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MINISTRY OF ENVIRONMENT

Water Quality Assessment and Objectives for the John Hart Lake Community Watershed and McIvor Lake

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EXECUTIVE SUMMARY

This document presents a summary of the ambient water quality of John Hart Lake and McIvor 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.

John Hart Lake, with a surface area of 363 ha, and McIvor Lake, with a surface area of 123 ha, are both part of the Campbell River watershed near the outlet end of Lower Campbell Lake, located to the west of Campbell River, BC. The City of Campbell River withdraws drinking water from John Hart Lake and McIvor Lake is considered a potential secondary drinking water source. BC Hydro has a dam at both the inlet and outlet of John Hart Lake. The lake water levels are controlled to ensure sufficient flows for the hydroelectric project, drinking water use and fisheries use downstream in the Campbell River. John Hart Lake reservoir is closed to public access but some unauthorized recreational activities occur there; McIvor Lake provides significant recreational opportunities (fishing, swimming and boating), and both lakes provide fish and wildlife habitat. These activities, as well as forestry, mining and, around McIvor Lake only, residential development, all potentially affect water quality in the lakes.

Water quality monitoring was conducted between 2003 and 2006. The results of this monitoring indicated that both lakes are oligotrophic and the overall state of the water quality is very good. All chemical, physical and biological parameters met provincial water quality guidelines with the exception of cadmium, which exceeded average aquatic life guidelines regularly in John Hart Lake; also, copper and zinc exceeded aquatic life guidelines on occasion in John Hart Lake.

In order to maintain and protect the water quality in John Hart Lake and McIvor Lake, ambient water quality objectives were set for temperature, water clarity (Secchi depth), dissolved oxygen, *Escherichia coli* , turbidity, total phosphorus, cadmium, copper, zinc and chlorophyll *a*.

Future monitoring recommendations include attainment monitoring at both lakes, every 3-5 years, depending on available resources and whether activities, such as forestry or development, are underway within the watershed. This monitoring should be conducted for one year on a quarterly basis at the deep station sites and also during the summer low flow and fall flush period (five weekly samples in 30 days) at the John Hart Lake inlet and outlet sites, and at the site of the future intake in Lower Campbell Lake.

Water Quality Objectives for John Hart Lake and McIvor Lake

Variable	Objective Value
Water temperature	≤ 15°C summer maximum (>15 m depth)
Secchi depth	Annual average ≥ 8 m
Dissolved oxygen	≥ 5 mg/L 1 m above substrate
***Escherichia coli* bacteria**	≤10 CFU/100 mL (90th percentile) with a minimum 5 weekly samples collected over a 30-day period
Turbidity	≤ 2.0 NTU maximum 5 m above substrate
Total phosphorus	≤5µg/L average during epilimnetic growing season (May –Sept)
Total cadmium	≤ 0.01 µg/L average
Total copper	≤ 4 µg/L maximum, ≤ 2 µg/L average (minimum 5 weekly samples collected over a 30-day period)
Total zinc	≤ 33 µg/L maximum, ≤ 7.5 µg/L average (minimum 5 weekly samples collected over a 30-day period)
Chlorophyll *a*	≤ 1.5 µg/L chlorophyll *a* maximum, eplimnetic growing season

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1.0 INTRODUCTION

The British Columbia (BC) Ministry of Environment (MOE) is conducting a program to assess water quality in priority watersheds. The purpose of this program is to accumulate the baseline data necessary to assess both the current state of water quality and long-term trends, and to establish ambient water quality objectives on a watershed specific basis. Water quality objectives provide goals that need to be met to ensure protection of designated water uses. The inclusion of water quality objectives into planning initiatives can help protect watershed values, mitigate impacts of land-use activities, and protect water quality in the context of both acute and chronic impacts to human and aquatic ecosystem health. Water quality objectives provide direction for resource managers, serve as a guide for issuing permits, licenses, and orders by MOE, and establish benchmarks for assessing the Ministry’s performance in protecting water quality. Water quality objectives and attainment monitoring results are reported out both to local stakeholders and on a province wide basis through forums such as State of the Environment reporting.

Vancouver Island’s topography is such that the many watersheds of the MOE’s Vancouver Island Region are generally small (<500 km^2). As a result the stream response times can be relatively short and opportunities for dilution or settling are often minimal. Rather than developing water quality objectives for each of these watersheds on an individual basis, an ecoregion approach has been implemented. The ecoregion areas are based on the ecosections developed by Demarchi (1996). However, for ease of communication with a wide range of stakeholders the term “ecoregion” has been adopted by Vancouver Island MOE regional staff. Thus, Vancouver Island has been split into six terrestrial ecoregions, based on similarities in characteristics such as climate, geology, soils, and hydrology (Figure 1).

Fundamental baseline water quality should be similar in all streams and all lakes throughout each ecoregion. However, the underlying physical, chemical and biological differences between streams and lakes must be recognized. Representative lake and stream watersheds within each ecoregion are selected, with an initial focus on streams, and a three year monitoring program is implemented to collect water quality and quantity data, as well as biological data. Standard base monitoring programs have been established for use in streams and lakes, to maximize data comparability between watersheds and among ecoregions, regardless of location. Water quality objectives will be developed for each of the representative lake and stream watersheds based on the data, and these objectives will also be applied on an interim basis to the remaining lake and stream watersheds within that ecoregion. Over time, other priority watersheds within each ecoregion will be monitored for one year to verify the validity of the objectives developed for each ecoregion and to determine whether the objectives are being met for individual watersheds.

Figure 1. Map of Vancouver Island Ecoregions

Partnerships formed between the MOE, local municipalities and stewardship groups are a key component of the water quality network. Water quality sampling conducted by the public works departments of local municipalities and stewardship groups has enabled the Ministry to significantly increase the number of watersheds studied and the sampling regime within these watersheds. These partnerships have: allowed the Ministry to study watersheds over a greater geographic range and in more ecoregions across Vancouver Island; resulted in strong relationships with local government and interest groups; provided valuable input and local support: and, ultimately, resulted in a more effective monitoring program.

The John Hart Lake community watershed provides the primary source of drinking water for the City of Campbell River, including the Main Supply System, the Industrial Park System and the Airport System. When this monitoring program began, McIvor Lake was being evaluated as a secondary source of drinking water should the John Hart Lake source prove insufficient or if there was a water quality concern in John Hart Lake; however, a different location, in Lower Campbell Lake, just upstream of McIvor Lake, is now being considered for this secondary intake. Both John Hart Lake and McIvor Lake have important fisheries values, with cutthroat trout, rainbow trout, Dolly Varden and steelhead reported as being present (FISS, 2006). Anthropogenic land uses within the watershed include recreation, power generation, mining, timber harvesting and, around McIvor Lake only, residential development. These activities, as well as natural erosion and the presence of wildlife, all potentially affect the water quality in John Hart and McIvor Lakes.

This report examines the existing water quality of John Hart Lake and McIvor Lake from 2003 - 2005 and recommends water quality objectives for these lakes based on potential impacts and water quality parameters of concern. John Hart Lake was designated as a community watershed in 2001, as defined under the *Forest Practices Code of British Columbia Act* (“the drainage area above the downstream point of diversion and which are licensed under the *Water Act* for waterworks purposes”). This designation was grandparented and continued under the *Forest and Range Practices Act* (FRPA) in 2004 and infers a level of protection. Some of the John Hart Lake community watershed is on private land, and the FRPA does not apply to these privately owned portions of the watershed. However, other Provincial agencies working with the MOE, use other tools, such as water quality objectives, and legislation, such as the *Private Managed Forest Land Act* and the *Drinking Water Protection Act*, to encourage management and protection of water quality within these watersheds.

2.0 WATERSHED PROFILE AND HYDROLOGY

2.1 BASIN PROFILE

The Campbell River watershed, which contains John Hart Lake and McIvor Lake, as well as Brewster, Lower Campbell, Upper Campbell and Buttle lakes and numerous streams (Figure 2), is very large, with a total area of 1,822 km^2. The distance from the head of Buttle Lake to the mouth of Campbell River is over 80 km. Campbell River itself is a sixth-order stream.

The community watershed portion of the John Hart Lake watershed is approximately 2,520 ha in area. The lake has a surface area of 363 ha, a perimeter of 27.8 km, a maximum depth of 22.9 m and a mean depth of 12.2 m (FISS, 2006) (Figure 3). The vast majority of the water (about 99%) flowing into John Hart Lake passes from Lower Campbell Lake through the Ladore Dam (see Figure 3). Similarly, flow out of John Hart Lake is controlled by withdrawals through the BC Hydro Penstocks and over the John Hart Dam.

McIvor Lake is considerably smaller but deeper than John Hart Lake, with a surface area of 123 ha, a perimeter of 8.5 km, a maximum depth of 45.5 m and a mean depth of 16.9 m (FISS, 2006). McIvor Lake is contiguous with Lower Campbell Lake, with the boundary between the two lakes delineated by the narrow waterway surrounding the island in the south-east corner of McIvor Lake (Figure 4). When this monitoring program began, McIvor Lake was considered a potential option for a secondary intake based on initial evaluations of its water quality (Henney and Harvey, 1988). Upon further evaluation and in consideration of watershed activities, its suitability as a drinking water intake will depend on source protection initiatives, Vancouver Island Health Authority source approval and appropriate source water treatment. Currently, a different location just upstream of McIvor Lake in Lower Campbell Lake is being considered as a secondary intake (Brunn, pers. comm. 2010).

Both John Hart Lake and McIvor Lake fall within the Coastal Western Hemlock biogeoclimatic zone (eastern very dry maritime, CWHxm1). The lakes fall within the

Nanaimo Lowland (NAL) ecoregion established for Vancouver Island by MOE staff (Figure 1).

The underlying geology of the two lakes is similar, and is described as the Vancouver Group – Karmutsen Formation. It is composed of basaltic volcanic rocks from the Middle to Upper Triassic Period, and described as basalt pillowed flows, pillow breccia, hyaloclastite tuff and breccia, massive amygdaloidal flows, minor tuffs, interflow sediment and limestone lenses (BCWRA, 2006).

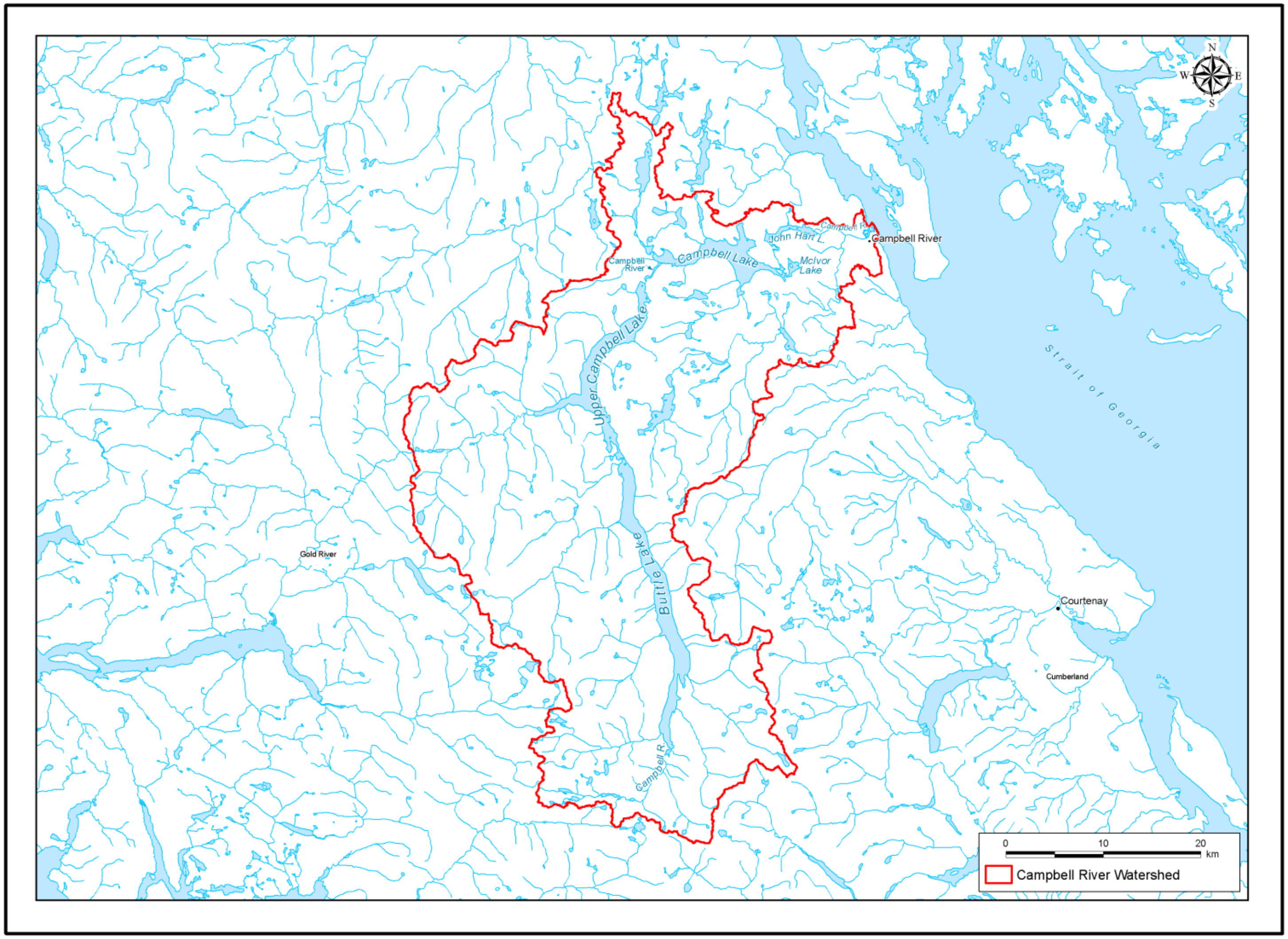

Figure 2. Map of Campbell River watershed, showing Buttle, Upper Campbell, Lower Campbell, John Hart and McIvor lakes.

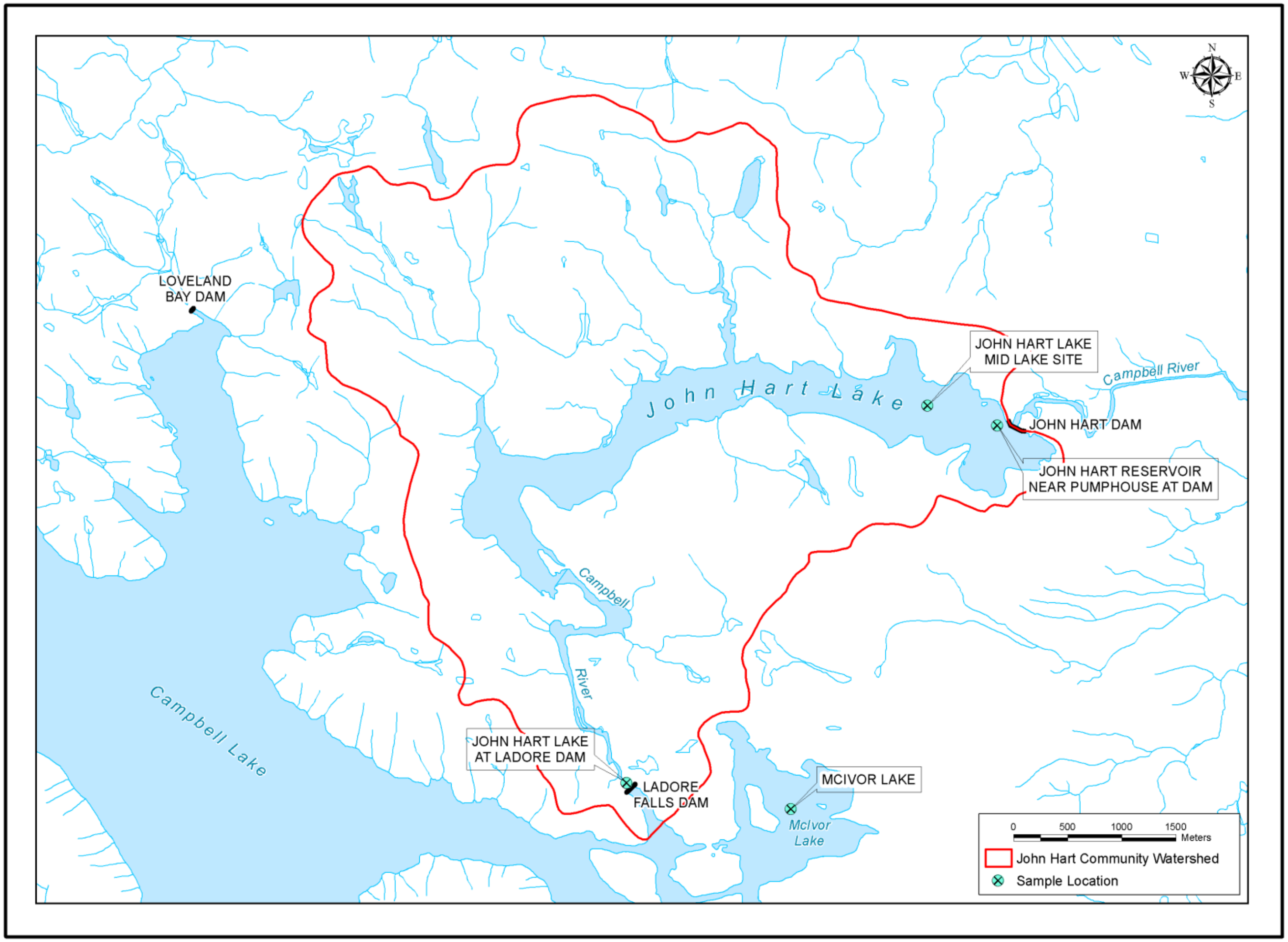

Figure 3. Map showing John Hart Lake with Community Watershed boundaries.

