Environmental Protection Division

Environmental Sustainability Division

Ministry of Environment

# Water Quality Assessment and Objectives for Kemp Lake Community Watershed

**Technical Report**

**October 2012**

**Library and Archives Canada Cataloguing in Publication**

**Phippen, B. W**
**Water quality assessment and objectives for Kemp Lake Community Watershed [electronic resource] : technical report.**

**An overview report is available separately.**
**Authors: Burke Phippen, Nicole Obee.**
**Includes bibliographical references.**
**Electronic monograph in PDF format.**
**Co-published by: Environmental Sustainability Division.**
**ISBN 978-0-7726-6628-4**

**1. Water quality--British Columbia--Kemp Lake Watershed. 2. Water quality--British Columbia--Sooke Region. I. Obee, Nicole, 1982- II. British Columbia. Environmental Protection Division III. British Columbia. Environmental Sustainability Division IV. Title.**

TD227 B75 P54 2012 363.739'420971128 C2012-980200-X

## EXECUTIVE SUMMARY

This document presents a summary of the ambient water quality of Kemp 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.

The Kemp Lake watershed, with an area of 620 ha, is located about 3 km northwest of the community of Sooke, British Columbia, and provides drinking water to the surrounding neighbourhood of approximately 1,000 people. The water uses to be protected in Kemp Lake include drinking water, irrigation, aquatic life, wildlife and recreation. The watershed includes private residences, agricultural land, and a light industrial area; both fishing and swimming occur in Kemp Lake. These activities, as well as forestry and wildlife, all potentially affect water quality in the lake.

Water quality monitoring considered in this report was conducted between 2006 and 2009. The results of this monitoring indicated that the overall state of the water quality is quite good, with occasionally slightly elevated turbidity levels and naturally high colour. There are indications that the lake may experience low dissolved oxygen and internal nutrient loading in late summer and early fall. All chemical, physical and biological parameters met provincial water quality guidelines with the exception of temperature, dissolved oxygen, pH, turbidity, total organic carbon, total phosphorus and some metals, which exceeded the drinking water and/or aquatic life guidelines on occasion. In order to maintain and protect water quality in Kemp Lake, ambient water quality objectives were set for temperature, dissolved oxygen, Secchi depth, turbidity, true colour, total organic carbon, total phosphorus and chlorophyll *a*.

Future monitoring recommendations include attainment monitoring 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 (March, May, August and October) at the deep-station site (at the

surface, mid water column, and above the lake bottom). Samples should be collected from the intake site during summer low flow and fall flush (five weekly samples in 30 days), to monitor objectives set for drinking water protection and to determine the need for an *Escherichia coli* objective.

**Water Quality Objectives for Kemp Lake**

| Variable | Objective Value |
|---|---|
| **Water temperature** | ≤ 15°C summer maximum hypolimnetic temperature (> 5 m depth) |
| **Dissolved oxygen** | ≥ 5 mg/L > 2 m above lake bottom<br>≥ 2 mg/L ≤ 2 m above lake bottom (May-August) |
| **Secchi depth** | ≥ 4 m annual average |
| **Turbidity** | ≤ 2 NTU maximum<br>< 1 NTU 95% of the time |
| **True colour** | ≤ 20 TCU maximum |
| **Total organic carbon** | ≤ 6 mg/L maximum |
| **Total phosphorus** | ≤10 µg/L maximum during spring overturn |
| **Chlorophyll *a*** | 1.5 µg/L to 2.5 µg/L (May-August) |

# TABLE OF CONTENTS

## LIST OF FIGURES



## LIST OF TABLES

## ACKNOWLEDGEMENTS

The author would like to thank the following individuals for their assistance in the preparation of this report: Kevin Rieberger, John Deniseger, and Deborah Epps, Ministry of Environment. We would also like to thank the stakeholders who reviewed and provided comments. In addition, we would like to recognize Kevin Rieberger, Deb Epps, Rosie Barlak and Dawn Marks for their assistance with the sampling program.

*Burke Phippen, RPBio.*
*BWP Consulting Inc.*
*Kamloops, BC*

*Nicole Obee, Environmental Impact Assessment Biologist*
*Environmental Protection Division*
*Ministry of Environment*

# 1.0 INTRODUCTION

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

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

Fundamental baseline water quality should be similar in all streams and all lakes throughout each ecoregion. However, the underlying physical, chemical and biological differences between streams and lakes must be recognized. Representative lake and stream watersheds within each ecoregion are selected (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. Water quality objectives will be developed for each of the representative lake and stream watersheds, and these objectives will also be applied on an interim basis to the remaining lake and stream watersheds within that ecoregion. Over time, other priority watersheds within each ecoregion will be monitored for one year to verify the validity of the objectives developed for each ecoregion, and to determine whether the objectives are being met for individual watersheds.


**Figure 1.** Map of Vancouver Island Ecoregions

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

This report examines the existing water quality of Kemp Lake for 2006-2009 and recommends water quality objectives for the lake based on potential impacts and water quality parameters of concern. Kemp Lake is a small lake located near the community of Sooke on Vancouver Island, providing drinking water to approximately 1,000 people, and supporting important fisheries and recreation values. Kemp Lake was designated a community watershed in 1999 under the *Forest and Range Practices Act* and, as such, is given special protection. Kemp Lake drains into Juan de Fuca strait through Kemp Stream, southwest of Sooke (Figure 2). Anthropogenic land uses within the watershed include residential and commercial development, recreational and agriculture use and forestry. These activities, as well as natural erosion and the presence of wildlife, all potentially affect water quality in Kemp Lake.

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

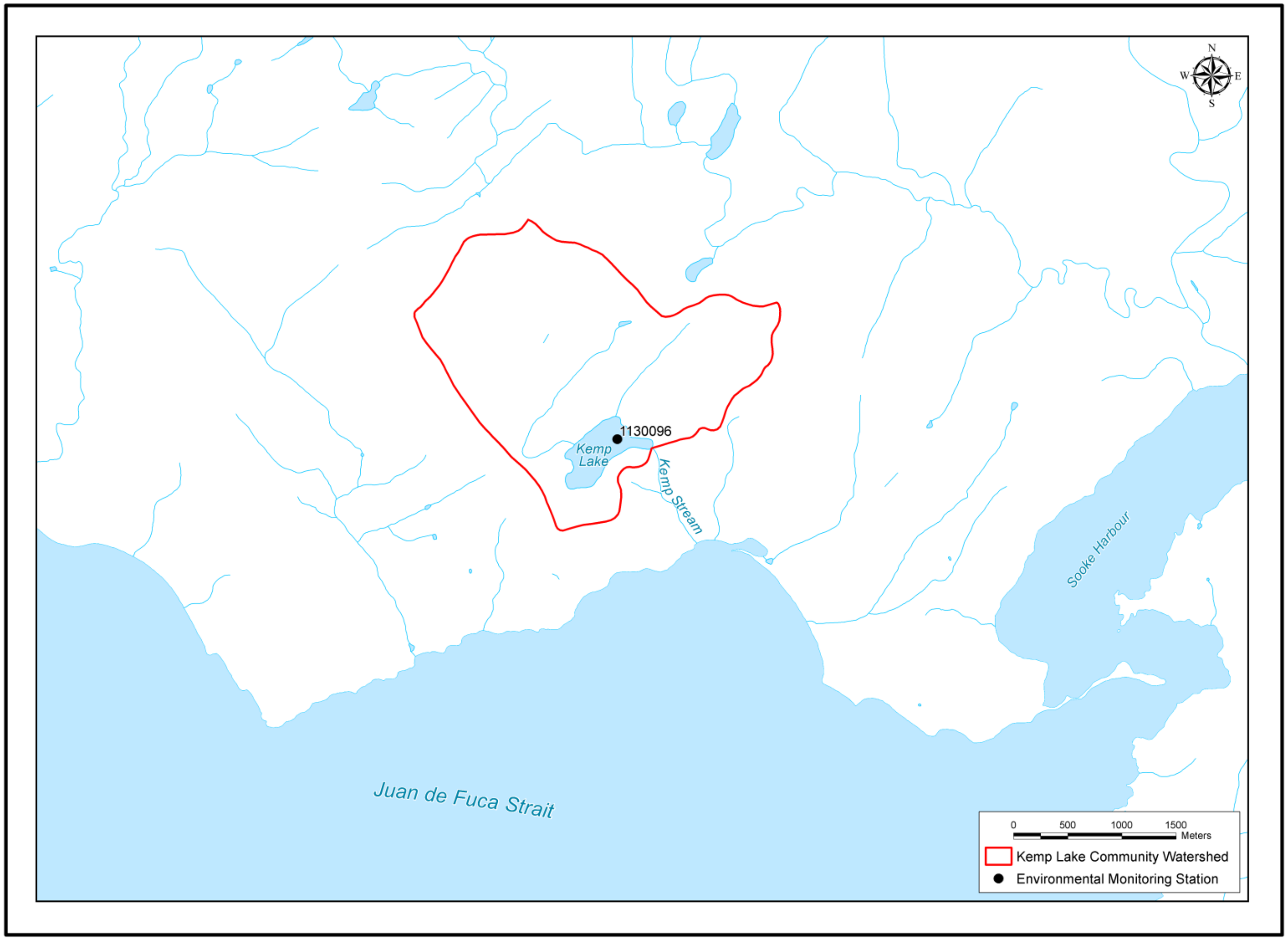


**Figure 2. Map of the Kemp Lake community watershed.**

# 2.0 WATERSHED PROFILE AND HYDROLOGY

## 2.1 BASIN PROFILE

The Kemp Lake watershed is 620 ha in area, and the designated community watershed portion of it (which does not include Kemp Stream downstream from the lake) is only 549 ha (BC Community Watershed Database, 2012). The lake itself has a surface area of 26 ha (Figure 3). The Kemp Lake watershed, including Kemp Lake, is located on the boundary between the municipality of Sooke and the unincorporated district of Otter Point in the Juan de Fuca Electoral Area. Kemp Lake provides drinking water to 450 residences (750 people) in Otter Point and several on the western edge of Sooke. Kemp Lake is situated 38 m above sea level, and the watershed extends to approximately 280 m elevation at its highest point. Kemp Lake is fed by Crossbow Creek and another small unnamed tributary and drains into Kemp Stream, a small creek about 1 km in length that empties into Juan de Fuca Strait. The lake has a maximum depth of 11 m, a mean depth of 4.7 m, and a total volume of approximately 1,228 $dam^3$ (cubic decametres where 1 $dam^3$ = 1,000 $m^3$ ) (Jackson and Blecic, 1996).

Kemp Lake falls within the Coastal Western Hemlock biogeoclimatic zone (very dry maritime, CWHxm2), and the Leeward Island Mountains (LIM) ecoregion established for Vancouver Island by MOE staff (Figure 1).

The underlying geology north of Kemp Lake is described as the Sooke Gabro - Metchosin Igneous Complex from the Cenozoic era, composed of gabbroic to dioritic intrusive rocks, while the area south of the lake (including the bedrock of the lake itself) is described as Sheeted Dykes - Metchosin Igneous Complex composed of diabase, feldspar diabase, microgabbro and basalt sheeted dykes (BCWRA 2012).

