BRITISH COLUMBIA

ENVIRONMENTAL PROTECTION DIVISION

ENVIRONMENTAL SUSTAINABILITY DIVISION

MINISTRY OF ENVIRONMENT

# Water Quality Assessment and Objectives for Comox Lake

TECHNICAL REPORT

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# EXECUTIVE SUMMARY

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

Comox Lake is a large lake, with a surface area of 2,100 ha, located near the village of Cumberland, BC. Drinking water supply is an important water use of this watershed. The Comox Valley Regional District withdraws drinking water from the Puntledge River downstream from Comox Lake, and the water quality of Comox Lake has a large influence on the quality of Comox Valley drinking water. BC Hydro has a dam at the outlet of Comox Lake. The lake water levels are controlled to ensure sufficient flows for the hydroelectric project, drinking water use and fisheries use downstream in the Puntledge River. Comox Lake also provides significant recreational opportunities (fishing, swimming, camping and boating) and fish and wildlife habitat. These activities, as well as forestry, residential and historical mining activities, all potentially affect water quality in Comox Lake.

Water quality monitoring was conducted between 2005 and 2008. 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 meet provincial water quality guidelines with the exception of microbiological indicators which exceeded drinking water guidelines on occasion in the outlet basin. A microbial source tracking study prepared for the Comox Strathcona Regional District in 2005 found that the predominant sources of fecal coliforms near the lake outlet were attributable to deer, dogs and seagulls (Clayton, 2005).

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

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 seven perimeter sites during the summer low flow and fall flush period (five weekly samples in 30 days). In addition, future monitoring should be conducted downstream of Comox Lake in the Puntledge River at the CVRD water intake location.

**Water Quality Objectives for Comox Lake**

| Variable | Objective Value |
|---|---|
| **Secchi depth** | Annual average ≥ 8 m |
| ***E. coli* Bacteria** | ≤10 CFU/100 mL (90$^{th}$ percentile) with a minimum 5 weekly samples collected over a 30-day period |
| **Turbidity** | ≤ 2 NTU maximum |
| **Total phosphorus** | ≤6 µg/L average during spring overturn |
| **Chlorophyll *a*** | ≤ 1.5 µg/L |
| **Water temperature** | ≤ 15°C summer maximum hypolimnetic temperature (>10m depth) |
| **Dissolved oxygen** | ≥ 5 mg/L at any depth throughout the year |

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## AKNOWLEDGEMENTS

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

Due to accessibility and holding time of samples only the six ecoregions on Vancouver Island are being considered at this time. 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 (initially stream focused) 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, 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 existing water quality of Comox Lake from 2005 - 2008 and recommends water quality objectives for the lake based on potential impacts and water quality parameters of concern. The Puntledge River, which flows through Comox Lake, is currently the primary source of drinking water for the Comox Valley Regional District (CVRD). The Puntledge River was designated as a community watershed in 1995. Community watersheds are defined under the *Forest Practices Code Act of BC* as “the drainage area above the most downstream point of diversion on a stream for a water use that is for human consumption and that is licensed under the *Water Act* for waterworks purpose or a domestic purpose if the licence is held by or is subject to the control of a water users’ community incorporated under the Water Act”. This designation was grandparented and continued under the *Forest and Range Practices Act* (FRPA) in 2004 and infers a level of protection. As the majority of the Puntledge River community watershed is on private land, the FRPA does not apply to most of the watershed. However, 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.

Comox Lake is part of the Puntledge River watershed, which includes Forbush Lake and Willemar Lake in the upper watershed, the Cruikshank River (which drains directly into Comox Lake) and a large number of tributary streams (Figure 2). Fish species in Comox

Lake include rainbow trout, brook trout, cutthroat trout, steelhead, Dolly Varden, kokanee, chinook salmon, chum salmon, coho salmon, Atlantic salmon, coastrange sculpin (formerly Aleutian sculpin), and threespine stickleback (FISS, 2009). Anthropogenic land uses within the watershed include recreational use, power generation, forestry, residential, and historical mining activities. These activities, as well as natural erosion and the presence of wildlife, all potentially affect water quality in Comox Lake.

The project consisted of five phases: collecting water quality data, gathering information on water use, determining of land use activities that may influence water quality, assessing water quality based on land use influences and establishing water quality objectives.

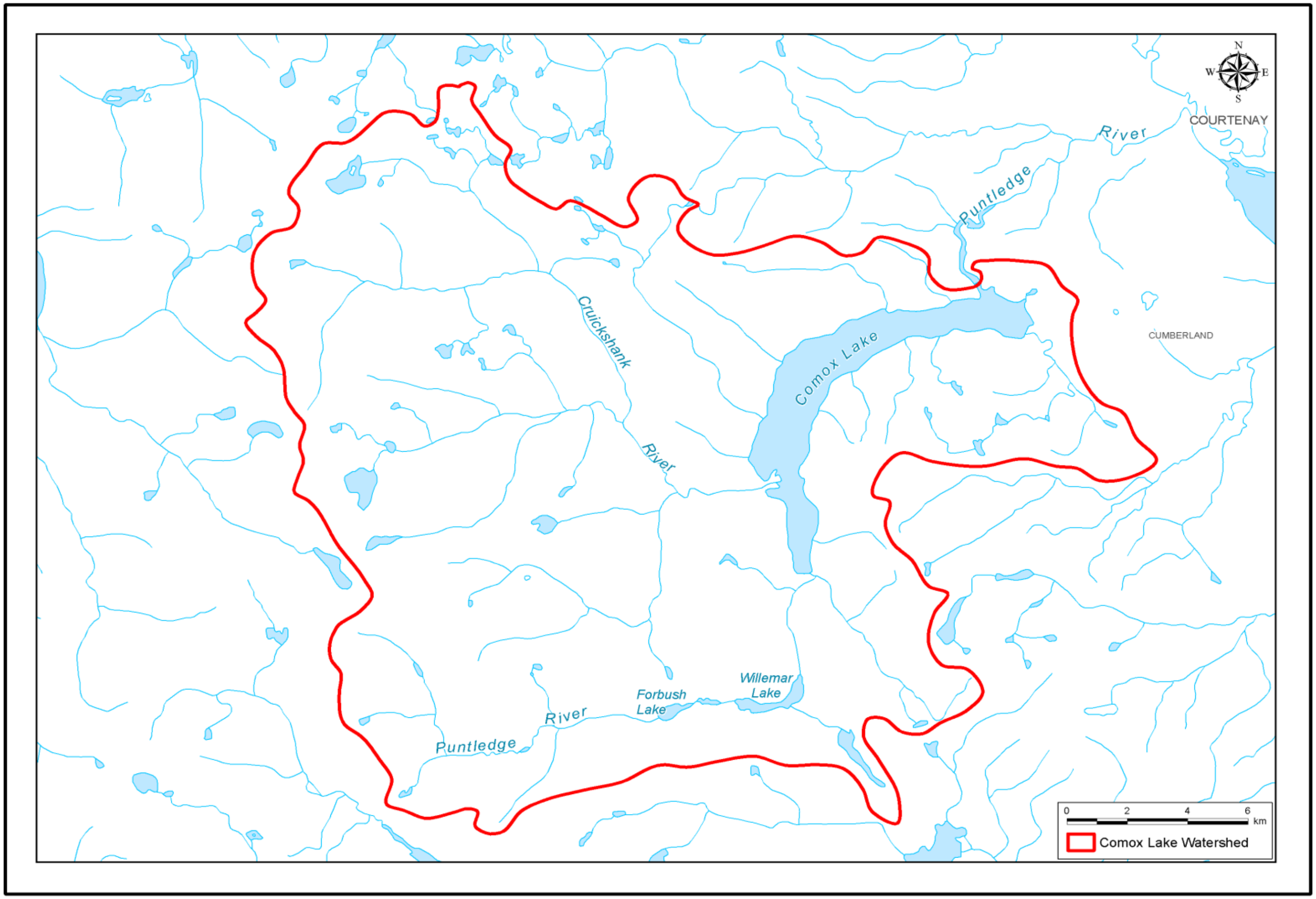


**Figure 2. Overview Map of Puntledge River watershed, including Comox Lake.**

# 2.0 WATERSHED PROFILE AND HYDROLOGY

## 2.1 BASIN PROFILE

The Puntledge River watershed, which contains Comox Lake, is relatively large. The community watershed portion (which includes all of the area upstream of Comox Lake, and extends downstream to the Comox Valley Regional District (CVRD) water intake near Courtenay) is 58,591 ha in area. The Puntledge River is 29 km in length and is a fifth-order or medium size stream. The elevation of Comox Lake is 138 m, with elevations within the watershed ranging from slightly over 2,000 m at the origin of Puntledge River (the Comox, Moving and Cliffe glaciers) to sea level where it enters the Strait of Georgia in the community of Courtenay. Comox Lake has a surface area of 2,100 ha, a maximum depth of 109 m, and a mean depth of 61 m (FISS 2009) (Figure 3).

Comox Lake 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). The lake falls within the Nanaimo Lowland (NAL) ecoregion established for Vancouver Island by MOE staff (Figure 1).

The underlying geology of Comox Lake is described as the Vancouver Group – Karmutsen Formation. It is composed of basaltic volcanic rocks from the Middle to Upper Triassic Period, and described as basalt pillowed flows, pillow breccia, hyaloclastite tuff and breccia, massive amygdaloidal flows, minor tuffs, interflow sediment and limestone lenses (BCWRA 2009).

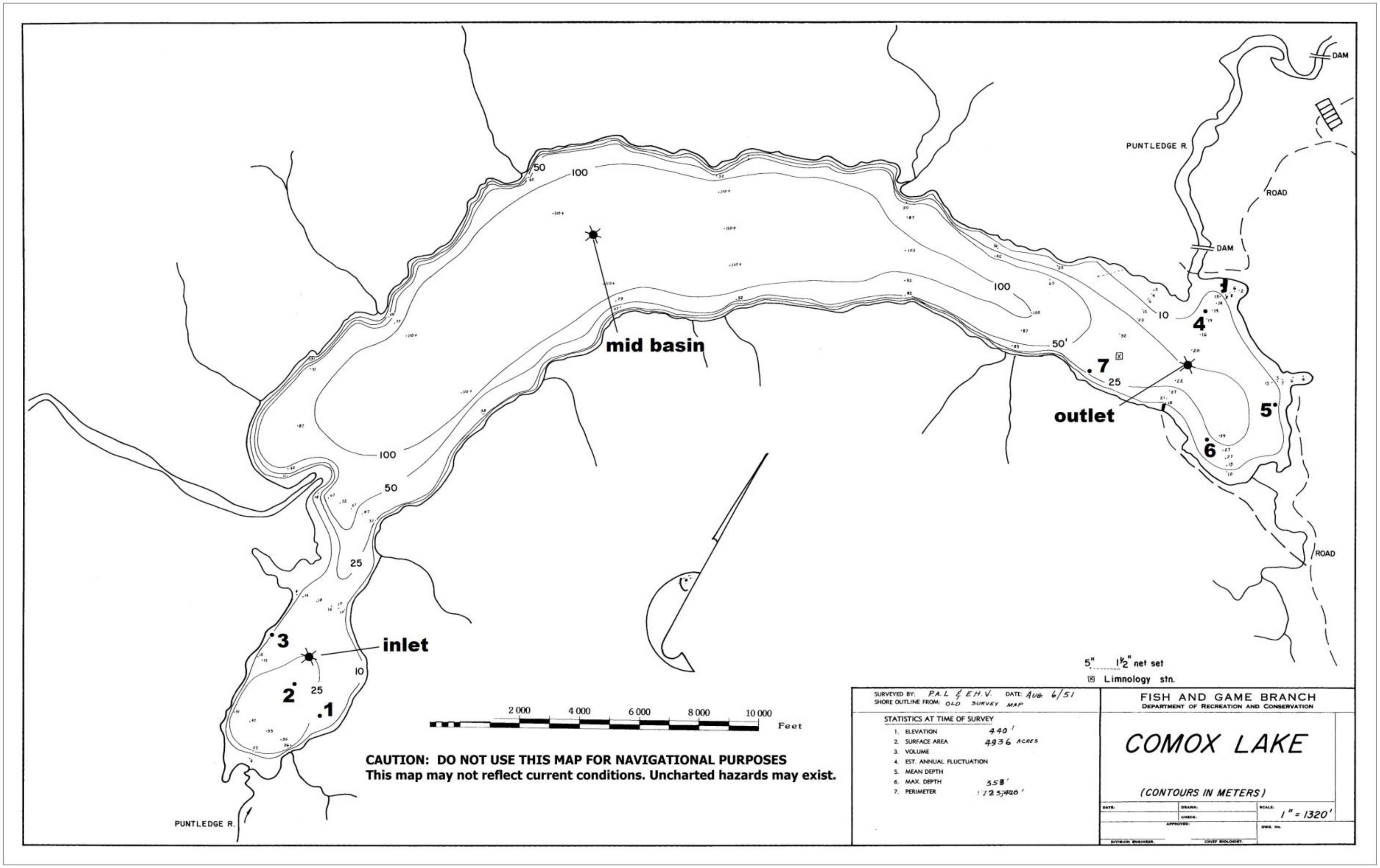


**Figure 3. Bathymetric map of Comox Lake, showing sampling locations (source: http://www.fishwizard.com).**

## 2.2 HYDROLOGY AND PRECIPITATION

Water levels in Comox Lake are controlled by the Comox Dam. These levels are guided by the 2004 BC Hydro Water Use Plan for the Puntledge River System (BC Hydro, 2004). Water Survey Canada (WSC) operated a hydrometric station on Comox Lake between 1993 and 2007. Minimum, maximum and average daily levels (in metres above sea level) are shown in Figure 4. The maximum daily water level measured between 1993 and 2007 was 136.146 m above sea level (asl) (on October 19, 2003), while the minimum level was 130.493 m asl (on November 5, 2002). In general, water levels were lowest during the spring and fall and highest during the summer, as attempts were made to conserve as much water as possible during the driest period of the year to ensure sufficient flow for the hydroelectric project, drinking water use and fisheries use.