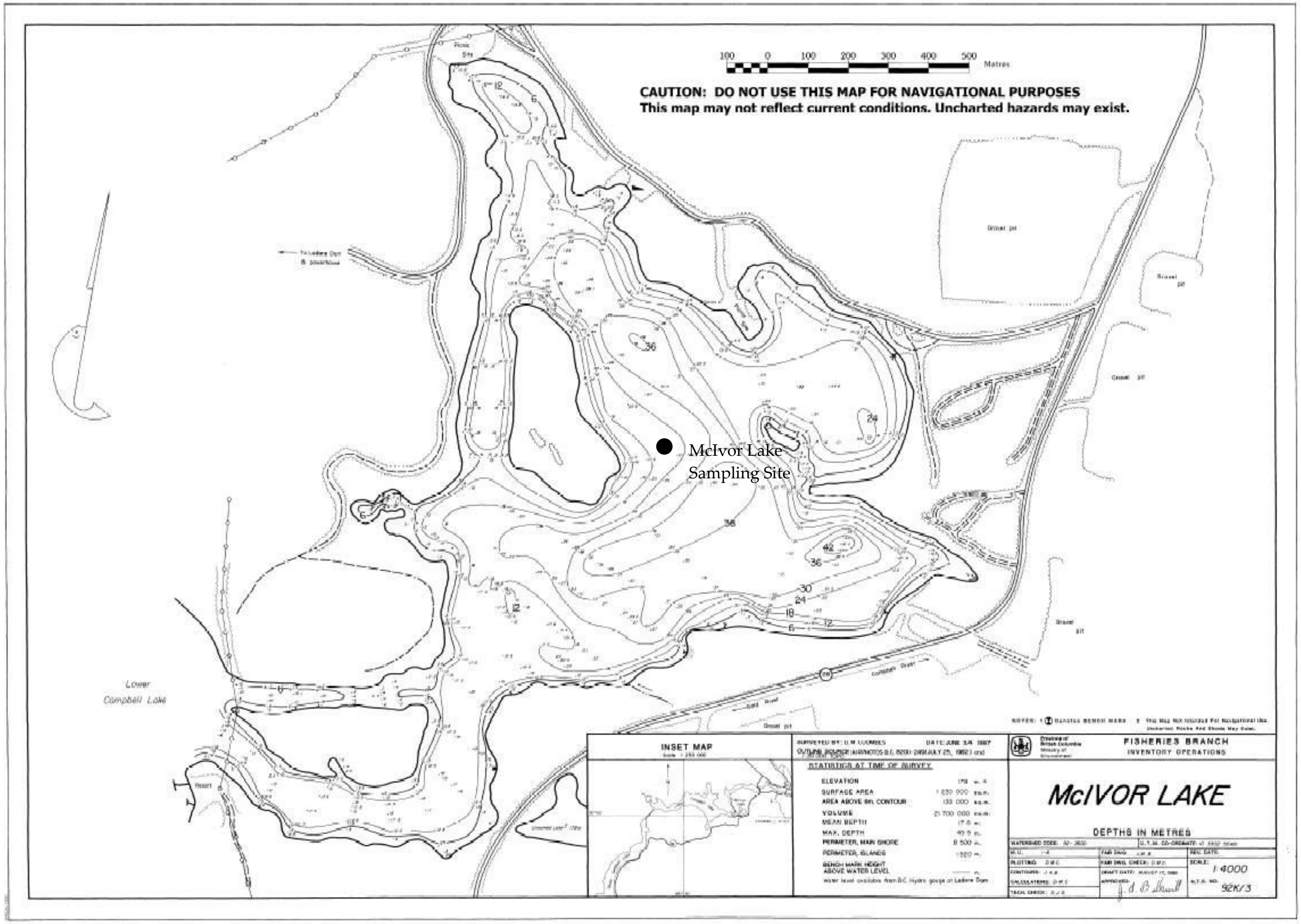

Figure 4. Bathymetric map of McIvor Lake (source: http://www.fishwizard.com).

2.2 HYDROLOGY AND PRECIPITATION

The nearest climate station to the watershed for which climate normal data were available was the Campbell River A station (elevation 105.5 m) (Environment Canada Climate Station 1021261). Average daily temperatures between 1971 – 2000 ranged from 1.3°C in January to 16.9°C in July and August. Average total annual precipitation between 1971 and 2000 was 1,452 mm, with 109 mm (water equivalent) (8%) of this falling as snow (Figure 5). Most precipitation (1,091 mm, or 75%) fell between October and March.

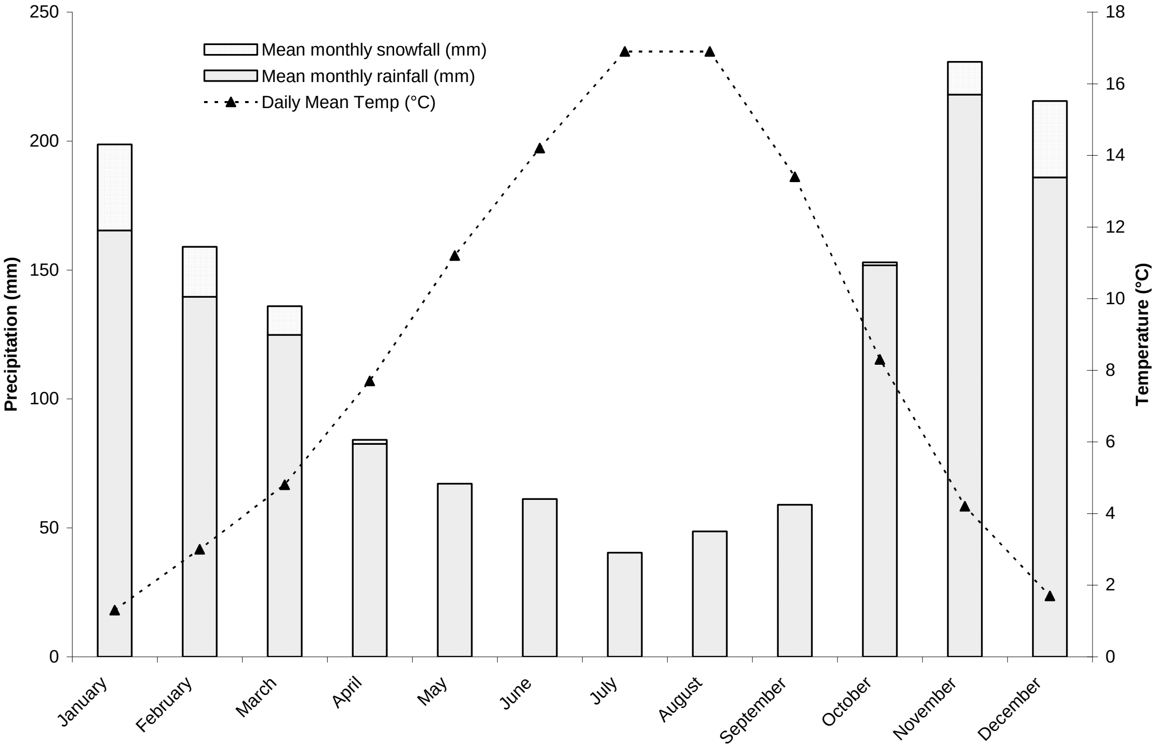

Figure 5. Climate data (1971 – 2000) for the Campbell River (Environment Canada Climate Station 1021261).

Water Survey Canada (WSC) operated a hydrometric station between 1910 and 1949 on the Campbell River at the outlet of Lower Campbell Lake (prior to the construction of the Strathcona and Ladore dams). Minimum, maximum and average discharges for this period are shown in Figure 6. Peak flows measured between 1910 and 1949 were approximately 858 m^3/s, while minimum flows were approximately 8 m^3/s (Figure 6).

Peak flows occurred during the winter corresponding to high rainfall, with a secondary spring peak likely corresponding to snowmelt in the upper watershed. These peaks would now be mitigated to some extent by the dams on Upper Campbell Lake and Lower Campbell Lake. Periodic discharge measurements have been made on 19 occasions on the spillway at the John Hart Lake Dam, with values ranging from 3.4 m^3/s to 11.5 m^3/s. The mean annual discharge of Campbell River near the City of Campbell River is 98.6 m^3/s (WSC, 2006).

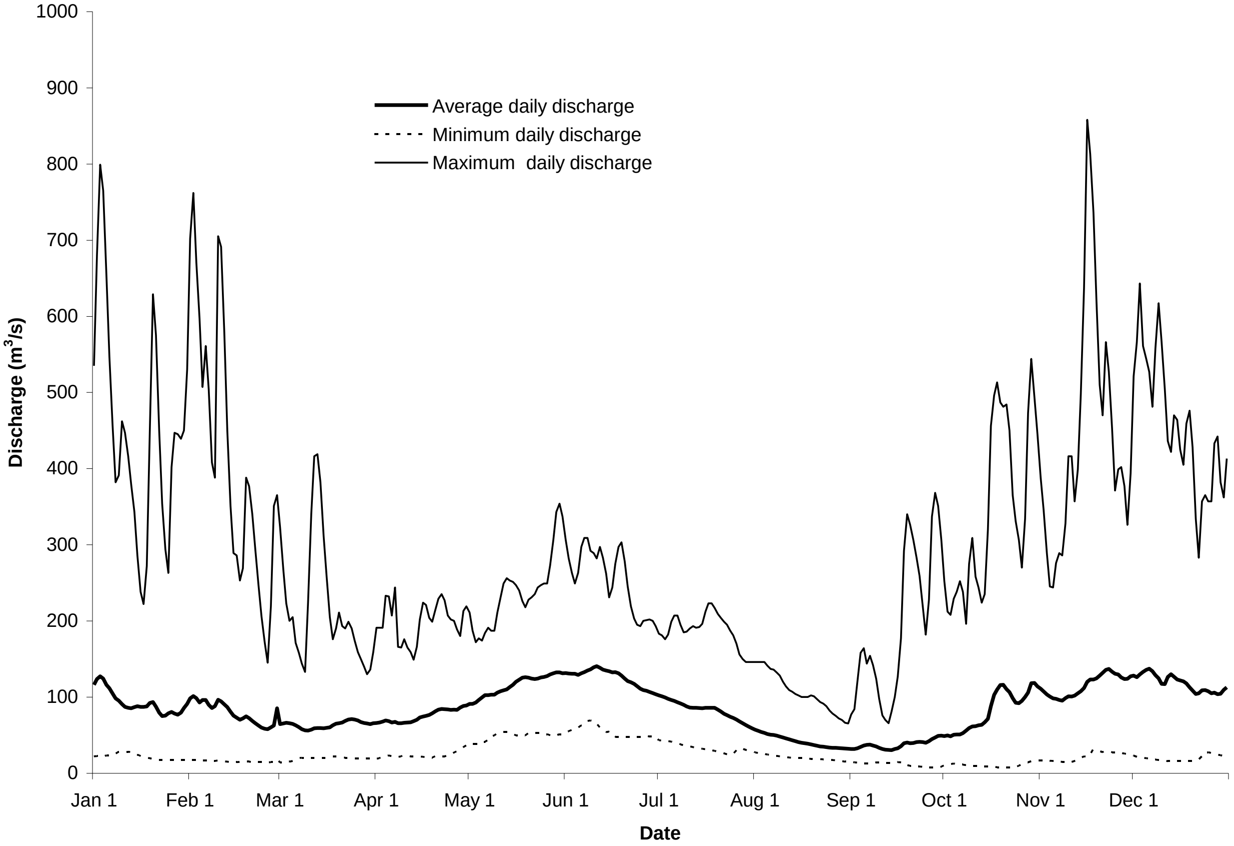

Figure 6. Minimum, maximum and average daily discharge data for the Campbell River at the outlet of Lower Campbell Lake (Water Survey Canada Station 08HD001) between 1910 and 1949 (WSC, 2006).

3.0 WATER USES

3.1 WATER LICENSES

Twenty-one water licenses from three points of diversion (PODs) have been issued for John Hart Lake (Table 1), and four water licenses from four PODs have been issued for McIvor Lake (Table 2). The licenses for John Hart Lake allow for the withdrawal of 10,496 dam^3/year (cubic decameters/year, where 1 dam^3 = 1,000 m^3) of water for consumptive uses (drinking water, etc.) and 363,808 dam^3/year of water for non-consumptive uses (power generation). The intake for the John Hart power station is through three penstocks located within the John Hart Dam. The dam and penstocks were built by BC Hydro in 1947, and in 1949 the then Village of Campbell River utilized these penstocks as the source for their new water supply system. This system continues to feed the main City of Campbell River water system. A secondary intake (independent of the penstocks) located near the John Hart Lake pumping station provides water for the Gordon Road and Industrial Park areas. The intakes on McIvor Lake provide water for domestic use to three residences on the lake, as well as for dust control.

Table 1. Summary of licensed water withdrawals from John Hart Lake.

Use	No. Licensed Withdrawals	Point of Diversion	Total Volume (dam^3/yr)	Principal Licensee
Waterworks – Local Authority	2	John Hart Lake	173.3	City of Campbell River
Waterworks – Local Authority	7	BC Hydro Penstocks	10,044.6	City of Campbell River
Power-General	2	BC Hydro Penstocks	363,808.2	BC Hydro
Other (Domestic, Irrigation, Greenhouses etc.)	10	John Hart Lake	277.9	Various

Table 2. Summary of licensed water withdrawals from McIvor Lake.

Use	No. Licensed Withdrawals	Total Volume (dam^3/yr)
Domestic	3	4.2
Dust Control	1	1.7

3.2 FISHERIES

Both John Hart Lake and McIvor Lake have recreational fisheries, with rainbow trout (*Oncorhynchus mykiss*), cutthroat trout (*O. clarkii*), Dolly Varden *(Salvelinus malma*) and steelhead (*O. mykiss*) reported as being present (FISS, 2006). McIvor Lake was stocked with steelhead in 2003.

3.3 RECREATION

As a community watershed, John Hart Lake is subject to legislation that prohibits motorized access and camping in the area and limits industrial activities and recreational access (UMA Engineering, 2004). However, unauthorized trails have been documented in the John Hart Lake watershed, and the presence of unrestricted logging roads throughout the watershed allows recreational access. Some off-road recreation also occurs including use by “mud-boggers”, vehicles that are equipped to go through riparian and boggy areas. Garbage dumping is made easier by the presence of illegal roadways (Richardson, 2010). There is a popular mountain biking trail system in the northern part of the watershed (see http://www.rivercitycycle.ca/). The area is also utilized by hikers, horseback riders, hunters, fishermen, as well as motorbikes and all-terrain vehicle (ATV) users (Brunn, pers. comm., 2010).

McIvor Lake is an extremely popular recreational area. Besides the residents that live on the lake, many other people from Campbell River and outlying areas, as well as tourists to Vancouver Island, use the lake for recreational purposes. Boating, fishing, swimming and various other water-based activities are very popular. There are three public-access beaches located on McIvor Lake at the north end of the lake off McIvor Lake Road: the main beach (which includes a picnic area and a sandy beach for swimming); Doggie Point Beach (a popular swimming area); and Lions Beach. A boat-ramp allowing access for motorized and non-motorized vessels is located between the main beach and the Doggie Point beach. There is also a pet cemetery on the waters edge at Doggie Point. The Campbell River Eagles, a water-ski club, also uses McIvor Lake as a base, and host a number of events on the lake each year. They have a ski-jump area located east of the main island, across from the boat launch.

3.4 FLORA AND FAUNA

The Campbell River watershed provides valuable habitat to a wide variety of species including blacktail deer (*Odocoileus hemionus columbianus*), black bear (*Ursus americanus*), cougar (*Puma concolor*), and numerous other small mammals and birds. The BC Conservation Data Centre reports the presence of two blue-listed plant species (the pointed rush, *Juncus oxymeris*, considered fairly secure; and the snow bramble, *Rubus nivalis*) that overlap the McIvor Lake watershed. The Northern Red-legged Frog, *Rana aurora*, and the Western Screech-Owl, *Megascops kennicottii kennicottii,* both blue-listed speces, are present in the Campbell River Watershed (BCCDC, 2011).

Hundreds of gulls are known to feed off solid waste in the Campbell River Landfill near McIvor Lake, then to use McIvor Lake as a resting area (Brunn, pers.comm, 2010).

3.5 DESIGNATED WATER USES

Designated water uses are those identified for protection in a specific watershed or waterbody. Water quality objectives are designed for the substances or conditions of concern in a watershed so that attainment of the objectives will protect the most sensitive designated uses. The preceding discussion demonstrates that water uses to be protected include drinking water, irrigation, recreation, wildlife and aquatic life.

4.0 INFLUENCES ON WATER QUALITY

It is estimated that 99% of the water entering John Hart Lake does so through the Ladore dam (City of Campbell River, 2005), and various small tributaries draining into the lake contribute relatively little water volume. Similarly, McIvor Lake is contiguous with Lower Campbell Lake, which therefore dictates the water quality within McIvor Lake. Coupled with this is the fact that John Hart Lake has a relatively short residence time – the volume of water entering (and leaving) the lake is large relative to the volume of water contained within the lake. The average residence time of water entering the lake is four days (Martin and Lawrence, 2004). This increases to as much as 14 days during dry periods and decreases to less than a day during periods of extremely high flows. The residence time of McIvor Lake is not known but is estimated to be longer than the annual average of 40-55 days residence time identified for Lower Campbell Lake (Hay and Company, 2006). Correspondingly, the residence time in McIvor Lake during August low-flow conditions is estimated to be longer than the August average of 100 days for Lower Campbell Lake (Hay and Company, 2006). Little is known about the circulation patterns within McIvor Lake, which acts as a dead-end “finger” of Lower Campbell Lake. Contaminants entering the lake probably remain and influence water quality for a longer period of time than they would in John Hart Lake.

Conclusions to be drawn from this are that processes and impacts in the upper Campbell River watershed (including Buttle Lake and Upper and Lower Campbell Lakes) likely affect water quality to a significant degree in both John Hart Lake and McIvor Lake. However, continuous sources of contamination within either the John Hart Lake or McIvor Lake watersheds may also significantly impact water quality on a long-term basis due to the fact that these impacts are not mitigated or diluted in the small tributaries before reaching the lakes. For this reason, influences on water quality throughout the Campbell River watershed will be considered, with special attention given to potential impacts near John Hart and McIvor lakes, and to the potentially longer residence time of McIvor Lake.

4.1 LAND OWNERSHIP

The majority (66.5%) of the Campbell River watershed falls within Provincial Parks (primarily Strathcona Provincial Park) , with Provincial Forest and TimberWest Forest Corporation-owned private lands composing another 12.1% and 11.5% of the watershed, respectively. A breakdown of land ownership for the entire Campbell River watershed is given in Table 3.

Table 3. Summary of land ownership within Campbell River watershed (from Dayton & Knight Ltd., 2001).

Land Owner	Area (ha)	Percent of Total Area
BC Hydro	104	0.07
Crown land within DCR Municipal Boundary – managed by BCAL*	987	0.67
0770809 BC Ltd – Private Land	2,484	1.70
Lakes	10,178	6.95
Unknown ownership outside of DCR** Municipal Boundary	333	0.23
Other private land outside DCR** Municipal Boundary	40	0.03
Provincial Park	97,404	66.52
Private land within DCR** Municipal Boundary	219	0.15
Provincial Forest	17,784	12.14
TimberWest – private land	16,899	11.54
Total	**146,432**	**100.00**

BCAL* – BC Assets and Land Corporation DCR** – District of Campbell River

The perimeter of John Hart Lake is relatively pristine, while the majority of the land surrounding McIvor Lake has been developed residentially. Thus, potential sources of contamination associated with households (such as runoff, septic fields, fertilizers and pesticides) may impact water quality in McIvor Lake.

