A Water Quality Assessment of Quamichan Lake (Vancouver Island, British Columbia): A Summary of Data Collected between 1951 and 2005

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Executive Summary

Quamichan Lake is located on Vancouver Island, 3 km north east of Duncan. It is a large shallow lake, with inlet and outlet streams that typically only flow during the winter. The lake is an important water source, recreational area and habitat for fish and other aquatic life. The lake often experiences algal blooms and fish kills periodically occur. These occurrences are related to the morphometry of the lake (shallow, low flushing rate) and to high levels of nutrients within the lake. The elevated nutrient levels appear to be largely influenced by internal loading mechanisms, although external influences (i.e. from agriculture, urban growth, deforestation activities) also would be contributing factors. Records indicate that these issues have been ongoing, with reports identifying concerns dating back to 1951.

This report has been completed in order to better understand and quantify the water quality status of Quamichan Lake. In doing so this report provides a chronological summary of the Ministry of Environment's (MOE) documentation on the Lake; and it provides a review of all available water quality data collected at Quamichan Lake (Deep Station Site –EMS E207465). Analysis involved amalgamating the MOE Environmental Protection Division's Environmental monitoring system (EMS) data (available for 1988-2005) with the Fisheries Department data (intermittent data dating back to 1951). The dataset was reviewed against the Federal and Provincial Water Quality Criteria to identify whether any exceedances occurred, and trends and influences on algal growth were reported. From this data, the following main conclusions were made:

General Water Quality

When compared against the Water Quality Guidelines (the 'Criteria'), the water quality of the lake was found to be poor, with several parameters exceeding the Criteria. Poorest conditions in terms of highest instantaneous values were often recorded in recent years (2004 and 2005). The following exceedances to the Criteria were identified over the period of study:

General Parameters

1. True Colour values exceeded the Drinking Water Criteria (for aesthetics) in 13% of samples, with exceedances occurring at various times of the year in 1992, 1999 and 2005.
2. Dissolved Oxygen (DO) data did not meet the Aquatic Life Criteria minimum in 26% of samples. Bottom values were typically below the Criteria from May through October. Low summer DO values has resulted in fish kills with occurrences reported in 1987, 1997, 1998, 2003 and 2004.
3. Temperature data exceeded the Drinking Water Criteria in 46% of samples. The Aquatic Life Criteria (for optimal rainbow trout rearing) was exceeded in 35% of samples. These exceedances initially occur in the surface waters with warming spring weather (May, June), and typically progress into the middle and bottom depths through the summer months (often until September).
4. The maximum and minimum pH Criteria for Drinking Water were not met in a total of 12% of samples, all occurring in 2005.
5. Turbidity values exceeded the Drinking Water Criteria for Health in 78% of samples. These exceedances were often seen during the winter, spring and fall sampling. The Drinking Water Criteria for Aesthetics was exceeded in 17% of samples, all occurring during the fall.

Nutrients

6. Total Organic Carbon values exceeded the Drinking Water Criteria (for chlorinated water) in 88% of samples. Exceedances were apparent throughout the year.
7. Total Phosphorus (TP) exceeded the Drinking Water and Recreation Criteria in 90% of samples. The lower range of the Aquatic Life Criteria was exceeded in 98% of samples and the higher range was exceeded in 83% of samples. TP values peaked during the late summer and were typically highest at the bottom depths.
8. Although Nitrogen parameters did not exceed the Criteria, they were reviewed in detail due to their importance to algal growth. Results indicated that Nitrite + Nitrate values were highest in the fall and that ammonia values were highest during the summer.

Biological Parameters

9. Chlorophyll a sampling was limited to only 4 samples (3 in 2004 and 1 in 2005). Values exceeded the Drinking Water Criteria in all 2004 samples representing winter, summer and fall periods. The fall value was the highest.
10. Secchi Depth data did not meet the minimum Recreation Criteria in 25% of samples. All exceedances occurred during June and July.
11. Fecal coliform and *Escherichia coli* data was limited to 2 days (March 2002 and November 2004). Both samples exceeded the Drinking Criteria for raw untreated water.

Metals

12. Total Copper values exceeded the Aquatic Life Criteria in 28% (lower range) and 5% of samples (upper range). All exeedances occurred during 1992 (in the late spring/summer and winter periods).
13. Total Iron data exceeded the Drinking and Aquatic Life Criteria in 16% of samples. All exceedances occurred during 1992; however, this was the only year where data was available from all seasons (other years only had spring data). Most of the exceedances are likely linked to low DO levels.
14. Total Manganese data exceeded the Drinking Water Criteria in 35% of samples, with all exceedances occurring during 1992. The Irrigation Criteria was exceeded in 9% of samples, with exccedances occurring both in 1992 and 2005. Peaks appeared during the late summer/early fall and appeared to be influenced by low DO levels in the bottom depths.
15. Total Thallium values exceeded the Aquatic Life Criteria in 19%. All of the exceedances occurred during 1992.
16. Total Zinc values exceeded the Aquatic Life Criteria in only one sample (representing 2% of data). This exceedance occurred in July 1992.

Trophic State and Algal Growth

In terms of biological productivity, Quamichan Lake is classified as being mesotrophic-eutrophic. Measures of productivity from the 2000s are higher than those of the 1990s, indicating that Quamichan Lake may be getting more productive with time. These conditions likely result from a high rate of nutrient supply (both internal and external), warm climatic conditions, poor flushing and shallow lake morphometry.

Diatoms and cyanobacteria dominate the phytoplankton community. These phytoplankton types are typical of eutrophic lakes. Cyanobacteria, in particular, are known to cause several problems including creating scums (Pick and Lean 1987), reducing lake oxygen levels (Barica 1975), and creating conditions which are toxic to animals (Carmichael 1981). The issue of toxicity is important, as all species identified at Quamichan Lake are know to have toxic compounds.

The bio-available Nitrogen to TP Ratio indicates that nitrogen is the limiting factor for plant growth in 93% of samples. Cyanobacteria are able to thrive in these conditions because they can fix atmospheric nitrogen and because phosphorus is plentiful.

Internal loading appears to have a very large influence on TP levels in Quamichan Lake. Data shows that during summer and early fall the lake bottom becomes anoxic, causing phosphorus to be released from the sediments. This phosphorus release exacerbates the overall problem by feeding algae growth which in turn causes oxygen levels to become low.

Recommendations

In order to address the water quality issues at Quamichan Lake, a coordinated effort from government agencies, landowners and water users will be necessary. The following actions are recommended:

1. Formalize a Stewardship Committee to lead the planning and implementation of future improvement strategies.
2. Develop a Watershed Management Plan that reviews and prioritizes suggestions made by professionals in the past.
3. Ensure that Quamichan Lake is included in the Cowichan River Planning Process.
4. Continue water quality monitoring.
5. Confirm that microbiological sampling conducted by the Ministry of Health reviews all water uses.
6. Review lethal dosage limits for toxin producing phytoplankton species. Compare results to species numbers found at Quamichan Lake.

Acknowledgements

I wish to give special thanks to Deb Epps and Rosie Barlak of the Ministry of Environment's Environmental Protection Division in Nanaimo. They provided valuable direction, data, technical input, and draft review comments, that were fundamental to the development of this report.

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1.0 Introduction

Quamichan Lake is located near Duncan, on Vancouver Island BC. The lake is an important water source, recreational area and habitat for fish and other aquatic organisms. The land surrounding the lake supports agricultural and residential activities, and has had continued development pressures. Poor water quality conditions including algal blooms and fish kills have been ongoing issues for residents living around the lake and for resource managers.

In order to help address the issues the Provincial Ministry of Environment's (MOE) Environmental Protection (EP) and Fisheries Departments have monitored water quality conditions at Quamichan Lake, with data available back to 1951. In recent years local stewards have also taken an active role by collecting water quality data and by identifying issues of concern.

2.0 Study Objectives

In efforts to understand the current water quality status and to bring about change at Quamichan Lake, the EP Division has commissioned this report which provides a comprehensive review of the lake's water quality issues and data.

The overall objective of this study is to conduct an analysis of Quamichan Lake's water quality data. This objective will be met by completing the following activities:

1. Conduct an MOE file review, and provide a chronological summary of all reported water quality issues.
2. Update the water quality raw data set by combining the EP Divison's EMS data (available for 1988 – 2005) with the Provincial Fisheries department's data (intermittent data dating back to 1951).
3. Identify the current general water quality status as compared to Provincial and Federal Water Quality Criteria,
4. Graph the water quality results and identify any trends;
5. Identify patterns and influences on trophic state and algal growth;
6. Provide recommendations, identifying additional measures required to further understand, maintain or improve water quality;

This information will be provided in a manner that is understandable to community members, government regulators, and scientists. It is anticipated that this information will aid in directing future efforts and government support/funding at improving the water quality of Quamichan Lake.

3.0 Site Description

3.1 General

Quamichan Lake is located on Vancouver Island, 3 km north east of Duncan. The lake is located in the Somenos Creek watershed, which is a sub-basin of the Cowichan River Watershed. (Figure 1).

The bathymetric map (Appendix 1) and Table 1 identify that generally Quamichan Lake is a large, shallow lake. Its major outlet stream is Quamichan Creek, and its inlet streams are MacIntyre and Elkington Creeks (Figure 2). The inlet and outlet streams are intermittent, flowing generally only during the winter period, and are typically dry during the low flow period (Yaworski 1985). The MOE Cowichan-Koksilah Water Management Plan (1986) further provided that the low flows of Quamichan Creek are affected by storage in Quamichan Lake, with records showing 0 flow in Quamichan Creek for 2 ½ – 3 ½ months of the year (August–mid October).