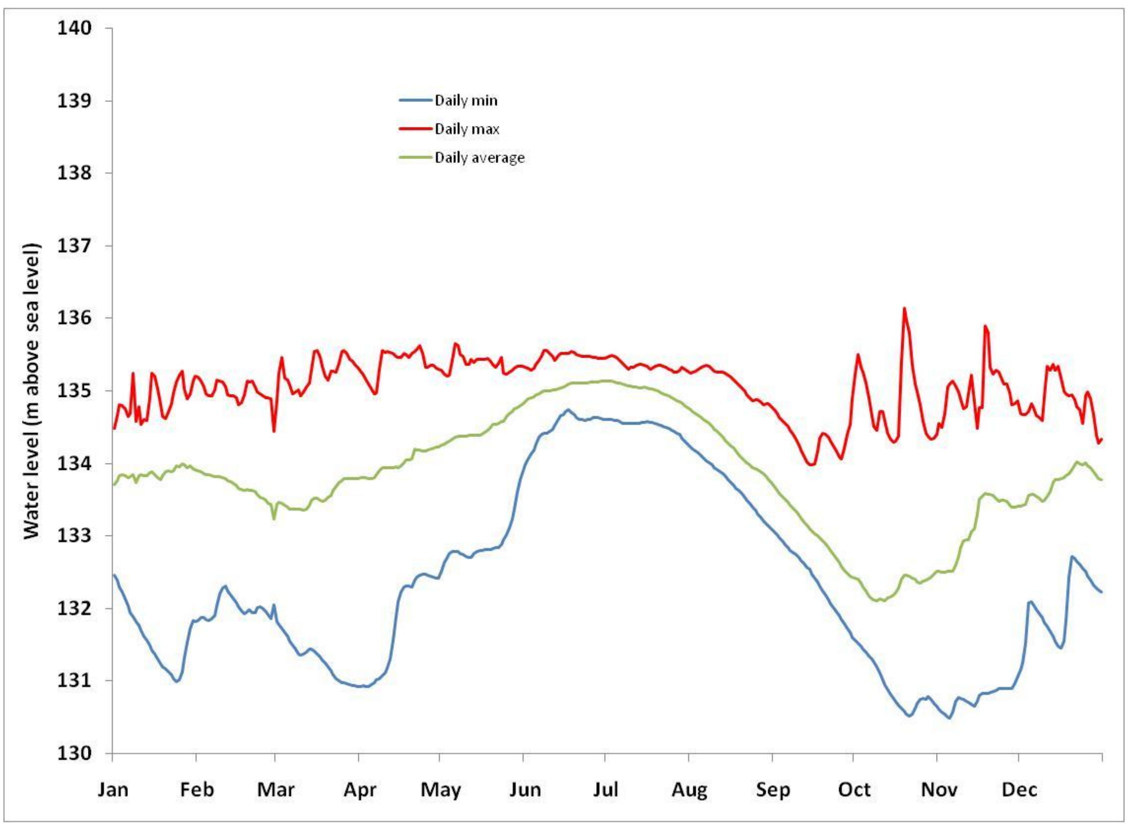


**Figure 4. Minimum, maximum and average daily water levels for Comox Lake (Water Survey Canada Station 08HB082) between 1993 and 2007 (Water Survey Canada Hydat Data, 2009).**

Water Survey Canada also operates a hydrometric station on the Puntledge River downstream from the BC Hydro Diversion. Minimum, maximum and average daily discharges between 1993 and 2007 are shown in Figure 5. As this hydrometric station is downstream from the BC Hydro Diversion, and because BC Hydro has a water license to divert 28.34 $m^3/s$, adding that volume to the values in Figure 5 would give an approximation of water levels just upstream from the diversion. The diversion is located approximately 3.7 km downstream from Comox Lake. The secondary intake for the CVRD is located 6.6 km downstream from Comox Lake, at the Puntledge River Pumping Station.

The nearest climate station to the watershed for which climate normal data (1971 – 2000) are available is the Comox A station (elevation 25.6 m) (Environment Canada Climate Station 1021830). Average daily temperatures range from 3°C in January to 17.6°C in July and August. Average total annual precipitation is 1,100 mm, with 74 mm (water equivalent) (6%) of this falling as snow (Figure 6). Most precipitation (917 mm, or 78%) falls between October and March, resulting in peak water levels during this period. Snowpack in the watershed reaches a maximum in May, and snowmelt coupled with glacial melt contributes to spring freshet and summer flows.

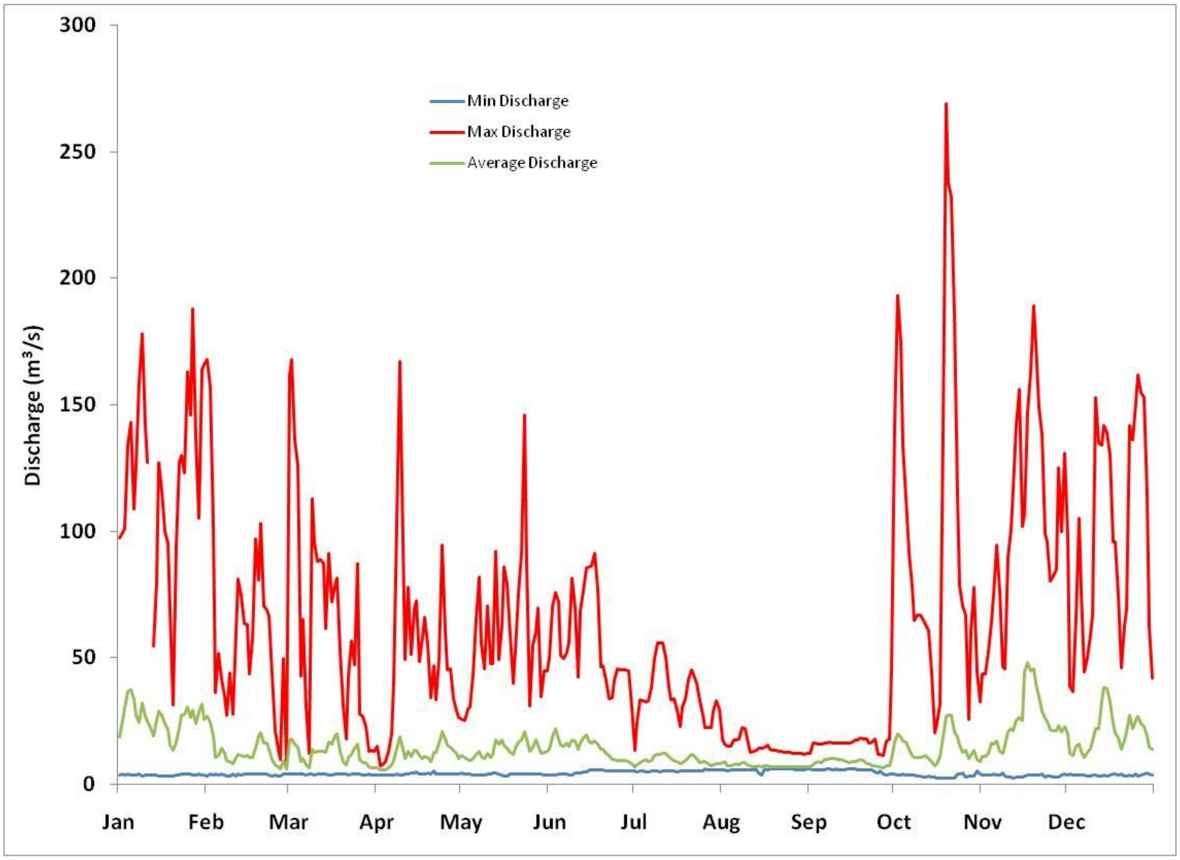


**Figure 5. Minimum, maximum and average daily water levels for the Puntledge River below the BC Hydro Diversion (Water Survey Canada Station 08HB084) between 1993 and 2007 (Water Survey Canada Hydat Data, 2009).**

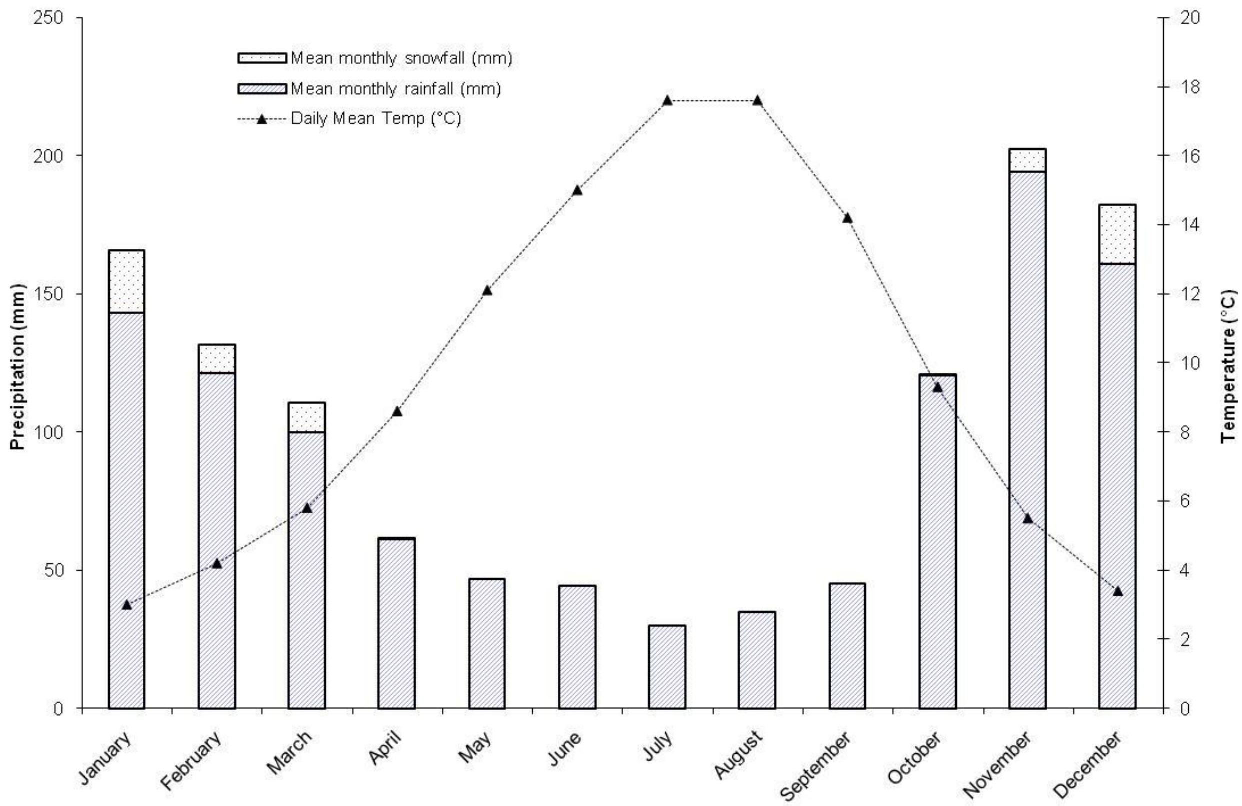


**Figure 6. Climate data (1971 – 2000) for Comox (Environment Canada Climate Station 1021830).**

# 3.0 WATER USES

## 3.1 WATER LICENSES

Drinking water supply is an important water use of this watershed. The Comox Valley Regional District withdraws drinking water from the Puntledge River downstream from Comox Lake, and the water quality of Comox Lake has a large influence on the quality of Comox Valley drinking water. The primary intake (which is gravity fed) for the CVRD is located at the BC Hydro Penstocks intake, approximately 3.7 km downstream from Comox Lake. A secondary intake is located at the Puntledge River Pump Station, 6.6 km downstream from Comox Lake. This intake is utilized only when the BC Hydro Penstocks are undergoing repairs or maintenance, usually only a few weeks a year. At present the Puntledge River watershed provides drinking water to approximately 38,000 people throughout the Comox Valley and will be increasingly relied upon for future population growth (CVRD, 2009).

There is only one water license issued for water withdrawals from Comox Lake itself, allowing for the withdrawal of 119.7 $dam^3$/year for fire protection, issued to the Courtenay and District Fish and Game Protection Association. However, there are several withdrawals from the Puntledge River downstream from Comox Lake and therefore the quality and quantity of water is a concern. BC Hydro has a license to withdraw 28.3 $m^3$/s (893,000 $dam^3$/a) from Puntledge River for hydrogeneration. BC Hydro and the Department of Fisheries and Oceans each have licenses for water storage in the Puntledge River, for conservation purposes. There are a number of domestic and irrigation licenses, as well as a license for fire protection on the Puntledge River. A summary of the licenses is given in Table 1.

**Table 1. Summary of licensed water withdrawals from the Puntledge River, downstream from Comox Lake.**

| Use | No. Licensed Withdrawals | Total Volume (dam$^3$/a) | Principal Licensee |
|---|---|---|---|
| Conservation-Use Of Water | 5 | 172,349 | Department of Fisheries and Oceans |
| Domestic | 5 | 8.3 | Various |
| Fire Protection | 1 | 1.7 | Comox Indian Band |
| Irrigation | 4 | 157.9 | Various |
| Power-General | 1 | 893,000 | BC Hydro |
| Storage-Power | 1 | 117,775 | BC Hydro |
| Waterworks Local Auth | 1 | 38,096 | CVRD |

### 3.2 FISHERIES

Fish species in Comox Lake include rainbow trout, brook trout, cutthroat trout, steelhead, Dolly Varden, kokanee, chinook salmon, chum salmon, coho salmon, Atlantic salmon, coast range sculpin (*Cottus aleuticus*) (also known as the Aleutian sculpin), and threespine stickleback (FISS, 2009). The outlet of Comox Lake is equipped by a fishway, and passage is controlled for fisheries management purposes (FISS, 2009). While there are several cataracts below Comox Lake (in the Puntledge River), they are made passable by fishways (FISS, 2009), and therefore anadromous fish are able to travel between Comox Lake and the ocean. Over the past five years, more than 200,000 steelhead and 2,000 anadromous cutthroat trout have been stocked in the Puntledge River (the vast majority as smolts, with a few adults). These stocking episodes occurred in 2004 to 2006, and it does not appear that stocking has occurred in recent years (FISS, 2009). The Department of Fisheries and Oceans (DFO) has also released hatchery fish in Comox Lake and its upper watershed tributaries in the past and may propose to continue this in the future. Furthermore, DFO is proposing other hatchery initiatives for the lake such as replacing the upper hatchery site (Mel Sheng, DFO pers. comm.).

### 3.3 RECREATION

Comox Lake is a very popular recreational area. There are 77 cabins on the lake (70 of which are used seasonally, the remaining seven are used year-round). As well, there are two designated campgrounds: the Cumberland campground on the south shore of the outlet basin and the Courtenay and District Fish and Game Protective Association campground on the north shore of the outlet basin. There are a number of popular day-use beaches for swimming, and walking, fishing and boating (power boats as well as canoes and kayaks) are also very popular activities on the lake. There are boat launches at both campgrounds.

### 3.4 FLORA AND FAUNA

The Puntledge River watershed provides habitat to a variety of species typical of west coast Vancouver Island, including blacktail deer, black bear, cougar, and numerous other small mammals and birds. The BC Conservation Data Centre reports the presence of one blue-listed plant species (the least moonwart (*Botrychium simplex*) considered imperiled or vulnerable provincially but secure globally, in the Comox Lake Bluffs Ecological Preserve), as well as one red-listed plant species (the Olympic onion (*Allium crenulatum)* considered imperiled on Mount Becher north of Comox Lake) within the Comox Lake watershed (British Columbia Conservation Data Centre, 2009).

