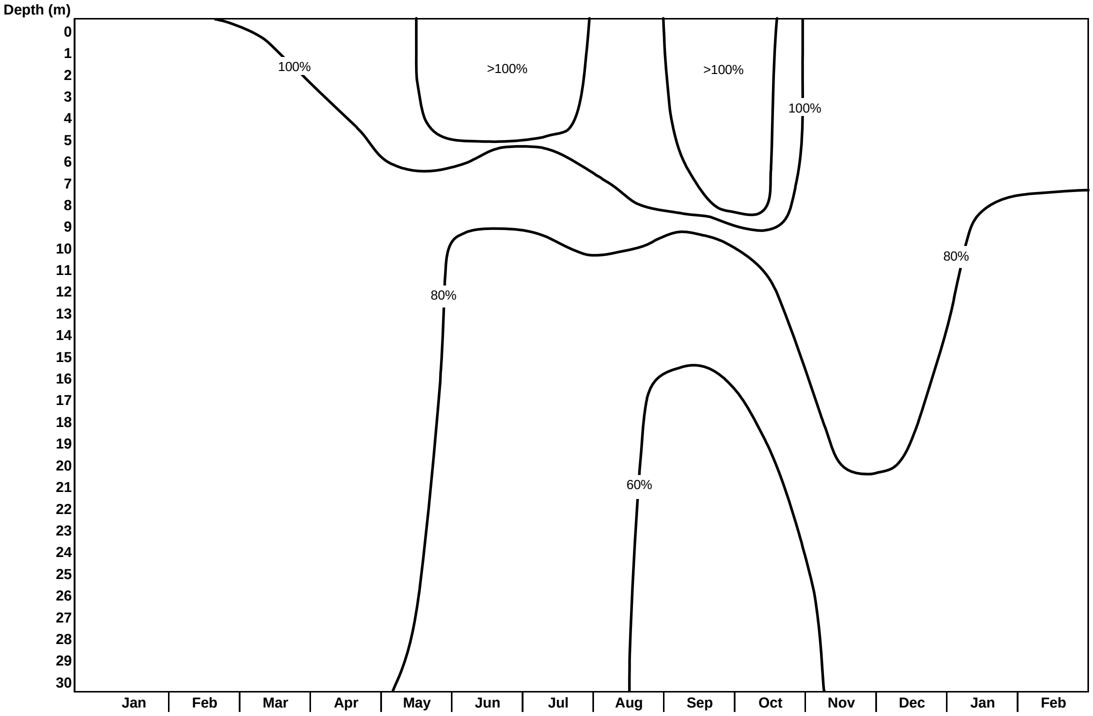

Figure 8: Time/depth dissolved oxygen profile for Shawnigan Lake north basin site (1199901), February 2003 – February 2004.

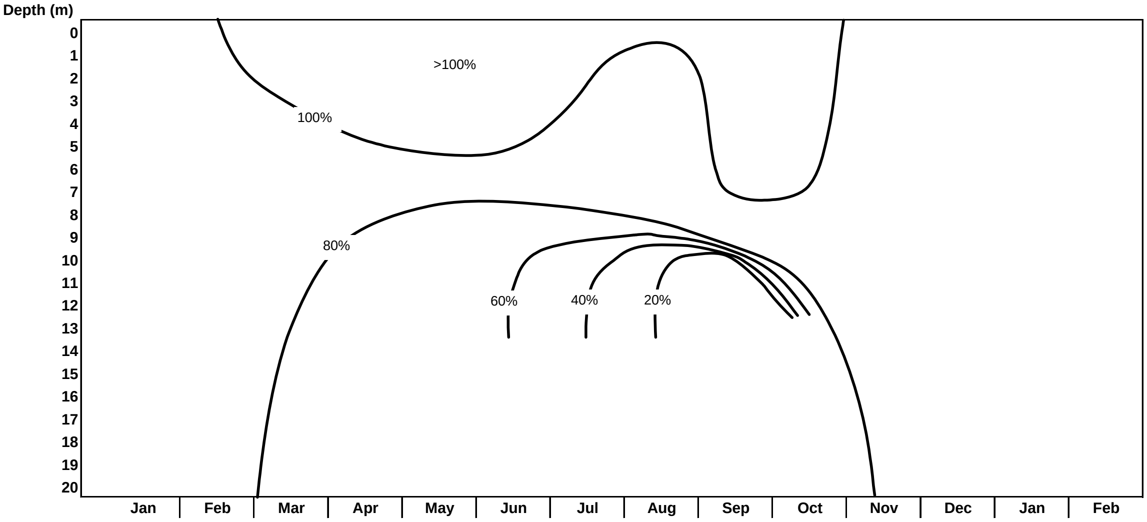

Figure 9: Time/depth dissolved oxygen profile for Shawnigan Lake south basin site (1199902), February 2003 – February 2004.

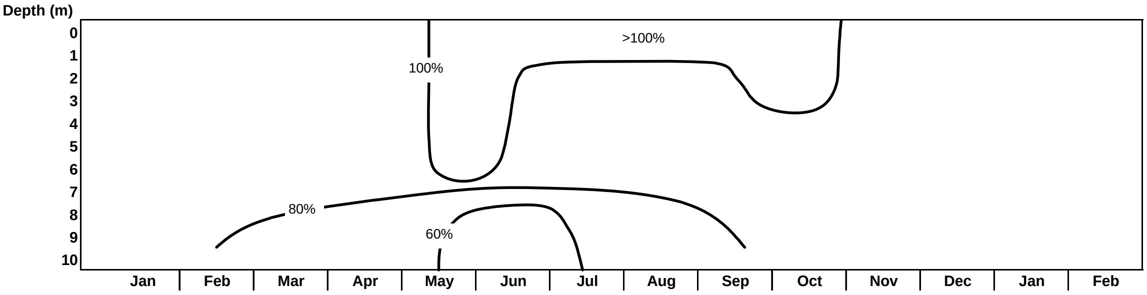

Figure 10: Time/depth dissolved oxygen profile for Shawnigan Lake west arm site (1199903), February 2003 – February 2004.

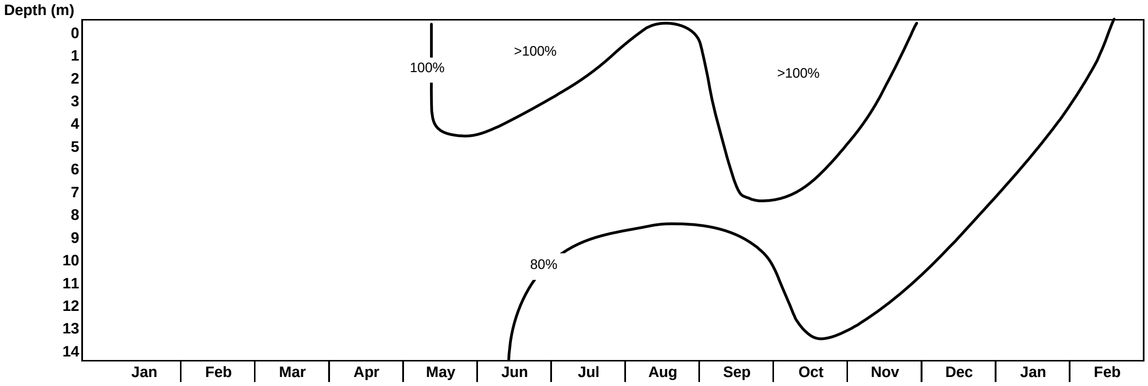

Figure 11: Time/depth dissolved oxygen profile for Shawnigan Lake north beach site (1199904), February 2003 – February 2004.