The study site where most water quality sampling has been conducted is depicted in Figure 2. This site has been chosen because it lies in the middle of the lake, in the deepest waters (see Section 4.2 Water Quality Data Collection).

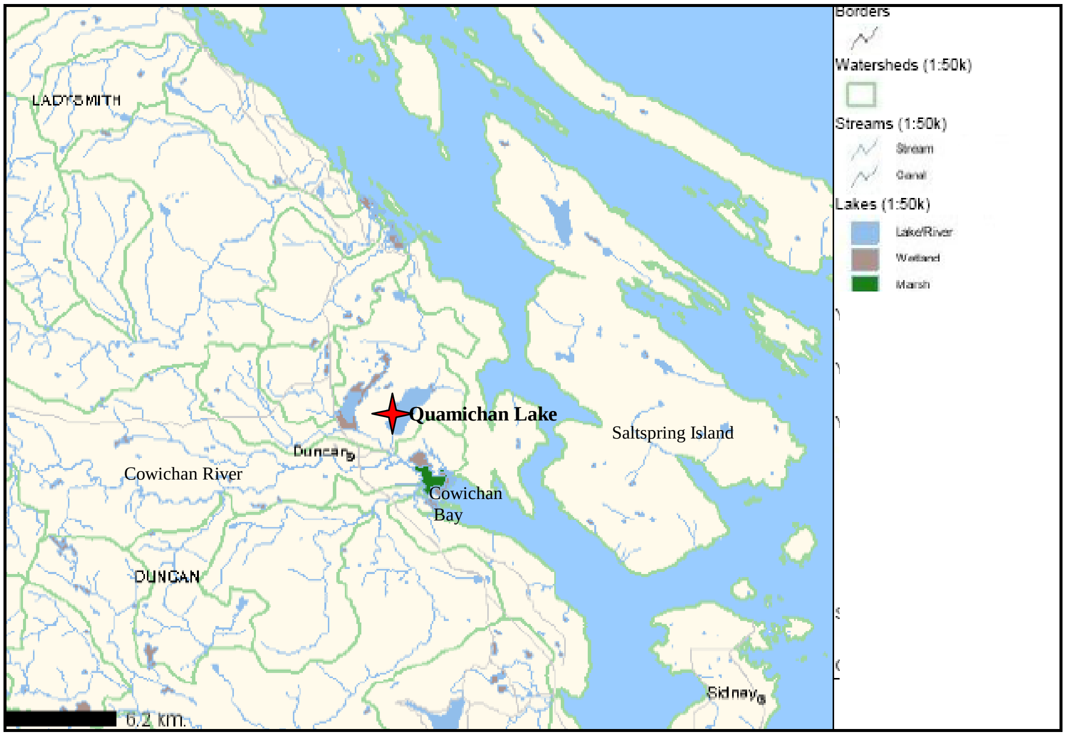


Figure 1. Location and Watershed Boundaries of Quamichan Lake (Fisheries and Oceans 2005).

Table 1. General Characteristics of Quamichan Lake (BC Fisheries 2005 and Holms 1996)

Elevation (m)	Lake Drainage area (km^2)	Lake Surface Area (ha)	Littoral Area (ha)	Max. Lake Depth (m)	Mean Lake Depth (m)	Volume (x10^6 m^3)	Perimeter (km)
26	16.3	313	141	9.1	5	1.48	8.6

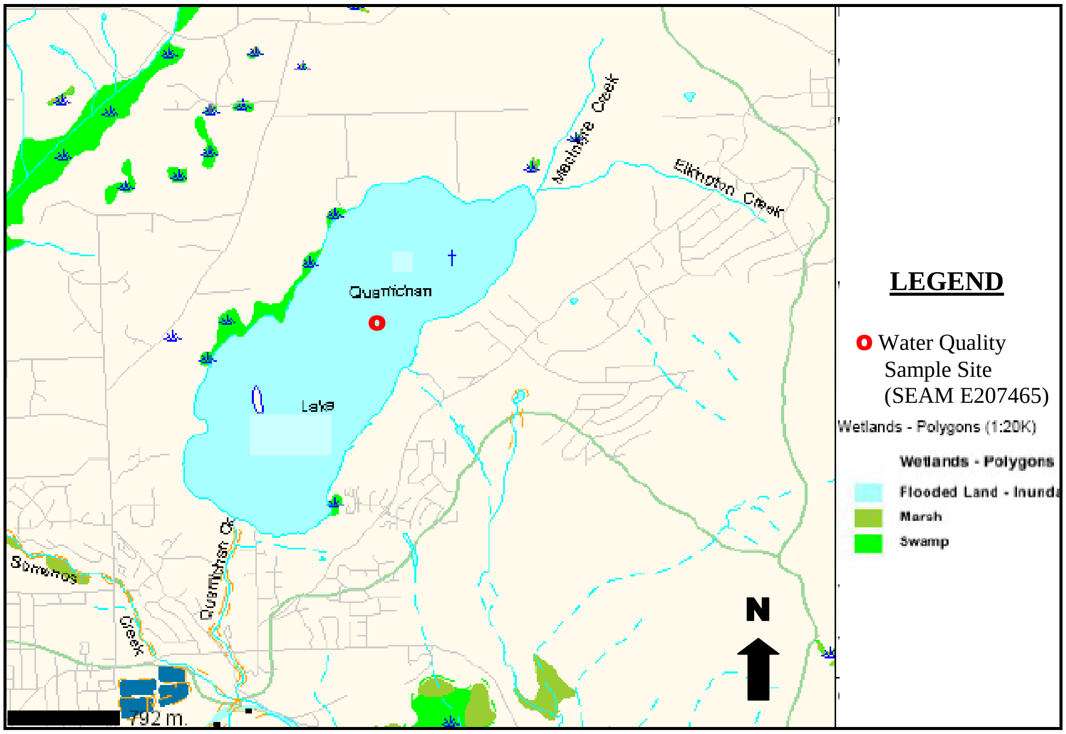


Figure 2. Detailed Map of Quamichan Lake Showing the Water Quality Study Site (Fisheries and Oceans 2005)

3.2 Land Use

Quamichan Lake is surrounded by both agricultural and residential land, and is under constant development pressures.

The Corporation of the District of North Cowichan's Official Community Plan (OCP) (2002) identifies that approximately half of the land surrounding Quamichan Lake lies within the provincially designated agricultural land reserve (ALR). The ALR is comprised of large sized properties, and encompasses most of the western and northern perimeter of the lake (Figure 3). Agricultural activities have resulted in extensive clearing and drainage, with at least 40 percent of the lower slopes of the basin reported to have been modified for this use (Burns 2002).

The OCP also provides that the south end of the lake is more densely populated and is where most residents currently live (see 'growth center' on Figure 3). Future urban expansion is slated for the remaining area along the eastern shore.

There are several wetland ecosystems around the lake, including areas at the lake inlet and outlet creeks, and along the western shore (Figure 4). These are designated as Environmentally Sensitive Areas under the OCP. Here development is limited and requires a special permit.

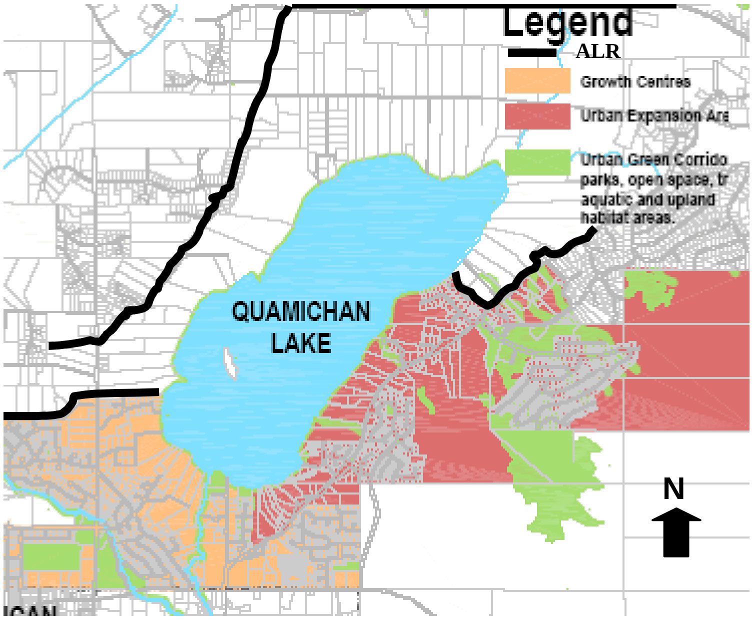


Figure 3. Land Use Surrounding Quamichan Lake (Corporation of the District of North Cowichan 2002).