### 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

In 2006, the Comox Valley Regional District (then the Regional District of Comox-Strathcona) initiated a watershed assessment for Comox Lake. As part of that assessment, CH2M Hill prepared a Contaminant Source Inventory which discusses potential threats to water quality (Benjamin and Vasarhelyi, 2006). Much of the information presented below is summarized from this report. A more detailed description of each potential influence on water quality can be found there. Within the Comox Lake watershed, there are no permitted waste discharges or range tenures and are therefore not discussed any further.

## 4.1 LAND OWNERSHIP

The upper portion of the Puntledge River watershed (upstream from Forbush Lake) as well as a small portion of the upper north-western slope above Comox Lake, are part of Strathcona Provincial Park. Much of the remaining watershed is comprised of privately owned lands managed for forestry activities. TimberWest Forest Corp. owns most of the Comox Lake watershed outside of Strathcona Provincial Park, including the bed and the majority of the shoreline of Comox Lake, with the exception of the area around the outlet basin shore. Hancock Forest Management Inc. owns part of the eastern portion of the Comox Lake watershed, above the shoreline, and part of the Lower Puntledge River Watershed. Other private land (private citizens) comprises a small portion of the watershed, as does Crown land, municipal land, land owned by BC Hydro and road right-of-way (see Table2).

Of the 77 cabins located around Comox Lake, 51 are on leased TimberWest properties along the southerly half of the lake (inlet basin and south eastern portion of main basin). The current lease agreements will expire in 2011. Almost all of these cabins are between 50 and 75 years old, and are used for an average of 45 days per year (Benjamin and Vasarhelyi, 2006). Water supply to the majority of the cabins is by gravity feed from nearby creeks, while the remaining cabin users pail water from Comox Lake. Typically, cabins use seepage pits for grey water and pit toilets for black water.

**Table 2. Summary of land use within the Comox Lake watershed (from Benjamin and Vasarhelyi, 2006).**

| Land Use | Area (ha) | % of total watershed area |
|---|---|---|
| Forestry | 28,075 | 60.84% |
| Park | 15,141 | 32.81% |
| Water | 2,250 | 4.88% |
| Crown Land | 412 | 0.89% |
| Private Land | 91 | 0.20% |
| BC Hydro | 11 | 0.02% |
| Municipal Land | 158 | 0.34% |
| Road Right-of-Way | 8 | 0.02% |
| Total | 46,146 | 100.0% |

The remaining 26 cabins are located on Comox Lake Land Corporation property at the east end of the lake. Of the 26 cabins, seven are used year-round, while the remaining 19 cabins are used from between 20 and 90 days annually. Fifteen of the cabins rely on wells for drinking water, five pump water directly from Comox Lake, and the remaining cabins pail water from the lake. Ten cabins have wastewater holding tanks, nine cabins have septic systems, and the remaining seven cabins have pit privy toilets and seepage pits for grey water. Potential impact from the cabins to surface waters include contamination from grey water or black water systems, garbage disposal, spilling of household chemicals or hydrocarbons, and inundation of cabins and waste disposal facilities during extreme flooding events and subsequent runoff of contaminants. The probable maximum flood, such as the 100 year flood event, for Comox Lake is estimated to be 140 m, and most cabins and waste disposal facilities are located below this elevation (Benjamin and Vasarhelyi, 2006). Fire suppression activity, if any of these cabins catch fire, could also be a significant source of water quality contamination.

### 4.2 LICENSED WATER WITHDRAWALS

Water withdrawals can affect flows downstream from the point of diversion, especially during periods of lower flows, if licensed withdrawals are large relative to the volume of water in the system. However, in the case of Comox Lake, BC Hydro is required to maintain a minimum three-day average flow of 5.7 $m^3$/s and a minimum instantaneous flow of 5.1 $m^3$/s between the diversion dam and the powerhouse. As well, a number of releases (allowing at least 12 $m^3$/s) are provided throughout the year to allow for fish migration, rearing and spawning. DFO also has water licenses for conservation purposes (see Section 3.1 ).

### 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.

Approximately 61% of the Comox Lake watershed is currently under active forestry management (Table 2), including lands owned by Timber West and Hancock. The majority of forestry activity takes place on privately owned lands and is 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.

Comox Lake experiences high levels of recreational activity, primarily during the summer months. Activities include camping, 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. Fecal coliforms could be associated with campgrounds (i.e. Cumberland Lake Park Campground and Courtenay and District Fish and Game Protective Association private campground), backcountry activity, swimmers (especially infants and toddlers) and pets. Debris left by picnickers, fuel spills and combustion by-products from ski-boats, jet-skis and other motorized craft, could all potentially impact water quality in Comox 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 excrete fecal coliforms in their feces, and can cause elevated levels of this indicator 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 coliforms.

The Comox Lake watershed contains valuable wildlife habitat, and provides a home for a wide variety of warm-blooded species. Waterfowl utilize Comox Lake extensively, especially in the northeast corner. 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, coal mining has occurred in the Browns River watershed, below the Comox Lake watershed (MINFILE, 2004). There are a few showings in the upper Cruikshank River watershed that contain a number of minerals, including gold, silver, copper, molybdenum, lead, and zinc. 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 water quality monitoring sites were established in Comox Lake: one in the inlet basin (Site E259497); one in the main basin (Site E259498), and one in the outlet basin (Site E259499) (see Figure 3). 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. To represent the worst case scenario, bacteriological samples were collected weekly for 5 consecutive weeks during summer low flow (August/September) and fall flush (October/November) periods, at seven near-shoreline locations in the inlet and outlet basins (Table 3 and Figure 3). 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 coliform concentrations. All samples were collected according to Resource Inventory Standards Committee (RISC) standards (Cavanagh *et al.*, 1994).

**Table 3. Description of bacteriological monitoring sites in Comox Lake.**

| Site No. | Site Description | Location (Lat/Long) |
|---|---|---|
| Site 1 | Larger brown cabin with green roof, SE side of bay, mid cluster of cabins, 3rd cabin from South end. | N49 33.958 W125 10.208 |
| Site 2 | Mid bay, directly in line with cabin with blue roof on west side of lake. | N49 33.980 W125 10.760 |
| Site 3 | Out from red cabin on west side of bay, 300m up from rock face. | N49 34.190 W125 11.030 |
| Site 4 | Fish and game club campground, near swimming area. | N49 38.351 W125 05.503 |
| Site 5 | SE cluster of cabins (5 cabins in cluster), sample near docks below Canada flag. | N49 38.141 W125 04.496 |
| Site 6 | South end homes/cabins, larger house with green trim, set back from lake. | N49 37.596 W125 04.575 |
| Site 7 | Cumberland campground beach, opposite cinder block building, near swimming float, half way between 2 picnic shelters. | N49 37.731 W125 06.135 |

Water quality samples were collected from March 2005 to March 2008 in Comox 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 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, non-filterable residue
- Carbon: total inorganic carbon, total organic carbon
- Nutrients: total phosphorus, nitrate, nitrite, ammonia, total Kjeldahl N
- Total and dissolved metals concentrations

Water chemistry analyses were conducted by Maxxam Analytics Inc. in Burnaby, British Columbia.

Depth profiles were conducted in the field for dissolved oxygen, water temperature, oxidation-reduction potential (ORP), pH and conductivity using a Hydrolab Surveyor 4. Measurements were made every metre between the surface and 10 m depth, and then, on most occasions, every five metres until the final sample was collected just above the bottom (as deep as 55 m at the inlet basin site, 125 m in the main basin, and 35 m in the outlet basin). Water clarity was measured at the deep stations on each sampling day using a Secchi disc, which is a 20 cm diameter circular plastic disk whose surface is divided into four quadrants alternating in colour between black and white. The disk is lowered into the water with a rope, and the depth at which it disappears from sight is termed the extinction, or Secchi, depth.

There was a concern that the field pH probe was not functioning properly for some of the sampling dates, as very low values (near 6.0 pH units) were occasionally measured at each of the sites. These values were considerably lower than the laboratory values reported for the same day, and therefore only the more reliable laboratory data were used in the report.

Microbiological samples were collected at the surface only for all seven 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 in 30 consecutive days for each site.

Phytoplankton and chlorophyll *a* samples were collected by taking one litre grab samples at a depth of 0.5 m at the seep stations. Chlorophyll *a* samples were field filtered using 0.45 µm filter paper and then analyzed at the laboratory (Maxxam Analytics Inc.). Phytoplankton samples were preserved with Lugol's solution and shipped on ice to the laboratory for analyses. Zooplankton samples were collected to determine community composition and densities using a 10 m vertical tow in a Wisconsin-style net with a mouth area of 0.07 $m^2$, a net opening diameter of 0.3 m and a mesh size of 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).

# 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 MOE water quality guidelines are used to assess water at the point of diversion of the natural stream into a waterworks system. These BC guidelines are also used to protect other designated water uses such as recreation and habitat for aquatic life. The development of water quality objectives 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 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 CVRD only treats drinking water through chlorine disinfection prior to distribution. To effectively treat the water for viruses and parasites, such as *Cryptosporidium* and *Giardia*, 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. While the water supply intake is located 3.7 km downstream in the Puntledge River, the intent is that protecting the water quality in Comox Lake will help ensure that the water quality at the Puntledge intake is of a high standard.

### 6.1 LIMNOLOGICAL CHARACTERISTICS

Limnological characteristics are generally considered those related to the dynamics of the lake, including whether thermal or chemical stratification occurs. Thermal stratification is driven by the fact that water is at its 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 1982)) 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. As well, if waters near the sediment become anoxic, chemical reactions can result that release nutrients and other chemical parameters from sediments back into the water column. This explanation of stratification is very simplified and there are a number of different factors that affect stratification and water chemistry; but it gives an overview of typical lake dynamics in the temperate zone.

### 6.1.1 Temperature

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 the 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 trout and salmonids are based on specific life history stages such as incubation, rearing, migration and spawning.

The water column in Comox Lake was unstratified during the winter months, with stratification beginning to occur sometime between March and May each year. By August each year, the water column was strongly stratified, with the thermocline occurring between 10 m and 30 m depth. Hypolimnetic temperatures remained between 5°C and 6°C throughout the year, while epilimnetic temperatures reached as high as 20.9°C over the course of the sampling program. As the results for all three basins were similar only the main basin data was used to depict seasonal variability (Figure 7).

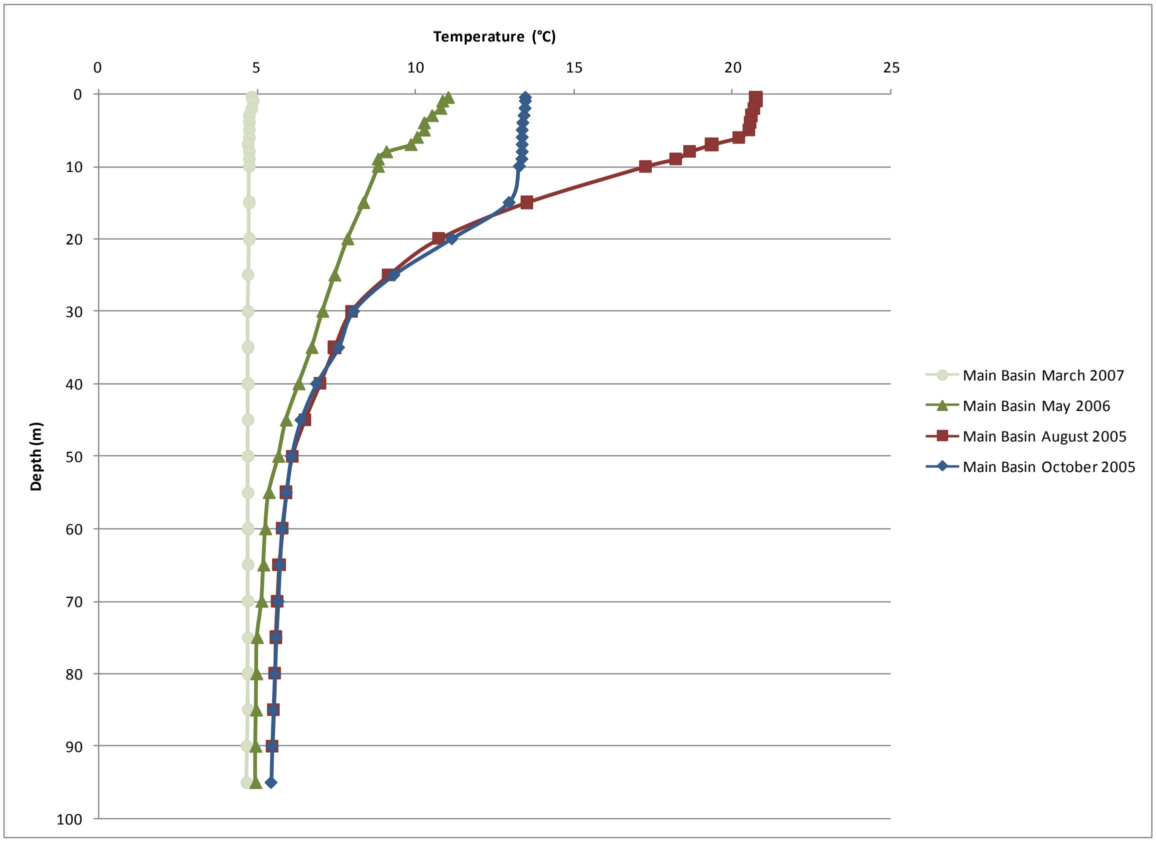


**Figure 7. Seasonal water temperatures measured at one to five metre intervals in Comox Lake in the main basin.**

As surface water temperatures are regularly around 20-21°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. Elevated water temperatures in the lower Puntledge River during August and September are a concern with respect to pink salmon mortality (Jensen *et al*., 2004), but it is possible that deeper water (rather than surface water) releases by BC Hydro during this time would help to mitigate this mortality. 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 Comox Lake***. This objective would also ensure that the aesthetic drinking water guideline of 15°C would be met, were the intake to be moved into Comox Lake at the appropriate depth.