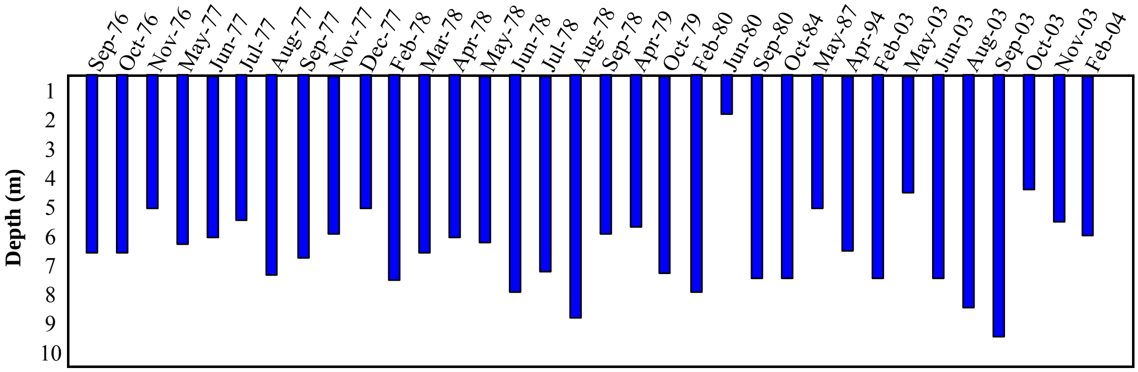

Figure 12: Secchi depths for the Shawnigan Lake north basin (1199901), September 1976 to February 2004.

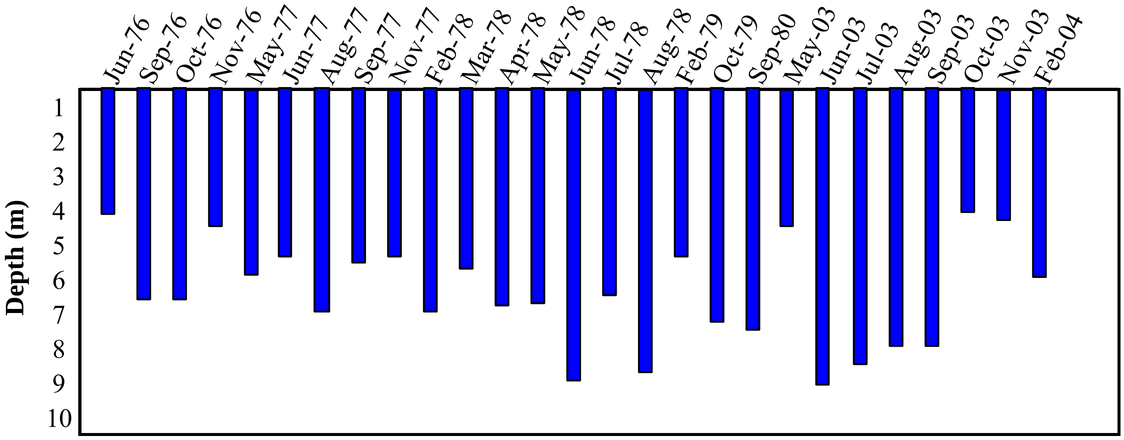

Figure 13: Secchi depths for the Shawnigan Lake south basin (1199902), September 1976 to February 2004.

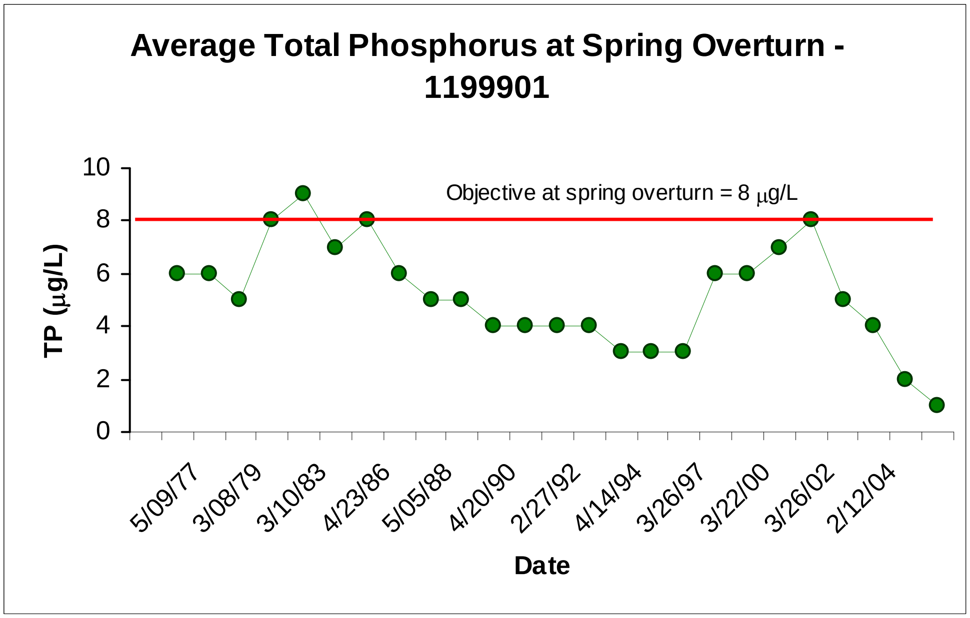

Figure 14: Average spring overturn total phosphorus concentrations for the Shawnigan Lake deep station (1199901), 1976 – 2005.

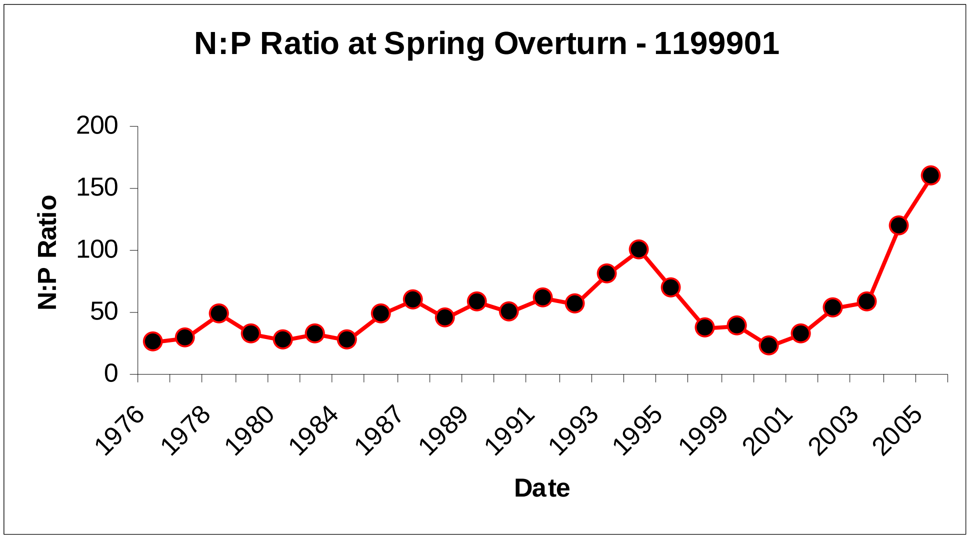

Figure 15: N:P ratios (total N: total P) at spring overturn, over time, for the Shawnigan Lake deep station (1199901).

