ENVIRONMENTAL PROTECTION DIVISION

ENVIRONMENTAL SUSTAINABILITY DIVISION

MINISTRY OF ENVIRONMENT

Water Quality Assessment and Objectives for Cowichan Lake

TECHNICAL REPORT

June 2011

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EXECUTIVE SUMMARY

This document presents a summary of the ambient water quality of Cowichan Lake, near the Town of Lake Cowichan, 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.

Cowichan Lake is the second largest lake on Vancouver Island, with a surface area of 6,204 ha. Cowichan Lake provides drinking water to the Town of Lake Cowichan, the Cowichan Valley Regional District, and there are numerous domestic drinking water licenses for both Cowichan Lake and the Cowichan River. Catalyst Paper Crofton Division has a weir at the east end of the lake. The lake water levels are controlled to ensure sufficient flows for the low flow fisheries period in late summer/early fall downstream in Cowichan River. The Cowichan watershed supports an abundance and diversity of both anadromous and resident salmonids that is unrivalled on Vancouver Island. Cowichan Lake also provides significant recreational opportunities (fishing, swimming, camping and boating) and wildlife habitat. These activities, as well as forestry, residential and historical mining activities, all potentially affect water quality in Cowichan Lake.

Water quality monitoring was conducted between 2008 and 2009. The results of this monitoring indicate the lake is oligotrophic and the overall state of the water quality is very good. All chemical, physical and biological parameters in the lake meet provincial water quality guidelines with the exception of microbiological indicators which exceeded drinking water guidelines on occasion near Youbou (site 2) and the marina. Furthermore, of the 11 tributary streams entering Cowichan Lake, three (Mckay Creek, Robertson Creek and Sutton Creek) had elevated turbidity and TSS concentrations following a rainstorm event.

In order to maintain and protect the water quality in Cowichan Lake, ambient water quality objectives were set for temperature, dissolved oxygen, water clarity (Secchi depth), total phosphorus, chlorophyll *a*, turbidity, TOC, and *E. coli*. In addition, turbidity

and total suspended solids objectives were recommended for the tributaries to Cowichan Lake.

Future monitoring recommendations include attainment monitoring at all three deep basin sites, 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 and also include microbiological indicators at the 12 perimeter sites during the summer low flow and fall flush period (five weekly samples in 30 days). Turbidity and TSS samples should be collected at the 11 tributary sites once weekly for five consecutive weeks in a 30 day period during the fall freshet. In addition, future monitoring should be considered at the Town of Lake Cowichan's water intake location, primarily for *E. coli*.

Water Quality Objectives for Cowichan Lake

Variable	Objective Value
Water temperature	≤ 15°C summer maximum hypolimnetic temperature (> 10m depth)
Dissolved oxygen	≥ 5 mg/L at any depth throughout the year
Secchi Depth	≥ 6.0 m minimum, ≥ 8.0 m average
Turbidity – lake sites	≤ 2 NTU maximum
Turbidity - tributaries	Max of 5 NTU; average of 2 NTU with a minimum 5 weekly samples collected over a 30-day period
TSS - tributaries	Max 26 mg/L; average of 6 mg/L with a minimum 5 weekly samples collected over a 30-day period
Total organic carbon	≤ 4 mg/L maximum
***E. coli* bacteria**	≤10 CFU/100 mL (90^{th} percentile) with a minimum 5 weekly samples collected over a 30-day period
Chlorophyll *a*	≤ 2 µg/L

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ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

The 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 longer term trends, and to establish ambient water quality objectives on a watershed specific basis. Water quality objectives provide goals that help ensure protection of designated water uses. The implementation 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 policy 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 (<500km^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 climate, geology, soils, and hydrology (see 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, 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. Watershed objectives will be developed for each of the representative lake and stream watersheds based on this 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. Overview 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 as well as by stewardship groups has enabled the Ministry to significantly increase the number of watersheds studied, as well as increase 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, and have resulted in strong relationships with local government and interest groups, provided valuable input and local support and, ultimately, have resulted in a more effective monitoring program.

This report examines the water quality of Cowichan Lake in 2008 and recommends water quality objectives for the lake based on potential impacts and water quality parameters of concern. Cowichan Lake is the second largest lake on Vancouver Island, and supports important fisheries and recreation values. Cowichan Lake provides drinking water to the Town of Lake Cowichan, as well as the Cowichan Valley Regional District. There are also numerous domestic drinking water licences for both Cowichan Lake and the Cowichan River. While Cowichan Lake is not a designated community watershed (under the *Forest and Range Practices Act)*, the MOE uses other tools, such as water quality objectives, and legislation, such as the *Private Managed Forest Land Act* and the *Drinking Water Protection Act*, to ensure that all watersheds and /or water supplies are managed in a consistent manner and to protect water quality within these watersheds.

The Cowichan River was designated a Canadian Heritage River in 2004 (one of only three rivers designated in British Columbia), based on its outstanding natural, cultural and recreational values. Cowichan Lake is part of the Cowichan River watershed, which includes Mesachie Lake, Bear Lake and Beaver Lake in the upper watershed, and a large number of tributary streams (Figure 2). The Cowichan River drains Cowichan Lake, entering the Strait of Georgia at Cowichan Bay. The Koksilah River is a tributary to the Cowichan River downstream from Cowichan Lake, entering the Cowichan River about 1.5 km upstream from its confluence with Cowichan Bay.

The Cowichan watershed supports an abundance and diversity of both anadromous and resident salmonids that is unrivalled on Vancouver Island.

Anthropogenic land uses within the watershed include recreational use, forestry, residential use, and historical mining activities. These activities, as well as natural erosion and the presence of wildlife, all potentially affect water quality in Cowichan Lake.

The project consisted of five phases: collecting water quality data, gathering information on water use and land use activities within the watershed, assessing water quality based on land use influences, establishing water quality objectives and making monitoring recommendations.

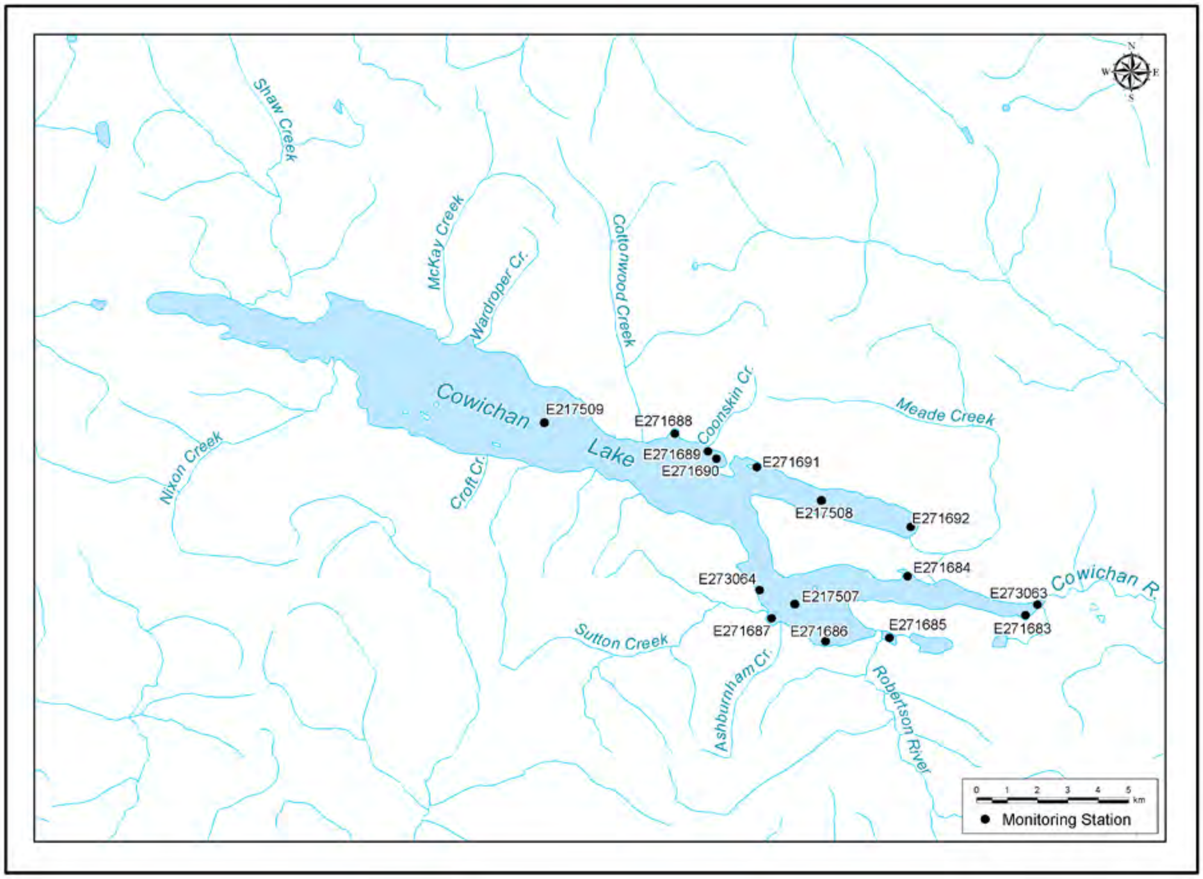

Figure 2. Overview Map of Cowichan Lake, including sampling locations.

2.0 WATERSHED PROFILE AND HYDROLOGY

2.1 BASIN PROFILE

The Cowichan River watershed, which contains Cowichan Lake, is relatively large, at approximately 1,227 km^2 in area. The Cowichan River is 50 km in length and is a fifth-order stream. The elevation of Cowichan Lake is 164 m, with elevations within the watershed ranging from slightly over 1,500 m on the northern side of the lake at Mount Landale, to sea level where it enters the Strait of Georgia at Cowichan Bay. Cowichan Lake is the second-largest lake on Vancouver Island (slightly smaller than Kennedy Lake, north of Ucluelet), with a surface area of

6,204 ha, a perimeter of 110 km, a maximum depth of 152 m, and a mean depth of 50 m (FISS 2010) (Figure 3a and 3b).

The Cowichan River watershed falls within the Coastal Western Hemlock biogeoclimatic zone (western very dry maritime, CWHxm2), with higher elevations passing through Mountain Hemlock (windward moist maritime, MHmm1) and Coastal Mountain-heather alpine (CMAunp). Cowichan Lake is in the Leeward Island Mountains (LIM) ecoregion of Vancouver Island (Figure 1).

The underlying geology of Cowichan Lake is described as the Nanaimo Group. It is composed of sedimentary rocks from the Upper Cretaceous Period, and described as boulder, cobble and pebble conglomerate, coarse to fine sandstone, siltstone, shale, and coal (BCWRA 2010).

