Water Quality Sampling Program for Elk Lake 2014-2015: Overview, Status and Phosphorus Budget

Elk Lake from Observatory Hill (Double Paradox Image Collaborative)

Provided to the Freshwater Fisheries Society of BC by Rick Nordin, Ph.D., as part of the Elk Lake Stewardship Project.

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Freshwater Fisheries Society of BC

HABITAT CONSERVATION TRUST FOUNDATION

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1. Executive Summary

Detailed water quality sampling of Elk Lake in 2014-15 shows continued deterioration of the aquatic environment that may put the lake's many recreational values at serious risk.

This was the first comprehensive sampling of the lake in more than 20 years; it resulted from an initiative of the Victoria Golden Rods & Reels Society (VGRRS) that led to a co-ordinated program involving the BC Ministry of the Environment, the Capital Regional District, the District of Saanich and the Victoria City Rowing Club. The last major study of the lake was conducted by the Ministry of the Environment in 1988 and published in 1992. It found that water quality was already at unacceptable levels and recommended remediation and continued monitoring. Due to a lack of progress toward remediation, the Ministry had ceased detailed monitoring by 1995.

This report analyzes most of the results of the 2014-15 sampling program and focuses on the internal loading of nutrients. Almost all of the key measurements are substantially worse than those reported in previous sampling results. In an environment like Elk Lake, this problem can become self-perpetuating, resulting in

- More oxygen depletion in the cool, deep levels, reducing fish habitat and the growth of lake-bottom organisms that are food sources for fish, and aiding the release of chemicals, particularly phosphorus, that would otherwise remain locked in bottom sediments;
- Increasing frequency of algae blooms, which are dominated by toxic cyanobacteria that are poisonous to humans and their pets;
- Accelerated growth of lake weeds, which impede swimmers, rowers, boaters and anglers, as well as adding to the already high levels of detrimental substances like phosphorus and organic carbon.

The key water quality indicator is phosphorus, most of which is released from bottom sediments in the summer through a process called internal loading. The magnitude of internal loading has doubled over the last 25 years and the concentration of phosphorous appears to have increased by a similar amount.

If the lake is to continue to be used in the same way as it has been, some drastic actions will be needed to maintain or improve its present condition. A restoration strategy will require assessment of the best approaches to be taken. The most promising appears to be aeration and /or some type of sediment treatment, accompanied by large-scale removal of aquatic plants.

It is essential that all government and non-government agencies and anyone else interested in the preservation and protection of Elk Lake work together in a collaborative manner. Progress in addressing the situation in the two decades between 1993 and 2013 has been disappointingly slow, but progress in the past two years has been very encouraging.

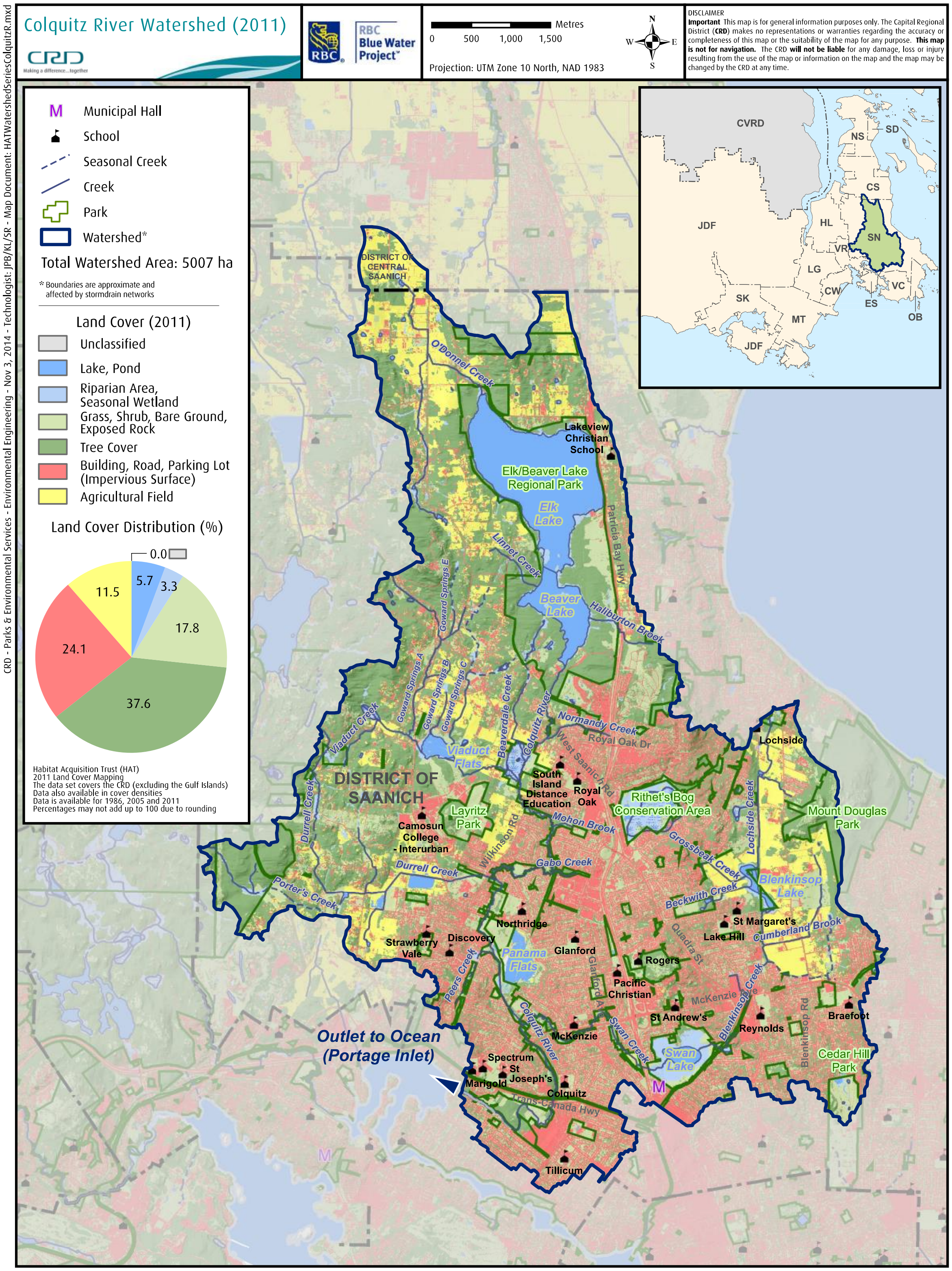
2. Background

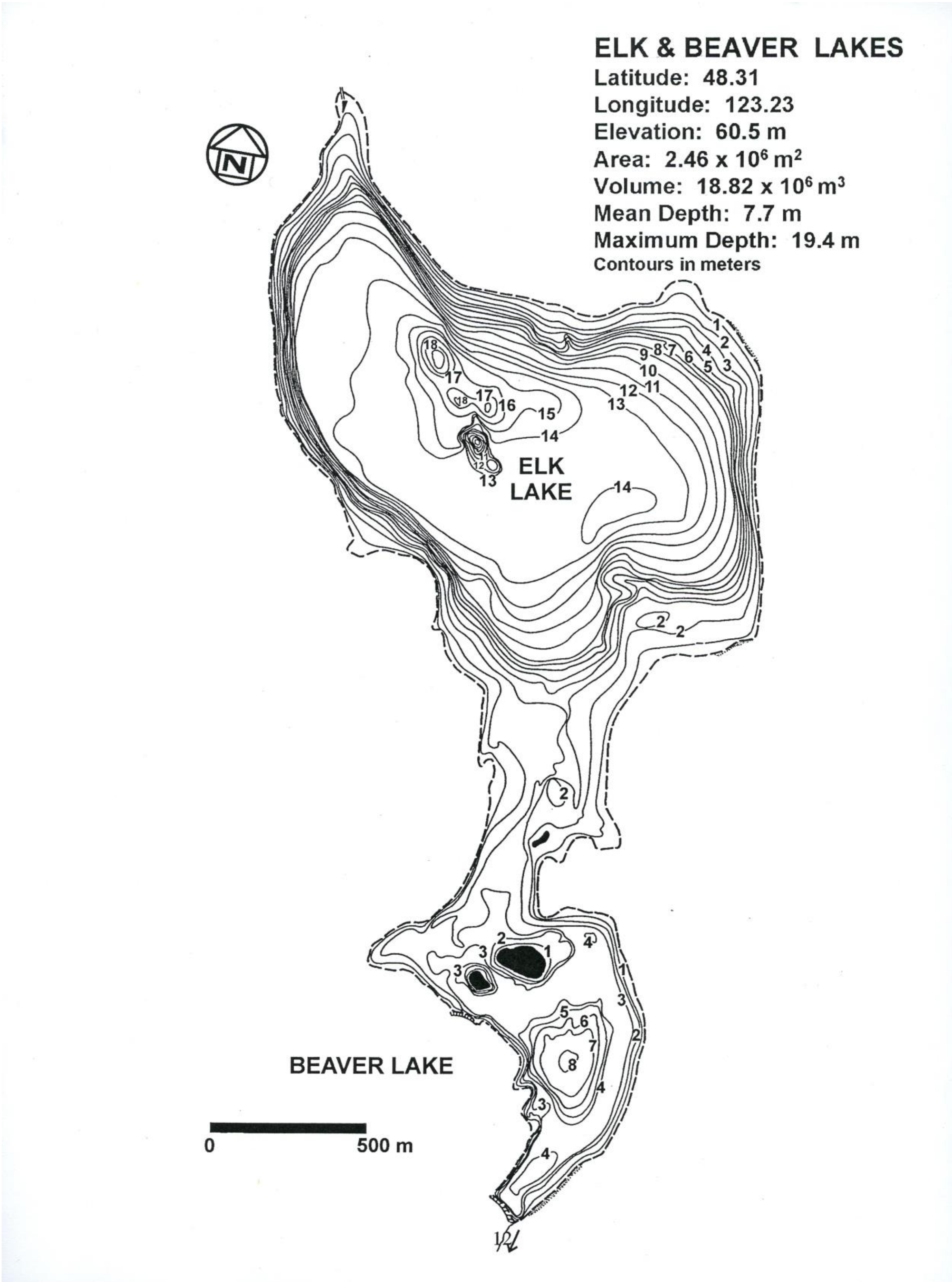
Elk Lake was chosen as the drinking water supply for the city of Victoria in the 1870s and used for that purpose until 1915 (Tolman 2015). A dam was constructed at the outlet of Beaver Lake to provide water storage and control of flow. The dam height was 16 feet. It increased the level of Beaver Lake and Elk Lake by five meters (see the photo of the dam on page 17 of Tolman's 2015 book) and changed the water body dramatically. The area now known as Beaver Lake, before the dam, was described as a swamp rather than a lake. Presently the morphometry is a single lake of two basins separated by a narrow channel. The term Elk Lake is used in this report refers to the two basins – which are often written as Elk/Beaver or Elk-Beaver. For the sake of simplicity, the term Elk Lake is used here but includes "Beaver Bay" as it is not really a separate lake. Elk Lake is at the upper portion of the important Colquitz Creek watershed and so the water quality of Elk Lake is important for this important salmon stream. A map of the Colquitz watershed with the land uses in the watershed is provided below (Thanks to CRD and Dale Green). A full sized pdf file of the map is included in the accompanying data CD. The lake area is estimated to be 2.24 km^2 and the relatively small watershed 8.59 km^2, and the shoreline length is 10.57 km.

Shown also below is a bathymetric map of the lake. The sampling site for Elk Lake is at the deepest point (18 m) of the lake and represents the conditions of the open water of the lake. The site is at 48.53265467 -123.40476751 or 48º 31' 57.557" N 123º 24' 17.163" W. The data collected during this study and previously by the Ministry of Environment is stored on their EMS database under site 1100844. The Beaver Bay sampling site is at the deepest depth in that part of the lake (8m) and is stored under EMS site E207470. The shallow depth of Beaver Bay means that it does not thermally stratify the same way as the main part of the lake but does have a notable oxygen deficit in the deeper waters because of the high carbon load from aquatic plant production, poor mixing due to the plants, and the poor exposure to wind action by the shoreline vegetation. Because of the water depth, the Beaver Bay area is dominated by aquatic plants and by the autumn, most of the surface area has visible heavy aquatic plant cover.

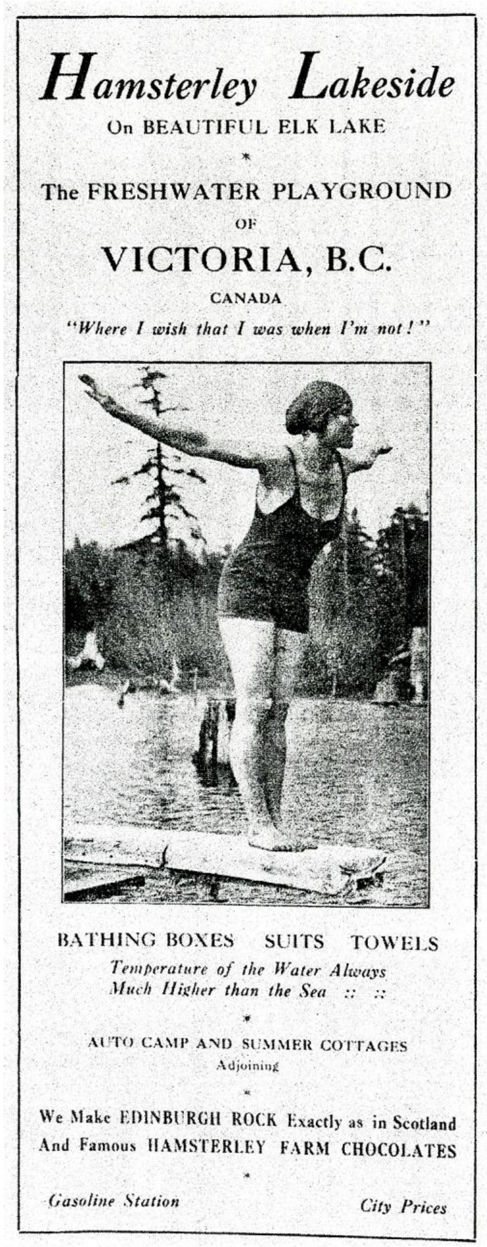
A bibliography of reports and relevant websites related to Elk Lake has been compiled by Usipiuk (2014). Many other reports and material have pieces of information that are potentially usefully including several University of Victoria graduate student theses (Nowlin 2003, Davies 2004, Matthews 2005).

CRD - Parks & Environmental Services - Environmental Engineering - Nov 3, 2014 - Technologist: JPB/KL/SR - Map Document: HATWatershedSeriesColquitzR.mxd





Bathymetric map from Spafard et al 2002



Elk Lake has been a key recreational resource for Victoria and the Capital Region for many decades. From the 1920s through the 1940s the lake was the focus of resort and water based recreation. The brochure at left is likely from the 1930s (from Pearson 1981). Elk / Beaver Lake as a Capital Regional Park was established in 1966.

A water quality monitoring program was carried out in 2014-2015 to provide an updated status of the water quality of Elk Lake. Because of perceived deterioration of both water quality and recreational fisheries, the sampling was designed to provide insight to what might be done to prevent further deterioration and possibly to improve water quality and fisheries. The emphasis of this report is on the water quality measurements and a re-assessment of what is known about the phosphorus loading to the lake that is seen as the key to the lakes human use.

Efforts are underway to identify processes to protect and potentially improve lake water quality for the many users of Elk and Beaver lakes – estimated at more than one and a half million visitors per year. The lake is an important and valuable asset to the Greater Victoria area. It receives heavy use for water based recreation (swimming, boating), recreational angling, and is a base for local, university and national rowing teams as well as being an aesthetic appeal and focus of a very popular park use – especially the 10 km running / walking trail around the lake.

The 12 month period that was sampled (February 2014 to February 2015), turns out not to have been a "normal" year in terms of climate - which often seems to happen when designing environmental monitoring programs. Rainfall was much lower than average and temperatures higher. The low precipitation generally results in lower runoff and lower nutrient inputs.

Key parameters measured were nutrients (several fractions of phosphorus and nitrogen), more than 20 metals, several fractions of carbon, major anions and cations and measures of mineral content (conductivity, total dissolved solids), colour and turbidity. Field measurements included temperature and dissolved oxygen profiles and Secchi (water clarity). Biological samples were taken for phytoplankton and zooplankton and benthic invertebrate numbers and identification.

Observations by the public suggest that water quality in Elk and Beaver Lakes has become unacceptable for many users. In recent years blooms of potentially toxic cyanobacteria have become increasingly frequent. Aquatic weeds have become increasing dense and problematic for rowers (Elk Lake is the location of the Rowing Canada training center) and potentially dangerous for swimmers. Elk Lake is the most heavily used lake on Vancouver Island by recreational fishermen who have complained that the fishing success and the quality of the fishing experience have declined in recent years.

A number of factors are likely responsible for these changes in the lake. The primary focus is on increased nutrient input into the lake – which directly results in the algal blooms and aquatic plant growth. Nutrients, particularly phosphorus, originate from residential, storm water runoff and agricultural activity in the watershed as well as from the accumulated nutrients in the lake bottom sediments. Introduced species (several species of fish as well as bullfrogs and other species) may also have a role in the changes in water quality and fishery success in the lake. Climate change may also be playing a significant role in the observed deterioration of water quality.

3.0 Introduction

In response to what is seen as deterioration in water quality and a declining quality of fisheries production, in 2013, Victoria Golden Rods and Reels (GRR) took the initiative to apply for a grant from the Habitat Conservation Trust Fund to provide a preliminary evaluation of Elk Lake in response to concerns about apparent changes in recent years. GRR approached and received support from several other groups and agencies for this initiative including BC Ministry of Environment (MoE), the Victoria City Rowing Club, the Capital Regional District and the District of Saanich.