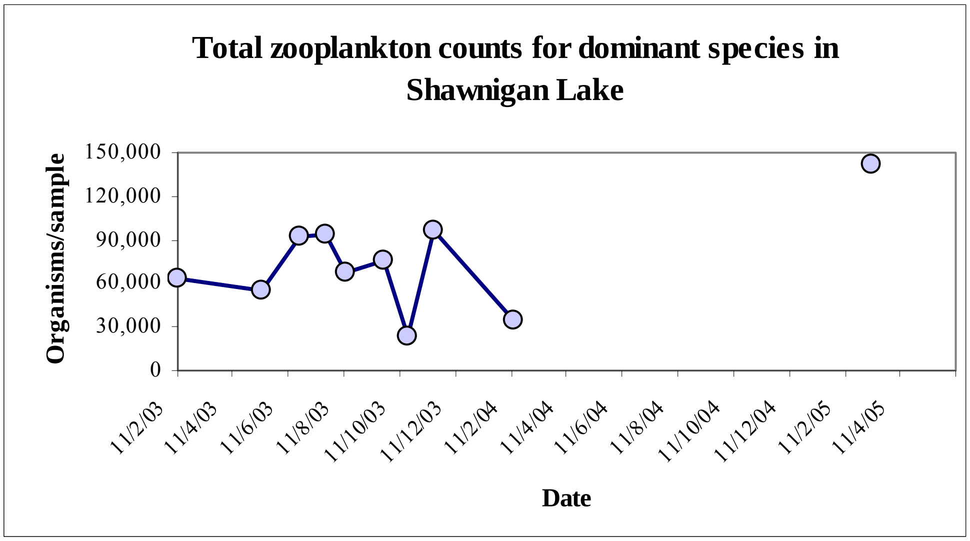

Figure 16: Total concentrations for dominant zooplankton species for Shawnigan Lake, February, 2003 to March , 2005.

APPENDIX 1

SUMMARY OF WATER QUALITY RESULTS FOR SITE 1199901 (NORTH BASIN)

(All results reported in mg/L unless otherwise noted. Less-than (<) values indicate some or all results were below analytical method detection limits.)

	1976 - 1979			1980 - 1989			1990 - 1999			2000 - Present		
	Mean	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**
General												
Alkalinity Total 4.5	16.4	1.1	18	16.0	0.5	9	17.1	0.4	2	16.7	1.3	28
Color True (Col. Unit)				10		1	9	5	14	9	3	58
Color TAC (TAC)	6	2	70	8	2	9	10	1	3			
Hardness Total				19.2	0.4	2	18.2	1.5	4	19.2	1.7	24
pH (pH units)	7.2	0.3	81	6.9	0.4	30	7.2	0.2	11	7.1	0.6	82
Residue Filterable	39	7	57	35	1	5	42	4	5			
Residue Nonfilterable	2	1	43	2	1	12	4	0	2	43	3	3
Residue Total	40	6	52	39	2	12	44	10	15	48	18	11
Specific Conductance (uS/cm)	49	5	115	54	3	15	55	5	14	53	5	73
Sulfate Dissolved				3.6	1.3	9	3.2	1.5	5	2.4	0.5	44
Silica Dissolved	4.6	0.8	32	4.9	0.6	9	5.3	0.4	14	5.6	0.6	44
Turbidity (NTU)	0.8	0.4	14	0.6	0.2	12	0.4	0.1	7	0.5	0.3	34
Nutrients												
Ammonia Dissolved	0.010	0.005	77	0.011	0.006	41	0.007	0.002	20	0.006	0.003	67
Carbon Total							7	0	4	8	0	49
Carbon Total Inorganic	3	1	52	4	2	9	4	0	4	4	0	52
Carbon Total Organic	3	1	68	3	2	9	3	0	4	3	0	53
Nitrate + Nitrite Dissolved	0.043	0.031	81	0.072	0.036	41	0.091	0.020	18	0.077	0.062	76
Nitrate Total	0.043	0.029	60							0.128	0.024	6
Nitrogen Kjeldahl Total	0.149	0.063	81	0.176	0.066	41	0.146	0.043	15	0.146	0.026	28
Nitrogen Total	0.182	0.071	77	0.240	0.077	30	0.230	0.019	5	0.213	0.061	66
Organic Nitrogen Total	0.15	0.06	63	0.17	0.07	30				0.01	0.03	30
Ortho-Phosphate Dissolved	<0.003		81	0.003	0.001	41				0.001	0.001	54
Phosphorus Total	0.006	0.002	81	0.007	0.002	39	0.004	0.001	20	0.006	0.003	92
Phosphorus Total Dissolved	0.004	0.001	59	0.005	0.002	40	0.003	0.001	20	0.004	0.002	77
Halides												
Bromide Dissolved							<0.05		5	<0.05		44
Chloride Dissolved				4.4	0.4	4	4.3	0.5	17	5.0	0.9	49
Flouride Dissolved										0.02	0.01	43
Flouride Total							0.01	0	5			
Metals												
Aluminum Total				0.03	0.01	2	0.06	0.01	13	<0.03		30
Antimony Total							<0.06		13	<0.00003		30
Arsenic Total							<0.06		13	<0.0002		30
Barium Total							0.005	0.001	13	0.005	0.001	30
Beryllium Total										<0.00002		30
Bismuth Total							<0.02		9	<0.00002		11
Cadmium Total				<0.01	0.0052	5	<0.006		13	<0.00001		30
Calcium Total	6.2	0.2	3	5.9	0.2	11	5.9	0.7	16	5.8	0.6	24
Cobalt Total				0.13	0.01	2	0.006	0.001	13	<0.005		30
Copper Total				<0.01		5	0.003	0.002	13	<0.005		30
Chromium Total				<0.01		3	0.006	0.004	13	0.007	0.008	27
Iron Total				0.09	0.09	2	0.051	0.009	13	0.031	0.014	21
Lead Total				<0.1		5	0.04	0.02	13	<0.0002		30
Lithium Total										0.0002	0.0001	9
Magnesium Total	1.1	0	3	1.0	0.1	11	1.12	0.09	16	1.12	0.09	24
Manganese Total				0.01	0	2	0.004	0.002	13	0.004	0.001	30
Molybdenum Total				0.01	0	2	<0.01		13	<0.00006		30
Nickel Total				<0.03		5	<0.01		13	<0.0002		30
Potassium Total							0.3	0.1	10	0.3	0.3	21
Selenium Total							<0.06		13	<0.0002		30
Silicon Total							2.42	0.24	16	2.24	0.20	19
Silver Total							<0.03		13	<0.00002		30
Sodium Total							2.8	0.2	10	3.0	0.6	24
Strontium Total							0.022	0.030	13	0.023	0.002	30
Sulfur Total							0.81	0.04	7	0.87	0.11	21
Tellurium Total										0.05	0	2
Thallium Total							<0.03		9	<0.000002		11
Tin Total							<0.06		13	<0.00001		30
Titanium Total							0.004	0.004	13	<0.002		21
Vanadium Total				<0.01		2	<0.01		13	<0.0002		30
Zinc Total				0.01	0	3	0.01	0.01	13	<0.003		30
Zirconium Total							<0.003		9	<0.005		2

APPENDIX 2
SUMMARY OF WATER QUALITY RESULTS FOR SITE 1199902 (SOUTH BASIN)

(All results reported in mg/L unless otherwise noted. Less-than (<) values indicate some or all results were below analytical method detection limits.)