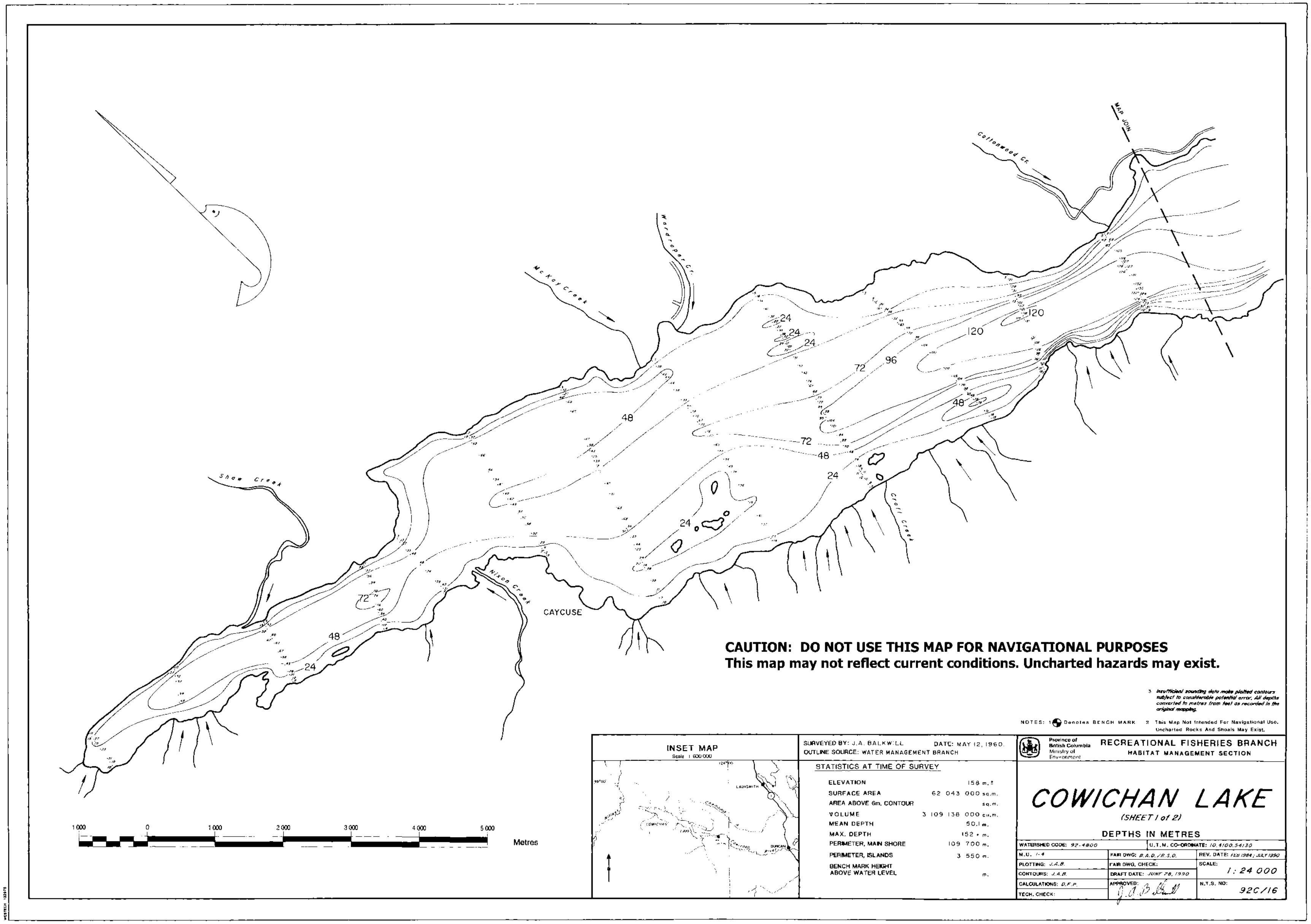

Figure 3a. Bathymetric map of east end of Cowichan Lake (source: http://www.fishwizard.com).

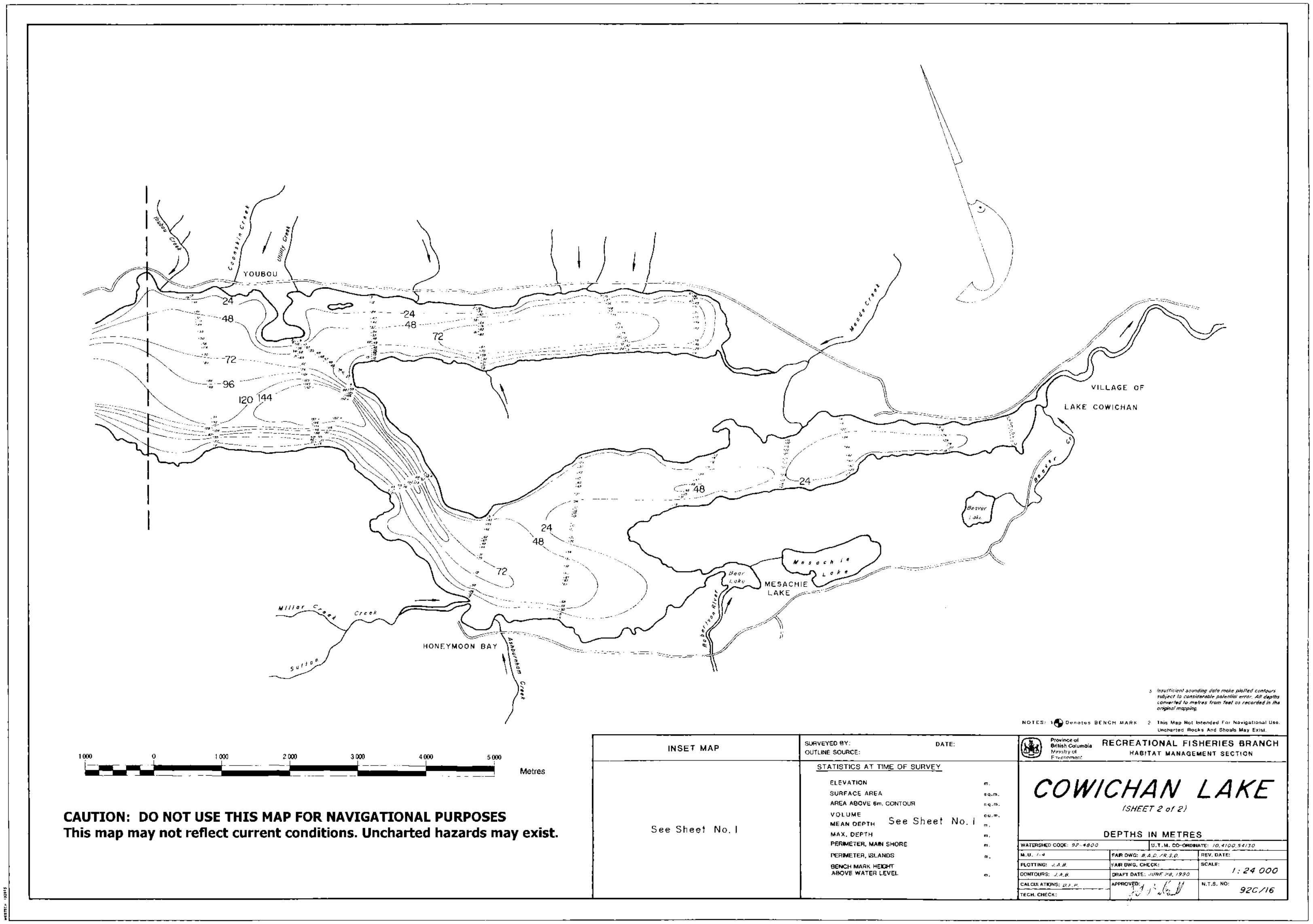

Figure 3b. Bathymetric map of west end of Cowichan Lake, (source: http://www.fishwizard.com).

2.2 HYDROLOGY AND PRECIPITATION

Water levels in Cowichan Lake are controlled by the Catalyst Paper Crofton Division's weir at the east end of the lake. These levels are guided by a "rule curve" originally developed between then-licensee Norske Canada and the MOE Water Management Branch. A "rule curve" is a set of target water levels that vary over the year to accommodate normal hydrologic patterns and water management priorities within a specific water body. Currently both provincial and federal fisheries agencies are in partnership with Catalyst and the Ministry of Forests, Lands and Natural Resource Operations (Water Stewardship Division) to release pulses of water from the weir for low flow fisheries concerns.

Water Survey Canada (WSC) operated a hydrometric station on Cowichan Lake between 1913 and 1921, and then again between 1954 and 2007 (WSC Station 08HA009). Minimum, maximum and average daily levels (in metres above sea level) are shown in Figure 4. The maximum daily water level measured was 165.388 m above sea level (asl) on January 21, 1968, while the minimum level was 161.029 m asl on September 30, 1915. In general, water levels are highest during the winter and lowest during the summer.

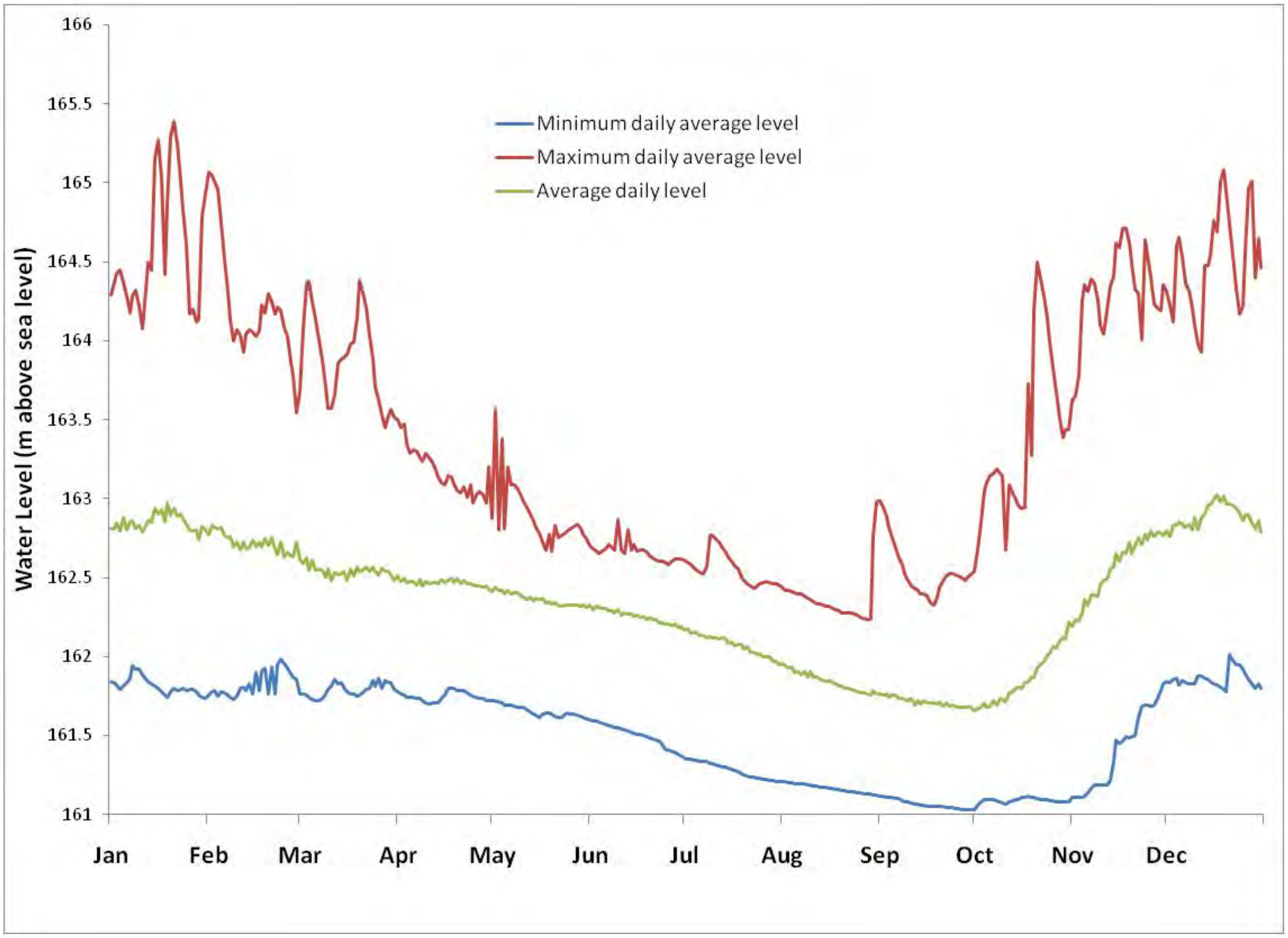

Figure 4. Minimum, maximum and average daily water levels for Cowichan Lake (Water Survey Canada Station 08HA009) between 1913 and 2007 (Water Survey Canada Hydat Data, 2010).