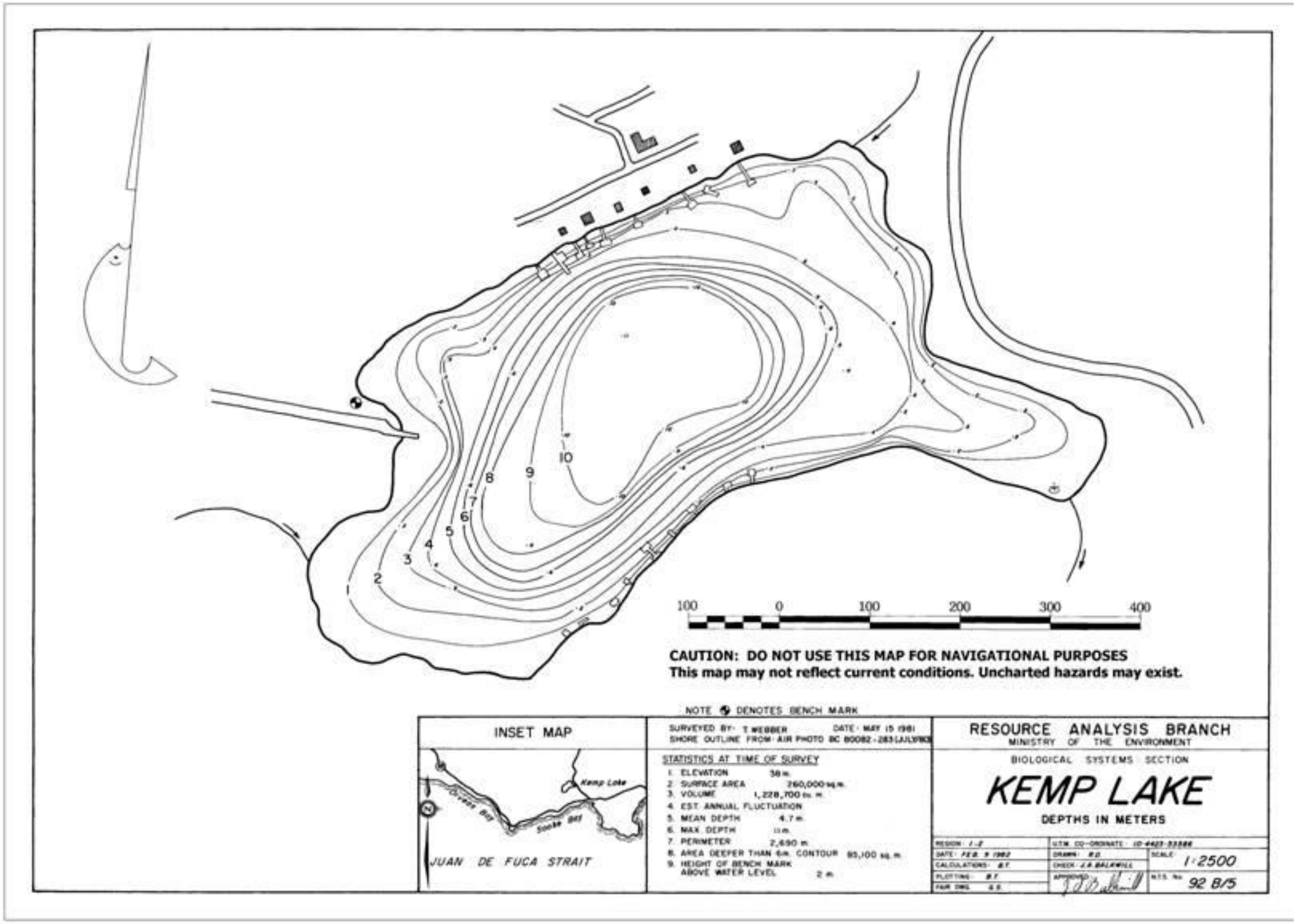


**Figure 3. Bathymetric map of Kemp Lake (source: BC Fisheries Inventory Data Query).**

### 2.2 HYDROLOGY AND PRECIPITATION

Water Survey Canada (WSC) measured water levels on Kemp Lake on a daily basis between early April and late September for eight years, between 1982 and 1989 (WSC Station 08HA052). The maximum daily water level measured during this time was 2.341 m (on April 7, 1988), the minimum level was 1.245 m (on September 18, 1988), and the average water level was 1.600 m (Figure 4). Water levels were highest during the winter, decreasing gradually over the course of the summer. Mean monthly discharge for Kemp Stream ranged from 3 L/second in July and August to 449 L/second in November, with a mean annual discharge of 186 L/second (Jackson and Blecic, 1996).

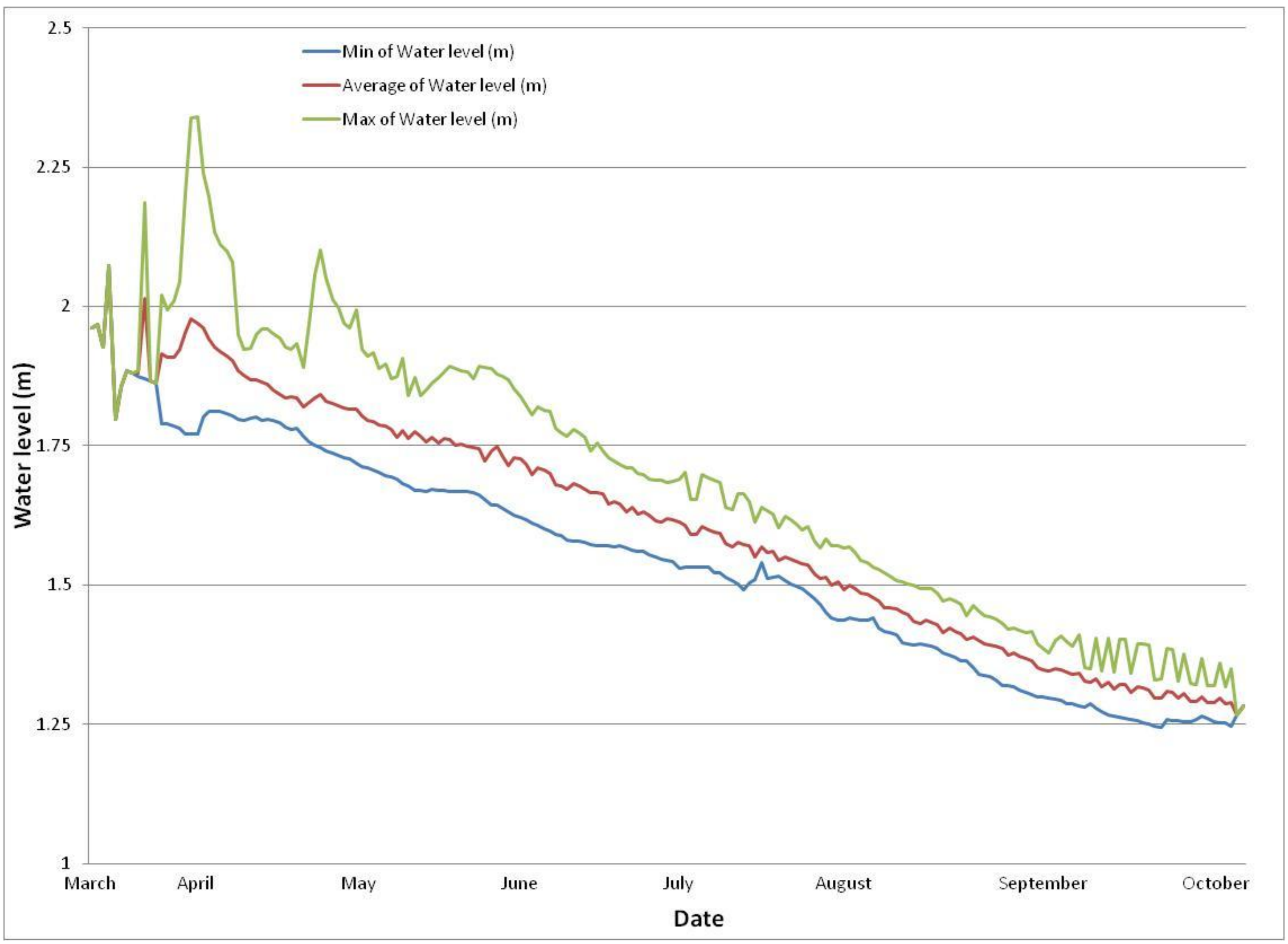


**Figure 4. A summary of water levels measured on Kemp Lake (Water Survey Canada Station 08HA052) between 1982 and 1989 (WSC Hydat Data, 2012).**

The nearest climate station to the watershed for which climate normal data (1971 – 2000) are available is the Victoria Marine station, located about 3 km from Kemp Lake at an elevation of 32 m (Environment Canada Climate Station 1018642). Average daily temperatures range from 4.4°C in January to 14.3°C in August. Average total annual precipitation is 1,266 mm, with 32 mm (water equivalent) (3%) of this falling as snow (Figure 5). Most precipitation (1,008 mm, or 80%) falls between October and March, resulting in peak water levels during this period.

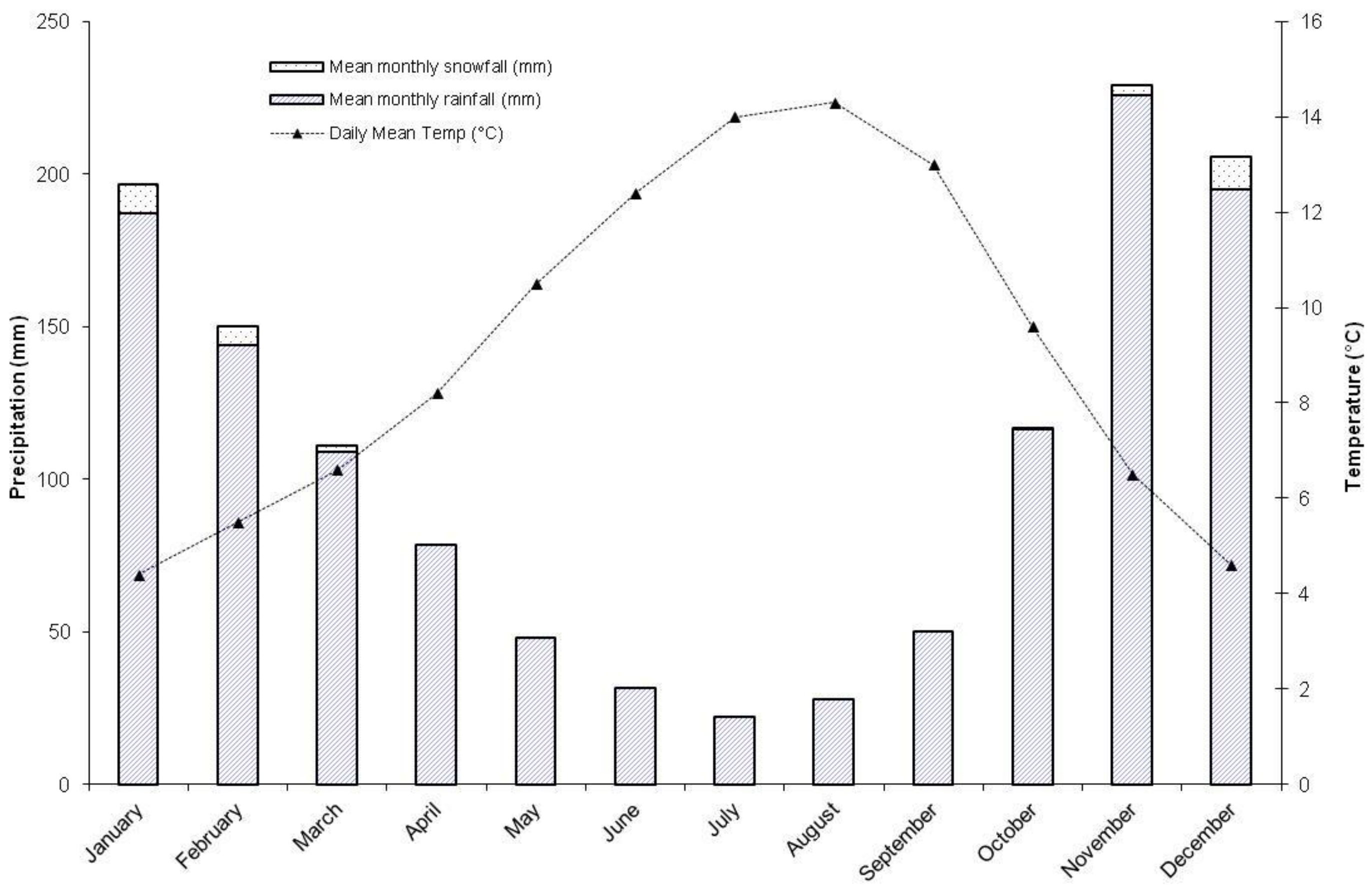


**Figure 5. Climate data (1971 – 2000) for Victoria Marine (Environment Canada Climate Station 1018642).**

# 3.0 WATER USES

## 3.1 WATER LICENSES

There are approximately 450 connections to the Kemp Lake waterworks (KLWD, 2009), servicing approximately 750 people. Two licenses have been issued to the waterworks, for a total volume of 165.9 $dam^3/yr$. In 2008, approximately 104.2 $dam^3$ of water was pumped through the waterworks (KLWD, 2009). There are also three licenses for domestic use, allowing a total of 3.3 $dam^3/yr$, and one license for irrigation, allowing a withdrawal of 6.2 $dam^3/yr$.