	1976 - 1979			**1980 - 1989**			**1990 - 1999**			**2000 - Present**		
	Mean	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**
General												
Alkalinity Total 4.5	16.3	1.8	14	16.3	0.5	3				15.1	2.2	30
Color True (Col. Unit)	5	0	2							10	5	45
Color TAC (TAC)	7	6	53	7	2	3						
Hardness Total										17.7	1.1	12
pH (pH units)	7.1	0.3	67	7.0	0.3	3				7.2	0.7	79
Residue Filterable	40	4	46							40	4	3
Residue Nonfilterable	3	1	33	3	1	3				42	5	3
Residue Total	43	4	43	47	1	3				53	6	6
Specific Conductance (uS/cm)	49	6	94	55	1	3				48	6	61
Sulfate Dissolved										2.5	0.4	21
Silica Dissolved	4.6	0.9	20	4.7	1.1	3				5.6	0.7	30
Turbidity (NTU)	1.6	2.4	11	0.9	0.6	3				0.9	1.3	30
Nutrients												
Ammonia Dissolved	0.019	0.032	63	0.032	0.036	7				0.010	0.019	51
Carbon Total										7	0	40
Carbon Total Inorganic	3	1	47	5	1	3				4	1	43
Carbon Total Organic	4	1	58	2	1	3				3	0	46
Nitrate + Nitrite Dissolved	0.038	0.030	67	0.036	0.030	7				0.073	0.056	51
Nitrate Total	0.041	0.031	49									
Nitrogen Kjeldahl Total	0.179	0.079	67	0.209	0.054	7				0.160	0.040	27
Nitrogen Total	0.204	0.086	62	0.238	0.079	5				0.224	0.074	51
Organic Nitrogen Total	0.17	0.06	54	0.18	0.06	5				0.15	0.03	30
Ortho-Phosphate Dissolved	<0.003		65	<0.003		7				0.001	0.001	45
Phosphorus Total	0.006	0.002	67	0.009	0.003	7				0.007	0.004	51
Phosphorus Total Dissolved	0.004	0.001	50	0.005	0.003	7				0.004	0.002	36
Halides												
Bromide Dissolved										<0.05		19
Chloride Dissolved										5.3	0.5	27
Flouride Dissolved										0.02	0	21
Metals												
Aluminum Total										<0.05		20
Antimony Total										<0.0001		20
Arsenic Total										<0.0001		20
Barium Total										0.004	0.001	20
Beryllium Total										<0.00002		20
Bismuth Total										<0.00002		11
Cadmium Total										<0.0001		20
Calcium Total	6.3	0.3	5	5.9	0.1	3				5.14	0.07	3
Cobalt Total										<0.001		20
Copper Total										<0.001		20
Chromium Total										<0.003		20
Iron Total										0.122	0.241	9
Lead Total										<0.0002		19
Lithium Total										0.0001	0.0001	11
Magnesium Total	1.2	0.1	5	1	0	3				1.1	0.1	12
Manganese Total										0.004	0.002	20
Molybdenum Total										<0.0001		20
Nickel Total										<0.0002		19
Potassium Total										0.2	0.1	9
Selenium Total										<0.0002		20
Silicon Total										2.28	0.26	9
Silver Total										<0.00002		20
Sodium Total										2.9	0.2	12
Strontium Total										0.0	0.0	20
Sulfur Total										0.84	0.05	9
Thallium Total										0.000008	0.000001	5
Tin Total										<0.0001		20
Vanadium Total										<0.0005		20
Zinc Total										0.003	0.002	19

APPENDIX 3

SUMMARY OF WATER QUALITY RESULTS FOR SITE 1199903 (WEST ARM)

(All results reported in mg/L unless otherwise noted. Less-than (<) values indicate some or all results were below analytical method detection limits.)

	1976 - 1979			1980 - 1989			1990 - 1999			2000 - Present		
	Mean	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**
General												
Alkalinity Total 4.5	16.8	1.2	4							20.9	3.3	22
Color True (Col. Unit)										9.1	5.9	22
Color TAC (TAC)	6	2	18							6		1
Hardness Total										28.3	1.9	2
pH (pH units)	7.3	0.2	24							7.2	0.5	49
Residue Filterable	40	4	16							47	10	22
Residue Nonfilterable	3	1	12							52	8	2
Residue Total	41	5	14							64	7	4
Specific Conductance (uS/cm)	54	4	24							64	13	44
Silica Dissolved	4.3	0.4	4							6.3	0.7	4
Turbidity (NTU)	0.8	0.2	5							1.0	0.0	23
Nutrients												
Ammonia Dissolved	0.009	0.007	23							0	0	21
Carbon Total Inorganic	3.000	1.000	16							5.100	1.000	2
Carbon Total Organic	3	1	18							3	0	4
Nitrate + Nitrite Dissolved	0.038	0.037	24							0	0	21
Nitrate Total	0.035	0.031	19									
Nitrogen Kjeldahl Total	0.160	0.076	24							0.180	0.040	20
Nitrogen Total	0.182	0.109	23							0.270	0.100	21
Organic Nitrogen Total	0.160	0.070	20							0.180	0.040	20
Ortho-Phosphate Dissolved	<0.003		23							0.002	0.002	16
Phosphorus Total	0.01	0.00	24							0.01	0.01	20
Phosphorus Total Dissolved	0.004	0	19							0.003	0.003	11
Metals												
Aluminum Total										0.0293	0.002	6
Antimony Total										<0.00003		6
Arsenic Total										<0.0001		6
Barium Total										0.0	0.0008	6
Beryllium Total										<0.00002		6
Bismuth Total										<0.00002		6
Cadmium Total										<0.00001		6
Calcium Total	6.4		1							9.1	0.7	2
Cobalt Total										<0.00002		6
Copper Total										0.0006	0.0001	6
Chromium Total										<0.0002		4
Lead Total										0.0001	0.0001	6
Magnesium Total										1.36	0.03	2
Manganese Total										0.0036	0.0004	6
Molybdenum Total										<0.00006		6
Nickel Total										<0.0001		6
Selenium Total										<0.0002		6
Silver Total										<0.00002		6
Strontium Total										0.0278	0.0024	6
Thallium Total										<0.000002		6
Tin Total										<0.00006		6
Vanadium Total										0.0003	0.0001	6
Zinc Total										0.0036	0.002	6

APPENDIX 4

SUMMARY OF WATER QUALITY RESULTS FOR SITE 1199904 (NORTH BEACH)

(All results reported in mg/L unless otherwise noted. Less-than (<) values indicate some or all results were below analytical method detection limits.)