### 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 therefore high biological productivity). If the euphotic zone (the zone where light penetration is sufficient to allow photosynthesis) lies above the thermocline, no photosynthesis occurs in deeper waters, and therefore oxygen depletion from 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 data was used to illustrate seasonal differences (Figure 8). In general, when the lake was thermally stratified, concentrations increased with depth, as water temperatures decreased (resulting in increased oxygen solubility). On occasion, especially during the fall months (when algae would be senescing), DO concentrations near the bottom of the inlet basin decreased slightly, with a minimum recorded value of 6.1 mg/L. This is likely due to decomposition of organic material that grew over the course of the summer. However, at shallower depths (more than 5 m above the substrate), concentrations consistently exceeded 8 mg/L, while all values measured in the main and outlet basins were above 8.5 mg/L. 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 Comox Lake at this time. However if human activities such as forestry, recreation 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. The objective is that ***DO concentrations measured at any depth in each basin, should be ≥ 5 mg/L during the summer months.***

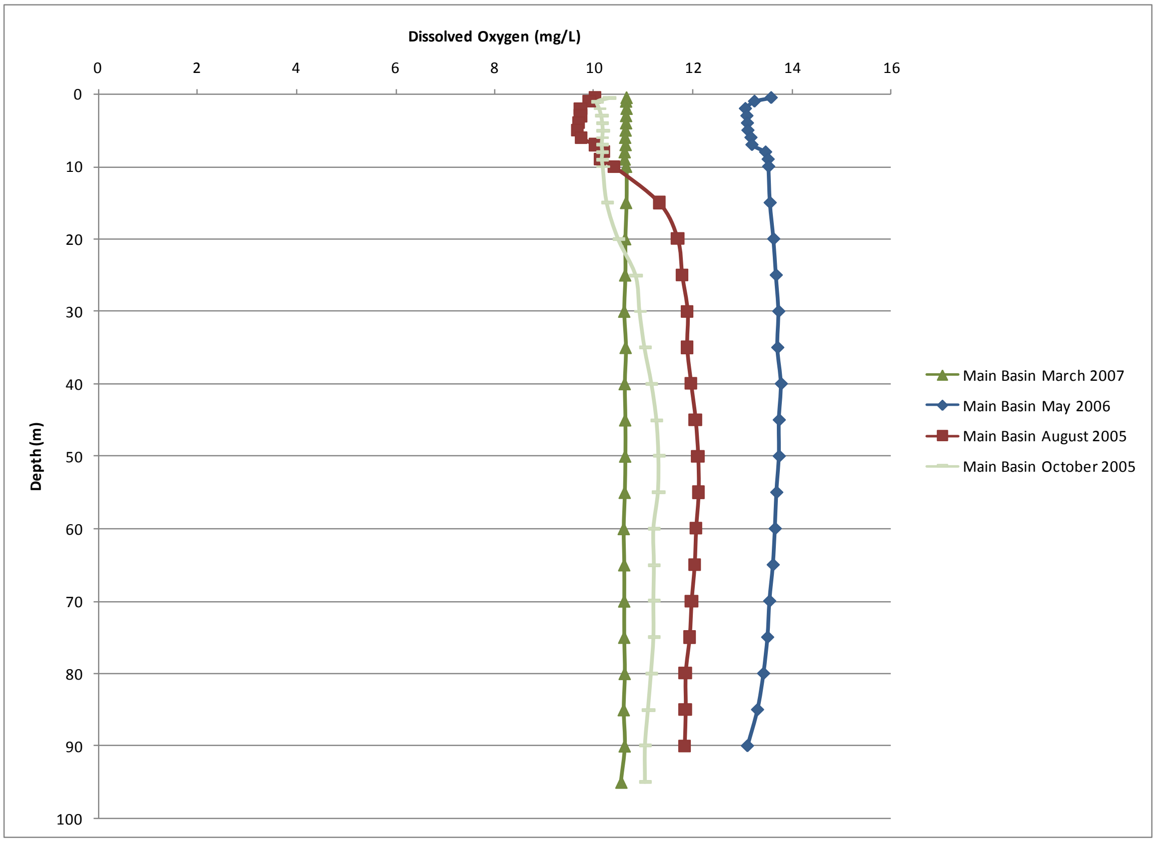


**Figure 8. Seasonal dissolved oxygen concentrations (mg/L) measured at one to five metre intervals in Comox Lake in the main basin.**

### 6.1.3 Water Clarity

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

Mean annual Secchi depths for Comox Lake are shown in Figure 9. Mean values are used because individual values can show high variability over the course of a year, or even a given month. Transient events such as rainfall or snowmelt runoff, as well as algal blooms, contribute to this variability. Mean Secchi depths for the period of record (between 2005 and 2007) were similar between basins, ranging from 8.5 m in the main and outlet basins (2007) to 11.1 m in the outlet basin (2005). All values easily met the recreational guideline of 1.2 m. to ensure that Secchi depths are maintained at the current level, a water quality objective is proposed: ***the mean annual Secchi depth (measured at least four times per year, once during each season) should exceed 8 m at all monitoring locations.*** To identify if the ranges in Secchi depth is a product of natural variability or anthroprogenic influences (in the outlet basin), it is recommended that a volunteer sampling program, such as that offered by the BC Lakes Stewardship Society (BCLSS) be undertaken. The BCLSS Level 1 sampling program involves Secchi depth readings along with surface temperature readings to be collected from May through to the end of September on a weekly or biweekly basis.

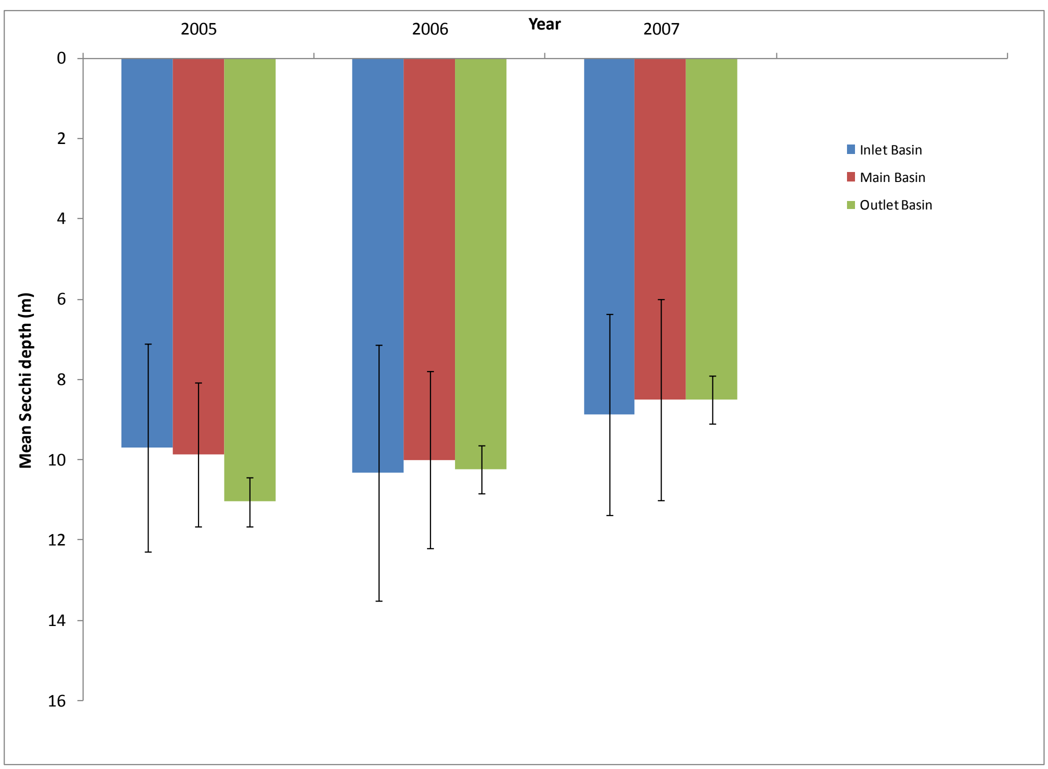


**Figure 9. Mean annual Secchi depth (includes standard deviation) measured in Comox Lake in the inlet, main and outlet basins.**

## 6.2 WATER CHEMISTRY

### 6.2.1 pH

pH measures the concentration of hydrogen ions 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 14 is alkaline (the higher the number, the more basic the water). The aesthetic objective for drinking water is a pH between 6.5 and 8.5 (McKean and Nagpal, 1991). Corrosion of metal plumbing may occur at both low and high pH outside of this range, while scaling or encrustation of metal pipes may occur at high pH. The effectiveness of chlorine as a disinfectant is also reduced outside of this range. The aquatic life guideline allows a pH range between 6.5 and 9.0 pH units. Outside of this range, toxicity to fish begins to occur (McKean and Nagpal, 1991).

pH at the inlet basin ranged from 6.7 to 7.6 pH units, from 6.8 to 8.0 pH units in the main basin, and from 6.5 to 7.8 pH units in the outlet basin. The mean pH at all of the sites was 7.3 pH units. With the exception of one low value measured in the outlet basin (6.5 pH units, measured near the surface on October 13, 2005), all values were within aquatic life and drinking water guidelines (which allow a minimum pH of 6.5). Deeper water samples measured on October 13, 2005 in the outlet basin had pH values of 7.2 and 7.4 pH units, and it is likely that the low surface water value was a result of almost 2 cm of rainfall the previous day (rain has a naturally low pH). Regardless, anthropogenic activities occurring within the watershed are not likely to have a significant impact on pH and it does not appear that pH is a concern, and therefore no water quality objective is proposed for this parameter.

**Table 4. Summary of pH values measured at each of the three monitoring locations on Comox Lake between 2005 and 2008.**

| | Minimum (pH units) | Maximum (pH units) | Average (pH units) | Std Dev | No. of Samples |
|---|---|---|---|---|---|
| Inlet basin | 6.7 | 7.6 | 7.3 | 0.26 | 39 |
| Main basin | 6.8 | 8.0 | 7.3 | 0.29 | 39 |
| Outlet basin | 6.5 | 7.8 | 7.3 | 0.31 | 36 |

### 6.2.2 Turbidity

Turbidity is a measure of the clarity or cloudiness of water, and is measured by the amount of light scattered by the particles in the water as nephelometric turbidity units (NTU). Elevated turbidity levels can decrease the efficiency of disinfection, potentially allowing pathogens to enter the water system. There are aesthetic concerns with cloudy water, and particulate matter can clog water filters and leave a film on plumbing fixtures, as well. 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 (Caux *et al.*, 1997). VIHA's goal for surface source drinking water for systems that do not receive filtration, such as Comox Lake, is that it demonstrate 1 NTU turbidity 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).

Turbidity values were consistently low in Comox Lake, with values ranging from 0.2 NTU to 0.7 NTU in the inlet basin, from 0.1 NTU to 0.8 NTU in the main basin, and from 0.2 to 0.9 NTU in the outlet basin. The residence time of Comox Lake, from the upper Puntledge River to the BC Hydro spillway, ranges from 14 months in the winter (when the water column is mixed and therefore inputs relative to the entire volume of the lake are small) to 12 weeks in the summer (when the lake is stratified, in effect isolating the water below the thermocline and greatly decreasing the volume of water moving through the lake) (Benjamin and Vasarhelyi, 2006). While the residence time varies seasonally it provides considerable settling time for suspended sediments entering the system from the upper Puntledge River. However, sediment inputs lower in the watershed (around the perimeter of Comox Lake) have a decreased residence time, such that inputs into the outlet basin could take from 1.5 to 24 hours to reach the BC Hydro spillway (Benjamin and Vasarhelyi, 2006). For this reason, a water quality objective is recommended to ensure that the exceptional water clarity of Comox Lake is maintained. ***The objective is that the maximum turbidity measured in any sample collected at the three monitoring locations should not exceed 2 NTU.*** These values are based on an allowable increase of 1 NTU above existing maximum background values, measured at each of these sites (Table 5. However, in accordance with VIHA's protocol for whether filtration is required, the Comox Valley Regional District, as water purveyors, should continue to sample turbidity levels at the water intake location to ensure that the appropriate treatment methods are applied. It is generally considered that turbidity values greater than 2 NTU may compromise disinfection effectiveness (Gary Anderson, VIHA, pers. comm. 2006).

It is further recommended that future attainment monitoring include a sampling site at the community drinking water intake in the Puntledge River to examine potential changes between the lake outlet and the river intake, 3.7 km downstream.

**Table 5. Summary of turbidity values measured at each of the three monitoring locations on Comox Lake between 2005 and 2008.**

| | Minimum (NTU) | Maximum (NTU) | Average (NTU) | Std Dev | No. of Samples |
|---|---|---|---|---|---|
| Inlet basin | 0.2 | 0.7 | 0.4 | 0.1 | 30 |
| Main basin | 0.1 | 0.8 | 0.3 | 0.2 | 30 |
| Outlet basin | 0.2 | 0.9 | 0.4 | 0.2 | 30 |

### 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 colour units (TCU) (Moore and Caux, 1997). The guideline is based on the fact that waters with true colour less than or equal to 15 TCU are in the blue to green colour range, while waters with higher colour values generally have a yellowish tinge (Moore and Caux, 1997).

Colour was measured 27 times at each site, with values consistently at or 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 CVRD uses chlorine to disinfect their drinking water, TOC concentrations in Comox Lake are of interest. TOC concentrations were measured 15 times at each of the three monitoring sites, with values ranging from 0.5 mg/L at each of the sites to a maximum of 1.9 mg/L at the outlet site. All values were well below the drinking water guideline for TOC of 4 mg/L to protect against disinfection by-products. As such, no water quality objective for TOC is proposed.

#### 6.2.4 Conductivity

Conductivity refers to the ability of a substance to conduct an electric current. The conductivity of a water sample gives an indication of the concentration of dissolved ions in the water and is measured in microsiemans per centimeter (µS/cm). The more ions dissolved in a solution, the greater the electrical conductivity. Because temperature affects the conductivity of water (a 1ºC increase in temperature results in approximately a 2% increase in conductivity), specific conductivity is used (rather than simply conductivity) to compensate for temperature. 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 Comox Lake were consistently low, ranging from 21 µS/cm to 44 µS/cm in the inlet basin, from 30 µS/cm to 38 µS/cm in the main basin, and from 30 µS/cm to 41 µS/cm in the outlet basin. Values were correlated with flows, with the highest conductivity occurring during low flows (when dilution was lowest) and conductivity values dropping during the winter (when dilution from rainfall was highest). Figure 10 illustrates this seasonal variability as represented by the main basin data. As there is no BC Water Quality Guideline for specific conductivity and the specific conductivity results observed were typical of coastal systems, no objective is proposed for specific conductivity in Comox Lake.