## 3.2 FISHERIES

Fish species in Kemp Lake include cutthroat trout, rainbow trout, prickly sculpin, threespine stickleback and smallmouth bass (FISS, 2012). Smallmouth bass are not native to the lake, but were introduced illegally sometime after 1983. Both cutthroat trout and rainbow trout have been stocked regularly in the lake, cutthroat trout beginning in 1927 and rainbow trout beginning in 1924. Since that time, approximately 120,000 cutthroat and 99,000 rainbow trout (as well as 5,000 steelhead) have been introduced to the lake, with stocking efforts continuing to date. In a stocking assessment, Silvestri and Fosker (2003) found a healthy population of cutthroat trout and smallmouth bass, but no rainbow trout in their samples.

## 3.3 RECREATION

Kemp Lake is easily accessible by road and supports a recreational fishery for cutthroat trout, rainbow trout and smallmouth bass. There is a boat launch, but only non-motorized vessels are permitted on the lake. There are designated public access areas as well, utilized during the summer months.

### 3.4 FLORA AND FAUNA

The Kemp Lake 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 vertebrate species, the Anguinae subspecies of ermine (*Mustela erminea anguinae*) (BCCDC, 2012).

### 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, aquatic life and wildlife. Water quality objectives are developed to protect the most sensitive water use at the site.

# 4.0 INFLUENCES ON WATER QUALITY

## 4.1 LAND OWNERSHIP

Most of the land within the Kemp Lake watershed is privately owned, with a small portion on crown land. There are a number of private residences within the watershed, some hobby farms, as well as a light industrial area. A risk assessment of the watershed as a drinking water supply, completed in 2003, suggests that the highest potential risks to water quality are related to run off from mixed land use including roads, light industrial activities, agriculture, and failing or poorly designed septic fields (Giles, 2003). The light industrial area is subject to a covenant that lists activities that will only be permitted if it is proven that the activities will not discharge or release substances into the storm water which would have an adverse effect on the quality of drinking water in Kemp Lake.

The drainage for the western portion of the watershed, which is primarily rural residential and agricultural use, has been channeled into road-side ditches that flow into Crossbow Creek near its drainage into Kemp Lake (KLWD, 2012).

## 4.2 LICENSED WATER WITHDRAWALS

Water withdrawals can affect flows downstream from the point of diversion, especially during periods of lower flows, if licensed withdrawals are large relative to the volume of water in the system. This can have significant impacts on the success of fisheries populations, as well as the benthic invertebrate populations that support the fish populations. Outflow from the lake into Kemp Stream is minimal during the summer months and the Sooke Water Allocation Plan (Jackson and Blecic, 1996) recommends water withdrawals only when flows exceed 60% of mean annual discharge. In the case of Kemp Stream, this would mean that withdrawals would only be permitted between the months of October and April, inclusive. It is likely that Kemp Stream has low summer flows either naturally or due to factors other than licenced water withdrawals, as the water withdrawals during May to September total less than 6% of the lake's volume.

### 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.

Because most of the land base within the Kemp Lake watershed is privately owned, any logging activity would be primarily by private land owners; this could potentially affect water quality in Kemp Lake. However, the risk assessment conducted in 2003 ranks the potential impacts to drinking water quality in Kemp Lake from these types of activities as low (Giles, 2003).

### 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.

Activities such as camping, ATV use, fishing and hunting may occur at various times of the year throughout the watershed. These land based activities 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). Activities such as swimming and fishing on Kemp Lake can potentially impact water quality in a number of ways. Microbiological contamination can be associated with swimmers and pets. The prohibition of motorized vessels on Kemp Lake lessens the risk posed by recreational fishing, although the potential for spills from batteries or other equipment does exist.

### 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, fecal contamination of water by animals can be a human health concern, although may be less risky than direct human contamination as inter-species transfer of pathogens tends to reduce the likelihood of development of human health impacts. Without specific source tracking methods, it is impossible to determine the sources of fecal contamination.

The Kemp Lake watershed contains valuable wildlife habitat, and provides a home for a wide variety of warm-blooded species, including large numbers of waterfowl. Therefore, a risk of fecal contamination from natural wildlife populations within the watershed does exist.

# 5.0 STUDY DETAILS

One sampling site was established at the deepest part of the lake, near the centre. Discrete water samples were collected from three depths (0.5 m, 5 m, and 10 m deep). Surface samples were collected by hand using plastic bottles provided by the lab conducting the analyses, and water column samples were collected using a Van Dorn bottle, then transferred to plastic bottles. All samples were shipped on ice to the laboratory for analysis. Samples were collected at the deep site on a quarterly basis, between February and November from 2006 to 2009. The drinking water intake is located on the west side of the lake at a depth of approximately 4 m; the BC MOE did not collect samples here, but the Kemp Lake Waterworks District samples raw water on a weekly basis for bacteriological parameters.

Based on the current knowledge of potential anthropogenic impacts to the sub-watersheds (generally associated with forestry, recreation and residential development), and natural features (wildlife) and the lack of authorized waste discharges within the watershed, the following water quality variables were included:

- Limnological: temperature, dissolved oxygen, water clarity
- Water chemistry: pH, turbidity, alkalinity, silica, true colour, total inorganic and organic carbon, specific conductivity, nutrients (total and dissolved phosphorus, nitrate/nitrite, ammonia, total Kjeldahl nitrogen), total and dissolved metals
- Biological: microbiological indicators, phytoplankton, zooplankton, chlorophyll *a*.

Depth profiles were conducted in the field at the deep water sites for parameters including dissolved oxygen, water temperature, oxidation-reduction potential (ORP), pH and conductivity using a Hydrolab Surveyor 4. Data were collected at one meter intervals from the surface to just above the lake bottom. Water clarity was measured at the deep station using a 20 cm diameter Secchi disc.

All samples were collected according to Resource Inventory Standards Committee (RISC) standards (BC MOE, 2003) by trained personnel. Chlorophyll *a* and water chemistry parameters analyses were conducted by Maxxam Analytics Inc. in Burnaby, BC; microbiological analyses were conducted by Cantest Laboratories in Burnaby, BC; and plankton taxonomy was conducted by Fraser Environmental Services in Surrey, BC.

Phytoplankton and chlorophyll *a* samples were collected by taking 1 L grab samples at a depth of 0.5 m at the deep station. Chlorophyll *a* samples were field filtered using 0.45 micron filter paper and then analyzed at the laboratory. 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 0.5 m and a mesh size of 80 µm. Zooplankton samples were preserved with formalin and shipped on ice to the lab for identification and enumeration.

## 6.0 WATER QUALITY ASSESSMENT AND OBJECTIVES

There are two sets of guidelines that are commonly used to determine the suitability of drinking water. The British Columbia water quality guidelines are used to assess the source of water prior to the point of diversion into a waterworks system. These BC guidelines are also used to protect other designated water uses such as recreation and habitat for aquatic life. The development of water quality objectives (*i.e.* the site-specific application of BC water quality guidelines) for a specific water body can be integrated into an overall fundamental water protection program designed to protect all uses of the resource, including drinking water sources.

The *Drinking Water Protection Act* and the Drinking Water Protection Regulation set 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. The Kemp Lake Waterworks District (KLWD) treats drinking water through chlorine disinfection prior to distribution. To effectively treat the water for viruses and parasites, such as *Cryptosporidium* and *Giardia*, the KLWD may be required to provide additional disinfection such as UV or ozone and/or treatment such as filtration.

A summary of water quality data is provided in Appendix I.

### 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, the water column will be easily mixed at 4°C. In the spring, the surface waters warm up and become less dense, and the temperature gradient is large enough that the wind-induced currents are unable to cause mixing, leading to summer stratification of the water column. In the fall, surface waters cool and the temperature gradient becomes small enough again for the wind-induced currents to cause the lake volume to mix, leading to a fall turnover of the lake. In the winter, the surface water cools below 4°C, becoming less dense, which leads to another stratification period. This stratification is broken down in the spring, and spring turnover occurs. For some lakes, particularly in coastal BC, the winter surface temperatures do not fall below 4°C for a long enough period to allow for a winter stratification, and thus these lakes are monomictic.

Water column stratification results in a division of the water column into three sections – the epilimnion or top layer, the metalimnion or middle layer (which contains the thermocline, the plane of maximum rate of decrease of temperature with respect to depth (Wetzel 2001) and the hypolimnion, or bottom layer. This can have various consequences to water chemistry, because in a strongly stratified lake, water in the hypolimnion does not mix with surface waters. If the depth of the hypolimnion is greater than the euphotic depth (the maximum depth at which photosynthesis meets or exceeds respiration), dissolved oxygen levels are not replenished because there is no exchange with the atmosphere (as there is in the epilimnion), or production of oxygen through photosynthesis. In some lakes, oxygen concentrations decrease sufficiently to impact fish species.

Dissolved oxygen levels in the hypolimnion can become depleted due to the decomposition of algae that dies and sinks to the bottom. 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 Stratification

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

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

The water column in Kemp Lake was unstratified during the winter months (thus classifying it as a warm monomictic lake), with stratification beginning to occur sometime between March and May. By August, the water column was strongly stratified, with the thermocline occurring between 3 m and 8 m depth. Hypolimnetic temperatures remained between 5°C and 9°C throughout the year, while epilimnetic temperatures reached as high as 22°C (Figure 6).

Summer surface water temperatures exceeded the drinking water guideline of 15°C, as well as the optimum temperature range for rearing of cutthroat trout (17°C), the most sensitive species in Kemp Lake for this parameter (Oliver and Fidler, 2001). Fish would typically need to stay within the thermocline (below 5 m during the late summer) to avoid physiological stresses associated with elevated water temperatures. In order to maintain a deep water refuge for fish, ***the proposed water quality objective for temperature is a summer maximum hypolimnetic (from six metres to the bottom of the lake) temperature of 15°C.*** This will ensure that trout are not overly restricted in the areas that they can feed. Placing the water intake below the thermocline depth would also allow the drinking water guideline to be met.