The BC MoE designed a water quality sampling program in a partnership with GRR to be carried out from spring 2014 to spring 2015, which will be used to establish an updated baseline for water quality. The cost for the analytical services (water chemistry) was $18,500 and covered by the BC Ministry of Environment with a contribution of $2,000 from GRR. CRD also contributed analytical services with a value of $3,600.

The last detailed evaluation of Elk Lake water quality was done in 1992 in a report by the BC Ministry of Environment written by Colin McKean. That report provided an excellent summary of pertinent information. At that time he noted:

“Recent observations by the public suggest that water quality in Elk and Beaver Lakes has deteriorated. Aquatic weeds such as coontail (*Ceratophyllum*), native water lilies and pondweeds (*Elodea*) are a problem in many near shore areas and are mechanically removed. Dense blooms of microscopic free floating algae cause excessive turbidity in the water and surface films that are aesthetically displeasing to recreational users. It is anticipated that increasing residential, agricultural and commercial development in the watershed will affect water quality. In response to these observations, the Capital Regional District and the Ministry of Environment undertook an extensive water quality monitoring program in 1988 to assess the water quality of Elk and Beaver lakes.”

The McKean report generated a set of water quality objectives to provide a quantitative basis to evaluate water quality. The Ministry monitored Elk Lake for several years in the 1990s and reported the results in a series of reports called Attainment Reports. Water quality attainment sampling was also done in 2007 to be used in the production of an attainment monitoring report; this report was never finalized.

The Attainment Report for the 1995 data (published in 1997), noted that the results for the monitoring, when compared to the lake water quality objectives, showed that the water quality was poor and since there was no restoration or remediation plans or expectation that the situation would become better, it was recommended that the regular monitoring program be curtailed.

The parameters measured during this period are essentially the same as those that are being monitored in the 2014 program: temperature, dissolved oxygen, chlorophyll a, water clarity and phytoplankton community structure. The summary table from the 1995 MoE attainment report is attached as an appendix at the end of this report. The quantitative objectives for water quality included:

- Hypolimnetic (deep water) temperature (objective <15ºC),
- Dissolved oxygen in the hypolimnion (>5 mg/L one m above the bottom),
- Chlorophyll a (a summer mean between 1.5 and 2.5 mg/L),
- Secchi (no reading less than 1.5 m) and
- Phytoplankton (less than 50% of algae being cyanobacteria – blue-green algae).

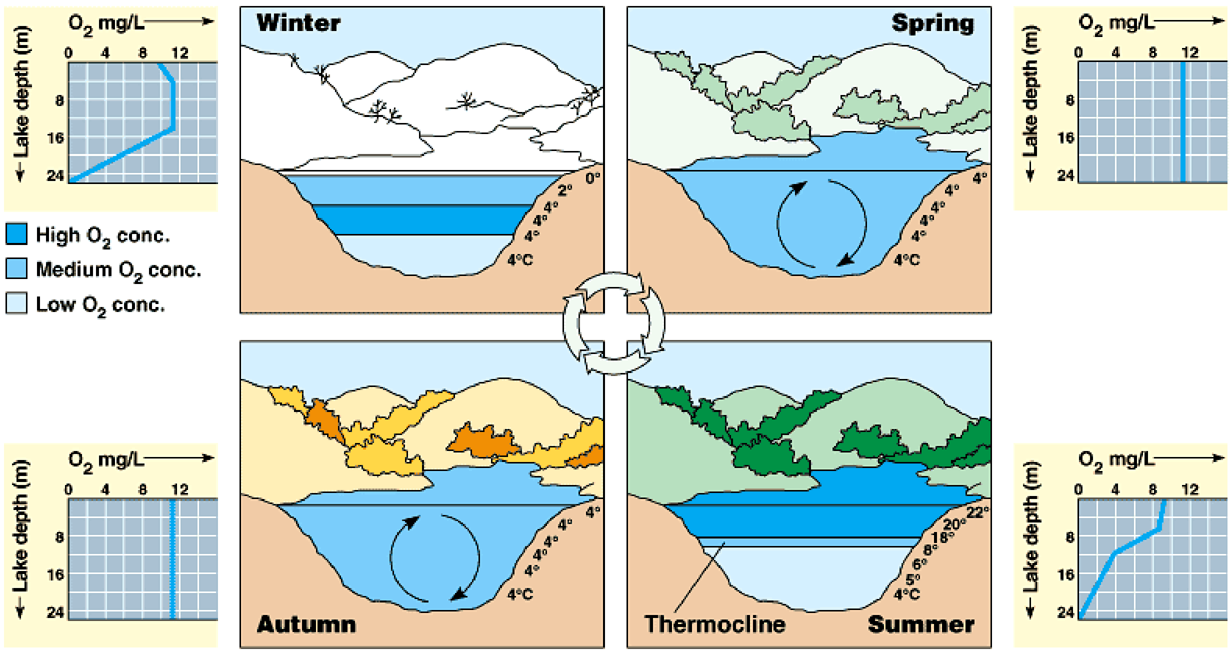
These objectives need to be revised (and are planned for the near future) but when tested in the past were mostly not met and similar results would be expected at the present time.

A preliminary overview of Elk Lake water quality was done by Nordin (2014) summarizing the Ministry's water chemistry database (Environmental Management System, EMS) for Elk Lake and providing some historical context for the lake water quality.

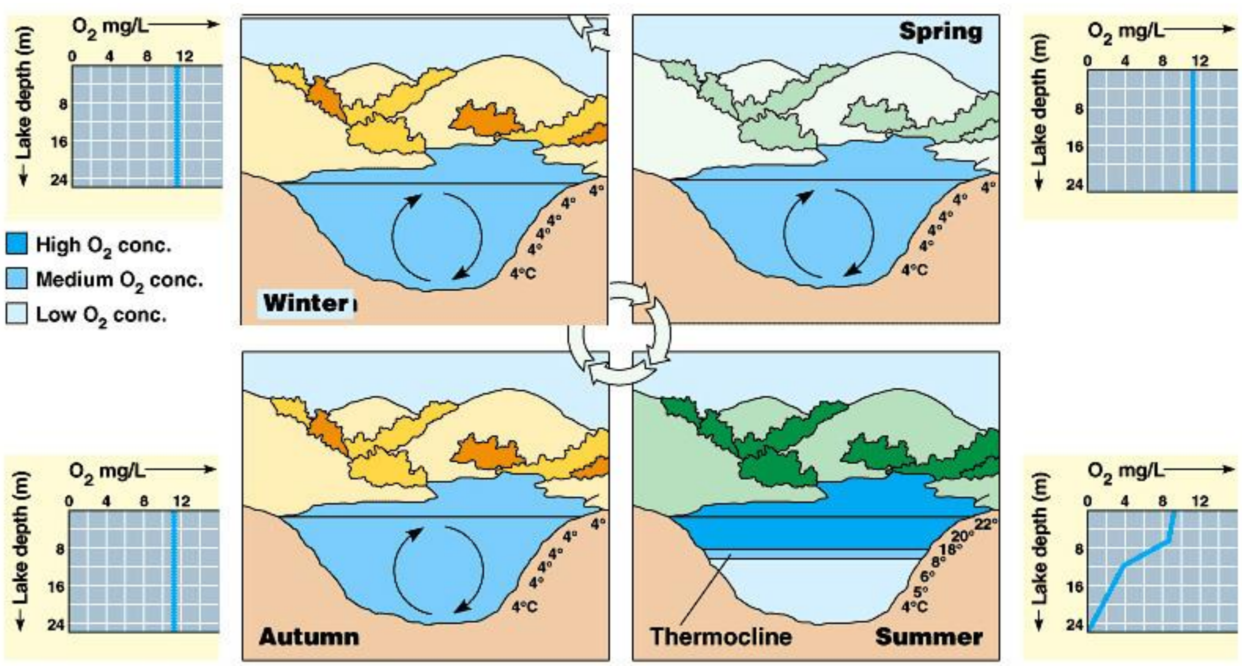
4. Technical Context

Lakes show a variety of annual temperature patterns based on their location and depth. Most BC interior lakes form layers (thermally stratify), during the summer with the cold water layer at the bottom (the hypolimnion) and a warm layer floating on top (the epilimnion). Because colder water is denser, it resists mixing into the warmer upper layer for much of the summer. In spring and fall, these lakes usually mix from top to bottom (overturn) as wind energy overcomes the reduced temperature and density differences between surface and bottom waters.

In the winter in colder areas of BC, lakes re-stratify under ice with the densest water (4 °C) near the bottom. These lakes are called dimictic lakes because they turn over twice per year. They are the most common type of lake in British Columbia and Canada in general. A descriptive drawing of the annual cycle of temperature stratification in **dimictic** lakes (lakes that have ice cover) is shown below.



Coastal lakes in BC (like Elk Lake) are different than the lakes described above. Coastal lakes stratify during the summer but are mixed from top to bottom typically from the end of October to the beginning of March. These coastal lakes stratify once during the annual cycle are termed **monomictic** lakes because they turn over only once per year. These lakes have water temperatures that do not fall below 4°C. A diagram of the seasonal changes for a monomictic lake is shown below.



Elk Lake as a coastal lake differs from most lakes in British Columbia in some very important aspects (Nordin et al 2004). As noted above, most interior lakes freeze in winter and therefore have a very different temperature stratification pattern than coastal lakes that are ice free and well mixed during the winter. Coastal lakes are often very biologically productive through the winter whereas ice covered lakes show little productivity. Elk Lake in 2011 through 2015 has had cyanobacterial (blue-green algae) blooms in January and February. Low elevation lakes on southern Vancouver Island and the Gulf islands (for example St Mary Lake, Prospect, Langford, Swan, Florence, Glen, Quennell), produce high amounts of algae and aquatic plants because they are in areas with rich soils and receive nutrients from sources like agriculture, septic tanks, storm runoff and soil disturbance. The timing of the main input of nutrients is important – in the autumn when the winter rains begin and the "first flush" of nutrients is moved from the watershed to the lake as the streams begin to flow.

Coastal lakes are distinctive in their **hydrology**. They receive most of their water inputs from October through March from winter rains and have very minimal inflows from April through September. Interior lakes are fed largely by spring snowmelt that occurs in May through August. Along with the water inputs, nutrients (nitrogen and phosphorus) are supplied with the higher flows so loadings in coastal lakes occur in winter as the nutrients are flushed off the watersheds (these nutrients then combine with nutrients released from internal loading processes) can trigger winter algal blooms.

Defining a watershed's size and characteristics is very important – especially land use. A **watershed** is defined as the entire area of land that moves the water it receives into a common water body. The term watershed is misused when describing only the land immediately around a water body or the water body itself. The true definition represents a much larger area than most people normally consider. Elk Lake has a very small watershed in proportion to the lake. McKean (1992) indicated that the watershed size was "approximately 8 km^2" (800 ha, 8 x 10^6 m^2) (present estimates are 8.6 km^2) however it is not clear if this included the lake area itself. The basic measurements of watershed and watershed boundaries need to be clearly defined. The lake area is 2.24 km^2 so the area that supplies water to the lake is small – about four times the area of the lake – which in comparison to many lakes is very small. One of the consequences of this is that the "flushing rate" (water exchange time or filling time) is quite long in relative terms at 4.4 years on average but much longer in dry years (McKean 1992). In general lakes that have longer water exchange times tend to be much more vulnerable to water quality deterioration. A clear definition of the watershed boundaries of Elk Lake is a key piece of information needed for managing the watershed. One area of concern is climate change that which might reduce the amount of rainfall and thus make water exchange times even longer.

Watersheds are where much of the hydrologic cycle occurs and play a crucial role in the purification of water. Although no "new" water is ever made, it is continuously recycled as it moves through watersheds and other hydrologic compartments (groundwater, evaporation). The quality of the water resource is largely determined by a watershed's capacity to buffer impacts and absorb pollution.

Every component of a watershed (vegetation, soil, wildlife, etc.) has an important function in maintaining good water quality and a healthy aquatic environment. It is a common misconception that detrimental land use practices will not impact water quality if they are kept away from the area immediately surrounding a water body. Poor land use practices in a watershed can eventually impact the water quality of the downstream lake environment. The major inflow to the lake, supplying a significant proportion of the water (and some nutrients) to the lake is O'Donnel Creek which was the subject of a major restoration effort about 20 years ago by the Golden Rods and Reels Society.

Elk Lake is located north of the Victoria metropolitan area in the District of Saanich, and is a very high value community resource for recreation (swimming, boating, rowing), fishing and general sightseeing and enjoyment. A 10 km walking / running path around the lake is heavily used. In 1992 it was estimated that the lake received 250,000 recreational visits and hosted 11,000 angler days (McKean 1992). In 2011 the Vancouver Island Lakes Questionnaire estimated 15,774 angler days (Kehler 2014 draft) making it the lake receiving the most fishing effort on Vancouver Island. CRD estimates that Elk Lake Park receives 1.5 million visits per year at present (2014).

4.1 What's Going on Inside Elk Lake?

Water column temperature readings serve as an important ecological indicator. The vertical temperature profile and the thermal stratification depth and strength determine much of the seasonal oxygen, phosphorus, and algal conditions. A typical annual cycle in Elk Lake:

- Winter period (November to February or early March): the lake is completely mixed top to bottom by the wind and is typically 4-6 degrees.
- March: the lake begins to thermally stratify with the surface temperatures increasing and the lake developing into thermally distinct layers – 7-8 degrees at the surface and 4-5 degrees in the deep waters.
- April: a thermocline (a zone of rapidly changing temperature, normally defined as greater than one degree per meter) has developed and the lake has become separated into a warm surface layer and a deep cold layer with the center of the thermocline is about 4 meters.
- June: the surface water has warmed to 12-15 degrees, the thermocline is centered at about 6 meters, and there is a cold layer below at 6-7 degrees.
- August: surface waters are 23-25°, the thermocline at 8 m and the deep water is 7-8°.
- October: the lake surface has cooled to 10-12° and the thermocline is at 10 m. With autumn cooling, the lake is cooled to the temperature of the deeper water and usually by November the lake mixes (overturns) and cools and mixes through December and January.

The consequence of the thermal stratification in the summer is that no oxygen can be supplied to the deeper waters and what little oxygen that is there is consumed by decomposition and respiration by bacteria, fungi, invertebrates and fish. The loss of oxygen in the deeper water has consequence for fish habitat (fish cannot use the deeper cooler waters) and for chemical processes (often, low oxygen facilitates the release of nitrogen and phosphorus from the rich bottom sediments).

The data from McKean (1992) for dissolved oxygen in 1988, indicated that by the beginning of June there is less than 1 μg/L (one microgram per liter, or one part per million) in the bottom waters and the depth below 9 meters is without significant oxygen until the lake mixes in October or early November. Having no oxygen in a large portion of the volume of the lake from June to October is very significant for fish and invertebrate production and is likely greatly constraining fish production. The low dissolved oxygen is also a major factor in the process of internal loading (the release of phosphorus from lake bottom sediments).

Data collected by the Ministry 1993 to 1995 and included in Groenevelt (2002) showed a similar pattern of low oxygen in the deeper water in summer. It is difficult to discern if any changes or trends are apparent between 1988 and 1995.

There are several other reports that have water quality data for Elk Lake which was collected in the 1970s and 1980s (Vuori 1971, Crane and Salmond 1971, Oliver 1972 (Beaver Lake) and Handley 1974, Holms 1996, Regnier 1998) and topic areas such as inflow stream flows and groundwater (Kohut 1980, Kenny 2004) that provide very valuable information – some of which is reviewed in this report.

4.2 Trophic Status

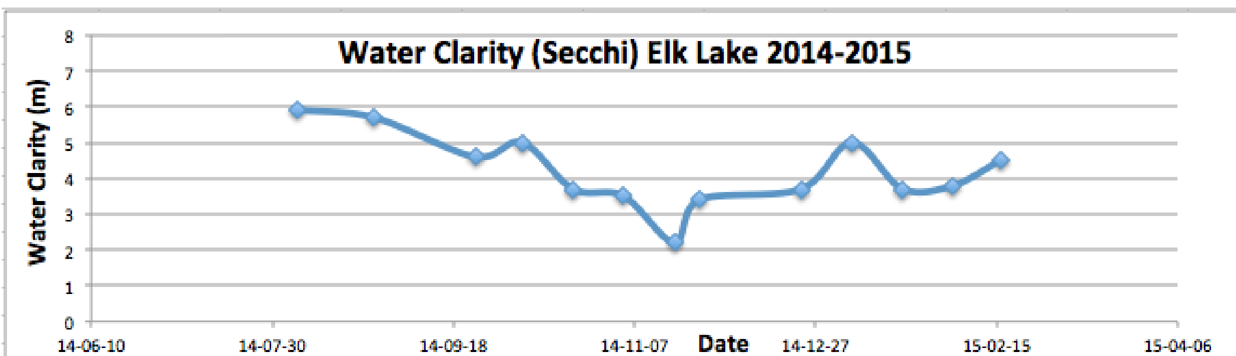
The term *trophic status* is used to describe a lake's level of biological productivity and depends on the amount of nutrients available for plant growth, including the tiny floating algae called phytoplankton. Algae are important to the overall ecology of the lake as they are the base of the food chain and because they are food for zooplankton, which in turn are food for other organisms, including fish. Lakes are generally categorized into three groups: oligotrophic (low productivity), mesotrophic (moderate productivity) and eutrophic (high productivity – undesirable for most human uses). In most lakes, phosphorus is the nutrient in shortest supply and thus acts to limit the production of aquatic life and is generally the key to the lakes biological productivity (trophic status). Many small lakes gradually become more eutrophic over time as lakes fill in and accumulate more nutrients – a process called eutrophication. Phosphorus inputs to a lake can be greatly influenced by human activities. When in excess, phosphorus accelerates plant growth and may artificially age a lake (termed cultural eutrophication – caused by human activities).