4.2 LICENSED WATER WITHDRAWALS

Water withdrawals can affect flows downstream from the point of diversion, especially during periods of lower flows, if licensed withdrawals are large relative to the volume of water in the system. However, in the case of John Hart Lake, BC Hydro is required to release a minimum of 3.5 m^3/s over the spillway to protect fish habitat in Campbell River downstream from the John Hart Lake Dam. BC Hydro controls the flows both into (through the Ladore Dam) and out of (through the John Hart Dam penstocks and over the spillway) John Hart Lake, and therefore licensed water withdrawals are not likely to affect water levels either in the lake or downstream in the Campbell River.

Similarly, flows into Lower Campbell Lake (and therefore McIvor Lake) are controlled through the Strathcona Dam located at the bottom of Upper Campbell Lake, and flows out of Lower Campbell Lake are controlled through the Ladore Dam. Again, licensed water withdrawals will not likely impact water levels in this controlled system.

4.3 FOREST HARVESTING AND FOREST ROADS

Forestry activities can impact water quality both directly and indirectly in several ways. The removal of trees can decrease water retention times within the watershed and result in a more rapid response to precipitation events and earlier and higher rain on snow events in spring. The improper construction of roads can change drainage patterns, destabilize slopes, and introduce high concentrations of sediment to streams.

Including lands managed as Provincial Forest and those privately owned by TimberWest and 0770809 BC Ltd (Table 3), approximately 25% of the Campbell River watershed is currently under active forestry management. The majority of forestry activities take place in the upper watershed, on Provincial Forest land governed by the FRPA. On private land, the *Private Managed Forest Land Act* potentially protects for human drinking water, both during and after harvest, as well as for fish habitat through requirements to retain sufficient streamside vegetation. As such, riparian areas where impacts are most likely to affect water quality may be protected, and any impacts that occur are mitigated by the long residence times of Buttle Lake, Upper Campbell Lake and Lower Campbell Lake.

4.4 RECREATION

Recreational activities can affect water quality in a number of ways. Erosion associated with 4-wheel drive and ATV vehicles, direct contamination of water from vehicle fuel, and fecal contamination from human and domestic animal wastes (e.g., dogs or horses) are typical examples of potential effects.

Unauthorized motorized vehicle access to the John Hart Lake watershed, and especially “mud-bogging” in wet areas, is likely a source for turbidity in the lake. Access increases the potential for contamination from fecal coliforms (from unauthorized camping and pets), fuel spills and garbage dumping. It also increases the risk of forest fires within the watershed, and their associated impacts on water quality. Potential fire-related impacts include post-fire sediment fluxes, which can affect drinking water treatment processes, and an increase of nutrient loads which can increase algal productivity (Meixner, 2004).

McIvor Lake experiences high levels of recreational activity, primarily during the summer months. Activities include swimming and sun-bathing, as well as fishing, jet-skiing and water-skiing, and various other water-based activities. There are concerns that these activities could significantly impact water quality in a number of ways. Bacteriological contamination associated with swimmers (especially infants and toddlers) and pets, debris left by picnickers, fuel and combustion by-products from ski-boats, jet-skis and other motorized craft all could significantly impact water quality in McIvor Lake.

4.5 WILDLIFE

Wildlife can influence water quality because warm-blooded animals can carry pathogens such as *Giardia lamblia*, which causes giardiasis or “beaver fever”, and *Cryptosporidium* oocysts which cause the gastrointestinal disease, cryptosporidiosis (Health Canada, 2004). In addition, warm-blooded animals excrete pathogens, including *Escherichia coli*, in their feces, and can cause elevated levels of microbiological indicators in water. Fecal contamination of water by animals is generally considered to be less of a concern to human health than contamination by humans because there is less risk of inter-species transfer of pathogens. However, without specific source tracking methods, it is impossible to determine the origins of indicator bacteria.

The watershed contains valuable wildlife habitat and provides a home for a wide variety of warm-blooded species. Therefore, the risk of contamination from endemic wildlife exists.

Gulls that have fed at the Campbell River Landfill then used McIvor Lake as a resting area have been observed to transport landfill solid waste material to McIvor Lake (Brunn, pers.comm., 2010). Contamination from solid waste and fecal coliforms associated with the quantity of gulls using McIvor Lake could impact water quality in the lake.

4.6 MINING

Mining activities can potentially impact water quality through the introduction of metals and other contaminants (e.g., sulphate) to the watershed. The leaching of acidic waste rock or adit discharges can also impact downstream water quality.. Mining activities generally include road construction and land-clearing, which can change water movement patterns and result in increased turbidity levels.

The primary mine operating within the Campbell River watershed is NVI Mining Ltd's (formerly Westmin, then Boliden) Myra Falls Operations, a mainly underground operation producing zinc, copper, gold, silver and lead concentrates (MINFILE, 2004, Henderson pers. comm., 2011). From 1966 to 1983, tailings from the mine were discharged to Buttle Lake, resulting in elevated concentrations of dissolved zinc, copper, cadmium and lead throughout the system (Nordin et al., 1985). However, remedial measures, such as land-based tailings impoundments and contaminate runoff capture and treatment, have resulted in decreases in metals concentrations throughout the system.

4.7 HIGHWAYS AND TRANSPORTATION

Highways and transportation corridors can influence water quality through run-off of pollutants such as oil and gasoline, and alter flow patterns. Highway 28 passes close to McIvor Lake, and Brewster Lake Road runs near John Hart Lake. If a vehicle transporting potential contaminants (such as a fuel truck) were to overturn on these roads near either lake, there is the potential for contaminants to impact water quality in the lakes.

5.0 STUDY DETAILS

Three water quality monitoring sites were established in John Hart Lake: Environmental Monitoring System (EMS) site E252669 is at the inlet of the lake (near the Ladore Dam); site 1130020 is at the outlet of the lake (near the BC Hydro Penstocks) and site E259337 is mid-lake, at the deepest point (see Figure 3). One water quality monitoring site was established in McIvor Lake: EMS site E207156 is near the deepest point (see Figure 4). The project consisted of four phases: collecting water quality data, gathering information on water use, determining land use activities that may influence water quality, and establishing water quality objectives.

Water quality data were collected from March 2003 to March 2006 in John Hart and McIvor lakes. Drinking water is one of the designated water uses in John Hart Lake and McIvor Lake and so water quality variables relevant to the protection of raw drinking water supplies were included. Based on the current knowledge of potential anthropogenic impacts to the sub-watersheds (generally associated with forestry, mining, recreation and residential development), natural features (wildlife), and the lack of authorized waste discharges within the watershed, the following water quality variables were included:

- Physical: pH, temperature, specific conductivity, true color, turbidity, non-filterable residue (total suspended solids)
- Carbon: dissolved organic carbon, total organic carbon, total inorganic carbon
- Nutrients: total phosphorus, orthophosphate, nitrate, nitrite, ammonia, total Kjeldahl nitrogen
- Total and dissolved metals concentrations, hardness
- Microbiological indicators: fecal coliforms, *E. coli*
- Biological: zooplankton, phytoplankton, chlorophyll *a*

The sampling schedule for each site is shown in Table 4. To represent the worst case scenario, water samples should have been collected at the John Hart Lake inlet and outlet sites on a weekly basis for five consecutive weeks during the summer low flow and fall flush periods from 2003-2005; however, due to sampling complications, only in 2004 were five consecutive weeks of sampling completed. Water quality samples were also usually collected on a quarterly basis for the remainder of the year from March 2003 to March 2006.

Table 4. Summary of monitoring schedule for water quality samples collected at John Hart Lake and McIvor Lake water quality monitoring sites.

Site Number	Site Name	Site coordinates	Sampling Schedule*
E259337	John Hart Reservoir, mid-lake (deep station)	50°02’31.92”N, 125°20’50.09”W	March, May, August 2003-2005, Sept 2003-2004, October 2005, March 2006
1130020	John Hart Reservoir at Pumphouse (outlet)	50°02’37.58”N , 125°20’29.27”W	August & September 2003-2004, November 2004-2005, 5-in-30 samples summer and fall 2004
E252669	John Hart Lake at Ladore Dam (inlet)	50°01’01.65”N , 125°23’40.20”W	August & September 2003-2004, November 2004-2005, 5-in-30 samples summer and fall 2004
E207156	McIvor Lake (deep station)	50°00’35.27”N , 125°21’58.27”W	March, May, August 2003-2005, Sept 2003-2004, October 2005, March 2006

***5-in-30 sampling represents a minimum of five weekly samples collected within a 30-day period.**

Samples were collected in strict accordance with Resource Inventory Standards Committee (RISC) standards (BC MOE, 2003) by trained personnel, including City of Campbell River staff. Chlorophyll *a* and water chemistry parameters analyses were conducted by Maxxam Analytics Inc. in Burnaby, BC; microbiological analyses were conducted by Cantest Laboratories in Burnaby, BC; and plankton taxonomy was conducted by Fraser Environmental Services in Surrey, BC.

At the deep stations, depth profiles were conducted in the field for dissolved oxygen, water temperature, oxidation-reduction potential (ORP), pH and specific conductivity using a Hydrolab Surveyor 4. Data were collected every metre between the surface and

10 m depth, and then, on most occasions, every 5 m until the final sample was collected just above the bottom (as deep as 19 m at the John Hart Lake mid-lake site and 34 m in McIvor Lake). Water clarity was measured at the deep stations on each sampling day using a 20 cm diameter Secchi disc.

For water chemistry parameters not measured using field instruments, grab samples were collected at three depths in the water column (0.5 m, 10 m and 1 m from the bottom) for the John Hart Lake and McIvor Lake deep stations, and at the surface only for the John Hart Lake inlet and outlet sites. Surface samples were collected by hand using plastic bottles provided by the lab conducting the analyses, and water column samples were collected using a Van Dorn bottle, then transferred to plastic bottles. All samples were shipped on ice to the laboratory for analysis. Samples from the inlet and outlet sites were analyzed for microbiological parameters and select chemical/physical parameters, and only during the five weekly samples in 30 day sampling.

Chlorophyll *a* and phytoplankton samples were collected at the deep stations by taking one litre grab samples at a depth of 0.5 m. Chlorophyll *a* samples were field filtered using 0.45 μm filter paper and shipped on ice to the laboratory for analyses. Phytoplankton samples were preserved with Lugol's solution. Zooplankton samples were collected to determine community composition and densities 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 0.3 m and a mesh size of 64 μm. Zooplankton samples were preserved with formalin. Plankton samples were shipped on ice to the lab for identification and enumeration.

Summary statistics were calculated on all available data, and 90th percentiles were calculated using data from a minimum of 5 weekly samples in 30 consecutive days for each site. Data are summarized in Appendix I.

6.0 WATER QUALITY ASSESSMENT AND OBJECTIVES

There are two sets of guidelines that are commonly used to determine the suitability of source water as a drinking water supply. The BC MOE water quality guidelines (available at http://www.env.gov.bc.ca/wat/wq/wq_guidelines.html) are used to assess water at the point of diversion of the natural stream into a waterworks system. These BC guidelines are also used to protect other designated water uses such as recreation and habitat for aquatic life. The development of water quality objectives (i.e., the site-specific application of BC water quality guidelines) for a specific water body can be integrated into an overall fundamental water protection program designed to protect all uses of the resource, including drinking water sources. Source water results may also be compared to benchmarks that are protective of human health (Guidelines for Canadian Drinking Water Quality (Health Canada, 2010)). The assessment of a water source as a drinking water supply, and standards for potable water, are outlined under the Province's *Drinking Water Protection Act* which is administered by the Ministry of Health and implemented by Regional Health Authorities.

The BC *Drinking Water Protection Act* sets minimum disinfection requirements for all surface supplies, as well as requiring drinking water to be potable. The Vancouver Island Health Authority (VIHA) determines the level of treatment and disinfection required based on both the source and end-of-tap water quality. As such, VIHA requires all surface water supply systems to provide two types of disinfection processes. The City of Campbell River disinfects drinking water with chlorination and ultraviolet light prior to distribution (Brunn, pers. comm., 2010), to protect against protozoan parasites such as *Giardia* and *Cryptosporidium*.

6.1 LIMNOLOGICAL CHARACTERISTICS

Limnological characteristics are generally considered those related to the dynamics of the lake, including thermal and chemical stratification of the water column. Thermal stratification is driven by the fact that water is at its most dense at about 4°C. In most BC lakes, surface waters cool in the fall and, as temperatures reach 4°C, the denser water settles to the bottom of the lake. Similarly, in the spring, colder water (near 0°C) gradually warms to 4°C, at which point it begins to settle to the bottom. These temperature changes, usually assisted by spring and fall wind-storms, result in a mixing of the water column.

During the summer (as well as in the winter, if there is ice cover), surface waters are considerably less dense than the colder water at the bottom. These differences in density provide resistance to mixing and, in the absence of continuous winds or strong water currents, the water column can become thermally stratified. This results in a division of the water column into three sections – the epilimnion or top layer, the metalimnion or middle layer (which contains the thermocline, the plane of maximum rate of decrease of temperature with respect to depth, with a rate of change greater than 1°C per metre (Wetzel, 2001) and the hypolimnion, or bottom layer. This can have various consequences to water chemistry because, in a strongly stratified lake, water in the hypolimnion does not mix with surface waters. If the depth of the hypolimnion is greater than the euphotic depth (the maximum depth at which photosynthesis meets or exceeds respiration), dissolved oxygen levels are not replenished because there is no exchange with the atmosphere (as there is in the epilimnion), or production of oxygen through photosynthesis. In some lakes, oxygen concentrations decrease sufficiently to impact fish species.

Dissolved oxygen levels in the hypolimnion can become depleted due to the decomposition of algae that dies and sinks to the bottom. If waters near the sediment become anoxic, chemical reactions can result that release nutrients and other chemical constituents from sediments back into the water column.

This explanation of stratification is very simplified as there are a number of factors involved; but it provides an overview of typical lake dynamics in the temperate zone.

6.1.1 Temperature Stratification

Temperature is important to the quality of drinking water supplies for both health and aesthetic reasons. As water temperature increases, so does the potential for biological growth. Increased biological growth will increase the amount of chlorine required to effectively disinfect the water. In addition, decaying organics in the water can cause taste and odor problems for the consumer. Water temperature is a critical factor for aquatic life. Fish and invertebrate's body temperatures are, to a large extent, controlled by their environment. Water temperature directly affects activity and physiological processes of fish and aquatic invertebrates at all life stages. The capacity for water to carry dissolved oxygen, which is critical to aquatic life, is inversely related to temperature. Temperature can also affect the toxicity of other parameters, such as ammonia, and increase the solubility of chemical compounds.

Water quality guidelines for temperature have been developed for several water uses (see Oliver and Fidler, 2001). For drinking water supplies, it is recommended that water temperature be less than 15°C to protect the aesthetic quality of the water. For the protection of aquatic life in lakes, the allowable change in temperature is +/-1°C from naturally occurring levels. In streams, the optimum temperature ranges for salmonids is based on species and specific life history stages such as incubation, rearing, migration and spawning.

The water column in John Hart Lake was unstratified during the winter months, becoming only weakly stratified during the summer months (Figure 7) with no defined thermocline. Temperatures between the surface and the bottom (about 20 m) did not vary by more than 6°C even during the middle of summer. This is strongly contrasted by the temperature profile of McIvor Lake (Figure 8), where surface temperatures were as much as 16.4°C higher than water near the bottom of the lake. McIvor Lake was unstratified in March, but by May surface temperatures were at least 7°C warmer than bottom waters, with the thermocline occurring between 8 m and 18 m in depth. The difference in stratification between the two lakes is due in part to the fact that McIvor Lake is considerably deeper than John Hart Lake (and therefore more energy is required to mix water throughout the water column), but also to the short residence time of John Hart Lake. The volume of water entering and leaving the lake is large relative to the actual volume of the lake, and acts as a giant blender, mixing the water column as the water travels through the lake. The fact that McIvor Lake is strongly thermally stratified lends credence to the hypothesis that its residence time is considerably longer than that of John Hart Lake, and is therefore more susceptible to impacts.

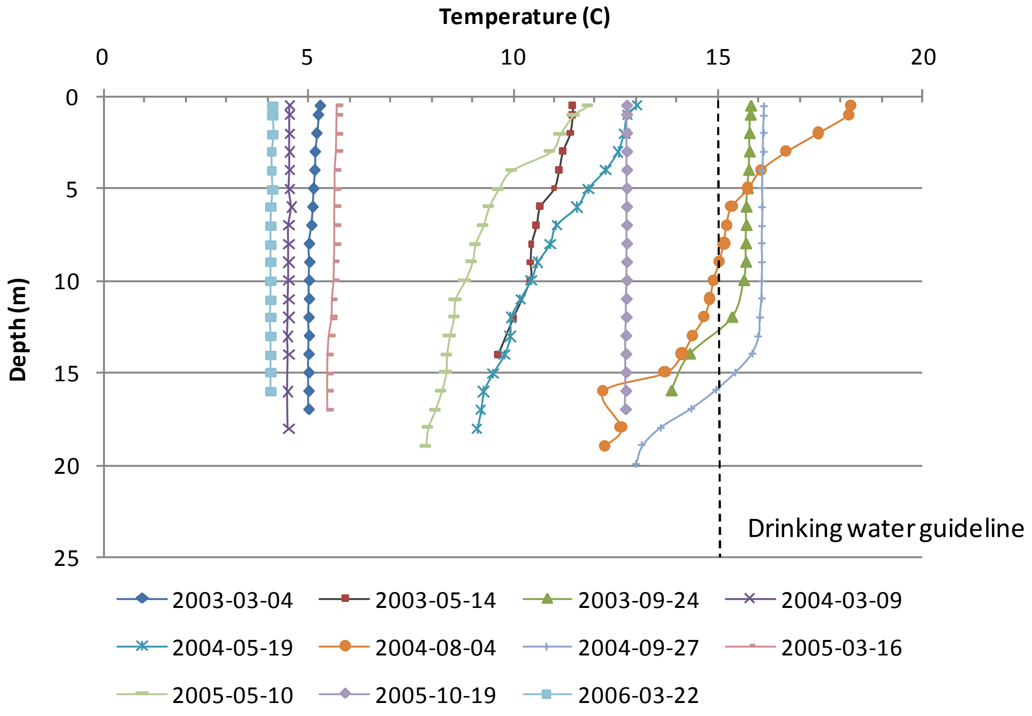

Figure 7. Water temperatures measured at 1 m intervals in John Hart Lake mid lake.