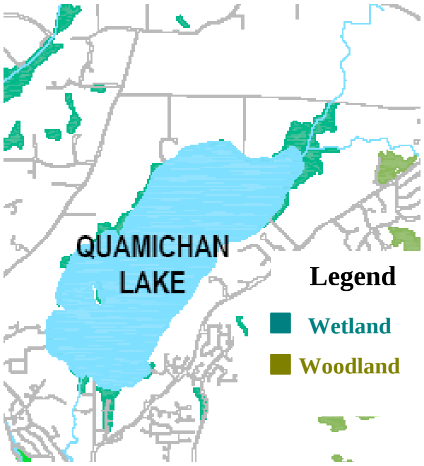


Figure 4. Environmentally Sensitive Areas near Quamichan Lake (Corporation of the District of North Cowichan 2002)

3.3 Water Uses

3.3.1 Recreation

Quamichan Lake is easily accessible to the residents of the Cowichan Valley (population 77,561), which includes the urban center of Duncan (population 4,871) (British Columbia.com 2005). The lake is scenic and is used for many recreational activities including swimming, fishing, sailing, windsurfing, canoeing and water-skiing (Epps 2005). Art Mann Municipal Park located on the lake's south shore, has a boat launch, picnic sites, and playground, providing public day use and access to the lake (Municipality of North Cowichan 2005).

3.3.2 Fisheries

Quamichan Lake is important to the recreational fishery of the Cowichan drainage (Corley-Smith 1988). The lake has limited natural recruitment of salmonids due to the marginal spawning habitat (low gradient and mud/peat substrate) of its outlet Quamichan Creek (Yaworski 1985). The inlet streams are intermittent, also only providing limited recruitment to the lake (Ptolemy 1985).

There is a small population of resident Cutthroat Trout that spawn in Quamichan Creek and return to Quamichan Lake as fry. These fish are considered a unique race and are noted for their large size and ability to survive in marginal conditions (Burns 2002).

Quamichan Lake has been stocked annually with Cutthroat and Rainbow Trout since 1917 (BC Fisheries 2005). The Fish Information Summary System provides that numbers and species of fish stocked have varied annually, with the 2005 year seeing 2,741 yearling Cutthroat Trout and 50 Cutthroat Trout adults placed in the lake (BC Fisheries 2005).

As part of a special study, Coho Salmon (juveniles) were stocked in the lake in 1987, in hopes that the lake would contribute to the rearing capacity of the Cowichan River (Corley-Smith 1988). Results are still under review, however, there were problems identified with smolts leaving the lake as a result of low water levels and an indistinct outlet (Burns 2002). In 1998 and 1990 Steelhead (fall fry) were also stocked in the lake (BC Fisheries 2005).

In addition to Cutthroat and Rainbow Trout, Quamichan Lake also supports Coho Salmon, Brown Catfish, Brown Bullhead, Prickly Sculpin, Pumpkinseed fish, and Threespine Stickleback. (BC Fisheries 2005, and Burns 2002)

3.3.3 Licenced Water Supply

Quamichan Lake provides water for domestic, irrigation, stock watering, and residential lawn/garden activities. The lake has a total of 43 current water withdrawal licences (representing 47 activities), that permit the extraction of 833 m^3 water/day (Table 2) (Land and Water BC 2005). Irrigation use makes up the bulk of the licenced withdrawals.

In terms of future licencing, the Cowichan –Koksilah Water Management Plan (MOE 1986) concluded the following:

> *Groundwater potential in the area is low to nil. There is adequate water available in Quamichan Lake for existing and potential licensed requirements. However, additional extractions from the lake could prolong the period of zero flow already occurring each year in Quamichan Creek. The Fisheries instream requirement is not being met and further analysis is required to determine the effect of further lake withdrawals on fisheries.*

Table 2. Total Licenced Water Withdrawals and Storage Volumes for Quamichan Lake

Licence Type	Number of Licences*	Water Quantity (per licence report)*	Water Quantity (converted to m^3/day)
Domestic	25	19,180 gallons/day	72.6
Irrigation	18	223.88 acre feet/annum	756
Stock Watering	2	750 gallons/day	2.8
Res. Lawn/Garden	2	0.5 acre feet/annum	1.7
Total			**833.1**

Data from Land and Water BC 2005

4.0 Water Quality Monitoring and Reporting History

A documentation review shows that Quamichan Lake has had a long history of water quality issues relating to high nutrient loads and subsequent algal blooms. Generally, the lake has been classified as being eutrophic (Willis Cunliffe and Tait 1974, Yaworski 1985). The water quality is known to be particularly poor during the summer where low oxygen, high temperature, and high algal growth conditions have impaired fisheries (causing fish kills), recreational activities, and licenced water use (Epps 2005). High nutrient concentrations (i.e. phosphorus) appear to be the key contributor to the occurrence of algal blooms in the lake; with the greatest phosphorus source likely to be internal loading from the bottom sediments (Nordin 1990). Agricultural fertilization, septic runoff, bordering pasture areas, and erosion could also likely be (external) contributors.

Because of the importance of the lake and the significance of its issues, a great deal of effort has gone into the collection of data, and into identifying issues of concern and opportunities for improvement over the years. These efforts have been lead by a variety of interested organizations and individuals, including federal, provincial and local governments, as well as local residents.

4.1 Chronological Review of Water Quality Issues

A Chronological Review and summation of the water quality issues as provided in the MOE file at the Nanaimo Regional office is as follows:

1951 (Vernon 1951), 1960 (AFH and WF 1960), and 1972 (Klein and Heathman 1972). Lake survey and fisheries reconnaissance reports indicate the presence of algal blooms and intermittent flows in the inlet and outlet creeks.

January 1974. Willis, Cunliffe and Tait (1974) completed a study on the conditions affecting the water quality of Quamichan Lake for the Municipality of the District of North Cowichan. The report concluded that the lake was in an advanced state of eutrification and that opportunities to improve conditions were limited. Solutions included: 1) identify and control major nutrient source inflow to the lake; 2) change the water movement to allow flushing at effective times rather than only during the winter flood period; 3) control lake levels with an adjustable weir to reduce the introduction of nutrients from flooded pastureland; 4) obtain additional information by completing the following:

- Conduct a flow measurement study in the creek draining the lake and in several (3) of the creeks flowing into the lake
- Inventory major fertilizer use in the watershed,
- Continue monitoring, include sampling at 6 lake locations,
- Collect bottom sediments to analyse total nitrogen and total phosphorus.

August 1979. A drainage feasibility study and benefit-cost analysis for Quamichan Lake was completed by Willis, Cunliffe and Tait (1979). The study provided preliminary plans for improvements to the drainage system and an analysis of the agricultural benefits that would result.

February 1985. Yaworski (1985) conducted a Small Lake Fisheries Enhancement Feasibility Study on Quamichan Lake. Water quality results indicated that Quamichan Lake was eutrophic with high nutrient levels. The low natural fish recruitment was attributed to limited spawning habitat area. Enhancement opportunities to improve recruitment were identified as being limited. Continued stocking with yearling cutthroat trout was recommended.

March 1987. DGV Engineering (1987) completed a Water Storage Feasibility Study for Quamichan Lake, at Ministry of Environment Lands and Parks (MELP) request. A low-level weir was recommended.

August 1987. Dr. Newroth (1987) responded to questions from Dr. Polack addressing aquatic weed issues. A list of aquatic plants identified in Quamichan Lake was provided, and species of concern were discussed. Aquatic plant control options were identified, with the installation of a bottom barrier recommended as the most cost-effective measure for small-scale treatment, and harvesting recommended for lake-wide treatment. Potential issues with the use of bio-control (i.e. grass carp, or white amur) were also outlined (i.e. ensuring sterility so that native fisheries were not impacted).

August 1987. Dr. Rick Nordin (1987) responded to algal questions from Dr. Polack. Nordin identified that nutrient enrichment is the primary cause of the algae and that its control in lakes is difficult. He outlined that in order to develop a strategy to reduce the nutrient input, identification of the nutrient source and timing is required. He also noted that while aeration could reduce the amount of nutrients liberated from the bottom, it is probably not applicable to Quamichan Lake because of its shallowness.

September 1987. Brams (1987) discussed Federal Fisheries Coho Research on Quamichan Lake. Brams explained that Coho were placed in the lake, which is not normally accessible to them, and the results of their introduction would be studied. He provided that Coho might experience difficulty leaving the lake because of the undefined nature of the outlet and the low flow conditions. He also noted that if the appropriate insect or shrimp-like creature is found to address the algae issues, it could be a benefit for fish.

September 1987. Fish Kill report completed by Provincial Fisheries (Scholten 1987).

September 1987. Quamichan Lake residents (1987) held a public meeting. The agenda identified that influences of waterfowl, animal, sewage, fertilizer and poor flushing on nutrient levels, and subsequent algae and weed growth would be discussed. Possible solutions to be reviewed included:

- Nutrients: reduce input, pickling liquor, aluminum addition, aeration, flushing and freshwater shrimp
- Weeds: reduce nutrients, local control by residents, cost-share control with small harvester, bottom barriers, sterile grass carp
- Lake pollution: assess to determine source (water fowl, human, animals)

January 1988. Fisheries Branch (Tutty 1988) responded to an invitation to attend a Public Works Committee meeting with the mayor and aldermen to discuss a proposed Quamichan Lake Management Plan. Fisheries provided an outline for a Management Plan that included but was not limited to the following components: Water Management (flood study & weir consideration), Water Quality (i.e. phosphorus assessment & options for removal), and Fisheries Management (i.e. debris removal at mouth of Quamichan Ck.).

January 1988. Polack (1988) produced a report that compiled inquiries made on Quamichan Lake issues and the resulting professional responses/technical information. Historic technical reports were also included. The compilation included for example, information on: aquatic plants of concern and their control options, algae and control options, nutrient contributions from geese and cattle, introductions of shrimp to reduce algae and of carp to control weeds, and bacterial pollution. The objective was to obtain assistance to develop a plan to assess and improve Quamichan Lake's water quality.