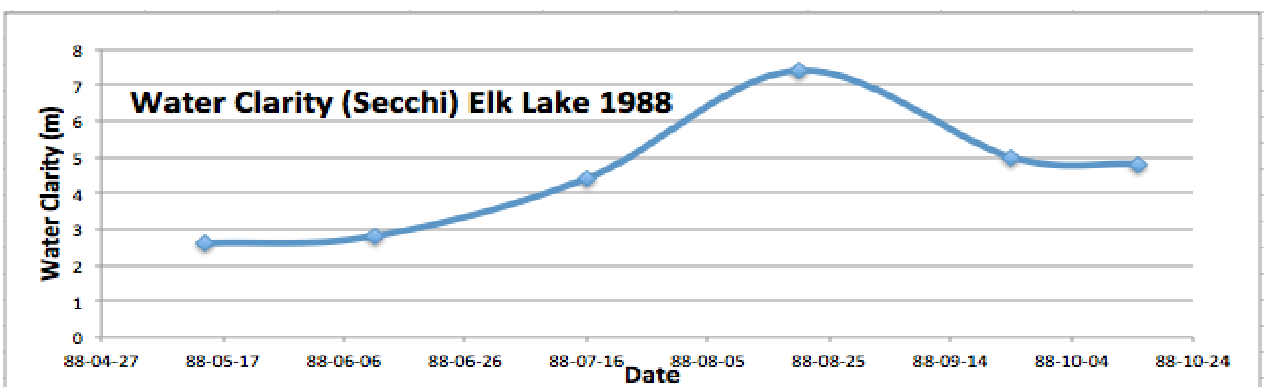
There are three measurements generally used to assess trophic state (biological productivity): **water clarity** (Secchi disc depth), **chlorophyll a** (algal pigments) and **phosphorus** concentration (assuming phosphorus is the limiting nutrient – which it clearly is in Elk Lake). In most freshwater aquatic ecosystems, generally one nutrient – usually phosphorus, is the element that controls biological production by being present in the lowest relative quantity for algae and bacteria. In some cases, nitrogen can be the limiting major nutrient. The ratio of nitrogen to phosphorus is used as an indicator of relative limitation and in the case of Elk Lake, it is phosphorus that the most important nutrient and determines trophic status.

4.2.1 Water clarity is measured using a Secchi disc, a 20 cm black and white disc that measures the depth of light penetration. The more productive a lake, the higher the algal growth and, therefore, the less clear the water becomes. Natural variation and trends in

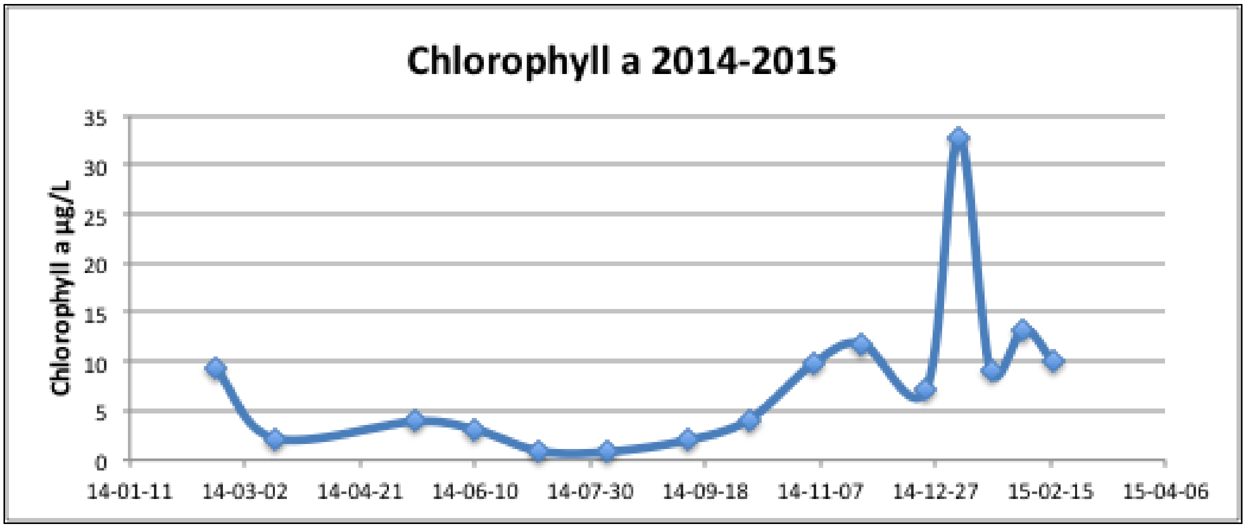
Secchi depth and temperature not only occur between years, but also throughout one season. In general, as temperatures increase during the summer months, Secchi depth decreases. As the temperature of the lake increases, so do the growth rates of some species of algae. Due to the increase in algae, the water clarity decreases. McKean (1992) reported Secchi data for 1988 (see below) and recommended a water quality objective for Secchi not less than 1.9 m. The seasonal average from the McKean Table 4 in the graph below is 4.5 m for 1988 and the average clarity for 2014-15 was 4.2 m with the measurements shown in the figure below. Note that the periods over which the measurements were taken are not the same. Based on these data, there was some decrease in water clarity between 1988 (4.5 m) and 2014 (4.2) but it is not a large difference. Historical data are included in Crane and Salmond (1971) – they recorded an average Secchi of 6 m in the October to December time period so not directly comparable but much better water clarity than recent data. The water quality objective set by McKean was for a minimum of 1.9 meters and this was met in 1988 and 2014 but that may be a result of setting a very conservative water quality objective and that may need to be re-examined?

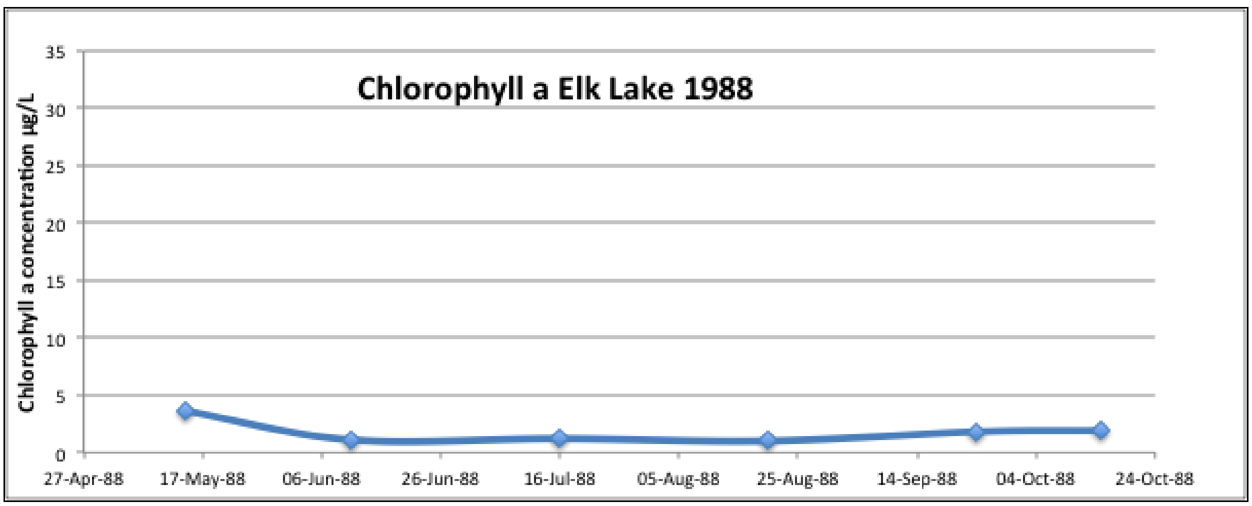
As a basis of comparison, annual average Secchi depths for Prospect Lake (a moderately productive lake similar to Elk Lake) is 4.2 m for 2000-2011 (BCLSS 2012), for Langford Lake 3.7 m for 1983-2004 (BCLSS 2005) and for Cowichan Lake (a larger oligotrophic (unproductive) lake) the average Secchi was 11.2 m for 2008-2011 for the South Arm (BCLSS 2014).





4.2.2 Chlorophyll is the second indicator of trophic status. Chlorophyll a concentrations are the result of extracting the chlorophyll pigment from algae in a water sample. The units that the concentrations are reported in are µg/L (micrograms per liter). McKean reported some data for 1988 (his Table 7 is reproduced below) and indicated the average Chlorophyll a was 1.7 µg/L for Elk Lake. For 2014, in contrast, the average for 2014-15 was 8 µg/L – but biased by an extraordinarily high value in January 2015 of 32.8 µg/L. If that value is excluded, the average is still a very high 6.2 µg/L. The difference between these two data sets is quite striking – much higher chlorophyll in 2014 than 1988.





It may also be useful to define some terms at this point. **Concentrations** of water chemistry measurements are either in **µg/L** (micrograms per litre, or parts per billion) or as **mg/L** (milligrams per litre, or parts per million). Nutients and chlorophyll are typically reported in µg/L, oxygen and many metals and general ions are reported as mg/L. **Mass** is a term used to describe weight in kilograms or tonnes. Mass divided by water volume provides concentration. **Loading** is a term that describes the mass of a substance supplied over some defined time period – usually per year or per day – so typically kg/yr (kilograms per year).

4.2.3 Phosphorus. The third trophic indicator for lakes is **phosphorus**. Phosphorus is THE key element that controls the water quality in the lake – its importance must be emphasized and much effort in the past and in the present is focused on quantifying phosphorus concentrations and phosphorus sources. A key measurement is phosphorus taken in early spring while the lake is mixed and this spring overturn concentration can be used as a baseline indicator of what the biological productivity in the summer might be, as it is a reasonable representation of the summer nutrient supply. Phosphorus is typically reported in µg/L (micrograms / liter). McKean reported Total Phosphorus (TP) spring overturn data for the period 1980 to 1990 and the mean for that period is 20 µg/L (parts per billion).

On the Ministry of Environment EMS database, there are only data from 1986 to present and the data show a trend of increasing concentration over time. The mean spring phosphorus concentration for 1986-2014 is 23 µg/L and a significant change from the 1980s data presented by McKean. At spring overturn for the last three years (2013, 2014 and 2015) has been 35, 33 and 44 µg/L. There can be variation from year to year depending on weather conditions – particularly temperature and rainfall. Years with high rainfall tend to result in higher nutrients being supplied to the lake but winter 2014-15 was very dry and the high spring phosphorus is probably more influenced by the 2014 internal loading than the precipitation pattern.

It is clear from the spring overturn data that there has been a significant increase in phosphorus. There are other ways of evaluating the changes in P – looking at deep water P concentrations in summer and changes in P mass in the lake. Both of these are discussed below. No water quality objective was set for phosphorus. In light of its importance, it should be used as a routine metric for lake health and an objective to be set in the future.

Summary for trophic status indicators. The water clarity average (>4 m) is reasonably good (in the mesotrophic range) in comparison to the two other indicators but there is evidence for deterioration over time. Both chlorophyll and phosphorus have increased in the most recent sampling and are indicative of eutrophic conditions and recent deterioration.

4.3 Elk Lake Temperature stratification and Dissolved Oxygen

4.3.1 Temperature Profiles

Tabulated below are the temperature data for the 2014-2015 sampling period. The table is divided into two parts: February to August 2014 and August 2014 to February 2015. The yellow highlights note when the lake was completely mixed top to bottom as seen by the similar temperatures: 17 February 2014 and 30 January 2015. The red highlights show the depths at which there is a significant change in temperature (the thermocline) where temperature changes more that 1 degree per meter.

The thermocline begins to be established in late April or early May and is well established by late May, isolating the deep water below 5 meters from any mixing with the surface water and any further supply of oxygen to the deep water until mid November when the lake again becomes mixed and oxygen re-supplied to the deep waters. The thermal stratification – with the warm surface water (**epilimnion**) separated from the deeper cold (denser) water (**hypolimnion**) results in a rapid depletion of oxygen in the deeper waters.

Winter lake average water temperatures in 2014 were about 4˚. In winter 2015 with much milder winter air temperatures, the lake surface temperatures were noticeably higher (5.7˚). The maximum surface water temperature was 24˚ in August. Deep water (hypolimnion) temperatures were 7 to 8 degrees when stratification was first established and warmed to 9˚ by November. The relatively high hypolimnion temperatures have implications for the rate of oxygen depletion in the lake and other processes like internal phosphorus loading that is discussed in more detail below.

Elk Lake temperature profiles (in degrees celsius) February to August 2014

Date Depth	17 Feb	15 Apr	29 Apr	13 May	27 May	10 Jun	25 Jun	8 July	23 July	6 Aug
0.5m	3.9	11.6	13.3	17.0	19.1	20.8	21.1	23.1	22.5	24.0
1 m	3.9	11.5	13.2	17.0	19	20.8	21.0	23.1	22.5	24.1
2	3.9	11.5	12.8	17.0	18.9	20.7	21.0	23.0	22.4	24.0
3	3.9	11.5	12.7	16.9	18.7	20.7	21.0	22.7	22.4	24.0
4	3.9	11.5	12.6	15.5	18.6	20.7	19.5	22.1	22.4	24.0
5	3.9	11.5	12.1	15.0	17.5	18.5	19.0	21.2	21.4	22.7
6	3.8	11.5	11.7	13.2	13.8	13.8	13.2	16.6	16.2	19.4
7	3.8	11.4	10.9	10.9	11.3	11.3	11.8	13.2	12.9	15.3
8	3.8	11.3	8.8	9.9	9.6	10.2	9.7	11.1	10.5	12.1
9	3.8	11.2	8.2	8.7	8.8	9.2	9.0	9.7	9.5	10.8
10	3.8	11.1	7.6	7.9	7.8	8.6	9.0	8.9	8.6	8.9
11	3.8	11	7.2	7.1	7.5	7.8	8.3	8.5	8.2	8.1
12	3.8	10.2	7.1	7.1	7.4	7.6	7.9	8.2	8.0	8.0
13	3.8	9.7	7.1	7.1	7.4	7.5	7.8	7.8	7.9	7.9
14	3.8	9	7.0	6.9	7.4	7.4	7.7	7.7	7.9	7.9
15	3.8	8.7	7.0	6.8	7.3	7.4	7.7	7.7	7.8	7.9
16	3.8	8.2	7.0		7.3	7.4	7.6		7.8	7.8
17	3.8	7.5	6.9		7.3	7.4	7.6		7.8	7.8

Elk Lake temperature profile (in degrees celsius) August 2014 to February 2015

	27 Aug	24 Sep	7 Oct	21 Oct	4 Nov	18 Nov	25 Nov	23 Dec	6 Jan 2015	20 Jan	3 Feb	15 Feb
0.5	23.5	19.4	18.1	16.9	13.6	9.4	8.9	7.0	5.7	5.7	6.4	7.6
1 m	23.5	19.4	18.1	16.1	13.5	9.4	8.9	7.0	5.6	5.7	6.4	7.6
2	23.5	19.4	17.3	16.1	13.4	9.3	8.9	7.0	5.5	5.7	6.3	7.5
3	23.4	19.4	17.7	16.1	13.3	9.2	8.9	7.0	5.5	5.7	6.3	7.3
4	23.1	19.4	17.7	16.1	13.3	9.1	8.9	7.0	5.4	5.7	6.2	7.1
5	22.9	19.4	17.6	16.1	13.3	9.1	8.9	7.0	5.4	5.7	6.2	6.8
6	22.1	19.3	17.6	16.1	13.3	9.1	8.9	7.0	5.4	5.7	6.2	6.7
7	17.7	17.1	17.5	16.1	13.3	9.1	8.9	7.0	5.4	5.7	6.2	6.4
8	13.8	14.7	17.2	15.8	13.3	9.1	8.9	7.0	5.4	5.7	6.2	6.3
9	11.4	12.5	14.4	15.5	13.3	9.1	8.9	7.0	5.4	5.7	6.2	6.2
10	9.7	9.4	11.3	15.5	13.1	9.1	8.9	7.0	5.4	5.7	6.2	6.2
11	8.7	8.6	9.4	12.0	11.9	9.1	8.9	7.0	5.3	5.7	6.1	6.0
12	8.2	8.4	8.8	9.7	9.6	9.1	8.9	7.0	5.3	5.7	5.8	5.9
13	8.1	8.4	8.6	9.0	9.1	9.1	8.9	7.0	5.3	5.7	5.7	5.9
14	8.0	8.3	8.5	8.7	8.9	9.0	8.9	7.0	5.3	5.7	5.7	5.9
15	8.0	8.3	8.0	8.6	8.9	9.0	8.9	7.0	5.3	5.7	5.7	5.9
16	8.0	8.3	8.4	8.6	8.9	9.0	8.9	7.0	5.3	5.7	5.7	5.9
17	8.0	8.3	6.9				8.9	7.0		5.7	5.7	5.9

4.3.2 Dissolved Oxygen. The 2014-2015 oxygen data, like the temperature data, are divided into two tables, February to August 2014 and August 2014 to February 2015. The yellow highlights indicate when the concentrations are similar top to bottom and are indicative of the lake being mixed top to bottom (17 Feb 2014 and 20 Jan 2015) as was also indicated by the temperature data. The blue highlighted data emphasize when the dissolved oxygen (DO) fell below 1 mg/L – a threshold of significance for biological and chemical processes and considering the accuracy of measuring equipment, an indicator of anoxia (lack of oxygen) for most purposes. The hypolimnion of the lake was anoxic from late May to mid November when the lake was destratified. This long period of anoxia is very serious.