	1976 - 1979			1980 - 1989			1990 - 1999			2000 - Present		
	Mean	Std. Dev.	n	Mean	Std. Dev.	n	Mean	Std. Dev.	n	Mean	Std. Dev.	n
General												
Alkalinity Total 4.5	17.3	0.7	2							16.9	0.9	20
Color True (Col. Unit)										8	3	20
Color TAC (TAC)	6	2	8									
Hardness Total										21.2	0.5	4
pH (pH units)	7.3	0.2	14							7.1	0.7	51
Residue Filterable	39	4	10							38	0	2
Residue Nonfilterable	3	1	7							39	1	2
Residue Total	43	3	9							55	3	4
Specific Conductance (uS/cm)	53	2	14							53	5	44
Turbidity (NTU)	0.8	0.4	5							0.5	0.3	22
Nutrients												
Ammonia Dissolved	0.0	0.0	14							0.0	0.0	21
Carbon Total Inorganic	3	0	6							4	0	4
Carbon Total Organic	3.000	1.000	6							3.500	0.100	4
Nitrate + Nitrite Dissolved	0.041	0.032	14							0	0	21
Nitrate Total	0.037	0.03	13									
Nitrogen Kjeldahl Total	0.149	0.056	14							0	0	21
Nitrogen Total	0.165	0.071	13							0.230	0.060	21
Organic Nitrogen Total	0.140	0.060	14							0.160	0.020	21
Ortho-Phosphate Dissolved	<0.003		14							0.002	0.001	16
Phosphorus Total	0.005	0.002	14							0.004	0.002	21
Phosphorus Total Dissolved	0.00	0.00	13							0.00	0.00	11
Metals												
Aluminum Total										0.022	0.0038	8
Antimony Total										<0.00003		8
Arsenic Total										<0.0001		8
Barium Total										0.0046	0.0004	8
Beryllium Total										<0.00002		8
Bismuth Total										<0.00002		8
Cadmium Total										<0.00001		8
Calcium Total	6.3		1							6.51	0.16	4
Cobalt Total										<0.00002		8
Copper Total										<0.001		8
Chromium Total										<0.0002		8
Iron Total										<0.03		6
Lead Total										<0.0001		7
Lithium Total										<0.00006		6
Magnesium Total	1.1		1							1.21	0.03	4
Manganese Total										0.0037	0.0011	8
Molybdenum Total										<0.00006		8
Nickel Total										<0.0002		7
Potassium Total										<1		2
Selenium Total										<0.0002		8
Silver Total										<0.00002		8
Sodium Total										3.48	0.21	4
Strontium Total										0.024	0.001	8
Sulfur Total										0.9	0	2
Tellurium Total										<0.05		2
Thallium Total										<0.000008		8
Tin Total										<0.00006		8
Titanium Total										<0.003		2
Vanadium Total										<0.0003		8
Zinc Total										<0.005		8
Zirconium Total										<0.005		2

APPENDIX 5

SUMMARY OF WATER QUALITY RESULTS FOR SITE E222045 (GALLEY RESTAURANT)

(All results reported in mg/L unless otherwise noted. Less-than (<) values indicate some or all results were below analytical method detection limits.)

	1976 - 1979			1980 - 1989			1990 - 1999			2000 - Present		
	Mean	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**
General												
Color True (Col. Unit)										12.0	3.0	3
Hardness Total										20.5		1
pH (pH units)										7.4	0.1	2
Specific Conductance (uS/cm)										61	2	5
Turbidity (NTU)										0.49	0.06	5
Nutrients												
Ammonia Dissolved										0.015	0.023	6
Carbon Total Inorganic										3.9		1
Carbon Total Organic										3.4		1
Nitrate + Nitrite Dissolved										0.043	0.050	6
Nitrogen Kjeldahl Total										0.16	0.02	5
Nitrogen Total										0.187	0.063	6
Organic Nitrogen Total										0.14	0.03	5
Phosphorus Total										0.004	0.002	6
Phosphorus Total Dissolved										0.002	0	2
Metals												
Aluminum Total										0.07	0.06	3
Antimony Total										<0.06		3
Arsenic Total										<0.06		3
Barium Total										0.005	0.001	3
Beryllium Total										<0.001		3
Bismuth Total										0.00004	0.00002	2
Cadmium Total										<0.006		3
Calcium Total										6.4		1
Cobalt Total										<0.006		3
Copper Total										<0.006		3
Chromium Total										<0.006		3
Iron Total										0.012		1
Lead Total										<0.06		3
Magnesium Total										1.10		1
Manganese Total										0.005	0.004	3
Molybdenum Total										<0.01		3
Nickel Total										<0.02		3
Potassium Total										0.2		1
Selenium Total										<0.06		3
Silicon Total										1.64		1
Silver Total										<0.01		3
Sodium Total										3.30		1
Strontium Total										0.025	0.002	3
Sulfur Total										0.82		1
Thallium Total										0.000003	0.000	2
Tin Total										<0.06		3
Titanium Total										<0.002		1
Vanadium Total										<0.01		3
Zinc Total										<0.002		3

APPENDIX 6

SUMMARY OF WATER QUALITY RESULTS FOR SITE E222048 (EASTER SEAL CAMP)

(All results reported in mg/L unless otherwise noted.)

	1976 - 1979			1980 - 1989			1990 - 1999			2000 - Present		
	Mean	Std. Dev.	n	Mean	Std. Dev.	n	Mean	Std. Dev.	n	Mean	Std. Dev.	n
General												
Color True (Col. Unit)										8.0	3.0	11
pH (pH units)										7.4	0.1	4
Specific Conductance (uS/cm)										59	2	8
Turbidity (NTU)										0.44	0.10	8
Nutrients												
Ammonia Dissolved										0.006	0.002	7
Carbon Total Inorganic										3.3		1
Carbon Total Organic										3.4		1
Nitrate + Nitrite Dissolved										0.059	0.049	7
Nitrogen Kjeldahl Total										0.16	0.02	5
Nitrogen Total										0.207	0.050	7
Organic Nitrogen Total										0.15	0.02	5
Phosphorus Total										0.004	0.002	7
Phosphorus Total Dissolved										0.002	0	4

APPENDIX 7
SUMMARY OF WATER QUALITY RESULTS FOR SITE E222055
(WEST SHAWNIGAN LAKE PARK)

(All results reported in mg/L unless otherwise noted. Less-than (<) values indicate some or all results were below analytical method detection limits.)

	1976 - 1979			1980 - 1989			1990 - 1999			2000 - Present		
	Mean	Std. Dev.	n	Mean	Std. Dev.	n	Mean	Std. Dev.	n	Mean	Std. Dev.	n
General												
Color True (Col. Unit)										9.0	3.0	9
Hardness Total										21.2	0.5	4
pH (pH units)										7.4	0.1	4
Specific Conductance (uS/cm)										60	2	11
Turbidity (NTU)										0.7	0.5	11
Nutrients												
Ammonia Dissolved										0.009	0.007	11
Carbon Total Inorganic										3.5		1
Carbon Total Organic										4.0		1
Nitrate + Nitrite Dissolved										0.054	0.051	11
Nitrogen Kjeldahl Total										0.16	0.02	5
Nitrogen Total										0.280	0.188	11
Organic Nitrogen Total										0.16	0.02	5
Phosphorus Total										0.006	0.004	11
Phosphorus Total Dissolved										0.003	0.001	7
Metals												
Aluminum Total										<0.06		4
Antimony Total										<0.06		4
Arsenic Total										<0.06		4
Barium Total										0.005	0	4
Beryllium Total										<0.001		4
Bismuth Total										<0.05		2
Cadmium Total										<0.006		4
Calcium Total										6.5	0.2	4
Cobalt Total										<0.006		4
Copper Total										<0.006		4
Chromium Total										<0.006		4
Iron Total										0.052	0.042	4
Lead Total										<0.06		4
Magnesium Total										1.20	0.00	4
Manganese Total										0.005	0.004	4
Molybdenum Total										<0.01		4
Nickel Total										<0.02		4
Potassium Total										<1.0		4
Selenium Total										<0.06		4
Silicon Total										1.8	0	2
Silver Total										<0.01		4
Sodium Total										3.50	0.2	4
Strontium Total										0.024	0.001	4
Sulfur Total										0.9	0.1	4
Tellurium Total										<0.05		2
Thallium Total										<0.03		2
Tin Total										<0.06		4
Titanium Total										0.003	0	4
Vanadium Total										<0.01		4
Zinc Total										<0.002		4
Zirconium Total										<0.005		2

APPENDIX 8
SUMMARY OF WATER QUALITY RESULTS FOR SITE E246900 (SHAWNIGAN LAKE RESORT)

(All results reported in mg/L unless otherwise noted. Less-than (<) values indicate some or all results were below analytical method detection limits.)