Water Survey Canada also operates a hydrometric station on the Cowichan River downstream from the Cowichan Lake weir (WSC Station 08HA002). Minimum, maximum and average daily discharges between 1913 and 2007 are shown in Figure 5.

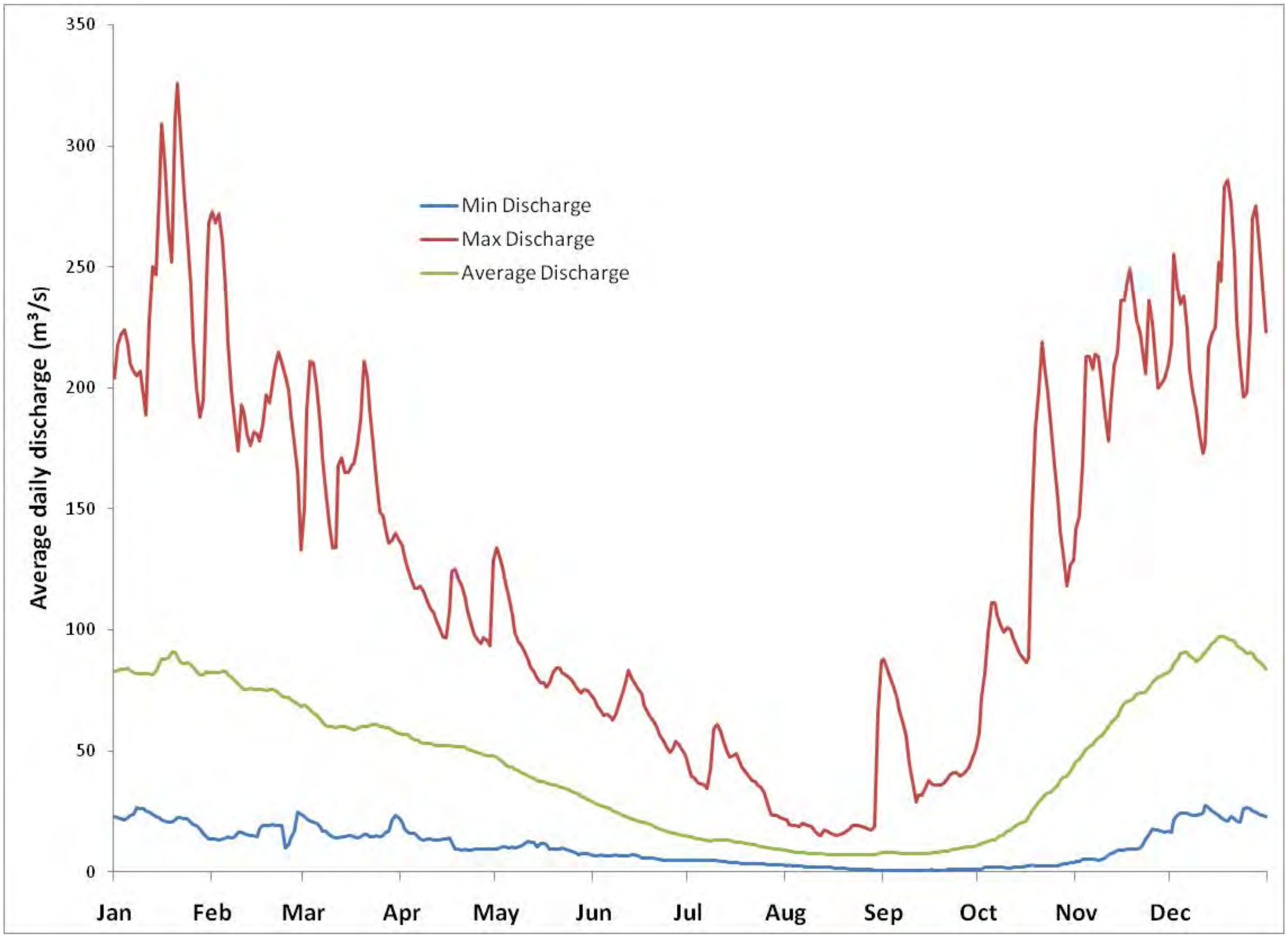

Figure 5. Minimum, maximum and average daily water levels for the Cowichan River below the Cowichan Lake weir (Water Survey Canada Station 08HA002) between 1913 and 2007 (Water Survey Canada Hydat Data, 2010).

The nearest climate station to the watershed for which climate normal data (1971 – 2000) are available is the Cowichan Lake Forestry station (elevation 176.8 m) (Environment Canada Climate Station 1012040). Average daily temperatures range from 2.6°C in January to 17.9°C in August. Average total annual precipitation is 2,170 mm, with 111.7 mm (water equivalent) (6%) of this falling as snow (Figure 6). Most precipitation (1749.3 mm, or 81%) falls between October and March, resulting in peak water levels during this period.

Snowpack in the watershed reaches a maximum between April and May, and snowmelt contributes to spring freshet and summer flows.

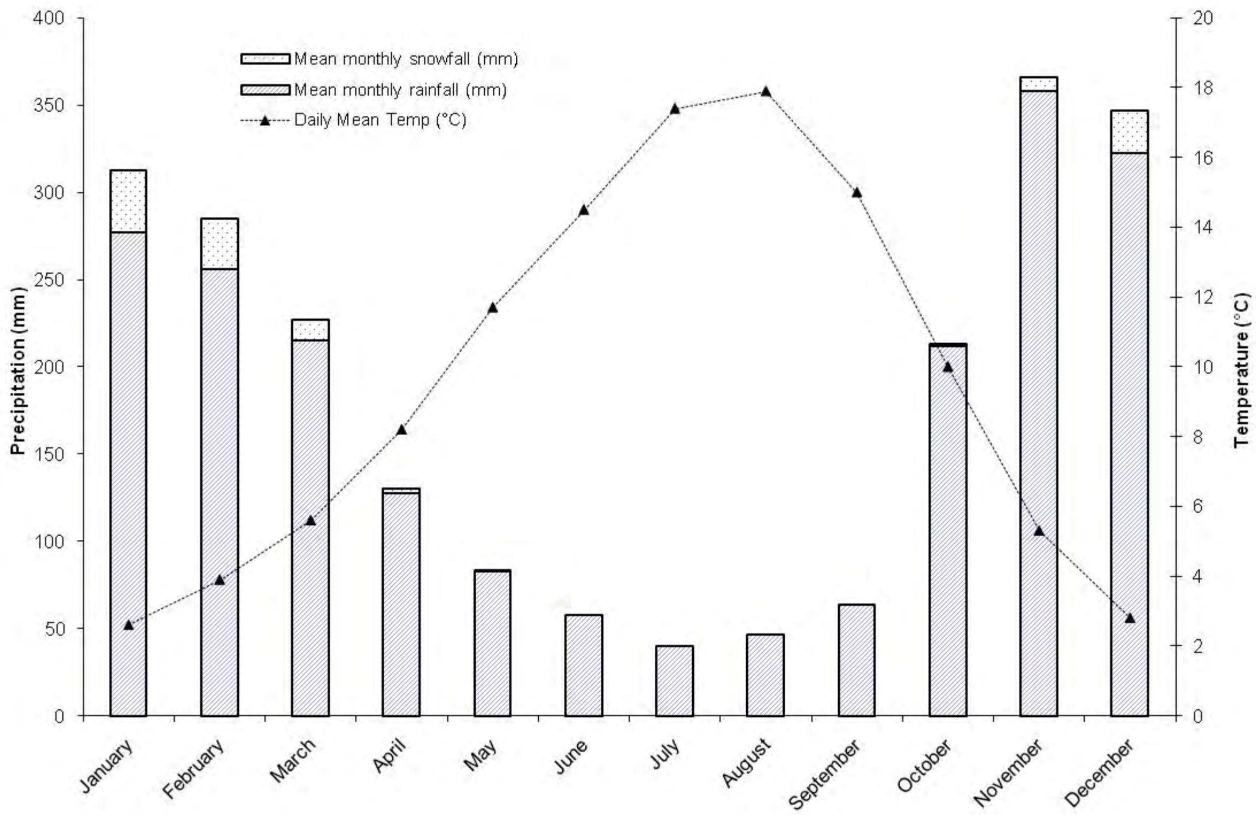

Figure 6. Climate data (1971 – 2000) for Cowichan Lake (Environment Canada Climate Station 1012040).

3.0 WATER USES

3.1 WATER LICENSES

Drinking water supply is an important water use in this watershed. The Town of Lake Cowichan (population approximately 3,000 people) and the Cowichan Valley Regional District (CVRD) both have water licenses to remove water from Cowichan Lake for waterworks purposes. Until 2009, the CVRD supplied approximately half of the water for the Honeymoon Bay Water System (about 45.5 dam^3/a) from Cowichan Lake, and the remainder from Ashburnham Creek. In 2009 they switched to a groundwater system, with water from Cowichan Lake as a backup system (Knodel-Joy, 2010 pers. comm.). In addition to the waterworks licenses, there are a number of domestic licenses allowing individuals to withdraw water for domestic use (including drinking water), and irrigation purposes. There are also a number of water licenses issued on the Cowichan River, for domestic and irrigation purposes, and the Catalyst Paper pulp mill in Crofton. Storage within Cowichan Lake is licensed to Catalyst Paper under their licenses on the Cowichan River. A summary of the water licenses issued for Cowichan Lake and Cowichan River is provided in Table 1 and Table 2, respectively.

Table 1. Summary of licensed water withdrawals from Cowichan Lake.

Use	**No. Licensed Withdrawals**	**Total Volume (dam^3/a)**	**Principal Licensee**
Domestic	47	47	Various
Enterprise	2	9	Saseenos Bay and Opus 10 resorts
Irrigation	3	26	Various
Land Improvement	1	2	Owners of Strata Plan VIS4663
Waterworks Local Authority	6	2,408	Town of Cowichan Lake and CVRD

Table 2. Summary of licensed water withdrawals from Cowichan River.

Use	No. Licensed Withdrawals	Total Volume (dam^3/a)	Principal Licensee
Conservation – construction works	1	2,208	Department of Fisheries and Oceans
Conservation – use of water	1	893	Department of Fisheries and Oceans
Domestic	16	18.25	Various
Irrigation	4	4	Various
Pulpmills	1	8,930	Catalyst Paper Corp.
Storage	2	61,305	Catalyst Paper Corp.

3.2 FISHERIES

The Cowichan watershed is world famous for its fishing, especially fly fishing. Anadromous species include chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), chum salmon (O. keta), and searun populations of winter-run steelhead (*O. mykiss*) and cutthroat trout (*O. clarki*). Resident species include brown trout (*Salmo trutta*), Dolly Varden char (*Salvelinus malma*), rainbow and cutthroat trout, and land-locked sockeye (kokanee) salmon (*O. nerka*) in Cowichan Lake. Smallmouth bass (*Micropterus dolomieu*), brown catfish (formerly brown bullhead) (*Ameiurus nebulosus*), lake lamprey (*Lampetra macrostoma)*, pacific lamprey (*L. tridentate*), prickly sculpin (*Cottus asper*), threespine stickleback (*Gasterostreus aculeatus*), and western brook lamprey (*L. richardsoni*) are also found in Cowichan Lake (FISS 2010). Life histories of both anadromous and resident salmonids are described in Lill, et al. (1975), and the Cowichan-Koksilah Water Management Plan (Ministry of Environment and Parks 1986).

The outlet of Cowichan Lake is equipped by a fishway, and passage is controlled for fisheries management purposes. Skutz Falls (located approximately 20.5 km downstream from Cowichan Lake) has a vertical drop of about 5.5 m over a distance of 90 m, but a fish ladder was installed in 1955 to facilitate fish passage. Therefore, anadromous fish are able to travel between Cowichan Lake and the ocean. Between 2005 and 2008, more than 200,000 steelhead smolts were stocked in the Cowichan River (FISS, 2010).