Elk Lake dissolved oxygen profiles February to August 2014

	17 Feb	15 Apr	29 Apr	13 May	27 May	10 Jun	25 Jun	8 July	23 July	6 Aug
0.5	11.0	10.7	11.6	11.8	10.9	6.9	8.7	8.4	7.6	7.7
1 m	10.8	10.7	11.6	11.9	10.4	6.9	8.4	8.5	7.6	6.5
2	10.8	10.5	11.7	12.0	10.1	7.3	8.5	8.5	7.4	4.4
3	10.8	10.5	11.7	12.0	9.9	6.9	8.5	8.6	7.4	2.1
4	10.8	10.7	11.7	11.8	9.7	6.8	8.3	8.7	7.5	3.7
5	10.4	10.7	11.5	11.8	10	6.9	8.1	8.5	7.0	3.2
6	10.4	10.7	11.4	10.9	10.4	7.1	7	7.4	6.8	4.4
7	10.1	10.7	11.2	9.2	8.3	5	5.3	5.8	3.7	2.5
8	10.8	10.6	10.6	8.6	7.3	2.4	2.7	3.5	1.3	1.8
9	11.0	10.6	10.3	7.8	7	2	1.9	1.8	0.7	0
10	11.0	10.4	9.3	7.5	5.2	1.9	1.8	0.9	0.5	0
11	10.9	10.7	8.5	7.5	3.3	0.6	0.8	0.7	0.5	0
12	11.0	10.7	6.3	5.9	3	0	0.5	0.6	0.4	0
13	11.0	10.6	6.0	4.9	2.8	0	0.5	0.6	0.4	0
14	10.9	10.4	5.8	4.9	2.6	0	0.5	0.6	0.4	0
15	10.6	10.3	5.0	3.7	2.4	0	0.5	0.6	0.4	0
16		10.0	4.7		2.2	0	0.5		0.4	0
17		9.3	3.7		2	0	0.4		0.4	0

Elk Lake dissolved oxygen profiles August 2014 to February 2015

	27 Aug	24 Sep	7 Oct	21 Oct	4 Nov	18 Nov	25 Nov	23 Dec	6 Jan 2015	20 Jan	3 Feb	16 Feb
0.5	7.4	7.0	9.3	8.8	9.5	8.7	9.1	10.4	11.8	11.2	12.3	13.0
1 m	7.5	7.1	9.2	8.7	9.4	8.7	9.1	10.4	11.6	11.2	12.4	13.1
2	7.5	7.3	9.2	8.7	9.4	8.7	9.0	10.4	11.6	11.1	12.4	12.8
3	7.4	7.3	9.1	8.6	9.2	8.6	8.9	10.4	11.5	11.1	12.4	12.7
4	7.4	7.4	8.9	8.6	9.1	8.4	8.9	10.4	11.5	11.1	12.4	12.7
5	7.4	7.4	8.8	9.3	9.0	8.6	8.8	10.4	11.5	11.1	12.4	12.1
6	7.0	7.2	8.6	8.7	8.9	8.5	8.8	10.3	11.4	11.1	12.4	12.0
7	5.2	4.5	8.2	8.7	8.9	8.5	8.8	10.4	11.4	11.1	12.4	11.0
8	5.7	1.52	7.2	8.5	8.8	8.5	8.8	10.3	11.4	11.1	12.4	11.2
9	0.8	0.7	2.1	7.4	8.0	8.6	8.8	10.3	11.4	11.1	12.4	10.5
10	0.7	0.6	1.2	6.8	1.9	8.4	8.8	10.3	11.3	11.0	12.4	11.0
11	0.4	0.5	1.0	3.8	0.9	8.6	8.8	10.3	11.3	11.0	11.9	9.3
12	0.4	0.4	0.7	1.6	0.9	8.4	8.8	10.3	11.3	11.0	10.9	8.7
13	0.3	0.4	0.6	1.3	0.7	8.3	8.7	10.3	11.2	11.0	10.4	8.7
14	0.3	0.4	0.6	1.1	0.6	7.8	8.1	10.3	11.2	11.0	10.2	8.7
15	0.3	0.4	0.5	0.9	0.6	6.5	8.0	10.3	10.9	10.8	9.9	8.2
16	0.3	0.4	0.4			2.3	7.7	10.3	10.4	10.8	9.5	8.1
17	0.3	0.4	0.4			0.8	6.9	10.2	9.8	10.5	9.2	8.0

There appears to be a trend of an increase in the amount of oxygen consumed in the hypolimnion over time. The DO data provided in McKean shows a slower loss of DO than the present data and the 1971 data of Crane and Salmond shows 3 mg/L of oxygen at 11 meters on October 12. In 2014, the DO at 11 meters was less than 1 mg/L by June 10 – five months earlier than the 1971 data. It seems clear that the oxygen depletion rates have increased significantly over time. The consequences are increased internal loading, reduced benthic productivity and loss of fish habitat since a large portion of the lake volume being unavailable to fish.

The Elk Lake water quality objective for dissolved oxygen is for 5 mg/L to be maintained one meter above the bottom through the summer. This objective was not even close to being met in 1988 in any of the Ministry Attainment reports (1993, 1994, 1995 and 2002 – Ministry of Environment 1994, 1996 1998, Phippen 2003) and is certainly not met in 2014.

An important application of the dissolved oxygen data is to calculate the rate of oxygen depletion in the hypolimnion which is an indicator of the rate of decomposition occuring in the deep waters of the lake. The data also have a practical application in estimating the oxygen supply needed to keep the hypolimnion aerobic if some form of aeration is considered as a restorative measure. The interval used for this estimate was the 14 day period between the samplings on 27 May and 10 June. After 10 June there was essentially no oxygen in the lake below 10 meters until the lake was mixed in November. The mass of oxygen below 7 meters (the bottom of the thermocline) on 13 May was calculated to be 3780 kg and on 10 June 1348 kg, a difference of 2432 kg between 13 May and 10 June or a loss of 174 kg oxygen per day during that period. This is a very signiificant amount of oxygen consumption. This is relevant to to potential considerations of aeration as it would represent the minimum amount of oxygen that would need to be supplied to the hypolimnion of the lake to maintain some oxygen at depth.

Summary for dissolved oxgen and temperature data. The temperature data show that the lake is becoming thermally stratified for a longer portion of the year which has implications for both chemical and biological processes. Surface water temperatures may also be increasing. Dissolved oxygen depletion appears to be increasing significantly with little oxygen in the bottom waters of the lake for as much as nine months of the year.

4.4 Water chemistry results 2014-2015

The paragraphs below provide some interpretation of the analytical results obtained. They are summarized in accompanying tables.

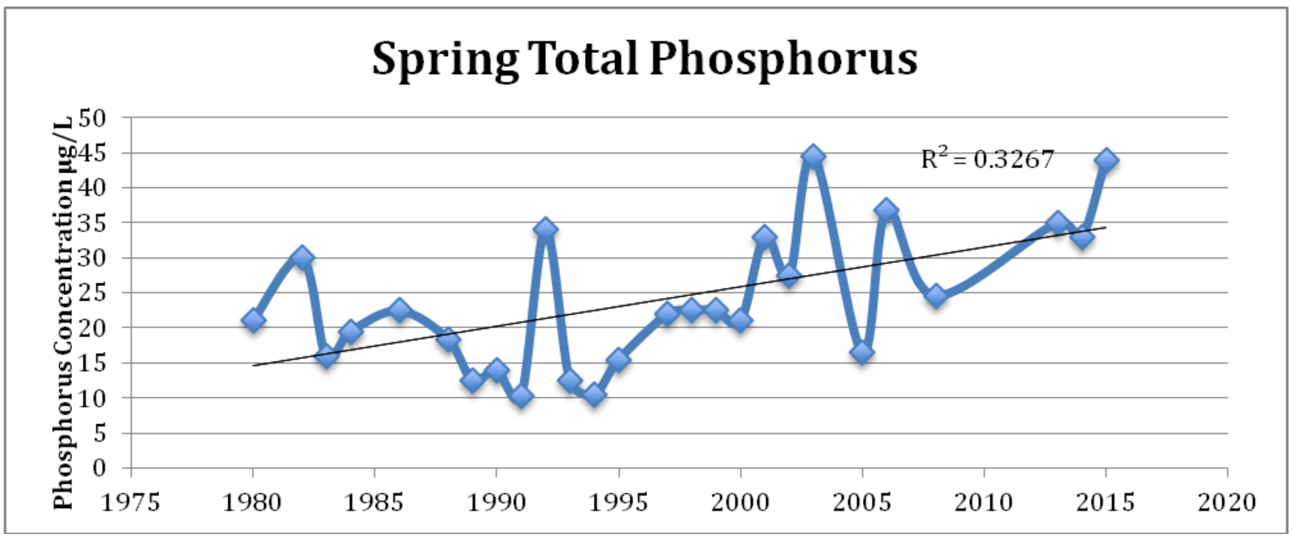
4.4.1 Phosphorus

Phosphorus is identified as a key water quality parameter in Elk Lake. The input and concentration of phosphorus is directly related to the productivity of the lake and the amount of algae in the water, the density of aquatic plants and the fish productivity. So phosphorus from the watershed (and recycling from lake sediments – see discussion below) affects the recreational use and fishing success of the lake.

The present undesireable conditions in the lake (frequent algal blooms, heavy aquatic plant growth) are a consequence of an increasing supply of phosphorus to the lake (phosphorus loading). Phosphorus concentration in the spring provides a measurement of the relative supply to the lake over the summer and measurements of phosphorus through the year provide information about the dynamics and sources of phosphorus. The spring phosphorus concentration is often used as an indicator of lake health. The Ministry of Environment has provided guidelines for water quality for nutrients (Nordin 1985) and suggest that spring phosphorus concentrations between 5-15 µg/L for lakes with important salmonid (cold water) recreational fisheries and concentrations of less than 10 µg/L phosphorus for lakes serving as drinking water supplies (to minimize algal density and water treatment costs) and for recreation (phosphorus concentration is directly related to water clarity which is key to water based recreation).

Spring overturn (when the lake water is mixed and more or less homogeneous from surface to bottom) is used as a important time to document phosphorus. The phosphorus concentration in February 2014 was 33 µg/L (average of three depths) and in February 2015, the lake water appears to have begun stratification with a concentration of 8 µg/L at the surface, 28 µg/L at 10 m and 72 µg/L at 17 m, so it is difficult to estimate an average. If the data for two weeks prior is used (20 January) when the lake appears to be more well mixed and the three samples were reasonably consistent, the average water column concentration is 44 ug/L. For 2015, and perhaps as a general trend, the lake stratification appears to begin earlier in the year which has implications for nutrients and fisheries.

The data for spring phosphorus over the period 1980-2015 is shown below. There appears to be a general trend of increasing concentration over this period. A linear regression line has been fitted. Year to year variation is expected but for this 36 year period, the spring phosphorus concentration seems to be increasing. For spring 2015, the spring TP is as high as has ever been recorded (44 µg/L, similar to2003). It should be noted that the MoE water quality guideline upper limit for a lake with cold water (trout) fisheries is 15 µg/L.



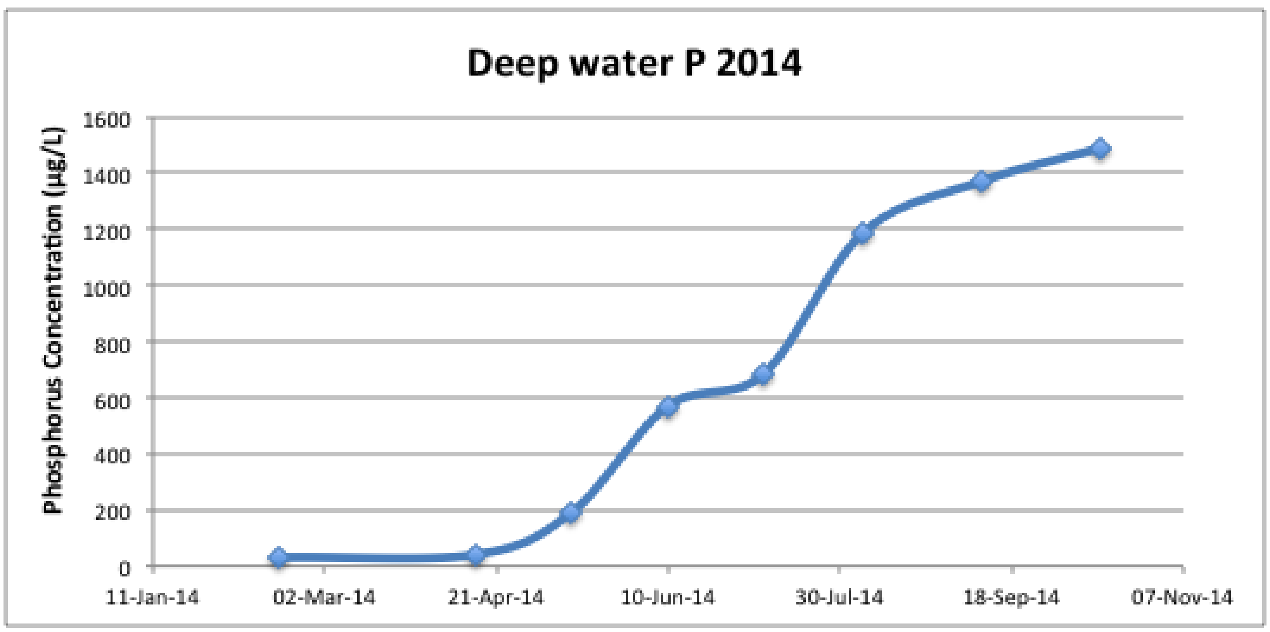
Data from from February to December 2014 for Total Phosphorus (in µg/L) are below.

	17 Feb	15 Apr	13 May	10 June	8 July	6 Aug	10 Sep	07 Oct	4 Nov	25 Nov	23 Dec
surface	29.6	10.4	11.1	16.1	9	9.2	8.2	11.4	21.9	45.6	32.5
10 m	36.5	40.8	54.7	47.0	136	462	256	104	24.1	46.9	
Deep (15-18 m)	32.2	47.7	192	570	710	1190	1370	1490	1450	70.8	29.9

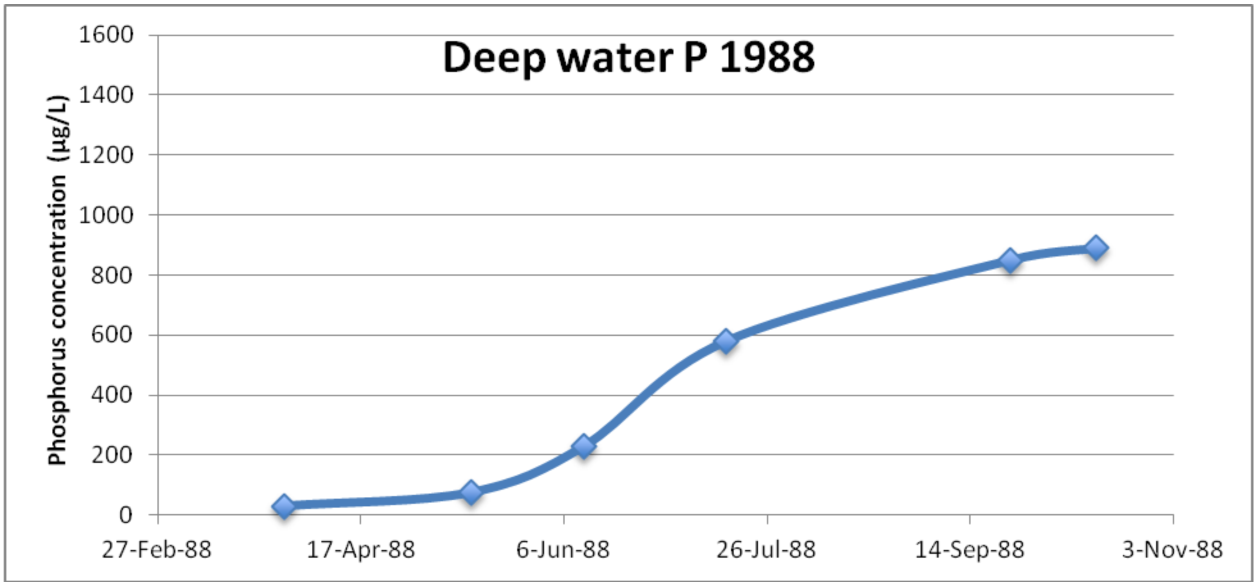
The concentrations for January and February 2015 are tabled below.

	6 Jan	20 Jan	3 Feb	16 Feb
surface	45.3	39	17.9	8.4
10 m	41.1	41	21.4	27.6
Deep (15-18 m)	40.7	52	38.2	72.4

The concentration of phosphorus in the deep water has also been used as an indicator of lake health and particularly the potential internal loading of phosphorus. A graph of deep water Total Phosphorus concentration for 2014 is shown in the graph below.



In comparison to previous data from previous years, the deep water concentrations are very high (1500 µg/L). In 1980, Nordin noted some concern that the deep waters increased from 20 µg/L in June to 50 µg/L in October and that by 3 November 1980 total P at 12 meters was 393 µg/L. In 1988 McKean reported the deepwater phosphorus increased from 30 at spring overturn to 890 µg/L in the deep water in mid October. His graph (his Figure 9) of deep water phosphorus is recreated below with the same y-axis scale in µg/L. It appears that deep water concentrations have increased significantly over the intervening period. The internal loading is the most significant source of phosphorus to the lake.