April 1988. Corley-Smith and Associates (1988) assessed the impact on the Cutthroat Trout population of Quamichan Lake from stocking the lake with Coho juveniles. Water quality conclusions provided that a high numerical abundance and low species diversity of phytoplankton was found, indicating lake eutrophication. As well, the lake's suitability for rearing sports fish, agricultural use, and human consumption could be affected by the blue green algae (i.e. can be toxic to mammals and can impart a muddy flavor to fish).

August 1988. The Corporation of the District of North Cowichan (1988) responded to the local stewardship group's requests to match funds pledged by local residents to undertake a water quality study, and to take subsequent action to address problems identified by the study. The District responded that while the local resident's efforts were supported, the costs to address the lake's problems were in excess of that which the local government could provide. Senior government support in covering the majority of water improvement costs would be required.

The District followed up by informing MELP Fisheries Program (Reid 1989) that $3,500 was raised by residents for a limnological study of Quamichan Lake. Fisheries' response was that if the study showed what the problem was, and if the solution related to fish habitat enhancement, then the Province could consider assisting with funding.

August 1990. BC Fisheries staff (Oliver 1990) collected temperature and oxygen data, and noted a heavy algal bloom.

October 1990. Provincial limnologist Rick Nordin (1990) provided BC Fisheries Program (Peter Law) with considerations to improve Quamichan Lake's water quality. The main nutrient source causing the algal problem was identified to be from the lake's bottom sediments, rather than runoff. Improvement strategies provided were as follows:

- Reduce cyanobacteria by altering conditions to encourage other phytoplanktonic forms. This involves lowering the pH of the lake by adding acid, since cyanobacteria thrive in the relatively high summer pH levels. At a lower pH, diatoms and green algae would dominate. Visual affects would improve since the diatoms and greens do not float on the surface and sedimentation rates would be higher. This should be tested in large experimental enclosures in the lake prior to full-scale treatment.
- Reduce the supply of phosphorus from the sediments by chemically binding or by sediment oxidation and consolidation. Aluminum or iron compounds would chemically bind phosphorus in lake sediments. On a small scale, oxidants such as nitrate could also be investigated to reduce the exchange rates between the sediments and water column. This would also require a summer of experimentation to determine doses and expected responses.
- Increase the export of phosphorus from the lake by increasing the water flow, or by selective removal of sediments from the zone of concern. Increasing the flow would provide the greatest certainty for improvement, but it would require the most in terms of cost and arrangements. Water could be obtained from the water pipeline supplying the Crofton pulp mill. The pipeline currently passes within 5 km of the lake, and

permission from the pulp mill may be granted to use some of the water during months when surplus is available (i.e. winter Nov.-Apr.).

- The use of hypolimnetic withdrawal also has a high likelihood of success. This would require installing a small diameter pipe (5 cm) and a pump to remove the semi-liquid decomposing recent sediments of the lake. Depending on the topography, establishment of siphon flow may be possible, but there may be problems with locating a site for discharging the sediments.

Approximate costs and areas where the Water Quality Branch could help were identified.

October 1990. BC Fisheries Biologist Ken Ashley (1990) responded to Rick Nordin's improvement strategy suggestions. He agreed with the plans, and offered the following considerations:

- Tests should be conducted in experimental enclosures before conducting full-scale pH reduction treatment. Circulating the lake with compressed air reduces pH. The system used depends on the lake morphometry, with other BC examples available at Langford Lake and in Interior lakes.
- Experience with aluminum addition in Washington State has shown effectiveness for only 2-4 years. Applying an oxidant is also relatively safe.
- The seasonal availability of water from the Crofton pulp mill is out of phase with the limnological requirements, although it would still increase the flushing rate.
- Discharging the waste resulting from hypolimnetic siphoning may be an issue with Waste Management Branch, but these nutrients could be a valuable addition to the Cowichan River.

The file does not indicate that any of Nordin's or Ashley's recommendations from 1990 were carried out at Quamichan Lake.

November 1994. A Stock Assessment Report was completed (Chan and McCulloch 1994). On the date of the study, the state of the fishery appeared to be good.

1996. Holmes (1988) completed the State of the Water Quality of Quamichan Lake Report summarizing data from 1988. Conclusions from this report were as follows:

- Spring sampling indicated that in recent years there were less nutrients in the water column (e.g. total phosphorus, total dissolved phosphorus, ammonia). This may be the result of a change in the amount of nutrients entering the lake or from a change in lake processes.
- Total phosphorus values were outside the limits for aquatic life in 1992 and 1993, but within the limits for 1994 and 1995. The criteria for drinking water and recreation use were exceeded in 1992, 1993 and 1995.
- Total phosphorus is the limiting nutrient for algal growth.
- Due to high fecal coliform levels, Art Mann Park Beach has been unfit for swimming since 1986. Values have increased between 1973 and 1995. This may be due to waterfowl populations.
- Three water quality indicators (aluminum, copper and zinc) exceeded the criterion for protecting aquatic life.

Recommendations included developing and implementing a remediation plan to improve water quality; continue monitoring to track exceedances to the criteria; and to identify water quality changes resulting from activities such as urbanization, changes in non-point discharge, and biological activity.

In June 1997 (Baraclough 1997), August 1998 (Broadland 1998), and August 2003 (Stephen 2003) fish kills were noted. Reports identified fish kills due to algal blooms and resulting oxygen depletion. The 2003 event was quite large with 100+ rainbow trout and stickleback reported mortalities, as well sculpins and sunfish.

March 2002. The Salmonid Protection and Production Plan for the Cowichan Valley Regional District (Burns 2002) report was produced. In terms of Quamichan Lake and its water quality, this report discussed that the lake has been enriched considerably, and that it is highly responsive to eutrophication due to its small catchment area, low flushing rate and shallow nature. Algae and rooted aquatic plants have also increased markedly. The report noted that of Quamichan Lake's eleven inlets, five are polluted by barnyard and pasture run-off. This report discussed opportunities for improving the fish production in Quamichan Creek. Improvement opportunities and planning requirements that were identified relating to Quamichan Lake and its water quality were as follows:

- Review the results of the coho colonization program. Relate the results to other similar lake stocking programs, and update program designs for Quamichan Lake.
- Provide an outlet control, through the placement of a low level weir (near the stream gauge in R5 of Quamichan Creek). Cut an improved channel from the weir to the lake and siphon the lake to some degree when the outlet falls below the lake level.
- Restrict further consumptive water use unless storage is possible.
- Address nutrient inputs from agricultural activities. Survey all basin farms to establish waste management needs.
- Check septic tanks (i.e. the area below Maple Bay Rd. north of the Garth Way is still on septic) to ensure appropriate function and that seepage to the watercourse is not occurring.
- Give a high priority to protecting the shore zone of Quamichan Lake (almost entirely class 1 with extensive riparian and shoal development but highly intruded), and the landscape unit at the outlet of Quamichan Lake.
- Aquire more greenspace/public land in the Quamichan Basin including in the Quamichan Lake shore zone.

September 2003. Local residents contacted the Provincial EP Division regarding water quality concerns (Epps 2005). Preliminary meetings occurred during the winter, and in the spring 2004 a volunteer lake sampling program was initiated. This involved local residents conducting biweekly sampling at the deep station site (EMS E207465), collecting temperature, dissolved oxygen, and secchi disk data.

In addition EP staff sampled at the deep station site three times in 2004 (February, August and November). This sampling included the collection of: nutrients and general parameter data at three depths, a water column profile, and plankton data (both plant and animal).

August 2004. During routine water quality sampling EP staff observed that a fish kill had just occurred on Quamichan Lake (Epps 2005). This was reported to Provincial Fisheries staff, and the incident was investigated.

November 2004. Quamichan Lake Stocking Assessment (Fosker and Philp 2004) was completed. The water quality results at the time of the assessment (Oct. 26, 2004) indicated that the temperature and oxygen values were suitable for fish in the upper 7m of the water column, but below this oxygen levels were not suitable for trout.

The August 2004 fish kill incident was also discussed. It was described as being extensive, resulting from depleted oxygen following the die-off of an algal bloom. This event was more severe than those of the past (i.e. August 2003, and June 1997) because all of the lake was affected, as opposed to the kill being localized to only the downwind portions. Following the 2004 event, data collected by EP staff indicated oxygen values at 2.3 -2.5 mg/L in the upper 2 m, and values which rapidly declined below the thermocline to 1.6 mg/L at 3m and 0.2 mg/L in the 2 m above the bottom.

Conclusions stated that current conditions were satisfactory for sustaining fish in the lake, but that the fish kills can deplete the trout population. The removal of natural lakeshore vegetation and development of lawns and pastures in extensive areas around the lake have resulted in elevated nutrient loading. These circumstances will cause algal blooms and resulting fish kills, particularly during warm and sunny summer weather.

March 2005. Provincial EP staff conducted spring overturn water quality sampling (Epps 2005).

May, August and November 2005. Provincial EP staff conducted water quality sampling (Epps 2005).