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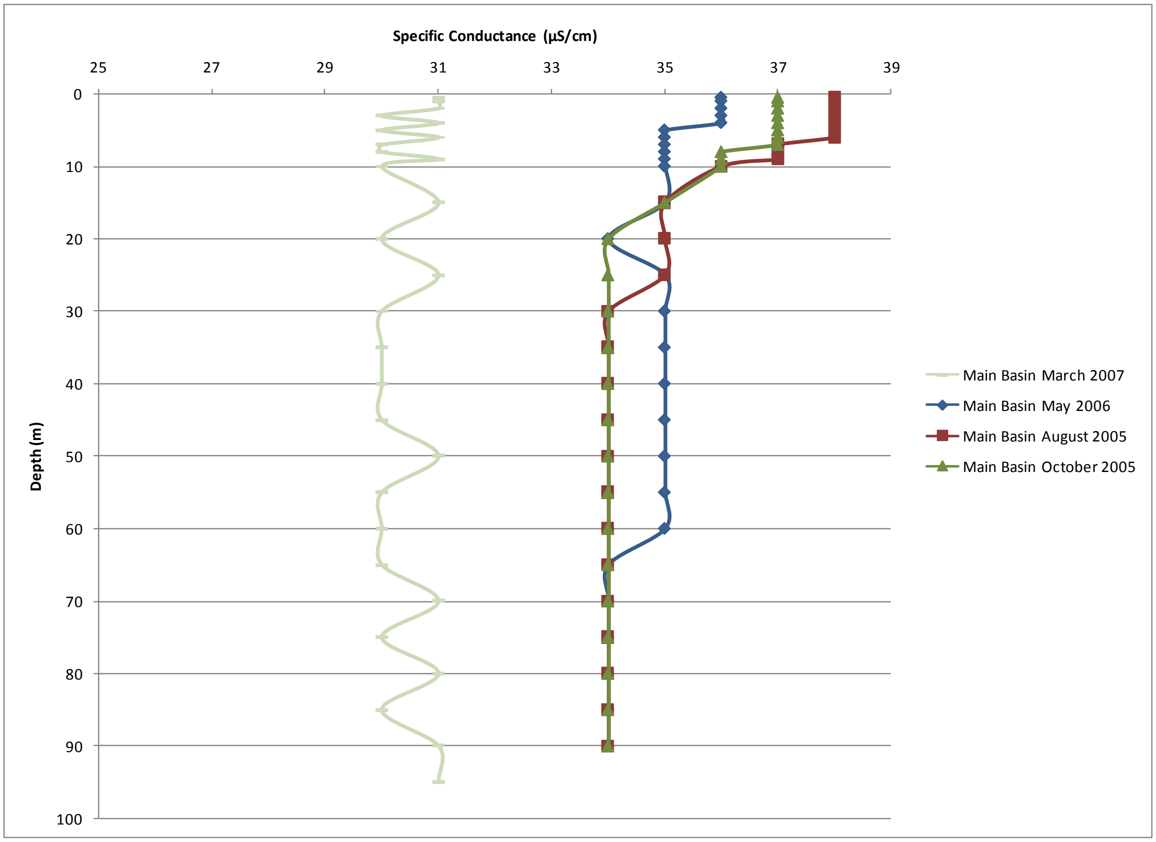


**Figure 10. Specific conductivity measured at one and five metre intervals in Comox Lake in the inlet, main and outlet basins during summer and main basin only during spring.**

### 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. However, if lakes are undergoing internal nutrient loading, typically eutrophic lakes, then the highest concentrations of phosphorus may be found in the fall. In watersheds where drinking water is a priority, it is desirable that nutrient levels remain low to avoid algal blooms and foul tasting water. Similarly, to protect aquatic life, nutrient levels should not be too high or the resulting plant and algal growth can deplete oxygen levels when it dies and begins to decompose, as well as during periods of low productivity when plants consume oxygen (*i.e.*, at night and during the winter under ice cover). Conversely, you do need a certain amount of nutrients 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 0.007 mg/L to 0.067 mg/L, with an average of 0.034 mg/L in Comox Lake at the inlet site.

Values were similar in the main basin, ranging from < 0.002 mg/L to 0.072 mg/L and an average of 0.037 mg/L, as well as the outlet basin (0.006 mg/L to 0.060 mg/L, with an average of 0.033 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, 2001). The guideline for maximum total phosphorus concentrations in B.C. lakes is 10 µg/L to protect drinking water and recreation, and a range of 5 to 15 µg/L to protect aquatic life when salmonids are the dominant species (Nordin, 1985).

Almost half (44 of 90) of all samples from the three sites analyzed for total phosphorus had concentrations below the detection limit (2 µg/L). The maximum values measured at the three sites ranged from 6 µg/L at both the main and outlet sites to 10 µg/L at the inlet site. The high phosphorus value at the inlet basin was only observed on one occasion (August 2006 at the bottom depth), otherwise the next highest value was 7 µg/L. As the slightly higher concentration of phosphorus in the inlet basin was only observed on one occasion, it is likely due to contributions/contamination of sediment particles that may have been stirred up in the bottom at the time of sampling. This is supported by the presence of some slightly higher total metal results at this site from the same sample date and depth.

Concentrations of nitrogen and phosphorus are generally low in Comox Lake. However, to protect fundamental water quality and to ensure a balance of nature, human use and recreational values, an objective is recommended for total phosphorus in Comox Lake. ***The objective is that the average concentration of total phosphorus during spring overturn not exceed 6 µg/L.*** Average spring overturn phosphorus levels at the three sites were well below the phosphorus guideline over the course of the study, and therefore should continue to be met, as long as significant new sources of nutrients do not emerge. This objective will act as a red flag should phosphorus values increase and will identify that further investigation is warranted.

#### 6.2.6 Metals

Total metals concentrations were measured between 36 and 39 times at the three sites on Comox Lake, while dissolved metals were measured between 27 and 30 times at the three sites. The concentrations of metals were well below guidelines for drinking water and aquatic life. The exception to this was cadmium: the detection limit used to measure total cadmium concentrations is 0.1 µg/L, which is greater than the aquatic life guideline of 0.01 µg/L (Nagpal *et al*., 2006). While all samples analyzed at the three sites had total cadmium concentrations at or below the detection limit, this metal is likely not a concern because there are no anthropogenic sources of cadmium within the watershed and cadmium concentrations likely reflect ambient conditions. However, when analytical methods with sufficiently low detection limits (< 0.005 µg/L or less) become available, they should be used to analyze future samples from the lake to ensure that cadmium is not a concern. 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 need to be considered.

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 Comox 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).

While no water licenses have been issued for domestic water use in Comox Lake, a proactive approach has been taken to ensure protection of the water quality now and for the future. Therefore, data are compared with the more stringent MOE drinking water source guideline, rather than the recreational guideline. At each of the seven sites, one set of five samples was collected in both summer and fall between 2005 and 2007, resulting in 30 samples per site. These samples were analyzed for fecal coliforms and *E. coli*, and both 90$^{th}$ percentiles and geometric means were calculated for each set of five samples.

In reviewing the 90$^{th}$ percentile data for both fecal coliforms and *E. coli* concentrations it is apparent that the inlet basin sites (1-3) are substantially lower than the outlet basin sites (4-7) and as such are likely reflective of background levels (Tables 6 and 7). There is very little activity in the inlet basin, with respect to bacteriological sources, besides a few seasonal cabins, whereas the outlet basin has full time residents, seasonal campgrounds, and more boat and human traffic on the lake. For the inlet basin, the fecal coliform 90$^{th}$ percentiles for the sample periods range from less than detection limits to a maximum of 16.4 CFU/100 mL (at Site 2), with only 2 out of 18 sample period results exceeding the BC drinking water guideline of 10 CFU/100 ml. The outlet basin fecal coliform 90$^{th}$ percentiles for the sample periods range from less than detection limits to a maximum of 192.4 CFU/100 mL (Site 6). Fifteen of the 24 sample period results exceed the BC MOE drinking water guideline. In both instances where bacteriological numbers were significantly elevated (at sites 4 and 6), high numbers of birds (generally seagulls) were observed at and near the sampling stations (*e.g.* sitting on log booms adjacent to docks), indicating a potential source. A microbial source tracking study prepared for the Comox Strathcona Regional District in 2005 found that the predominant sources of fecal coliforms near the lake outlet were attributable to deer, dogs and seagulls (Clayton, 2005).

**Table 6. Summary of 90th percentiles of fecal coliform concentrations (CFU/100 mL) for groups of five samples collected within a 30-day period.**

| Location Basin | Site # | Aug 11 - Sept 9, 2005 | Oct 14 - Nov 10, 2005 | Aug 30 - Sep 13, 2006 | Oct 17 - Nov 22, 2006 | Aug 9 - Sept 13, 2007 | Oct 23 - Nov 22, 2007 |
|---|---|---|---|---|---|---|---|
| Inlet | 1 | < 1.0 | < 1.0 | < 1.0 | 3.6 | 5.8 | 14.6 |
| Inlet | 2 | < 1.0 | 9.8 | < 1.0 | 4.8 | 16.4 | 3.6 |
| Inlet | 3 | < 1.0 | 3.0 | < 1.0 | 2.8 | 4.0 | 4.0 |
| Outlet | 4 | < 1.0 | 18.6 | 3.2 | 42.2 | 49.2 | 190.4 |
| Outlet | 5 | 17.0 | 3.6 | 23.6 | 20.6 | 26.4 | 10.2 |
| Outlet | 6 | 1.0 | 4.8 | 6.0 | 5.6 | 192.4 | 172.0 |
| Outlet | 7 | 4.0 | 62.2 | 52.8 | 3.6 | 17.0 | 29.8 |

**Table 7. Summary of 90th percentiles of *E. coli* concentrations (CFU/100 mL) for groups of five samples collected within a 30-day period.**

| Location Basin | Site # | Aug 11 - Sept 9, 2005 | Oct 14 - Nov 10, 2005 | Aug 30 - Sep 13, 2006 | Oct 17 - Nov 22, 2006 | Aug 9 - Sept 13, 2007 | Oct 23 - Nov 22, 2007 |
|---|---|---|---|---|---|---|---|
| Inlet | 1 | < 1.0 | 1.6 | < 1.0 | 3.6 | 5.8 | 4.2 |
| Inlet | 2 | < 1.0 | 8.2 | < 1.0 | 3.8 | 16.4 | 2.2 |
| Inlet | 3 | < 1.0 | 2.2 | < 1.0 | 2.8 | 4.0 | 2.2 |
| Outlet | 4 | < 1.0 | 6.6 | 2.0 | 23.2 | 41.6 | 88.4 |
| Outlet | 5 | 3.8 | 4.0 | 10.4 | 12.6 | 23.6 | 5.0 |
| Outlet | 6 | < 1.0 | 3.6 | 6.2 | 3.8 | 142.4 | 20.0 |
| Outlet | 7 | 1.0 | 38.6 | 44.2 | 2.6 | 17.0 | 20.6 |

The *E. coli* 90th percentiles for the inlet basin range from less than detection limits to a maximum of 16.4 CFU/100 mL. Similar to fecal coliforms, the results are generally well below the BC MOE drinking water guideline, with only one exceedance occurring in the summer of 2007. For the outlet basin, the *E. coli* 90th percentiles for the sample periods range from below detection limits to a maximum of 142.4 CFU/100 ml. There were 12 exceedances of the BC MOE drinking water guideline for *E. coli* out of the 24 sample period results, including each of the 8 results in 2007.

Geometric means were calculated for fecal coliform and *E. coli* concentrations in each set of five samples (Table 8 and 9). The maximum geometric mean for fecal coliforms was 64.7 CFU/100 mL at Site 6, considerably below the BC recreational guideline level of 200 CFU/100 mL. Similarly, the maximum geometric mean for *E. coli* was 53.9 CFU/100 mL, also measured at Site 6. This is slightly lower than the recreational guideline of 77 CFU/100 mL for *E. coli* in recreational waters. The primary contact recreation guidelines for fecal coliforms and *E. coli* were not exceeded at any of the seven sampling sites on the six occasions when the sampling frequency was sufficient to determine compliance. However, occasional elevated values of both fecal coliforms and *E. coli* were observed, especially in the outlet basin. Possible contamination from hubs of activity including campgrounds and boat launches, as well as cabins, pets, waterfowl and wildlife could all be contributing to the bacteria levels reported here.

**Table 8. Summary of geometric means of fecal coliform concentrations (CFU/100 mL) for groups of five samples collected within a 30-day period.**

| Site # | Aug 11 - Sept 9, 2005 | Oct 14 - Nov 10, 2005 | Aug 30 - Sep 13, 2006 | Oct 17 - Nov 22, 2006 | Aug 9 - Sept 13, 2007 | Oct 23 - Nov 22, 2007 |
|---|---|---|---|---|---|---|
| 1 | < 1.0 | 1.3 | < 1.0 | 1.6 | 1.6 | 3.6 |
| 2 | < 1.0 | 2.5 | 1.0 | 1.8 | 2.2 | 1.6 |
| 3 | < 1.0 | 1.7 | 1.0 | 1.3 | 1.4 | 1.4 |
| 4 | 1.0 | 2.7 | 1.5 | 7.9 | 13.8 | 20.9 |
| 5 | 4.2 | 1.4 | 5.5 | 6.2 | 7.5 | 7.0 |
| 6 | 1.0 | 1.9 | 2.9 | 3.0 | 64.7 | 8.9 |
| 7 | 1.4 | 11.7 | 7.4 | 1.6 | 2.6 | 3.9 |

**Table 9. Summary of geometric means of *E. coli* concentrations (CFU/100 mL) for groups of five samples collected within a 30-day period.**

| Site # | Aug 11 - Sept 9, 2005 | Oct 14 - Nov 10, 2005 | Aug 30 - Sep 13, 2006 | Oct 17 - Nov 22, 2006 | Aug 9 - Sept 13, 2007 | Oct 23 - Nov 22, 2007 |
|---|---|---|---|---|---|---|
| 1 | < 1.0 | 1.5 | < 1.0 | 1.6 | 1.6 | 2.3 |
| 2 | < 1.0 | 2.1 | < 1.0 | 1.6 | 2.2 | 1.2 |
| 3 | < 1.0 | 1.4 | 1.0 | 1.3 | 1.4 | 1.2 |
| 4 | < 1.0 | 1.5 | 1.3 | 6.1 | 9.5 | 12.0 |
| 5 | 1.6 | 1.3 | 2.7 | 4.5 | 4.0 | 4.1 |
| 6 | < 1.0 | 1.6 | 2.5 | 2.1 | 53.9 | 3.8 |
| 7 | 1.0 | 6.2 | 4.3 | 1.4 | 2.2 | 3.1 |

For Comox 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 results for the inlet basin are relatively low and are reflective of background or natural conditions. However, it appears that bacteria are a potential concern in the outlet basin of Comox 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 Comox Lake. ***Therefore, a water quality objective is proposed for* E. coli *to protect drinking water sources. The objective is that the 90$^{th}$ 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 Comox Lake. Samples should be collected during the late summer, as well as during the fall freshet, when concentrations of bacteria are likely at their highest.***

As Comox Lake is the primary source of water for the Comox Valley, this objective will provide both a level of protection for the drinking water supply (from Puntledge River intake) and for the people removing water directly from the lake for drinking purposes (as reportedly occurs at some of the cabins (Benjamin and Vasarhelyi, 2006)). However, to prevent health risks these non-licensed withdrawals for domestic purposes from Comox Lake should receive some level of treatment prior to consumption. In addition, the people participating in primary-contact recreation sports will also benefit from the proposed bacteriological objective as it is substantially lower that the provincial recreation guideline. In this case drinking water is the more sensitive use and as such a recreational water quality objective for *E. coli* is not proposed.