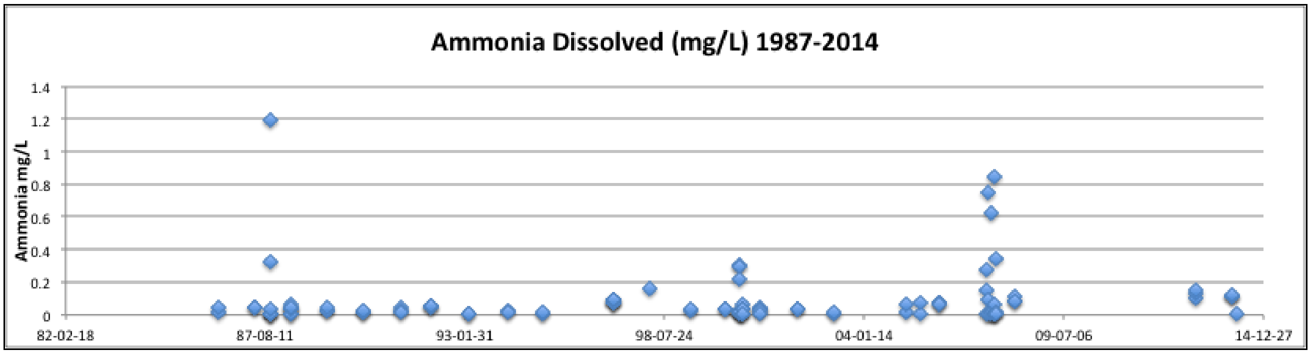


Co-incidently with these increases in deep water phosphorus are increases in deep water iron and manganese. These simultaneous increases are typical when the mechanism for phosphorus release is related to phosphorus binding by iron. The mechanism was first described by Mortimer (1941) and has been discussed by many limnologists since that time (see the textbooks of Wetzel (2001) and Kalff (2002) for much more detailed discussion). A simplistic explanation is that in lake water with high oxygen concentrations, phosphorus becomes bound to oxidized iron compounds and is deposited to the sediment from the water column and deposited in the lake bottom sediments. In lakes which have hypolimnetic oxygen through the summer (most oligotrophic lakes), phosphorus is permanently bound in the lake sediments to these oxydized iron compounds. However in lakes which have a high hypolimetic oxygen demand (from decomposition of organic materials) and oxygen concentrations are very low, the oxydized iron (which is very insoluble) is transformed to the reduced form of iron (which is very soluble) , and which has a low binding capacity to phosphorus and the phosphorus is released from the sediment back into the water column. The common term for this process is “internal loading”.

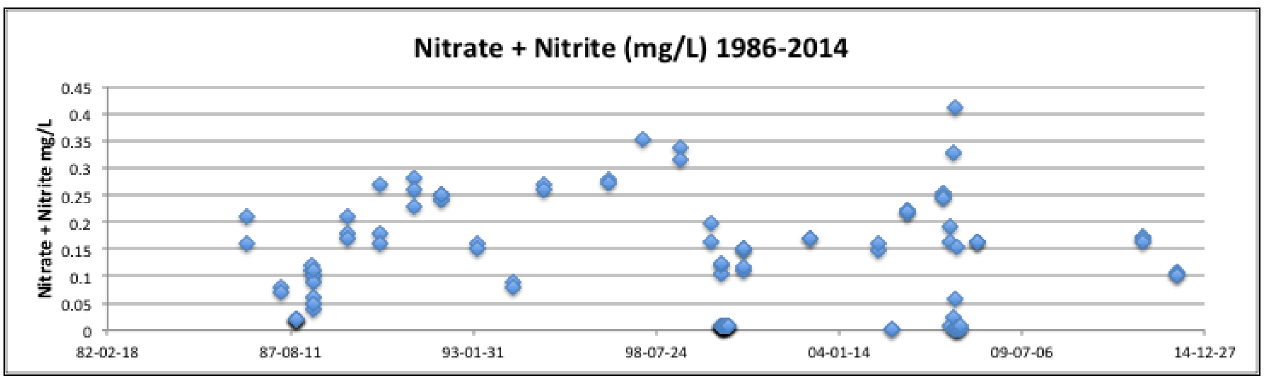
Internal loading of phosphorus was described by McKean (1982) as the major source of phosphorus loading to the lake water. See the discussion of lake phosphorus budgets below.

4.4.2 Nitrogen

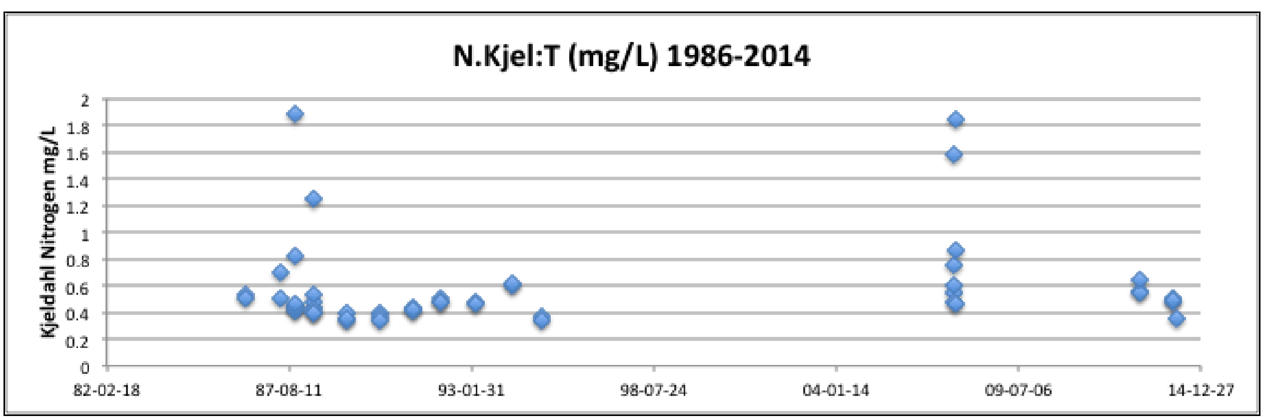
Several different forms of nitrogen are typically measured. **Ammonia** is the reduced organic form. The only time it was sampled was spring overturn 2014 (17 February) and concentrations were relatively high but consistent: 110-120 ug/L and February 2015 when the surface samples were very low (27 µg/L), 10 m was 156 and 16 m 254 – a notable gradient from surface to the bottom – presumably a result of decomposition at or near the bottom sediments which is another indication of severe oxygen depletion. A graph of the historical data up to 2014 is shown below (note the y-axis scale is in mg/L).



Nitrate-Nitrite is the oxydized inorganic form and was also relatively high. The only new samples were from February 2014 and February 2015. The 2014 samples averaged 104 µg/L and the 2015 samples 166 µg/L. Previous data up to 2014 is shown below (y-axis is in mg/L)

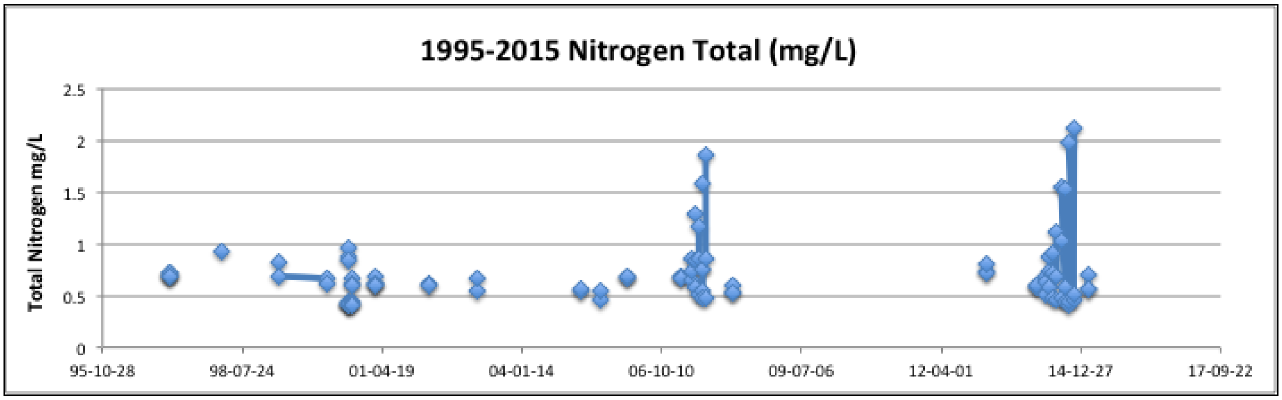


Kjeldahl nitrogen is a measurement that includes both organic N and ammonia. Again only two sets of samples were taken at spring overturn and the results reflect the results for organic N and ammonia and are within the range of previous results.



Organic nitrogen also has only the two sample sets from February 2014 and 2015. Data are summarized in the summary table below.

The most detailed 2014 data are for total nitrogen. The spring sampling gave results of 593µg/L (average of three sample depths). Deep water samples (typically 16 m) over the summer gradually increase, by July 8 to 1110 µg/L, by 6 August to 1550 µg/L, and by November to 2120 ug/L (2.12 mg/L). The spring 2015 samples showed concentrations more or less homogenous in the water column averaging 608 µg/L – similar to the previous spring and similar to concentrations measured in the past 20 years.



Summary Table for Nitrogen concentrations 2014-2015.

	ammonia	nitrate+nitrite	Kjeldahl N	Organic N	Total N
Average µg/L	112	104	449	337	840
maximum	264	193	562	393	2120
minimum	27	101	369	238	437
Number of samples	8	6	8	7	28

Nitrogen to Phosphorus ratios are used as a diagnostic of relative limitation for algal growth between these two major nurients. For 2014 at spring overturn the ratio (by weight) of TN:TP was 593:33 or 18:1 and 2015 overturn 608:44 or about 14:1, both indicating that phosphorus is the more limiting nutrient. Typical N:P metabolic demand by plants is about 7:1 by weight. Elk Lake biological productivity is related directly to phosphorus input and concentration.

Nitrogen is also very important as an indicator of watershed disturbance – particularly land use and sewage disposal – although the latter may not be as important in the Elk lake watershed. Nitrogen compounds tend to be more mobile through soils than phosphorus (which seem to be trapped efficiently in southern Vancouver Island soils) and are more efficiently transported from the watershed to streams and lakes and through groundwater than is Phosphorus. Changing lake water N:P ratios over time can also be used as a measure of environmental change. Nitrogen (the organic nitrogen and ammonia fractions) can also play a role in oxygen depletion as they are broken down or oxidized in the nitrogen cycle – and the deep water deoxygenation of the lake is a major factor in the internal loading of P.

Low N:P ratios – ratios approaching the 7:1 average balance, are often indicators that nitrogen may be at some times limiting for some algal species. This is especially important for many cyanobacteria species since, if they become limited by nitrogen, they can use nitrogen gas in the water as a source of nitrogen – capturing it to be used in their metabolic processes. The ability of "fix" atmospheric nitrogen gives the species that are capable of doing this – and this includes two of the dominant species in Elk Lake (*Aphanizomenon* and *Anabaena*) a considerable advantage over all other algal species and allows them to become dominant. Both species are potential toxin producers.

4.4.3 Metals

A suite of metals was measured (silver, aluminum, arsenic, boron, barium, beryllium, bismuth, cadmium, cobalt, chromium, copper, iron, lithium, magnesium, manganese, molybdenum, nickel, lead, antimony, selenium, tin, strontium, titanium, uranium, vanadium, zircomim and zinc). Some are indicators of watershed disturbance or of heavy metal contamination. No values showed evidence of these problems. The data are summarized in Appendix Table at the back of the report.

Two metals – iron and manganese – showed concentrations that are indicative of a strongly reducing environment (low oxygen) in the deep water in summer and support the hypothesis that these metals as well as phosphorus are being released from the lake bottom sediments during periods of oxygen depletion. One notably high concentration of dissolved iron (1.03 mg/L) was seen 10 June at the onset of hypolimnetic oxygen depletion. High values of total iron were noted on June 10 at 16 m 1.05 mg/L, 8 July at 14 m (1.43 mg/L), 6 August at 16 m (1.84 mg/L), 10 Sept at 13.5 m (3.49 mg/L), 7 Oct at 14 m(3.97 mg/L), and 4 Nov at 15 m (4.06 mg/L). For comparison, spring overturn concentrations in February 2015 were variable ranging from 0.04 to 0.16 mg/L.

Manganese also showed substantially elevated concentrations similar to iron. The highest concentration of dissolved Mn was in September at 1.05 mg/L dissolved and 1.62 mg/L total. November and December concentrations were nearly as high. Spring overturn samples in February 2015 ranged between 0.03 and 0.13 mg/L.

The high concentrations of iron and manganese are indicators that when conditions in the lake during the period when oxygen in the deep water is very low, is very strongly reducing and this may paly a role in other chemical processes and transformation – especially the sulphur cycle and generation of hydrogen sulphide and the release of phosphorus from sediments. The sediments represent a very large pool of nutrients and metals that can have significant effects on the water quality of the lake.

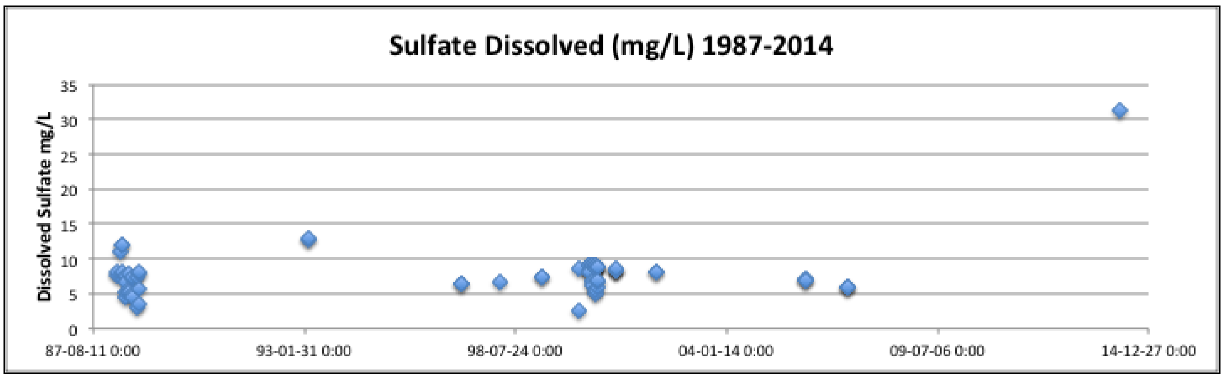
4.4.4 General Ions

There are a number of water quality parameters which can be used as indicators of lake water chemistry changes – especially in the long term.

Alkalinity was measured once during this study. On 25 March 2014, the concentration was 139 µg/L. Calcium was measured six times and the average was 19.8 mg/L (range 19.3-20.4). Hardness was measured six times. The mean concentration was 68.4 (range 66.5-70.6)

Chloride was measured once in the 2014-2015 sampling program at 17 mg/L. Potassium likewise at 2.6 mg/L and sodium at 9.8 mg/L. Sulphate was measured at 31.4 mg/L (which seems to be innacurate since all previous mesurements were mostly in the 5-10 mg/L range)

Sulphate is a key element in the phosphorus cycle and is present in anoxic bottom waters as hydrogen sulphide which is extremely toxic to fish and other organisms. Most values shown are in a similar range except for the notable sample at 16 m depth (close to the bottom) on 27 December 2014.



Total Dissolved Carbon (1 sample) was 42.3 mg/L, Dissolved Inorganic Carbon (carbonate and bicarbonate) (also a single sample) was 36.2 mg/L. Total Organic Carbon was measured three times with a mean of 5.5 mg/L. Dissolved Organic Carbon was measured three times with a mean of 5.2 mg/L. There are not sufficient data to examine trends but organic carbon cycling in the lake – production by algae and decomposition by bacteria and algae are important factors in the oxygen depletion issue in the lake.

Coliform bacteria were not monitored as part of this program although have been an important issue (Times Colonist 1993b). Beach bacteriological sampling is done by Vancouver Island Health Authority during the summer but are not summarized here.

Some of the earliest water chemistry results for the lake were provided by Deborah LeFrank and referenced as Saanich 1968. Analytical methods of the time were not sufficient to measure phosphorus accurately but some basic measurements provide a reference point to how the present water chemistry of the lake has changed. Measures of general ions (total dissolved solids, conductivity, calcium, sulphate, chloride etc) have been used as a measure of watershed change and environment degradation in the Laurentian Great Lakes and a lake on Vancouver Island (Beeton 1965, Nordin et al 2007).

The table below summarizes these early General Ion data from Elk Lake (Saanich 1968).

	17 April 1968	1 August 1968	8 Oct 1968 surface	8 Oct 1968 6m	19 Oct 1968 surface	19 Oct 1968 6m	Present concentration (and % increase)
Total Dissolved Solids (TDS)(mg/L)*	80 /89	73	80	85	64	81	160 (103%)
Conductivity µS/cm	120 /135	100	123	125			195 (62%)
Calcium mg/L	13.7 /14.4	14	16.6	16.5	14.6		20 (33%)
Sulphate mg/L	8.6	6.8			5.9	5.8	8.5 (26%)
Chloride mg/L	8.8	8.9	9.3	9.4		9.0	17 (87%)
Total Nitrogen µg/L	290/230	300	140	150	320		600 (52%)

- Fishery Branch surveys were done May 1971 (Chudyk and Erickson 1971) and in May and October 1973 (Burns and Klein 1973, Klein and Burns 1973) reported TDS in the 115 mg/L range.

These data also reinforce that the lake has undergone considerable deterioration in terms of the input of ions from the watershed – and likely similar inputs of nutrients and other water chemistry constituents.

Summary for water chemistry indicators. The data for 2014-2015 shows a significant increase in nutrients (phosphorus and nitrogen) and in other water quality indicators over the period for which records exist

4.5 Nutrient Loading

One of the important goals of the present project is to provide a phosphorus budget for the lake – to determine what the sources of phosphorus to the lake are in quantified terms as a means of deciding what restoration efforts are appropriate and how resources to restore and protect the lake are to be allocated. In 2014, an updated estimate was planned for two of the sources: the internal loading and the inflow streams – O'Donnel and two smaller streams in the northeast part of the watershed.