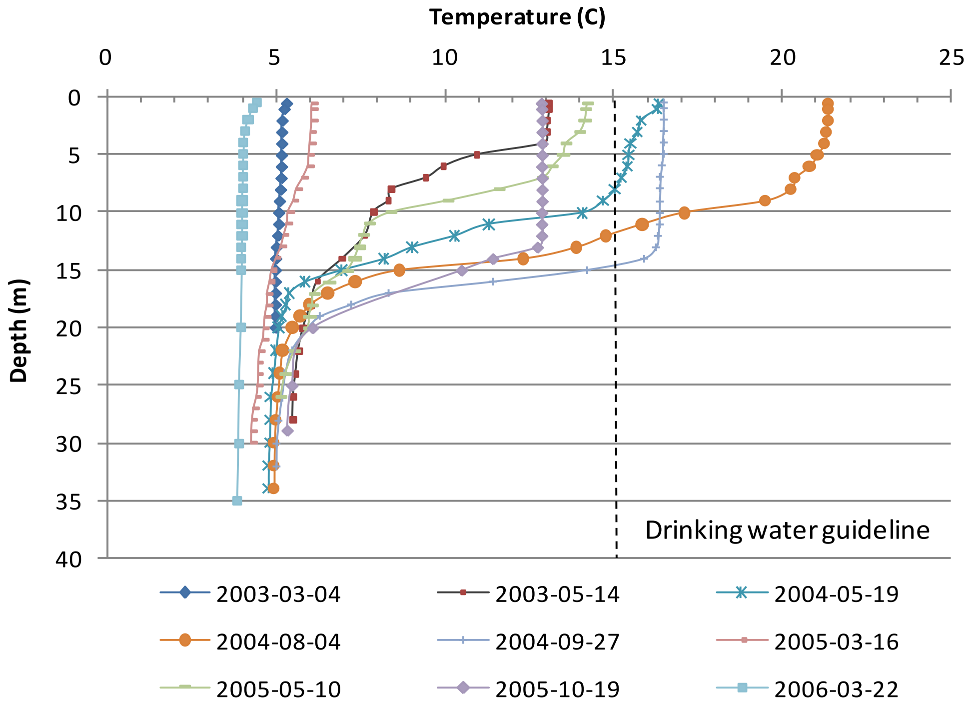

Figure 8. Water temperatures measured at 1 m intervals in McIvor Lake at the deepest point.

As surface water temperatures in John Hart Lake and McIvor Lake can reach 18 to 21°C in August, fish would typically need to stay within or below the thermocline to avoid physiological stresses associated with elevated water temperatures. In an attempt to ensure that deeper waters remain cool enough to provide a refuge for fish, ***the proposed water quality objective for temperature is that, during the summer, water temperatures should not exceed 15°C at depths greater than 15 m in John Hart Lake and McIvor Lake***. This objective would also ensure that the aesthetic drinking water guideline of 15°C would be met, were the intake in either lake to be positioned at least 15 m deep.

6.1.2 Dissolved Oxygen

Dissolved oxygen levels are important for the survival of aquatic organisms, especially species sensitive to low oxygen levels, such as salmonids. Oxygen becomes dissolved in water on the surface of lakes as a result of diffusion from the atmosphere, as well as from photosynthetic activity from plants and algae. When deeper waters no longer mix with surface waters due to stratification, concentrations of dissolved oxygen can decrease. This occurs as a result of decomposition of organic materials, especially in eutrophic lakes (i.e., lakes with high levels of nutrients and high biological productivity). If the euphotic zone lies above the thermocline, no photosynthesis occurs in deeper waters, and therefore oxygen depletion occurs as a result of decomposition. The aquatic life guideline for the minimum instantaneous dissolved oxygen concentration is 5 mg/L (BC MOE, 1997).

Dissolved oxygen concentrations were generally very high in both lakes (Figure 9, Figure 10). Concentrations were mostly above 10 mg/L in John Hart Lake throughout the water column, except in October 2005 when levels throughout the entire water column were slightly lower between 9 and 10 mg/L, and in September of 2004, when they gradually decreased with depth to 7.0 mg/L near the bottom of the lake. This latter observation was the period when the lake was most thermally stratified (Figure 7). In McIvor Lake, dissolved oxygen concentrations tended to increase with depth until mid depths, due to the fact that solubility of oxygen increases as temperatures decrease. From mid to bottom depths temperatures tended to decrease slightly again. Even when the lake was strongly stratified, oxygen concentrations in the deeper portion of the lake remained high. One exception was in October 2005, when dissolved oxygen was less than 10 mg/L at the surface, decreasing to 7.7 mg/L at the bottom.

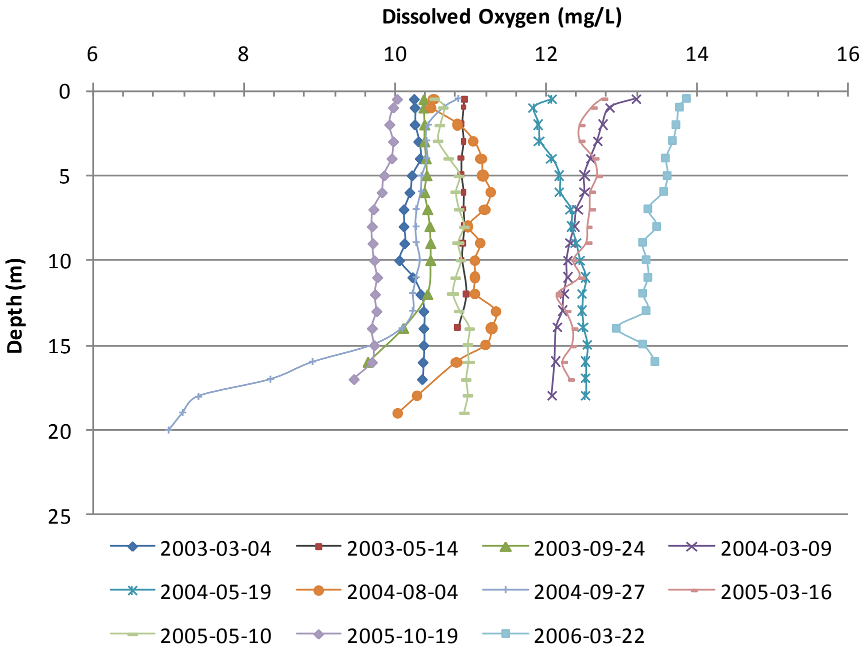

Figure 9. Dissolved oxygen concentrations measured at 1 m intervals in John Hart Lake mid lake.

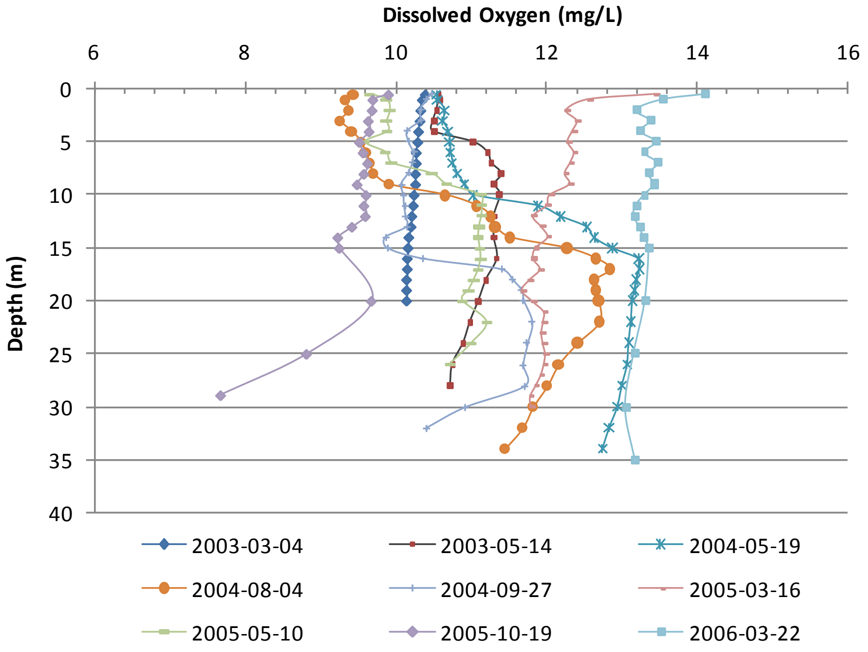

Figure 10. Dissolved oxygen concentrations measured at 1 m intervals in McIvor Lake at the deepest point.

High dissolved oxygen concentrations in the deeper portion of the lake during stratification suggests that there is low biological productivity and therefore low oxygen demand. As such, it does not appear that dissolved oxygen concentrations are a concern in John Hart or McIvor Lake at this time. However if activities such as forestry or land development increase in the watershed, there is the potential for nutrient loading and a resulting increase in lake productivity. The establishment of a water quality objective for dissolved oxygen would serve as an early warning sign for impact from future activities. ***The proposed objective is that dissolved oxygen concentrations in the bottom metre of the lake, measured at the deepest point in each basin, should remain above 5 mg/L during the summer months.***

6.1.3 Water Clarity

As water clarity is primarily affected by colour, suspended solids and algal growth, Secchi disks provide a simple, inexpensive means of indicating changes in a number of important parameters. As well, because the disks are inexpensive and simple to use, laypeople can be easily trained in their use. For this reason, Secchi depths are a popular and useful measurement for volunteer water stewards, as well as water quality professionals. Lakes with high Secchi depths tend to be oligotrophic (low biological productivity), while eutrophic lakes (those with high biological productivity) tend to have low Secchi depths. The recreational guideline for Secchi depths is a minimum of 1.2 m (Caux, et al., 1997).

Mean annual extinction depths for John Hart and McIvor Lakes are shown in Figure 11. Where available, mean values are used because individual values can show high variability over the course of a year, or even a given month. Transient events such as rainfall or snowmelt runoff, as well as algal blooms, contribute to this variability. Mean Secchi depths for the period of record (between 2003 and 2006) were similar between lakes, ranging from 8 m in McIvor Lake (2006) to 12.5 m in John Hart Lake (2005). All values easily met the recreational guideline of 1.2 m. To ensure that Secchi depths are maintained at the current level a water quality objective is proposed: ***the mean annual Secchi depth (measured at least four times per year, once during each season) should exceed 8 m at all of the monitoring locations.*** To identify if the range in Secchi readings is a product of natural variability or anthroprogenic influences in McIvor Lake, it is recommended that a volunteer sampling program, such as that offered by the BC Lakes Stewardship Society (BCLSS) be undertaken. The BCLSS Level 1 sampling program includes Secchi depth readings along with surface temperature readings to be collected from May through the end of September on a weekly or biweekly basis.

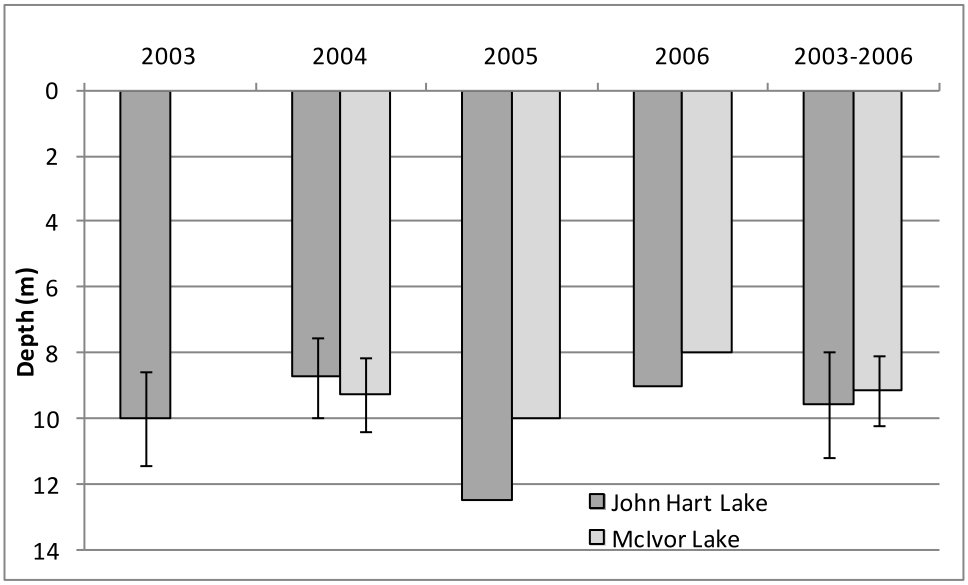

Figure 11. Mean annual Secchi depth (in m) measured in John Hart Lake and McIvor Lake. Error bars represent standard deviations.

6.2 WATER CHEMISTRY

6.2.1 pH

pH measures the concentration of hydrogen ions (H^+) in water. The concentration of hydrogen ions in water can range over 14 orders of magnitude, so pH is defined on a logarithmic scale between 0 and 14. A pH between 0 and less than 7 is acidic (the lower the number, the more acidic the water) and a pH between 7 and 14 is alkaline (the higher the number, the more basic the water). The aesthetic objective for drinking water is a pH between 6.5 and 8.5 (McKean and Nagpal, 1991). Corrosion of metal plumbing may occur at both low and high pH outside of this range, while scaling or encrustation of metal pipes may occur at high pH. The effectiveness of chlorine as a disinfectant is also reduced outside of this range. The aquatic life guideline allows a pH range between 6.5 and 9.0 pH units. Outside of this range, toxicity to fish begins to occur (McKean and Nagpal, 1991).

pH in both John Hart Lake and McIvor Lake was slightly acidic to near neutral. In John Hart Lake, pH ranged from 6.1 to 7.5 pH units at the mid-lake site. In McIvor Lake, pH ranged from 6.1 to 7.7 pH units. Typically we would expect to see the lowest pH values during the winter months, when inputs from low-pH rainwater are at their highest, but no such seasonal trends were seen in either of the lakes. It would appear that occasional low pH is a natural phenomenon in both John Hart and McIvor Lakes, and it is not likely that anthropogenic activities will impact pH in these lakes. Therefore ***no objective is proposed*** for pH John Hart or McIvor Lake.

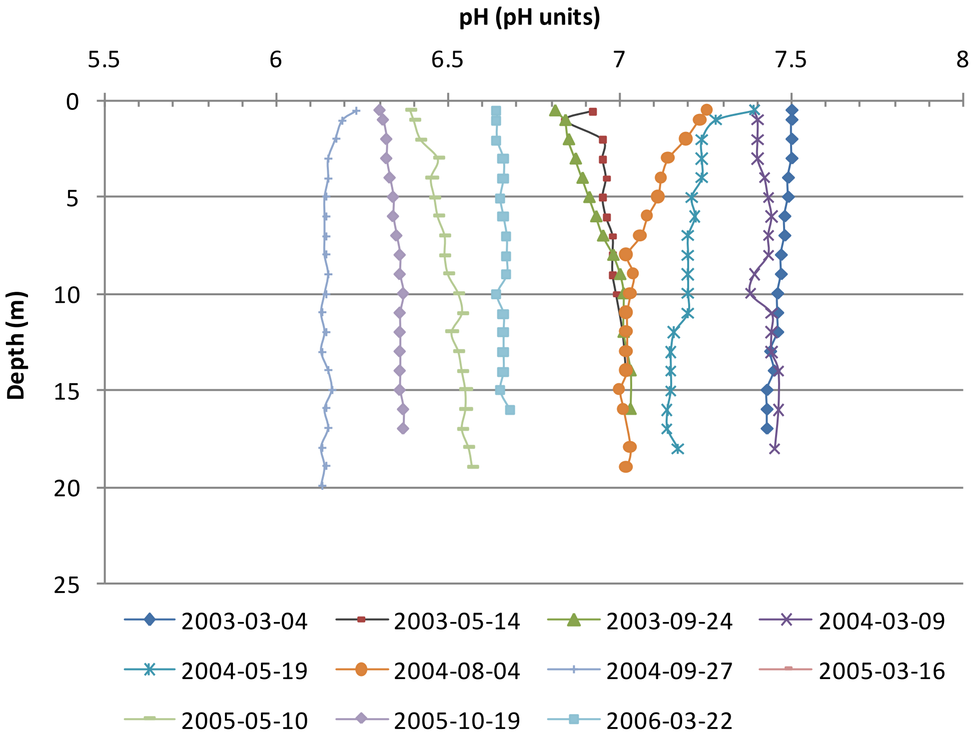

Figure 12. pH measured at 1 m intervals in John Hart Lake mid lake.

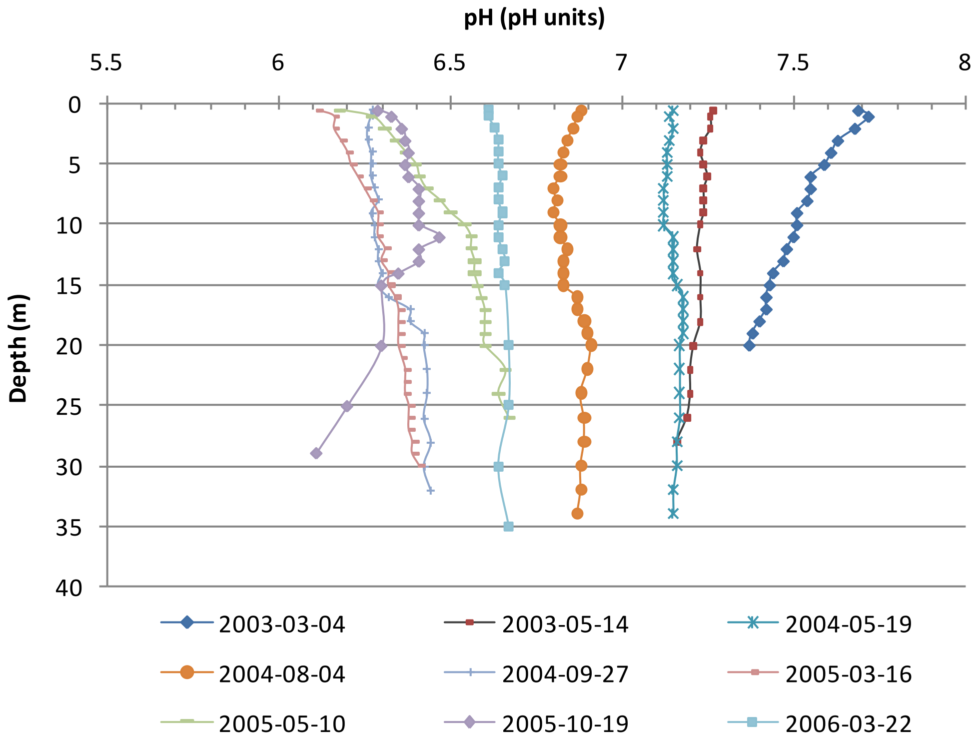

Figure 13. pH measured at 1 m intervals in McIvor Lake at the deepest point.

