Summary of the Available Information on Shawnigan Lake, with an Emphasis on Water Quality

Prepared for the Shawnigan Basin Society

by

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Executive summary / What have we learned?

This report condenses and simplifies the results of studies on different aspects of Shawnigan Lake. The studies deal primarily with the water quality because Shawnigan Lake is an import drinking water source and recreational area. However, to understand or interpret possible or measured changes in water quality, it is important to recognize what factors influence the water quality. In the Shawnigan Lake watershed, agriculture (livestock and organic and inorganic fertilizers), forestry (logging) and urban development (septic fields) are possible sources of nutrients and contaminants. No data are available - except for possible contamination from septic systems - so possible changes from published literature are identified. In the lake, there is one native salmonid (kokanee), two stocked species (rainbow and cutthroat trout), and the three introduced species (yellow perch, pumpkinseed and smallmouth bass). The brown bullhead was introduced as well, but is now quite scarce. The introductions were unauthorized and the dates are unknown, but these species can significantly affect the aquatic community structure due to inter-related aspects of their life histories. There are no data on the fish populations of the lake and thus only possible changes in the lake ecology due to the introduced species are discussed.

Shawnigan Lake is 7.2 km long oriented south to north. It is 1.4 km across at the widest point and 150 m wide at the narrowest point in the west arm - a shallow arm somewhat isolated from the main body of the lake - and has one main deep basin to 50m in the northern half and several smaller basins to 28 m in the southern half. The main tributaries to the lake are Shawnigan Creek from the south, McGee Creek on the west side and the west arm inflow in the northwest corner. The outlet is at the north end. The lake water stratifies in early summer as the surface waters warm and it mixes in the fall. The residency time of the lake water is about one year and thus nutrients and possible contaminants are flushed yearly. In fact, this short residency time has been identified as an important factor in maintaining good water quality in Shawnigan Lake.

Different sampling sites have been used in different studies, although the main sites in the north and south basins and the west arm are consistent. One site in the north end of the lake near the CVRD drinking water intake is considered separately. The sites used in the more detailed studies are shown and in cases where different sites are used, the data are summarized by general location: mid-lake sites in the different basins, perimeter sites based on the end or side of the lake, inflows creeks and outflow creek.

Phosphorus is the limiting nutrient and thus increases in phosphorus can increase productivity due to increased algal growth making the water aesthetically displeasing as a drinking water source and for recreational use. Also, algae can also contribute to taste and make treatment of the water for drinking more difficult also certain cyanobacteria (blue green algae) produce heptatoxins and neurotaoxins, with serious health consequences. Chlorophyll *a* is the measure of primary productivity because it is contained in all plant material and is thus a consistent measure of phytoplankton levels. The number of phytoplankton cells is not a good measure of primary productivity because the cells are of different sizes. Zooplankton consume phytoplankton as do some fish such as the native kokanee. Juvenile fish – native, stocked and introduced - consume zooplankton and adult fish add aquatic insects, crayfish and other fish to their diet.

Assessment of the water quality data is based three inter-related criteria: those developed and characteristic of oligotrophic lakes (clear with low productivity); those recommended for drinking water supplies; or more stringent levels based on present conditions. The water quality data – limnological characteristics, water chemistry, chlorophyll *a*, phytoplankton and zooplankton – indicate that, in general Shawnigan Lake is oligotrophic (clear with low productivity) and the measured variables are within the drinking water guidelines and the water quality objectives. However, there are some exceptions and unknowns, which warrant mention.

The mean total phosphorus concentrations in the west arm and in the inlet to the west arm exceeded the water quality objective (8 µg/L at spring turnover), but not the drinking water guideline (≤ 10 µg/L) in the periods 1977-79 and 2003-04. The mean concentrations in the main basins, perimeter sites and inflow and outflow creeks were all < 8µg/L. Levels at the north end of the lake - near the CVRD drinking water intake - sampled between September 2010 and January 2012 had a mean of 6 ± 1.96 µg/L with four of sixty-six values > 8 µg/L. The drinking water criterion is to limit algal growth, not because the phosphorus itself is harmful, except in very high concentrations.

The mean (± 95% CL) chlorophyll *a* levels in the north and south basins, west arm and north end of the lake in 2003-04 were less than 3 µg/L, which is the threshold for oligotrophic lakes, but exceeded the criterion in the 1977-79 sampling period. The pronounced decrease between 1977-79 and 2003-04 did not correspond to a change in phosphorus suggesting that the decrease was due to increased grazing by zooplankton on the phytoplankton. Corresponding to this change in the lake water was a decrease in algal biomass in the sediments, which showed a peak beginning in the early 1970s and ending in the 1990s. Chlorophyll *a* levels near the CVRD drinking water intake reached 8.61 µg/L in the period between September 2010 and January 2012, but the mean level is not known. The high values were related to turbidity and thus some of the phosphorus may have been adsorbed to particulates, perhaps due to runoff into the lake.

The zooplankton species present were smaller in size than is typical of an oligotrophic lake, probably because the larger individuals were consumed by the juvenile fish.

During chlorination, there is potential for the formation of chlorine disinfection by-products (DBP), particularly trihalomethanes (THM), which are a health hazard. Total organic carbon (TOC) concentration is used as a measure of the potential for the formation of THM. The mean levels of TOC at the four lake sites (north and south basins, west arm and north end of the lake) in the 2003-04 sampling period were within the objective of 4mg/L. However, samples collected between September 2010 and January 2012 near the CVRD drinking water intake had values that ranged from 2.6 to 6 mg/L, with at least one spike (11.02mg/L) in June 2011. During this period, the values of THM and other possible DBPs within the CVRD North Water distribution system exceeded the regulatory guideline level of 0.100mg/L, probably associated with the high TOC in the intake water.

Microbiological indicators are used to test drinking water supplies and recreational waters for possible fecal contamination from endotherms (warm blooded animals). Possible human mediated sources of fecal material to Shawnigan Lake are runoff from agricultural land (livestock and manure as fertilizer) and improperly maintained or located septic systems. Fecal material from water fowl and mammals living in the watershed can also enter the lake. The various criteria for different microbial indicators for the different water uses are tabulated. In addition, the fecal coliform and *E. coli* data from four main studies are summarized based on whether or not they met the criterion for a raw drinking water source with disinfection. Most of the licensed water intakes met the criteria in 2003/04 as did the sites in the north and south basins, but some samples in collected between 2010 and 2012 exceeded the criteria. (Note: the authors of the study of the water at the CVRD intake indicated that their results cannot be related to data from other sources.) The fecal coliform (or *E. coli*) levels in the perimeter sites, and the inflow and outflow creeks did not for the most part meet the criteria. In fact, levels in Shawnigan Creek inflow in 2003-04 were over 80 times the criterion.

It is possible to identify the percent of the DNA in *E. coli* collected in Shawnigan Lake samples that came from different animals. In 2012, samples from near the CVRD North Water System intake had the greatest contamination from bears (20%), horses (18.6%), humans (14.3%), dogs (10.0%) and gulls (10.0%). An unknown source, which may be water fowl accounted for 12.5%. The relative importance of septic input, recreational input and runoff is not known, although studies using N^{15}/N^{14} suggest that septic input is important.

Recommendations

There are on-going studies in Shawnigan Lake, primarily on the water quality. If it is not in included in these studies, more information of the cyanobacteria present should be addressed. Also, the relative importance of *E. coli* from septic systems, recreational input and runoff should be investigated. However, there are two additional aspects of the lake ecology that should be addressed – fisheries and macrophyte biology. There is no information on the fish populations and how the introduced species – particularly the smallmouth bass – has modified the lake ecology. Three possible consequences are discussed in the report: effects of diet on the prey species; competition with native species; and changes in the littoral areas due to spawning locations and behaviour. One expected change is a decrease in crayfish, which is an important food for adult smallmouth bass and an associated increase in periphyton (attached alage), the main food of the crayfish. Anecdotal comments by residents suggest this may be occurring, but it has not been quantified. The increase in periphyton would not be due to an increase in nutrient levels, but because of the introduced smallmouth bass. Also, zooplankton is a major food for juvenile fish and the introduced fish can affect the zooplankton populations, which was observed in 2003-04. The zooplankton graze on phytoplankton and the decreased productivity between 1997-79 and 2003-04 was attributed to increased grazing by zooplankton. However, if the fish numbers increase they may further decrease the zooplankton numbers and sizes which could reduce the control of the zooplankton on the phytoplankton.

There are anecdotal reports of increased macrophytes. When these are removed by hand, pieces can fall off and produce new plants. Also, the wakes from motorboats can disturb the sediment and possibly change the distribution of macrophytes. The introduced species spawn in the littoral areas and this may affect the macrophytes.

Given the importance of Shawnigan Lake as a drinking water source, a study on the effects of the introduced fish species is highly recommended given the potential for changes in the lake ecology and the possible consequences to the phytoplankton, zooplankton and periphyton populations and the numbers of the native kokanee. Information on the macrophytes numbers and species and how they are affected by wakes from boats, spawning fish and general disruption of the littoral areas as well as how they can be controlled should be considered as well.