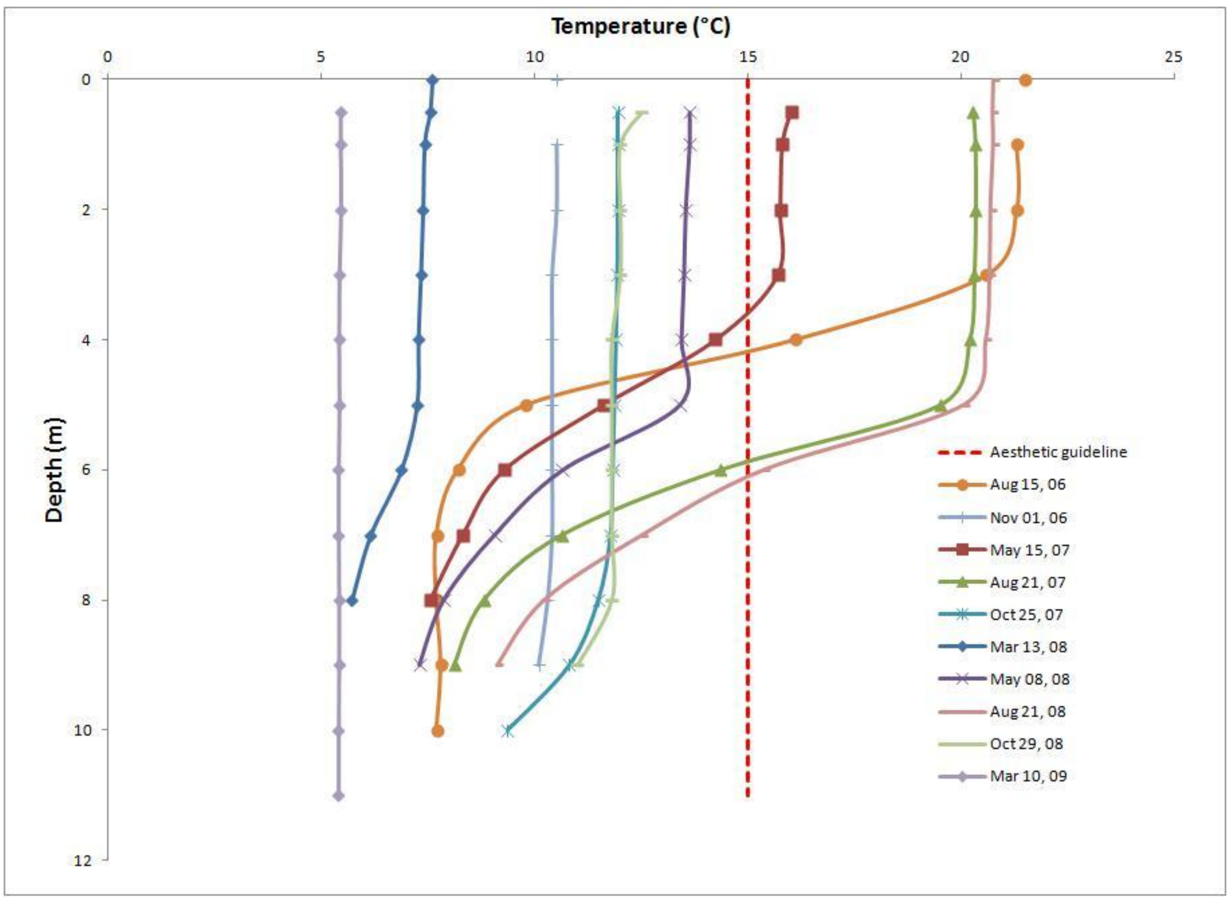


**Figure 6. Seasonal water temperatures measured at one metre intervals in Kemp Lake.**

### 6.1.2 Dissolved Oxygen

Dissolved oxygen (DO) levels are important for the survival of aquatic organisms, especially species sensitive to low oxygen levels such as salmonids. Oxygen becomes dissolved in water on the surface of lakes as a result of diffusion from the atmosphere, as well as from photosynthetic activity from plants and algae. When deeper waters no longer mix with surface waters, due to stratification, concentrations of DO can decrease. This occurs as a result of decomposition of organic materials, especially in eutrophic lakes (*i.e.*, lakes with high levels of nutrients and 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 (B.C. Ministry of Environment, 1997).

Dissolved oxygen concentrations were generally at or near saturation throughout the water column for that portion of the year when the lake was unstratified. As the water column became stratified and deeper water no longer mixed with surface waters, dissolved oxygen concentrations began to decrease with depth (Figure 7). The minimum concentration of dissolved oxygen measured in Kemp Lake was 0.3 mg/L, at 9 m depth on August 21, 2007, and each summer the minimum aquatic life guideline was not met. As DO concentrations may be a concern, ***a water quality objective is proposed: the objective is that DO concentrations measured at least 2 m above the lake bottom should be above 5 mg/L at all times.***

Additionally, total phosphorus concentrations in the hypolimnion are influenced by DO concentrations (see Section 6.2.5 ). The minimum DO concentration necessary to prevent phosphorus release at the sediment-water interface is 2 mg/L (Marsden, 1989). For this reason, an additional DO objective is proposed: ***the objective is that DO concentrations in the bottom 2 m of the lake, measured at the deepest point, should be > 2 mg/L during the summer months (May to August).***

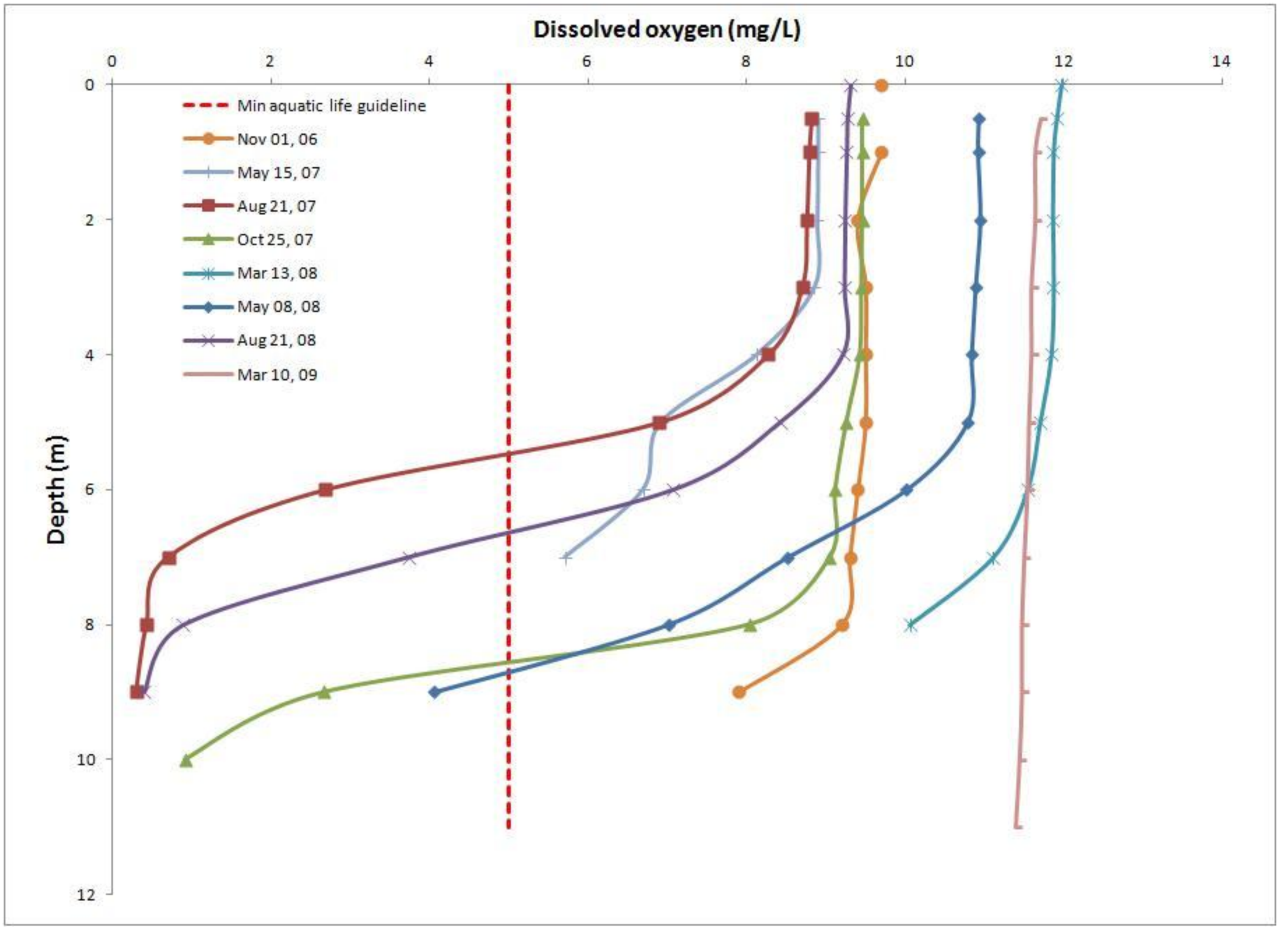


**Figure 7. Seasonal dissolved oxygen concentrations (mg/L) measured at one metre intervals in Kemp Lake.**

### 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 measuring 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 Health Canada recreational guideline for Secchi depths is a minimum of 1.2 m (Health Canada, 2012). Secchi depths measured at the deep site ranged from 2.4 m to 5.3 m, with an average of 3.6 m. All values were well above the recreational guideline of 1.2 m. In order to maintain the existing recreational water quality of Kemp Lake, a water quality objective for Secchi depth is recommended. ***The water quality objective is that the mean annual Secchi depth (based on a minimum of four measurements each year) be at least 4 m.***

## 6.2 WATER CHEMISTRY

### 6.2.1 pH

pH measures the concentration of hydrogen ions ($H^+$) in water. The concentration of hydrogen ions in water can range over 14 orders of magnitude, so pH is defined on a logarithmic scale between 0 and 14. A pH between 0 and less than 7 is acidic (the lower the number, the more acidic the water) and a pH greater than 7 and less than 14 is alkaline (the higher the number, the more basic the water). The aesthetic objective for drinking water is a pH between 6.5 and 8.5 (Nagpal *et al.*, 2006). 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.

Field and lab pH values ranged from 6.38 to 8.07 pH units. The pH was occasionally below both the drinking water and aquatic life guideline of 6.5 pH units. Typically, we would expect to see the lowest pH values during the winter months, when inputs from low-pH rainwater are at their highest, and in general this trend can be seen in Kemp Lake. The pH also changed with depth, remaining steady or increasing in the first few metres due to reductions in carbon dioxide resulting from photosynthesis, and then decreasing in deeper waters as light penetration decreases.

It appears that occasional low pH is a natural phenomenon in Kemp Lake and it is not likely that anthropogenic activities will impact pH. Therefore, ***no objective is proposed*** for pH in Kemp Lake at this time. However, it is included in the monitoring program and should continue to be evaluated for trends.

### 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. As well, there are aesthetic concerns with cloudy water, and particulate matter can clog water filters and leave a film on plumbing fixtures. The BCMOE guideline for drinking water that does not receive treatment to remove turbidity is an induced turbidity over background of 1 NTU when background is not more than 5 NTU. VIHA follows the Canadian Drinking Water Quality Guidelines which states that drinking water at the point of treatment should be below 1 NTU (95% of days) and not above 5 NTU on more than 2 days in a 12 month period (Dr. Paul Hasselback, VIHA, pers. comm, 2012).