June 2005. A multi-agency meeting was held to discuss Quamichan Creek. The meeting was initiated as a result of concerns over beaver dams on Quamichan Creek flooding agricultural lands at the north end of Quamichan Lake (Burns 2005). Meeting minutes as they related to Quamichan Lake Water Quality Planning were as follows (Haddow 2005):

- A longer range planning commitment is necessary, with connections to the Cowichan River Planning processes currently in progress. The District of North Cowichan would be asked to lead the development of a watershed plan, because of the extent of urban development influences on the watershed.
- Landowners requested a coordinated approach to drainage system management to deal with the obstruction and flooding issues in McIntyre and Quamichan Creeks.
- Water quality concerns in the lake were discussed. Solutions included:
  - ⇒ Reducing nutrient flows to the lake, by educating current and future land owners (including golf courses) on appropriate lawn and landscape management practices; having farmers follow a nutrient management plan that assures crops take up all nutrients applied; maintaining drainage systems to reduce flooding; fencing livestock away from the lake; decreasing waterfowl populations (i.e. by hunting, and discouraging feeding); checking septic system function and conducting required maintenance/upgrading; checking storm drains for possible cross connections with sewer lines.
  - ⇒ Improving storm water management, by infiltrating or storing road surface and roof top water rather than by removing the water to the storm drain system.
  - ⇒ Constructing a weir on Quamichan Creek, to increase water flow out of the lake during the spring summer and fall period. This would benefit Trout and Coho.
  - ⇒ Construct a lake aeration system, to increase water oxygen levels (similar to that of St. Mary's and Glen Lake's).
  - ⇒ Release salvaged Coho fry into Quamichan Lake, as they would take up and remove nutrients from the lake. This would require improving the outlet or building the weir.

August 2005. Wayne Haddow (2005) provided the results of the June 2, 2005 Quamichan Watershed meeting to the District of North Cowichan, with a request for the District to take a lead role in developing and implementing a watershed management plan. Suggested items for the management plan included:

- Inviting all interest groups to meet, to initiate the development of the plan; ensuring to discuss the creation of a weir on Quamichan Creek.
- Completing a survey of elevations on lowlands and stream bottoms of Quamichan and McIntyre Creeks and the adjacent lowland areas.
- Clearing the outlet of Quamichan Creek.
- Obtaining Environment Canada's water level information for the stream gauge on Upper Quamichan Creek.

August and October 2005. Provincial EP staff conducted water quality sampling (Epps, 2005).

4.2 Water Quality Data Collection

The Province's Water Quality Section has collected data at Quamichan Lake from 1988 to 2005. This information has been stored in the Province's EMS database, and is identified as EMS E207465. The database shows that parameters sampled and frequencies of data collected have varied throughout the years, with no data collected during 1989, 1990, 1991, 1996 and 2003. As depicted in Figure 2, all data was collected at the Deep Station Site located in the southeast portion of the lake (Latitude 49^{o} 04' 13" N, Longitude 123 ^{o} 48' 30" W).

A review of MOE's Nanaimo Regional Fisheries file, provided additional water quality data going back to 1951. For the preparation of this report, the EMS spreadsheet for Quamichan Lake was updated with these additional records, in order to provide an extensive data set for improved analysis. Table 3 provides a list of the inclusions from the Fisheries file.

The updated spreadsheet incorporating the EMS and the Fisheries data, has not been not included in this report, due to its size. A copy of this spreadsheet can be obtained through a request to the MOE Nanaimo Regional Office.

Table 3. Additional water quality data added to the Provincial EP EMS spreadsheet for the preparation of this report

Reference	Sampling Date	Data Collected
Vernon 1951.	July 19, 1951	secchi depth, total dissolved solids (TDS)
Klein and Heathman 1972.	May 2, 1972	secchi depth, temperature, dissolved oxygen (DO)
Yaworski 1985.	July 3, 1985	pH, TDS, specific conductance, nitrogen (organic, total kjel, dissolved ammonia), total phosphorus (TP), secchi depth
Scholten 1987.	September 21, 1987	temperature, DO, secchi depth
Corley-Smith and Assoc. 1987.	October 15, 1987	temperature, DO, secchi depth, specific conductance
Corley-Smith and Assoc. 1988.	May 14, 1987; October 2, 1987; February 3, 1988	secchi depth, TDS, conductivity
Corley –Smith and Assoc. 1988.	May 11, 1988	temperature, DO, pH, TDS
Corley –Smith and Assoc. 1989.	March 16, 1989	temperature, DO
Author unknown 1989.	June 23, 1989	temperature
Oliver 1990.	Aug 15, 1990	temperature, DO, secchi depth
Author unknown 1990.	April 12, 1990	secchi depth, temperature
Chan & McCulloch 1994.	Nov 24, 1994	secchi depth, temperature
J. Baraclough 1997.	June 20, 1997	secchi depth, temperature, DO
Fosker and Phlip 2004.	October 25, 2004	secchi depth, temperature, DO, pH
Ministry of Environment / Quamichan Lake Stream Keepers 2004.	June 1, 8, 15, 23; July 1, 8, 14, 27; August 10, 18, 31	temperature, DO
Epps 2005.	August 4, 2005	Full compliment of WQ data (incl. anions, metals, nutrients, physical, and misc).
Epps 2005.	October 19, 2005	true colour, TP, turbidity

5.0 Methods

5.1 Limnological Sampling

Generally, water sample collection followed BC sampling standards. Sampling since 1997 followed the methodologies and practices laid out in the following BC Resource Inventory Committee (RIC) Sampling Manuals: Ambient Fresh Water and Effluent Sampling Manual (RIC 1997), and Freshwater Biological Sampling Manual (RIC 1997). Water samples requiring laboratory analysis were shipped, according to protocols, to the laboratory under contract to the Provincial Government at the time. All laboratories followed standard Canadian analysis methodologies and samples were analysed using equipment that was available at the time.

Epps (2005), provided the following specifics on sampling methods used for recent field measurements (February, August, and November 2004; and February 2005) collected by EP field staff at Quamichan Lake:

> Grab samples were taken for chemical analysis. Water column samples were collected using a Van Dorn sampler. Samples were shipped on ice in coolers to government-contracted laboratories for analysis. Water chemistry grab samples were taken at 2-3 depths throughout the water column (surface, mid and 1 m from bottom) and analyzed for the following parameters:
>
> > Physical: pH, color true, specific conductance, turbidity
> > General inorganics: alkalinity
> > Nitrogen: total Kjeldahl, total, total organic, ammonia, nitrate+nitrite
> > Phosphorus: total, total dissolved
> > Metals: total metals
> > Carbon: total inorganic and total organic
>
> A Hydrolab Surveyor 4 was used to obtain field based data on temperature, dissolved oxygen, pH, specific conductance and oxidation-reduction potential. Water was sampled at 1 m intervals down to the lake bottom (approximately 8 m).
>
> Chlorophyll a samples were collected using a hand-operated vacuum pump to filter 500 mL. of surface water through a 0.45 micron membrane filter. The filter paper was then analyzed for chlorophyll a. The phytoplankton and zooplankton samples were preserved with Lugols and formalin, respectively. All biological samples were placed in coolers with ice and shipped to the government-approved lab for species identification and counts.

Lake stewards collected water quality data in June to August 2004. Dissolved oxygen and temperature profiles were collected using a YSI dissolved oxygen meter. Secchi depth was also recorded following standard methods.

5.2 Water Quality Guidelines

In order to report on the status of Quamichan Lake, all data was reviewed against the British Columbia Approved Water Quality Guidelines (Ministry of Environment 1998), and the Canadian Council of Ministers of the Environment, Canadian Environmental Quality Guidelines (CCME 2003). These together will herein be identified as ‘the Criteria’.

Each parameter that has established Water Quality Criteria had its values reviewed against the Criteria. For a given parameter, data was compared to the limits set for all applicable defined water uses. With this, drinking water, aquatic life, and recreation uses were commonly triggered for review, but estuary and marine use limits were not considered. Water uses where the Criteria were within the range of Quamichan Lake's values were reviewed and all results were summarized. Those water uses where the Quamichan values were much lower than the Criteria were generally not recorded.

5.3 Graphing with Depth

For graphing purposes, both measured values and respective depths were presented to best depict trends and spatial relationships. In order to complete this, and to keep graphs relatively unencumbered, data was grouped into standard depth ranges, and values within these ranges were averaged when graphing. The depths representing Surface, Mid and Bottom zones were selected based on data availability and zones of expected uniform values. Depth ranges and the selection rationale for the parameters reviewed in detail are as follows:

For **Temperature, DO** and **pH** parameters, profiles of data were often available from the surface to the bottom, inclusive. With this vast amount of data, the following depth ranges were selected, because they most closely represent typical stratified conditions (epilimnion, metalimnion, hypolimnion):

- Surface (0 – 2 m)
- Mid Depth (2.1 – 6.9 m)
- Bottom (7 – 8 m)

For **all other parameters** depth ranges were determined by finding the closest fit of the available data to the zones of uniform values (i.e. stratified conditions). With this, consideration had to be given to the fact in recent years, data was often collected at a depth of 1.0 m from the bottom. This grab sample was intended to provide bottom readings, although because of lowered lake levels it often meant that samples were collected at 6 m (rather than between 7 and 8 m as was designated above for the bottom). Because of this, the mid depth and bottom depth ranges had to be adjusted from those demarcated for temperature, DO and pH. The depth ranges for all other parameters are thus as follows:

- Surface (0 - 2 m)
- Mid Depth (2.1 – 5.9 m)
- Bottom (6-8 m)

5.4 Averaging Values Below Detection Limits

An average was provided for parameters that underwent detailed review. For statistical purposes values below detection limits were treated as a zero when averages were calculated.

6.0 Overview of Water Chemistry Results

6.1 Parameters That Exceeded the Water Quality Criteria

Each parameter having established Water Quality Criteria had its values reviewed against the Criteria. Parameters reviewed, Criteria exceedances and the frequency of the exceedances are summarized in **Appendix 2 - Table 7**.