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1. Introduction

“Shawnigan is the most obvious place on the lower island where there is a conflict between natural beauty and people.” It means we must preserve these lakes “or bid good-bye to them forever.” Since these words by Health Minister Ralph Loffmark were recorded by John Driscoll in the July 5, 1969 edition of the Victoria Daily Times, numerous studies and surveys have been completed on various aspects of Shawnigan Lake and its watershed. These studies fall in several – in some cases overlapping – categories: lake morphology and hydrology, land and water uses, water quality, sediment history, and fisheries habitat suitability (Nordin and McKean, 1984; Talbot, 1985; Holmes, 1996; Webber, 1996; Best et al., 2000; Reiberger et al., 2004; Rieberger, 2007; Worley Parsons, 2009; Mazumder, 2010; Water and Aquatic Sciences Research Program, 2012; Hutchinson, 2011). This list is not exclusive as information from earlier reports (Stonehouse, 1969; Black et al., 1977; McKinnel, 1978; Lucey and Jackson, 1983) is included in Nordin and McKean (1984), and various thesis from the University of Victoria (Furey, 2003; Nowlin, 2003; Davies, 2004) are referenced in Reiberger et al. (2004). Also, information on the geology and soils of the watershed (Wiens and Nagpal, 1984) are available and not considered in detail in this report. However, given the data available and the various recommendations for future studies and actions, the public still had significant concerns about the water quality and quantity and the leadership in moving forward (Judith Cullington and Associates with Moyer Creative Communications Inc., 2012). But since 2012 and under the initial vision of CVRD area director Bruce Fraser several positive developments have and are occurring beginning with the formation of the non-profit Shawnigan Basin Society (SBS). The SBS has raised significant monies through tax allocation and donations and with the support of the Ecological Design Panel and input from the community has retained the services Silva Ecosystems Consulting Ltd to prepare an Ecosystem-Based Conservation Plan for Shawnigan Lake Watershed. In addition, using tax allocation monies the SBS initiated the discussions to define and develop a Shawnigan Basin Authority (SBA) is to give the community an organized voice in watershed governance. But most of the initiatives deal with future studies and planning and thus the SBS discussed the merit of having the background and existing information on the lake summarized and made available to the public. This report is the results of these discussions. It is a non-critical summary of the available information on the given topics, including an overview as to why results are important to the long term survival of the Shawnigan Lake ecosystem and the resultant uses of the lake and its water. Emphasis is on the lake and its tributaries, although some data on the characteristics of the watershed (geology and soils) are included.

2. Watershed Description and Lake Hydrology

Shawnigan Lake Watershed covers 69.4 km^2 and is contained within the Shawnigan Lake Community Watershed, which is 110 km^2 and also includes the land draining to Shawnigan Creek, the outlet from the north end of lake that empties into Saanich Inlet at Mill Bay. The watershed has a maximum elevation of 610m GSC (Geodetic Survey of Canada) and a minimum elevation of approximately 116 m GSC at the lake level (Bryden and Barr, 2002, from Reiberger, 2007).

The lake, which is aligned from south to north, 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 main body of the lake has one main deep basin to 50m in the northern half and several smaller basins to 28 m in the southern half. There are three main tributaries: Shawnigan Creek at the south end of the lake, which originates from Devereaux and Stebbings Lakes; McGee Creek on the west shore; and the West Arm inflow in the northwest corner of the lake (Reiberger et al., 2004). Other inflows include Roundhouse Creek and Unnamed Creek to the north basin on the west side, two Landfill Creeks and Village Creek from the northeast to the north basin, and East Shawnigan Creek to the south basin (Nordin and McKean, 1984). The lake water residency time is approximately one year (Nordin and McKean, 1984).

The outflow from Shawnigan Lake to Shawnigan Creek at the north end of the Lake is partially regulated by a dam or weir (Best et al., 2000; Hutchinson, 2011). The first dam, which consisted of flashboards and stop-logs was installed in 1964 about 450 m downstream from the lake outlet to store water and prevent flooding. It was replaced in 2008 by a new weir with metal gates and a fish ladder. During the summer, the water levels are gradually reduced using the “curve rule”, which dictates the rate of change in water levels from 116.3m to 115.75m. The winter flows are mediated as possible. These controls do not affect the summer stratification of the lake waters or the flushing and residency time of the lake water.

3. Land Use in the Shawnigan Lake Watershed

There are three main land-uses in the watershed: agriculture, urban development and forestry.

3.1 Agriculture

Approximately 9.5% of the land base is under the Agricultural Land Reserve (ALR), including the land along 1 km of the southern shoreline (Reiberger et al. (2004). The use of the agricultural land is not known but nutrients from fertilizers and manure can enter surface waters directly by runoff or indirectly via groundwater (Sharpley and Moyer, 2000; Turner and Haygarth, 2000; Bohlke, 2002; Burkart and Stoner, 2008) and coliform bacteria from manure can be flushed into the surface waters. Fertilizers are also used on urban lawns and animals (e.g. horses) are not restricted to agricultural land.

3.2 Urban Development

The town of Shawnigan Lake has grown over the past 25 years from a rural community with mostly seasonal residences to a permanent community with year round residents, many of whom commute to Victoria. And the growth continues. Most of the development is along the north end of the lake, but many residences occur along the periphery of the lake where the zoning is suburban residential or urban residential (Reiberger et al., 2004). [*Check Community Plan]*

There were five waste management discharge permits to ground in 2004and numerous septic fields (Reiberger et al., 2004). The discharge permits are at least 400 m from the lake (400 to 4100m) with a total discharge of approximately 800 m^3/d (Reiberger et al., 2004), but the depths to groundwater are not known nor are any requirements for groundwater monitoring.

In a properly constructed and maintained septic field, the solids settle in the tank and the effluent moves to the tile field and out to the unsaturated soil and saturated soil (groundwater) where microbiological and chemical reactions occur. The septic effluent contains high levels of the dissolved organic carbon (DOC), nitrogen, particularly ammonia, phosphorus, and ions such as sodium, calcium and chloride (Wilhelm et al., 1994) and bacterial wastes. The bacteria are supposed to be integrated into the soil. The DOC is oxidized primarily to carbon dioxide and the ammonia is oxidized to nitrate, which is soluble in water and found in levels that exceed the British Columbia drinking water guideline of 10mg nitrate-N/L (Nordin and Pommen, 2001)) in the effluent plume (Wilhelm et al., 1994). Phosphorus advances slowly (Wilhelm et al., 1994) as some is adsorbed to soil particles, but Robertson et al. (1998) found increased levels – above the objective for Shawnigan Lake (see Section 5**)** –10 m from a septic field in sandy soils. In fact, two to four years after this septic tank was decommissioned, sodium, calcium, chloride, and nitrate returned to background levels, but ortho-phosphate levels remained high (Robertson and Harman, 1999). Given that some of the old septic fields around Shawnigan Lake are most probably less than 10 m from the lake and from the groundwater level at the lake's edge, the septic plumes may enter groundwater and the lake. Saturated and perhaps anoxic conditions can occur near the lake during high water which could comprise proper functioning of the tile field.

3.3 Forestry

Forestry has been a mainstay industry in British Columbia since the initial settlement by immigrants. It was the main activity in the Shawnigan Lake Watershed from the 1860s to the mid 1990s and is still the major land use designation today. The potential effects of forestry and milling on the watershed, particularly the lake, were not a priority in the initial days but the impacts of forestry are now recognised and best practices guidelines have been developed and are enforced where possible. At present government jurisdiction on privately owned forest land is shared between the provincial government and the regional district. The following is divided into three parts: the historical forestry activities from the 1860s to the mid 1990s and some of the consequences on the lake; general effects of logging on the watershed, particularly the lake; and the on-going and expected logging activities in the watershed.

3.3.1 The 1860s to the mid 1990s

Logging, sawmills, log booms, log storage, fires and the railway built to move the forestry products are an important part of the history of the Shawnigan Lake Watershed (G. Treloar, pers. comm.; www.shawniganlakemuseum.com) and have influenced the lake quality, particularly the long-term effects on the sediments (Nordin and Mclean, 1994; Best et al., 2000). Logging began in the 1880s on the islands and in the 1890s on the east side of the lake; by 1910 all of the immediate lakeshore around the lake had been logged, to some extent. Logs were stored and moved on the water in log booms and stored on land on the west side, at the present location of the Provincial Park. Debris from the log booms settled on the lake bottom and debris from the log storage area was probably flushed into the lake. The E&N railway moved on the east side of the lake and by the 1920s, railways lines and spurs, which moved the forest products, were common, particularly on the west side. The railways included three railway bridges across Shawnigan Creek near the lake outflow, which may have contributed to the sediment accumulation at the outflow (Best et al., 2000). The first of several sawmills was built at now Mill Park on the east side of Shawnigan Lake in 1890. The waste sawdust was dumped onto the lake and the area around the mill is still covered in chips. In addition, there are two boats from the mill on the bottom of the lake near the old mill site. Runoff and debris from the fires at the mill in 1918, 1934 and 1945 probably entered the lake. The mill closed after the last fire. Fires were not restricted to the mills as there was a severe forest fire on in 1860s that burnt to the west shore of the lake. But there were prosperous times in Shawnigan Lake and visitors came from Victoria and Nanaimo by the E&N railway to stay at Morton House and after it burned in 1902, Shawnigan Lake Hotel.

3.3.2 Logging – points to consider

The forest ecosystem is a complex interaction of plants, animals and soils, which work together to maintain a healthy natural environment with sustained benefits to society. Loss of large forested areas is an environmental, cultural and social loss to a rural community and should be addressed in land-use planning decisions. This means that management planning and harvesting must be done in an ecologically responsible way to ensure a healthy and sustainable forest community. The forest ecosystem is not static nor is it isolated and changes in the forests affect adjacent areas such as lakes, in this case Shawnigan Lake. The purpose of this summary is not to describe the complexities of the forest ecosystem, but to outline the contribution of trees to water movement and mineral (nutrient) cycles within the ecosystem and thus outline how the removal of large numbers of trees will affect these cycles and the possible/probably consequences to the land and the adjacent lake.

Trees play an important role in the water movement in forests. Evapotranspiration removes water from the soil via the roots and up the trunk to the leaves and the atmosphere. The foliage intercepts precipitation and mediates its rate of input to the soil. The trees themselves store water and the roots help maintain the soil structure and stability. All of these functions help regulate the soil water content and reduce the chance of extensive and rapid overland flow of water and suspended materials (erosion) – including soil nutrients and bacteria – to creeks and the lake.