Turbidity values ranged from 0.3 NTU to 20.6 NTU in Kemp Lake, with an average of 2.3 NTU. There were three instances when turbidity exceeded 9 NTU – all of these samples were collected at the maximum depth (either 9 or 10 metres) in either August or October, and samples collected on the same day from shallower depths were all approximately 1 NTU. This suggests that either the sampling bottle came in contact with the lake bottom, causing sediment to rise into the water column, thereby increasing turbidity, or turbidity levels near the bottom of the lake are considerably higher than in the remainder of the water column during the late summer and early fall, prior to lake turnover. The low DO results at the bottom in August and October suggest that the lake is being impacted by land use and experiencing a cycle of algae die-off, depleted oxygen, and potentially nutrient re-release, as described in Section 6.1. Thus the turbidity results in Kemp Lake are not reflective of natural background conditions and are elevated on occasion. As the water quality guideline for turbidity is based on background conditions, a different representative watershed is needed as a surrogate for background conditions in Kemp Lake.

The ecoregion approach adopted by the Vancouver Island region (see Section 1.0) allows objectives from a representative watershed within an ecoregion to be applied to other watersheds without objectives. All the lakes within the Leeward Island Mountains ecoregion that have approved water quality objectives are much larger and therefore not comparable to Kemp Lake. Nearby unimpacted lakes of similar size include Maxwell Lake (Southern Gulf Islands ecoregion) and Sugsaw Lake (Windward Island Mountains ecoregion). All three are within the same biogeoclimatic zone, but Maxwell is more similar to Kemp with respect to surface area and mean and maximum depth, and as such, Maxwell Lake will be used to represent background conditions for Kemp Lake. Maxwell Lake results showed a background turbidity of 1 NTU (Epps and Phippen, *in progress)*. Therefore, ***it is recommended that total turbidity measured should not exceed a maximum of 2.0 NTU at any time (1 NTU above ambient levels) and that turbidity at the intake be < 1 NTU 95% of the time.*** It should be noted elevated turbidity values are considered likely to affect disinfection in a chlorine-only system (Dr. Paul Hasselback, VIHA, pers. comm, 2012). The requirement for turbidity at the intake to be <1 NTU 95% of the time is included to align with VIHA criteria. It is recognized that the BC MOE sampling frequency is not sufficient to compare to this objective, and it is up to the water purveyor to meet the sampling requirements for comparison to the VIHA criteria. As noted in Section 5.0, BC MOE has not sampled at the drinking water intake. In future monitoring, samples should be taken here at a depth of 4 m to compare to any objectives that are set to protect drinking water use.

### 6.2.3 Colour and Total Organic Carbon

Colour in water is caused by dissolved and particulate organic and inorganic matter. True colour is a measure of the dissolved colour in water after the particulate matter has been removed, while apparent colour is a measure of the dissolved and particulate matter in water. Colour can affect the aesthetic acceptability of drinking water, and the drinking water guideline is that the maximum should not exceed 15 TCU (true colour units) (Moore and Caux, 1997). This objective only applies to systems where the ambient colour is less than 15 TCU. Colour is also an indicator of the amount of organic matter in water. When organic matter is chlorinated it produces disinfection by-products (DBPs) such as trihalomethanes (THMs) and haloacetic acids (HAAs) (Health Canada, 2008).

Colour was measured 36 times, with values ranging from < 5 TCU to 60 TCU, and an average of 16 TCU. Fourteen samples had true colour concentrations exceeding the drinking water guideline of 15 TCU. These observations and anecdotal evidence suggest that the colour in Kemp Lake is often naturally higher than the 15 TCU threshold, and the lake likely hovers around the colored versus non colored lake classification, based on the BC water quality guidelines (background less than or equal to 20 TCU = noncolored). Additionally, it is possible that agricultural and rural residential land uses around the lake have increased the colour. This is supported by the fact that, as with turbidity, the highest values were seen at the bottom depth in August or October, suggesting land use activities are causing increased nutrient inputs to the lake which can cause algae blooms followed by late summer and early fall die-offs. The range of true colour in Kemp Lake is similar to that seen in Maxwell Lake, where colour concentrations ranged from below detection limits (< 5 TCU) to 60 TCU. As mentioned above, Maxwell Lake can be used to represent background for Kemp Lake. As such, a water quality objective based on Maxwell Lake is proposed: ***the maximum colour measured in Kemp Lake should not exceed 20 TCU at any time of year***. While this objective may be exceeded at the bottom depth prior to fall turnover, long-term land use planning may ameliorate this.

Colour is closely correlated with organic carbon concentrations, as humic acids (high in organic carbon) are often major contributors to colour in water. Elevated total organic carbon (TOC) levels (above 4.0 mg/L) can result in higher levels of DBPs in finished drinking water if chlorination is used to disinfect the water (Moore, 1998). As the KLWD uses chlorine to disinfect their drinking water, TOC concentrations in Kemp Lake are of interest. TOC concentrations were measured 36 times, with values ranging from 3.4 mg/L to 8.0 mg/L. Twenty-three values exceeded the drinking water guideline for TOC of 4 mg/L to protect against disinfection by-products. This range of TOC concentrations is similar to that seen in Maxwell Lake, where TOC concentrations ranged from 3.0 mg/L to

7.5 mg/L. Using Maxwell Lake as a reference site, as discussed above, and based on existing TOC concentrations, the following objective is proposed: ***maximum concentration of TOC in any sample collected at the intake should not exceed 6 mg/L.*** It is recognized that this objective exceed the provincial drinking water guidelines for TOC, however it reflects natural background levels (*i.e.* those seen in Maxwell Lake). Any subsequent watershed management planning should limit further increases in true colour and TOC given the high background levels. If there are concerns over DBP formation, water treatment alternatives may need to be examined.

For both colour and TOC, monitoring should also be done at the drinking water intake.

### 6.2.4 Conductivity

Conductivity refers to the ability of a substance to conduct an electric current. The conductivity of a water sample gives an indication of the concentration of dissolved ions in the water. The more ions dissolved in a solution, the greater the electrical conductivity. Temperature affects the conductivity of water (a 1ºC increase in temperature results in approximately a 2% increase in conductivity), so specific conductivity is normalized to 25ºC (*i.e.* specific conductivity) to allow comparisons to be made. Coastal systems, with high annual rainfall values and typically short water retention times, generally have low specific conductivity (<80 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 Kemp Lake were ranged from 57 µS/cm to 117 µS/cm, with lower conductivity typically measured during the spring (when dilution from rainfall is greatest). The highest conductivity levels occurred in samples collected just above the substrate, which suggests that the sampling device may have come in contact with the lake bottom, causing sediments to rise into the water column. 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 Kemp Lake.

#### 6.2.5 Nutrients (Nitrate, Nitrite and Phosphorus)

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

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

Nitrogen concentrations were generally measured in terms of dissolved nitrite ($NO_2$) + dissolved nitrate ($NO_3$). Dissolved nitrate + nitrite concentrations ranged from < 0.002 mg/L to 0.36 mg/L, with an average of 0.16 mg/L in Kemp Lake. The combined concentrations of nitrate and nitrite were well below the existing aquatic life guidelines. No objective is proposed for nitrogen concentrations in Kemp Lake.

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

Total phosphorus concentrations measured at the deep water site ranged from 3 µg/L to a maximum of 44 µg/L, with an average of 12 µg/L. The two highest concentrations (44 µg/L and 38 µg/L) were recorded in October and were found in samples collected near the bottom of the lake. As noted above, they corresponded to higher turbidity and colour and lower dissolved oxygen, suggesting that algae die-off and oxygen depletion is causing internal nutrient loading in Kemp Lake. The average spring overturn total phosphorus concentrations were 9 µg/L, 12 µg/L and 13 µg/L at the surface, 5 m and 10 m depths, respectively, and the overall spring average was 11 µg/L, placing the lake in a mesotrophic category (Nordin, 1985). Ideally the spring overturn phosphorus concentration should consistently meet the drinking water guideline (10 µg/L). It is possible that residences and agriculture (including potentially faulty septic systems and fertilizer use) are contributing nutrients to Kemp Lake, and these elevated nutrient levels are potentially impacting aquatic life and drinking water during the summer months. Therefore, a water quality objective is recommended for total phosphorus concentrations in Kemp Lake: ***the maximum total phosphorus concentration collected during spring overturn (i.e., before the lake begins to stratify in April ) should not exceed 10 µg/L.***

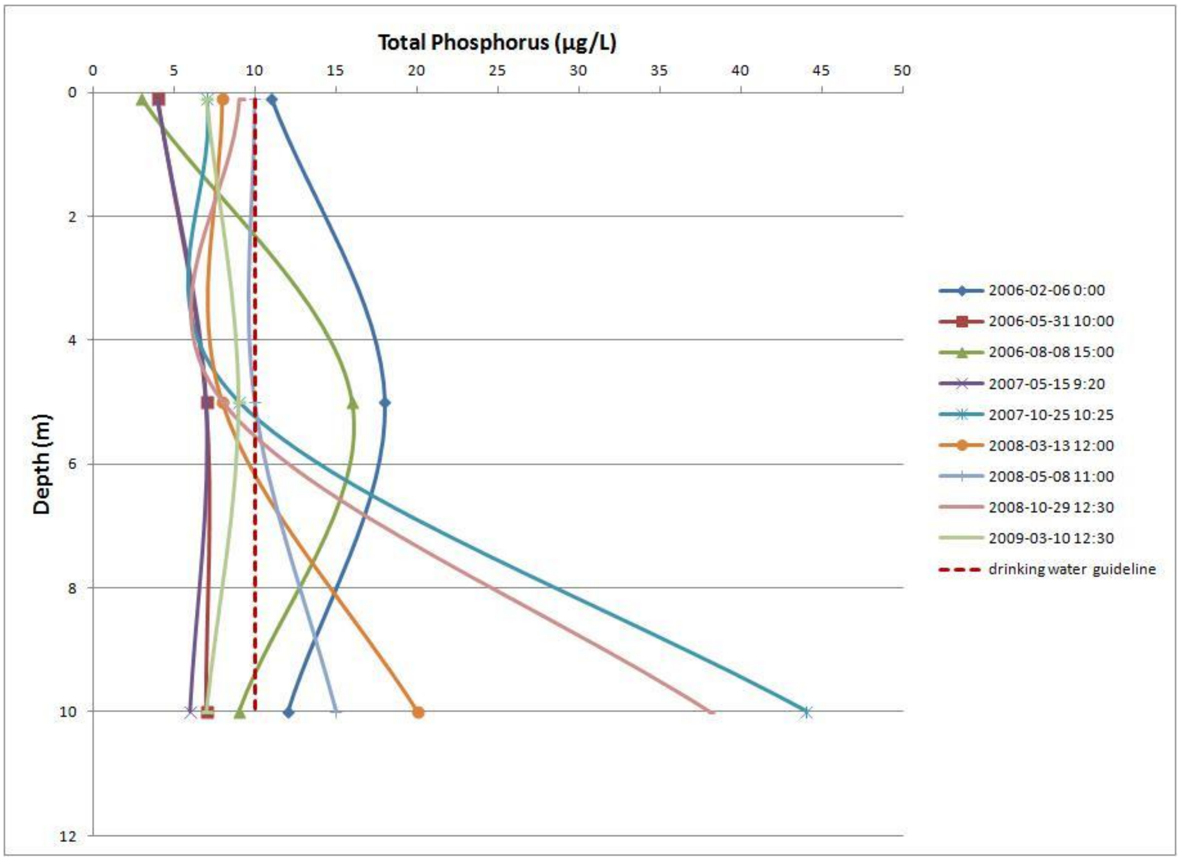


**Figure 8. Seasonal total phosphorus levels (µg/L) measured at the surface, mid-water column and 1 m above the bottom in Kemp Lake.**

### 6.2.6 Metals

Total metals concentrations were measured 33 to 36 times for most metals. The concentrations of all metals were well below guideline levels, with a few exceptions. Total iron concentrations ranged from 0.083 mg/L to 2.300 mg/L with an average of 0.364 mg/L for nine samples. The maximum concentration exceeds the drinking water and aquatic life guideline of 1 mg/L (Phippen *et al.*, 2008). The maximum value occurred in a sample collected at the bottom of the lake in October, when turbidity, colour and phosphorus were high and dissolved oxygen was low. During the other two sampling events when these conditions were present, iron was not measured but it is possible that it was also elevated at those times. In conditions of depleted oxygen, iron bound to phosphorus can be released from anoxic sediments (Phippen *et al*., 2008), and it is possible that this caused the high iron reading. At this time, there is not enough information to develop an objective for iron.