The only new data available are the lake water chemistry data – to evaluate the internal loading. Data from the stream inflows is not yet available but will become available at a later date. No new data for evaluating the other potential sources of P (septic tanks, atmospheric loading or birds) were collected.

Key to deciding on a strategy for peventing further deterioration of Elk Lake or for determining a strategy for lake restoration, is making an estimate of what the sources of phosphorus are that are responsible for the algal blooms, aquatic plant growth and oxygen depletion problem. McKean (1992) gave the following as the major sources of phosphorus to the lake:

Internal Loading from Hypolimnion	950 kg/yr	(71%)
Septic tank inflows	246 kg/yr	(18%)
O'Donnel Creek	87 kg/yr	(6.5%)
Atmospheric loading	38 kg/yr	(2.8%)
Ephemeral Creeks	36 kg/yr	(2.7%)
Birds	9 kg/yr	(0.7%)
Total	1336 kg/yr	

Internal loading was estimated by comparing the mass of phosphorus in the lake over the period of the year at times when detailed water chemistry sampling was done (five dates between February 2014 and January 2015. At spring overturn, with the water mixed top to bottom, P mass (the amount of phosphorus in the lake is easily calculated – it is the product of the concentration and the lake volume. When the lake is stratified, the concentration at each depth is matched with the volume of water that the sample represents (for example the sample taken at 0.5 m would represent the volume of water from 0 to 1 m depth, and the concentration of phosphorus taken from 10 m would be multiplied by the volume of water from the 10 to 11 meter depth (97140 m^3) and the P mass for the whole lake calculated as a sum of the mass calculated from individual depths and concentrations. This sum of the masses at each depth provides an estimate of P mass in the lake for that date. The table below shows the P mass at dates where there was sufficient data.

Phosphorus mass in Elk Lake 2014-2015

	17 February	8 July	6 August	7 October	20 January
P Mass (kg)	503	352	1966	2319	763

What the data show is that there was an increase in P mass in the lake water over the summer (characteristic of internal loading) and that amounted to about 2000 kg if the difference between July and October is used (2319 minus 352) and would be more than double the estimated internal loading estimated by McKean (950 kg P). This is the single most important finding from the 2014 sampling program. Some of the increase in P in the water column was precipitated and returned to the sediments after the lake was re-oxygenated with lake destratification in November and lake mixing through December and January. The 2014 data represent a very considerable increase from the McKean data of 1988. It is important to appreciate that the sediments contain very high concentration of phosphorus which is the source of this increase. Rieberger (1992) published data for sediment concentrations of many elements in lake sediments for Elk Lake including phosphorus (926 ug/g essentally 926 parts per million) where, for comparison, the phosphorus in lake water at spring overturn in recent years has been 30-40 μg/L (essentially 0.03-0.04 parts per million) – a factor of 25,000 times difference in phosphorus concentration between the very rich bottom sediments and the water.

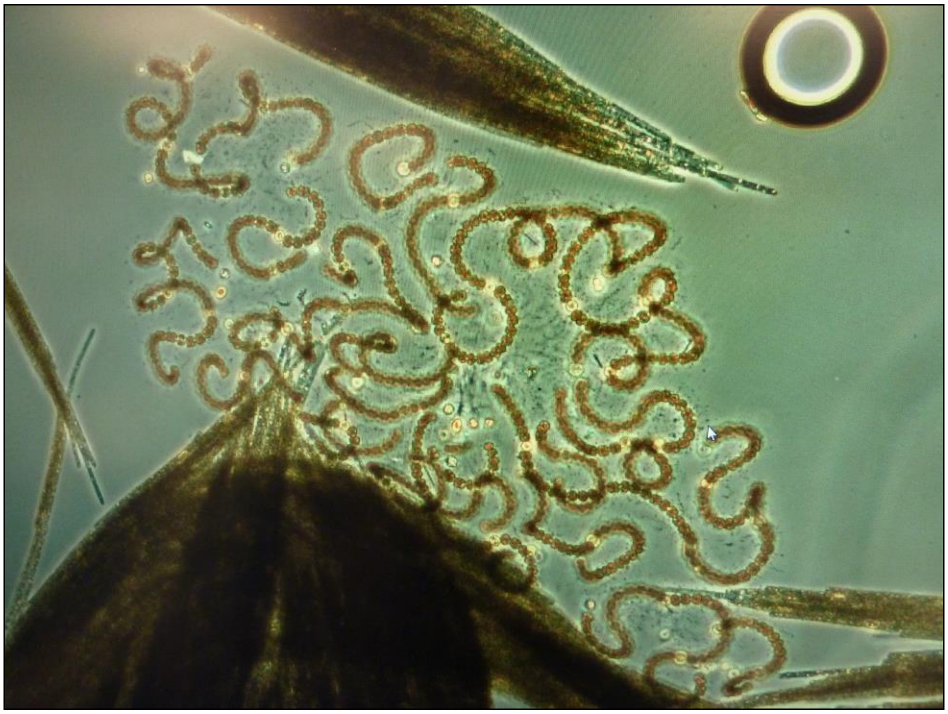
Summary for phosphorus loading. The most dramatic indication that the lake is deteriorating is a significant change in the amount of internal loading phosphorus from the lake sediments. Comparing the 1988 estimate to the 2014 data indicates a doubling in size of the phosphorus from that source.

4.6 Biological Sampling

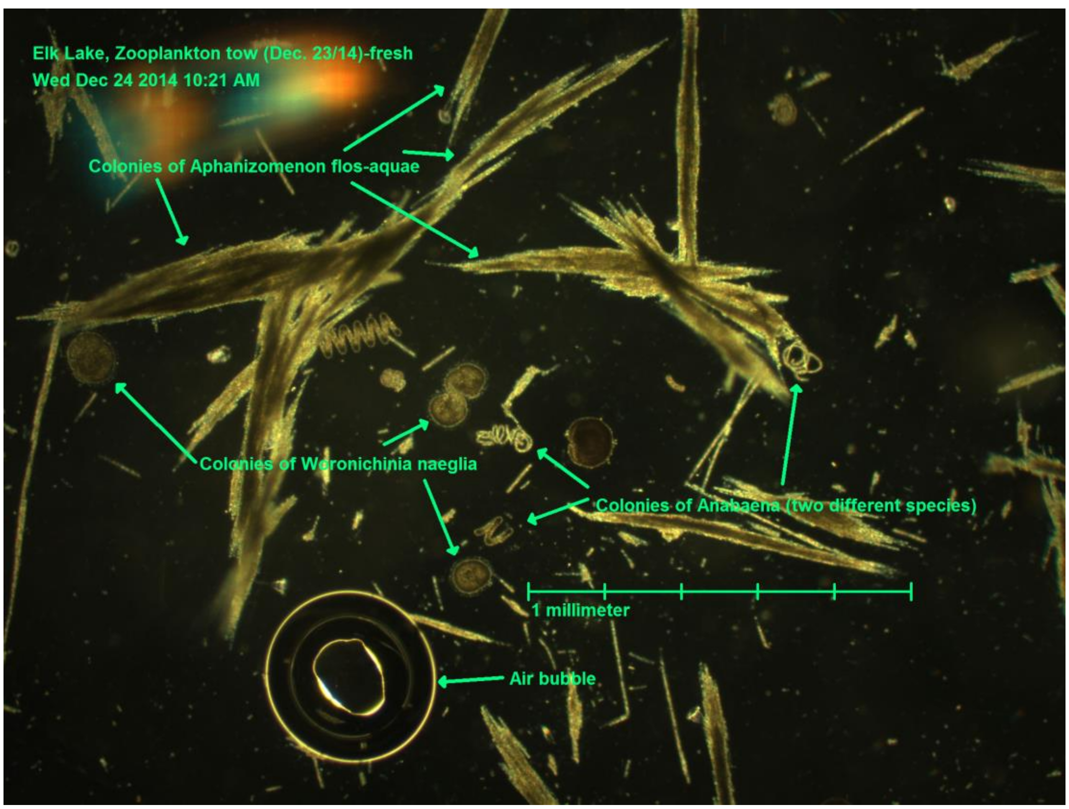
4.6.1 Phytoplankton

Phytoplankton are microscopic algae that float in the lake water and are the base of the food chain and their numbers are directly related to the nutrient (phosphorus in this case) concentration in the lake. The algae that are in the lake water are of interest for a number of reasons. Their numbers are the primary determinant of the water clarity of the lake (measured as Secchi disc depth) which is a characteristic of the lake character that the public is very aware. Green murky water with high amount of phytoplankton is very unattractive for recreational users of the lake. The phytoplankton species present are also important. The relative amounts of cyanobacteria (also called blue-green algae) are indicators of potential toxin production as well as efficiency for the food chain – cyanobacteria are less desireable and less nutrious for the grazing zoplankton which are at the next level in the food chain. Below is a photograph through a microscope of a sample from Elk Lake in December 2013 showing two of the common cyanobacterial species: *Aphanizomenon* and *Anabaena*.

A "bloom" is when the numbers of phytoplankton increase dramatically and visible mats of algae can be seen floating on the surface. Blooms tend to be unpredictable – at least with our present knowledge. Both of the photos below were from "bloom" conditions.



Another photograph (with annotations) from 23 December 2014 is shown below – courtesy of Laura Kline of CRD.



Below is a summary table of the dominant phytoplankton species in the lake and the relative proportion (by number) of the total number of algal cells that cyanobacteria represent in Elk Lake.

What is apparent from the summary is that cyanobacteria are the dominant group for most of the year and in most cases comprise greater than 50 of the numbers. Some of these dominant taxa (*Aphanizomenon, Anabaena*) are potentially toxic an have been documented in many other locations around the world as producing potent neurotoxis and hepatotoxins.

Blooms of cyanobacteria in the winter are a more frequent occurance in recent years (although winter sampling of Elk Lake has not been common). Reports in the media and public awareness as well government (CRD and VIHA) awareness is reflected in posting of warning signs about cyanobacteria are evidence that this is a potentially serious problem for bathers and for dogs. The 2014 New Year Polar Bear Swim was transferred to Thetis Lake (Times Colonist 2013b) as a result of a visible bloom and testing that confirmed that the bloom contained high concentrations of the neurotoxin anatoxin. The same relocation occurred again in January 2015.

The table below summarizes the species, number of cells and relative proportion of cyanobacteria in the 2014-2015 sampling. The cyanobacteria spcies are marked with an asterix (*)

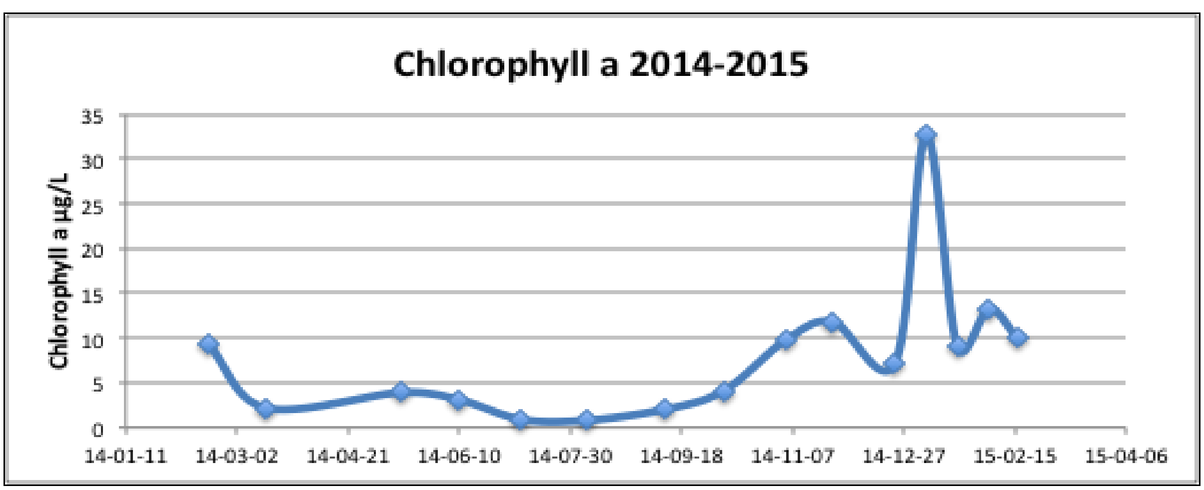
	Dominant taxa cyanobacteria(*)	Total cells /mL	Per cent cyanobacteria
15 Apr 2014	*Ankyra, Anabaena*, Rhodomonas*	7635	94%
13 May 2014	*Anabaena*, Woronichinia*, Rhodomonas*	26724	97%
10 June 2014	*Sphaerocystis, Anabaena**	2686	16%
8 July 2014	*Anabaena*, Dinobryon, Fragilaria*	2408	53%
6 Aug 2014	*Nephriochlamys, Fragilaria, Anabaena**	627	10%

10 Sept 2014	*Dinobryon, Rhodomonas*	686	13%
7 Oct 2014	*Anabaena*, Dinobryon*	1648	74%
4 Nov 2014	*Woronichinia*, Anabaena**	2919	84%
25 Nov 2014	*Anabaena*, Woronichinia*, Selenastrum*	3082	82%
23 Dec 2014	*Aphanizomenon**	2921	86%
6 Jan 2015	*Aphanizomenon**	13023	99%
20 Jan 2015	*Aphanizomenon**	1585	64%
3 Feb 2015	*Aphanizomenon**	7323	73%
16 Feb 2015	*Aphanizomenon**	6850	83%

Note: Some species were initially counted as filaments or colonies. *Anabaena* and *Woronchinia* were counted as 100 cells/ colony, *Aphanizomenon* as 35 cells /filament.

Another measurement that was made in 2014-2015 was chlorophyll a – to obtain a different measure of the amount of phytoplankton in the water. The figure below (also presented in the section 4.2.2 on trophic indicators) shows the changes over the sampling period. In general the chlorophyll concentration follows the same pattern as the numbers of algae in the table above with highest values in the bloom conditions of November 2014 through February 2015.

Chlorophyll a concentrations Elk Lake 2014-2015



4.6.2 Zooplankton

The zooplankton are the microscopic animals that live in the water of the lake are an important component of the food chain of the lake – the step between phytoplankton and fish. Zooplankton numbers and community composition are also useful ecological indicators.

The summary table below shows the relatively low numbers of crustacean zooplankton (copepods and cladocerans). Particularly notable is the the almost complete lack of adult copepods and low numbers of the immature stages. In a productive lake like Elk, the zooplankton numbers would be expected to be much higher. Two reasons for the low numbers might be poor food quality (the phytoplankton being predominantly cyanobacteria) and / or heavy predation by fish. The introduction of perch and sunfish would be a possible reason for low numbers of the largest size zooplankton which tend to be selectively eaten by fish. The other implication of low zooplanton numbers is that low numbers of zooplankton would have less effect on grazing of phytoplankton – thus higher numbers of algae in the water. Numbers in the table below are number of animals per sample (10 m vertical tow with a 150 µm zooplankton net mesh with a 20 cm mouth diameter.

Sample Date	14 Apr 2014	13 May	10 Jun	8 Jul	6 Aug	10 Sep	7 Sep	4 Nov	25 Nov	23 Dec	6 Jan 2015	20 Jan	3 Feb	16 Feb
Cyclopoid copepods														
Calanoid copepods	1*										1	1	1**	
Copepodites	27	26	28	7	14	27	8	10	9	2		2	9	7
Nauplii	72	95	39	9	23	11	11	2	5	4	2	6	12	14
Cladocerans-*Daphnia*	26	20	30	7	13	9	1	4	6	14	17	19	34	7
Cladocerans-*Bosmina*					67			2		1	1	4	4	

*Eurytemora **Senecella

Rotifers were also sampled as part of the zooplankton community. A summary of their numbers is included in a table in the Appendix of the report.

These data are in marked contrast to the data of Crane and Salmond who reported much higher numbers and higher diversity – 18 species of zooplankton were reported with the two dominants being *Daphnia* and *Ceriodaphnia* and significant numbers of Cyclopoid copepods. Neither *Ceriodaphnia* or Cyclopoid copepods were even reported in 2014. These reduced numbers would indicated either that the productivity of these organisms has been greatly reduced or that the grazing pressure on them by small fish is extremely high.

4.6.3 Benthos

The benthos are the community of organisms that live on and in the bottom sediments of the lake. In Elk Lake there are several important groups. Familiar to most are the chironomids - otherwise known as bloodworms or midges of which there are several species.

Also very important in Elk Lake are the chaoborids (commonly called glass worms), and oligochates (aquatic earthworms).

The summary table below lists the numbers found in sampling in 2014-2015. One group counted was ephippia – the resting stages of cladocera – which are deposited on the sediments in large numbers when the cladocera encounter unfavourable conditions and then hatch when conditions (food, oxygen, temperature) becomes more favourable.

The numbers of these benthic organisms seems relatively low in comparison the overall high biological productivity of the lake. The low numbers are likely related to the long period of anoxia that the deep waters of the lake experience. The benthos are a key component of food for fish (and birds) and their low number may be a factor in poor fish productivity. In 1971 Crane and Salmond reported numbers of chironomids of 67 per grab (2881/m2) and Chaoborus at 7 per grab (301 / m2). This was in October through December – a relatively unproductive time of year – and notable higher than the 2014 data.

Benthos summary table. Numbers are individuals per square meter. Samples in May and June were duplicated to document the variation between samples.