6.2.2 Turbidity

Turbidity is a measure of the clarity or cloudiness of water, and is measured by the amount of light scattered by the particles in the water as nephelometric turbidity units (NTU). Elevated turbidity levels can decrease the efficiency of disinfection, allowing microbiological contaminants to enter the water system. As well, there are aesthetic concerns with cloudy water, and particulate matter can clog water filters and leave a film on plumbing fixtures. The guideline for drinking water that does not receive treatment to remove turbidity is an induced turbidity over background of 1 NTU when background is less than 5 NTU and a maximum change from background of 5 NTU (during turbid flow periods) (Caux et al., 1997). VIHA's goal for surface sources of drinking water for systems that do not receive filtration, such as John Hart Lake, is turbidity levels of 1 NTU or less (95% of days) and not above 5 NTU on more than 2 days in a 12-month period when sampled at the intake (Enns, pers. comm., 2009).

Turbidity values were consistently low in both John Hart Lake and McIvor Lake. Maximum turbidity values measured in John Hart Lake ranged from 0.7 NTU at the outlet site to 1.4 NTU (the only value that was above 1.0 NTU) at the Ladore Dam. At the mid-lake site, the maximum recorded turbidity was 0.9 NTU. This concurs with the results of the continuous automated turbidity monitoring conducted by the City of Campbell River, which show turbidity values consistently below 1 NTU (City of Campbell River, 2005, 2006). In McIvor Lake, the maximum recorded turbidity was 0.4 NTU. Residence times of the numerous upstream lakes in the watershed provide considerable settling time for suspended sediments entering the system any significant distance from the two lakes. As well, with the low residence time of John Hart Lake, elevated turbidity resulting from any small-scale disturbance such as a small landslide near the lake would be flushed through the lake in a matter of a few days. Concern is greater for McIvor Lake, in that its residence time is unknown but likely at least seven times longer than that of John Hart Lake. Particulate matter (especially smaller, lighter materials such as clay which are slow to settle out of the water column) introduced to the lake through runoff or slope failures are more likely to cause longer-term problems. For this reason, a water quality objective is recommended, to ensure that the exceptional water clarity of John Hart Lake and McIvor Lake is maintained. ***The objective is that the maximum turbidity measured in any sample collected at the four monitoring locations at least five metres above the substrate should not exceed 2 NTU.*** These values are based on allowing an increase of 1 NTU above existing maximum background values, measured at each of these sites. However, in accordance with VIHA’s protocol for whether filtration is required, the City of Campbell River, as water purveyors, should continue to sample turbidity levels at the water intake location to ensure that the appropriate treatment methods are applied. It is generally considered that turbidity values greater than 2 NTU may compromise disinfection effectiveness (Gary Anderson, VIHA, pers. comm. 2006). Careful management of the riparian areas of both John Hart Lake and McIvor Lake should continue to minimize future risks.

6.2.3 Colour and Total Organic Carbon

Colour in water is caused by dissolved and particulate organic and inorganic matter. True colour is a measure of the dissolved colour in water after the particulate matter has been removed, while apparent colour is a measure of the dissolved and particulate matter in water. Colour can affect the aesthetic acceptability of drinking water, and the aesthetic water quality guideline is a maximum of 15 true colour units (TCU) (Moore and Caux, 1997). Colour is also an indicator of the amount of organic matter in water. When organic matter is chlorinated it produces disinfection by-products (DBPs) such as trihalomethanes (THMs) and haloacetic acids (HAAs) (Health Canada, 2008).

Colour was only measured on a few occasions in both lakes (five times at the mid-lake site in John Hart Lake and five times in McIvor Lake), with values consistently at or below the detection limit of 5 TCU. Thus, all values were well below the drinking water guideline of 15 TCU and as such ***no water quality objective for colour is proposed.***

Colour is closely correlated with organic carbon concentrations, as humic acids (high in organic carbon) are often major contributors to colour in water. Elevated total organic carbon (TOC) levels (above 4.0 mg/L) can result in higher levels of DBPs in finished drinking water if chlorination is used to disinfect the water (Moore, 1998). As the City of Campbell River uses chlorine to disinfect their drinking water, TOC was measured in both John Hart and McIvor lakes on a number of occasions. TOC concentrations ranged from at or below detection limits (0.5 mg/L) at all three sites in John Hart Lake to a maximum of 2.1 mg/L at the mid-lake site, 2.5 mg/L at the outlet site and 2.6 mg/L at the Ladore dam. In McIvor Lake, TOC levels ranged from 0.6 mg/L to 2.0 mg/L. All values were well below the drinking water guideline for TOC of 4.0 mg/L. This is supported by the results of analyses for THMs and HAAs conducted in 2004 by the University of Victoria, which showed levels of these compounds throughout the distribution system at concentrations well below the drinking water guidelines (City of Campbell River, 2005). As such, ***no water quality objective for TOC is proposed.***

6.2.4 Conductivity

Conductivity refers to the ability of a substance to conduct an electric current. The conductivity of a water sample gives an indication of the amount of dissolved ions in the water. The more ions dissolved in a solution, the greater the electrical conductivity. Temperature affects the conductivity of water (a 1ºC increase in temperature results in approximately a 2% increase in conductivity), so conductivity is normalized to 25ºC (i.e. specific conductivity) to allow comparisons to be made. Coastal systems, with high annual rainfall values and typically short water retention times, generally have low specific conductivity (<80 microsiemens/centimeter (µS/cm)), while interior watersheds generally have higher values. Increased flows resulting from precipitation events or snowmelt tend to dilute the ions, resulting in decreased specific conductivity levels with increased flow levels. Therefore, water level and specific conductivity tend to be inversely related. However, in situations such as landslides, where high levels of dissolved and suspended solids are introduced to the stream, specific conductivity levels tend to increase. As such, significant changes in specific conductivity can be used as an indicator of potential impacts.

Specific conductivity values measured in John Hart Lake and McIvor Lake were similar. Values ranged from 38 µS/cm to 54 µS/cm at the John Hart Lake mid-lake site, while specific conductivity in McIvor Lake ranged from 38 µS/cm to 52 µS/cm. Values were correlated with flows, with the highest conductivity occurring during low flows (when dilution was lowest) and conductivity values dropping during the winter (when dilution from rainfall was highest) (Figure 14, Figure 15). As there is no BC Water Quality Guideline for specific conductivity and the specific conductivity observed was typical of coastal systems, ***no objective is proposed for specific conductivity*** in John Hart Lake or McIvor Lake.

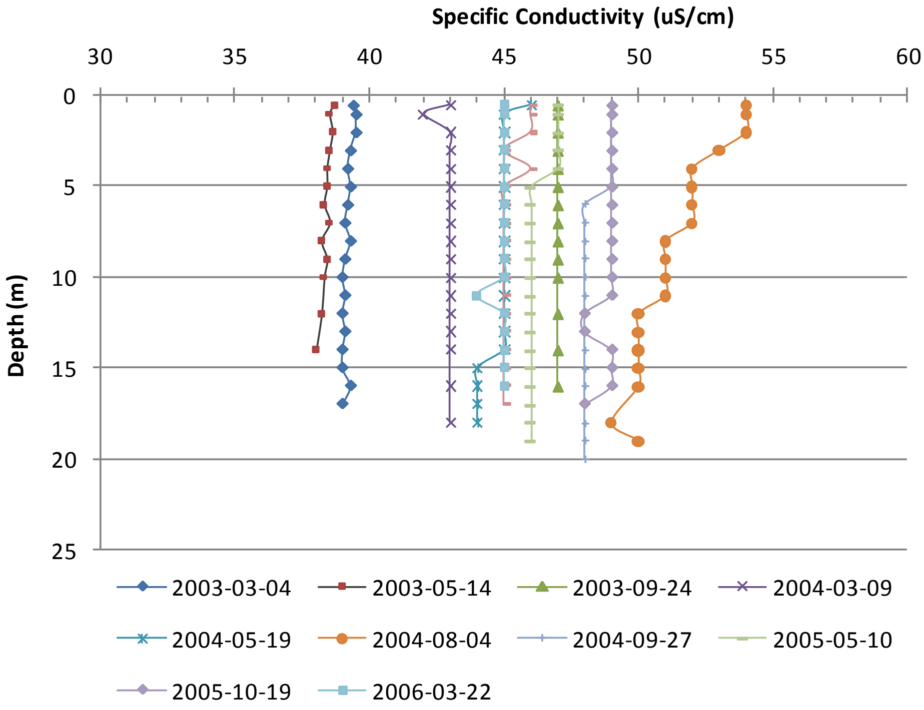

Figure 14. Specific conductivity measured at 1 m intervals in John Hart Lake near the outlet.

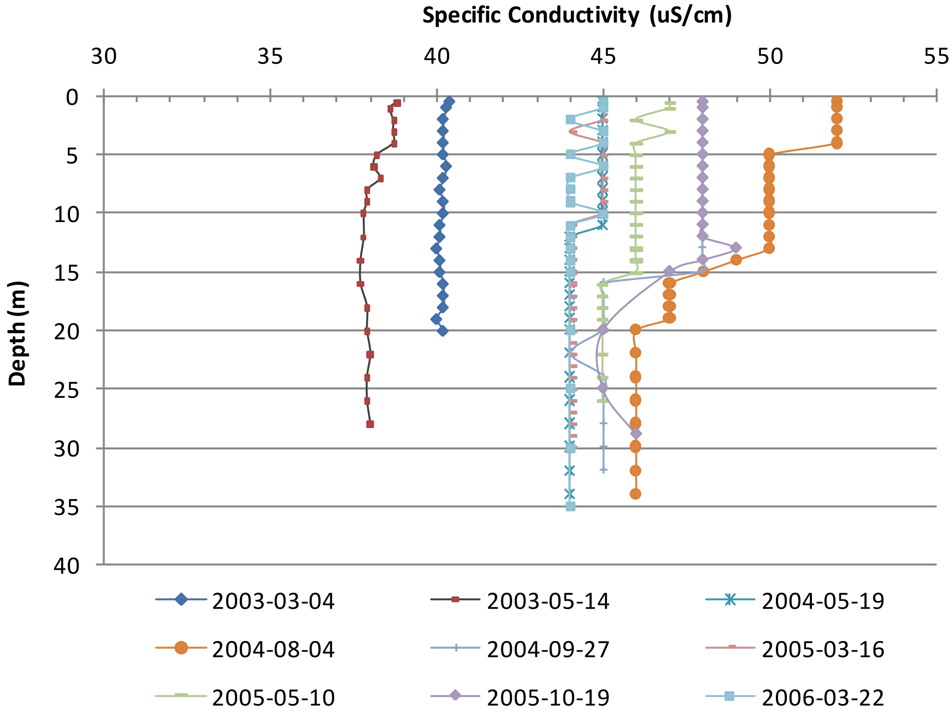

Figure 15. Specific conductivity measured at 1 m intervals in McIvor Lake at the deepest point.

6.2.5 Nutrients (Nitrate, Nitrite and Phosphorus)

Nitrogen (including nitrate and nitrite) and phosphorus are important parameters, since they tend to be the limiting nutrients in biological systems. Productivity is therefore directly proportional to the availability of these parameters. Nitrogen is usually the limiting nutrient in terrestrial systems, while phosphorus tends to be the limiting factor in freshwater aquatic systems. Lakes are typically sampled during the spring and fall because this is when turnover, or vertical mixing of the water column, occurs. Generally, spring turnover is when the highest concentrations of phosphorus are found. Later in the season, phosphorus is bound in micro-organisms such as phytoplankton, and is therefore found in lower quantities in solution. However, if lakes are undergoing internal nutrient loading, as typically occurs in eutrophic lakes, then the highest concentrations of phosphorus may be found in the fall. In watersheds where drinking water is a priority, it is desirable that nutrient levels remain low to avoid algal blooms and foul tasting water. Similarly, to protect aquatic life, nutrient levels should not be too high or the resulting plant and algal growth can deplete oxygen levels when it dies and begins to decompose, as well as during periods of low productivity when plants consume oxygen (i.e., at night and during the winter under ice cover). Conversely, a certain amount of nutrients in a lake system are needed to maintain productivity (i.e. 5 – 15 µg/L total phosphorus for aquatic life) (Nordin, 2001).

The guideline for the maximum concentration for nitrate in drinking water is 10 mg/L as nitrogen and the guideline for nitrite is a maximum of 1 mg/L as nitrogen. When both nitrate and nitrite are present, their combined concentration must not exceed 10 mg /L as N. For the protection of freshwater aquatic life, the nitrate guidelines are a maximum concentration of 31.3 mg/L and an average concentration of 3 mg/L. Nitrite concentrations are dependent on chloride; in low chloride waters (i.e., less than 2 mg/L) the maximum concentration of nitrite is 0.06 mg/L and the average concentration is 0.02 mg/L. Allowable concentrations of nitrite increase with ambient concentrations of chloride (Meays, 2009).

Nitrogen concentrations were generally measured in terms of dissolved nitrate (NO_3) + dissolved nitrite (NO_2). Dissolved nitrate + nitrite concentrations ranged from 0.003

mg/L to 0.044 mg/L, with an average of 0.024 mg/L in John Hart Lake at the mid-lake site. In McIvor Lake, nitrate + nitrite concentrations ranged from below detection limits (< 0.002 mg/L) to 0.08 mg/L, with an average of 0.028 mg/L. The combined concentrations of nitrate and nitrite were well below the existing aquatic life guidelines. As part of the nitrogen cycle, nitrite quickly converts to nitrate when oxygen is present. Therefore, nitrite concentrations would only be a concern under extended periods of ice cover when oxygen concentrations might be limited and nitrite could not be converted to nitrate. Though some short-term partial ice cover occurs on McIvor Lake, extended freezing is not an issue with either John Hart Lake or McIvor Lake. ***Therefore no nitrogen guideline is proposed for nitrate or nitrite for either lake.***

In lakes, a well defined relationship exists between total phosphorus concentrations (measured at spring overturn) and the amount of algal biomass (measured as chlorophyll *a*) produced in a lake during the growing season. Since phosphorus is much less difficult to measure than algal biomass, and can be easily correlated to other important lake characteristics such as water clarity and hypolimnetic dissolved oxygen, the guideline for nutrients and algae in lakes is presented in terms of total phosphorus concentrations (Nordin, 2001). The guideline for maximum total phosphorus concentrations in B.C. lakes is 10 µg/L to protect drinking water and recreation, and a range of 5 to 15 µg/L to protect aquatic life when salmonids are the dominant species (Nordin, 2001). In lakes where the epilimnetic residence time is less than six months (this applies to John Hart Lake and likely McIvor Lake as well), average guidelines for total phosphorus apply to mean epilimnetic growing season (May-September) concentrations instead of spring overturn concentrations (Nordin, 2001).

Total phosphorus concentrations ranged from below detectable limits (< 2 µg/L) for 14 of 28 samples collected at the John Hart Lake mid-lake site to a maximum of 9 µg/L. In McIvor Lake, total phosphorus concentrations ranged from below detection limits (< 2 µg/L) to a maximum of 6 µg/L, with most values (17 of 28) below the detection limit. The maximum concentrations of phosphorus were above 5 µg/L only twice in John Hart Lake and once in McIvor Lake, and in both lakes were only observed in the deepest samples, where there is a chance that the sample may have been influenced by contributions/contamination of sediment particles that may have been stirred up in the bottom at the time of sampling. This is supported by the presence of some slightly higher total metal results from the same sample date and depth on which 9 µg/L was observed in John Hart Lake.

In John Hart Lake there is no defined epilimnion, thus values from throughout the water column were considered to determine the mean growing season total phosphorous value of 3 µg/L. In McIvor Lake the epilimnion ranges from the top 5 m in May to the top 15 m in September and the mean epilimnetic growing season total phosphorous was 2.7 µg/L. In both lakes, the mean epilimnetic total phosphorus concentration was well below the phosphorous guideline.

Phosphorus concentrations were generally low in both John Hart Lake and McIvor Lake**.** However, to protect fundamental water quality and to ensure that nutrification does not occur in these lakes, ***an objective is recommended for total phosphorus in both John Hart Lake and McIvor Lake. The objective, given the less than 6 months residence time of water in John Hart Lake and likely McIvor Lake, is that the mean epilimnetic concentration of total phosphorus during the growing season (sampled monthly May – September) not exceed 5 µg/L in either of the lakes. This level will ensure that biological productivity remains low, and will protect salmonid species.*** Average May – September epilimnetic phosphorus levels at both mid-lake sites should continue to meet the water quality objective, as long as significant new sources of nutrients do not emerge. This objective will act as a warning should phosphorus values increase and will indicate that further investigation is warranted.

6.2.6 Metals

Metal concentrations have historically been a concern in the Campbell Lake watershed, resulting from the discharge of tailings from the Myra Falls Operations mine directly into Buttle Lake. Water samples were collected throughout the Campbell River watershed in 1981 as part of a study of impacts of the mine to water quality throughout the watershed. This study found dissolved cadmium, copper, lead and zinc in John Hart Lake at concentrations as high as 1.8 µg/L, 20 µg/L, 6 µg/L and 70 µg/L, respectively (Nordin et al., 1985). However, remedial measures taken by the mine to mitigate these impacts have greatly decreased metals concentrations throughout the watershed (Table 5).

Table 5. Comparison of maximum concentrations of all samples of dissolved cadmium, copper, lead and zinc (µg/L) in John Hart Lake between 1981 and 2003-2006 and in McIvor Lake 2003-2006.

Metal	John Hart Lake 1981	John Hart Lake 2003-2006	McIvor Lake 2003-2006 (n=13)
Dissolved cadmium	1.8	0.8	0.1
Dissolved copper	20	4.4	1.0
Dissolved lead	6	0.2	0.1
Dissolved zinc	70	14.2	9.6

In the 2003-2006 sample period, requisite sampling frequencies for comparison to average guidelines were sufficient (a minimum of five weekly samples in 30 days) on only two occasions in 2004 at both the Ladore Dam site and at the outlet on John Hart Lake. These recent data show average concentrations of total copper, lead and zinc were well below the guidelines for the protection of drinking water.

Guideline levels for these metals are quite low because they are hardness-dependent (higher hardness levels may ameliorate the toxicity of some metals) and water in John Hart Lake and McIvor Lake is very soft, with hardness levels between 20 mg/L and 30 mg/L $CaCO_3$. A hardness of 20 mg/L $CaCO_3$ was used to calculate all guidelines requiring hardness values.

All sets of samples for cadmium exceeded the average cadmium working (i.e. not yet formally approved by the BC MOE) water quality guideline for the protection of aquatic life (0.01 µg/L) (Table 6). It should be noted that the detection limit for total cadmium was 0.01 µg/L and accuracy of results is greatly reduced near detection limits. One set of samples for both total copper and total zinc exceeded the applicable average guideline for aquatic life (3.6 µg/L versus the average guideline of 2.0 µg/L for total copper, and 9.4 µg/L versus the average aquatic life guideline of 7.5 µg/L for total zinc), both from the outlet site on John Hart Lake during the fall flush period. Total copper maximum concentrations (5.4 µg/L) exceeded the guidelines for the protection of aquatic life (4 µg/L) in John Hart Lake.