Dissolved aluminum was not sampled, but one sample had concentrations of total aluminum above the dissolved aluminum guideline of a maximum of 0.1 mg/L. Total aluminum concentrations ranged from 0.0078 mg/L to 0.112 mg/L with an average of 0.044 mg/L for 33 samples. This suggests that if dissolved aluminum was sampled there is potential for occasional maximum guideline exceedances. The mean concentration of total aluminum was below the average dissolved aluminum guideline of 0.05 mg/L. Slightly elevated aluminum levels appear to be a natural occurrence on Vancouver Island (Barlak *et al*., 2010). Thus, the occasional elevated value observed in Kemp Lake is unlikely a concern and no objective is recommended.

Total cadmium exceeded the working aquatic life guideline of 0.01 µg/L on four occasions. It is recommended that the detection limit be no more than one tenth of the guideline value (Cavanagh *et al*, 1997). In the case of cadmium, the detection limit should be 0.001 µg/L or lower, but it is currently 0.005 µg/L. As such, the results do not provide enough information to determine background levels in the lake, and no objective is proposed at this time.

Total copper exceeded the aquatic life guideline of 3.9 µg/L on one occasion, with a value of 15.2 µg/L. All other values were below the guideline. The exceedance occurred in a surface water sample, and was not associated with high turbidity or instances of other high metal results. The cause of this high copper reading is unclear, and it appears to be an anomaly, therefore no copper objective is proposed.

Metals should continue to be monitored, both at the deep station and the intake site, and the suite should include total iron, dissolved aluminum, total cadmium and total copper.

With the exception of iron, anthropogenic activities are not likely impacting concentrations of any of these metals. 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. Levels of organics can be measured by looking at dissolved organic carbon (DOC). Concentrations of DOC at the deep water site ranged from 2.4 mg/L to 5.6 mg/L, with an average of 4.3 mg/L. These relatively high DOC concentrations support that no objective is needed for the metals listed above.

## 6.3 BIOLOGICAL ANALYSIS

Objectives development has traditionally focused on physical, chemical and bacteriological parameters. Biological data has been underutilized 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 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 impart taste and odour to drinking water, requiring expensive treatments to remove algal particles.

If algae are not removed prior to chlorination, disinfection by-products can be formed that are potentially carcinogenic (Nordin, 2001). Some species of phytoplankton (specifically "blue-green algae", or cyanobacteria) can contain toxins. Allergic reactions to algae in drinking water, or from exposure to algae while swimming, are also common. Aesthetically, algal blooms reduce water clarity and can result in an unpleasant "scum" on the surface of the water, as well as give the water a strong odour.

Changes in algal biomass 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 such as suckers. 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 were sampled at the deep-water station on 13 occasions between 2005 and 2009. The results were summarized and the dominant species for each site are listed in Table 1. 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.

A total of 66 species were identified, as well as 79 genera (some of the specimens found could be identified only to the genus level). Cell concentrations tended to be lower early in the year (February/March and May average was 973 cells/mL) and higher as the summer progressed (August and October average was 3134 cells/mL), generally peaking in August.

In the spring, the phytoplankton community in Kemp Lake was dominated by diatoms (*Melosira italica* or *Asterionella formosa*) and Cryptomonads (*Chroomonas acuta*). In May, this dominance either persisted or shifted to green algae from the genus *Volvox* or the blue-green algae *Anacystis elachista*. In the summer, the community was dominated by green algae (*Sphaerocystis schroeteri*) and blue-green algae (*Lyngbya limnetica*) and, in

2008, also the green algae *Crucigenia tetrapedia* and the diatom *M. italica*. In the fall, blue-green algae were dominant, either *A. elachista* or *L. limnetica*. Overall, the phytoplankton community found in Kemp Lake is consistent with mesotrophic conditions (Wetzel, 2001) as indicated by the water chemistry results (6.2.5). There are not sufficient data to propose a water quality objective for phytoplankton community structure in Kemp Lake at this time. However, monitoring should continue as this information is useful in assessing water quality.

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 at the deep site ranged from 0.8 µg/L to a maximum of 42.3 µg/L, with an average concentration of 5.6 µg/L. The maximum concentration occurred on March 10, 2009, and the next highest concentration was only 3.6 µg/L. It is possible that the March 10, 2009 value was an anomaly; phytoplankton, zooplankton, phosphorus and turbidity results were all relatively low on that date. If the high reading is omitted, the average chlorophyll *a* concentration is 2.0 µg/L, suggesting that the lake is low productivity. However, the low dissolved oxygen and high phosphorus at depths in the summer and fall suggest that the lake is being affected by land use and experiencing internal loading. For this reason, a chlorophyll *a* objective is proposed to ensure that this parameter does not increase over time. ***The water quality objective for chlorophyll* a *in Kemp Lake is a summer (May through August) concentration between 1.5 µg/L and 2.5 µg/L.*** Dillon and Rigler (1975) recommended this range of chlorophyll *a* in order to protect fishery and recreational values in lakes and it was subsequently used for other southern Vancouver Island lakes (e.g., Elk and Beaver Lakes (McKean 1992) and Langford Lake (Rieberger, 2007)).

**Table 1. Summary of dominant (*i.e.* >10% of sample) phytoplankton species for Kemp Lake (number of cells/mL and % of total sample).**

| | 13-Oct-05 | | 06-Feb-06 | | 31-May-06 | | 15-Aug-06 | | 31-Mar-07 | | 15-May-07 | | 21-Aug-07 | | 25-Oct-07 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % |
| Order : Centrales | | | | | | | | | | | | | | | | |
| *Melosira italica* | | | | | | | | | | | | | | | | |
| Order : Chlorococcales | | | | | | | | | | | | | | | | |
| *Botryococcus braunii* | 1140 | 28.2% | | | | | | | | | | | | | | |
| *Crucigenia quadrata* | | | | | | | | | | | | | | | 123.2 | 16.1% |
| *Crucigenia tetrapedia* | | | | | | | | | | | | | | | | |
| *Quadrigula lacustris* | | | | | | | | | | | | | | | | |
| Order : Chroococcales | | | | | | | | | | | | | | | | |
| *Anacystis elachista* | 2394 | 59.2% | | | 672 | 42.3% | 336 | 10.0% | | | | | | | | |
| Order : Cryptomonadales | | | | | | | | | | | | | | | | |
| *Chroomonas acuta* | | | 19.6 | 25.9% | | | | | 201.4 | 35.7% | | | 81.2 | 14.0% | | |
| Order : Nostocales | | | | | | | | | | | | | | | | |
| *Anabaena spp.* | | | | | | | | | | | 285.6 | 14.4% | | | | |
| Order : Ochromonadales | | | | | | | | | | | | | | | | |
| *Dinobryon divergens* | | | | | | | | | | | 369.6 | 18.6% | | | | |
| *Mallomonas akrokomos ?* | | | | | | | | | 81.7 | 14.5% | | | | | | |
| Order : Oscillatoriales | | | | | | | | | | | | | | | | |
| *Lyngbya limnetica* | | | | | | | 845.6 | 25.3% | | | | | 112 | 19.3% | 152.6 | 20.0% |
| *Lyngbya cf limnetica* | | | | | | | | | | | | | | | | |
| Order : Pennales | | | | | | | | | | | | | | | | |
| *Asterionella formosa* | | | 11.2 | 14.8% | | | | | 193.8 | 34.3% | | | | | | |
| Order : Tetrasporales | | | | | | | | | | | | | | | | |
| *Sphaerocystis schroeteri* | | | 11.2 | 14.8% | 291.2 | 18.3% | 1388.8 | 41.5% | | | | | | | | |
| Order : Volvocales | | | | | | | | | | | | | | | | |
| *Volvox spp.* | | | | | | | | | | | 896 | 45.1% | | | | |
| UID colonial algae | | | | | | | | | | | | | | | | |

Table 3 (continued)

| | 13-Mar-08 | | 08-May-08 | | 21-Aug-08 | | 29-Oct-08 | | 10-Mar-09 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. | % | No. | % | No. | % | No. | % | No. | % |
| Order : Centrales | | | | | | | | | | |
| *Melosira italica* | | | 296.8 | 38.5% | 1036 | 20.1% | 1680 | 34.2% | 428.4 | 43.3% |
| Order : Chlorococcales | | | | | | | | | | |
| *Botryococcus braunii* | | | | | | | | | | |
| *Crucigenia quadrata* | | | | | | | | | 134.4 | 13.6% |
| *Crucigenia tetrapedia* | | | | | 935.2 | 18.1% | | | | |
| *Quadrigula lacustris* | | | 112 | 14.5% | | | | | | |
| Order : Chroococcales | | | | | | | | | | |
| *Anacystis elachista* | | | | | | | | | | |
| Order : Cryptomonadales | | | | | | | | | | |
| *Chroomonas acuta* | 408.8 | 48.7% | 190.4 | 24.7% | | | | | 123.2 | 12.5% |
| Order : Nostocales | | | | | | | | | | |
| *Anabaena spp.* | | | | | 691.6 | 13.4% | | | | |
| Order : Ochromonadales | | | | | | | | | | |
| *Dinobryon divergens* | | | | | | | | | | |
| *Mallomonas akrokomos ?* | | | | | | | | | | |
| Order : Oscillatoriales | | | | | | | | | | |
| *Lyngbya limnetica* | | | | | 1414 | 27.4% | | | | |
| *Lyngbya cf limnetica* | | | | | | | 2385.6 | 48.6% | | |
| Order : Pennales | | | | | | | | | | |
| *Asterionella formosa* | 260.4 | 31.0% | | | | | | | | |
| Order : Tetrasporales | | | | | | | | | | |
| *Sphaerocystis schroeteri* | | | | | | | | | 156.8 | 15.9% |
| Order : Volvocales | | | | | | | | | | |
| *Volvox spp.* | | | 84 | 10.9% | | | | | | |
| UID colonial algae | | | | | 526.4 | 10.2% | | | | |

### 6.3.2 Zooplankton

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

Zooplankton were sampled at the deep-water station on 12 occasions between 2005 and 2009. The dominant species (*i.e.* >10% of sample) are listed in Table 2. The more detailed set of taxonomic analysis results for zooplankton can be obtained from the MOE office in Nanaimo, BC.

A total of 22 zooplankton species and 32 genera (not all genera were identified to species level) were identified in Kemp Lake. Unlike the phytoplankton samples, concentrations were fairly consistent throughout the year (approximately 20,000 organisms/sample), with the exception of the August 2007 sample at 67,483 organisms/sample and the May 2008 sample at 48,939 organisms per sample.

The zooplankton community of Kemp Lake was composed predominately of rotifers and copepods, and to a lesser degree cladocerans. Rotifers were the dominant group, especially *Asplancha* spp., *Keratella cochlearis*, *K. longispina* and *Polyarthra* spp.. Other rotifers that dominated in some years included *Gastropus* spp., *K. bostoniensis*, *Synchaeta* spp., *Hexarthra* sp., *Pompholyx* sp. and *Trichocerca* spp..