3.3 RECREATION

Cowichan Lake is a very popular recreational area. The communities of Lake Cowichan (population 2,948), Youbou (population 734) and Honeymoon Bay (population 610) all rely heavily on tourism to support their economies, and their populations swell considerably during the summer months. There are also a number of cabins along the north-eastern shoreline of the lake, many of which have boat slips. As well, there are a number of designated campgrounds: Gordon Bay Provincial Campground near Honeymoon Bay (126 sites); the Lakeview Municipal Campground on the north shore west of the Town of Lake Cowichan (56 sites); Beaver Lake Resort on Beaver Lake (65 sites); Cowichan Lake RV Resort near Youbou (60 sites); Peters Pond Campground in Honeymoon Bay; four campsites maintained by TimberWest; and three campsites maintained by the BC Forestry Service. All of these campgrounds have beaches for swimming, and most have boat launches as well. The Cowichan Lake Education Center (CLEC), a full service conference and education facility, is located on the shores of Cowichan Lake just west of the Town of Lake Cowichan. Swimming, fishing and boating (power boats, canoes, and kayaks) are all very popular activities on the lake.

3.4 WILDLIFE AND PLANTS

The Cowichan Lake watershed provides habitat to a variety of species typical of west coast Vancouver Island, including Roosevelt elk, blacktail deer, black bear, cougar, and numerous other small mammals and birds. The BC Conservation Data Centre reports the presence of four blue-listed vascular plant species: Smith’s fairybells (*Prosartes smithii*); waterwort water-milfoil (*Myriophyllum quintense*); dwarf bramble (*Rubus lasiococcus)*; and California-tea (*Rupertia physodes*), as well as one red-listed plant species, the Olympic onion (*Allium crenulatum*) near Cowichan Lake (BCCDC, 2010). Cowichan Lake also contains a red-listed vertebrate species, the Cowichan Lake lamprey (*Lampretra macrostoma*). This species is found only in Cowichan and Mesachie lakes and nowhere else in the world, but populations appear to be relatively stable.

3.5 DESIGNATED WATER USES

Designated water uses are those water uses that are designated for protection in a watershed or waterbody. Water quality objectives are designed for the substances or conditions of concern in a watershed so that their attainment will protect the designated uses. Based on the preceding discussions, the water uses to be protected should include drinking water, irrigation, primary-contact recreation, and protection of wildlife and aquatic life. Water quality objectives are developed to protect the most sensitive water use at the site.

4.0 INFLUENCES ON WATER QUALITY

4.1 LAND OWNERSHIP

Almost all of the land surrounding Cowichan Lake is privately owned. In addition to the communities of Lake Cowichan, Youbou and Honeymoon Bay (as well as the smaller communities of Caycuse and Mesachie Lake), there are numerous private residences located along the lakeshore (primarily along the central southern shore and the north-eastern shore). Many of these residences have private boat docks, allowing them to moor their watercraft at their residences.

Potential impacts from residential and/or urban development generally involve potential runoff from properties (which may contain a variety of contaminants including pesticides, fertilizers, fecal material from domestic pets, etc.), oil and gasoline spills resulting from storage of fuel near the water and spills during refilling of watercraft, and septic material originating from faulty septic beds or sewage collection lines. Several large urban development proposals are planned for the Woodland shores and Youbou area over the next 10 years. These larger developments can also impact water quality through the proliferation of impervious surfaces and increased sediment loadings from land disturbance.

There are a number of public and private sewage systems in the communities and residences surrounding Cowichan Lake. The Town of Lake Cowichan has a municipal sewage collection and treatment system servicing the vast majority of residences and businesses within the Town boundaries. The sewage treatment system discharges into the Cowichan River downstream from Cowichan Lake, and so there would be no impact from this system on the quality of water in Lake Cowichan. However, there are a few residences (all properties on Greendale Road east of Nootka Crescent; the Cowichan Lake Education Centre (CLEC); and the community of South Shore Acres, located west of the CLEC) that still rely on septic systems to dispose of waste water.

Outside the Town of Lake Cowichan, the CVRD operates three sewer systems along the shores of Cowichan Lake. The Mesachie Lake sewer system services about 50 homes by gravity collection and primary treatment with large septic tanks and ground disposal. The system is in relatively poor condition but the CVRD plans to upgrade the system in the near future (Knodel-Joy, pers. comm. 2010).

The community of Youbou has a sewer system that was built in 2005/06 which is capable of servicing up to 76 homes using a septic tank effluent pump collection system, a recirculating textile filter, gravity drum-type filters, UV disinfection and ground disposal. This treatment is considered to be high quality secondary, exceeding Class B (Knodel-Joy, pers. comm. 2010). However not all residences in the Youbou area are hooked up to the sewage system so there is potential for septic contamination from failing or aged septic fields.

The Bald Mountain Sewer system, located on the land which separates the north and south arms of the lake, was completed in 2009 and will have capacity for 340 homes at potential build out, although no homes have been connected to date. It has gravity collection with a Saniterm Membrane Bioreactor Plant with the potential for three membranes, and ground disposal to rapid infiltration basins. The treatment is considered Class A (Knodel-Joy, pers. comm. 2010).

Two other notable sewer systems located on Cowichan Lake are privately operated: Marble Bay in the south arm, and the Stin-Qua strata in Honeymoon Bay. Residences outside of the areas discussed above rely on individual private septic systems.

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. This can have significant impacts on the success of spawning salmon, as well as the survival of juvenile salmonids. However, in the case of Cowichan Lake, Catalyst Paper releases water from the weir in accordance with the “rule curve” negotiated between then-licensee NorskeCanada and the MOE Water Management Branch. To ensure that there is sufficient water to allow releases during the low-flow season, Catalyst Paper has water licenses allowing them to store water in Cowichan Lake (see Section 3.1). Because of recent dry years, there has been a discussion between various proponents to raise the level of the weir, to ensure that there is sufficient water to release in the fall. This discussion has met with resistance from land-owners, who are concerned that higher water levels will impact their foreshore properties.

4.3 FOREST HARVESTING AND FOREST ROADS

Forestry activities can impact water 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 spring freshets. The improper construction of roads can change drainage patterns, destabilize slopes, and introduce high concentrations of sediment to streams.

Logging has historically occurred throughout much of the upper Cowichan Lake watershed, including a log dump at Honeymoon Bay. Today, the majority of forestry activity takes place on privately owned lands, and is therefore governed by the *Private Managed Forest Land Act*. As such, the forest management objective for water quality is to protect human drinking water, both during and after harvest. Managers are also required to retain sufficient streamside mature trees and understory vegetation to protect fish habitat (including water temperatures, channel stability, and stream bank stability).

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.

Cowichan Lake experiences high levels of recreational activity, primarily during the summer months. As discussed in Section 3.3, there are a large number of campgrounds and recreational properties surrounding the lake. 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 potentially impact water quality in a number of ways. Bacteriological contamination associated with campgrounds, 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, could all potentially impact water quality in Cowichan Lake.

Backcountry activities such as camping, ATV use, fishing and hunting all occur at various times of the year throughout the watershed. These land based activities also increase the risk of forest fires within the watershed, and their associated impacts on water quality. Potential 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).

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. In addition, warm-blooded animals may excrete pathogens 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 Cowichan Lake watershed contains valuable wildlife habitat, and provides a home for a wide variety of warm-blooded species, including large numbers of waterfowl. Therefore, a risk of fecal contamination from natural wildlife populations within the watershed does exist.

4.6 MINING

Mining activities can impact water quality by introducing high concentrations of metals to the watershed, depending on the location, and leaching of waste rock or adit discharges can contribute to acidification of the water. Mining activities generally result in road construction and land-clearing, which can change water movement patterns and result in increased turbidity levels.

Historically, there have been five mines within the upper Cowichan Lake watershed that have produced minerals (copper, gold, silver, lead, zinc, molybdenum, manganese, and rhodonite) including two near Gordon Bay Provincial Park (MINFILE, 2004). It is not known if these past producers are having any impact on water quality. There are also a relatively large number of showings all around the lake containing various minerals. However, these showings have not been developed, and if development were to occur, they would have to undergo a series of environmental impact assessments to ensure that watershed resources (including water quality) were not significantly impacted.

5.0 STUDY DETAILS

Three deep-water water quality monitoring sites were established in Cowichan Lake: one in the south arm, midway between Honeymoon Bay and Goat Island (Site E217507); one in the north arm (E217508), and one in the main basin approximately 4 km west of the Youbou mill (Site E217509) (see Figure 2). All sites were located mid-lake, in the deepest part of the basin. Sampling at the three lake basin sites was conducted in March and November, while the water column was mixed, and during May/June and August, when the water column was thermally stratified.

In addition to the deep-water sites, 12 perimeter sites were also established, to help identify specific areas of bacteriological concern and possibly give some indication as to the source of contamination (Table 3 and Figure 2). Bacteriological samples were collected weekly for five consecutive weeks during summer low flow (August/September) and fall flush (October/November) periods. The bacteriological monitoring sites were selected in areas closest to cabins and campgrounds as well as areas habituated by waterfowl, as these are the areas likely to have the highest bacteriological concentrations.

Finally, 11 inflow sites were established near the mouth of some of the larger tributaries, to determine if these are significantly impacting water quality in Cowichan Lake. Water samples at these sites were collected weekly for five consecutive weeks during fall flush (October/November) and analyzed for total suspended solids and turbidity. The 11 creeks were as follows: Robertson Creek, Ashburnham Creek, Sutton Creek, Croft Creek, Nixon Creek, Shaw Creek, McKay Creek, Wardropper Creek, Cottonwood Creek, Coonskin Creek and Meades Creek.

All samples were collected according to Resource Inventory Standards Committee (RISC) standards (Cavanagh et al., 1994).

Table 3. Description of bacteriological monitoring sites in Cowichan Lake.

Area	Site No.	EMS ID	Site Description	Location (Lat/Long)
East End	Site 1	E271683	Cowichan Lake – Marina	N48 29 29 W124 4 0
East End	Site 2	E271684	Cowichan Lake – Marble Bay	N48 50 0 W124 7 10
East End	Site 3	E273063	Cowichan Lake at Head of South Arm	N48 49 45 W124 4 14
Bear Lake	Site 4	E271685	Bear Lake – Lake Cowichan	N48 48 55 W124 7 42
Honeymoon Bay	Site 5	E271686	McKenzie Bay – Lake Cowichan	N48 48 53 W124 9 25
Honeymoon Bay	Site 6	E271687	Honeymoon Bay – Lake Cowichan	N48 49 19 W124 10 52
Honeymoon Bay	Site 7	E273064	Honeymoon Bay #2	N48 49 45 W124 11 22
North Arm	Site 8	E271688	Youbou #1 – Cottonwood Estates	N48 52 49 W124 13 10
North Arm	Site 9	E271689	Youbou #2 - West	N48 52 30 W124 12 18
North Arm	Site 10	E271690	Youbou #3 - East	N48 52 11 W124 12 14
North Arm	Site 11	E271691	Youbou #4 – Billy Goat Islands	N48 52 1 W124 11 9
North Arm	Site 12	E271692	Cowichan Lake – Sunset Beach	N48 51 35 W124 7 30

Water quality data were collected from May 2008 to March 2009 in Cowichan Lake. Grab samples were taken at three depths in the water column (0.5 m, 10 m and 1 m from the bottom) for the three deep stations and at the surface for the perimeter and inflow sites. Surface samples were collected by hand and water column samples were collected using a Van Dorn bottle. The deep station samples were analyzed for the following parameters:

- Physical: pH, true color, specific conductivity, turbidity, alkalinity, silica
- Carbon: total inorganic carbon, total organic carbon
- Nutrients: total phosphorus, nitrate, nitrite, ammonia, total Kjeldahl N

Depth profiles were conducted in the field at the deep water sites for dissolved oxygen, water temperature, oxidation-reduction potential (ORP), pH and conductivity using a Hydrolab Surveyor 4. Data were collected every metre between the surface and 15 m depth, and then, on most occasions, every five metres until the final reading was made just above the bottom (as deep as 70 m in the south arm, 80 m in the north arm, and 95 m in the main basin). Water clarity was measured at the deep stations on each sampling day using a 20 cm diameter Secchi disc.