The trees store large amounts of carbon, which they fix from carbon dioxide during photosynthesis, and other nutrients such as nitrogen and phosphorus, which they acquire from the soil water. The nutrients are passed from the vegetation to herbivores that consume plants, omnivores that consume plants and animals and carnivores that consume other animals, in a hierarchical, but non-linear sequence. The cycles continue as trees shed their leaves, animals produce wastes, and trees and animals die and thus provide food for decomposers such as bacteria and fungi, which gradually release the nutrients from the dead material for use by other organisms, including more trees. These cycles are dynamic, although gradual and the nutrients are retained within the different components of the forest ecosystem. Removing the trees removes the nutrients, particularly the carbon stored in the trees and causes an abrupt change in the food (and habitat) available for the animals, which leads to a decrease in biodiversity. In addition, logging leaves a pool of nutrients in the soil that can be leached with soil material to adjacent surface waters or to groundwater before being used by new growth in the large deforested area. If the land is not left to re-generate, the loss of nutrients to the surface waters and groundwater is enhanced. If the land is used solely to grow more trees of one species, the nutrient cycles continue, but some fertilization may be required and the complexity of the system and the associated buffers to ecosystem disruptions are reduced.

3.3.3 Recent logging activities

Barry Gates (pers. comm.), provided a summary of the logging activities in the Shawnigan Lake Watershed: Approximately 65% of the watershed is in the Rural Resource Zone designated for forestry/ agricultural operations. Of this 30% is crown land mainly allocated to woodlot operations. Private forest land ownership is 24% Timberwest, 16.5% Island Timberlands, 18.6% other private holdings, 7.6% lake bottom and 3.3% infrastructure. Most private holdings fall under provincial jurisdiction and have been harvested using the industry standard ‘variable green tree retention’ (clearcut with reserves) silviculture system. The harvesting of almost all private forest land has occurred within the past 30 years as it has come into rotation with the majority being harvested in the past 15 years. The majority of crown land has been allocated to woodlot operations with some going to BC Timber Sales and ‘no tender’ contracts to Malahat Band. Important to note is that all private forest lands and crown woodlot tenures have management plans which convert natural forest structures to short rotation monocultures albeit at a much slower rate on crown lands than on private lands. These ‘tree farms’ are managed for a single commodity, wood fiber, with a resulting loss of biodiversity and ecological services to the community. Only about 10% of the Shawnigan Lake Watershed – Elkington Forest and designated parks / community woodlot - are permanently protected to maintain their ecological integrity. The rate of logging in the watershed has been intensive and the cumulative impacts of logging have moved the watershed outside of the Range of Natural Variability, that is, from an ecologically safe zone to an ecologically at risk zone. This means the composition, structure and function of ecosystems, including biodiversity has been degraded so that they no longer provide the same level of ecological protection for the community they have in the past.

The direct impacts are that excessive runoff and erosion of soils due to logging enters the lake primarily via the tributary streams and each of the three main tributary sub-basins which have been harvested. South Shawnigan Creek contains the protected Elkington Forest and the Malahat Band lands in the upper reaches, but otherwise, most of this sub-basin has been logged. Almost all of the McGee Creek sub-basin has been logged and about 60% of the West Arm inlet has been harvested. Areas around the smaller tributaries on both the east and west side are being harvested.

4. Water Use

Shawnigan Lake is a popular recreation area – boating and swimming - but the lake also supports native, stocked and introduced species of fish, and the water is used for drinking. Because groundwater is also an important drinking water source and because there is a close connection between ground water and surface water a summary of information on the aquifers and wells is included as well.

4.1 Boating and Swimming

The parks on Shawnigan Lake are maintained by Cowichan Valley Regional District (CVRD) (www.cvrd.bc.ca/index.aspx?NID=271&PREVIEW=Yes) and BC Parks www.env.gov.bc.ca/bcparks/explore/parkpgs/w_shawn/. The CVRD electoral area B has five parks with beach access for swimming: three lake shore parks - Mason's Beach, Old Mill Park and Shawnigan Wharf Park - on the north and east side of the lake; one island park – Memory Island Park - in the south basin; and one river park – Williams River Park - on the Shawnigan Creek outflow from the lake. There is a boat ramp at the Shawnigan Wharf Park and also at Recreation Road Park on the west side of the lake. The web site gives the other facilities that are available at these parks. West Shawnigan Lake Provincial Park has beach access and various facilities that are identified on the web site; there is no boat ramp, but one located nearby that can be used. In addition to the official parks there are numerous private swimming areas and boat docks.

The main water quality variable measured on swimming beaches is Coliform levels (see section 5.3 Microbiological Indicators), but esthetics (e.g. algal growth and macrophytes) is important as well. The effects of boating on Shawnigan Lake are not documented, but one general result of motor boats is from the wakes they create - particularly large ones near to shore – which damage some of the literal areas as the motors stir up the sediment. In 1982, the CVRD (CVRD, 1982) prepared an overview for the management of Shawnigan Lake. It contained the boating regulations and rules, including the maximum speeds for motorized vessels and the need to prevent excessive wakes, particularly near shore. It is not known if these regulations and rules are enforced.

4.2 Fisheries

Kokanee is the only native salmonid in Shawnigan Lake (Best, 2000). It is a descendant of sockeye salmon (*Oncrhynchus nerka*) landlocked in the lake after the retreat of the last ice sheets and the resulting changes in the levels of the land and ocean (Best, 2000). Sculpins (probably the prickly sculpin *Cottus asper*) are native as well, but according to long-term residents the numbers are substantially reduced. Cutthroat trout (*O. clarki*) and rainbow trout (*O. mykiss*) have been stocked since the early1900s in numbers up to 50 000 for cutthroat trout and 1000 000 for rainbow trout (Figure 1) for total of 478 363 for cutthroat trout and 1 708 696 or rainbow trout, but no cutthroat trout have been added since 2004 and only 4300 rainbow trout were added in 2014 (www.gofishbc.com/fish-stocking-reports/archive-reports.aspx).

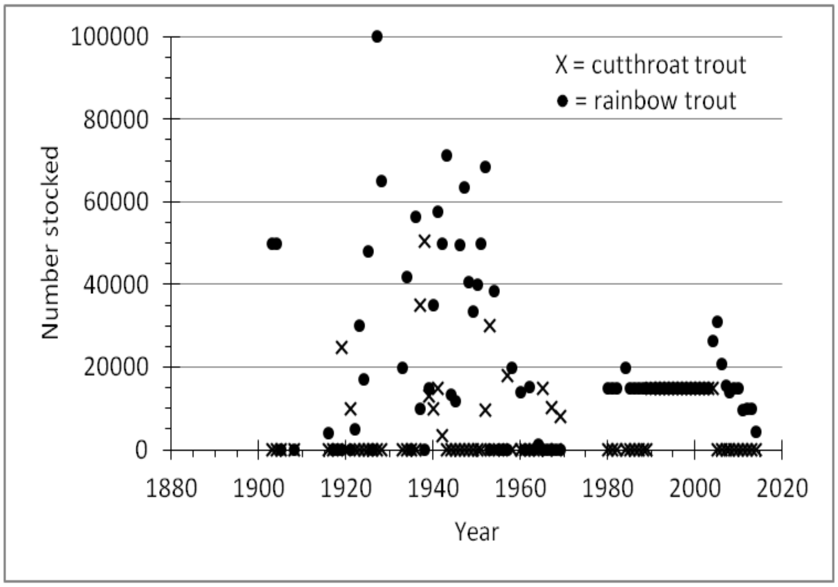

Figure 1. The number of cutthroat trout and rainbow trout stocked in Shawnigan Lake each year from 1903 to present.

Other introduced species of fish include smallmouth bass (*Micropteus dolomieu*), yellow perch (*Perca flavascens*), pumpkinseed (*Lepomis gibbosus*) and brown bullhead (*Ameiurus nebulosus*, previously *Ictaluris nebulosus*) (see Clifford and Guiguet, 1958; Runciman and Leaf, 2009; and references therein for more details). There are no accounts of authorized stocking of these species in Shawnigan Lake, but Spider, Langford and Florence lakes were stocked with general "bass/sunfish" between 1901 and 1923 (Runciman and Leaf, 2009). The brown bullhead numbers have decreased dramatically, although there are some sightings, including one caught in 2013 in the north end by a junior resident, Brock Musselwhite (B. Musselwhite, pers. comm.). Biological synopses are available that summarize the information on the remaining introduced species (e.g. smallmouth bass, Brown et al., 2009a; pumpkinseed, Jordan et al., 2009; yellow perch, Brown et al., 2009b) and there are general textbooks that include information on the ecology of these fish (e.g. Wootton, 1998). There are no studies on the fisheries of Shawnigan Lake, but the introduced species can significantly modify the lake ecology due to important and inter-related aspects of the life histories.

Spawning locations and behaviour: Kokanee and the introduced cutthroat trout and rainbow trout spawn in streams whereas yellow perch, pumpkinseed and smallmouth bass spawn primarily in the littoral areas of the lake. The pumpkinseed and smallmouth bass build redds (nests) for spawning and guard the eggs and to some extent the young, whereas the yellow perch do not build redds or guard the young. In these littoral areas, success of reproduction can be high, particularly for the smallmouth bass (Brown et al., 2009). In addition, the use of the littoral areas by these introduced species can affect the physical structure of these areas, simply due to redd construction and residency during reproductive periods.

Diet and competition: The introduced species (yellow perch, pumpkinseed and smallmouth bass) and the native kokanee and all consume zooplankton and aquatic insects and perhaps some phytoplankton (e.g. kokanee) when they are small (juveniles) and some species (e.g. kokanee and pumpkinseed) continue feeding largely on these foods as adults suggesting potential for competition among the young of these species in Shawnigan Lake, which can affect the native kokanee. Pumpkinseed, yellow perch and salmonids are important food for adult - and somewhat larger - smallmouth bass and once established in a new ecosystem the smallmouth bass rapidly dominate (Brown et al., 2009a), which will reduce the native and introduced salmonid stocks.

Effect of smallmouth bass on prey species: Young (small) smallmouth bass consume zooplankton as do the other unauthorized introduced species. Zooplankton feed on phytoplankton and thus a significant increase in the number of smallmouth bass may affect the zooplankton numbers and thus the phytoplankton populations. This may affect the algal component of the water and sediments (see Section 6. Biological Analyses).