Copepod nauplii were most abundant in the spring, and were not identified to species. Cladocerans were among the dominant zooplankton species in only two samples (February

6, 2006 and August 21, 2008), and made up only 10% of each sample. The two species present were *Daphnia pulex* and *Diaphanosoma brachyurum*.

There are not sufficient data to propose a water quality objective for zooplankton community structure in Kemp Lake at this time. However, monitoring should continue as this information is useful in assessing water quality.

**Table 2. Summary of dominant (*i.e.* >10% of sample) zooplankton species for Kemp Lake (number of cells/sample and % of total sample).**

| | 13-Oct-05 | | 06-Feb-06 | | 31-May-06 | | 31-Mar-07 | | 15-May-07 | | 21-Aug-07 | | 25-Oct-07 | | 13-Mar-08 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % | No. | % |
| Sub-class : Copepoda nauplii | | | | | | | | | | | | | | | | |
| Copepoda: nauplii | 1367 | 14% | 1867 | 31% | 2700 | 11% | 3433 | 14% | 3033 | 17% | | | | | 6784 | 39% |
| Cyclopoida: UID copepodid | | | | | | | | | | | | | | | | |
| UID Calanoida / Cyclopoida nauplii | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Order : Cladocera | | | | | | | | | | | | | | | | |
| *Daphnia pulex* | | | 600 | 10% | | | | | | | | | | | | |
| *Diaphanosoma brachyurum* | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Phylum : Rotifera | | | | | | | | | | | | | | | | |
| *Asplanchna sp.* | | | | | | | | | | | | | | | | |
| *Gastropus spp.* | | | | | 8200 | 33% | | | 3867 | 22% | | | | | | |
| *Hexarthra sp.* | 2667 | 27% | | | | | | | | | | | | | | |
| *Kellicottia bostoniensis* | | | | | | | | | | | | | | | | |
| *Kellicottia longispina* | | | | | 3433 | 14% | 4833 | 20% | 8833 | 49% | | | | | | |
| *Keratella cochlearis* | | | | | | | | | | | 16100 | 24% | 13550 | 64% | | |
| *Polyarthra spp.* | | | | | | | | | | | | | | | 7552 | 43% |
| *Pompholyx sp.* | | | 667 | 11% | | | | | | | | | | | | |
| *Synchaeta spp.* | | | 1133 | 19% | | | 7533 | 31% | | | | | | | | |
| *Trichocerca spp.* | | | | | | | | | | | 12000 | 18% | | | | |
| | | | | | | | | | | | | | | | | |
| Large ciliate | | | | | | | | | | | 16800 | 25% | | | | |

Table 4 (continued)

| | 08-May-08 No. | % | 21-Aug-08 No. | % | 29-Oct-08 No. | % | 10-Mar-09 No. | % |
|---|---|---|---|---|---|---|---|---|
| Sub-class : Copepoda nauplii | | | | | | | | |
| Copepoda: nauplii | | | | | | | | |
| Cyclopoida: UID copepodid | | | | | 610 | 10% | | |
| UID Calanoida / Cyclopoida nauplii | | | | | | | 2000 | 13% |
| | | | | | | | | |
| Order : Cladocera | | | | | | | | |
| *Daphnia pulex* | | | | | | | | |
| *Diaphanosoma brachyurum* | | | 2000 | 10% | | | | |
| | | | | | | | | |
| Phylum : Rotifera | | | | | | | | |
| *Asplanchna sp.* | 32200 | 66% | | | | | | |
| *Gastropus spp.* | | | | | | | | |
| *Hexarthra sp.* | | | 2300 | 11% | | | | |
| *Kellicottia bostoniensis* | | | | | | | 3600 | 24% |
| *Kellicottia longispina* | | | | | 600 | 10% | | |
| *Keratella cochlearis* | | | 5600 | 27% | 3200 | 51% | 4100 | 27% |
| *Polyarthra spp.* | | | | | 900 | 14% | 2100 | 14% |
| *Pompholyx sp.* | | | | | | | | |
| *Synchaeta spp.* | | | | | | | | |
| *Trichocerca spp.* | | | | | | | | |
| | | | | | | | | |
| Large ciliate | | | | | | | | |

## 7.0 SUMMARY OF PROPOSED WATER QUALITY OBJECTIVES

In British Columbia, water quality objectives are mainly based on approved or working water quality guidelines. These guidelines were established to prevent specified detrimental effects from occurring with respect to a designated water use. Identified water uses for Kemp Lake that are sensitive and should be protected are drinking water, irrigation, aquatic life and wildlife. The water quality objectives recommended here take into account impacts from current land use and any potential future impacts that may arise within the watershed, as well as reference conditions from a nearby lake. 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 3.

**Table 3. Summary of proposed water quality objectives for Kemp Lake.**

| Variable | Objective Value |
|---|---|
| **Water temperature** | ≤ 15°C summer maximum hypolimnetic temperature (> 5 m depth) |
| **Dissolved oxygen** | ≥ 5 mg/L > 2 m above lake bottom<br>≥ 2 mg/L ≤ 2 m above lake bottom (May-August) |
| **Secchi depth** | ≥ 4 m annual average |
| **Turbidity** | ≤ 2 NTU maximum<br>< 1 NTU 95% of the time |
| **True colour** | ≤ 20 TCU maximum |
| **Total organic carbon** | ≤ 6 mg/L maximum |
| **Total phosphorus** | ≤10 µg/L maximum during spring overturn |
| **Chlorophyll *a*** | 1.5 µg/L to 2.5 µg/L (May-August) |

## 8.0 MONITORING RECOMMENDATIONS

The recommended water quality monitoring program for Kemp Lake is summarized in Table 4. It is recommended that future attainment monitoring occur once every 3-5 years based on staff and funding availability, and whether activities, such as forestry or development, are underway within the watershed. Attainment sampling is generally conducted throughout a one year period. Water quality parameters to monitor include some that are supplemental to core water quality objectives monitoring.

**Table 4. Proposed schedule for future water quality monitoring in Kemp Lake.**

| Frequency and timing | Characteristic to be measured |
|---|---|
| Deep station site (3 depths per site) - quarterly sampling (March, May, August, October) | pH, specific conductivity, turbidity, colour, TOC, DOC, nitrogen species, total phosphorus, total and dissolved metals including iron and hardness (spring overturn only), *chlorophyll a*, DO, temp profiles and Secchi disk |
| Intake site – 5-in-30 sampling in summer and fall | Turbidity, TOC, total and dissolved metals including iron, hardness, *E. coli* |
| Deep station site - twice per year (spring overturn and summer) | Phytoplankton and zooplankton |

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

The monitoring should consist of full water chemistry sampling at the deep basin location (three depths – surface, 10 m and 1 m from bottom) and include physical measurements of dissolved oxygen, temperature and water clarity. Analysis of the deep station samples should include pH, specific conductivity, turbidity, true colour, TOC, nutrients, total and dissolved metals and hardness. When samples are collected from 1 m above the lake bottom, care should be taken to ensure that sediments are not disturbed to prevent contamination. In addition, we recommend sampling take place at the intake site, to ensure that objectives that are set to protect drinking water are being met. These samples should be taken at a depth of 4 m (the depth of the intake) and should consist of five samples in a 30-day period during the summer low-flow and fall flush seasons. General water chemistry (turbidity, TOC, total and dissolved metals and hardness), as well as bacteriological monitoring for *Escherichia coli* should be conducted here. During objectives development sampling, no samples were taken for bacteriological parameters. They have a high importance with respect to drinking water sources and recreation, which is why it is recommended that *E. coli* sampling be included in attainment monitoring.

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) at the deep basin site. Phytoplankton and zooplankton samples should be collected twice per sample year, at spring overturn and during the summer.

## LITERATURE CITED

Barlak, R., D. Epps and B. W. Phippen. 2010. Water Quality Assessment and Objectives for the Englishman River Community Watershed. Environmental Protection Division, British Columbia Ministry of Environment, Nanaimo, B.C.

BC Community Watershed Database. 2012. Available online at: http://www.env.gov.bc.ca/wsd/data_searches/comm_watersheds/index.html

British Columbia (BC) Conservation Data Centre: Conservation Data Centre Mapping Service [web application]. 2012. Victoria, British Columbia, Canada. Available online at: http://maps.gov.bc.ca/imf50/imf.jsp?site=cdc (February 2012).

BC MOE (British Columbia Ministry of Environment). 1997. Ambient water quality criteria for dissolved oxygen. Available online at: http://www.env.gov.bc.ca/wat/wq/BCguidelines/do/index.html

BC MOE (British Columbia Ministry of Environment). 2003. British Columbia field sampling manual for continuous monitoring and the collection of air, air-emission, water, wastewater, soil, sediment, and biological samples. Available online at: http://www.env.gov.bc.ca/epd/wamr/labsys/field_man_03.html.

BC Water Resource Atlas. [web application] 2012. Ministry of Environment. Available online at: http://www.env.gov.bc.ca/wsd/data_searches/wrbc/ (February 2012).

Caux, P.-Y., D.R.J. Moore, and D. MacDonald. 1997**.** Ambient Water Quality Guidelines (Criteria) for Turbidity, Suspended and Benthic Sediments. Victoria, B.C. : Water Management Branch, Ministry of Environment, Lands and Parks, 1997.

Cavanagh, N., R.N. Nordin, and P.D. Warrington. 1997. *Freshwater Biological Sampling Manual.* B.C. Ministry of Environment and Resource Information Standards Committee, Victoria, BC

Demarchi, D.A. 1996. An Introduction to the Ecoregions of British Columbia . B.C. Ministry of Environment, Lands and Parks. Victoria, B.C.

Epps, D. and B. W. Phippen. In progress. Water Quality Assessment and Objectives for Cusheon Lake, Maxwell Lake, St. Mary Lake and Weston Lake: Saltspring Island, BC. Technical Report. Environmental Protection Division, British Columbia Ministry of Environment, Nanaimo, B.C.

Fisheries Information Summary System (FISS) Database. 2012. Ministry of Environment and Department of Fisheries and Oceans. Available online at: http://www.bcfisheries.gov.bc.ca/fishinv/fiss.html

Hasselback, Paul. 2012. Vancouver Island Health Authority. Central Vancouver Island Medical Health Officer.

Health Canada. 2008. Guidelines for Canadian Drinking Water Quality. [Online] 2008. http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eay/sum_guide-res_recom/index_e.html.

Health Canada. 2012. Guidelines for Canadian Recreational Water Quality. [Online] http://www.hc-sc.gc.ca/ewh-semt/alt_formats/pdf/pubs/water-eau/guide_water-2012-guide_eau/guide_water-2012-guide_eau-eng.pdf

Jackson, C. and B. Blecic. 1996. Sooke Water Allocation Plan, September 9, 1996. Regional Water Management, Vancouver Island Region, Nanaimo, B.C. 87 pp.

Giles, G.E. 2003. Risk Assessment of Kemp Lake as a Raw Water Source. Prepared for Kemp Lake Waterworks District. Kemp Lake, BC. Available online: http://www.kemplakewaterworks.bc.ca/reports/KL%20Risk%20Assess%20Summary.pdf

Kemp Lake Waterworks District. 2012. Personal communication with Joanne Hemphill, trustee.