Water quality analyses for bacteriological indicators should, and are, being conducted at the CVRD intake by CVRD staff to ensure that the level of treatment that the water undergoes before drinking is sufficient to protect consumers. Should the CVRD intake be moved to within Comox Lake, efforts should be made to locate it such that exposure to bacteriological contamination is minimized (e.g. further from shore, and below the water surface).

### 6.3.2 Phytoplankton

Phytoplankton populations can have significant impacts on water quality, and may give an indication of contaminant and nutrient levels in a lake. Algal blooms resulting from elevated nutrient levels can impair water quality in a number of ways. Algae can clog water filters and can impact taste and odour 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) also contain toxins. Allergic reactions to algae in drinking water, or from exposure to algae while swimming, are also common. Aesthetically, algal blooms reduce water clarity and can result in an unpleasant "scum" on the surface of the water, as well as give the water a strong odour.

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

Phytoplankton samples were collected for all three basins in Comox Lake; the results were summarized and the dominant species for each site are listed in Table 10 to 12. Dominant species were those that made up at least 10% of the total cells present in the sample. The complete results of taxonomic analysis for phytoplankton can be obtained from the MOE office in Nanaimo.

Phytoplankton was sampled 13 times between March 2005 and March 2008. A total of 58 species were identified. Overall the inlet basin tended to have lower plankton concentrations (average of 255 cells/mL) and higher species richness (the number of different species occurring) (average of 48 species). Whereas the main and outlet basin had similar average species richness (38). The outlet basin tended to have higher overall concentrations of plankton (average of 312 cells/mL). In general, algal concentrations were quite low in all three basins, which is typical of oligotrophic lakes.

The phytoplankton community in Comox Lake was dominated most years by diatoms from the Order Centrales, with *Cyclotella glomerata* and *Rhizosolenia eriensis/longiseta* comprising the majority of the plankton community in most samples. Pennate diatoms were also common in both the inlet and outlet basins, especially *Achnanthes minutissima*. During the winter months, a number of species from three other orders (Chlorococcales, Cryptomonadales, and Dinokontae) were present, but they were not seen in significant numbers during the summer months (in the June or August samples). In October, 2005 and 2006, two species of blue-green algae (*Anacystis* cf *elachista* var. *conferta* and *Anacystis limneticus*, from the Order Chroococcales) were present in significant numbers in all three of the basins. Overall the phytoplankton community found in Comox 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.

**Table 10. Summary of dominant (*i.e.* >10% of sample) phytoplankton species for the inlet basin of Comox Lake, 2005 – 2008 (number of cells/mL and % of total sample).**

| | 9-Mar-05 | 1-Jun-05 | 11-Aug-05 | 13-Oct-05 | 14-Mar-06 | 30-May-06 | 16-Aug-06 | 17-Oct-06 | 20-Mar-07 | 21-Jun-07 | 9-Aug-07 | 23-Oct-07 | 19-Mar-08 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Order: Centrales** | | | | | | | | | | | | | |
| *Cyclotella glomerata* | | 150 40% | | | | | 70 44% | | 14 31% | 67 14% | | 31 39% | 32 37% |
| *Melosira italica* | 17 31% | | | | | | | | | | | | |
| *Rhizosolenia eriensis/longiseta* | | 52 14% | 398 76% | | 17 18% | 49 38% | | 53 25% | | | 529 72% | | |
| *Rhizosolenia sp.* | | | | | | | | | | 333 68% | | | |
| **Order: Chlorococcales** | | | | | | | | | | | | | |
| *Scenedesmus cf dentriculatus* | | | | 22 12% | | | | | | | | | |
| *Sphaerocystis schroeteri* | | | | | | | | | | | | 8 11% | |
| **Order: Chroococcales** | | | | | | | | | | | | | |
| *Anacystis cf elachista var. conferta* | | | | | | | 22.0 14% | 56 26% | | | | | |
| *Anacystis limneticus* | | | | 39 22% | | | | | | | | | |
| **Order: Cryptomonadales** | | | | | | | | | | | | | |
| *Chroomonas acuta* | | | | 20 11% | | | | | 8 19% | | | 15 20% | 24 27% |
| **Order: Dinokontae** | | | | | | | | | | | | | |
| *Peridinium cf inconspicuum* | | | | 20 11% | | | | | | | | | |
| **Order : Ochromonadales** | | | | | | | | | | | | | |
| *Dinobryon bavaricum* | | | | | | | | | | | | | |
| *Dinobryon spp.* | | | | | | 13.0 10% | | | | | | | |
| **Order: Pennales** | | | | | | | | | | | | | |
| *Asterionella formosa* | | | | | | 18% 14% | | | | | | | |
| *Achnanthes minutissima* | 10 18% | | | | 14.0 15% | 18% 14% | | | 6 13% | | | | 10 11% |
| *Fragilaria crotonensis* | | | | | | | | | 10 22% | | | | |
| *Tabellaria flocculosa* | | 50 14% | | | | | | | | | | | |

**Table 11. Summary of dominant (*i.e.* >10% of sample) phytoplankton species for the main basin of Comox Lake, 2005 – 2008 (number of cells/mL and % of total sample).**

| | 9-Mar-05 | 1-Jun-05 | 11-Aug-05 | 13-Oct-05 | 14-Mar-06 | 30-May-06 | 16-Aug-06 | 17-Oct-06 | 20-Mar-07 | 21-Jun-07 | 9-Aug-07 | 23-Oct-07 | 19-Mar-08 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Order: Centrales** | | | | | | | | | | | | | |
| *Cyclotella glomerata* | 7 23% | 224 56% | | 22 20% | 4 14% | 39 20% | 67 53% | 113 38% | 17 32% | 101 15% | 76 10% | 35 78% | |
| *Rhizosolenia eriensis/longiseta* | | 86 22% | 367 84% | | | 57 30% | | 62 20% | | 465 69% | 616 82% | | 11 16% |
| **Order: Chlorococcales** | | | | | | | | | | | | | |
| *Crucigenia quadrata* | | | | 11 10% | | | | | 6 11% | | | | |
| **Order: Chroococcales** | | | | | | | | | | | | | |
| *Anacystis cf elachista var. conferta* | | | | 28 25% | | | | 42 14% | | | | | |
| **Order: Cryptomonadales** | | | | | | | | | | | | | |
| *Chroomonas acuta* | 15 50% | | | 20 18% | 22.0 73% | | | | 11 22% | | | | 34 48% |
| **Order : Ochromonadales** | | | | | | | | | | | | | |
| *Dinobryon bavaricum* | | | | | | 23.0 11% | | | | | | | |

**Table 12. Summary of dominant (*i.e.* >10% of sample) phytoplankton species for the outlet basin of Comox Lake, 2005 – 2008 (number of cells/mL and % of total sample).**

| | 9-Mar-05 | 1-Jun-05 | 11-Aug-05 | 13-Oct-05 | 14-Mar-06 | 30-May-06 | 16-Aug-06 | 17-Oct-06 | 20-Mar-07 | 21-Jun-07 | 9-Aug-07 | 23-Oct-07 | 19-Mar-08 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Order: Centrales** | | | | | | | | | | | | | |
| *Cyclotella cf bodanica* | 4 13% | | | | | | | | | | | | |
| *Cyclotella glomerata* | 11 35% | 203 61% | | 35 42% | | 81 32% | 57 56% | | 7 36% | 90 11% | | 38 66% | 10 21% |
| *Rhizosolenia eriensis/longiseta* | | 59 18% | 210 81% | | 17 20% | 69 27% | | 106 25% | | 666 79% | 955 89% | | 7 15% |
| *Rhizosolenia sp.* | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| **Order: Chroococcales** | | | | | | | | | | | | | |
| *Anacystis cf elachista var. conferta* | | | | 17 20% | | | | 238 55% | | | | | |
| *Anacystis limneticus* | | | | 20 23% | | | 24.0 23% | | | | | | |
| | | | | | | | | | | | | | |
| **Order: Cryptomonadales** | | | | | | | | | | | | | |
| *Chroomonas acuta* | | | | | 38.0 60% | | | | 7 36% | | | | 15 32% |
| *Cryptomonas ovata/erosa* | | | | | | | | | | | | 13 22% | |
| | | | | | | | | | | | | | |
| **Order: Dinokontae** | | | | | | | | | | | | | |
| *Peridinium cf inconspicuum* | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| **Order : Ochromonadales** | | | | | | | | | | | | | |
| *Dinobryon spp.* | | | | | | 70.0 28% | | | | | | | |
| | | | | | | | | | | | | | |
| **Order: Pennales** | | | | | | | | | | | | | |
| *Achnanthes minutissima* | 6 17% | 32 10% | | | | | | | 3 14% | | | | 8 18% |
| *Fragilaria crotonensis* | 7 22% | | | | | | | | 3 14% | | | | |

Chlorophyll *a* acts as a surrogate for more detailed phytoplankton sampling, as it measures the photosynthetic pigment typically found in phytoplankton. Chlorophyll *a* concentrations are generally very closely correlated with total phosphorus concentrations (Nordin, 2001). Values below 3 µg/L are considered an indication of low productivity and values above 15 µg/L are generally considered to indicate high productivity. Agriculture, sewage effluent, forest harvesting, urban development and recreational activities can add nutrients to a lake, increasing chlorophyll *a* concentrations (Cavanagh *et al*., 1997). Concentrations of chlorophyll *a* measured in the three basins ranged from < 0.5 µg/L to a maximum of 1.2 µg/L in the main basin. While no objective for phytoplankton is proposed for Comox Lake, ***we recommend a water quality objective for Comox Lake allowing a maximum of 1.5 µg/L chlorophyll* a.** 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 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/abundance.

Zooplankton samples were collected 12 times for all three basins in Comox Lake between March 2005 and March 2008, with the exception of the inlet basin where the August 2007 sample was not taken. In addition zooplankton samples for all sites were not collected in June 2007 due to equipment malfunction. The results were summarized and the dominant species (*i.e*. >10% of sample) for each site are listed in Table 13 to 15. The more detailed set of taxonomic analysis results for zooplankton can be obtained from the MOE office in Nanaimo, BC.

A total of 25 zooplankton species were identified in Comox Lake. Overall zooplankton species richness was similar between the three basins, with an average number of species of 17, 17, and 18 for the inlet, main and outlet basins, respectively. However, the species average density was higher at the outlet basin at 5,916 cells/mL, as compared to the inlet (4,963 cells/mL) and main (5,270 cells/mL) basins. Since zooplankton feed on phytoplankton the higher density observed in the outlet basin is likely linked to the higher concentrations of phytoplankton seen in the outlet basin. Concentrations of zooplankton were highest in the summer and fall and lowest in the March samples.

The zooplankton community of Comox Lake was composed predominately of four groups: rotifers, cladocerans, calanoid copepods and cyclopoid copepods. In all of the basins, the zooplankton community was dominated by three rotifer genera: *Keratella cochlearis*, *Polyarthra*, and *Synchaeta*. *Keratella* and *Polyartha* species are known to be cold water rotifers and develop maximal population densities in midwinter to early spring (Wetzel, 2001). Another dominant rotifer, *Callotheca*, was observed in the summer and fall of 2006 only at all three basins. In addition, *Callotheca* was identified as a dominant species at the outlet basin only in June 2005 and August 2007.

The dominant calanoid copedod in this study was *Diaptomus oregonensis*, which was typically only observed in March. During the spring, copepod nauplii (newly hatched copepods) were also very prevalent, dominating the zooplankton population at all three basins. By late summer/early autumn, the small cladoceran, *Bosmina longirostris*, becomes dominant in response to loss of the thermal stratification in lakes and the increased nutrient regeneration from the deeper waters (Wetzel, 2001). The zooplankton communities observed in Comox Lake are consistent with oligotrophic conditions; therefore, no objective is recommended for zooplankton at this time.

**Table 13. Summary of dominant (*i.e.* >10% of sample) zooplankton species for the inlet basin of Comox Lake, 2005 – 2008 (number of cells/mL and % of total sample).**

| | 9-Mar-05 | 1-Jun-05 | 11-Aug-05 | 13-Oct-05 | 14-Mar-06 | 30-May-06 | 16-Aug-06 | 17-Oct-06 | 20-Mar-07 | 21-Jun-07 | 9-Aug-07 | 23-Oct-07 | 19-Mar-08 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Subclass : Copepoda** | | | | | | | | | | no data | no data | | |
| Copepod nauplii | 267 14% | | | | 147 11% | 1200 14% | | | 427 53% | | | | 780 61% |
| **Order : Cyclopoida** | | | | | | | | | | | | | |
| *Diacyclops thomasi* | | | | | | | | | | | | | 159 12% |
| **Order: Calanoida** | | | | | | | | | | | | | |
| *Diaptomus oregonensis* adult | | | | | | | | | | | | | |
| *Diaptomus oregonensis* copepodid | | 1925 16% | | | | 1133 13% | | | | | | | |
| **Order: Cladocera** | | | | | | | | | | | | | |
| *Bosmina longirostris* | 240 13% | | 1280 13% | 1653 13% | 167 12% | 973 11% | 1020 10% | | | | | 5160 35% | |
| *Daphnia ambigua* | | | 1800 18% | | | | | | | | | 3660 25% | |
| *Holopedium gibberum* | | | 1227 12% | | | | | | | | | | |
| **Phylum: Rotifera** | | | | | | | | | | | | | |
| *Callotheca sp.?* | | | | | | | 1770 16% | 1107 15% | | | | | |
| *Gastropus sp.* | | | 1240 12% | | | | | | | | | | |
| *Keratella cochlearis* | 213 11% | | 1587 16% | 1480 12% | 440 32% | 973 11% | 1320 12% | 2800 39% | 120 15% | | | 2670 18% | |
| *Polyarthra sp.* | | 2225 18% | | 6440 51% | 200 14% | 1040 12% | 3810 35% | 933 13% | | | | | |
| *Synchaeta sp.* | 773 40% | 2800 23% | | | 213 15% | 1387 16% | | | | | | | |