Phytoplankton and chlorophyll *a* samples were collected by taking 1 L grab samples at a depth of 0.5 m at the deep stations. Chlorophyll *a* samples were field filtered using 0.45 µm filter paper and then analyzed at Maxxam Analytics Inc., Burnaby, BC. Phytoplankton samples were preserved with Lugol's solution and shipped on ice to the laboratory for identification and enumeration. Zooplankton samples were collected using a 10 m vertical tow in a Wisconsin-style net with a mouth area of 0.07 m^2, a net opening diameter of 0.5 m and a mesh size of 80 µm. Zooplankton samples were preserved with formalin and shipped on ice to the lab for identification and enumeration. Phytoplankton and zooplankton taxonomy was done by Fraser Environmental Services, in Surrey, British Columbia. All biological samples were collected following Ministry of Environment approved methods (Cavanagh et al., 1997).

Microbiological samples were collected at the surface only for all 12 near-shore sites and analyzed for fecal coliforms and *E. coli*. Bacteriological analyses were conducted by Cantest Laboratories in Burnaby, British Columbia. Geometric means were calculated using data from a minimum of 5 weekly samples over 30 consecutive days for each site.

6.0 WATER QUALITY ASSESSMENT AND OBJECTIVES

There are two sets of guidelines that are commonly used to determine the suitability of drinking water. The British Columbia water quality guidelines are used to assess the source of water prior to the point of diversion into a waterworks system. These BC guidelines are also used to protect other designated water uses such as aquatic life habitat and recreation. 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.

The *British Columbia 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 treatment processes. Currently the Town of Lake Cowichan and the CVRD treat drinking water through chlorine disinfection only prior to distribution, but it is unlikely that individual domestic water license holders treat water prior to using it in their homes. To effectively treat the water for viruses and parasites, such as *Cryptosporidium* and *Giardia*, the Town of Lake Cowichan and the CVRD may be required to provide additional disinfection such as UV or ozone and/or treatment such as filtration.

The data collected in this study are summarized in Appendix 1. Additional information collected by the Cowichan Lake and River Stewardship Committee as part of the BC Lake Stewardship and Monitoring Program were reviewed and incorporated where appropriate, such as secchi depth, water temperature and dissolved oxygen results (BCLSS, 2008).

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 most dense at about 4°C. In most lakes in BC, 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 (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 can increase chlorine demand and reduce the effects of the chlorination process. 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 Cowichan Lake was unstratified during the winter months (thus classifying it as a warm monomictic lake), with stratification beginning to occur sometime between March and May. By August, the water column was strongly stratified, with the thermocline occurring between 10 m and 20 m in depth. Hypolimnetic temperatures remained between 5°C and 8°C throughout the year, while epilimnetic temperatures reached as high as 21.8°C, at the south arm site. As the results for all three basins were similar only the main basin (Site E217509) data was used to depict seasonal variability (**Figure 7**).

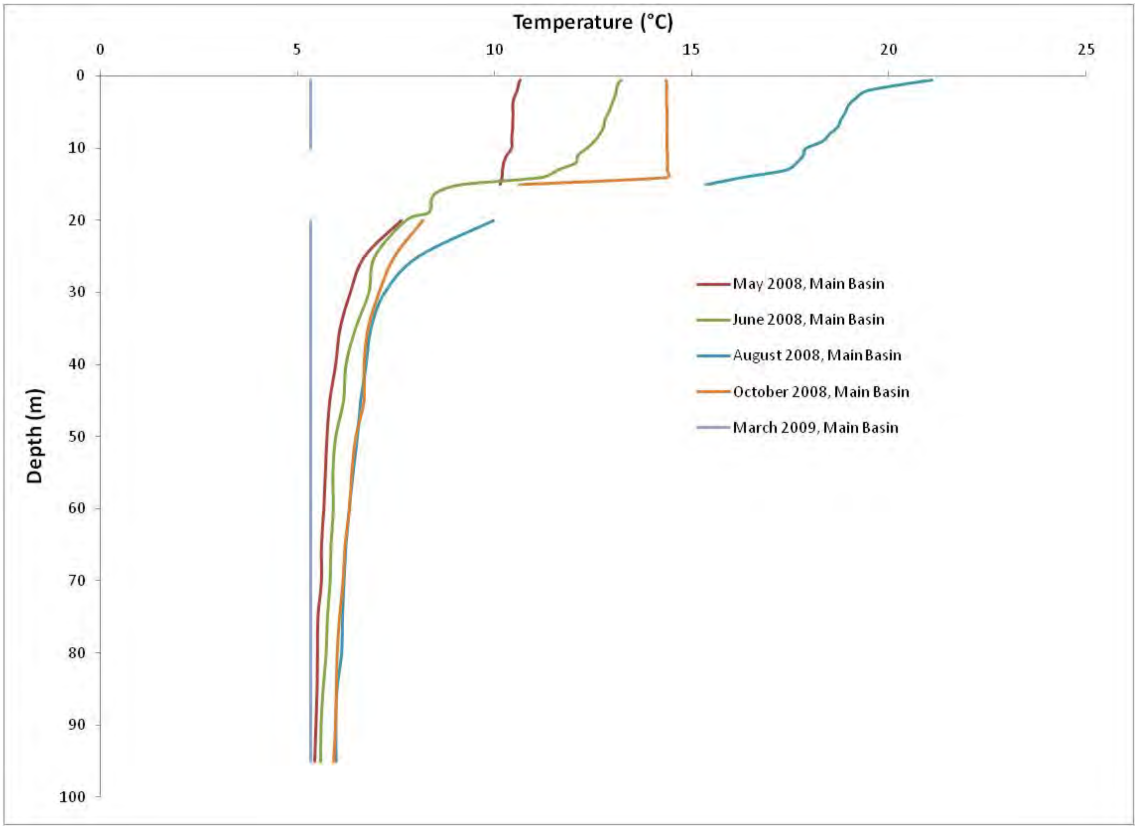

Figure 7. Seasonal water temperatures measured at 1m to 5 m metre intervals in Cowichan Lake in the main basin (Site E217509).

As surface water temperatures are regularly 20-22°C in July and 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 10 m in Cowichan Lake***. This objective would also ensure that the aesthetic drinking water guideline of 15°C would be met, provided that water intakes are located at least 10 m deep in the lake.

6.1.2 Dissolved Oxygen

Dissolved oxygen (DO) 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 DO 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 as a result of decomposition occurs. The guideline for the minimum instantaneous DO concentration for aquatic life is 5 mg/L (BC Ministry of Environment, 1997).

Dissolved oxygen concentrations were consistently at or near saturation levels in each of the three basins. As DO levels were similar for all three basins only the main basin (Site E217509) data was used to illustrate seasonal differences (Figure 8). In general, when the lake was thermally stratified, concentrations increased through the thermocline as water temperatures decreased (resulting in increased oxygen solubility). DO concentrations near the bottom of the lake decreased slightly throughout the year, with a minimum recorded value of 8.5 mg/L in each of the basins. Even when the lake was strongly stratified, oxygen concentrations in the deeper portion of the lake remained high, suggesting that there is low biological productivity and therefore low oxygen demand. As such, it does not appear that DO concentrations are a concern in Cowichan Lake at this time. However if activities such as forestry or land development increase in the watershed, there is the potential for increased nutrient loading and a resulting increase in lake productivity. The establishment of a water quality objective for DO would serve as an early warning sign for impact from future activities. Thus, the objective is that ***DO concentrations measured at any depth in each basin, should remain above 5 mg/L during the summer months.***

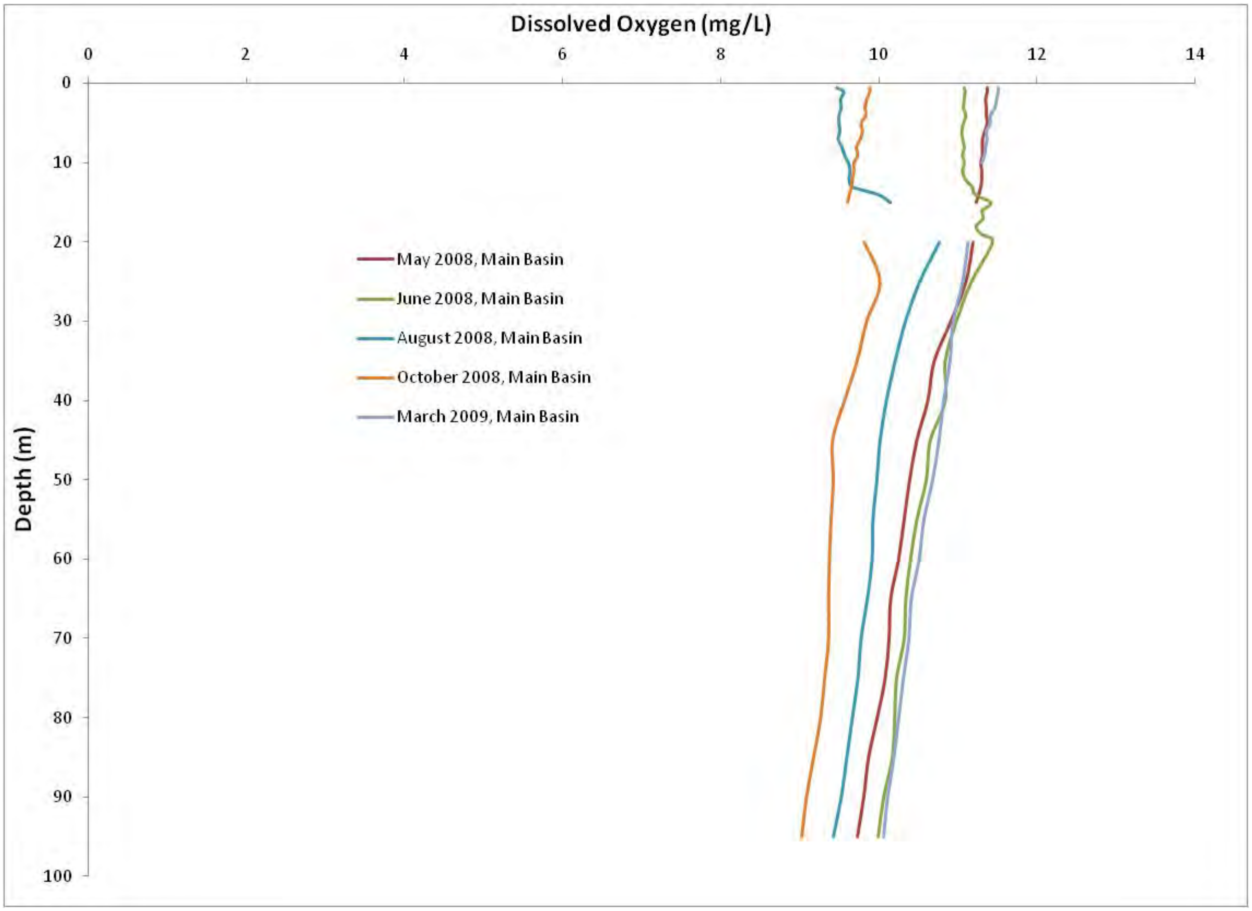

Figure 8. Seasonal dissolved oxygen concentrations (mg/L) measured at 1 m to 5 m metre intervals in Cowichan Lake in the main basin (Site E217509).