The results indicate that the following parameters exceeded the Criteria during the sample period, and these will be reviewed in greater detail in the section to follow:

General Parameters

- Colour, True
- Dissolved Oxygen
- Temperature
- pH
- Turbidity

Nutrients

- Carbon, Total Organic
- Phosphorus, Total

Biological

- Chlorophyll a
- Extinction Depth
- Coliforms, Fecal
- *Escherichia coli*

Metals

- Copper, Total
- Iron, Total
- Manganese, Total
- Thallium, Total
- Zinc, Total

6.2 Nitrogen Parameters

As Table 7 (Appendix 2) provides, none of the nitrogen parameters had values that exceeded the Criteria. Although the Criteria were not exceeded, the following nitrogen parameters will also be reviewed in detail in the section that follows, because of their significance as nutrients and their influence on algal growth:

- Nitrate +Nitrite, Dissolved
- Ammonia

6.3 Metals With High Detection Limits

When comparing data to the Criteria, many metal parameters had minimum limits of detection that were significantly higher than the Criteria between 1992 and 2002. These values could not provide an accurate account of whether the Criteria were met or not. For these parameters more emphasis was put on the 2004 and 2005 data, which had much lower detection limits. The lower limits of detection are likely the result of improved and more precise technologies.

As indicated in Table 7 (Appendix 2), metals where the high detection limits were noted between 1992 and 2002 were as follows:

- Antimony
- Arsenic
- Cadmium
- Copper
- Lead
- Manganese
- Nickel
- Selenium
- Silver
- Thallium

6.4 Review of Annual Averages for Parameters Undergoing Detailed Review

Annual averages were reviewed to help quantify results between the years and to indicate any trends for the parameters that had a detailed review. For each parameter, the most significant time periods and/or depth ranges were selected for this evaluation. Results are provided in **Appendix 2- Table 8,** and summarized as appropriate in the detailed reviews.

7.0 Detailed Review of Water Chemistry Results:

General Parameters

7.1 Colour, True

> *True colour is a measure of dissolved colouring compounds in water. Colour is regarded as a pollution problem in terms of aesthetics, and increased colour may interfere with light passage impeding photosynthesis. Anthropogenic influences may include agriculture and industrial effluent* (RIC 1998).

True colour data has been collected annually at Quamichan Lake between 1992 and 2005 (excluding 1996 and 2003). A review of all raw data indicates that values ranged from <5 - 20 true colour units (TCU), with an average of 9.5 TCU. The Drinking Water Criteria (max. for aesthetics) of 15 TCU was exceeded by 7 out of 52 samples (13%). These exceedances occurred at various times of the year in 1992 (February, August, & September), 1999 (April) and 2002 (March). Peak values of 20 TCU were recorded for all of these dates. The lowest values (below detectable levels) were recorded in February & November 2004 and May 2005.

Figure 5 depicts True Colour data with depth at Quamichan Lake, and the results indicate the following:

- In 1992 where data was collected monthly, the annual cycle indicated that values peaked in the late winter (February), gradually dropped through the spring to a low in June, rose to peak again through the summer (August – September), and fell slightly through the fall and early winter months. Wetzel (2001) described that most color of lake water results from large concentrations of dissolved organic matter (DOM); however, large suspensions of inorganic materials such as clays, and large concentrations of suspended algae can also contribute to the color of a lake. It is postulated that DOM influences the True Colour baseline at Quamichan Lake, which appears to be around the 5 TCU mark and that peaks are dependent on seasonal influences. Assuming this, algae could be the key contributor to colour peaks during the growing season, and the addition of clays and fine sediments would contribute during the winter rainy period.
- It is uncertain what caused the highs experienced in February 1992 and March 2002. These highs do not follow that which would be expected from the annual cycle, and do not appear to be explained by a review of the other parameters.
- When the values between the depth ranges were compared, the majority of samples showed consistency with depth. Where differences between the depths occurred, the surface depths more often had the higher value indicating a greater influence.

Other than 1992, where data was collected monthly, most data was collected during the spring. Average spring values provided in Appendix 2-Table 8, indicates fluctuations over the years, with 2004 and 2005 values having the lowest values and 1992, 1999 and 2002 having the highest.

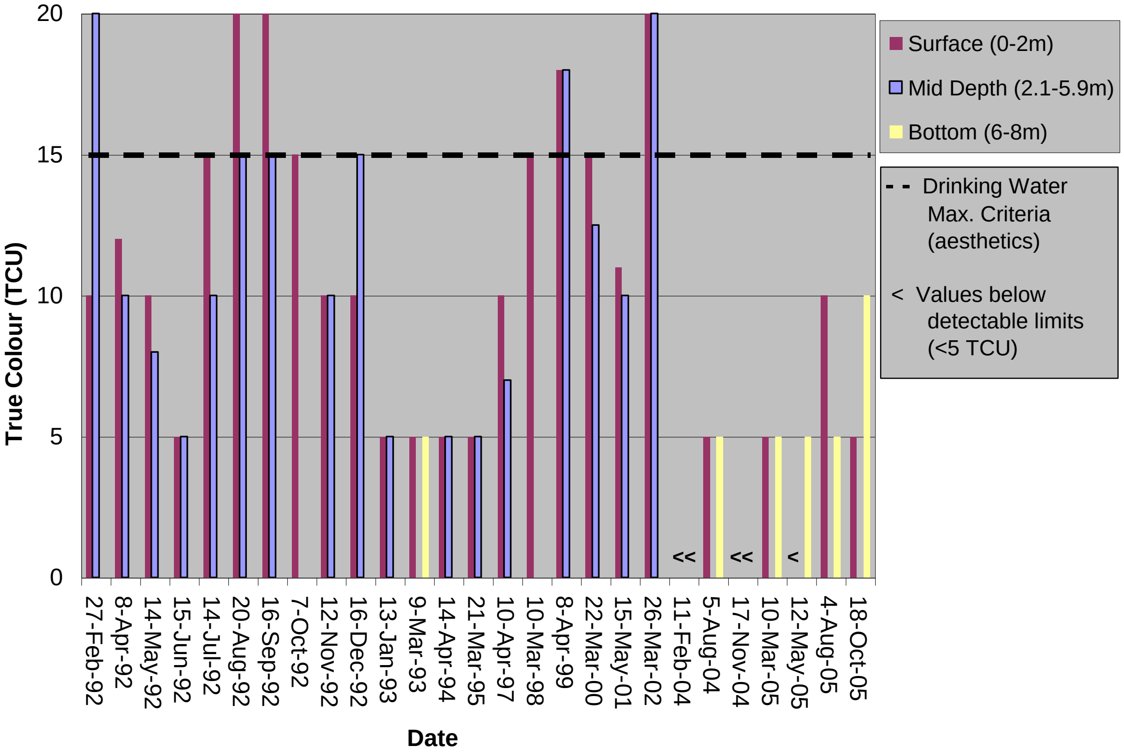


Figure 5. True Colour with depth at the Quamichan Lake deep station site, for the period of 1992-2005.

7.2 Dissolved Oxygen (DO)

DO is crucial to life in lakes. The BC Lakes Stewardship Society (BCLSS 2003) summarizes that oxygen enters the water from the air, by wind, and plant photosynthesis; and that it is consumed by respiration of animals and plants, including during the bacterial decomposition of dead organisms. The BCLSS (2003) also explains that the productivity of a lake influences its DO availability, with unproductive (oligotrophic) lakes having sufficient DO to support life at all depths through the year; while productive (eutrophic) lakes typically do not have enough DO, particularly near the bottom where dead organisms accumulate.

DO data has been collected at Quamichan Lake in 1972, 1987-1990, 1994, and 2004-2005. A review of all raw data indicates that DO values ranged from 0.04 to 20.00 mg/L, and averaged 6.9 mg/L. The minimum DO Criteria for Aquatic Life Stages other than Buried Embryo/Alevin is 5 mg/L. This minimum was not met in 26% of samples collected at Quamichan Lake.

Figure 6 depicts DO values averaged into the three depth ranges between 1972 and 2005. An annual representative profile, showing DO values throughout the water column for the period of June 2004 – May 2005 is also provided in Figure 7. From these charts, the following is evident:

- DO values show an annual pattern of being uniform or nearly uniform with depth through the winter (November – February), with values throughout the water column being high and exceeding the minimum Aquatic Life Criteria of 5mg/L. As the surface temperatures increase through the spring and into the summer, DO levels at the lower depths decrease, with bottom depth values typically falling substantially below the Criteria from May-October, and middle depths values falling below the Criteria from June – September. By mid November, water column DO values equilibrate, with mid and bottom depth values increasing to become more hospitable to aquatic life.

- Over the years, bottom DO levels in the fall have tended to be around the 5 mg/L mark, and have rose as high as 12 mg/L through to the spring. The summer bottom levels have dropped as low as 0.21 mg/L (Aug 2004), and during the summer of 2004 where intensive sampling was conducted a bottom average 1.17 mg/L was calculated.