Table 6. Summary of maximum and 5 sample in 30 day average total metals concentrations (µg/L) in John Hart Lake and McIvor Lake compared with aquatic life (AL) (guidelines based on average hardness 20 mg/L). Values in bold exceed aquatic life guidelines.

	John Hart Lake max	John Hart Lake avg	McIvor Lake max	Avg AL guideline	Max. AL guideline
Total cadmium	0.9	**0.04-0.27**	0.1	0.01	n/a
Total copper	**5.4**	0.9 – **3.6**	1.0	2	4
Total lead	0.5	0.02 – 0.3	0.1	4	10
Total zinc	32.6	4.2 – **9.4**	26.1	7.5	33

Elevated levels of these metals may be a natural phenomenon in the Campbell River watershed, as the geology of the area is rich in minerals and metals. In that case, aquatic life within the watershed would have evolved with these elevated metals species present, and therefore likely not be impacted. However, it is also possible that occasional higher concentrations may be linked to mining activities. It is anticipated that ongoing mine site treatment and remediation efforts will continue to reduce metals loadings from current operational levels. For this reason, we propose long-term objectives for total cadmium, total copper and total zinc concentrations in John Hart Lake and McIvor Lake.

Average total cadmium concentrations should not exceed 0.01 µg/L. This is based on the equation *10 exp (0.86[log{hardness}]-3.2)* where hardness is reported as mg/L $CaCO_3$. Ideally, detection limits that are no more than 10% of the working guideline level should be used to ensure accuracy, which in this case would mean using an analytical method with a detection limit of 0.001 µg/L for total cadmium. Currently detection limits of only 0.01 µg/L are available.

Maximum total copper concentrations should not exceed 4 µg/L, and average concentrations (based on a minimum of five weekly samples collected within a 30-day period) should not exceed 2 µg/L. Maximum concentration is based on the equation *0.094(hardness)+2* where hardness is reported as mg/L $CaCO_3$.

Maximum concentrations of total zinc should not exceed 33 µg/L in any single sample, and the average of at least five weekly samples collected in a 30-day period should not

exceed 7.5 µg/L. Maximum concentration is based on the equation *33 + 0.75 x (hardness -90)* where hardness is reported as mg/L $CaCO_3$.

Metal speciation determines the biologically available portion of the total metal concentration. Only a portion of the total metals level is in a form which can be toxic to aquatic life. Naturally occurring organics in the watershed can bind substantial proportions of the metals which are present, forming metal complexes which are not biologically available. The relationship will vary both seasonally and depending upon the metal (e.g., copper has the highest affinity for binding sites in humic materials). Levels of organics, as measured by dissolved organic carbon (DOC), vary from ecoregion to ecoregion. To aid in future development of metals objectives, DOC has been included in the John Hart Lake and McIvor Lake monitoring program.

6.3 BIOLOGICAL ANALYSES

Objectives development has traditionally focused on physical, chemical and bacteriological parameters. Biological data has been under-utilized due to the highly specialized interpretation required and the difficulty in assessing the data quantitatively. Notwithstanding this problem, with few exceptions, the most sensitive use of our waterbodies is aquatic life. Therefore biological objectives need to be incorporated into the overall water quality objectives development program.

6.3.1 Microbiological Indicators

Fecal contamination of surface waters used for drinking and recreating can result in high risks to human health from pathogenic microbiological organisms as well as significant economic losses due to closure of beaches (Scott et al., 2002). The direct measurement and monitoring of pathogens in water, however, is difficult due to their low numbers, intermittent and generally unpredictable occurrence, and specific growth requirements (Krewski et al., 2004; Ishii and Sadowsky, 2008). To assess risk of microbiological contamination, from fecal matter, resource managers commonly measure fecal indicator bacteria levels (Field and Samadpour, 2007; Ishii and Sadowsky, 2008). The most commonly used indicator organisms for assessing the microbiological quality of water are the total coliforms, fecal coliforms (a subgroup of the total coliforms more appropriately termed thermotolerant coliforms as they can grow at elevated temperatures), and *E. coli* (a thermotolerant coliform considered to be specifically of fecal origin) (Yates, 2007).

There are a number of characteristics that suitable indicator organisms should possess. They should be present in the intestinal tracts of warm-blooded animals, not multiply outside the animal host, be nonpathogenic and have similar survival characteristics to the pathogens of concern. They should also be strongly associated with the presence of pathogenic microorganisms, be present only in contaminated samples and be detectable and quantifiable by easy, rapid, and inexpensive methods (Scott et al., 2002; Field and Samadpour, 2007; Ishii and Sadowsky, 2008).

Total and fecal coliforms have traditionally been used in the assessment of water for domestic and recreational uses. However, research in recent years has shown that there are many differences between the coliforms and the pathogenic microorganisms they are a surrogate for, which limits the use of coliforms as an indicator of fecal contamination (Scott et al., 2002). For example, many pathogens, such as enteric viruses and parasites, are not as easily inactivated by water and wastewater treatment processes as coliforms are. As a result, disease outbreaks do occur when indicator bacteria counts are at acceptable levels (Yates, 2007; Haack et al., 2009). Additionally, some members of the coliform group, such as *Klebsiella*, can originate from non-fecal sources (Ishii and Sadowsky, 2008) adding a level of uncertainty when analyzing data. Waters contaminated with human feces are generally regarded as a greater risk to human health, as they are more likely to contain human-specific enteric pathogens (Scott et al., 2002). Measurement of total and fecal coliforms does not indicate the source of contamination, which can make the actual risk to human health uncertain; thus it is not always clear where to direct management efforts.

The BC-approved water quality guidelines for microbiological indicators were developed in 1988 (Warrington, 2001) and include *E. coli*, enterococci, *Psudomonas aeruginosa*, and fecal coliforms. The monitoring programs of the BC MOE have traditionally measured total coliforms, fecal coliforms, *E. coli* and enterococci, either alone or in combination, depending on the specific program. As small pieces of fecal matter in a sample can skew the overall results for a particular site, the 90th percentiles (for drinking water) and geometric means (for recreation) are generally used to determine if the water quality guideline is exceeded, as extreme values would have less effect on the data. The BC MOE drinking water guideline for raw waters receiving disinfection only is that the 90th percentile of at least five weekly samples collected in a 30-day period should not exceed 10 CFU/100 mL for either fecal coliforms or *E. coli* (Warrington, 2001).

Microbiological samples were only collected at John Hart Lake. Fecal coliforms ranged from below detectable limits (< 1 CFU/100 mL) to a maximum of 38 CFU/100 mL for the 17 samples collected at the Ladore Dam, and from below detectable limits (< 1 CFU/100 mL) to 8.0 CFU/100 mL for 17 samples collected at the John Hart Lake outlet site. The requisite sampling frequency (a minimum of five samples within a 30-day period) was met in 2004 on only two occasions at both the Ladore Dam site and at the outlet of John Hart Lake, with 90th percentile values of 1.6 CFU/100 mL and 2.0 CFU/100 mL at the Ladore Dam site, and 1.0 CFU/100 mL and 6.8 CFU/100 mL at the outlet site. Fecal coliform concentrations were highest during the low-flow period (August and September), corresponding to the peak recreation season, warmest temperatures, and maximum retention times.

E. coli concentrations ranged from below detection limits (< 1 CFU/100 mL) to 20 CFU/100 mL for the 17 samples collected at the Ladore Dam, and from below detection limits (< 1.0 CFU/100 mL) to 3.0 CFU/100 mL for the 17 samples collected at the outlet site. As with fecal coliforms, the 90th percentiles value could be determined on only two occasions at each site, and ranged from < 1.0 CFU/100 mL to 2.0 CFU/100 mL at the Ladore Dam site and from 1.0 CFU/100 mL to 2.6 CFU/100 mL at the outlet site. As with fecal coliforms, the highest values were seen in August and September, during periods of lowest flow.

For John Hart Lake, the majority of the results for both fecal coliforms and *E. coli* were the same when at or near detection limits; however, when values above 3 CFU/100 mL were observed for fecal coliforms, *E. coli* values tended to be lower. This is not surprising as *E. coli* is a component of the fecal coliforms group. Studies have shown that *E. coli* is the main thermotolerant coliform species present in human and animal fecal samples (94%) (Tallon et al., 2005) and at contaminated bathing beaches (80%) (Davis et al., 2005). Therefore, in cases where fecal coliform counts were greater than *E. coli*, we can assume a high likelihood of contributions from non-fecal sources. Thus, the value added benefit of measuring both groups is limited.

Overall the bacteriological results for John Hart Lake were relatively low and are reflective of natural or background conditions. The drinking water guidelines for fecal coliforms and *E. coli* were not exceeded at either of the sampling sites when requisite sampling frequency was sufficient to determine compliance. However, occasional elevated values of both fecal coliforms and *E. coli* were seen at the Ladore Dam site on

John Hart Lake. Fecal coliforms and *E. coli* were not measured in McIvor Lake, but it is likely that they were present in higher concentrations than those seen in John Hart Lake due to the higher recreational use, bird use and higher residential density (with potential septic bed failures, presence of domestic pets, etc.). Therefore, it appears that coliform bacteria are a potential concern in both John Hart Lake and McIvor Lake and should continue to be monitored and assessed. Given the uncertainty in linking thermotolerant (i.e. fecal) coliforms to human sources of sewage, we recommend using *E. coli* as the microbiological indicator for John Hart Lake and McIvor Lake. ***Thus, the proposed water quality objective is that the 90th percentile of a minimum of five weekly samples collected within a 30-day period must not exceed 10 CFU/100 mL for*** **E. coli** ***at the outlet of John Hart Lake, or at the site of the future water intake on McIvor Lake.*** Samples should be collected during the late summer low flow period, when concentrations of coliform bacteria are likely at their highest, and during the fall flush period when contaminants are washed down from terrestrial areas. This guideline will minimize the risk of bacteriological contamination but not the risk of parasites such as *Cryptosporidium* or *Giardia*. However, the ultraviolet treatment that is part of the City of Campbell River's water system will provide protection from these parasites. People participating in primary-contact recreation sports in McIvor Lake will also benefit from the proposed bacteriological objective as it is substantially lower that the provincial recreation guideline. In this case drinking water is the more sensitive use and as such a recreational water quality objective for *E. coli* is not proposed.

6.3.2 Phytoplankton

Phytoplankton populations can have significant impacts on water quality, and may give an indication of nutrient levels in a lake. Algal blooms resulting from elevated nutrient levels can impair water quality in a number of ways. Algae can clog water filters and can impact taste and odour of drinking water, requiring expensive treatments to remove algal particles. If algae are not removed prior to chlorination, by-products can be formed that are potentially carcinogenic (Nordin et al., 1985). Some species of phytoplankton (specifically "blue-green algae"or cyanobacteria) also contain toxins. Allergic reactions to algae in drinking water, or from exposure to algae while swimming, are also common.

Aesthetically, algal blooms reduce water clarity and can result in an unpleasant “scum” on the surface of the water, as well as give the water a strong odour.

Changes in algal populations can also affect other biota in the lake, including the zooplankton populations that feed on the algae and fish that feed either on algae, zooplankton or aquatic invertebrates. Increased algal concentrations can decrease available oxygen during the night or under ice cover, or at depth as it decomposes. Decreased water clarity resulting from high algal concentrations can reduce feeding visibility, and elevated algal concentrations often result in a shift from sport fish, such as salmonids, to less desirable species. Some species of algae can also impart a “muddy” flavour to fish flesh (Nordin, 2001), decreasing the popularity of sports fishing on a given lake.

Phytoplankton samples were collected at John Hart Lake and McIvor Lake; the results were summarized and the dominant species for each site are listed in Table 7 and 8. Dominant species were those that made up at least 10% of the total cells present in the sample. The complete results of taxonomic analysis for phytoplankton can be obtained from the MOE office in Nanaimo. Phytoplankton was sampled 13 times between March 2003 and March 2006. Generally, the number of species observed and plankton concentrations were very similar between both lakes (Table 9). Between 2003 and 2006, a total of 121 species were identified in John Hart Lake and 14 of these (plus two unidentified flagellate species) were dominant; 123 species were identified in McIvor Lake and 15 of these (plus one unidentified flagellate species) were dominant. McIvor Lake had 15 species not observed in John Hart Lake, while John Hart Lake had 18 species not observed in McIvor Lake. Overall John Hart Lake had a higher average phytoplankton concentration in March and August only (274 vs. 256 cell/mL and 321 vs. 246 cells/mL, respectively); in the May and Sept/Oct samples McIvor 2003-2006 average concentrations were slighly higher (247 vs. 236 cell/mL and 329 vs. 298 cells/mL, respectively). John Hart Lake also had slightly higher 2003-2006 average species richness (the number of different species occurring), with an average of 53 species versus 51 in McIvor Lake; this was also observed seasonally. In general, algal concentrations were low in both lakes, which is typical of oligotrophic lakes.

Table 7. Summary of dominant (*i.e.* >10% of sample) phytoplankton species for John Hart Lake, 2003 – 2006 (number of cells/mL and % of total sample).

	2003-03-04		2003-05-14		2003-08-19		2003-09-24		2004-03-09		2004-05-19		2004-08-04		2004-09-27		2005-03-16		2005-05-10		2005-08-17		2005-10-19		2006-03-22	
Order : Centrales																										
Cyclotella glomerata	69	15%	64	34%			126	27%	31	18%	67	22%			52	17%	41	27%	108	50%			15	13%	140	47%
Melosira italica									50	29%	42	14%											13	11%		
Rhizosolenia eriensis / longiseta															99	32%	17	11%							39	13%
Order : Chlorococcales																										
Crucigenia crucifera							112	24%													45	14%				
Scenedesmus cf denticulatus											34	11%					25	17%								
Order : Chroococcales																										
Anacystis elachista							84	18%																		
Order : Cryptomonadales																										
Chroomonas acuta									24	14%																
Cryptomonas ovata / erosa			22	12%																						
Order : Ochromonadales																										
Dinobryon divergens																					41	13%				
Order : Oscillatoriales																										
Lyngbya limnetica													49	10%												
Order : Pennales																										
Asterionella formosa	90	19%																							32	11%
Order : Rhizochrysidales																										
Gloeocystis ampla					39	22%															55	17%				
Sphaerocystis schroeteri											34	11%														
Phylum : Chrysophyta (Golden-Brown Algae)																										
Chrysophyte flagellate	120	25%																								
Unidentified ALGAL																										
Unidentified flagellate			24	13%																						
TOTAL per SAMPLE	471		190		176		471		174		301		467		310		152		216		318		115		301	

Table 8. Summary of dominant (*i.e.* >10% of sample) phytoplankton species for McIvor Lake, 2003 – 2006 (number of cells/mL and % of total sample).

	2003-03-04		2003-05-14		2003-08-19		2003-09-24		2004-03-09		2004-05-19		2004-08-04		2004-09-27		2005-03-16		2005-05-10		2005-08-17		2005-10-19		2006-03-22	
Order : Centrales																										
Cyclotella glomerata	123	23%					101	18%	25	13%			50	15%	34	15%	42	26%	31	20%					28	20%
Melosira italica			35	20%					31	15%											34	19%	31	16%	24	17%
Melosira italica/ambigua	54	10%																								
Rhizosolenia cf eriensis																									18	13%
Order : Chlorococcales																										
Crucigenia quadrata																					22	13%				
Scenedesmus cf denticulatus					22	10%					95	23%														
Order : Chroococcales																										
Anacystis elachista					56	26%	209	37%					147	43%												
Anacystis limneticus															78	35%										
Order : Cryptomonadales																										
Chroomonas acuta	63	12%							31	15%															22	16%
Order : Nostocales																										
Anabaena spp.																					18	10%				
Order : Ochromonadales																										
Dinobryon bavaricum									25	13%																
Dinobryon divergens							63	11%									31	19%								
Order : Pennales																										
Asterionella formosa									32	16%													55	27%		
Order : Rhizochrysidales																										
Gloeocystis ampla					36	17%															27	15%				
Sphaerocystis schroeteri											146	36%											22	11%		
Unidentified ALGAL																										
Unidentified flagellate			56	32%																						
TOTAL per SAMPLE	524		176		217		562		199		409		346		227		159		155		174		199		140	

Table 9. Seasonal averages of total number of species and cell/mL for all phytoplankton 2003 – 2006 data for John Hart Lake and McIvor Lake .

		John Hart Lake					**McIvor Lake**				
		2003	2004	2005	2006	**AVG**	2003	2004	2005	2006	**AVG**
Total number of species	**March**	36	46	45	40	**42**	49	43	31	40	**41**
	May	48	51	56		**52**	46	42	64		**51**
	August	59	62	62		**61**	51	57	60		**56**
	Sept/Oct	52	57	64		**58**	59	52	55		**55**
	ANNUAL AVG	49	54	57	40	**53**	51	49	53	40	**51**
Total number of cells/mL	**March**	471	174	152	301	**274**	524	199	159	140	**256**
	May	190	301	216		**236**	176	409	155		**247**
	August	176	467	318		**321**	217	346	174		**246**
	Sept/Oct	471	310	115		**298**	562	227	199		**329**
	ANNUAL AVG	327	313	200	301	**282**	370	295	172	140	**269**

The phytoplankton community in John Hart Lake was dominated most seasons by diatoms from the Order Centrales, with *Cyclotella glomerata* comprising the majority of the plankton community in most samples (13% - 50% of cells present). This is typical of oligotrophic lakes (Wetzel, 2001). An exception to this was in March 2003 when a species of golden-brown algae of the Phylum Chrysophyta was the dominant species (25% of cells present). Golden-brown algae are often associated with oligotrophic lakes (Wetzel, 2001) and, though not consistently found as a dominant species on John Hart Lake from 2003-2006, this singular dominant occurrence is not of concern. Exceptions also occurred in August of each year; in August 2003 and 2005 *Gloeocystis ampla* from the Order Rhizochrysidales were dominant (17% – 22% of cells present), and in August 2004 *Lyngbya limnetica* from the Order Oscillatoriales were dominant (10% of cells present). *Crucigenia crucifera* and *Scenedesmus* cf *denticulatus* from the Order Chlorococcales were also common in multiple seasons and years. In September 2003 a species of blue-green algae (*Anacystis elachista* from the Order Chroococcales) was amongst the dominant species present. Overall the phytoplankton community found in John Hart Lake is consistent with oligotrophic conditions, as indicated by the water chemistry results, therefore no objective is recommended for phytoplankton.