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 water quality. 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).

Secchi readings were collected during each field trip conducted in 2008/09. Secchi depths measured in the south arm ranged from 6.3 m to 10.5 m, with an average of 8.0 m. In the north arm, values ranged from 7.0 m to 13.1 m, with an average of 9.4 m, while in the main basin, values ranged from 6.9 m to 13.4 m, with an average of 8.8 m.

As well, a local stewardship group, the Cowichan Lake and River Stewardship Committee, collected Secchi data for Cowichan Lake between 2004 and 2007. The stewardship group belongs to the BC Lake Stewardship Society, which as part of a collaborative project with MOE entitled the *BC Lake Stewardship and Monitoring Program*, assists volunteer groups with monitoring lake health. Over the sampling time period, Secchi depths ranged from 6.5 m to 16.0 m, with mean annual measurements ranging from 9.1 m to 12.7 m. All values were well above the recreational guideline of 1.2 m. ***However, to ensure the exceptional water clarity occurring in Cowichan Lake is not impaired, we recommend a water quality objective for Secchi depths. The minimum Secchi depth should not be less than 6 m at any time, and seasonal averages of Secchi depths (at least 12 samples, collected between spring and fall), should not be less than 8 m.*** These recommendations are based on the minimum values seen in the south arm.

Table 4. Secchi depths measured in Cowichan Lake in the south arm (Site E217507), north arm (Site E217508) and main basin (Site E217509) by MOE in 2008/09.

Location	Minimum	Maximum	Average	Std Dev	No. of values
South Arm	6.3	10.5	8.0	1.5	6
North Arm	7.0	13.1	9.4	2.3	6
Main Basin	6.9	13.4	8.8	2.4	6

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 greater than 7 and less than 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).

Based on pH measurements measured in the field at 1 to 5 m intervals from the surface to bottom of the lake at each of the three deep water sites, pH in the south arm ranged from 6.8 to 8.2 pH units, from 6.7 to 8.1 pH units in the north arm, and from 6.6 to 8.2 pH units in the outlet basin. The mean pH in the south arm was 7.5 pH units, while in the north arm and main basin it was 7.4 pH units. Water samples were also collected at the surface, at 10 m depth, and just above the bottom at each of the three deep water sites, and sent to the laboratory for analysis. pH values were considerably less variable in the laboratory samples, with values ranging from 7.2 to 7.7 pH units in the south arm, from 7.1 to 7.6 pH units in the north arm, and from 7.2 to 7.7 pH units in the main basin.

All values were within aquatic life and drinking water guidelines. Current anthropogenic activities within the watershed are not likely to have a significant impact on pH and it does not appear that pH is a concern, therefore no water quality objective is proposed for this parameter.

6.2.2 Turbidity and Total Suspended Solids

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, potentially allowing pathogens 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 MOE 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 of 5 NTU at any time (Caux et al., 1997). For the protection of aquatic life, the MOE turbidity guideline recommends a mean of 2NTU in 30 days when background is less than or equal to 8NTU. VIHA's goal for surface sources of drinking water for systems that do not receive filtration, such as Cowichan 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 (Charmaine Enns, VIHA pers. comm., 2009).

Total suspended solids (TSS, also referred to as non-filterable residue or NFR) include all of the undissolved particulate matter in a sample. This value should be closely correlated with the turbidity value, however, unlike turbidity it is not measured by optics. Instead, a quantity of the sample is filtered, and the residue is dried and weighed so that a weight of residue per volume is determined. No TSS guideline has been established for drinking water at this time. However, for the protection of aquatic life, the maximum acceptable increase in TSS concentration over background is 25 mg/L at any one time in 24 hours when background is less than or equal to 25 mg/L (clear flows) and an induced TSS concentration of 5 mg/L over background concentrations at any one time for a duration of 30 days (clear flows). Initially, less frequent monitoring may be appropriate to determine the need for more extensive monitoring (Caux *et al.* 1997). TSS was not measured at the deep-water sites (usually, suspended materials precipitate fairly rapidly from the water column once it enters a lake or slow-flowing body of water), but it was measured at the 11 tributary sites.

Turbidity values were consistently low in Cowichan Lake, with values ranging from 0.3 NTU to 1.6 NTU in the south arm, from 0.2 NTU to 0.6 NTU in the north arm, and from 0.2 to 0.5 NTU in the main basin (Table 5). The maximum value (1.6 NTU, measured at 0.5 m depth in the south arm) occurred on October 16, 2008, when a total of 23.2 mm of rainfall had occurred in the previous 48 hours. It is possible that the precipitation caused short-term increased turbidity in tributaries near the sampling location, resulting in elevated levels in the south arm. However, turbidity values measured in the nearest tributaries (Sutton Creek and Ashburnham Creek) on that day were only 0.4 NTU at both sites. The next highest value measured in the south arm was 0.7 NTU.

Table 5. Summary of turbidity values measured at each of the three deep-water monitoring locations on Cowichan Lake in 2008.

	Minimum (NTU)	Maximum (NTU)	Average (NTU)	Std Dev	No. of Samples
South arm	0.3	1.6	0.47	0.33	16
North arm	0.2	0.6	0.3	0.11	17
Main basin	0.2	0.5	0.31	0.09	15

Turbidity results for each of the 11 sites are summarized in Table 6, while TSS results are summarized in Table 7. Turbidity values measured at the tributary sites were generally low over the five-week period, with the exception of one sampling date (November 12, 2008). In the week prior to this date, 10.2 cm of rainfall was recorded at the Environment Canada North Cowichan weather station (Station ID 1015630). It was on this date that the maximum turbidity value at each site was recorded. Elevated turbidity levels are likely a result of run-off carrying particulate matter into the creeks. Even with these elevated levels, average turbidity was generally below 1 NTU. Similarly, TSS concentrations were generally very low (usually below the detection limits, < 1 mg/L), except on November 12, 2008, when elevated concentrations were measured. Concentrations were highest in Sutton Creek (27 mg/L), McKay Creek (16 mg/L) and Robertson Creek (14 mg/L).

Table 6. Summary of turbidity values (NTU) measured between October 16 and November 12, 2008 at the 11 tributary sites.

	Min	Max	Average	Std. dev.	No. of samples
Ashburnham Creek	0.3	1.7	0.68	0.6	5
Coonskin Creek	0.2	0.5	0.34	0.1	5
Cottonwood Creek	0.2	0.4	0.28	0.1	5
Croft Creek	0.2	1.1	0.42	0.4	5
McKay Creek	0.2	4.1	1.02	1.7	5
Meades Creek	0.2	0.9	0.4	0.3	5
Nixon Creek	0.2	1.0	0.42	0.3	5
Robertson Creek	0.2	2.7	0.76	1.1	5
Shaw Creek	0.1	1.3	0.48	0.5	5
Sutton Creek	0.3	5.4	1.52	2.2	5
Wardropper Creek	0.1	0.5	0.24	0.2	5

Table 7. Summary of TSS concentrations (mg/L) measured between October 16 and November 12, 2008 at the 11 tributary sites.

	Min	Max	Average	Std. dev.	No. of samples
Ashburnham Creek	< 1	5	1.8	1.8	5
Coonskin Creek	< 1	2	1.2	0.4	5
Cottonwood Creek	< 1	3	1.6	0.9	5
Croft Creek	< 1	6	2.0	2.2	5
McKay Creek	< 1	16	4.0	6.7	5
Meades Creek	< 1	2	1.2	0.4	5
Nixon Creek	< 1	4	1.6	1.3	5
Robertson Creek	< 1	14	3.6	5.8	5
Shaw Creek	< 1	4	1.6	1.3	5
Sutton Creek	< 1	27	6.4	11.5	5
Wardropper Creek	< 1	< 1	< 1	0.0	5

While turbidity values in both the lake and tributaries, and TSS concentrations in the tributaries, are generally low, it appears that occasional moderate values can occur. In order to protect the exceptional clarity of water in Cowichan Lake, a water quality objective is proposed. ***The objective is that the maximum turbidity measured in any sample collected at the three deep lake monitoring locations should not exceed 2 NTU.*** This value is based on allowing an increase of 1 NTU above existing maximum background values, using the main basin site as reference (see Table 5. This site has the least influence from existing anthropogenic activities and as such best represents background conditions in the lake**.** It should be noted that turbidity values above 2 NTU are considered likely to affect disinfection in a chlorine-only system. An alternative to the objective of 2 NTU would be to treat the raw water prior to chlorination to remove some of the turbidity and increase chlorine efficiency.

Forest harvesting activities currently occur, or have occurred in the past, in most of the tributary drainages sampled. As such water quality objectives are recommended for both turbidity and TSS in the tributaries, to protect the aquatic life in the tributaries and the water quality in Cowichan Lake for both aquatic life and drinking water purposes. ***Thus, it is recommended that maximum turbidity values should not exceed 5 NTU at any time and the mean of five weekly samples in 30 days should not exceed 2 NTU in any of the tributaries monitored. In addition, the maximum total suspended solids measured in the tributaries should not exceed 26 mg/L at any time and the mean of five samples in 30-days should not exceed 6 mg/L.*** Means of five weekly samples in 30 days were chosen (rather than maximum values of 30 samples in a 30 day period, as recommended in the guideline) considering the practicality of and resources available for monitoring, as well as local hydrology and the fact that Vancouver Island streams have clear flows for most of the year.

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 recreational waters, and the recreational guideline is that the 30-day average (based on a minimum of five samples) should not exceed 15 true color units (TCU) (Moore and Caux, 1997).

Colour was measured between 15 and 17 times at each lake site, with values consistently below the detection limit of 5 TCU. Thus, all values were well below the recreation 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 disinfection by-products in finished drinking water if chlorination is used to disinfect the water (Moore and Caux, 1997). As the Town of Lake Cowichan and the CVRD use chlorine to disinfect their drinking water, TOC concentrations in Cowichan Lake are of interest. TOC concentrations were measured between 15 and 17 times at each of the three lake monitoring sites, with values ranging from 0.6 mg/L in the south arm to a maximum of 4.1 mg/L in the north arm. A water quality objective for TOC is proposed because the maximum value measured in the north arm exceeded the drinking water guideline for TOC of 4 mg/L. ***The objective is that the maximum concentration of TOC in any sample collected at any of the three deep water stations should not exceed 4 mg/L.***

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 concentration 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 25 °C (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 μS/cm), while interior watersheds generally have higher values. Increased flows resulting from precipitation events or snowmelt tends 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 Cowichan Lake were consistently low, ranging from 45 µS/cm to 54 µS/cm in the south arm, from 45 µS/cm to 52 µS/cm in the north arm, and from 45 µS/cm to 51 µS/cm in the main basin. During the summer months, conductivity was highest in the epilimnion likely as a result of warmer water temperatures. As there is no BC Water Quality Guideline for specific conductivity and the levels observed were typical of coastal systems, no objective is proposed for specific conductivity in Cowichan Lake.

6.2.5 Nutrients (Nitrate, Nitrite and Phosphorus)

The concentrations of 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/or fall because this is when turn-over, or vertical mixing of the water column, occurs. Generally, spring turn-over is when the highest concentrations of phosphorus are found. Later in the season, phosphorus is assimilated by micro-organisms such as phytoplankton, and is therefore found in lower quantities in solution. 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 is required in a lake system to maintain productivity (i.e. 5 -15 µg/L total phosphorus for aquatic life).

The guideline for the maximum concentration for nitrate for drinking water, recreation and aesthetics is 10 mg/L as nitrogen. 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 nitrite (NO_2) + dissolved nitrate (NO_3). Dissolved nitrate + nitrite concentrations ranged from 0.002 mg/L to 0.072 mg/L, with an average of 0.033 mg/L in Cowichan Lake in the south arm. Values were similar in the north arm, ranging from < 0.002 mg/L to 0.077 mg/L and an average of 0.030 mg/L, as well as the main basin (< 0.002 mg/L to 0.07 mg/L, with an average of 0.034 mg/L). The combined concentrations of nitrate and nitrite were well below the existing aquatic life guidelines.