	1976 - 1979			1980 - 1989			1990 - 1999			2000 - Present		
	Mean	Std. Dev.	n =	Mean	Std. Dev.	n =	Mean	Std. Dev.	n =	Mean	Std. Dev.	n =
General												
Color True (Col. Unit)										9.0	3.0	6
Hardness Total										22.8	5.8	6
pH (pH units)										7.4	0.1	4
Specific Conductance (uS/cm)										63	10	10
Turbidity (NTU)										0.53	0.14	10
Nutrients												
Ammonia Dissolved										0.008	0.009	9
Carbon Total Inorganic										3.8		1
Carbon Total Organic										3.8		1
Nitrate + Nitrite Dissolved										0.063	0.069	9
Nitrogen Kjeldahl Total										0.16	0.01	6
Nitrogen Total										0.229	0.086	9
Organic Nitrogen Total										0.16	0.01	6
Phosphorus Total										0.004	0.002	9
Phosphorus Total Dissolved										0.002	0.001	5
Metals												
Aluminum Total										0.04	0.02	6
Antimony Total										<.06		6
Arsenic Total										<0.06		6
Barium Total										0.005	0.001	6
Beryllium Total										<0.001		6
Bismuth Total										<0.05		5
Cadmium Total										<0.006	0.002	6
Calcium Total										7.04	1.95	6
Cobalt Total										<0.006		6
Copper Total										<0.006		6
Chromium Total										<0.006		6
Iron Total										0.093	0.157	6
Lead Total										<0.006		6
Magnesium Total										1.28	0.21	6
Manganese Total										0.015	0.028	6
Molybdenum Total										<0.01		6
Nickel Total										<0.02		6
Potassium Total										0.9	0.2	6
Selenium Total										<0.06		6
Silicon Total										2.43		1
Silver Total										<0.01		6
Sodium Total										3.81	0.55	6
Strontium Total										0.026	0.008	6
Sulfur Total										1	0.3	6
Tellurium Total										<0.05		5
Thallium Total										<0.03		5
Tin Total										<0.06		6
Titanium Total										<0.003		6
Vanadium Total										<0.01		6
Zinc Total										0.005	0.001	6
Zirconium Total										<0.005		5

APPENDIX 9
SUMMARY OF WATER QUALITY RESULTS FOR SITE 1199906 (SHAWNIGAN LAKE INFLOW)

(All results reported in mg/L unless otherwise noted. Less-than (<) values indicate some or all results were below analytical method detection limits.)

	1976 - 1979			1980 - 1989			1990 - 1999			2000 - Present		
	Mean	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**
General												
Alkalinity Total 4.5	8.4		1									
Color True (Col. Unit)							14	1	4	10	5.0	9
Color TAC (TAC)	11	4	29									
Hardness Total										19.4	4.8	7
pH (pH units)	7.1	0.2	31				7.1	0.0	4	7.3	0.3	4
Residue Filterable	40	10	28									
Residue Nonfilterable	2	1	28				<5	0	4			
Residue Total	41	10	29									
Specific Conductance (uS/cm)	51	14	31							51	9	16
Turbidity (NTU)	0.65	0.30	19							0.39	0.46	16
Nutrients												
Ammonia Dissolved	0.008	0.003	31							0.005	0.000	16
Carbon Total Inorganic	2	1	11				2.3	0.1	4.0	2.8	2.0	4
Carbon Total Organic	3	1	11				3.2	0.7	4.0	2.6	2.2	4
Nitrate + Nitrite Dissolved	0.225	0.164	31							0.128	0.078	16
Nitrate Total	0.230	0.160	31									
Nitrogen Kjeldahl Total	0.12	0.06	31							0.11	0.05	5
Nitrogen Total	0.340	0.189	31							0.227	0.092	16
Organic Nitrogen Total	0.11	0.06	31							0.10	0.00	5
Ortho-Phosphate Dissolved	0.003	0.001	31									
Phosphorus Total	0.005	0.001	31							0.005	0.003	16
Phosphorus Total Dissolved	0.004	0.001	27							0.005	0.002	12
Metals												
Aluminum Total										0.04	0.02	7
Antimony Total										<0.06		7
Arsenic Total										<0.06		7
Barium Total										0.003	0.001	7
Beryllium Total										<0.001		7
Bismuth Total										<0.05		5
Cadmium Total										<0.006		7
Calcium Total	4.2	0.7	14							5.45	3.18	12
Cobalt Total										<0.006		7
Copper Total										<0.006		7
Chromium Total										<0.006		7
Iron Total										0.041	0.016	7
Lead Total										<0.06		7
Magnesium Total	0.9	0.1	14							2.23	3.74	12
Manganese Total										0.002	0.001	7
Molybdenum Total										<0.01		7
Nickel Total										<0.02		7
Potassium Total										0.8	0.4	7
Selenium Total										<0.06		7
Silicon Total										3.70	0.62	2
Silver Total										<0.01		7
Sodium Total	3.3		2							3.29	0.45	7
Strontium Total										0.025	0.007	7
Sulfur Total										0.66	0.14	7
Tellurium Total										<0.05		5
Thallium Total										<0.03		5
Tin Total										<0.06		7
Titanium Total										<0.03		7
Vanadium Total										0.010	0.002	7
Zinc Total										<0.005		7
Zirconium Total										<0.005		7

APPENDIX 10

SUMMARY OF WATER QUALITY RESULTS FOR SITE 1199909 (McGEE CREEK)

(All results reported in mg/L unless otherwise noted. Less-than (<) values indicate some or all results were below analytical method detection limits.)

	1976 - 1979			1980 - 1989			1990 - 1999			2000 - Present		
	Mean	Std. Dev.	n	Mean	Std. Dev.	n	Mean	Std. Dev.	n	Mean	Std. Dev.	n
General												
Alkalinity Total 4.5	26.9		2									
Color True (Col. Unit)							14	2	3	16	10.0	9
Color TAC (TAC)	14		26									
Hardness Total										38.0	6.5	6
pH (pH units)	7.5		30				7.5	0.1	3	7.6	0.2	4
Residue Filterable	59.9		28									
Residue Nonfilterable	1.5		28				<5	0	3			
Residue Total	61.8		29									
Specific Conductance (uS/cm)	80.2		30							74	14	13
Turbidity (NTU)	0.7		17				0.34	0.07	3	0.36	0.27	13
Nutrients												
Ammonia Dissolved	0.010		30							<0.005		12
Carbon Total Inorganic	6.5		10				5.5	0.3	3	6.6	3.0	4
Carbon Total Organic	3.4		11				3.8	0.8	3	2.9	2.2	4
Nitrate + Nitrite Dissolved										0.167	0.123	13
Nitrate Total	0.253		57									
Nitrogen Kjeldahl Total										0.14	0.06	4
Nitrogen Total										0.288	0.140	13
Organic Nitrogen Total	0.12		30							0.10	0.10	4
Ortho-Phosphate Dissolved	<0.003		27									
Phosphorus Total	0.005		29							0.006	0.002	13
Phosphorus Total Dissolved	0.004		25							0.005	0.002	9
Metals												
Aluminum Total										0.07	0.06	6
Antimony Total										<0.06		6
Arsenic Total										<0.06		6
Barium Total										0.013	0.002	6
Beryllium Total										<0.001		6
Bismuth Total										<0.05		4
Cadmium Total										<0.006		6
Calcium Total	10.4		15							11.6	2	6
Cobalt Total										<0.006		6
Copper Total										<0.006		6
Chromium Total										<0.006		6
Iron Total										0.061	0.064	6
Lead Total										<0.06		6
Magnesium Total	2.0		15							2.19	0.39	6
Manganese Total										0.003	0.004	6
Molybdenum Total										<0.01		6
Nickel Total										<0.02		6
Potassium Total										0.7	0.4	6
Selenium Total										<0.06		6
Silicon Total										4.08	0.31	2
Silver Total										<0.01		6
Sodium Total	2.4		2							1.96	0.34	6
Strontium Total										0.025	0.005	6
Sulfur Total										1.04	0.5	6
Tellurium Total										<0.05		4
Thallium Total										<0.03		4
Tin Total										<0.06		6
Titanium Total										0.004	0.002	6
Vanadium Total										<0.01		6
Zinc Total										0.004	0.001	6
Zirconium Total										<0.005		4

APPENDIX 11

SUMMARY OF WATER QUALITY RESULTS FOR SITE 1199911 (WEST ARM INFLOW)

(All results reported in mg/L unless otherwise noted. Less-than (<) values indicate some or all results were below analytical method detection limits.)