In McIvor Lake, the diatoms *C. glomerata* and *Melosira italica* from the Order Centrales were consistently amongst the dominant species present in most seasons. *C. glomerata* was the most dominant species (comprising 20% -26% of cells present) in March of each year except 2004, when the pennate diatom *Asterionella formosa* was the most dominant (16% of cells present). All of these species are typical of oligotrophic lakes (Wetzel, 2001). *Sphaerocystis schroeteri* of the Order Rhizochrysidales was the dominant species (36% of cells present) in May 2004. *Crucigenia quadrata* and *Scenedesmus* cf *denticulatus* from the Order Chlorococcales, *Chroomonas acuta* from the Order Cryptomonadales, and *Dinobryon* sp. from the Order Ochromonadales were amongst the dominant species in multiple seasons and years. The blue-green algae *Anacystis* sp. from the Order Chroococcales was the dominant species in August and September of 2003 and 2004 (26% - 43% of species present), but was not dominant at all in 2005. *Anabaena* sp. of the Order Nostocales (not dominant in John Hart Lake) and *Gloeocystis ampla* from the Order Rhizochrysidales (observed in John Hart Lake in August) were amongst the dominant species in McIvor Lake in August only. Presence of *Anacystis* sp. and *Anabaena* sp. can be associated with higher temperatures and nutrients (Wetzel, 2001) and should be noted. Nutrient data support that McIvor Lake is a nutrient poor lake and thus nutrients are not an issue; however, surface temperatures in McIvor Lake in August 2004 (the only summer date with temperature data) were approximately 3°C higher than those in John Hart Lake and may account for the dominance of these species in McIvor Lake. In September 2004 surface temperatures in both lakes were similar and the dominance persisted; this may suggest that the low flushing rate of McIvor Lake is also influencing the phytolplankton community composition. Overall, the phytoplankton community in McIvor Lake is similar to that of John Hart Lake and generally consistent with the oligotrophic conditions indicated by the water chemistry results. Therefore, no objective is recommended for phytoplankton.

Chlorophyll *a* acts as a surrogate for more detailed phytoplankton sampling, as it measures the photosynthetic pigment typically found in phytoplankton. Chlorophyll *a* concentrations are generally very closely correlated with total phosphorus concentrations (Nordin, 2001). Values below 3 μg/L are considered an indication of low productivity and values above 15 µg/L are generally considered to indicate high productivity. Agriculture, sewage effluent, forest harvesting, urban development and recreational activities can add nutrients to a lake, increasing chlorophyll *a* concentrations (Cavanagh et al., 1997).

Concentrations of chlorophyll *a* measured in John Hart Lake mid-lake ranged from < 0.5 µg/L (for 6 of the 12 samples) to a maximum of 1.5 µg/L. In McIvor Lake, concentrations ranged from < 0.5 µg/L (for 6 of the 11 samples) to a maximum 1.3 µg/L. ***To ensure that increases in productivity associated with nutrification do not occur in these lakes, a water quality objective is recommended for both John Hart and McIvor Lakes allowing a maximum of 1.5 µg/L chlorophyll a during the eplimnetic growing season.***

6.3.3 Zooplankton

Phytoplankton are called primary producers because they are capable of producing their own energy through photosynthesis. Zooplankton represent the second trophic level in a lake, generally preying upon phytoplankton and other zooplankton species. Zooplankton communities are sensitive to changes in phytoplankton community, as well as changes to water quality. They do not have negative impacts on water quality or impair water uses in the way that phytoplankton can, but their species composition and densities can give insights into water quality. Specifically, zooplankton respond to dissolved oxygen concentrations, contaminants and food quality and abundance.

Zooplankton samples were collected 13 times for both John Hart Lake and McIvor Lake between March 2003 and March 2006. The results were summarized and the dominant species (i.e. >10% of sample) for each site are listed in Table 10 and 11. The more detailed set of taxonomic analysis results for zooplankton can be obtained from the MOE office in Nanaimo, BC.

Table 10. Summary of dominant (*i.e.* >10% of sample) zooplankton species for John Hart Lake, 2003 – 2006 (total organisms/sample and % of total sample).

	2003-03-04		2003-05-14		2003-08-19		2003-09-24		2004-03-09		2004-05-17		2004-08-04		2004-09-27		2005-03-16		2008-05-10		2005-08-17		2005-10-19		2006-03-22	
Subclass : Copepoda																										
Copepod nauplii	1333	52%	2000	14%					767	11%					725	11%	500	14%	1013	13%			307	20%	820	21%
Phylum : Rotifera																										
Conochilus sp.							1550	33%							850	13%										
Kellicottia longispina			2867	20%							967	14%									1240	15%			440	11%
Keratella cochlearis	533	21%	1467	10%	4033	30%	650	14%	4633	67%	1433	21%	3660	58%	1550	23%	1400	40%	880	11%	1860	22%	253	16%	830	21%
Keratella quadrata																	575	16%								
Polyarthra sp.			5667	40%	1800	13%	575	12%	1000	14%	2933	44%	780	12%					3547	45%	2900	34%	280	18%	720	18%
Ptygura / Callotheca sp.							825	18%							1675	25%										
Synchaeta					3767	28%							700	11%											430	11%
TOTAL per SAMPLE	2555		14168		13443		4675		6902		6700		6362		6737		3521		7805		8520		1548		3909	

Table 11. Summary of dominant (*i.e.* >10% of sample) zooplankton species for McIvor Lake, 2003 – 2006 (total organisms/sample and % of total sample).

	2003-03-04		2003-05-14		2003-08-19		2003-09-24		2004-03-09		2004-05-19		2004-08-04		2004-09-27		2005-03-16		2005-05-10		2005-08-17		2005-10-19		2006-03-22	
Subclass : Copepoda																										
Copepod nauplii	1400	22%			775	14%			3000	34%			960	18%			293	33%	460	13%			707	12%	2220	26%
Order : Cyclopoida																										
Diacyclops thomasi copepodid	1167	18%													1000	13%			420	12%						
Unidentified Cyclopoida Copepodite																	200	23%								
Order : Calanoida																										
Unidentified Calanoida Copepodite					600	11%																				
Order : Cladocera																										
Daphnia rosea					700	13%					1131	14%							540	15%			1067	19%		
Phylum : Rotifera																										
Ascomorpha spp.															1175	15%										
Conochilus sp.							800	12%											520	14%						
Kellicottia longispina			2875	22%							1365	17%	570	11%			160	18%	640	18%	2920	53%			1180	14%
Keratella cochlearis	933	15%	1375	10%	650	12%	1350	21%	2800	32%			1050	20%	1650	21%							880	15%	1240	15%
Polyarthra sp.	1400	22%	5292	40%			1400	21%	1133	13%	1690	21%	840	16%					440	12%					1700	20%
Ptygura / Callotheca sp.															950	12%										
Ptygura					650	12%																				
TOTAL per SAMPLE	6360		13204		5464		6555		8857		7907		5281		7823		887		3599		5462		5717		8429	

A total of 40 zooplankton species were identified in John Hart Lake and 7 of these (plus unidentified copepod nauplii species) were dominant; 40 species were identified in McIvor Lake and 9 of these (plus one unidentified copepod nauplii and 2 unidentified copepodite species) were dominant. McIvor Lake had 11 species not observed in John Hart Lake, while John Hart Lake had 11 species not observed in McIvor Lake (Table 12). The overall 2003-2006 average zooplankton concentrations in John Hart Lake were slightly higher in May and August (9,558 vs. 8,237 total organsims/sample and 9,441 vs. 5,403 total organsims/sample, respectively); while in March and Sept/Oct samples McIvor 2003-2006 average concentrations were slighly higher (6,133 vs. 4,222 total organsims/sample and 6,698 vs. 4,320 total organsims/sample, respectively). It should be noted thatZooplankton biomass tends to be negatively correlated with flow velocity (Wetzel, 2001) and thus lower biomass could be associated with decreased residence time (and increased flow) in John Hart Lake during the rainy season. McIvor Lake had slightly higher 2003-2006 average species richness, with an average of 22 species versus 19 in John Hart Lake; this trend was also observed seasonally. In general, zooplankton concentrations were low in both lakes, which is typical of oligotrophic lakes.

Table 12. Seasonal averages of total number of species and total organisms/sample for all zooplankton 2003 – 2006 data for John Hart Lake and McIvor Lake .

		John Hart Lake					**McIvor Lake**				
		2003	2004	2005	2006	**AVG**	2003	2004	2005	2006	**AVG**
Total number of species	**March**	14	17	23	19	**18**	21	18	9	40	**22**
	May	16	20	22		**19**	20	22	19		**20**
	August	19	18	21		**19**	22	25	21		**23**
	Sept/Oct	18	21	21		**20**	22	26	21		**23**
	YEARLY AVG	17	19	22	19	**19**	21	23	18	40	**22**
Total number of organisms per sample	**March**	2,555	6,902	3,521	3,909	**4,222**	6,360	8,857	887	8,429	**6,133**
	May	14,168	6,700	7,805		**9,558**	13,204	7,907	3,599		**8,237**
	August	13,443	6,362	8,520		**9,441**	5,464	5,281	5,462		**5,403**
	Sept/Oct	4,675	6,737	1,548		**4,320**	6,555	7,823	5,717		**6,698**
	YEARLY AVG	8,710	6,675	5,348	3,909	**6,885**	7,895	7,467	3,916	8,429	**6,618**

The zooplankton community of both John Hart Lake and McIvor Lake was composed predominately of four groups: rotifers, cladocerans, calanoid copepods and cyclopoid copepods. In John Hart Lake, the zooplankton community was dominated by three rotifer genera: *Keratella cochlearis*, *Polyarthra*, and *Synchaeta*. In McIvor Lake the zooplankton community was also dominated by *K. cochlearis* and *Polyarthra*, but not *Synchaeta*. *Keratella* and *Polyartha* species are known to be cold water rotifers and develop maximal population densities in midwinter to early spring (Wetzel, 2001); they were amongst the most dominant genera in both lakes throughout the year. Two other rotifer genera, *Callotheca* and *Conochilus*, were amongst the dominant genera in John Hart Lake in September of 2003 and 2004 only. In September 2004, *Callotheca* was also amongst the dominant genera in McIvor Lake, while *Conochilus* was amongst the dominant genera in McIvor Lake in September 2003 and May 2005 only. Their absence in the fall of 2005 in both lakes is probably due to that samples were collected slightly later, in October, of that year. During the spring, copepod nauplii (newly hatched copepods) were also very prevalent, dominating the zooplankton population in McIvor Lake all years and in John Hart Lake in 2003 and 2006 only (though it was amongst the dominant species each year). The cyclopoid copepod *Diacyclops thomasi*, unidentified calanoid copepods, the cladoceran *Daphnia rosea* and the rotifers *Ascomorpha* sp., *Kellicottia longispina* and *Ptygura* sp. were amongst the dominant species in McIvor Lake but not in John Hart Lake. In John Hart Lake the dominant species in the zooplankton community show less variation throughout the year, likely due to lack of stratification in the lake as a result of its high flushing rate. The zooplankton communities observed in John Hart Lake and McIvor Lake are consistent with oligotrophic conditions (Wetzel, 2001) and watershed characteristics (Deniseger et al., 1988, Nordin et al., 1985); therefore, no objective is recommended for zooplankton at this time.

7.0 SUMMARY OF PROPOSED WATER QUALITY OBJECTIVES AND MONITORING SCHEDULE

In BC, water quality objectives are based mainly on approved or working water quality guidelines. These guidelines are established to prevent specified detrimental effects from occurring with respect to a designated water use. Designated water uses for John Hart Lake and McIvor Lake that are sensitive and should be protected are drinking water, irrigation, recreation, wildlife and aquatic life. The water quality objectives recommended here (Table 13) take into account background conditions, impacts from current land use and any known potential future impacts that may arise within the watershed. These objectives should be periodically reviewed and revised to reflect any future improvements or technological advancements in water quality assessment and analysis.

Table 13. Summary of proposed water quality objectives for John Hart Lake and McIvor Lake.

Variable	Objective Value
Water temperature	≤ 15°C summer maximum (>15 m depth)
Secchi depth	Annual average ≥ 8 m
Dissolved oxygen	≥ 5 mg/L 1 m above substrate
***Escherichia coli* bacteria**	≤10 CFU/100 mL (90th percentile) with a minimum 5 weekly samples collected over a 30-day period
Turbidity	≤ 2.0 NTU maximum 5 m above substrate
Total phosphorus	≤5 µg/L average during epilimnetic growing season (May – September)
Total cadmium	≤ 0.01 µg/L average
Total copper	≤ 4 µg/L maximum, ≤ 2 µg/L average (minimum 5 weekly samples collected over a 30-day period)
Total zinc	≤ 33 µg/L maximum, ≤ 7.5 µg/L average (minimum 5 weekly samples collected over a 30-day period)
Chlorophyll *a*	≤ 1.5 µg/L chlorophyll *a* maximum, eplimnetic growing season

The recommended water quality monitoring program for John Hart Lake and McIvor Lake is summarized in Table 14. It is recommended that future attainment monitoring occur once every 3-5 years based on staff and funding availability, and whether activities, such as forestry or development, are underway within the watershed. Water quality parameters to monitor include some that are supplemental to core water quality objectives monitoring.

Table 14. Proposed schedule for future water quality and benthic invertebrate monitoring in John Hart Lake and McIvor Lake.

Frequency and timing	Characteristic to be measured	Site
Quarterly sampling (once each season, including spring overturn)	Profile (every metre): temperature, pH, dissolved oxygen, specific conductivity, oxidation-reduction potential (ORP) Secchi depth Grab samples (three depths per site: surface, 10 m and 1 m from bottom): pH, specific conductivity, colour, turbidity, TOC, DOC, total phosphorous, nitrogen species, total and dissolved metals, hardness, Chlorophyll *a* (surface only)	Deep Stations: E259337, E207156
Summer and fall (once a week for five consecutive weeks)	*E. coli*, total and dissolved metals	Inlet and outlet: E252669, 1130020; future intake in Lower Campbell Lake 50°00’21.23”N, 125°24’04.91” W)
Twice per year (summer and spring overturn)	Phytoplankton and zooplankton	Deep Stations: E259337, E207156

In order to capture the periods where water quality concerns are most likely to occur (*i.e.*, freshet and summer low-flow) we recommend that, at the John Hart Lake Inlet and Outlet sites and at the future intake in Lower Campbell Lake a minimum of five weekly samples be collected within a 30 day period between August and September, as well as between October and November. Samples collected during the winter months should coincide with rain events whenever possible. In this way, the two critical periods (maximum residence time/minimum dilution and maximum turbidity), will be monitored. Samples should be analyzed for total and dissolved metals and bacteriology (including *E. coli*).

In addition, at the deep station sites in each lake, quarterly monitoring (including spring overturn sampling) should occur. Grab samples (three depths per site – surface, 10 m and 1 m from bottom) should be collected and analyzed as listed in Table 14. One spring overturn and one summer sample date should include phytoplankton and zooplankton samples. Quarterly depth profiles (data collected at each metre) should be taken including temperature, pH, dissolved oxygen, conductivity and oxidation-reduction potential.

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APPENDIX I. SUMMARY OF WATER QUALITY DATA

Table 15. Summary of general water chemistry at Site 1130020, John Hart Lake near Pumphouse (outlet).

Parameter	Min	Max	Average	StdDev	Number of Samples
Ag-D (mg/L)	<0.00002	<0.00002	<0.00002	0	16
Ag-T (mg/L)	<0.00002	<0.00002	<0.00002	0	16
Al-D (mg/L)	0.0047	0.0103	0.0074	0.0016	16
Al-T (mg/L)	0.0058	0.021	0.0118	0.0036	16
As-D (mg/L)	<0.0001	0.0001	0.0001	0.0000	16
As-T (mg/L)	<0.0001	0.0002	0.0001	0.0000	16
Ba-D (mg/L)	0.00229	0.00301	0.00262	0.00019	16
Ba-T (mg/L)	0.0025	0.00327	0.00278	0.00024	16
Be-D (mg/L)	<0.00002	0.00004	0.00002	0.00001	16
Be-T (mg/L)	<0.00002	0.00003	0.00002	0.00000	16
Bi-D (mg/L)	<0.00002	<0.00002	<0.00002	0	16
Bi-T (mg/L)	<0.00002	<0.00002	<0.00002	0	16
Ca-D (mg/L)	6.34	8.6	7.83	0.68	16
Ca-T (mg/L)	6.81	8.67	7.85	0.50	16
Cd-D (mg/L)	<0.00001	0.00062	0.00009	0.00017	16
Cd-T (mg/L)	0.00001	0.00061	0.00011	0.00018	16
Co-D (mg/L)	<0.000005	0.000008	0.000005	0.000001	16
Co-T (mg/L)	<0.000005	0.000017	0.000008	0.000004	16
Cr-D (mg/L)	<0.0002	0.0003	0.0002	0.0000	16
Cr-T (mg/L)	<0.0002	0.0003	0.0002	0.0000	16
Cu-D (mg/L)	0.00052	0.00437	0.00185	0.00116	16
Cu-T (mg/L)	0.00059	0.00539	0.00238	0.00146	16
Li-D (mg/L)	<0.00005	0.00019	0.00007	0.00004	16
Li-T (mg/L)	<0.00005	0.00021	0.00009	0.00006	16
Mg-D (mg/L)	0.72	0.88	0.82	0.04	16
Mg-T (mg/L)	0.73	0.87	0.81	0.04	16
Mn-D (mg/L)	0.000014	0.0036	0.00094	0.00117	16
Mn-T (mg/L)	0.00272	0.0118	0.0048	0.0022	16
Mo-D (mg/L)	0.00012	0.0002	0.00014	0.00002	16
Mo-T (mg/L)	0.00013	0.00022	0.00015	0.00002	16
Ni-T (mg/L)	<0.00005	0.00034	0.00017	0.00010	16
Ni-D (mg/L)	<0.00005	0.00032	0.00014	0.00008	16
Pb-D (mg/L)	<0.00001	0.00018	0.00005	0.00005	16
Pb-T (mg/L)	0.00001	0.0005	0.00021	0.00017	16

Parameter	Min	Max	Average	StdDev	Number of Samples
Sb-D (mg/L)	0.000009	0.000027	0.000018	0.000005	16
Sb-T (mg/L)	0.000013	0.000032	0.000021	0.000004	16
Se-D (mg/L)	<0.0002	0.0004	0.0002	0.0001	16
Se-T (mg/L)	<0.0002	0.0003	0.0002	0.0000	16
Sn-D (mg/L)	<0.00001	<0.00001	<0.00001	0	16
Sn-T (mg/L)	<0.00001	0.00002	0.00001	0.00000	16
Sr-D (mg/L)	0.0104	0.0124	0.01138	0.00057	16
Sr-T (mg/L)	0.0111	0.0128	0.01178	0.00052	16
Tl-D (mg/L)	<0.000002	0.000002	0.000002	0.000000	16
Tl-T (mg/L)	<0.000002	0.000003	0.000002	0.000000	16
U--D (mg/L)	<0.000002	0.000008	0.000005	0.000001	16
U--T (mg/L)	<0.000002	0.000011	0.000007	0.000002	16
V--D (mg/L)	0.0001	0.00045	0.00020	0.00009	16
V--T (mg/L)	0.00012	0.00063	0.000256	0.000124	16
Zn-D (mg/L)	0.0026	0.0142	0.0059	0.0030	16
Zn-T (mg/L)	0.0035	0.0167	0.0072	0.0035	16
Alkalinity Total 4.5 (mg/L)	17.5	22.3	21.0	1.4	16
Carbon Total Organic (mg/L)	<0.5	2.5	1.3	0.6	15
Coli:Fec (CFU/100mL)	<1	8	1.8	1.9	17
E Coli (CFU/100mL)	<1	3	1.2	0.5	17
Hardness Total (D) (mg/L)	18.80	25.00	22.95	1.87	16
Hardness Total (T) (mg/L)	20.01	25.23	22.96	1.37	16
Residue Non-filterable (mg/L)	<1	4	1.4	1.0	16
Turbidity (NTU)	0.17	0.7	0.35	0.13	16

Table 16. Summary of general water chemistry at Site E259337, John Hart Lake mid-lake.