	15-Apr-2014	13 May 2014 a	13 May 2014 b	10 June 2014 a	10 June 2014 b	10-Sep-14	10-Oct-2014	11-Jan-2015	03-Feb-2015
Chaoborus	776	474	1724	216	86	1379	172	1422	2715
Chironomids	431	43	86	302	86	259	129	129	302
Oligochaetes	690	603	4698	345	172	1293	2284	172	216
Epphipia	35773	3448	8103	14654	4655	31722	20343	89907	55168

The low numbers of benthic organisms (as with the zooplankton) is a disturbing finding. Low biological numbers in both these communities is a result of either poor growth and reproduction due to deteriorated habitat (a large part of the volume lake has little or no oxygen and no cold water refude)or that the grazing pressure is extemely high. The latter seems more likely, especially after the introduction of Yellow Perch in the recent past.

4.6.4 Aquatic Plants

An important component of the Elk Lake ecosystem is the aquatic plant community. The littoral zone of the lake (depth less than 6 m) comprises a large proportion of the lake - about 45 % of the lake surface area of Elk Lake and about 60% if the Beaver Lake part of the lake is included. Beaver Lake / Bay is virtually all in the littoral zone (less than 6 m). Aquatic plants are likely to colonize lake bottom at least to 6 meters. The Beaver Lake part of the system is completely covered by aquatic plants in late summer. The only detailed plant species survey that has been done was by the Ministry of Environment and 60 species of plants in Elk Lake were identified (see the table in the appendix). The plants come to the lake surface in the summer and interfere with the use of the lake by swimmers and especially rowers. *Ceratophyllum* and *Elodea* are two of the most abundant species and because of their long linear growth form are seen by many as lake users as particular nuisances. The invasive aquatic plant Eurasian Milfoil (*Myriophyllum spicatum*), although present in other lakes on Vancouver Island has not been reported from Elk Lake although two native species of *Myriophyllum* were reported in the Ministry of Environment survey.

Crane and Salmond (1971) looked at aquatic plants and estimated that they covered 66 ha or 37% of the surface area of Elk Lake. They also estimated the biomass of aquatic plants in the lake (dominants being *Ceratophyllum* and *Elodea*) at about 1000 tonnes (wet weight). The latter estimate seems very low in the light of present plant biomass – or the plant density was lower at that time.

The harvesting of aquatic plants was an ongoing operation for many years but has been curtailed in the past two years because the harvester purchased in 1979 is no longer functional as of 2013. Nordin (1981) reported that in 1980, 358 tonnes of aquatic plants had been removed from the lake. A newpaper story in 2003 reported that up to that time 7,000 tonnes of aquatic plants had been removed from the lake over that time (Dutton 2003). Assuming the period referred to was 1979 to 2002 (23 years) the average harvest would be about 300 tonnes per year. A pilot project in 2014 assessed the use of a smaller harvester (Cleverly 2014).

An article in the Dogwood Star from the Saanich Archives mentioned that in 1967 "Certain key areas were also treated for aquatic weed control with good results". No details about what the treatment consisted of but that "Chemical applications controlled the algae problem efficiently and in the opinion of the Health Officer, prevented problems of itch and pollution".

The plants represent a resource for small fish – a refuge from predation so they do serve an essential purpose and a food souce for small invertebrates which also are a key link in the lake's food chain.

However aquatic plants are likely also a mechanism by rooted aquatics for moving phosphorus out of the sediment and into the water column. Plants that draw nutrients from the bottom sediments into the biomass of the plant are cycling nutrients from the sediments back into the water. When the plants die back in the autumn much of the nutrients in the biomass are released back into the water as the plants decay. In the winter the bottom sediments are covered with a layer of decaying aquatic plant fiber.

A continuing program of harvesting seems to be an essential part of maintaining the use of the lake for rowers, swimmers and fisherman.

Summary for biological indicators. For the groups of organisms examined, there is evidence for changes in numbers of algae in the lake and a dominance by cyanobacteria which are very undesireable. Low numbers of organisms in the zooplankton and benthic communities are likely related to deteriorating conditions like dissolved oxygen as well as a changing fish population and introduced species. Aquatic plants are present in high densities and likely have effects on water quality as well as recreational use of the lake and fish populations.

4.7 Fisheries

The fish population is an essential part of the Elk Lake ecology and must be considered in any evaluation of water quality. There are many interactions between fish and other biological and chemical components of water quality that need to be considered and if the overall lake heath is to be considered, fish are an important and integral part.

Elk is the most popular fishing lake on Vancouver Island (more than 15000 angler days per year) and is important for that use alone.

No new data were collected on fisheries during this study. However many anecdotal reports were supplied by anglers that the fishing experience had decreased in quality in recent years

– less fishing success and comments about the introduced species and the proliferation of aquatic plants. The plants impede boat operation and fishing gear use and require boat cleaning

Fishery Branch surveys were done in May 1971 (Chudyk and Erickson 1971) and in May and October 1973 (Burns and Klein 1973, Klein and Burns 1973). The original survey reports are posted on the web on the Habitat Wizard site) and are also included on a CD accompanying the report that has copies of literature used here and other pieces of literature relevant to Elk Lake. Vancouver Island has a relative small number of native species if fish (16 species, Taylor 2004) and it appears that there were probably only three species in the lake historically (Cutthroat Trout, Brown Bullhead and Prickly Sculpin). All other species have been introduced. The May 1971 survey had some fragmentary data on water quality (Total Dissolved Solids (TDS) 115-120 mg/L, Secchi 5.5 m, disssolved oxygen 12 mg/L at the surface and 9 mg/L at 11.5 m).

The May 1973 survey provided some additional water quality data (TDS 116, Secchi 4.8 m, temperature profiles (14.7 C at the surface 12.1 C at 8.3 m) and DO (11 mg/L at the surface, 6 mg/L at 11.2 m) and mentioned “extensive weed beds” and the results of a net survey of fish in the lake: 3 cutthroat, 2 rainbow trout, 42 pumpkinseed and 82 brown bullhead. In October another standard gillnet sample set was done resulting in 9 cutthroat, 28 smallmouth bass, 59 pumpkinseed sunfish, 2 prickly sculpin and 340 brown bullhead.

In June through September 1974 some additional fish sampling was done and the relative proportions of the fish community were reported as 77.5% sunfish, 14.5% stocked rainbow trout, 4.3% catfish, 2.1% Cutthroat Trout and 1.6% smallmouth bass.

These data from 1973-74 give a rough idea of what the relative proportions of the species were at that time. As a point of comparison, in 2014 when the outlet dam for the lake was replaced, a fish salvage operation was carried out in the construction area. It was not a proper sampling but does provide a sense of the relative proportions of fish in the Beaver Lake end of the lake at that time. In total 1261 fish were moved: 836 Prickly Sculpin, 228 Smallmouth Bass, 151 Pumpkinseed, 31 Yellow Perch, 8 Carp, 3 Largemouth Bass, 3 Brown Bullhead and one Rainbow Trout. Three species new to Elk Lake since the 1973-74 surveys are Yellow Perch, Largemouth Bass and Carp. These species were presumably illegal introductions. All three of these species potentially might affect water quality. Yellow Perch in gazing zooplankton and benthos, largemouth Bass as predators on other species – particularly Rainbow Trout, and Carp as bottom feeders, stirring up the bottom, resuspending sediments and nutrients and increasing turbidity.

Elk Lake has been stocked annually with sterile rainbow trout since usually several stocking are carried out per year with “catchable” (200 g plus size). In 2014, nine stockings were made with about 18,000 fish (gofishbc.com website). The goal for stocking is to stock a number of fish that is equivalent to the number of angler days for a particular lake. (Silvestri 2014)

4.8 Introduced species and endangered species

Western Painted Turtles are endangered – partly because of ecological change and partly because of competition with introduced exotics. Concern about survival of the species have been expressed (Peninsula News Review 2010)

Much media attention has been devoted to the introduction of the Eastern Bullfrog to the lakes of the CRD area – including Elk Lake. The ecological consequences of their presence is not clear although another exotic species introduction makes a complex situation even more difficult to manage or rehabilitate.

Summary for fish and exotic species information. The fish community of the lake has been completely changed from its historical community. Introduction of exotic species and deterioration of water quality have resulted in a changed system that is difficult to understand and manage.

5. Discussion

5.1 Elk Lake Fish Populations

Elk Lake appears to have deteriorated to the point where many of the public uses of the lake have been affected. The recreational fishery according to many users has become far less attractive. There are two main species that two different groups of anglers are interested in. The longest interest has been in the trout fishing (both the stocked Rainbow Trout and the native Cutthroat) and that for decades has been the target of many recreational anglers and it has by most accounts become less satisfying. The changes in water quality with more frequent algal blooms and poor water clarity, does not favour visual feeders like trout. The minimal cold water refuge available in summer when the deep cooler waters are deprived of oxygen, is also a disadvantage to trout who prefer cooler water temperatures but have do not have access to a cold water refuge. The severe oxygen depletion also depresses the production of benthic organisms like chironomids that are a food source for trout. Other lake conditions, like the high density and coverage of aquatic plants and the introduction of several other non-native fish species which directly compete for food and prey on smaller trout, limit the success of the trout fishery despite a large investment in stocking Rainbow Trout.

A second fishery that has become well established and appears to be doing well under the present conditions, is for bass. Smallmouth bass were introduced into many lakes on Vancouver Island a hundred years ago and the introduction was likely significant. The e-fauna website (linnet.geog.ubc.ca) that documents introduced species states "This eastern North American species was introduced into B.C. to provide angling opportunities and although it is a popular recreational species, it is not a native species and none of our native fishes have coevolved with this efficient predator. Consequently, it has a devastating impact on small species. On Vancouver Island, it has eliminated the native fish species and macroinvertebrates in most of the lakes where it has been introduced."

Pumpkinseed sunfish were likely introduced at the same time as smallmouth bass to provide a food source. Largemouth bass have much more recently been introduced into Elk Lake as well as Yellow Perch – apparently to provide a compatible food source. Both species of bass as well as the pumpkinseed and perch are much more suited to the present conditions at Elk Lake. They thrive in the warm surface waters and find the heavy aquatic plant growth suit their growth and survival. The bass fishery seems to be thriving without any active fishery management activity.

The relatively recent (in the last 20 years) introduction of Carp is of particular concern. Carp are destructive of native habitat and although they appeal to some anglers, are an extremely undesirable species to have in Elk Lake. Photos below are courtesy Dennis Gedney.

5.2 Aquatic Plants

The proliferation of aquatic plants in Elk Lake is an issue with swimmers, boaters, fishers, and rowers. A significant percentage of Elk Lake has aquatic plants at or near the surface by late summer and the Beaver Lake part of the water body is completely clogged with dense mats of aquatic plants. Aquatic plants have been identified in newspaper stories since the 1960s and Saanich Parks and Recreation used chemical treatments to control algae in Elk Lake in 1967 and also it was reported that "certain key areas were treated for aquatic weed control with good results" (Dogwood Star 1968).

From 1979 to 2013, a harvester was used to cut and remove aquatic plants from the lake (Times Colonist 2003). Certain areas were targeted – beaches, boat launches and rowing courses but the goal appears to have been to reduce the biomass in key areas to reduce risk of swimmers becoming entangled (a safety issue) and reduce the annoyance factor that the public complained about. The removal of 300-500 tonnes of plant biomass annually is likely a very small percentage of the plant biomass in the lake and would have little effect on removing any significant amount of either nutrients (phosphorus and nitrogen) or carbon (which when decomposed contributes to the oxygen deficit of the lake). The scale of the program should be considered to be largely cosmetic. In 2014 a smaller machine was contracted to harvest aquatic plants (Times Colonist 2014b)

Large scale plant harvesting would be a major ongoing and expensive commitment and how much it would contribute to reducing the phosphorus input is beyond the scope of this report but should be evaluated. There is considerable information available and many examples from other parts of the world. In the USA with many shallow warm water lakes, the management options are wider, with extensive use of herbicides to control aquatic plants but this option is not available (or recommended) for Elk Lake. Many other techniques are available for reducing the growth of aquatic plants – many of which were developed in BC as part of the Eurasian Milfoil control program operated by the BC Ministry of Environment in the 1980s. Techniques like bottom barriers (to prevent light from reaching the lake bottom), harvesting complete plants (rather than simply trimming the tops off) using underwater rotovators, biological controls (using insect predators, or herbivorous fish like sterile grass carp – the latter would not be acceptable to regulatory agencies).

The chapter on Macrophyte Biomass Control in the in the book by Cooke et al (2005) provides much more information. The aquatic plant issue, although related to the nutrient loading problem, needs to be dealt with as a separate topic as it is unclear if a reduction of input of phosphorus would result in a proportional reduction in plant biomass. This seems unlikely as many plants species are rooted and obtain their nutrients from the sediments rather than the water although some species do.

5.3 Nutrient Management

The overwhelmingly dominant source of nutrients to the lake is the internal loading process that is facilitated by the hypolimnetic oxygen depletion between May and November. The 2014 data indicate that the internal load of phosphorus from the sediments (about 2000 kg) has more than doubled in the past 25 years – as has the spring phosphorus concentration. Lakes tend to become more productive over time (the process of eutrophication) and this has been accelerated by human landuse (and the raising of the lake level) over the past 150 years. The eutrophication process is one that tends to be unidirectional and feeds itself. The initial small loadings from land disturbance (land clearing, roads, agriculture etc) have essentially “primed the pump” of eutrophication, leading to an initial small oxygen depletion which caused a small internal loading, which then results in increasingly large internal loads to the point where at present, the internal loading seems to be at least 80% of the total P load to the lake. Other sources quantified by McKean (1992) but not revisited as part of this study, represent relatively smaller amounts (septic tank inputs 246 kg/yr, O’Donnel Creek

87 kg/yr, atmospheric loading 38 kg, small creeks 36 kg and birds 9 kg – in comparison to the 950 kg internal loading he estimated – about 70% of the total load at that time)

The magnitude of the annual internal loading is difficult to convey. Perhaps to visualize better, 2000 kg of phosphorus would be represented by a thousand 10 kg bags of the general purpose 20-20-20 (20% P by weight) commercial fertilizer available in garden shops. Perhaps 20 pallets each stacked with 50 bags of fertilizer might be more visual?

From this information it would seem there would be little benefit to the lake water quality in reducing smaller sources like septic tanks or agriculture until the overwhelmingly important source that the internal loading represents.

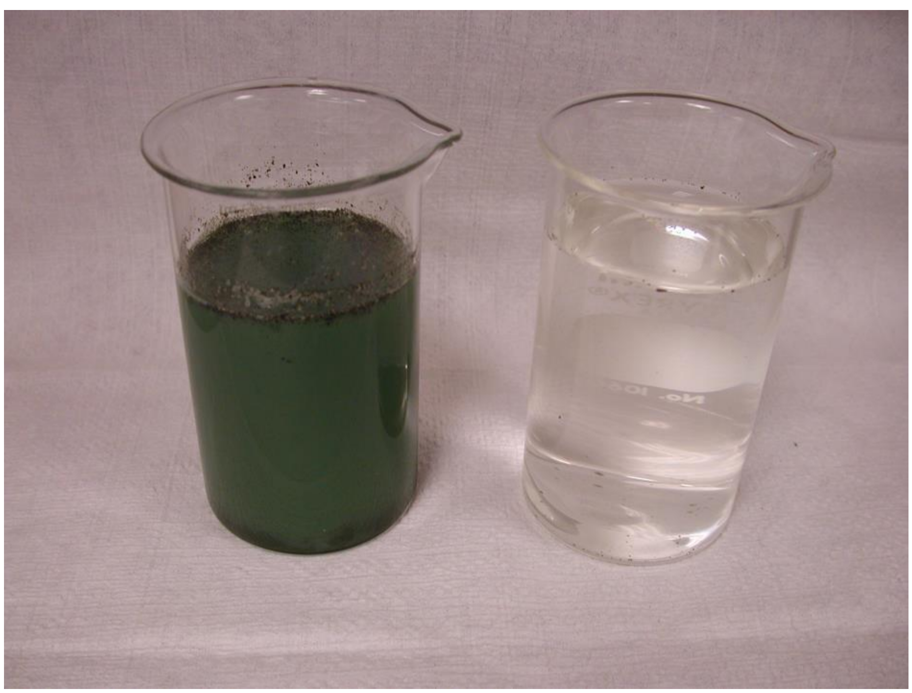
McKean (1992) recognized this as well and recommended considering aeration as a way of reducing the internal loading and this would still seem to be a viable option that should be investigated further. There has been several applications of aeration in the Victoria area (Langford Lake , Glen Lake) and use of aeration in St. Mary Lake on Saltspring Island. St. Mary Lake is similar in many ways to Elk (size, P internal loading) and some benefit might be gained from examining their experience. The aerators there provided an initial benefit but some problems were encountered and are no longer being used. If aeration is to be considered, the experience from St Mary Lake needs to be examined in some detail.

There are other techniques for dealing with internal loading. One approach that has been used is treatment of bottom sediments (again see the book by Cooke et al for much more detail). The internal loading in Elk Lake seems to be a well documented phosphorus – iron bonding and release mechanism. A possible means of reducing internal loading might be to add iron to the sediments to hold the phosphorus in the sediments. Other sediment treatments to reduce internal loading have used calcium (lime) or aluminum sulphate (alum) added to the sediments. Sediment treatment would require considerable research before it were to be considered and it may not be acceptable to regulatory agencies.