Low DO levels are known to result in a variety of undesirable affects on a lake's water quality, including:

- DO affects the solubility and availability of nutrients, and therefore the productivity of aquatic ecosystems (RIC 1998). The release of Total Phosphorus from the sediments as a result of diminished DO is a particularly significant issue to Quamichan Lake, which will be reviewed in detail further in this report (see Section 8.2.3 DO Influence on Phosphorus Release From Sediments).
- Low DO levels can lead to changes in lake biota, by altering zooplankton migration, growth, reproduction and survival (Nordin 1985). Low DO levels also affect fish by altering their food supply and creating poor habitat conditions (Nordin 1985).
- Low DO levels diminish drinking water quality, particularly because the bottom waters are the preferred location for water intakes due to their low algal biomass and cooler temperatures *(*Nordin 1985).

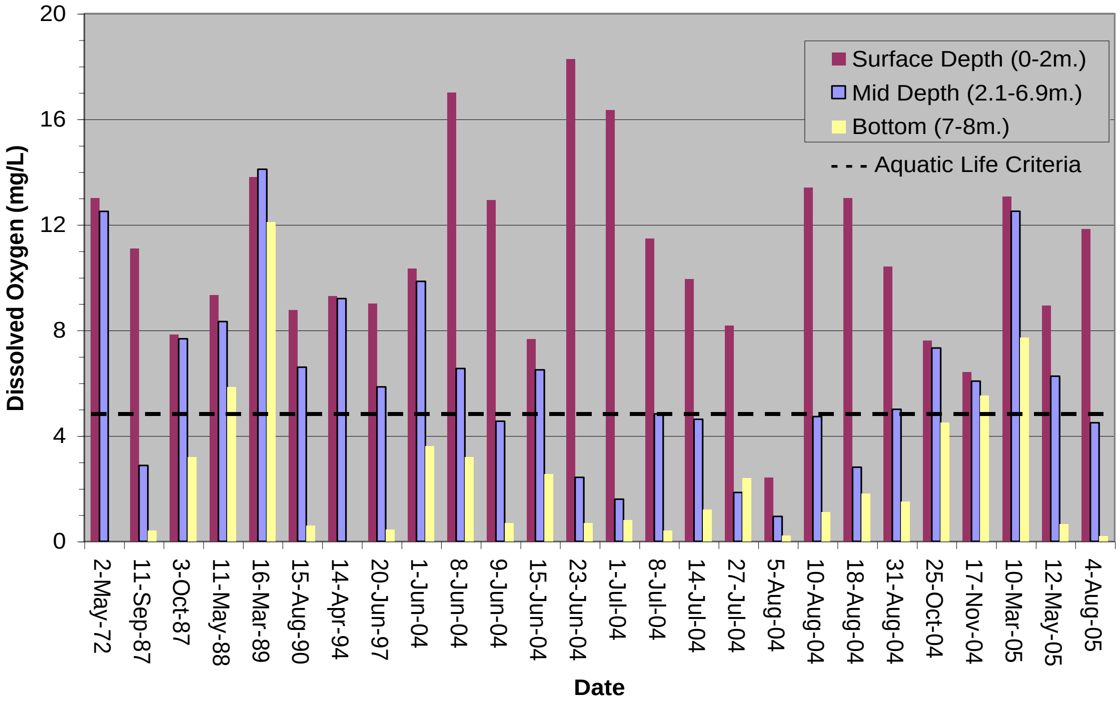


Figure 6. Dissolved Oxygen averaged with depth at the Quamichan Lake deep station site, for the period of 1972 – 2005.

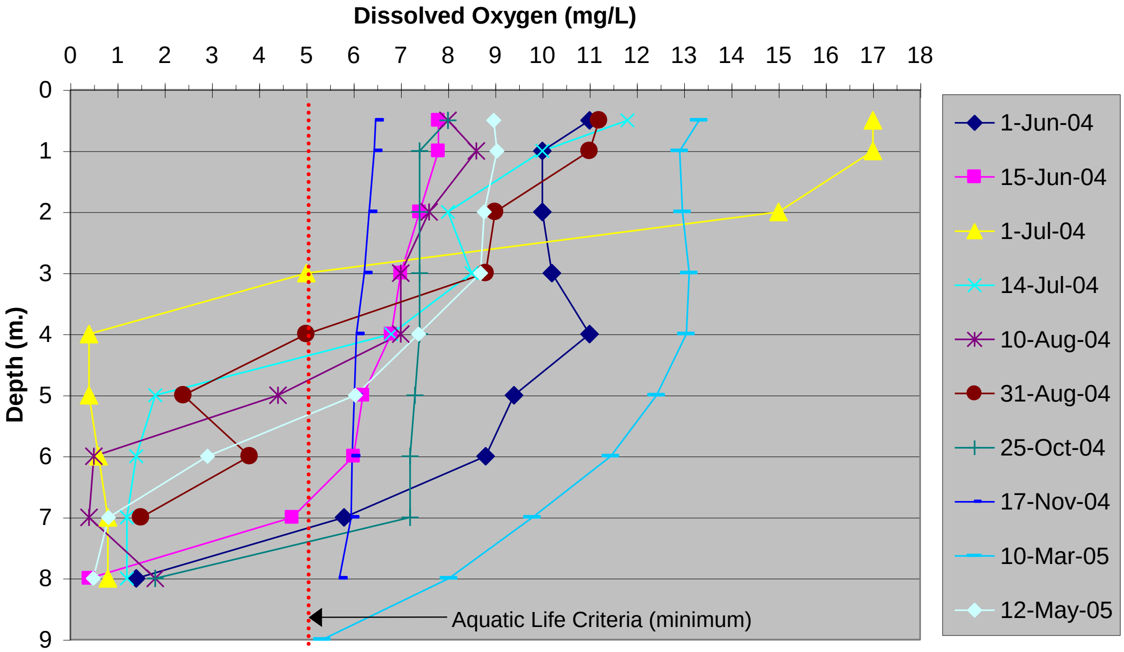


Figure 7. Representative annual Dissolved Oxygen profile (June 2004 – May 2005) at the Quamichan Lake deep station site.

7.2.1 DO and Fish Kills

The frequency of DO not meeting the Aquatic Life Criteria (minimum 5mg/L) has been found to impact fish, particularly during the summer when they seek out cooler waters in the bottom depths. Table 8 (Appendix 2) provides that during the summer period (July – August), the cooler bottom water DO values have been very low averaging 0.195 – 1.17 mg/L. No obvious increasing or decreasing trend is apparent for the data available. The impacts that these conditions have on the fish are evident, with fish kills periodically occurring at Quamichan Lake. As the Chronological Review provides (Section 4.1) fish kills were reported to have occurred in September 1987 (Scholten 1987), June 1997 (Baraclough 1997), August 1998 (Broadland 1998), August 2003 (Stephen, 2003), and August 2004 (Epps 2005).

Fish kills are typical of productive lakes such as Quamichan Lake, and are triggered by algal growth (BCLSS 2003). Fish kills often occur during the summer months because as this report will reveal, it is during this period that light, temperature and nutrient conditions are often optimal for algal growth. When the algae decompose and/or respire, they use up the DO resulting in DO deficiencies in the bottom depths in particular (BCLSS 2003). The fact that the water column is stratified during the summer also exacerbates the problem, because this results in little mixing between the DO deficient bottom depths and the oxygenated surface waters (see Section 7.3 Temperature).

Algal blooms and subsequent DO deficiencies and fish kills can also occur when the water column mixes, bringing nutrient rich waters up from the bottom depths (BCLSS 2003). At

Quamichan Lake this mixing or turnover occurs during the fall (see Section 7.3 Temperature), and is likely the cause for the September 1987 fish kill.

Fosker and Philp (2004) provided additional specific details on the fish kill events that occurred at Quamichan Lake. They described that prevailing winds typically concentrate algal blooms on the downwind end of the lake, exacerbating the problem there while at the same time mitigating the situation in the upwind portion of the lake. Because of this, they reported that the June 1997 and August 2003 fish kills were relatively localized, with fish surviving in other parts of the lake. Fosker and Philp (2004) further identified that the August 2004 event was more severe with dead fish found over the whole of the lake, not only the downwind portions. DO measurements collected by Provincial EP staff one week following the fish kill confirm that the whole area of the lake experienced low DO levels (Deniseger 2004).

These DO results are depicted in Figure 6 on Aug. 5, 2004. The data indicates extremely deficient DO values, not only at the bottom depths, which is typical, but right up the water column to the surface, which would have left the fish with no place to seek refuge. These DO values as a water column average were the lowest overall recorded for the lake. A review of other parameters on this date indicates that other records were set, with ammonia and carbon levels being the highest ever recorded, and bottom total phosphorus reaching the highest values for the year. Temperature values were also high but typical for August. The 2004 fish kill thus appears to have followed the typical cycle of high summer temperatures and nutrient levels fuelling an algal bloom. The bloom's die off and its decomposition on the bottom resulted in the lowered DO levels and the elevated ammonia levels (which is the end-product of bacterial decomposition of organic matter (Wetzel 2001)). The high phosphorus levels would also be related, occurring as a result of the anoxic bottom conditions causing the release of phosphorus from the sediments into the water column (see Section 8.2.3 DO Influence on Phosphorus Release From Sediments). The high total organic carbon levels could also be indicative of the elevated level of degrading algal material in the lake.

7.3 Temperature

The significance of lake temperature is summarized by RIC (1998) as follows:

> *Temperature affects the solubility of many chemicals and can therefore influence the effect of pollutants on aquatic life. Increased temperatures elevate the metabolic oxygen demand, which in conjunction with reduced oxygen solubility, impacts many species. Vertical stratification patterns that naturally occur in lakes affect the distribution of dissolved and suspended compounds.*

Quamichan Lake has significant algal concerns, with temperature playing an important role in the algal cycle. Temperature is associated with increased light and heat, which fuel photosynthesis and increase algal growth. In addition, temperature stratification patterns in the lake also affect oxygen availability, which in turn affect phosphorus levels entering the water column from the bottom sediments (see Section 8.2.3 DO Influence on Phosphorus Release From Sediments).