Kemp Lake Waterworks District. 2009. Kemp Lake Waterworks District Trustee Report for 2008. Presented at 2009 Annual Meeting. Kemp Lake, BC. Available online: http://www.kemplakewaterworks.bc.ca/reports/annual_reports/TrusteeAnnualReport_2008.pdf

McKean, C. 1992. Saanich Peninsula area, Elk and Beaver Lakes, Water Quality Assessment and Objectives Technical Appendix. British Columbia Ministry of Environment, Lands and Parks, Water Management Division.

Marsden, M.W. 1989. Lake restoration by reducing external phosphorus loading: the influence of sediment phosphorus release. *Freshwater Biology* 21:139-162.

Meays, C. 2009. Water Quality Guidelines for Nitrogen (Nitrate, Nitrite and Ammonia) – Overview Report Update. Province of British Columbia. Ministry of Environment. Victoria. Available online at: http://www.env.gov.bc.ca/wat/wq/wq_guidelines.html

Meixner, T. 2004. Wildfire impacts on water quality. Southwest Hydrology. P 24-25.

MINFILE 2012. Ministry of Energy and Mines Mineral Inventory. Available online at: http://www.em.gov.bc.ca/mining/geolsurv/minfile/

Moore, D.R.J. and P.-Y. Caux. 1997. Ambient Water Quality Criteria for Colour in British Columbia: Technical Appendix. Ministry of Environment. Victoria, BC. http://www.env.gov.bc.ca/wat/wq/BCguidelines/colour/index.html

Moore, D.R. J. 1998. Ambient Water Quality Criteria for Organic Carbon in British Columbia. Province of British Columbia. Ministry of Environment, Lands and Parks. Victoria. Available online at: http://www.env.gov.bc.ca/wat/wq/BCguidelines/orgcarbon/index.html

Nagpal, N., L. Pommen and L. Swain. 2006. A Compendium of Working Water Quality Guidelines for BC. B.C. Ministry of Environment, 2001. Victoria, BC. Available online: http://www.env.gov.bc.ca/wat/wq/BCguidelines/working.html

Nordin, R.N. 2001. Water Quality Criteria for Nutrients and Algae – Overview Report. B.C. Ministry of Environment, 2001. Victoria, BC. Available online: http://www.env.gov.bc.ca/wat/wq/BCguidelines/nutrients/nutrients.html

Nordin, R.N. 1985. Water Quality Criteria for Nutrients and Algae – Technical Appendix. B.C. Ministry of Environment, 1985. Victoria, BC. Available online: http://www.env.gov.bc.ca/wat/wq/BCguidelines/nutrients/nutrientstech.pdf

Oliver, G.G. and L.E. Fidler. 2001. Towards a water quality guideline for temperature in BC. Prepared for Water Quality Section , Ministry of Environment, Lands and Parks. Victoria BC. Available online at: http://www.env.gov.bc.ca/wat/wq/BCguidelines/temptech/index.html

Phippen, B., C. Horvath, R. Nordin, N Nagpal. 2008. Ambient water quality guidelines for iron. B.C. Ministry of Environment. Victoria, BC. Available online: http://www.env.gov.bc.ca/wat/wq/BCguidelines/iron/iron_tech.pdf

Rieberger, K. 2007. Water quality assessment and objectives for Langford Lake – Technical Assessment. British Columbia Ministry of Environment, Water Stewardship Division.

Silvestri, S. and G. Fosker. 2003. Kemp Lake Stocking Assessment 2003. West Coast Planning Unit, Ministry of Environment, Lands and Parks, Nanaimo, BC. Available online: http://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=3834

Water Survey Canada. 2012. Environment Canada Hydat Online Database. Station: 08HA052 Kemp Lake. Available online at: http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm?cname=WEBfrmMeanReport_e.cfm

Wetzel, R.G. 2001. Limnology: Lake and river ecosystems (Third edition). Academic Press, New York.

# Appendix I. Summary of Water Quality Data

**Table A-1. Summary of general water chemistry at 1130096, Kemp Lake at Deepest Point**

| | Minimum | Maximum | Average | Std Dev | No. of samples |
|---|---|---|---|---|---|
| Alkalinity pH 8.3 (mg/L) | < 0.5 | < 0.5 | < 0.5 | 0 | 3 |
| Alkalinity Total 4.5 (mg/L) | 12.4 | 33 | 19.7 | 5.0 | 36 |
| Ammonia Dissolved (mg/L) | < 0.005 | 0.55 | 0.047 | 0.108 | 30 |
| Ammonia: T (mg/L) | 0.01 | 0.55 | 0.10 | 0.17 | 10 |
| Bicarbonate (mg/L) | 21 | 40 | 28.7 | 10.0 | 3 |
| Bromide Dissolved (mg/L) | 0.1 | 0.1 | 0.1 | 0 | 6 |
| Carbon Dissolved Organic (mg/L) | 2.4 | 5.6 | 4.3 | 0.7 | 24 |
| Carbon Total Inorganic (mg/L) | 2.5 | 8.9 | 5.0 | 1.6 | 33 |
| Carbon Total Organic (mg/L) | 3.4 | 8 | 4.5 | 1.0 | 36 |
| Carbonate (mg/L) | < 0.5 | < 0.5 | < 0.5 | 0 | 3 |
| Chlorophyll A (mg/L) | 0.0008 | 0.0423 | 0.006 | 0.012 | 11 |
| Chloride: D (mg/L) | 6.2 | 9.7 | 8.4 | 1.6 | 9 |
| Color True (Col.unit) | < 5 | 60 | 16.0 | 12.1 | 36 |
| Diss Oxy (mg/L) | 0.3 | 11.97 | 8.80 | 3.07 | 82 |
| Secchi depth (m) | 2.4 | 5.3 | 3.6 | 0.9 | 11 |
| Hardness Total (T) (mg/L) | 15.8 | 29.4 | 20.4 | 4.0 | 12 |
| Nitrogen Kjeldahl: Tot (mg/L) | 0.16 | 0.97 | 0.29 | 0.21 | 15 |
| Nitrate (NO3) Dissolved (mg/L) | 0.002 | 0.02 | 0.014 | 0.010 | 3 |
| Nitrate + Nitrite Diss. (mg/L) | < 0.002 | 0.36 | 0.16 | 0.15 | 36 |
| Nitrogen - Nitrite Diss. (mg/L) | < 0.002 | 0.007 | 0.004 | 0.003 | 3 |
| Nitrogen (Kjel.) Tot Diss (mg/L) | 0.14 | 0.42 | 0.24 | 0.07 | 21 |
| Nitrogen Organic-Total (mg/L) | 0.12 | 0.42 | 0.22 | 0.06 | 36 |
| Nitrogen Total (mg/L) | 0.16 | 0.98 | 0.42 | 0.16 | 36 |
| Nitrogen Total Dissolved (mg/L) | 0.242 | 0.626 | 0.426 | 0.111 | 21 |
| NO2+NO3 (mg/L) | 0.01 | 0.36 | 0.17 | 0.15 | 10 |
| ORP (mV) | 19 | 500 | 249.6 | 143.7 | 72 |
| Ortho-Phosphate Dissolved (mg/L) | < 0.001 | 0.012 | 0.005 | 0.003 | 24 |
| pH (pH units) | 6.38 | 8.07 | 7.23 | 0.38 | 108 |
| Phosphorus Tot. Dissolved (mg/L) | 0.002 | 0.037 | 0.010 | 0.008 | 27 |
| P--T (mg/L) | 0.003 | 0.044 | 0.012 | 0.009 | 27 |
| Residue Filterable 1.0u (mg/L) | 26 | 64 | 48.3 | 14.8 | 6 |
| Silica :D (mg/L) | 1.6 | 10.4 | 6.6 | 2.1 | 34 |
| Specific Conductance (µS/cm) | 57 | 117 | 71.6 | 8.2 | 102 |
| Sulphate: D (mg/L) | 0.8 | 2.8 | 1.8 | 0.9 | 6 |
| Temp (C) | 5.39 | 21.5 | 11.7 | 4.8 | 104 |

| | Minimum | Maximum | Average | Std Dev | No. of samples |
|---|---|---|---|---|---|
| Turbidity (NTU) | 0.3 | 20.6 | 2.3 | 4.0 | 33 |
| | | | | | |
| Ag-T (µg/L) | < 0.005 | 0.03 | 0.014 | 0.008 | 33 |
| Al-T (mg/L) | 0.0078 | 0.112 | 0.043 | 0.035 | 33 |
| As-T (µg/L) | 0.06 | 0.2 | 0.1 | 0.05 | 33 |
| Ba-T (µg/L) | 0.98 | 4.66 | 1.8 | 0.7 | 33 |
| Be-T (µg/L) | < 0.01 | 0.02 | 0.02 | 0.01 | 33 |
| Bi-T (µg/L) | < 0.005 | < 0.02 | < 0.02 | 0.01 | 33 |
| B--T (mg/L) | 0.007 | < 0.05 | < 0.03 | 0.02 | 18 |
| Ca-T (mg/L) | 3.22 | 10.03 | 5.95 | 2.57 | 12 |
| Cd-T (µg/L) | < 0.005 | 0.03 | 0.01 | 0.01 | 33 |
| Co-T (µg/L) | 0.021 | 2.38 | 0.23 | 0.50 | 33 |
| Cr-T (µg/L) | < 0.1 | 0.4 | 0.22 | 0.07 | 33 |
| C--T (mg/L) | 6 | 13 | 9.7 | 1.8 | 33 |
| Cu-T (µg/L) | 0.81 | 15.2 | 1.7 | 2.4 | 33 |
| Fe-T (mg/L) | 0.083 | 2.3 | 0.364 | 0.727 | 9 |
| Hg-T (ug/g) | 0.17 | 0.33 | 0.25 | 0.11 | 2 |
| K--T (mg/L) | < 1 | < 1 | < 1 | 0 | 3 |
| Li-T (µg/L) | 0.05 | < 0.5 | < 0.3 | 0.2 | 33 |
| Mg-D (mg/L) | 1.83 | 2.45 | 2.29 | 0.23 | 6 |
| Mg-T (mg/L) | 1.89 | 2.83 | 2.25 | 0.31 | 12 |
| Mn-T (mg/L) | 0.002 | 1.44 | 0.13 | 0.32 | 36 |
| Mo-T (mg/L) | < 0.00005 | 0.00005 | 0.00005 | 0 | 33 |
| Na-T (mg/L) | 5.15 | 5.42 | 5.25 | 0.15 | 3 |
| Ni-T (µg/L) | 0.14 | 7.21 | 0.50 | 1.2 | 33 |
| Pb-T (µg/L) | < 0.01 | 0.135 | 0.05 | 0.03 | 33 |
| Sb-T (µg/L) | 0.009 | 0.09 | 0.02 | 0.02 | 33 |
| Se-T (µg/L) | 0.04 | 0.4 | 0.1 | 0.1 | 33 |
| Si-T (mg/L) | 0.832 | 3.69 | 2.476 | 1.279 | 6 |
| Sn-T (µg/L) | 0.01 | 0.2 | 0.04 | 0.04 | 33 |
| Sr-T (mg/L) | 0.01 | 0.0222 | 0.0144 | 0.0026 | 36 |
| S--T (mg/L) | 0.8 | 0.9 | 0.8 | 0.1 | 3 |
| Ti-T (µg/L) | 0.5 | 6.0 | 2.1 | 2.1 | 9 |
| Tl-T (µg/L) | < 0.002 | 0.005 | 0.002 | 0.001 | 33 |
| U--T (µg/L) | < 0.002 | 0.016 | 0.004 | 0.003 | 33 |
| V--T (µg/L) | < 0.2 | 2.0 | 0.4 | 0.3 | 33 |
| Zn-T (µg/L) | < 0.1 | 8.0 | 2.4 | 1.6 | 36 |