Parameter	Min	Max	Average	StdDev	Number of Samples
Ag-D (mg/L)	<0.00002	<0.00002	<0.00002	0	4
Ag-T (mg/L)	<0.00002	<0.00002	<0.00002	0	13
Al-D (mg/L)	0.0117	0.0157	0.0137	0.0023	4
Al-T (mg/L)	0.0099	0.0343	0.0158	0.0059	13
As-D (mg/L)	0.0001	0.0002	0.0002	0.0001	4
As-T (mg/L)	<0.0001	0.0002	0.0001	0.0001	13
Ba-D (mg/L)	0.00229	0.0026	0.00245	0.00013	4
Ba-T (mg/L)	0.00187	0.00354	0.00263	0.00042	13
Be-D (mg/L)	<0.00002	0.00005	0.00003	0.00002	4
Be-T (mg/L)	<0.00002	0.00003	0.00002	0.00000	13
Bi-D (mg/L)	<0.00002	<0.00002	<0.00002	0	4
Bi-T (mg/L)	<0.00002	<0.00002	<0.00002	0	13
C--T (mg/L)	5.9	8.1	7.1	0.7	7
Cd-D (mg/L)	<0.00001	0.00001	0.00001	0	4
Cd-T (mg/L)	0.00001	0.00006	0.00002	0.00001	13
Co-D (mg/L)	<0.000005	0.000010	0.000007	0.000002	4
Co-T (mg/L)	<0.000005	0.000017	0.000009	0.000004	13
Cr-D (mg/L)	<0.0002	0.0003	0.0003	0.0001	4
Cr-T (mg/L)	<0.0002	<0.0002	<0.0002	0.0000	13
Cu-D (mg/L)	0.00054	0.00076	0.00065	0.00012	4
Cu-T (mg/L)	0.00058	0.00123	0.00076	0.00017	13
Li-D (mg/L)	<0.00005	0.00019	0.00010	0.00007	4
Li-T (mg/L)	<0.00005	0.00059	0.00014	0.00016	13
Mn-D (mg/L)	0.00048	0.00317	0.00162	0.00135	4
Mn-T (mg/L)	0.00141	0.00586	0.00247	0.00117	13
Mo-D (mg/L)	0.00013	0.00014	0.000138	0.00001	4
Mo-T (mg/L)	0.00011	0.00016	0.00014	0.00001	13
Ni-D (mg/L)	<0.00005	0.00005	0.00005	0	4
Ni-T (mg/L)	<0.00005	0.00007	0.00005	0.00001	13
Pb-D (mg/L)	<0.00001	0.00005	0.00003	0.00002	4
Pb-T (mg/L)	<0.00001	0.00023	0.00005	0.00006	13
Sb-D (mg/L)	0.000017	0.000018	0.000018	0.000001	4
Sb-T (mg/L)	<0.000005	0.00002	0.000016	0.000004	13
Se-D (mg/L)	<0.0002	0.0003	0.0003	0.0001	4
Se-T (mg/L)	<0.0002	0.0004	0.0003	0.0001	13
Sn-D (mg/L)	<0.00001	0.00002	0.00001	0.00001	4
Sn-T (mg/L)	<0.00001	0.00003	0.00001	0.00001	13
Sr-D (mg/L)	0.0103	0.0109	0.0105	0.00028	4

Parameter	Min	Max	Average	StdDev	Number of Samples
Sr-T (mg/L)	0.00902	0.0121	0.01102	0.00094	13
Tl-D (mg/L)	<0.000002	<0.000002	<0.000002	0	4
Tl-T (mg/L)	<0.000002	0.000005	0.000002	0.000001	13
U--D (mg/L)	0.000006	0.000007	0.000007	0.000001	4
U--T (mg/L)	0.000005	0.000010	0.000007	0.000001	13
V--D (mg/L)	0.00017	0.00032	0.000245	0.00008	4
V--T (mg/L)	0.00018	0.00039	0.00028	0.00006	13
Zn-D (mg/L)	0.005	0.0066	0.0058	0.0007	4
Zn-T (mg/L)	0.0052	0.0326	0.0102	0.0080	13
Alkalinity Total 4.5 (mg/L)	17.3	29.6	19.4	3.9	9
Amonia Dissolved (mg/L)	<0.005	0.009	0.006	0.001	28
Carbon Dissolved Organic (mg/L)	0.7	2.4	1.5	0.8	6
Carbon Total Inorganic (mg/L)	4.9	7.4	5.5	0.9	7
Carbon Total Organic (mg/L)	0.5	2.1	1.5	0.7	9
Chlorophyll A (mg/L)	<0.0005	0.0015	0.0008	0.0004	12
Chlrid:D (mg/L)	0.8	1.1	0.9	0.1	5
Color True (Col.unit)	<5	<5	<5	0	5
Diss Oxy (mg/L)	7	13.87	11.21	1.28	194
ExtDepth (m)	7.5	12.5	9.6	1.6	8
Nitrate (NO3) Dissolved (mg/L)	0.02	0.039	0.031	0.010	5
Nitrate + Nitrite Diss. (mg/L)	0.003	0.044	0.024	0.013	28
Nitrogen (Kjel.) Tot Diss (mg/L)	0.03	0.12	0.06	0.03	11
Nitrogen - Nitrite Diss. (mg/L)	<0.002	0.002	0.002	0	5
Nitrogen Organic-Total (mg/L)	0.03	0.11	0.06	0.03	11
Nitrogen Total (mg/L)	0.03	0.17	0.08	0.03	28
Nitrogen Total Dissolved (mg/L)	0.063	0.163	0.094	0.030	11
ORP (mV)	353	444	387	28	194
Ortho-Phosphate Dissolved (mg/L)	0.004	0.005	0.005	0.001	2
P--T (mg/L)	<0.002	0.009	0.003	0.002	28
Phosphorus Tot. Dissolved (mg/L)	<0.002	0.007	0.003	0.001	26
Res:Tot (mg/L)	30	42	36	8	2
Residue Filterable 1.0u (mg/L)	26	38	32.4	5	5
Residue Non-filterable (mg/L)	-6	16	5	16	2
Silica:D (mg/L)	3	4.3	3.6	0.3	28
Specific Conductance (uS/cm)	38	54	45.4	3.7	194
Temp (C)	4.08	18.24	9.95	4.41	194
Turbidity (NTU)	0.3	0.9	0.43	0.23	7
pH (pH units)	6.13	7.5	6.85	0.44	176

Table 17. Summary of general water chemistry at Site E252669, John Hart Lake at Ladore Dam (inlet).

Parameter	Min	Max	Average	StdDev	Number of Samples
Ag-D (mg/L)	<0.00002	<0.00002	<0.00002	0	16
Ag-T (mg/L)	<0.00002	<0.00002	<0.00002	0	16
Al-D (mg/L)	0.0067	0.0119	0.0091	0.0018	16
Al-T (mg/L)	0.0092	0.0276	0.0153	0.0056	16
As-D (mg/L)	<0.0001	0.0002	0.0001	0.0000	16
As-T (mg/L)	<0.0001	0.0002	0.0001	0.0000	16
Ba-D (mg/L)	0.00204	0.00295	0.00260	0.00027	16
Ba-T (mg/L)	0.00215	0.00363	0.00278	0.00038	16
Be-D (mg/L)	<0.00002	0.00004	0.00002	0.00001	16
Be-T (mg/L)	<0.00002	0.00004	0.00002	0.00001	16
Bi-D (mg/L)	<0.00002	<0.00002	<0.00002	0	16
Bi-T (mg/L)	<0.00002	<0.00002	<0.00002	0	16
Ca-D (mg/L)	6.29	8.44	7.83	0.72	16
Ca-T (mg/L)	6.52	8.66	7.81	0.59	16
Cd-D (mg/L)	<0.00001	0.00075	0.00018	0.00024	16
Cd-T (mg/L)	0.00001	0.00087	0.00022	0.00027	16
Co-D (mg/L)	<0.000005	0.000007	0.000005	0.000001	16
Co-T (mg/L)	<0.000005	0.000014	0.000008	0.000003	16
Cr-D (mg/L)	<0.0002	0.0002	0.0002	0.0000	16
Cr-T (mg/L)	<0.0002	0.0003	0.0002	0.0000	16
Cu-D (mg/L)	0.00048	0.00287	0.00101	0.00063	16
Cu-T (mg/L)	0.00055	0.00294	0.00124	0.00068	16
Li-D (mg/L)	<0.00005	0.00017	0.00006	0.00003	16
Li-T (mg/L)	<0.00005	0.00022	0.00007	0.00005	16
Mg-D (mg/L)	0.7	0.87	0.82	0.05	16
Mg-T (mg/L)	0.68	0.87	0.80	0.04	16
Mn-D (mg/L)	<0.000008	0.00223	0.000256	0.000537	16
Mn-T (mg/L)	0.00118	0.00889	0.00363	0.00220	16
Mo-D (mg/L)	0.00011	0.00019	0.00014	0.00002	16
Mo-T (mg/L)	0.00013	0.00019	0.00016	0.00002	16
Ni-D (mg/L)	<0.00005	0.00039	0.00014	0.00009	16
Ni-T (mg/L)	<0.00005	0.00037	0.00018	0.00011	16
Pb-D (mg/L)	<0.00001	0.00006	0.00002	0.00001	16
Pb-T (mg/L)	<0.00001	0.00032	0.00006	0.00008	16
Sb-D (mg/L)	0.000013	0.000027	0.000019	0.000004	16
Sb-T (mg/L)	0.00001	0.000028	0.000019	0.000004	16
Se-D (mg/L)	<0.0002	0.0005	0.0002	0.0001	16
Se-T (mg/L)	<0.0002	0.0003	0.0002	0.0000	16

Parameter	Min	Max	Average	StdDev	Number of Samples
Sn-D (mg/L)	<0.00001	0.00002	0.00001	0.00000	16
Sn-T (mg/L)	<0.00001	0.00008	0.00002	0.00002	16
Sr-D (mg/L)	0.00964	0.0123	0.01123	0.00075	16
Sr-T (mg/L)	0.00995	0.0131	0.01167	0.00072	16
Tl-D (mg/L)	<0.000002	0.000004	0.000002	0.000001	16
Tl-T (mg/L)	<0.000002	0.000004	0.000002	0.000001	16
U--D (mg/L)	<0.000002	0.000009	0.000006	0.000002	16
U--T (mg/L)	<0.000002	0.000011	0.000007	0.000002	16
V--D (mg/L)	0.00013	0.00048	0.00024	0.00008	16
V--T (mg/L)	0.00016	0.00047	0.00027	0.00008	16
Zn-D (mg/L)	0.0021	0.0086	0.0045	0.0015	16
Zn-T (mg/L)	0.0039	0.0088	0.0056	0.0014	16
Alkalinity Total 4.5 (mg/L)	18.0	22.1	21.0	1.0	16
Carbon Total Organic (mg/L)	<0.5	2.6	1.2	0.6	15
Coli:Fec (CFU/100mL)	<1	38	5.1	10.7	17
E Coli (CFU/100mL)	1	20	2.4	4.6	17
Hardness Total (D) (mg/L)	18.59	25.00	22.92	2.00	16
Hardness Total (T) (mg/L)	19.08	25.21	22.79	1.60	16
Residue Non-filterable (mg/L)	<1	4	1.4	1.0	16
Turbidity (NTU)	0.2	1.39	0.43	0.29	16

Table 18. Summary of general water chemistry at Site E207156, McIvor Lake at deepest point.

Parameter	Min	Max	Average	StdDev	Number of Samples
Ag-D (mg/L)	<0.00002	<0.00002	<0.00002	0	4
Ag-T (mg/L)	<0.00002	<0.00002	<0.00002	0	13
Al-D (mg/L)	0.0061	0.0182	0.0098	0.0057	4
Al-T (mg/L)	0.0064	0.0198	0.0101	0.0038	13
As-D (mg/L)	0.0001	0.0002	0.0001	0.0001	4
As-T (mg/L)	<0.0001	0.0002	0.0001	0.0000	13
Ba-D (mg/L)	0.00229	0.00263	0.00249	0.00014	4
Ba-T (mg/L)	0.00186	0.00308	0.00262	0.00035	13
Be-D (mg/L)	<0.00002	0.00003	0.00002	0.00001	4
Be-T (mg/L)	<0.00002	0.00006	0.00002	0.00001	13
Bi-D (mg/L)	<0.00002	<0.00002	<0.00002	0	4
Bi-T (mg/L)	<0.00002	0.00003	0.00002	0.00000	13
C--T (mg/L)	5.3	8	6.5	1.1	7
Cd-D (mg/L)	<0.00001	0.0001	0.00003	0.00005	4
Cd-T (mg/L)	<0.00001	0.00011	0.00002	0.00003	13
Co-D (mg/L)	<0.000005	0.000013	0.000008	0.000004	4
Co-T (mg/L)	<0.000005	0.000039	0.000012	0.000012	13
Cr-D (mg/L)	<0.0002	0.0003	0.0002	0.0001	4
Cr-T (mg/L)	<0.0002	<0.0002	<0.0002	0.0000	13
Cu-D (mg/L)	0.00045	0.00096	0.00064	0.00022	4
Cu-T (mg/L)	0.00048	0.00103	0.00067	0.00017	13
Li-D (mg/L)	<0.00005	0.00016	0.00008	0.00006	4
Li-T (mg/L)	<0.00005	0.00041	0.00012	0.00012	13
Mn-D (mg/L)	0.000239	0.001850	0.001021	0.000900	4
Mn-T (mg/L)	0.000912	0.002670	0.001862	0.000504	13
Mo-D (mg/L)	0.00011	0.00018	0.00014	0.00003	4
Mo-T (mg/L)	0.00011	0.00016	0.00014	0.00001	13
Ni-D (mg/L)	<0.00005	0.00008	0.00006	0.00002	4
Ni-T (mg/L)	<0.00005	0.00019	0.00006	0.00004	13
Pb-D (mg/L)	<0.00001	0.00007	0.00003	0.00003	4
Pb-T (mg/L)	<0.00001	0.00014	0.00004	0.00004	13
Sb-D (mg/L)	0.000017	0.000021	0.000018	0.000002	4
Sb-T (mg/L)	<0.000005	0.000025	0.000017	0.000006	13
Se-D (mg/L)	0.0002	0.0003	0.0003	0.0001	4
Se-T (mg/L)	<0.0002	0.0004	0.0003	0.0001	13
Sn-D (mg/L)	<0.00001	0.00003	0.00002	0.00001	4
Sn-T (mg/L)	<0.00001	0.00004	0.00002	0.00001	13
Sr-D (mg/L)	0.0103	0.0105	0.0104	0.00008	4

Parameter	Min	Max	Average	StdDev	Number of Samples
Sr-T (mg/L)	0.00889	0.0127	0.01104	0.00103	13
Tl-D (mg/L)	<0.000002	<0.000002	<0.000002	0	4
Tl-T (mg/L)	<0.000002	0.000003	0.000002	0.000000	13
U--D (mg/L)	0.000004	0.000009	0.000006	0.000002	4
U--T (mg/L)	0.000004	0.000011	0.000006	0.000002	13
V--D (mg/L)	0.00008	0.00023	0.00018	0.00007	4
V--T (mg/L)	0.00008	0.00031	0.00022	0.00006	13
Zn-D (mg/L)	0.004	0.0096	0.0057	0.0026	4
Zn-T (mg/L)	0.0045	0.0261	0.0090	0.0074	13
Alkalinity Total 4.5 (mg/L)	17.5	23.2	19.7	1.8	9
Amonia Dissolved (mg/L)	<0.005	0.016	0.006	0.003	28
Carbon Dissolved Organic (mg/L)	0.7	2.2	1.5	0.6	6
Carbon Total Inorganic (mg/L)	4.4	6.2	5.4	0.7	7
Carbon Total Organic (mg/L)	0.6	2	1.1	0.5	9
Chlorophyll A (mg/L)	<0.0005	0.0013	0.0008	0.0003	11
Chlrid:D (mg/L)	0.9	1	0.9	0.1	5
Color True (Col.unit)	<5	<5	<5	0	5
Diss Oxy (mg/L)	7.67	14.13	11.23	1.26	218
ExtDepth (m)	8	10	9.2	1.1	5
Nitrate (NO3) Dissolved (mg/L)	0.038	0.060	0.043	0.009	5
Nitrate + Nitrite Diss. (mg/L)	<0.002	0.080	0.028	0.020	28
Nitrogen (Kjel.) Tot Diss (mg/L)	0.03	0.08	0.05	0.01	11
Nitrogen - Nitrite Diss. (mg/L)	<0.002	0.004	0.002	0.001	5
Nitrogen Organic-Total (mg/L)	0.03	0.07	0.05	0.01	11
Nitrogen Total (mg/L)	0.04	0.12	0.08	0.02	28
Nitrogen Total Dissolved (mg/L)	0.06	0.123	0.091	0.020	11
ORP (mV)	314	427	386	24	218
Ortho-Phosphate Dissolved (mg/L)	0.002	0.007	0.004	0.002	4
P--T (mg/L)	<0.002	0.006	0.003	0.001	28
Phosphorus Tot. Dissolved (mg/L)	<0.002	0.004	0.002	0.000	26
Res:Tot (mg/L)	24	30	27	4	2
Residue Filterable 1.0u (mg/L)	22	38	29	6	5
Residue Non-filterable (mg/L)	-14	-2	-8	8.5	2
Silica:D (mg/L)	3.2	4	3.5	0.3	28
Specific Conductance (uS/cm)	37.7	52	44.7	3.3	218
Temp (C)	3.88	21.37	8.85	4.97	218
Turbidity (NTU)	0.17	0.35	0.23	0.07	7
pH (pH units)	6.11	7.72	6.75	0.42	218