Juvenile and adult smallmouth bass consume fish, but also crayfish, which may reduce crayfish numbers (see Brown et al., 2009a). Crayfish graze on attached algae (periphyton) and aquatic plants (macrophytes) and eat aquatic insects and thus a reduction in numbers of crayfish can increase the abundance of these food items, particularly the periphyton and macrophytes. Long-term residents suggest there is a decrease in crayfish numbers and an increase in periphyton, but there are no data available. If the increase in numbers of smallmouth bass has occurred and the numbers of crayfish has decreased, the probable resulting increase in attached periphyton is not due to changes in nutrients, but due to alteration of the aquatic ecosystem by the introduced smallmouth bass.

4.3 Drinking Water

There are two licensed drinking water intakes from Shawnigan Lake: the CVRD North Water System, which supplies water to Shawnigan Beach Estates, a condominium and an elementary school (www.cvrd.bc.ca/index.aspx?NID=380) and the Lidstech Holdings Ltd. dba: Shawnigan Village Waterworks, which supplies water to the village of Shawnigan Lake. The CVRD North Water System withdraws water through two pipes from the west side of the northern most inlet (end of Decca Road) of the lake where chlorination occurs (Decca Road Treatment Building [DRTB]). The water then moves to the distribution system in response to water levels in the two water storage reservoirs. The total volume removed per diem or per month is not known, but the total capacity of the two reservoirs is 265 000 gal. As a secondary water source, the CVRD North system has a groundwater well on Ingot Drive. Water from the well is pumped to the DRTB. Lidstech Holdings Ltd. removes waster from Shawnigan Lake on the east side of the northern most inlet (end of Shawnigan-Mill Bay Road). In 2008, they provided a base water supply of 804 000 gal.

In addition to the formal water removal from Shawnigan Lake, there are numerous lakeside residents that use the lake for drinking water. The residents away from the lake rely on groundwater.

4.4 Groundwater aquifers and wells

There are eight aquifers (Figure 2) within the Shawnigan Lake watershed, including the outlet (BC Water Resources Atlas [www.env.gov.bc.ca/wsd/data_searches/wrbc/index.html]). Each aquifer is classified (Aquifer Classification Database [http://a100.gov.bc.ca/pub/wells/public/common/aquifer_report.jsp]) according to the BC Aquifer Classification System (Bernardinucci and Ronneseth, 2002). One important objective of the classification system is to provide a standard base of information that can be used in management, protection and remediation of the aquifers (Bernardinucci and Ronneseth, 2002). Numerous factors are considered, but there are two main components: classification and ranking value. The classification component characterizes the aquifer with respect to the level of development (water supply relative to demand) and the vulnerability to contamination, based on existing development. The ranking value assigns a number indicative of its relative importance based on seven criteria: productivity, vulnerability to surface contamination, area, water demand, water use, and quality and quantity concerns. The classification components for the eight aquifers within the Shawnigan lake watershed are shown in Figure 2. The Roman numerals are for development. There are three levels: I is heavy, II is moderate, and III is light development. The letters are for vulnerability. Again there are three levels: A is for high, B is for medium and C is for light vulnerability. Aquifers 203 surrounding Shawnigan Lake and 206 in Mill Bay have a classification of IIA (Figure 2) indicating that they are moderately developed and highly vulnerable. Aquifers with this classification usually require particular care and attention with respect to land use activities that could affect water quality (Bernardinucci and Ronneseth, 2002). Aquifers 202, 204 and 207 are IIB (moderate development and vulnerability) and aquifers 197, 201 and 205 are IIC (moderate development and low vulnerability (Figure 2). Aquifers in these classifications may be able to support additional withdrawal; however, until site specific studies are conducted, these areas require care and attention for land-use activities that might affect water quality or quantity (Bernardinucci and Ronneseth, 2002).

The aquifers are either bedrock or unconsolidated sand and gravel as indicated – although not precisely – by the information from well records (Figure 3). Within the Shawnigan Lake watershed there are over 1000 wells, but in the area shown in Figure 3 there are about 3000 (Drillwell Enterprises Ltd., Duncan, pers. comm) indicating the extensive use of groundwater in the south Cowichan valley.

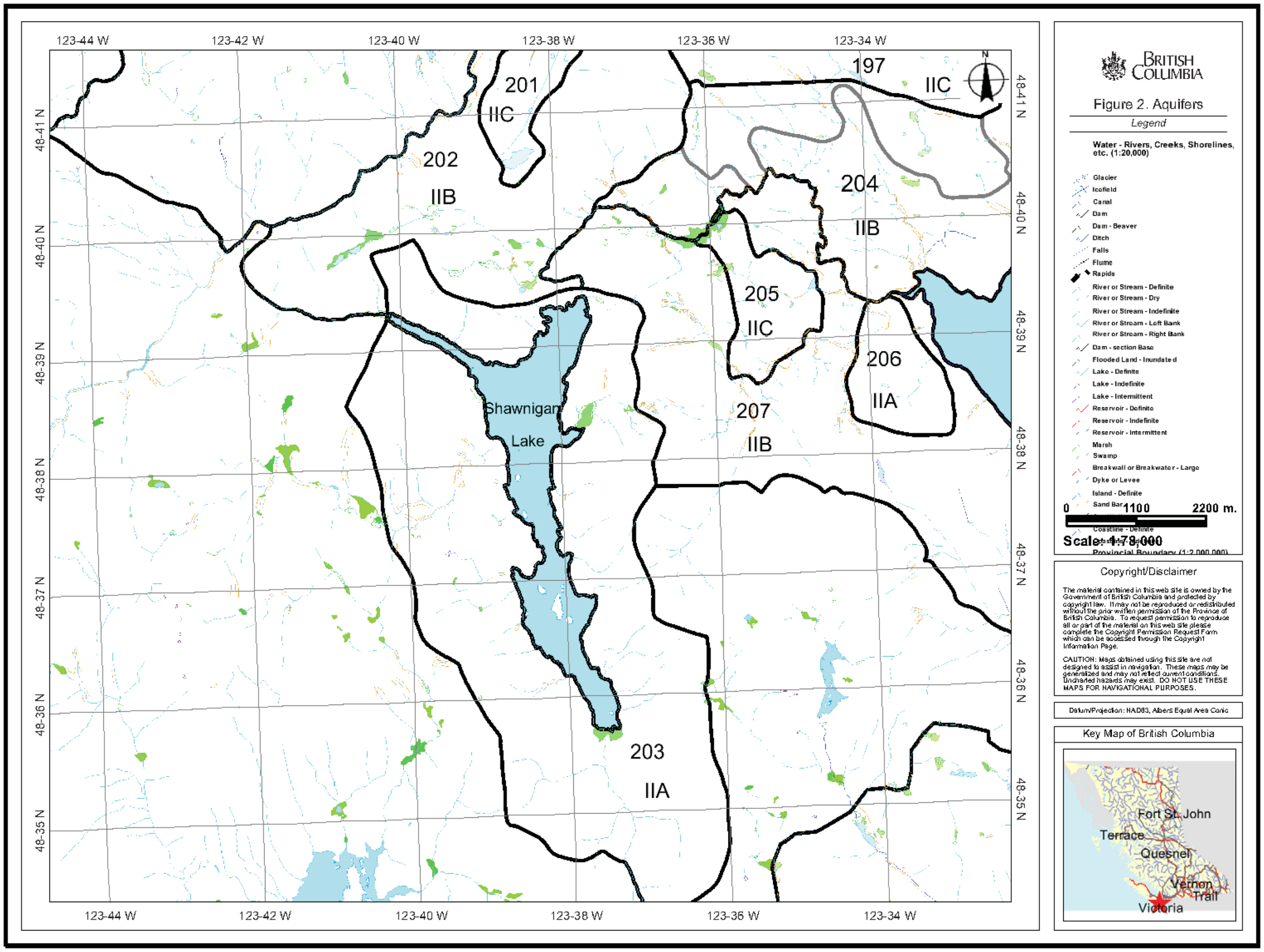

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Figure 2. The aquifer numbers and their classification on the Shawnigan Lake watershed. See text for details.