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, 1985). The guideline for maximum total phosphorus concentrations in BC 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, 1985). Minimum values recorded at each of the three lake sites were below the detection limit (< 0.002 mg/L), with maximum values ranging from 0.004 mg/L in the north arm to 0.006 mg/L in the main basin.

Concentrations of nitrogen and phosphorus are low in Cowichan Lake, and below the respective guidelines. For this reason, no objective is proposed for either nitrogen or phosphorus in Cowichan Lake at this time.

6.2.6 Metals

Total and dissolved metals concentrations were not measured as part of the 2008/09 sampling program due to funding restrictions. However when reviewing historical samples as well as the spring overturn samples collected in March 2010, the concentrations of all metals were well below the applicable guidelines for drinking water and aquatic life. Therefore, there is no need for site specific water quality objectives for metals at this time. However if future monitoring results or land use activities in the watershed identify a need for follow up, the development of site specific objectives for metals will have to be addressed.

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 Cowichan Lake long term monitoring program (see Section 8).

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 applying the data quantitatively. Notwithstanding this problem, with few exceptions, the most sensitive use of our water bodies is aquatic life. Therefore biological objectives need to be incorporated into the overall objectives development program.

6.3.1 Microbiological Indicators

The microbiological quality of surface waters used for drinking and recreating is important, as contamination of these systems can result in high risks to human health 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 health risks, resource managers commonly measure fecal indicator bacteria levels (Field and Samadpour, 2007; Ishii and Sadowsky, 2008), whose presence is used to indicate the fecal contamination of water. 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 *Escherichia 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 and should not multiply outside the animal host. They should be nonpathogenic and have similar survival characteristics to the pathogens of concern. They should be strongly associated with the presence of pathogenic microorganisms and present only in contaminated samples. And finally, they should 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. Perhaps the greatest limitation of the traditional approaches is that the measurement of total and fecal coliforms does not indicate the source of contamination. 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). Without knowing the source of contamination, the actual risk to human health is uncertain and it is not always clear where to direct management efforts.

The BC-approved water quality guidelines for microbiological indicators were developed in 1988 (Warrington, 1988) 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 90^{th} 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 90^{th} 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). The recreational water guideline is that the geometric mean of at least five samples collected in a 30-day period should not exceed 77 CFU/100 mL for *E. coli* or 200 CFU/100 mL for fecal coliforms (Warrington, 2001).

As both the Town of Cowichan Lake and the CVRD withdraw water from Cowichan Lake for drinking water, and because there are a number of domestic licences issued for the lake, the more stringent drinking water MOE guideline will be used to assess fecal coliforms and *E. coli* in the water samples collected at the near-shore sites. At each of the 12 sites, one set of five samples was collected in both summer and fall in 2008, for a total of 10 samples from each site. These samples were analyzed for fecal coliforms and *E. coli*, and both 90th percentiles and geometric means were calculated for each set of five samples.

The range of fecal coliform concentrations, as well as 90th percentiles and geometric means of each set of five samples, is given in Table 8. The highest concentration of fecal coliforms in a single sample was 2,300 CFU/100 mL measured at Site 1 - Marina (see Figure 2). Most sites had samples below the detection limit (< 1 CFU/100 mL). Six sets of samples had 90th percentiles exceeding the drinking water guideline of 10 CFU/100 mL. These exceedances were fairly evenly spread out geographically, with one occurring in the east end of the south arm, one in Bear Lake, one near Honeymoon Bay, and three in the north arm (two at the Youbou West site and one at the head of the north arm). All of the geometric means were well below the recreational guideline of 200 CFU/100 mL.

Table 8. Data summary of fecal coliform concentrations (CFU/100 mL) at each of the twelve monitoring locations on Cowichan Lake.

			Min	Max	90th Percentile	Geomean
1	Marina	Summer	5	2,300	1400	52
		Fall	< 1	8	7	2
2	Marble Bay	Summer	< 1	7	5	2
		Fall	< 1	5	4	2
3	Head of South Arm	Summer	< 1	8	6	2
		Fall	< 1	7	4	12
4	Bear Lake	Summer	2	14	10	4
		Fall	1	9	7	3
5	McKenzie Bay	Summer	< 1	13	9	2
		Fall	< 1	2	2	1
6	Honeymoon Bay 1	Summer	< 1	4	3	2
		Fall	< 1	2	2	1
7	Honeymoon Bay 2	Summer	< 1	14	10	3
		Fall	< 1	1	1	1
8	Cottonwood Estates	Summer	< 1	6	5	2
		Fall	< 1	4	3	1
9	Youbou West	Summer	< 1	19	17	8
		Fall	1	15	11	3
10	Youbou East	Summer	< 1	7	5	2
		Fall	< 1	1	1	1
11	Billy Goat Islands	Summer	< 1	1	1	1
		Fall	< 1	9	6	2
12	Sunset Beach	Summer	< 1	130	78	3
		Fall	< 1	2	2	1

E. coli concentrations are summarized in Table 9. The highest concentration of *E. coli* in any individual sample was 15 CFU/100 mL, at the Youbou West site. The 90th percentile of only one set of samples (the summer set of samples from Youbou West, with a 90th percentile of 11 CFU/100 mL) exceeded the drinking water guideline, and the geometric mean of each group of samples was well below the recreational guideline.

Table 9. Data summary of *E. coli* concentrations (CFU/100 mL) at each of the twelve monitoring locations on Cowichan Lake.

			Min	Max	90th Percentile	Geomean
1	Marina	Summer	1	12	10	2
		Fall	< 1	7	6	2
2	Marble Bay	Summer	< 1	4	3	2
		Fall	< 1	3	3	1
3	Head of South Arm	Summer	< 1	6	5	2
		Fall	< 1	6	4	1
4	Bear Lake	Summer	< 1	11	8	3
		Fall	1	8	7	3
5	McKenzie Bay	Summer	< 1	4	3	2
		Fall	< 1	2	2	1
6	Honeymoon Bay 1	Summer	< 1	4	3	2
		Fall	< 1	1	1	1
7	Honeymoon Bay 2	Summer	< 1	10	8	3
		Fall	< 1	1	1	1
8	Cottonwood Estates	Summer	< 1	5	4	2
		Fall	< 1	2	2	1
9	Youbou West	Summer	< 1	15	11	3
		Fall	< 1	13	9	3
10	Youbou East	Summer	< 1	7	5	2
		Fall	< 1	1	1	1
11	Billy Goat Islands	Summer	< 1	1	1	1
		Fall	< 1	4	3	1
12	Sunset Beach	Summer	< 1	1	1	1
		Fall	< 1	2	2	1

For Cowichan Lake, the majority of the results for both fecal coliforms and *E. coli* were the same. 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 levels in each of the basins are relatively low. However, occasional elevated concentrations of bacteria were found in each of the basins, as well as in Bear Lake. 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 Cowichan Lake. ***Therefore, a water quality objective is proposed for* E. coli *to protect drinking water sources. The 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 all sites within Cowichan Lake. Samples should be collected during the late summer, as well as during the fall freshet, when concentrations of coliform bacteria are likely at their highest.***

As Cowichan Lake is the primary source of drinking water for the various communities and individual residences surrounding the lake, this objective will provide both a level of protection for the drinking water supply and for the people removing water directly from the lake for drinking purposes. However, it should be emphasized that these licensed withdrawals for domestic purposes from Cowichan Lake should receive some level of treatment prior to consumption. In addition, people participating in primary-contact recreation sports will also benefit from the proposed bacteriological objective as it is substantially lower that the provincial recreation guidelines. 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 impart taste and odour to 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, 1985). Some species of phytoplankton (specifically “blue-green algae”, or cyanobacteria) can 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 sportfish, such as salmonids, to less desirable species. Some species of algae can also impart a “muddy” flavour to fish flesh (Nordin, 1985), decreasing the popularity of sportfishing on a given lake.

Phytoplankton were sampled at each of the three deep-water stations on three occasions (May 21, 2008, August 13, 2008 and October 16, 2008). An additonal sample was collected at the south arm site, on March 18, 2009, but limited funding precluded sample collection at the other two sites on that date. The results were summarized and the dominant species for each site are listed in Table 10. 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.

Table 10. Summary of dominant (i.e. >10% of sample) phytoplankton species for Cowichan Lake (number of cells/mL and % of total sample).

Site	E217507 – South Arm				E217508 – North Arm			E217509 – Main Basin		
Date	**21-May-08**	**13-Aug-08**	**16-Oct-08**	**18-Mar-09**	**21-May-08**	**13-Aug-08**	**16-Oct-08**	**21-May-08**	**13-Aug-08**	**16-Oct-08**
Order : Centrales										
Cyclotella cf. glomerata		49 44%	95 48%	130 39%			85 48%			90 37%
Cyclotella glomerata	426 47%				356 48%	77 38%		356 45%	78 29%	
Rhizosolenia eriensis / longiseta	221 24%			53 16%	252 34%			213 27%		
Order : Chroococcales										
Anacystis cf. elachista						42 21%	28 16%		42 16%	
Order : Cryptomonadales										
Cryptomonas ovata / erosa									36 14%	
Order : Dinokontae										
Peridinium cf. inconspicuum		15 14%								
Order : Ochromonadales										
Dinobryon cf. bavaricum						24 12%				
Dinobryon divergens			25 13%				25 14%			27 11%
Order : Pennales										
Asterionella formosa	160 17%			71 21%				154 20%		
Fragilaria crotonensis										42 17%

A total of 116 species were identified. The south arm had slightly more species present (101 species total in the four samples collected, versus 90 in the north arm in three samples and 87 in the main basin). Phytoplankton concentrations were higher in May than in August or October at all three sites. The plankton concentrations are still low in March suggesting that productivity in the lake has not started. The phytoplankton community in Cowichan Lake was dominated by diatoms from the Order Centrales, with *Cyclotella glomerata* and *Rhizosolenia eriensis/longiseta* comprising the majority of the plankton community in the three samples. Pennate diatoms were also common at all three monitoring sites, especially *Asterionella Formosa* in the May 21 sample. It should be noted that infrequent plankton sampling makes it very difficult to get an accurate picture of what's going on in the lake, especially under eutrophic conditions. However, the phytoplankton community found in Cowichan Lake is consistent with the oligotrophic conditions as indicated by the water chemistry results (Section 6.2.5), therefore no objective is recommended for phytoplankton.

Chlorophyll *a* provides 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, 1985). 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 the three basins ranged from < 0.5 µg/L to a maximum of 1.6 µg/L in the main basin. Average concentrations ranged from 0.7 µg/L in the south arm and north arm, to 0.8 µg/Lin the main basin. While no objective for phytoplankton is proposed for Cowichan Lake, ***we recommend a water quality objective for Cowichan Lake allowing a maximum of 2.0 µg/L chlorophyll* a *at any of the deep water monitoring stations.*** Concentrations of chlorophyll *a* higher than this objective would give an indication that nutrient levels (and therefore productivity) are increasing.

6.3.3 Zooplankton

Phytoplankton are called primary producers, because they are capable of producing their own energy through photosynthesis. Zooplankton, on the other hand, represent the second trophic level in a lake, generally preying upon phytoplankton, as well as 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 was sampled at each of the three deep-water stations on three occasions (May 21, 2008, August 13, 2008 and October 16, 2008). An additonal sample was collected at the south arm site, on March 18, 2009, but limited funding precluded sample collection at the other two sites on that date. The results are summarized and the dominant species (*i.e.* >10% of sample) for each site are listed in Table 11. The more detailed set of taxonomic data for zooplankton can be obtained from the MOE office in Nanaimo, BC.