	1976 - 1979			1980 - 1989			1990 - 1999			2000 - Present		
	Mean	Std. Dev.	n	Mean	Std. Dev.	n	Mean	Std. Dev.	n	Mean	Std. Dev.	n
General												
Alkalinity Total 4.5	41.5		1									
Color TAC (TAC)	20.6		25				21	4	3	21	15	10
Hardness Total										51.8	12.0	7
pH (pH units)	7.3		29				7.2	0.1	3	7.7	0.2	4
Residue Filterable	79.9		25									
Residue Nonfilterable	2.4		14				<5	0	3			
Residue Total	81.7		26									
Specific Conductance (uS/cm)	107		29							111	26	14
Turbidity (NTU)	1.7		20				1.05	0.10	3	0.97	0.68	14
Nutrients												
Ammonia Dissolved	0.013		29							0.094	0.333	14
Carbon Total Inorganic	10.5		10				6.9	0.4	3	9.0	3.6	4
Carbon Total Organic	4.3		10				4.6	0.9	3	3.5	2.9	4
Nitrate + Nitrite Dissolved										0.291	0.335	14
Nitrate Total	0.475		29									
Nitrogen Kjeldahl Total										0.18	0.11	5
Nitrogen Total										0.341	0.187	14
Organic Nitrogen Total	0.19		29							0.19	0.09	5
Phosphorus Total	0.010		28							0.010	0.004	14
Phosphorus Total Dissolved	0.006		25							0.006	0.003	10
Metals												
Aluminum Total										0.06	0.02	7
Antimony Total										<0.06		7
Arsenic Total										<0.06		7
Barium Total										0.007	0.001	7
Beryllium Total										<0.001		7
Bismuth Total										<0.05		5
Cadmium Total										<0.006		7
Calcium Total	14.5		15							16.8	3.9	7
Cobalt Total										<0.006		7
Copper Total										0.009	0.009	7
Chromium Total										<0.006		7
Iron Total										0.068	0.025	7
Lead Total										<0.06		7
Magnesium Total	2.0		14							2.38	0.59	7
Manganese Total										0.006	0.003	7
Molybdenum Total										<0.01		7
Nickel Total										<0.02		7
Potassium Total										0.8	0.4	7
Selenium Total										<0.06		7
Silicon Total										5.43	0.15	2
Silver Total										<0.01		7
Sodium Total	3.0		2							3.90	0.38	7
Strontium Total										0.055	0.033	7
Sulfur Total										1.09	0.8	7
Tellurium Total										<0.05		5
Thallium Total										<0.03		5
Tin Total										<0.02		7
Titanium Total										<0.03		7
Vanadium Total										<0.01		7
Zinc Total										0.006	0.002	7
Zirconium Total										<0.005		5

APPENDIX 12
SUMMARY OF WATER QUALITY RESULTS FOR SITE 1199916 (INFLOW, EAST SHAWNIGAN LAKE ROAD)

(All results reported in mg/L unless otherwise noted.)

	1976 - 1979			1980 - 1989			1990 - 1999			2000 - Present		
	Mean	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**	**Mean**	**Std. Dev.**	**n**
General												
Color True (Col. Unit)										6.0	5.0	5
Hardness Total										18.3		1
pH (pH units)										7.3	0.2	3
Specific Conductance (uS/cm)										60	5	7
Turbidity (NTU)										0.4	0.2	7
Nutrients												
Ammonia Dissolved										0.005	0.000	7
Carbon Total Inorganic										3.4	0.9	3
Carbon Total Organic										2.0	1.6	3
Nitrate + Nitrite Dissolved										0.105	0.094	7
Nitrogen Kjeldahl Total										0.12	0.07	4
Nitrogen Total										0.206	0.092	7
Organic Nitrogen Total										0.14	0.04	4
Phosphorus Total										0.005	0.005	7
Phosphorus Total Dissolved										0.003	0.002	4
Metals												
Aluminum Total										0.04		1
Antimony Total										<0.05		1
Arsenic Total										<0.05		1
Barium Total										0.003		1
Beryllium Total										<0.0002		1
Bismuth Total										<0.05		1
Cadmium Total										<0.002		1
Calcium Total										5.43		1
Cobalt Total										<0.005		1
Copper Total										<0.005		1
Chromium Total										<0.005		1
Iron Total										0.014		1
Lead Total										<0.03		1
Magnesium Total										1.15		1
Manganese Total										0.001		1
Molybdenum Total										<0.005		1
Nickel Total										<0.008		1
Potassium Total										<1		1
Selenium Total										<0.03		1
Silver Total										<0.01		1
Sodium Total										3.32		1
Strontium Total										0.018		1
Sulfur Total										1.3		1
Tellurium Total										<0.05		1
Thallium Total										<0.03		1
Tin Total										<0.02		1
Titanium Total										<0.003		1
Vanadium Total										<0.005		1
Zinc Total										<0.005		1
Zirconium Total										<0.005		1

APPENDIX 13
SUMMARY OF WATER QUALITY RESULTS FOR SITE 1199912 (SHAWNIGAN CREEK OUTFLOW)

(All results reported in mg/L unless otherwise noted. Less-than (<) values indicate some or all results were below analytical method detection limits.)