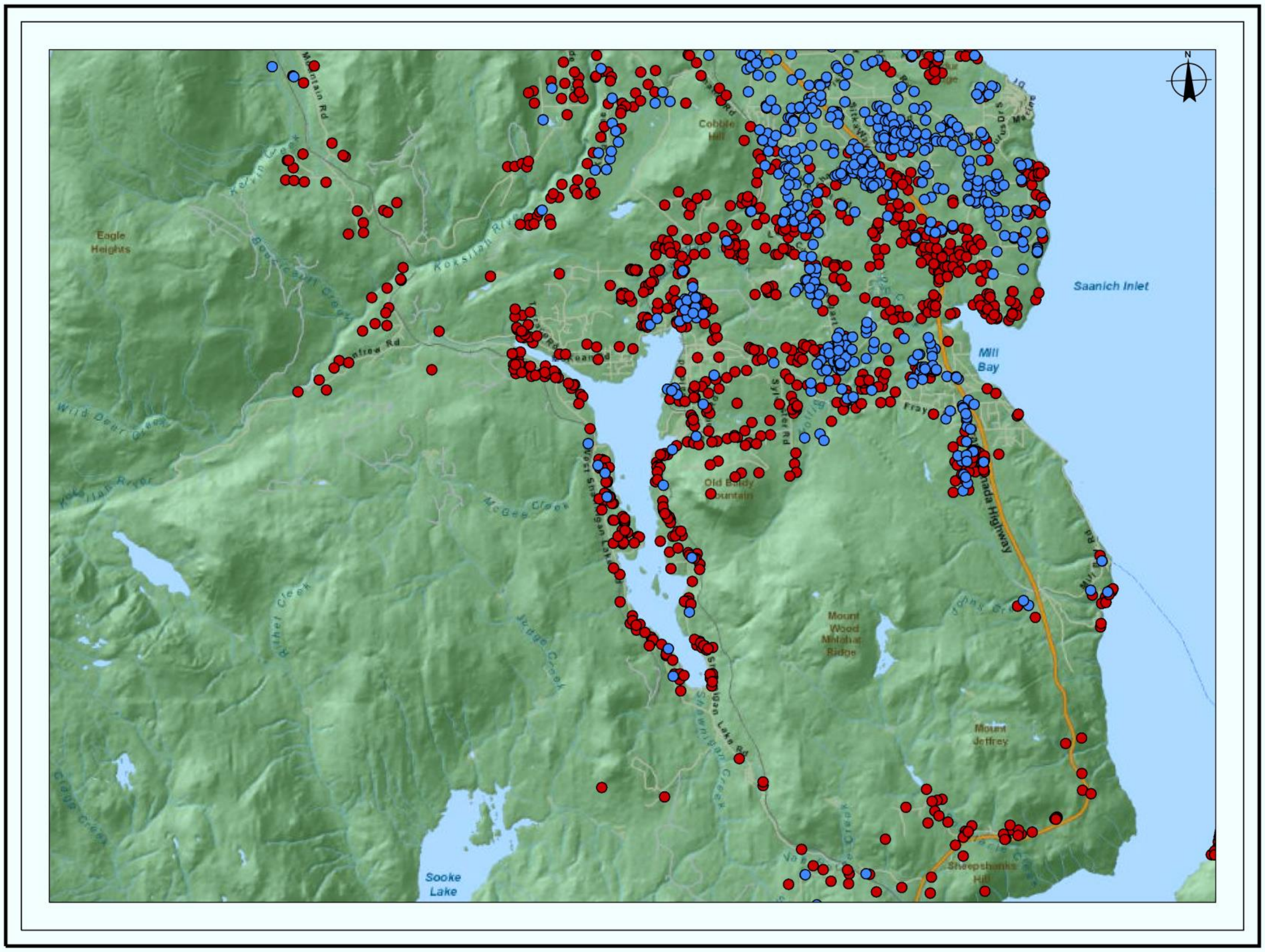

Figure 3. Groundwater well in the Shawnigan Lake basin and surrounding areas. Red are in bedrock. Blue are unconfined.

5. Water Quality

The water quality concerns and associated data are discussed in three parts: limnological characteristics, water chemistry, and biological indices. Each section begins with a general explanation of why the different variables are of interest in summarizing water quality.

Different studies sampled from different locations and used a different numbering scheme. However, Nordin and McKean (1984), Rieberger et al., (2004) and Rieberger (2007 all sampled the same four lake sites: deep in north basin, deep in south basin, midpoint in West Arm and north end near Mason's Beach (Table 1; Figure 4). Other sites are from the inflow and outflows and along the perimeter of the lake and slightly different locations were sampled by Nordin and Mckean (1984) and Rieberger (2007). Mazumder (2011 and 2012) sampled at the CVRD North Water System intake at the north end of the lake. This should be site 14 (Table 1; Figure 4), but it is considered separately. All of the sampling sites used by Rieberger (2007) are in Table 1 and Figure 4.

Table 1. The numbers, locations and descriptions for sampling sites in Shawnigan Lake shown in Figure 4.

Site Number	Site Location	Site Description
1	Lake	Deepest point of north basin, approximate depth is 50m
2	Lake	Deepest point of south basin, midway between Memory Island and west shore, approximate depth is 28m
3	Lake	West Arm, mid-channel, half-way up arm, approximate depth is 9m
4	Lake	North end of lake near Mason's Beach, approximate depth is 15m
5	Inflow	Shawnigan Creek inflow at south end of lake
6	Inflow	McGee Creek on west side of lake
7	Inflow	Inflow to the West Arm
8	Inflow	Inflow to the lake at East Shawnigan Lake Road
9	Outflow	Shawnigan creek outflow at north end of lake
10	Perimeter	Galley restaurant, marina dock on east side of lake
11	Perimeter	Easter Seal p beach, camp float on east side of lake
12	Perimeter	West Shawnigan Lake Park, beach on west side of lake
13	Perimeter	Shawnigan lake Resort, dock on northwest end of lake
14	Perimeter	CVRD North Water System intake
15	Perimeter	Lidstech Holdings - dba - Shawnigan Village Waterworks intake

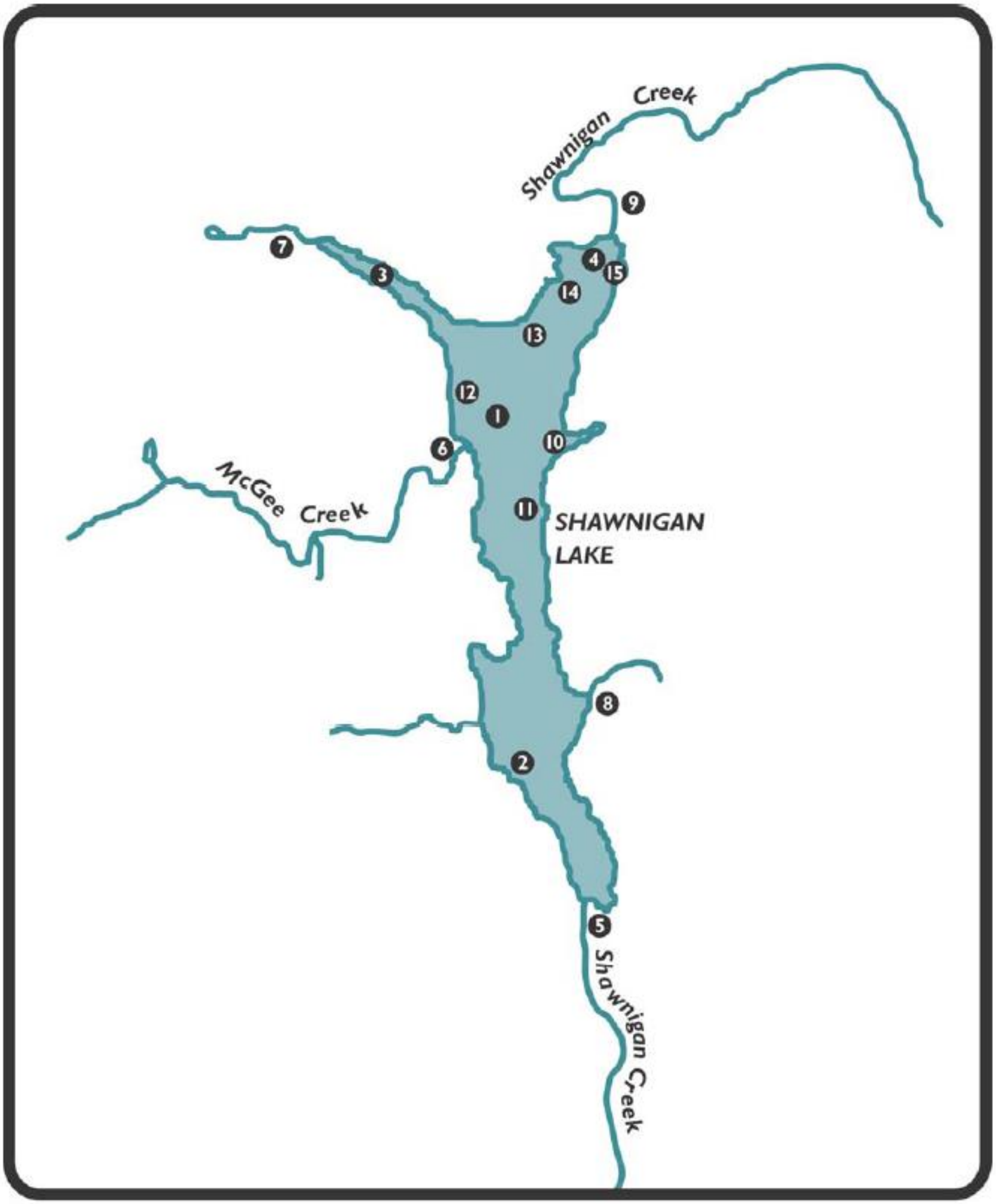

Figure 4. Sampling locations used by Rieberger (2007). Sites 1 -4 also used by Nordin and McKean (1984) and Rieberger et al. (2004)

Rieberger et al. (2004) and Rieberger (2007) contain the same data so the reference used in the following is Rieberger (2007) because Rieberger (2007) used the data to set objectives.

5.1 Limnological Characteristics

Lakes, which are usually water bodies between input and output streams or rivers, have unique limnological characteristics due to seasonal changes in temperature, wind and precipitation that affect the density, mixing and flushing of the lake water. The density of water increases with decreasing temperature (until freezing) and thus changes in the water temperature result in both thermal stratification and mixing (turnover) of the lake water. Shawnigan Lake is monomictic because there is only one turnover per year. In spring, as the temperature increases, the surface waters (epilimnion) warm and the deeper waters (hypolimnion) remain cool. Between the epilimnion and hypolimnion is the thermocline, a layer with a steep temperature gradient. The temperature and thus density difference prevents mixing, which is reduced further due to the low flows in the inflow and outflow streams. In fall, the decrease in temperature, compounded with increased precipitation and wind, result in mixing of the waters so that the lake temperatures are mostly uniform. The increased precipitation also increases the movement of water into and out of the lake, which flushes the lake. Recall that the residence time is about one year.

The three variables used to define the limnological characteristics are temperature stratification, dissolved oxygen and water clarity.

5.1.1 Temperature stratification

In the north and south basins, the thermocline occurs at about 8m, the surface waters reach 20° - 22°C in July and August when the hypolimnion is 8-14°C and the waters at all depths fall to 4° - 6° in December through March (Nordin and Mckean, 1984; Rieberger, 2007). There is less stratification and earlier turnover in the west arm than in the two main basins, probably due to its long slender morphology. Also, stratification and turnover occur earlier in the shallow waters of the northern part of the lake (Rieberger, 2007). The warm surface water above the thermocline, which is present in spring and summer are where the algae use nutrients to grow. The deeper cool waters are more suitable for fish. When the water mixes the algae moves to deeper levels and may die and become part of the sediment

5.1.2 Dissolved Oxygen

Dissolved oxygen is required for aquatic life. The water quality objective of an instantaneous reading of 5g/L at any depth is to minimize stress in salmonids, the most sensitive fish species in the lake (Rieberger, 2007). Occasional values within the hypolimnion did not meet the objective, but depressed hypolimnetic values are not uncommon in lakes and the guideline was met throughout the water column most of the time (Rieberger, 2007).