**Table 14. Summary of dominant (*i.e.* >10% of sample) zooplankton species for the main basin of Comox Lake, 2005 – 2008 (number of cells/mL and % of total sample).**

| | 9-Mar-05 | 1-Jun-05 | 11-Aug-05 | 13-Oct-05 | 14-Mar-06 | 30-May-06 | 16-Aug-06 | 17-Oct-06 | 20-Mar-07 | 21-Jun-07 | 9-Aug-07 | 23-Oct-07 | 19-Mar-08 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Subclass : Copepoda** | | | | | | | | | | no data | | | |
| Copepod nauplii | 440 60% | | | | 507 40% | 413 10% | | | 1320 85% | | | | 2532 86% |
| | | | | | | | | | | | | | |
| **Order : Cyclopoida** | | | | | | | | | | | | | |
| *Diacyclops thomasi* | | | | | | | | | | | 1133 35% | | |
| | | | | | | | | | | | | | |
| **Order: Calanoida** | | | | | | | | | | | | | |
| *Diaptomus oregonensis* adult | | | | | 209 17% | | | | | | | | 295 10% |
| *Diaptomus oregonensis* copepodid | | 1467 11% | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| **Order: Cladocera** | | | | | | | | | | | | | |
| *Bosmina longirostris* | | | 1325 13% | | | | 1453 12% | | | | 533 16% | 3525 38% | |
| *Daphnia ambigua* | | | | | | | 1893 15% | | | | | | |
| *Holopedium gibberum* | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| **Phylum: Rotifera** | | | | | | | | | | | | | |
| *Callotheca sp.?* | | | | | | | 1860 15% | 860 16% | | | | | |
| *Gastropus sp.* | | | | | | | | | | | | | |
| *Keratella cochlearis* | 107 15% | | 4775 47% | 1020 11% | 267 21% | | 3200 25% | 1560 30% | | | 533 16% | 3025 32% | |
| *Polyarthra sp.* | | 4467 33% | | 4980 54% | | 1307 32% | 1307 10% | 1360 26% | | | | | |
| *Synchaeta sp.* | | | | | | 1240 30% | | | | | | | |

**Table 15. Summary of dominant (*i.e.* >10% of sample) phytoplankton species for the outlet basin of Comox Lake, 2005 – 2008 (number of cells/mL and % of total sample).**

| | 9-Mar-05 | 1-Jun-05 | 11-Aug-05 | 13-Oct-05 | 14-Mar-06 | 30-May-06 | 16-Aug-06 | 17-Oct-06 | 20-Mar-07 | 21-Jun-07 | 9-Aug-07 | 23-Oct-07 | 19-Mar-08 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Subclass : Copepoda** | | | | | | | | | | no data | | | |
| Copepod nauplii | 360 17% | | | | 307 23% | | | | 453 41% | | | | 1000 60% |
| **Order : Cyclopoida** | | | | | | | | | | | | | |
| *Diacyclops thomasi* | 203 10% | | | | | | | | | | | | |
| **Order: Calanoida** | | | | | | | | | | | | | |
| *Diaptomus oregonensis* adult | | | | | | | | | 151 14% | | | | 158 10% |
| *Diaptomus oregonensis* copepodid | | | | | | | | | | | | | |
| **Order: Cladocera** | | | | | | | | | | | | | |
| *Bosmina longirostris* | | | 813 13% | 2320 34% | | | | | 112 10% | | | 8970 43% | |
| *Daphnia ambigua* | | | | | | | | | | | | | |
| *Holopedium gibberum* | | | | | | | | | | | | | |
| **Phylum: Rotifera** | | | | | | | | | | | | | |
| *Callotheca sp.?* | | 820 11% | | | | | | 587 12% | | | 3600 27% | | |
| *Gastropus sp.* | | | | | | | | | | | 1200 10% | | |
| *Keratella cochlearis* | 870 41% | | 2973 47% | 940 14% | 427 33% | | 9280 61% | 2173 46% | 253 23% | | 1120 9% | 3960 19% | |
| *Polyarthra sp.* | 240 11% | 2860 37% | | 2060 30% | 267 20% | 1147 19% | | 640 13% | | | 2400 19% | 2370 11% | |
| *Synchaeta sp.* | | 1820 23% | | | | 3027 49% | | | | | | | |

## 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 are established to prevent specified detrimental effects from occurring with respect to a designated water use. Identified water uses for Comox 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 16.

**Table 16. Summary of proposed water quality objectives for Comox Lake.**

| Variable | Objective Value |
|---|---|
| **Secchi depth** | Annual average ≥ 8 m |
| ***E. coli* Bacteria** | ≤10 CFU/100 mL (90$^{th}$ percentile) with a minimum 5 weekly samples collected over a 30-day period |
| **Turbidity** | ≤ 2 NTU maximum |
| **Total phosphorus** | ≤6 µg/L average during spring overturn |
| **Chlorophyll *a*** | ≤ 1.5 µg/L |
| **Water temperature** | ≤ 15°C summer maximum hypolimnetic temperature (>10m depth) |
| **Dissolved oxygen** | ≥ 5 mg/L at any depth throughout the year |

## 8.0 MONITORING RECOMMENDATIONS

The recommended water quality monitoring program for Comox Lake is summarized in Table 17. 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.

**Table 17. Proposed schedule for future water quality monitoring in Comox 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 depth |
| Perimeter sites (surface grab sample) - summer and fall (weekly for five consecutive weeks in 30 day period) | *E. coli* |
| Deep station sites - twice per year (summer and spring overturn) | Phytoplankton and zooplankton taxonomy |

†: Measured every metre between the surface and 10 m, and every 5 m between 10 m and the bottom.

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 seven perimeter sites once weekly for five consecutive weeks in a 30-day period both in late summer and mid-fall.

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.

In addition, future monitoring should be conducted downstream of Comox Lake in the Puntledge River at the CVRD water intake location. Parameters of concern to monitor include turbidity, TSS, TOC, DOC, nutrients, total and dissolved metals as well as *E. coli*. Samples should be collected once weekly for five consecutive weeks in a 30-day period both in late summer and mid-fall to capture worst case scenario conditions. Monitoring at this location would examine potential changes in water quality between the lake outlet and the community drinking water river intake located 3.7 km downstream.

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# APPENDIX I. SUMMARY OF WATER QUALITY DATA

**Table I-A. Summary of general water chemistry at E259497, Comox Lake inlet basin.**

| | Minimum | Maximum | Average | Std Dev | No. of samples |
|---|---|---|---|---|---|
| Ag-D (mg/L) | < 0.0001 | < 0.0001 | < 0.0001 | 0 | 30 |
| Ag-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| Al-D (mg/L) | 0.0018 | 0.011 | 0.0062 | 0.0028 | 30 |
| Al-T (mg/L) | 0.0071 | 0.0222 | 0.0124 | 0.0042 | 39 |
| As-D (mg/L) | < 0.0001 | 0.0002 | 0.0001 | 0.0000 | 30 |
| As-T (mg/L) | < 0.0001 | 0.0003 | 0.0001 | 0.0001 | 39 |
| Ba-D (mg/L) | 0.0003 | 0.0004 | 0.0003 | 0 | 30 |
| Ba-T (mg/L) | 0.0003 | 0.0004 | 0.0003 | 0 | 39 |
| B--D (mg/L) | 0.01 | 0.012 | 0.011 | 0.001 | 6 |
| B--T (mg/L) | 0.01 | 0.012 | 0.011 | 0.001 | 6 |
| Be-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 30 |
| Be-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| Bi-D (mg/L) | < 0.0001 | < 0.0001 | < 0.0001 | 0 | 30 |
| Bi-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| Cd-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 30 |
| Cd-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| Co-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 30 |
| Co-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| Cr-D (mg/L) | < 0.0001 | 0.0002 | 0.0002 | 0 | 30 |
| Cr-T (mg/L) | < 0.0001 | 0.0004 | 0.0002 | 0.0001 | 39 |
| Cu-D (mg/L) | 0.0003 | 0.0017 | 0.0005 | 0.0003 | 30 |
| Cu-T (mg/L) | 0.0002 | 0.0028 | 0.0006 | 0.0006 | 39 |
| Hg-D (mg/L) | < 0.0001 | 0.0005 | 0.0001 | 0.0001 | 18 |
| Hg-T (mg/L) | < 0.0001 | 0.0015 | 0.0002 | 0.0003 | 27 |
| Li-D (mg/L) | < 0.0001 | 0.0005 | 0.0002 | 0.0002 | 30 |
| Li-T (mg/L) | < 0.0001 | 0.0005 | 0.0002 | 0.0001 | 39 |
| Mn-D (mg/L) | 0.0001 | 0.0067 | 0.0009 | 0.0013 | 30 |
| Mn-T (mg/L) | 0.0009 | 0.0135 | 0.0026 | 0.0023 | 39 |
| Mo-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 30 |
| Mo-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| Ni-D (mg/L) | < 0.0001 | 0.0003 | 0.0001 | 0.0001 | 30 |
| Ni-T (mg/L) | < 0.0001 | 0.0005 | 0.0002 | 0.0001 | 39 |
| Pb-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 30 |
| Pb-T (mg/L) | < 0.0001 | 0.0003 | 0.0001 | 0 | 39 |
| Sb-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 30 |
| Sb-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| Se-D (mg/L) | < 0.0001 | 0.0005 | 0.0002 | 0.0001 | 30 |
| Se-T (mg/L) | < 0.0001 | 0.0004 | 0.0002 | 0.0001 | 39 |
| Sn-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 30 |
| Sn-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| Sr-D (mg/L) | 0.0073 | 0.0096 | 0.0081 | 0.0006 | 30 |
| Sr-T (mg/L) | 0.0072 | 0.0092 | 0.0080 | 0.0006 | 39 |
| Tl-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 30 |
| Tl-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| U--D (mg/L) | < 0.0001 | < 0.0001 | < 0.0001 | 0 | 30 |
| U--T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| V--D (mg/L) | 0.0001 | 0.0005 | 0.0004 | 0.0001 | 30 |

| | Minimum | Maximum | Average | Std Dev | No. of samples |
|---|---|---|---|---|---|
| V--T (mg/L) | 0.0002 | 0.0006 | 0.0004 | 0.0001 | 39 |
| Zn-D (mg/L) | < 0.0001 | 0.0091 | 0.0028 | 0.0031 | 30 |
| Zn-T (mg/L) | < 0.0001 | 0.0112 | 0.0028 | 0.0032 | 39 |
| | | | | | |
| Alkalinity Total 4.5 (mg/L) | 14.8 | 23.4 | 18.8 | 2.6 | 27 |
| Ammonia Dissolved (mg/L) | < 0.005 | 0.063 | 0.007 | 0.010 | 33 |
| Ca-D (mg/L) | 6.47 | 13.9 | 9.9 | 3.7 | 6 |
| Carbon Total Inorganic (mg/L) | 3.2 | 6.4 | 4.7 | 1.1 | 15 |
| Carbon Total Organic (mg/L) | < 0.5 | 1.4 | 0.7 | 0.3 | 15 |
| Chlorophyll A (mg/L) | < 0.0005 | 0.001 | 0.0007 | 0.0002 | 11 |
| Chloride Dissolved (mg/L) | < 0.5 | 1.6 | 0.6 | 0.2 | 27 |
| Coliforms fecal (CFU/100mL) | < 1 | < 1 | < 1 | 0 | 1 |
| Color True (Col.unit) | < 5 | 5 | 5 | 0 | 27 |
| C--T (mg/L) | < 3.7 | 6.9 | 5.3 | 1.1 | 15 |
| Diss Oxy (mg/L) | 6.14 | 13.92 | 11.19 | 1.48 | 201 |
| E Coli (CFU/100mL) | < 1 | < 1 | < 1 | 0 | 1 |
| Ext Depth (m) | 8 | 13.5 | 9.8 | 2.0 | 9 |
| Hardness Total (D) (mg/L) | 16.2 | 21 | 18.7 | 2.3 | 6 |
| Mg-D (mg/L) | 0.77 | 1.06 | 0.89 | 0.11 | 10 |
| Nitrate (NO3) Dissolved (mg/L) | < 0.005 | 0.065 | 0.036 | 0.018 | 15 |
| Nitrate + Nitrite Diss. (mg/L) | 0.007 | 0.067 | 0.034 | 0.018 | 39 |
| Nitrogen - Nitrite Diss. (mg/L) | < 0.002 | 0.003 | 0.002 | 0.000 | 15 |
| Nitrogen (Kjel.) Tot Diss (mg/L) | < 0.02 | 0.09 | 0.043 | 0.017 | 39 |
| Nitrogen Organic-Total (mg/L) | < 0.02 | 0.09 | 0.04 | 0.02 | 39 |
| Nitrogen Total (mg/L) | 0.05 | 0.14 | 0.08 | 0.02 | 39 |
| Nitrogen Total Dissolved (mg/L) | < 0.048 | 0.144 | 0.077 | 0.021 | 39 |
| ORP (mV) | 60 | 450 | 316.2 | 113.5 | 182 |
| Ortho-Phosphate Dissolved (mg/L) | 0.003 | 0.005 | 0.0035 | 0.001 | 4 |
| pH (pH units) | 5.31 | 8.31 | 6.90 | 0.70 | 240 |
| Phosphorus Tot. Dissolved (mg/L) | < 0.002 | 0.011 | 0.003 | 0.002 | 27 |
| P--T (mg/L) | < 0.002 | 0.01 | 0.003 | 0.002 | 31 |
| Residue Filterable 1.0u (mg/L) | 20 | 46 | 28.8 | 6.6 | 24 |
| Residue Non-filterable (mg/L) | < 4 | < 4 | < 4 | 0 | 3 |
| Silica:D (mg/L) | 1.3 | 5.5 | 4.3 | 1.0 | 37 |
| Specific Conductance (µS/cm) | 29 | 44 | 36.7 | 3.2 | 231 |
| Temp (C) | 4.48 | 20.47 | 9.43 | 4.85 | 201 |
| Turbidity (NTU) | 0.2 | 0.7 | 0.4 | 0.1 | 30 |