5.4 Lake Restoration

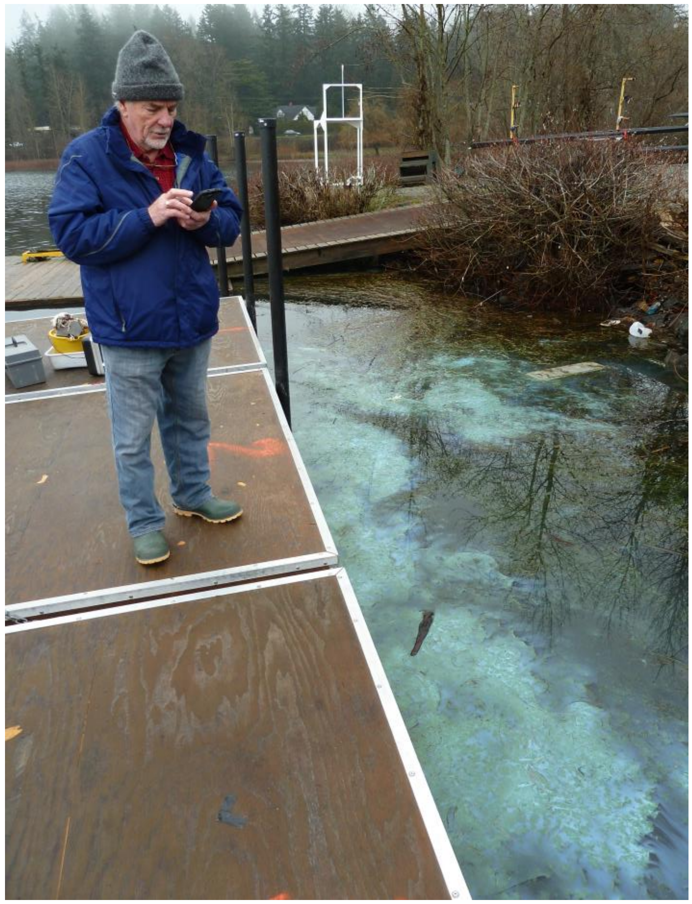
How to restore Elk Lake is still a major question to be considered but that it needs to be restored and more actively managed is not an issue. Elk Lake is very important to Victoria area residents as well as for visitors. An economic analysis of the value of the lake might provide a point of reference. Replacement cost? What it would be required to aquire the land and excavate a 18 meter deep lake and reconstruct the facilities and infrastructure would likely be beyond anyone's imagination, so why not restore and protect the valuable resource that is there.

The urgency in this issue is probably best examined in the context of human heath and safety – as well as ecological and economics. In the past 5 years there have been several notable cyanobacterial blooms. Media reports in 2009, 2011, 2012, 2013 and 2014 (Times Colonist 2012a,b) have raised concern about safety of people using the lake and also about dogs who might drink lake water containg cyanobacterial toxins (Saanich News 2012, Victoria News 2013, Times Colonist 2012, 2013a). The most emphatic evidence of the risk of cyanobacterial blooms and toxins occurred in late December 2013 when a bloom became very visible and was tested for toxins and found to have very high levels of anatoxin, a powerful neurotoxin that is produced by cyanobacteria. As a result the annual New Year Polar Bear Swim was moved from Elk Lake to Thetis Lake. (Victoria Times Colonist 2013b, and see photo below).



Sample of Elk Lake water (left) and tap water, December 2013

There was also a bloom in January 2015. In that case the dieoff of the cyanobacteria showed the characteristic turquoise blue-green coloration of dying cyanobacteria in the water.



Algal bloom Elk Lake January 2015

There have been numerous anecdotal accounts of dogs becoming ill after drinking Elk Lake water and athletes becoming ill after participating in thiathelon events that included a swim in Elk Lake and some organizations are reconsidering using Victoria and Elk Lake as an event venue because of the poor water quality. Even social media have commented on the poor water quality. The Trip Advisor website has had reviews stating "Great Park but watch the water quality" and "This is a beautiful park to hike – but if you are planning on swimming watch out, the quality of the water is often horrid and there are advisories for health" and "Scuzzy water". (TripAdvisor.ca)

Cyanobacterial blooms and toxin production in lakes worldwide are becoming more frequent in recent years (O'Neil et al 2010, Taranu et al 2015) and there is considerable concern in the scientific community about the ecological (Cottingham et al 2015, Kosten et al 2012) and health implications of these cyanabacterial blooms. An article in *Scientific American* discussed the link of algal toxins to ALS and other neurodegenerative diseases (Konkel 2014, also see Holdcamp et al 2012). Many other articles investigating cyanobacterial toxins have been published recently (eg Levesque et al 2014) raising concern that these toxins may have wider health implications that are presently understood. For this reason alone (as a precautionary principle) that some effort should be made to improve the water quality of Elk Lake.

Water clarity (or lack of it) is another heath and safety issue for swimmers – and has been for some time. A newspaper article (Dogwood Star 1969) described a proposal to have scuba gear available for lifeguards at Elk and Beaver swimming beaches after a drowning death when lifeguards could not find the swimmer in the "murky water of the lake".

Another long standing (non-scientific) issue that needs to be addressed is a clarificaton of the jurisdictional roles of the government agencies involved: Saanich, CRD, VIHA, Federal Government (DFO, Transport Canada) and Provincial Government (Environment and FLNRO). Since the creation of the park in the 1966, the roles and resposibilities have changed (see Times Colonist 1993b) and no clear definition of jurisdictions seems to exist. This may be critical in solving the problems associated wth the lake.

Other issues include lake level control – high lake levels in 2014 (Times Colonist 2014) and 2015 have prompted many public complaints and the artificially high water levels (where beavers may also be a factor?) may contribute to water quality deterioration by exacerbating shoreline erosion. Photo taken 22 April 2015 east of the Rowing Club.

In summary, these issues seem to be the most important:

The aquatic plants are not only an aesthetic problem but a health / safety problem and an ecological one (it represents a huge loading to the lake of biodegradable carbon). Efforts should be made to re-establish a harvesting program. A mapping and biomass survey would likely serve as an essential first step in a harvesting program.

A review of options for lake restoration should be made. Aeration was recommended by McKean in 1992 and was included in the CRD Parks management plan but no progress has been made on whether aeration is appropriate. The water quality of the lake has become a great concern regarding the ecological changes that have occurred and for potential human health concerns as well.

It is essential that all the government and non-government agencies and anyone else interested in the preservation and protection of Elk Lake work together in a collaborative manner. For the two decades between 1993 and 2013 progress has been dismally slow but the progress in the past two years has been very encouraging.

5.5 Limitations of the Report and Future Work

A significant piece of information that will be the subject of a future report is to compile and interpret the stream flow and water chemistry information that was collected for three inflow streams in 2014 and 2015. The intention of this part of the study was to provide an estimate of the nutrient input from the watershed streams – to assess their relative importance and compare to the data that were collected in 1988. The watershed inputs of agriculture / landuse and sewage comprised about 25% of the P inputs in 1988 and it is critical to know the present inputs. It is very important that an accurate phosphorus budget can be provided – this would be the basis of any strategy to improve the lake water quality. A present re-evaluation of watershed inputs is being done by a graduate student at the University of Victoria (Lisa Rodgers) as part of her Masters degree and that information should be available in the next few months.

St Mary Lake on Saltspring Island is in the same limnological region as Elk Lake and has a very similar size and a similar problem of eutrophication. Much data (water chemistry and biology) have been collected for St Mary Lake and it would be a useful exercise to compare what is known about the two lakes and the understanding of the processes in each. St Mary has had aeration units installed in the lake and the application of that experience to Elk Lake would be quite useful. As an example re-evaluation of nutrient loading from septic tanks at St Mary showed that intial estimates were too high and the contribution from that source is relatively small (Hodgins and Stewart 2014). Much other information is available on the Saltspring Watershed Protection Authority website (http://ssiwatersheds.ca/).

A thorough evaluation of the options for lake restoration needs to be carried out. There are several potential in-lake restoration technologies to deal with the water quality issue: aeration, sediment treatment / sealing, or dredging. There may be other possibilities (biomanipulation, chemical manipulation), as well but a thorough review of the literature and the applicability of different approaches needs to be done. The issue of aquatic plant growth is a separate and very important issue and there are different approaches to deal with this problem as well: harvesting, dredging, bottom barriers and other possibilities. Again a thorough review of options of this topic area is needed.

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Many people have contributed to gathering of the data that are reported here. The initiative and energy of Mick Collins have been the reason much of this work has been completed – he had provided support, encouragment and leadership in the effort to impove Elk Lake not only for fishermen but for all users of the lake.

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Water quality samplers Clive Lane, Jim MacDonald, Pat Psaila and Dennis Gedney

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Appendix Table: Ministry of Environment 1995 Water Quality Objectives Attainment report published 1997.

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TABLE 2

ELK AND BEAVER LAKES WATER QUALITY OBJECTIVES - 1995

VARIABLE & OBJECTIVE	MEASUREMENT				CONCLUSION
	SITE	DATE	n	VALUE	
Temperature 15°C max in hypolimnion	Elk Lake 1100844 at centre	Jun 29 - Sep 28	4	9.5 - 14.4 °C at 7 to 9 m (start of hypolimnion)	Objective met
	Beaver Lake E207470 at centre	Jun. 29	1	16.2 °C at 5 m	Obj. not met
			1	13.2 °C at 6 m	Obj. met
		Jul. 27	1	17.6 °C at 5 m	Obj. not met
		Aug. 30	1	17.8 °C at 5 m	Obj. not met
			1	15.0 °C at 6 m	Obj. met
		Sep. 28	1	17.8 °C at 5 m	Obj. not met
				15.0 °C at 6 m	Obj. met
Dissolved Oxygen 5 mg/L min 1 m above sediment May - August	Elk Lake 1100844 at centre	Jun 29 - Aug 30	3	< 2 - 2.2 mg/L at 9 m	Objective not met
	Beaver Lake E207470 at centre	Jun 29 - Aug 30	3	1 - 4 mg/L at 5 to 6 m	Objective not met
Chlorophyll-a 1.5 - 2.5 ug/L av of duplicates at 0,2,4,6 m May - August	Elk Lake 1100844 at centre	Jun 29 - Sep 28	16	< 0.5 - 4.2 ug/L duplicates at 0,2,4,6 m av = 2.2 ug/L	Objective met
	Beaver Lake E207470 at centre	Jun 29 - Sep 28	12	2.3 - 19.9 ug/L duplicates at 0,2,4 m av = 9.6 ug/L	Objective not met
Water Clarity 1.9 m min Secchi disc reading	Elk Lake 1100844 at centre	Jun 29 - Sep 28	4	4.6 - 5.5 m	Objective met
	Beaver Lake E207470 at centre	Jun. 29	1	3.8 m	Obj. met
		Jul 27 - Sep 28	3	1.1 - 1.7 m	Obj. not met
Phytoplankton Community < 50 % Cyanophytes (cells/mL at surface) May - August	Elk Lake 1100844 at centre	Jun. 29	1	53.5 % Cyanophytes	Obj. not met
		Jul. 27	1	6.3 % Cyanophytes	Obj. met
		Aug. 30	1	24.9 % cyanophytes	Obj. met
		Sep. 28	1	68.3 % Cyanophytes	Obj. not met
	Beaver Lake E207470 at centre	Jun. 29	1	83.4 % Cyanophytes	Obj. not met
		Jul. 27	1	37.3 % Cyanophytes	Obj. met
		Aug. 30	1	81.7 % cyanophytes	Obj. not met
		Sep. 28	1	42.9 % Cyanophytes	Obj. met

Summary of metals analysis for water samples from Elk Lake 2014-2015.

All units are ug/L (except as noted). MDL is the analytical Minimum Detection Limit

metal	Mean	n=	minimum	maximum	comment
Silver dissolved	<0.005	28	<0.005	<0.005	All <MDL
Silver total	<0.005	35	<0.005	0.724	Max error?
Aluminum diss	4.5	28	0.85	20.2	
Aluminum total	26.8	28	5.3	168	
Arsenic diss	1.11	28	0.76	2.08	
Arsenic total	1.35	28	0.76	2.42	
Boron diss	36.9	28	20	50	
Boron total	38.0	28	20	50	
Barium diss	8.21	28	1.93	12.9	
Barium total	11.7	28	8.52	49.6	
Beryllium tot & diss		28		<0.01	All<MDL
Bismuth diss		28		<0.005	All <MDL
Bismuth total	0.006	28	<0.005	1.0	Max error?
Cadmium diss	0.006	28	<0.005	0.026	
Cadmium total	0.010	28	<0.005	0.059	
Cobalt diss	0.039	28	0.014	0.118	
Cobalt total	0.067	28	0.021	0.500	Max error?
Chromium diss	0.110	28	0.1	0.4	Max error?
Chromium total	0.131	28	0.1	1.0	Max error?
Copper diss	0.45	28	0.069	0.81	
Copper total	0.58	28	0.257	1.53	
Iron diss	73.5	28	1.5	1030	
Iron total	665	28	11.6	4060	
Lithium tot& diss				<0.5	All <MDL
Magnesium diss	4.60	28	4.28	4.86	mg/L
Magnesium total	5.01	30	4.09	17.9	Max error?
Manganese diss	0.181	28	0.0005	1.05	mg/L
Managanese total	0.336	30	0.001	1.62	mg/L
Molybdenum diss	0.42	28	0.2	0.55	
Molybdenum total	0.44	32	0.2	1.2	
Nickel diss	0.34	28	0.2	0.6	
Nickel Total	0.40	32	0.26	1.1	
Lead diss	0.010	28	0.005	0.070	
Lead total	0.10	32	0.016	0.78	
Antimony diss	0.1	28	0.05	0.14	
Antimony total	0.11	32	0.06	0.5	
Selenium diss	0.043	28	0.04	0.09	
Selenium total	0.057	32	0.04	0.52	
Tin diss	0.23	28	0.2	1.0	
Tin total	0.35	32	0.2	5.0	
Strontium diss	0.083	28	0.77	0.09	
Strontium total	0.085	32	0.77	0.11	
Titanium diss	0.002	28	0.002	0.003	
Titanium total	0.013	32	0.002	0.361	
Uranium diss	0.01	28	0.002	0.018	
Uranuium total	0.08	32	0.005	2.24	Max error?
Vanadium diss	0.8	28	0.52	1.24	
Vanadium total	1.0	32	0.55	5.0	
Zinc diss	1.2	28	0.1	16.3	Max error?
Zinc total	1.88	32	0.2	6.68	

"Max error" indicates that one value (maximum reported) is suspicious and needs to be assessed and will affect the mean value calculated.

Zooplankton – Rotifer community sampled 2014-2015. Numbers in the table below are number of animals per sample (10 m vertical tow with a 150 µm zooplankton net mesh with a 20 cm mouth diameter.

Sample Date	14 Apr 2014	13 May	10 Jun	8 Jul	6 Aug	10 Sep	7 Sep	4 Nov	25 Nov	23 Dec	6 Jan 2015	20 Jan	3 Feb	16 Feb
Rotifer- *Keratella*	54	187	106	45	21	1	40	61	20	27	20	34	70	33
Rotifer- *Kellicottia*	32	94	8	2	74	3	13	1	1			1	2	
Rotifer- *Polyarthra*	1	19	26	19	418	1	73	11	12	1		1	2	2
Rotifer- *Conochilus*		5	26				2							
Rotifer- *Asplanchna*		4	7		3	2	48		1					
Rotifer- *Chromogaster*			2	3		1		22	5					
Rotifer- *Filinia*					7									
Rotifer- *Branchionus*							18		1					

Aquatic plant survey of Elk and Beaver Lakes. Species presence list – survey probably done about 1995 by BC Ministry of Environment

VEGETATION

POTAMOGETON L.	MYRIOPHYLLUM L.	SPARGANIUM L.
LEMNA L.	UTRICULARIA L.	RANUNCULUS L.
ISOETES L.	NUPHAR J.E.SMITH	NYMPHAEA L.
ELODEA RICHARD	CERATOPHYLLUM L.	POLYGONUM L.
MYOSOTIS L.	SCIRPUS L.	ELEOCHARIS R. BR.
VERONICA L.	NITELLA (AGARDH) LEONHARD	CHARA L.
POTAMOGETON ROBBINSII OAKES	POTAMOGETON PECTINATUS L.	POTAMOGETON ZOSTERIFORMIS FERN.
POTAMOGETON PRAELONGUS WULF.	POTAMOGETON PERFOLIATUS L.	POTAMOGETON NATANS L.
POTAMOGETON AMPLIFOLIUS TUCKER.	POTAMOGETON GRAMINEUS L.	POTAMOGETON PUSILLUS L.
POTAMOGETON OBTUSIFOLIUS MERTENS & KOCH	MYRIOPHYLLUM VERTICILLATUM L.	SPARGANIUM EURYCARPUM ENGELM.
SPARGANIUM ANGUSTIFOLIUM MICH.	LEMNA MINOR L.	LEMNA TRISULCA L.
SPIRODELA POLYRHIZA (L.) SCHLEID.	UTRICULARIA VULGARIS L.	RANUNCULUS FLAMMULA L.
RANUNCULUS AQUATILIS L.	NUPHAR POLYSEPALUM ENGELM.	BRASENIA SCHREBERI GMEL.
ELODEA CANADENSIS RICH.	VALLISNERIA SPIRALIS L.	NAJAS FLEXILIS (WILLD.) R. & S.
CERATOPHYLLUM DEMERSUM L.	HIPPURIS VULGARIS L.	POLYGONUM AMPHIBIUM L.
POLYGONUM HYDROPIPEROIDES MICHX.	MENYANTHES TRIFOLIATA L.	CICUTA DOUGLASII (DC) COULT. & ROSE
SIUM SAUVE WALT.	OENANTHE SARMENTOSA PRESL.	VERONICA AMERICANA SCHW.
MIMULUS GUTTATUS D.C.	IRIS PSEUDACORUS L.	TYPHA LATIFOLIA L.
LYSIMACHIA THYRSIFLORA L.	POTENTILLA PALUSTRIS (L.) SCOP.	MYOSOTIS LAXA LEHM.
DULICHIUM ARUNDINACEUM (L.) BRITT.	ELEOCHARIS PALUSTRIS (L.) R. & S.	SCIRPUS LACUSTRIS L.
MIMULUS L.		