One change that has occurred between the work by Nordin and Mckean (1984) and Reiberger (2007) is an improvement in the oxygen depletion rate. Oxygen is required for the decomposition of organic matter and thus oxygen is deleted with an increase in dead organic matter. Nordin and Mckean (1984) suggested that the high oxygen depletion rate was due to decomposition of the wood waste on the bottom of the lake, but the decrease in oxygen depletion rate found by Reigerger (2007) is consistent with a decrease in chlorophyll *a*, a measure of phytoplankton in the lake. This means that there is less phytoplankton and less to decompose as it dies and settles on the sediment at the bottom.

5.1.3 Water Clarity

Water clarity or transparency is important to allow light penetration for phytoplankton and algae growth, but transparency is a simple measure of changes in water quality because it decreases with increasing colour (frequently due to increased dissolved organic matter), suspended sediments or algal abundance. Clarity is measured in two ways: Secchi disk reported as depth that the distinction between black and white on the disk is apparent; and turbidity reported in Nephelometric Turbidity Units (NTU). Numerous factors can affect clarity measured using a Secchi disk and care must be taken in collecting the information (Rieberger, 2007). At the two main sample sites in the north and south basins, the levels were fairly consistent between 1976 and 2004, with an overall mean of 6m, deeper than the objective of an annual mean measured monthly of ≥ 5m.

Turbidity is a measure of the suspended material in the water, due to soil particles such as clays, silts and organic matter and micro-organisms. Turbidity is an important variable because the suspended materials make the water aesthetically displeasing, bacteria can grow on the suspended materials, and the suspended materials can interfere with disinfection of drinking water (www.for.gov.bc.ca/hts/risc/pubs/aquatic/interp-o1.htm#1-5). The water quality objective for turbidity in Shawnigan Lake is a mean monthly value that does not exceed 1 NTU with no sample to exceed 5 NTU (Rieberger, 2007). It applies to sites in the two main basins, which according to Rieberger (2007) are most likely to be near domestic intakes. In the lake, the turbidity values were all less than 5 NTU, the guideline for the protection of aquatic life and most were less than 1 NTU (Rieberger, 2007; Mazumder, 2012).

In the inflow streams, last sampled in 2004, turbidity was highest in the west arm inflow (mean = 0.97 NTU). The values in Shawnigan Creek inflow were similar to those in the south basin and the turbidity in McGee Creek were similar to those in the north basin site. The dates of these samples and their timing relative to rainfall events and input due to logging activities is not known.

5.2 Water Chemistry

The water chemistry variables measured can be divided into general variables (pH, alkalinity and total dissolved solids), halides, metals and nutrients (nitrogen and phosphorus), and total organic carbon and disinfection by-products), which are discussed individually below. Most of the data are from the lake, but information from the other sites is included where available.

5.2.1 General variables (pH, alkalinity and total dissolved solids)

pH: The pH, which ranges from 0 to 14 is a measure of the hydrogen ion concentration (logarithm of the reciprocal hydrogen ion concentration); low values are high hydrogen ion concentration (acidic) and high values are low hydrogen ion concentration (alkaline). The Shawnigan lake water is neutral pH (mean = 7.1 – 7.2).

Alkalinity: Alkalinity is a measure of the water's ability to neutralize acids. At the Shawnigan Lake basin sites the alkalinity was 15.1mg/L to 20.9 /L indicating a moderate sensitivity to acid inputs (Rieberger, 2007).

Total dissolved solids (TDS): The TDS are both organic and inorganic, include an array of ions (e.g. calcium, chloride, magnesium and iron) and are primarily a measure of aesthetics of the water. The ions conduct electricity and TDS is measured as specific conductivity – the ability of the water to conduct electricity – which is low (mean 48 µS/cm to 64 µS/cm) in the Shawnigan Lake basin sites (Reiberger, 2007). Similar levels occurred in the Shawnigan Creek and McGee Creek inflows, but higher levels (mean = 111µS/cm) occurred in the west arm inflow (Rieberger, 2007).

5.2.2 Halides (bromide, chloride and fluoride)

The concentrations of halides were determined from the north and south basin sites. Dissolved bromide was less than the detectable limit, and dissolved chloride and dissolved fluoride were less than the raw drinking water guideline and the protection of aquatic life (Rieberger, 2007)

5.2.3 Metals

Metals were collected primarily from the north and south basin sites and most were less than the detection limit. For the metals that were present in detectable levels, the concentrations were below the British Columbia approved or working guidelines suggesting that metals are not cause for concern at least until 2006 (Rieberger, 2007).

5.2.4 Nutrients (nitrogen and phosphorus)

Nitrogen and phosphorus are the main nutrients, but others that are not discussed in this summary include calcium, cobalt, copper, iron, magnesium, manganese, molybdenum, potassium, silica, sodium and zinc. In addition to levels of nitrogen and phosphorus, the ratio of total nitrogen to total phosphorus is used to determine if the water is nitrogen (N) limited (TN/TP < 20) or phosphorus (P) limited (TN/TP >20). See Rieberger (2007) for details. Shawnigan Lake is phosphorus limited (see ***Phosphorus*** below)

Nitrogen: There are several organic and inorganic forms of reactive nitrogen compounds that move via lightning and biological and chemical processes among the atmosphere and terrestrial and aquatic components. Due to human development (e.g. septic wastes, artificial fertilizers, manure, cultivation of nitrogen fixing legumes, combustion of fossil fuels), the cycle is no longer balanced and different forms of nitrogen can accumulate in different components of the cycle. In lakes, nitrogen is a required nutrient for phytoplankton, periphyton (attached algae) and macrophytes (aquatic plants), but high levels (10 mg/L) of one important form - nitrate – can make the water unsuitable as drinking water, particularly for children. The water quality objective for total nitrogen is a mean concentration of 0.25 mg/L at spring turnover. Figure 5 shows the mean total nitrogen levels at the lake and inflow and outflow sites for the two sampling periods (1976-1979 and 2000 -2006). It is not known the timing of the lake samples, but four sites on the west side of the lake exceeded the objective in the 2000-2006 period: the inflow to the West Arm (site 7), the West Arm (site 3), McGee Creek (site 6) and West Shawnigan Lake Park (site 12).

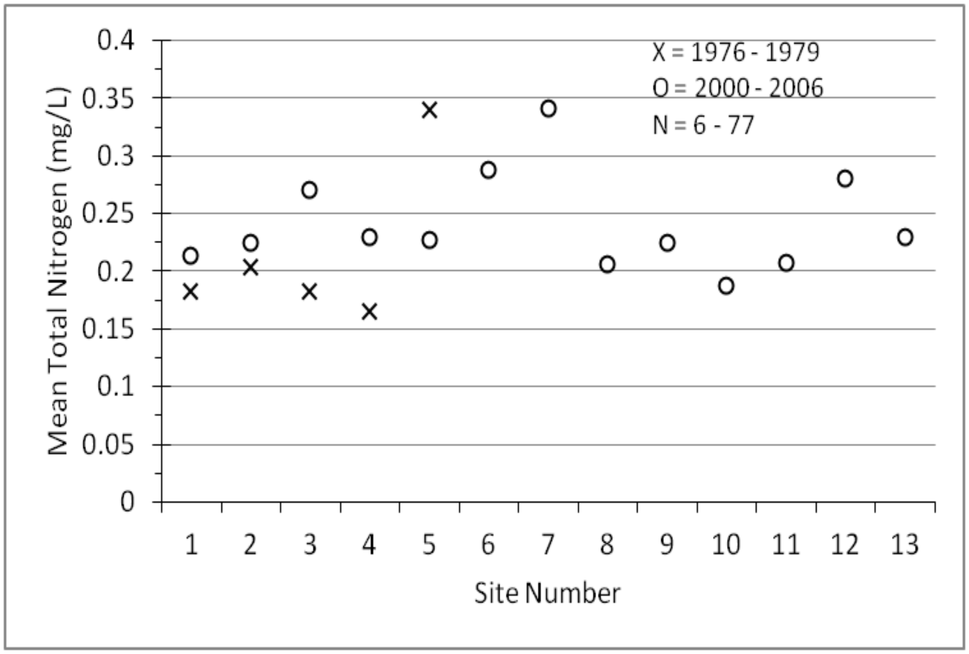

Figure 5. Mean total nitrogen concentrations (mg/L) at the mid lake sites (1-4), the inflow sites (5-8), the lake perimeter sites (10-13), and the outflow site (9) during the two time periods (1976-1979 and 2000-2006). The site locations are given in Figure 1. Data from Reiberger (2007).

Samples collected in 2010 through 2012 from near the CVRD North System intake (Mazumder, 2012) had total nitrogen levels below the 0.25 mg/L objective.

Phosphorus: Phosphorus moves within and between terrestrial and aquatic ecosystems *via* physical, chemical and biological process. The gaseous component is negligible. It is required for several metabolic processes in both animals and plants (e.g. phytoplankton in lakes), but is usually the least abundant nutrient in fresh water and referred to as the limiting nutrient. That means that increases in phosphorus levels in the water increase algal growth, although some increase in nitrogen may be required as well.

It has been generally assumed that the phosphorus in soils is adsorbed and unavailable for movement in groundwater (Holman et al., 2008; USGS, 2013). However, manure, inorganic phosphorus containing fertilizers, and septic wastes all contribute to subsurface and groundwater levels of phosphorus (Robertson et al., 1998; Sharpley and Moyer, 2000; Turner and Haygarth, 2000) and its subsequent input to adjacent surface waters via groundwater (Holman et al., 2008) or erosion. Most, but not all detergents are phosphate-free since the need to reduce phosphorus in fresh waters was first recognized (e.g. Dillon and Rigler, 1974; Schindler, 1978).