**Table A-2. Summary of general water chemistry at E259498, Comox Lake main basin.**

| | Minimum | Maximum | Average | Std Dev | No. of samples |
|---|---|---|---|---|---|
| Ag-D (mg/L) | < 0.0001 | < 0.0001 | < 0.0001 | 0 | 30 |
| Ag-T (mg/L) | < 0.0001 | < 0.0001 | < 0.0001 | 0 | 39 |
| Al-D (mg/L) | 0.001 | 0.0122 | 0.006 | 0.003 | 30 |
| Al-T (mg/L) | 0.0057 | 0.02 | 0.011 | 0.004 | 39 |
| As-D (mg/L) | < 0.0001 | 0.0002 | 0.0001 | 0 | 30 |
| As-T (mg/L) | < 0.0001 | 0.0002 | 0.0001 | 0 | 39 |
| Ba-D (mg/L) | 0.0002 | 0.0004 | 0.0003 | 0 | 30 |
| Ba-T (mg/L) | 0.0003 | 0.0004 | 0.0004 | 0 | 39 |
| B--D (mg/L) | 0.009 | 0.011 | 0.010 | 0.0008 | 6 |
| B--T (mg/L) | 0.009 | 0.011 | 0.010 | 0.0010 | 6 |
| Be-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 30 |
| Be-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| Bi-D (mg/L) | < 0.0001 | < 0.0001 | < 0.0001 | 0 | 30 |
| Bi-T (mg/L) | < 0.0001 | < 0.0001 | < 0.0001 | 0 | 39 |
| Cd-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 30 |
| Cd-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| Co-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 30 |
| Co-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| Cr-D (mg/L) | < 0.0001 | 0.0002 | 0.0002 | 0 | 30 |
| Cr-T (mg/L) | < 0.0001 | 0.0004 | 0.0002 | 0.0001 | 39 |
| Cu-D (mg/L) | 0.0003 | 0.0015 | 0.0005 | 0.0002 | 30 |
| Cu-T (mg/L) | 0.0003 | 0.0017 | 0.0005 | 0.0003 | 39 |
| Hg-D (mg/L) | < 0.0001 | 0.0003 | 0.0001 | 0.0001 | 18 |
| Hg-T (mg/L) | < 0.0001 | 0.0005 | 0.0002 | 0.0001 | 27 |
| Li-D (mg/L) | < 0.0001 | 0.0005 | 0.0002 | 0.0002 | 30 |
| Li-T (mg/L) | < 0.0001 | 0.0005 | 0.0002 | 0.0001 | 39 |
| Mn-D (mg/L) | 0.0001 | 0.0013 | 0.0004 | 0.0003 | 30 |
| Mn-T (mg/L) | 0.0006 | 0.0023 | 0.0011 | 0.0004 | 39 |
| Mo-D (mg/L) | < 0.0001 | < 0.0001 | < 0.0001 | 0 | 30 |
| Mo-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| Ni-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 30 |
| Ni-T (mg/L) | < 0.0001 | 0.0002 | 0.0001 | 0 | 39 |
| Pb-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 30 |
| Pb-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| Sb-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 30 |
| Sb-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| Se-D (mg/L) | < 0.0001 | 0.0004 | 0.0002 | 0.0001 | 30 |
| Se-T (mg/L) | < 0.0001 | 0.0004 | 0.0002 | 0.0001 | 39 |
| Sn-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 30 |
| Sn-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| Sr-D (mg/L) | 0.007 | 0.0082 | 0.0075 | 0.0003 | 30 |
| Sr-T (mg/L) | 0.007 | 0.0083 | 0.0076 | 0.0004 | 39 |
| Tl-D (mg/L) | < 0.0001 | < 0.0001 | < 0.0001 | 0 | 30 |
| Tl-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| U--D (mg/L) | < 0.0001 | < 0.0001 | < 0.0001 | 0 | 30 |
| U--T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 39 |
| V--D (mg/L) | 0.0001 | 0.0005 | 0.0003 | 0.0001 | 30 |
| V--T (mg/L) | 0.0002 | 0.0005 | 0.0004 | 0.0001 | 39 |
| Zn-D (mg/L) | < 0.0001 | 0.008 | 0.0023 | 0.0028 | 30 |
| Zn-T (mg/L) | < 0.0001 | 0.0095 | 0.0022 | 0.0030 | 39 |

| | Minimum | Maximum | Average | Std Dev | No. of samples |
|---|---|---|---|---|---|
| Alkalinity Total 4.5 (mg/L) | 15.1 | 21.5 | 16.7 | 1.7 | 27 |
| Ammonia Dissolved (mg/L) | < 0.005 | 0.016 | 0.006 | 0.002 | 33 |
| Ca-D (mg/L) | 5.39 | 13.11 | 8.96 | 3.91 | 6 |
| Carbon Total Inorganic (mg/L) | 3.4 | 5.5 | 4.3 | 0.7 | 15 |
| Carbon Total Organic (mg/L) | 0.5 | 1.3 | 0.8 | 0.3 | 15 |
| Chlorophyll A (mg/L) | 0.0005 | 0.001 | 0.0007 | 0.0002 | 12 |
| Chloride Diss (mg/L) | 0.5 | 0.7 | 0.5 | 0.0 | 27 |
| Coliforms, Fecal (CFU/100mL) | 1 | 1 | 1 | 0 | 1 |
| Color True (Col.unit) | < 5 | 5 | 5 | 0 | 27 |
| C--T (mg/L) | 4.1 | 6.5 | 5.1 | 0.7 | 15 |
| Diss Oxy (mg/L) | 8.48 | 13.73 | 11.31 | 1.24 | 226 |
| E Coli (CFU/100mL) | 1 | 1 | 1 | 0 | 1 |
| ExtDepth (m) | 7 | 13 | 9.6 | 2.0 | 9 |
| Hardness Total (D) (mg/L) | 15.1 | 17.1 | 16.3 | 0.9 | 6 |
| Mg-D (mg/L) | 0.73 | 0.86 | 0.78 | 0.05 | 12 |
| Nitrate (NO3) Dissolved (mg/L) | 0.001 | 0.07 | 0.04 | 0.02 | 15 |
| Nitrate + Nitrite Diss. (mg/L) | < 0.002 | 0.072 | 0.037 | 0.023 | 39 |
| Nitrogen - Nitrite Diss. (mg/L) | < 0.002 | 0.003 | 0.002 | 0.000 | 15 |
| Nitrogen (Kjel.) Tot Diss (mg/L) | < 0.02 | 0.07 | 0.039 | 0.01 | 39 |
| Nitrogen Organic-Total (mg/L) | < 0.02 | 0.07 | 0.039 | 0.01 | 39 |
| Nitrogen Total (mg/L) | 0.04 | 0.13 | 0.076 | 0.02 | 39 |
| Nitrogen Total Dissolved (mg/L) | 0.046 | 0.129 | 0.076 | 0.022 | 39 |
| ORP (mV) | 59 | 465 | 352.8 | 102 | 226 |
| Ortho-Phosphate Dissolved (mg/L) | 0.003 | 0.005 | 0.004 | 0.001 | 4 |
| pH (pH units) | 6.15 | 8.31 | 7.03 | 0.52 | 264 |
| Phosphorus Tot. Dissolved (mg/L) | < 0.002 | 0.006 | 0.003 | 0.001 | 27 |
| P--T (mg/L) | < 0.002 | 0.006 | 0.003 | 0.001 | 31 |
| Residue Filterable 1.0u (mg/L) | 14 | 44 | 27.5 | 6.7 | 24 |
| Residue Non-filterable (mg/L) | < 4 | < 4 | 4 | 0 | 3 |
| Silica:D (mg/L) | 3.2 | 6.2 | 4.3 | 0.6 | 37 |
| Specific Conductance (µS/cm) | 30 | 38 | 34 | 2.0 | 256 |
| Temp (C) | 4.67 | 20.74 | 8.86 | 4.71 | 227 |
| Turbidity (NTU) | 0.1 | 0.8 | 0.3 | 0.2 | 30 |

**Table A-3. Summary of general water chemistry at E259499, Comox Lake main basin.**

| | Minimum | Maximum | Average | Std dev | No. of samples |
|---|---|---|---|---|---|
| Ag-D (mg/L) | < 0.0001 | < 0.0001 | < 0.0001 | 0 | 27 |
| Ag-T (mg/L) | < 0.0001 | < 0.0001 | < 0.0001 | 0 | 36 |
| Al-D (mg/L) | 0.0012 | 0.0104 | 0.0063 | 0.0030 | 27 |
| Al-T (mg/L) | 0.0064 | 0.049 | 0.0143 | 0.0074 | 36 |
| As-D (mg/L) | < 0.0001 | 0.0002 | 0.0001 | 0 | 27 |
| As-T (mg/L) | < 0.0001 | 0.0003 | 0.0001 | 0.0001 | 36 |
| Ba-D (mg/L) | 0.0003 | 0.0004 | 0.0004 | 0 | 27 |
| Ba-T (mg/L) | 0.0003 | 0.0005 | 0.0004 | 0.0001 | 36 |
| B--D (mg/L) | 0.009 | 0.01 | 0.0095 | 0.0005 | 6 |
| B--T (mg/L) | 0.01 | 0.012 | 0.011 | 0.001 | 6 |
| Be-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 27 |
| Be-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 36 |
| Bi-D (mg/L) | < 0.0001 | < 0.0001 | < 0.0001 | 0 | 27 |
| Bi-T (mg/L) | < 0.0001 | < 0.0001 | < 0.0001 | 0 | 36 |
| Cd-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 27 |
| Cd-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 36 |
| Co-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 27 |
| Co-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 36 |
| Cr-D (mg/L) | < 0.0001 | 0.0002 | 0.0002 | 0 | 27 |
| Cr-T (mg/L) | < 0.0001 | 0.0004 | 0.0002 | 0.0001 | 36 |
| C--T (mg/L) | 3.4 | 7 | 5.72 | 1.14 | 15 |
| Cu-D (mg/L) | 0.0003 | 0.0008 | 0.0004 | 0.0002 | 27 |
| Cu-T (mg/L) | 0.0003 | 0.0013 | 0.0005 | 0.0002 | 36 |
| Hg-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0.0000 | 15 |
| Hg-T (mg/L) | < 0.0001 | 0.0005 | 0.0001 | 0.0001 | 24 |
| Li-D (mg/L) | < 0.0001 | 0.0005 | 0.0002 | 0.0002 | 27 |
| Li-T (mg/L) | < 0.0001 | 0.0005 | 0.0002 | 0.0002 | 36 |
| Mg-D (mg/L) | 0.73 | 0.88 | 0.79 | 0.05 | 12 |
| Mn-D (mg/L) | 0 | 0.0008 | 0.0004 | 0.0002 | 27 |
| Mn-T (mg/L) | 0.0003 | 0.0164 | 0.0017 | 0.0026 | 36 |
| Mo-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 27 |
| Mo-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 36 |
| Ni-D (mg/L) | < 0.0001 | 0.0002 | 0.0001 | 0 | 27 |
| Ni-T (mg/L) | < 0.0001 | 0.0003 | 0.0001 | 0.0001 | 36 |
| Pb-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 27 |
| Pb-T (mg/L) | < 0.0001 | 0.0006 | 0.0001 | 0.0001 | 36 |
| Sb-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 27 |
| Sb-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 36 |
| Se-D (mg/L) | < 0.0001 | 0.0004 | 0.0002 | 0.0001 | 27 |
| Se-T (mg/L) | < 0.0001 | 0.0006 | 0.0002 | 0.0001 | 36 |
| Sn-D (mg/L) | < 0.0001 | 0.0002 | 0.0000 | 0.0000 | 27 |
| Sn-T (mg/L) | < 0.0001 | 0.0002 | 0.0000 | 0.0000 | 36 |
| Sr-D (mg/L) | 0.007 | 0.0083 | 0.0077 | 0.0003 | 27 |
| Sr-T (mg/L) | 0.0067 | 0.0085 | 0.0077 | 0.0005 | 36 |
| Tl-D (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 27 |
| Tl-T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 36 |
| U--D (mg/L) | < 0.0001 | < 0.0001 | < 0.0001 | 0 | 27 |
| U--T (mg/L) | < 0.0001 | 0.0001 | 0.0001 | 0 | 36 |
| V--D (mg/L) | < 0.0001 | 0.0005 | 0.0004 | 0.0001 | 27 |
| V--T (mg/L) | 0.0002 | 0.0006 | 0.0004 | 0.0001 | 36 |

| | Minimum | Maximum | Average | Std dev | No. of samples |
|---|---|---|---|---|---|
| Zn-D (mg/L) | < 0.0001 | 0.0088 | 0.0020 | 0.0026 | 27 |
| Zn-T (mg/L) | < 0.0001 | 0.0104 | 0.0019 | 0.0029 | 36 |
| | | | | | |
| Alkalinity Total 4.5 (mg/L) | 15 | 21.4 | 16.5 | 1.5 | 27 |
| Ammonia Dissolved (mg/L) | < 0.005 | 0.019 | 0.006 | 0.003 | 30 |
| Ammonia Total (mg/L) | 0 | 0 | 0 | 0 | 3 |
| Ca-D (mg/L) | 5.4 | 12.3 | 8.8 | 3.7 | 6 |
| Carbon Total Inorganic (mg/L) | 2.9 | 6.1 | 4.7 | 1.0 | 15 |
| Carbon Total Organic (mg/L) | 0.5 | 1.9 | 1.0 | 0.4 | 15 |
| Chlorophyll A (mg/L) | < 0.0005 | 0.0012 | 0.0008 | 0.0003 | 12 |
| Chloride: Diss (mg/L) | < 0.5 | 0.7 | 0.5 | 0.1 | 27 |
| Coliforms, Fecal (CFU/100mL) | < 1 | < 1 | < 1 | 0 | 1 |
| Color True (Col.unit) | < 5 | 5 | 5 | 0 | 27 |
| Diss Oxy (mg/L) | 8.93 | 13.59 | 11.21 | 1.19 | 138 |
| E Coli (CFU/100mL) | < 1 | < 1 | < 1 | 0 | 1 |
| ExtDepth (m) | 7 | 14 | 9.92 | 2.4 | 10 |
| Hardness Total (D) (mg/L) | 15.2 | 17.1 | 16.2 | 1.0 | 6 |
| N.Kjel:T (mg/L) | 0.04 | 0.07 | 0.05 | 0.02 | 3 |
| Nitrate (NO3) Dissolved (mg/L) | 0.004 | 0.058 | 0.034 | 0.019 | 15 |
| Nitrate + Nitrite Diss. (mg/L) | 0.006 | 0.06 | 0.033 | 0.018 | 36 |
| Nitrogen - Nitrite Diss. (mg/L) | < 0.002 | 0.002 | 0.002 | 0 | 15 |
| Nitrogen (Kjel.) Tot Diss (mg/L) | 0.02 | 0.08 | 0.05 | 0.01 | 33 |
| Nitrogen Organic-Total (mg/L) | < 0.02 | 0.08 | 0.05 | 0.01 | 36 |
| Nitrogen Total (mg/L) | 0.04 | 0.14 | 0.08 | 0.03 | 36 |
| Nitrogen Total Dissolved (mg/L) | 0.039 | 0.135 | 0.079 | 0.026 | 33 |
| NO2+NO3 (mg/L) | 0.01 | 0.05 | 0.03 | 0.02 | 3 |
| ORP (mV) | 73 | 458 | 343.7 | 111.4 | 138 |
| Ortho-Phosphate Dissolved (mg/L) | 0.003 | 0.005 | 0.004 | 0.001 | 4 |
| pH (pH units) | 6.17 | 7.85 | 7.04 | 0.50 | 174 |
| Phosphorus Tot. Dissolved (mg/L) | < 0.002 | 0.005 | 0.003 | 0.001 | 24 |
| P--T (mg/L) | < 0.002 | 0.006 | 0.003 | 0.001 | 28 |
| Residue Filterable 1.0u (mg/L) | < 10 | 38 | 25.1 | 7.0 | 24 |
| Residue Non-filterable (mg/L) | < 4 | 5 | 4.3 | 0.6 | 3 |
| Silica:D (mg/L) | 3.5 | 5.2 | 4.3 | 0.5 | 34 |
| Specific Conductance (µS/cm) | 30 | 41 | 34.6 | 2.1 | 168 |
| Temp (C) | 4.92 | 20.94 | 10.25 | 4.70 | 138 |
| Turbidity (NTU) | 0.2 | 0.9 | 0.4 | 0.2 | 30 |