A total of 42 zooplankton species were identified in Cowichan Lake. Overall zooplankton species richness was highest in the south arm, with 36 species, compared with 33 species in the north arm and 31 species in the main basin. However, the average density of zooplankton tended to be slightly higher in the north arm at 21,822 cells/mL, compared with an average of 18,190 cells/mL in the south arm and 16,647 cells/mL in the main basin. As occurred with the phytoplankton samples, the samples collected at each site on May 21, 2008 had considerably higher concentrations of zooplankton compared with the other sampling dates.

Table 11. Summary of dominant (i.e. >10% of sample) zooplankton species for Cowichan Lake (number of cells/mL and % of total sample).

Site:	E217507 – South Arm								E217508 – North Arm						E217509 – Main Basin					
Sample date:	21-May-08		13-Aug-08		16-Oct-08		18-Mar-09		21-May-08		13-Aug-08		16-Oct-08		21-May-08		13-Aug-08		16-Oct-08	
Sub-class : Copepoda																				
Order : Cyclopoida																				
UID Cyclopoid copepodid							1,500	18%												
Order : Calanoida																				
UID Calanoid copepodid							1,000	12%												
Phylum : Rotifera																				
Kellicottia longispina							1,200	14%												
Keratella cochlearis	7,950	21%	10,100	62%	5,900	58%	3,100	36%	5,650	16%	12,375	69%	7,100	54%	3,825	14%	8,420	62%	4,300	48%
Polyarthra sp.	15,600	41%			1,200	12%			17,800	52%			2,200	17%	11,400	42%			1,700	19%

The zooplankton community of Cowichan Lake was composed predominately of rotifers. In all of the basins, the zooplankton community was dominated by two rotifer genera: *Keratella cochlearis* and *Polyarthra*. *Keratella* and *Polyartha* species are known to be cold water rotifers and develop maximal population densities in midwinter to early spring (Wetzel, 2001). An unidentified cyclopoid copepod and calanoid copepod were also dominant in the March 18, 2009 sample collected in the south arm, as was the rotifer *Kellicottia longispina.*

Additional zooplankton species, such as cladocerans, calanoid copepods and cyclopoid copepods, were present in most of the samples collected at all three basins however they were deemed non-dominants, as they comprised of less than 10% of the total sample size. Overall, the zooplankton species, similar to the phytopkankton species are indicative to oligotrophic lake conditions. It appears that the P-limiting conditions, as suggested by low chlorophyll *a* concentrations, have resulted in an increased abundance of smaller bodied zooplankton species like rotifers. Therefore, no objective is recommended for zooplankton at this time.

7.0 SUMMARY OF PROPOSED WATER QUALITY OBJECTIVES

In British Columbia, water quality objectives are mainly based on approved or working water quality guidelines. These guidelines were established to prevent specified detrimental effects from occurring with respect to a designated water use. Identified water uses for Cowichan Lake that are sensitive and should be protected are drinking water, recreation, irrigation, aquatic life and wildlife. The water quality objectives recommended here take into account background conditions, impacts from current land use and any 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.

The proposed objectives are summarized in Table 12.

Table 12. Summary of proposed water quality objectives for Cowichan Lake.

Variable	Objective Value
Water temperature	≤ 15°C summer maximum hypolimnetic temperature (> 10m depth)
Dissolved oxygen	≥ 5 mg/L at any depth throughout the year
Secchi Depth	≥ 6.0 m minimum, ≥ 8.0 m average
Turbidity – lake sites	≤ 2 NTU maximum
Turbidity - tributaries	Max of 5 NTU; average of 2 NTU with a minimum 5 weekly samples collected over a 30-day period
TSS - tributaries	Max 26 mg/L; average of 6 mg/L with a minimum 5 weekly samples collected over a 30-day period
Total organic carbon	≤ 4 mg/L maximum
***E. coli* bacteria**	≤10 CFU/100 mL (90th percentile) with a minimum 5 weekly samples collected over a 30-day period
Chlorophyll *a*	≤ 2 µg/L

8.0 MONITORING RECOMMENDATIONS

The recommended water quality monitoring program for Cowichan Lake is summarized in Table 13. 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. Attainment sampling is generally conducted throughout a one year period.

Table 13. Proposed schedule for future water quality monitoring in Cowichan Lake.

Frequency and timing	Characteristic to be measured
Deep station sites (3 depths per site) - quarterly sampling (March, May, August, October)	pH, specific conductivity, TSS, turbidity, colour, TOC, DOC, nitrogen species, total phosphorus, total and dissolved metals (spring overturn only), chlorophyll *a* DO and temperature profiles, and secchi disk
Perimeter lake sites (surface grab sample) - summer and fall (weekly for five consecutive weeks in 30 day period)	*E. coli*
Tributary sites (surface grab sample) - fall (weekly for five consecutive weeks in 30 day period)	Turbidity and TSS
Deep station sites - twice per year (summer and spring overturn)	Phytoplankton and zooplankton

In order to capture the periods where water quality concerns are most likely to occur (*i.e.*, fall flush and summer low-flow, as well as spring overturn) we recommend quarterly sampling for a one year period. Samples collected during the winter months should coincide with rain events whenever possible. In this way, the two critical periods (minimum dilution and maximum turbidity), will be monitored.

The monitoring should consist of full water chemistry sampling at the three basin locations (three depths per site – surface, 10 m and one meter from bottom) and include physical measurements of dissolved oxygen, temperature and water clarity. The deep station samples should be analyzed for general water chemistry (including pH, specific conductivity, TSS, turbidity, true colour, TOC, DOC and nutrients) as well as total and dissolved metals (including hardness) concentrations (spring overturn only).

Bacteriological samples (*E. coli*) should be collected at the 12 perimeter sites once weekly for five consecutive weeks in a 30-day period both in late summer and mid-fall. In addition, future monitoring should be considered at the Town of Lake Cowichan's water intake location, primarily *E. coli*.

Turbidity and TSS samples should be collected at the 11 tributary sites once weekly for five consecutive weeks in a 30-day period during fall freshet to capture the "worst case" scenario.

Biological sampling should continue to be a part of the attainment monitoring program. Chlorophyll *a* samples should be collected (at surface only) one each sampling date (i.e. quarterly) for all three deep basin sites. Phytoplankton and zooplankton samples should be collected twice per sample year, at spring overturn and during the summer.

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APPENDIX I. SUMMARY OF WATER QUALITY DATA

Table A-1. Summary of general water chemistry at E217507, Cowichan Lake South Arm.

	Minimum	Maximum	Average	Std Dev	No. of samples
Alkalinity Total 4.5 (mg/L)	15	23	19.4	3.3	16
Ammonia Dissolved (mg/L)	< 0.005	0.093	0.016	0.025	16
Carbon Dissolved Organic (mg/L)	< 0.5	1.7	1.1	0.4	16
Carbon Total Inorganic (mg/L)	3.4	7.3	4.8	1.3	16
Carbon Total Organic (mg/L)	0.6	2.1	1.3	0.4	16
Chlorophyll *a* (mg/L)	< 0.0005	0.0012	0.0007	0.0003	5
Color True (Col.unit)	< 5	< 5	< 5	0	16
C--T (mg/L)	4.7	8.5	6.1	1.3	16
Extinction Depth (m)	6.3	10.5	8.0	1.5	6
Kjeldahl Nitrogen (mg/L)	< 0.02	0.08	0.05	0.02	16
Nitrate + Nitrite Diss. (mg/L)	< 0.002	0.072	0.033	0.029	16
Nitrogen Organic-Total (mg/L)	< 0.02	0.08	0.04	0.02	16
Nitrogen Total (mg/L)	< 0.02	0.14	0.08	0.03	16
NO2+NO3 (mg/L)	< 0.02	0.07	0.03	0.03	15
Ortho-Phosphate Dissolved (mg/L)	< 0.001	0.003	0.002	0.001	16
pH (pH units)	7.2	7.7	7.5	0.2	16
P--T (mg/L)	< 0.002	0.005	0.003	0.001	16
Silica - D (mg/L)	2.8	3.8	3.3	0.3	16
Specific Conductance (µS/cm)	45	54	49.9	2.8	16
Turbidity (NTU)	0.3	1.6	0.5	0.3	16

Table A-2. Summary of general water chemistry at E217508, Cowichan Lake North Arm.

	Minimum	Maximum	Average	Std Dev	No. of samples
Alkalinity Total 4.5 (mg/L)	15	22	18.1	2.9	17
Ammonia Dissolved (mg/L)	< 0.005	0.006	0.005	0.000	17
Carbon Dissolved Organic (mg/L)	< 0.5	4.3	1.4	1.2	17
Carbon Total Inorganic (mg/L)	3.9	6.5	5.0	0.8	17
Carbon Total Organic (mg/L)	0.9	4.1	1.7	1.0	17
Chlorophyll *a* (mg/L)	< 0.0005	0.0013	0.0007	0.0003	9
Color True (Col.unit)	< 5	< 5	< 5	0	17
C--T (mg/L)	4.9	10.6	6.6	1.7	17
Extinction Depth (m)	7	13.1	9.4	2.3	6
Kjeldahl Nitrogen (mg/L)	< 0.02	0.09	0.04	0.02	17
Nitrate + Nitrite Diss. (mg/L)	< 0.002	0.077	0.030	0.031	17
Nitrogen Organic-Total (mg/L)	< 0.02	0.09	0.04	0.02	17
Nitrogen Total (mg/L)	0.03	0.11	0.07	0.03	17
NO2+NO3 (mg/L)	< 0.02	0.08	0.03	0.03	17
Ortho-Phosphate Dissolved (mg/L)	< 0.001	0.002	0.002	0.001	17
pH (pH units)	7.1	7.6	7.5	0.1	17
P--T (mg/L)	< 0.002	0.004	0.003	0.001	17
Silica - D (mg/L)	2.9	4.3	3.4	0.4	17
Specific Conductance (µS/cm)	45	52	49.1	2.4	17
Turbidity (NTU)	0.2	0.6	0.3	0.1	17

Table A-3. Summary of general water chemistry at E217509, Cowichan Lake Main Basin.

	Minimum	Maximum	Average	Std Dev	No. of samples
Alkalinity Total 4.5 (mg/L)	15	23	18.9	3.0	15
Ammonia Dissolved (mg/L)	< 0.005	0.006	0.005	0.000	15
Carbon Dissolved Organic (mg/L)	< 0.5	1.7	1.0	0.4	15
Carbon Total Inorganic (mg/L)	2.2	6.1	4.4	1.2	15
Carbon Total Organic (mg/L)	0.9	1.7	1.2	0.3	15
Chlorophyll *a* (mg/L)	< 0.0005	0.0016	0.0008	0.0005	5
Color True (Col.unit)	< 5	< 5	< 5	0	15
C--T (mg/L)	3.3	7.5	5.6	1.3	15
Extinction Depth (m)	6.9	13.4	8.8	2.4	6
Kjeldahl Nitrogen (mg/L)	< 0.02	0.08	0.04	0.02	15
Nitrate + Nitrite Diss. (mg/L)	< 0.002	0.07	0.034	0.029	15
Nitrogen Organic-Total (mg/L)	< 0.02	0.08	0.04	0.02	15
Nitrogen Total (mg/L)	< 0.02	0.15	0.07	0.04	15
NO2+NO3 (mg/L)	< 0.02	0.07	0.04	0.03	14
Ortho-Phosphate Dissolved (mg/L)	< 0.001	0.005	0.002	0.001	15
pH (pH units)	7.2	7.7	7.5	0.1	15
P--T (mg/L)	< 0.002	0.006	0.003	0.001	15
Silica - D (mg/L)	2.9	3.8	3.3	0.3	15
Specific Conductance (µS/cm)	45	51	49.2	2.0	15
Turbidity (NTU)	0.2	0.5	0.3	0.1	15