Phosphorus exists in numerous forms, both organic and inorganic and soluble and adsorbed to particulates. Three phosphorus analyses were determined for the waters in Shawnigan Lake: dissolved and available (called orthophosphate), total dissolved (includes orthophosphate and some additional inorganic and organic compounds) and total phosphorous (includes all of the soluble phosphorous and that attached to organic and inorganic materials). The total phosphorus levels are used in the water quality objective of an average concentration of 8 µg/L at spring turnover (Rieberger, 2007). The mean monthly concentrations of total phosphorus in the periods 1976-1979 and 2000-2006 at the lake and inflow and outflow sites are shown in Figure 6.

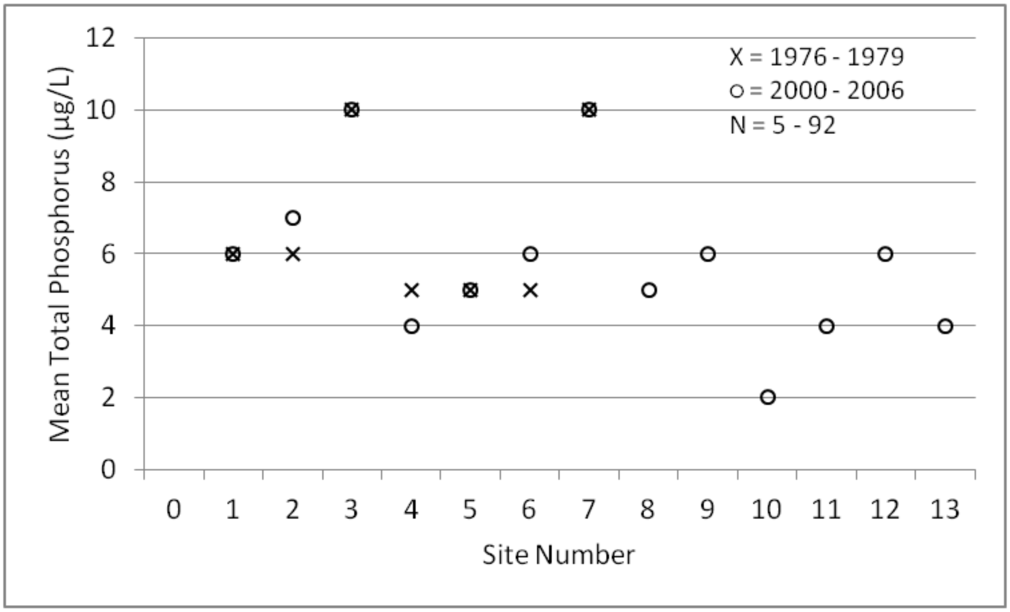

Figure 6. Mean total phosphorus concentrations (µg/L) at the mid lake sites (1-4), the inflow sites (5-8), the lake perimeter sites (10-13), and the outflow site (9) during the two time periods (1976-1979 and 2000-2006). The site locations are given in Figure 1. Data from Reiberger (2007).

The times that the samples were collected is not known, but the samples from the west arm inflow (site 7) and the west arm (site 3) had mean levels above the objective in both sample periods. However, these mean levels are equal to the drinking water quality guideline of ≤ 10µg/L set to limit algal growth in fresh water (Nordin, 2001).

Total phosphorus levels from near the CVRD North System intake in September 22, 2010 through January 26, 2012 were less than the stated objective of 7 µ/L in 61/66 samples (Mazumder, 2012). [This objective is lower than the 8 µg/L suggested by Rieberger (2007.] Values greater than the objective were recorded in September, 2010 (12.75 µ/L), February, 2011 (ca 10 µ/L), June 2011 (12.77 µ/L), December 2011 (8.32 µ/L) and January 2012 (8.0 µ/L). These times are all within the winter months, but other samples during this period were less than the objective. No reason for these higher levels is suggested (Mazumder, 2012).

5.2.5 Total organic carbon and disinfection by-products

During chlorination of drinking water, certain organic acids (particularly humic and fulvic) react with chlorine producing disinfection by-products (DBPs), particularly trihalomethanes (THM), which are a health hazard. It involves a complex series of reactions, which are affected by the acid concentrations, chlorine dose, contact time, pH, temperature and bromide concentration. (www.env.gov.bc.ca/wat/wq/BCguidelines/orgcarbon/index.html). However, to access the raw drinking water for the potential formation of THM, the total organic carbon concentration is used. Total organic carbon can also give the water an objectionable colour making the water aesthetically displeasing. To minimize the formation of THMs and maintain aesthetically pleasing drinking water, The BC Ministry of Environment gives a guideline for TOC in raw drinking water of 4mg/L (www.env.gov.bc.ca/wat/wq/BCguidelines/orgcarbon/index.html). This is also the objective for Shawnigan Lake water at the four lake sites (Rieberger, 2007). The mean levels of TOC at the four lake sites were less than the objective in all decades from 1970s to 2006 (Rieberger, 2007). Samples from near the CVRD North System intake in September 22, 2010 through January 26, 2012 had values that ranged from 2.7 to 6 mg/L with at least one spike (11.02 mg/L) in June, 2011 (Mazumder, 2012).

Mazumder (2012) measured THM concentrations as well as other possible DBPs in treated drinking water from three locations within distribution system: the chlorination station, the middle point, and the end of the system. The values frequently exceeded the regulatory guidelines of 0.100mg/L (Water and Aquatic Sciences Research Program, 2012) given by Health

Canada (www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/trihalomethanes/index-eng.php#t). This is probably related to the high TOC values in the intake water.

5.3 Microbiological Indicators

Microbiological indicators are used to test drinking water supplies and recreational waters for possible fecal contamination from endotherms (sometimes referred to as warm blooded animals). There are many possible fecal pathogens that can cause numerous illnesses, but the indicators used are present in large numbers in the feces and their presence suggests the possible presence of other pathogens. This does not obviate the harmful effects of the indicators themselves. Possible human mediated sources of fecal material to Shawnigan Lake are runoff from agricultural land (livestock and manure as fertilizer) and improperly maintained or located septic systems. Fecal material from water fowl and mammals living in the watershed can also enter the lake water.

Several microbiological indicators have been used in different studies in Shawnigan Lake: total coliforms, fecal coliforms, *Escherichia coli* (*E. coli*), non *E. coli* coliforms and *Enterococci* (Nordin and Mckean, 1984; Webber, 1996; Rieberger, 2007; Mazumder, 2011, 2012). Total coliforms are a group of bacteria that live in the intestines of endotherms and are also found in the soil. Fecal coliforms are the thermo-resistant coliform bacteria found in the faeces of these animals and *E. coli* is the major species of fecal coliforms. Non *E. coli* bacteria are as the name suggests, the coliform species excluding *E. coli*. *Enterococci* are bacteria that are also found in the feces of endotherms, but are more resistant to sunshine and salinity than *E. coli* and are recommended as the indicator species in marine waters (Warrington et al., 2001). *E. coli* is the recommended indicator organism for fresh water drinking supplies and recreational water use (Warrington et al., 2001; Health Canada, 2012). In addition to the different indicators, the data are recorded in two ways: 90th percentile and geometric mean of samples collected over 30 days (drinking water) or 5 days (recreation use). The recreational guidelines are also provided for the maximum in a single sample.

The criteria for the microbial indicators depend on the water use. The two main uses are recreation and drinking water, but within each of these there are sub-categories. These are summarized in Table 2, although for recreation, only those for direct contact (swimming) are given.

Table 2. Criteria for microbial indicators for three classes of drinking water (without treatment, with disinfection only, and partial treatment [filtration or sedimentation and disinfection]) and for primary contact recreation (swimming). Drinking water criteria from Warrington et al. (2001); Recreational water criteria from Health Canada (2012).

Raw Drinking Water – No Treatment		
E. coli	**Fecal coliforms**	***Enterococci***
• Not present in any 100ml sample	• Not present in any 100ml sample	• Not present in any 100ml sample
Raw Drinking Water – Disinfection Only		
• ≤ 10/100mL in at least 90% of samples over 30-day period	• ≤ 10/100mL in at least 90% of samples over 30-day period	• ≤ 3/100mL in at least 90% of samples over 30-day period
Raw Drinking Water – Partial Treatment (filtration or sedimentation and disinfection)		
• ≤ 100/100mL in at least 90% of samples over 30-day period	• ≤ 100/100mL in at least 90% of samples over 30-day period	• ≤ 25/100mL in at least 90% of samples over 30-day period
Recreational Water – Primary Contact (swimming)		
• ≤ 200/100mL geometric mean (minimum 5 samples) • ≤ 400/100mL (single maximum concentration		• ≤ 35/100mL geometric mean (minimum 5 samples) • ≤ 70/100mL (single maximum concentration

It is unrealistic to summarize all of the data collected on microbial indices given the different variables, different locations, and different recording procedures in four main studies. But the data are important because Shawnigan Lake is an important drinking water source. Warrington et al. (2001) indicate that if there is no ratio to correct *E. coli* to fecal coliforms, the *E. coli* should be considered numerically equal to fecal coliforms. The data in Table 3 include fecal coliforms (Nordin and Mckean, 1984; Webber, 1996); Rieberger, 2007) and *E. coli* (Rieberger, 2007, Mazumder, 2012). Where the data were not given as the 90th percentile, the value was accessed to be less or greater than the objective of ≤ 10/100mL CFU in at least 90% of the samples collected over a 30 day period for raw drinking water with disinfection .

Table 3. The results of fecal coliform and/or *E. coli* data from four different studies based on the drinking water criteria for raw drinking water with disinfection only. The criterion (Table 2) is ≤ 10/100mL CFU in at least 90% of samples over 30-day period. x = criteria not met, ✓ = criteria satisfied. ? = occasional high value, 90th percentile estimated.