	1976 - 1979			1980 - 1989			1990 - 1999			2000 - Present		
	Mean	Std. Dev.	n	Mean	Std. Dev.	n	Mean	Std. Dev.	n	Mean	Std. Dev.	n
General												
Alkalinity Total 4.5	16.4		2									
Color True (Col. Unit)										9	3	11
Color TAC (TAC)	6		224									
Hardness Total										35.0	39.9	8
pH (pH units)	7.2		28							7.4	0.1	4
Residue Filterable	37.9		23									
Residue Nonfilterable	1.8		18									
Residue Total	40.8		24									
Specific Conductance (uS/cm)	53.9		28							82	80	14
Turbidity (NTU)	0.8		17							1.3	3.1	14
Nutrients												
Ammonia Dissolved	0.011		28							0.040	0.086	14
Carbon Total Inorganic	2.9		11							3.5	1.0	4
Carbon Total Organic	3.2		11							3.0	0.4	4
Nitrate + Nitrite Dissolved										0.069	0.075	14
Nitrate Total	0.044		28									
Nitrogen Kjeldahl Total										0.20	0.16	5
Nitrogen Total										0.224	0.085	14
Organic Nitrogen Total	0.159		28							0.17	0.06	5
Ortho-Phosphate Dissolved	<0.003		28									
Phosphorus Total	0.007		28							0.007	0.006	14
Phosphorus Total Dissolved	0.004		28							0.003	0.001	10
Metals												
Aluminum Total										0.06	0.06	9
Antimony Total										<0.06		9
Arsenic Total										<0.06		9
Barium Total										0.014	0.019	9
Beryllium Total										<0.001		9
Bismuth Total										<0.05	0	7
Cadmium Total										<0.006		9
Calcium Total	6.0		15							13.57	14.26	9
Cobalt Total										<0.006		9
Copper Total										<0.006		9
Chromium Total										<0.006		9
Iron Total										0.652	1.223	9
Lead Total										<0.06		9
Magnesium Total	1.0		15							2.93	3.45	9
Manganese Total										0.137	0.263	9
Molybdenum Total										<0.01		9
Nickel Total										<0.02		9
Potassium Total										0.8	0.4	9
Selenium Total										<0.06		9
Silicon Total										1.72	0.01	2
Silver Total										<0.01		9
Sodium Total	3.0		2							8.56	10	9
Strontium Total										0.051	0.055	9
Sulfur Total										1.7	1.59	9
Tellurium Total										<0.05		7
Thallium Total										<0.03		7
Tin Total										<0.06		9
Titanium Total										<0.003		9
Vanadium Total										<0.01		9
Zinc Total										<0.005		9
Zirconium Total										<0.005		7

APPENDIX 14
GLOSSARY

Alkalinity
A measure of the water's ability to neutralize acids usually indicating the presence of carbonate, bicarbonates or hydroxides.

Ambient
Refers to conditions in the surrounding environment.

Ammonia
A measure of the most reduced inorganic form of nitrogen in water and includes dissolved ammonia (NH_3) and the ammonium ion (NH_4^+).

Aquifer
A geological formation or structure that stores or transmits water, or both, such as to wells and springs.

Bathymetric map
A map showing the depth (bottom contours) of water in lakes, streams, or oceans.

Chlorphyll *a*
The primary green-coloured pigment found in plants and algae which traps and converts light energy to chemically stored energy.

Colour, true
A measure of the dissolved colouring compounds in water. The colour of water is attributed to the presence of organic and inorganic materials which absorb different light frequencies.

Community watershed
Any natural watershed area on which a community holds a valid water licence issued under the *Water Act*.

Designated water use
A water use that is to be protected at a specific location.

Disinfection
The process of killing or rendering harmless microbiological organisms in water that cause disease by the application of a disinfectant (e.g. chlorine, chloramines, ozone, ultraviolet radiation).

Disinfection by-products
Chemicals (e.g. trihalomethanes) formed when a disinfectant (e.g., chlorine) is added to water containing organic matter. Such by-products are suspected to be human carcinogens.

Dissolved oxygen (DO)
Oxygen dissolved in water and essential for respiration by most aquatic organisms.

Enterocci
Bacteria species inhabiting the gut of humans and other warm blooded animals which are used as an indicator of water contamination. Some forms can be pathogenic.

Epilimnion
The surface layer of a thermally stratified lake.

***Escherichia coli* (*E. coli*)**
A coliform bacteria inhabiting the gut of humans and other warm blooded animals which are used as an indicator of water contamination. Some forms are are pathenogenic (e.g., O157:H7).

Eutrophication
Increasing nutrient content in a body of water over time. This natural process may be accelerated by nutrient-rich discharges from agriculture or sewage, resulting in algal blooms, excessive growth of macrophytes or undesirable changes in water quality.

Fall freshet
A sudden increased period of stream flow as a result of heavy rainfall typical of coastal areas in the fall.

Fecal coliforms
Enteric bacteria inhabiting the gut of humans and other warm blooded animals which are used as an indicator of water contamination.

Fecal streptococci
A group of bacteria normally present in large numbers in the intestinal tracts of warm-blooded animals other than humans, which are sometimes used as an indicator of contamination

Geometric mean
The N^{th} root of the product of N observations.

Grab sample
A single sample taken at a given place and time.

Hardness
The hardness of water is generally due to the presence of calcium and magnesium in the water. Hardness is reported in terms of calcium carbonate as mg/L. Waters with values exceeding 120 mg/L are considered hard while values below 60 mg/L are considered soft.

Hypolimnion
The cooler, deeper waters of a thermally stratified lake.

Isotherm
A line drawn on a map or chart linking all points of equal or constant temperature.

Kjeldahl nitrogen
A measure of both the ammonia and the organic forms of nitrogen.

Limnology
The study of fresh water bodies including biological, geological, physical and chemical aspects.

Littoral
The region along the shore of a non-flowing body of water.

Macrophyte
The larger aquatic plants, including aquatic mosses, liverworts, larger algae and vascular plants.

Morphometry
The physical characteristics of a lake such as size and shape of a lake basin, mean depth, maximum depth, volume, drainage area, and flushing rate.

90th percentile
The value in a data set at which 90% of the results fall below. For example, a data set consisting of 10 samples are ranked from lowest to highest with the 9th highest value representing the 90th percentile.

Nitrate + nitrite (NO_3 + NO_2)
A measure of the most oxidized and stable form of N in a water body (NO_3) and an intermediate form (NO_2) that occurs in the biological conversion of NH_4 to NO_3.

Oligotrophic
A water body with limited nutrient input or cycling, resulting in low levels of biomass production.

Ortho-phosphorus
A measure of the inorganic oxidized and biologically available form of soluble phosphorus.

pH
A measure of the hydrogen ion concentration of a solution which provides a quantitative expression of its acidity or alkalinity ranging, from 0 to 14. pH 7 is neutral, less than 7 is acidic and more than 7 is alkaline or basic.

Phytoplankton
An assemblage of small plants suspended in the water column with little or no powers of locomotion.

Primary productivity
A measure of algal producitivity or rate of growth in a body of water; the primary productivity measures the mass of carbon used annually by algae per unit area of lake surface.

Recreational primary contact
Activities like swimming and water sports where a person has or risks direct contact with water through immersion or ingestion.

Secchi disc
A black and white disk used to measure the transparency or clarity of water in a lake by measuring the depth at which it can be seen.

Specific conductance
A quantitative measure of the ability of water to conduct an electrical current, related to the type and concentration of ions in solution. Specific conductance can be used for approximating the total dissolved solids concentration in water.

Thermal stratification
The vertical temperature stratification of a lake which consists of: (a) the upper layer (**epilimnion**), (b) the middle layer (**thermocline**) and (c) the bottom layer (**hypolimnion**).

Thermocline
A well defined vertical temperature change or boundary; often associated with **thermal stratification** in lakes.

Total nitrogen
A measure of all forms of nitrogen (organic and inorganic).

Total Phosphorus
A measure of all forms of phosphorus (organic and inorganic).

Water column
The portion of an aquatic or marine environment extending from the water surface to the bottom or the surface of the sediment.

Water Quality Guideline
Numerical value(s) for a physical, chemical or biological characteristic of water, biota or sediment which must not be exceeded to prevent specified detrimental effects from occurring to water use.

Water Quality Objective
A water quality guideline adapted to protect the most sensitive designated water use at a specified location with an adequate degree of safety, taking local circumstances into account.

Water residence time
A measure of measure of how often, usually in years, water is replaced in a lake based on flows into and out of the system.

Watershed
All lands enclosed by a continuous hydrologic drainage divide and lying upslope from a specified point on a stream.

Zooplankton
Microscopic animals which swim freely in the water column or are carried about by water currents. Many feed on **phytoplankton** and are in turn a staple diet of small fish.