Location	**Nordin and McKean, 1984**	**Webber, 1996**	**Rieberger, 2007** **Summer/Freshet**	**Mazumder, 2012** **Summer/Winter[2]**
Mid-lake sites				
- North basin	✓	✓		
- South basin	✓	✓		
- West Arm	x	✓		
Perimeter sites				
- North end	✓ ?	x	✓ / x	
- South end		✓		
- East side		x	✓ / x	
- West side		✓	x / x	
Inflows				
- Shawnigan Creek	x	✓	x / x	
- McGee Creek	x		x / x	
- West Arm inflow		x	x / x	
- East on Shawnigan Rd			/ x	
Outflow				
- Shawnigan Creek	x		x / x	
Licensed drinking water intakes				
- Lidstech Holdings			/ ✓	
- CVRD North			/ ✓	x / ✓?

2 = These samples are for the epilimnion and hypolimnion at the north end of the lake by the CVRD North System Intake. The data are read from two figures.

The samples collected in from the licensed water intakes by Rieberger (2007) are well within the criterion for raw drinking water with disinfection (Table 3). The 90th percentile for *E. coli* for the CVRD North intake at depths 0.1 and 6m were 1 and 3 CFU/100mL, respectively and the 90th percentile for the Lidstech Holdings intake at 0.1 and 6m were 3 and 1 CFU/100mL, respectively (Rieberger, 2007). These samples were collected November 9, 2004 to December 6 2004, which would be during freshet. However in 2010 – 2012 the *E. coli* levels in the water from near the CVRD intake exceeded the criteria for drinking water with disinfection.

Rieberger (2007) found high fecal coliform and *E. coli* levels in the inflows to the lake (e.g. 90th percentile for E. coli of 820 CFU/ 100mL in Shawnigan Creek inflow, 64 CFU in McGee Creek inflow, and 19 in West Arm inflow in 2003 and in most cases the water was not suitable as a drinking water source with disinfection (Table 3). The perimeter sites were for the most part unsuitable as a drinking water source with disinfection, as well (Table 3). The mid-lake sites were generally good (Table 3). Nordin and McKean (1984) found positive levels of fecal coliforms in only 5/26 samples from the north basin and 1/26 from the south basin and all of the levels were < 5 MPN/100mL.

Mazumder (2012) incubated the *E. coli* colonies to obtain more bacteria and used polymerase chain reaction (PCR) to obtain sufficient DNA from the bacteria for DNA analysis. He then compared the DNA from the lake *E.coli* to those from known possible source animals – called bacterial source tracking. In 2012, they found the greatest contamination from black bears (20%), horses (18.6%), humans (14.3%), dogs (10.0%) and gulls (10.0%) and noted that almost one-half of the contamination (in bacteria from horses, humans and dogs) was associated with recreation in and around the lake (swimming, camping, riding and hiking). The results from 2012 are somewhat different than in 2011 when the contribution of horses was greater (27.5%) and that of black bears less (10%). No mention is made of septic tanks. This somewhat contradicts information presented by Mazumder (2010) who used stable isotopes (N^{15}/N^{14}) as a measure fecal contamination of waters by carnivores and suggested the carnivores are humans and the fecal contamination(high N^{15}/N^{14} ratio) in Shawnigan Lake was from septic fields. However, even if it is other mammals that are an important source of fecal contamination, this does not obviate the importance of the high *E. coli* levels in the water that is a drinking water source. It does suggest that more perimeter and inflow streams samples should be examined for trace bacteria sourcing to assess the contribution from septic tanks.

6. Biological Analysis (Chlorophyll *a*, Phytoplankton and Zooplankton)

Rieberger (2007) gives a detailed biological interpretation the results from Nordin and McKean (1984) and the work by Rieberger et al., (2004) and Rieberger (2007) on the results of the chlorophyll *a*, phytoplankton and zooplankton. Some main points are noted below. In addition, subsequent data from Mazumder (2012) are included.

6.1 Chlorophyll *a*

Chlorophyll *a* is a measure of plankton biomass, which is an indication of lake productivity. Lakes with low productivity – clear water with little obvious algae – are called oligotrophic. Recall that phosphorus is the limiting nutrient in Shawnigan Lake and changes in phosphorus can affect productivity. The mean chlorophyll *a* values in Shawnigan Lake in 1977 – 1979 and 2003 – 2004 indicate oligotrophic conditions (Table 4, Rieberger, 2007). The values decreased from 1977 to 2004 suggesting a decrease in productivity, perhaps due to zooplankton grazing (Rieberger, 2007). The concentration in the deep water sites in the north (site 1) and south (site 2) basins ranged from <0.5 µg/L to 1.5 µg/L and 1.6 µg/L, respectively (Rieberger, 2007). The West Arm (site 3) and north beach (site 4) sites had higher concentrations in May (2.6 µg/L and 2.3 µg/L, respectively) with concentrations below the detection limits in the other months.

Table 4. Chlorophyll *a* concentrations at four sites in Shawnigan Lake in two sampling periods. N = Number of samples; 95% CL (95% confidence limit estimated from standard deviation (95% CL = SD x $N^{1/2}$ x 2)

Sample site (see Table 1 and Figure 4)	1977 – 1979 Mean ± 95% CL (N)	2003 – 2004 Mean ± 95% CL (N)
North basin – site 1	3.04 ± 0.99 (12)	0.78 ± 0.25 (8)
South basin – site 2	2.95 ± 1.03 (10)	0.94 ± 0.30 (8)
West Arm – site 3	2.24 ± 0.52 (8)	1.24 ± 0.65 (7)
North end of lake - site 4	0.3 ± 0 (3)	0.78 ± 0.37 (8)

Mazumder (2012) found higher levels of chlorophyll *a* 0.65 – 8.61 µg/L, with the higher levels associated with increased turbidity in the fall of 2010 and late fall periods of 2011. These also correspond to increased total phosphorus levels (see section 5.2.4)

6.2 Phytoplankton

Rieberger (2007) discusses the differences in the dominant phytoplankton species found by Nordin and McKean (1984) in 1977-1979 and Rieberger (2007) in 2003 – 2004, as well as seasonal differences in the samples collected by Rieberger in 2003 and 2004. Phytoplankton populations are seasonally variable and depend on nutrients, physical factors such as temperature, light and pH, and the presence of other populations (e.g. zooplankton and fish), that can consume phytoplankton. The different phytoplankton species are different sizes so numbers cannot be used as a measure of productivity, only about the habitat requirements of the different species. For the most part, the species are indicative of oligotrophic waters.

6.3 Zooplankton

Between 1977/78 and 2003, the numbers and assemblages of zooplankton increased significantly in all of the months from May through September (Rieberger, 2007). However, many of the species present in 2003 have small body sizes, which are not expected in a healthy lake. Young of the native kokanee, officially introduced rainbow and cutthroat trout, and the unauthorized introduced yellow perch, pumpkinseeds and smallmouth bass all feed on the zooplankton and even on some phytoplankton which ,may contribute to the unexpected size of the zooplankton.

7. Sediments

The only data on the sediments is in a power point presentation by Mazumder (2010). As it is just the slides, the interpretation here is speculative. Some points concerning the water quality have been included in previous sections (e.g. Sections 6. Microbiological Indicators).

Mazumder (2010) examined sediment cores from an unknown site in Shawnigan Lake (at the CVRD intake?) and another in Sooke Lake. He sectioned the cores and for each section determined the date of deposition using an isotope of lead (Pb^{210}), algal content (mg/g organic matter), the concentration of two pigments (mg/g organic matter) and the N^{15} /N^{14} (0/00).

7.1 Algal and Pigment Concentrations

Algal biomass, carotenoids (large group of plant pigments) and zeaxanthin (pigment in blue green algae) in Shawnigan lake were consistently higher in Shawnigan Lake than Sooke Lake. The algal biomass was 3 to 10 times greater and more variable with specific peaks in Shawnigan Lake than Sooke Lake. The pigments showed various peaks in both lakes. The largest peak in Shawnigan Lake for algal biomass and pigments began in the early 1970s and decreased in the early 1990s. The highest algal biomass was 0.5 mg/g organic matter. In lake water, algal productivity is assessed using chlorophyll *a* concentrations (Section 7.2 Chlorophyll *a*). The mean chlorophyll a levels in the water in 1977/79 were about three times greater in than in

2003/04 (Table 4). The levels in the sediments were about 2 times greater at the peak level in 1982-1988 than in and the level in 2003. However, most of the levels in the lake were indicative of an oligotrophic lake.

The algal biomass in the sediments is an interesting history of the lake. In the fall turn over and winter flushing, much of the algae would be deposited in the sediments or flushed from the lake. Chlorophyll *a* is a measure of algal productivity, but algal productivity is dependent on numerous interacting biological and physical processes within the lake. In general, nutrient levels as well as sunlight, temperature and pH affect the build up of algae and zooplankton and some fish consume algae and of course young fish consume zooplankton.

7.2 δN^{15}

Nitrogen is taken up by plants and the nitrogen in plants is converted to proteins in animals. Some of the protein is excreted in urine and feces. There are two stable isotopes of nitrogen: the abundant form N^{14} and the rare form N^{15}. Because the two stable isotopes are different weights, they behave differently in the environment and the proportions of the two isotopes differ in plants, herbivores, omnivores and carnivores and in the feces of the consumers. The δN^{15} is a measure of the relative amount of N^{15} present and is used – sometimes with stable isotopes of other elements - as a tracer of the source of the N^{15} in water, particularly from animal (human) wastes in sewage (e.g. Costanzo et al., 2001). Mazumder (2010) compared δN^{15} in Daphnia (a zooplankton) and in the sediments from Shawnigan and Sooke Lakes and showed higher δN^{15} in Shawnigan Lake in both cases, which he attributed to greater septic input to Shawnigan Lake. One interesting result was the general increase in the sediments of both Shawnigan and Sooke lakes from 1972 to 2004.

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