Quamichan Lake temperature data is available for 1972, 1987-1990, 1994, 1997 and 2004 - 2005. A review of all raw data indicates that temperature values ranged from 4.8 – 26.0^{o}C, and averaged 17.0^{o}C. The Drinking Water Criteria is 15^{o}C max. and the Aquatic Life Criteria (for optimal rainbow trout rearing) is 18°C max. The Drinking Criteria was exceeded in 46% of individual collected samples. The Aquatic Life Criteria was exceeded in 35% of samples. Temperatures generally exceeded the Drinking Water Criteria in the surface depths starting in May, with exceedances progressing into the bottom depths in June through to September. The Aquatic Life Criteria is typically exceeded in the surface depths in June, in the mid depths by July, and in the bottom depths by August, extending until September. The extents of the exceedances are due largely to the facts that the lake is relatively shallow and that it has no inflow during the summer.

Figure 8 displays the temperature results averaged with depth, and Figure 9 provides an annual representative temperature profile showing the 2004/05 data. The interpretation of this data can be summarized as follows:

Seasonal Temperature Cycle

- The lake's water column is coolest and mixed with a uniform (or isothermal) temperature during the winter (November - April data).
- The waters then become stratified during late spring through the spring as surface temperatures increase (i.e. May). During this stratified period an upper layer of uniform temperature waters exists (the epilimnion), and below the surface temperatures decrease with depth forming a thermocline (the metalimnion layer). A hypolimnion layer, or area of constant temperature in the lowest stratum occurs. There is resistance to mixing during this period, due to the differences in temperature and densities of each of the layers.
- Throughout the summer, solar heat penetrating into the water column increases the surface temperature of the water, moving the epilimnion lower. By June, the lake becomes nearly uniform in temperature. During the hottest periods of summer (July and August data), the waters become stratified again, with the surface layer getting much warmer (up to 25°C) than the lower depths. This is not to say that the bottom depths are cool, as they maintain temperatures typically exceeding the Criteria.
- Although little late summer/early fall data is available for Quamichan Lake, during this period lakes typically experience cooling surface waters. The cool layer sits on the warmer bottom layers until such time that a fall turnover occurs. This is where the warmer and less dense bottom waters mix with sinking cooler and denser surface waters, resulting in an isothermal water column (Wetzel 2001). The Quamichan Lake data shows that this mixing occurs by October. Nutrients being distributed up through the water column from the bottom are a significant and important result of the fall turnover event for Quamichan Lake.

Peak Values

- Although the peak value of 26°C was reported at 0.5m on July 27, 2004, comparable highs occurred during each summer sampled. Table 8 (Appendix 2) also confirms that summer averages for the water column (21-22.3°C) and for bottom depths (18.2-19°C) have been consistently high over the years. These high temperatures leave no place for fish to seek refuge during the warm summer months. The poor habitat availability for fish would also be exacerbated by the low oxygen availability at depth described earlier, placing added stresses on the fish and resulting in die-offs.

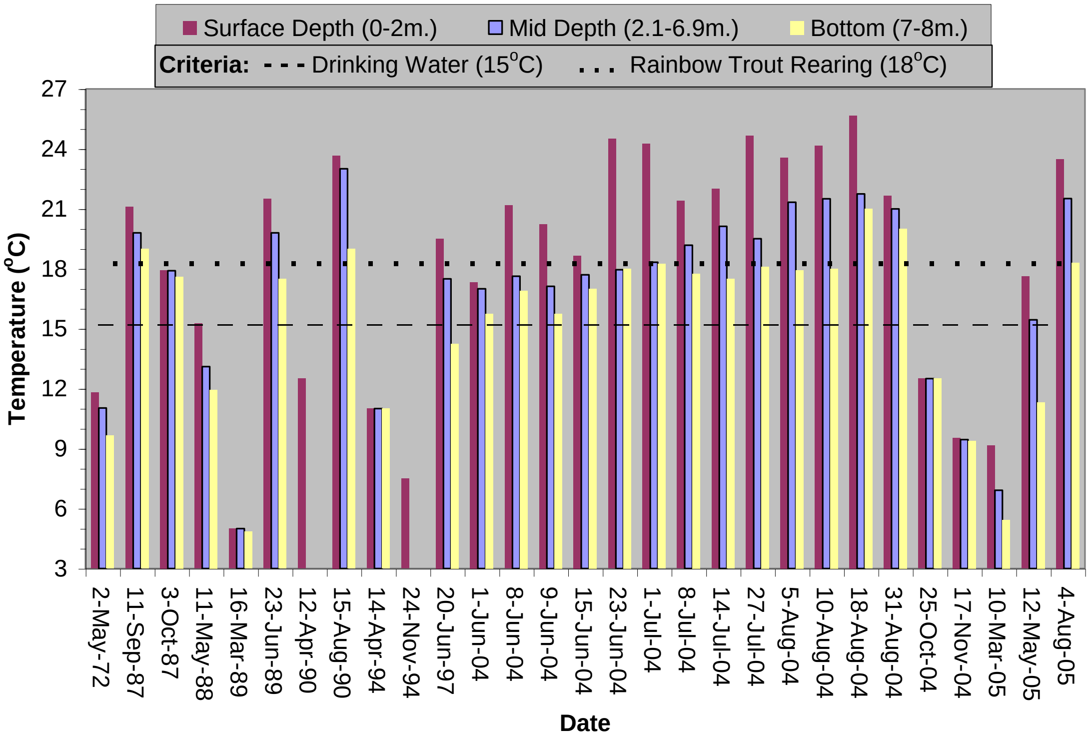


Figure 8. Temperature data averaged with depth at the Quamichan Lake deep station site, for the period of 1972 – 2005.

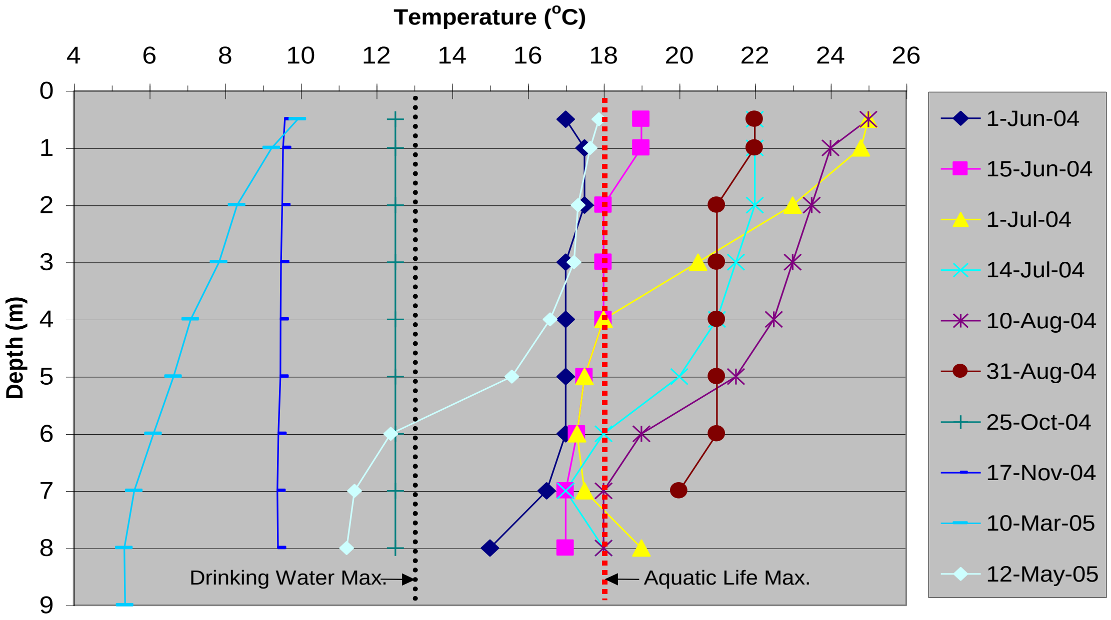


Figure 9. Representative annual Temperature profile (June 2004 – May 2005) at the Quamichan Lake deep station site.

7.4 pH

RIC (1998) offers the following general background description on pH:

> *pH is a measure of hydrogen-ion concentration, with levels below 7 indicating acidic conditions, and above 7 basic conditions. pH is significant because high values tend to facilitate the solubilization of ammonia, heavy metals and salts. Low pH levels tend to increase carbon dioxide and carbonic acid concentrations. Anthropogenic influences on pH can include agricultural activities, mining, industrial effluents, and acidic precipitation.*

pH data has been collected at Quamichan Lake in 1972, 1985, 1988, 1993-1995, 1997-2002, and 2004-2005. pH values ranged from 6.2-8.9 pH units. The average calculated from all sampling data is 7.3 pH units, indicating that the lake generally has a neutral pH. The Drinking Water Criteria is range between pH 6.5-8.5 and the Recreation/Irrigation Criteria ranges between pH 5-9. Individual raw data values indicate that overall most samples (88%) fell within the Drinking Criteria, and that no exceedances to the Recreation/Irrigation Criteria occurred.

The Maximum pH Criteria for Drinking Water was exceeded in 5/85 (or 6%) samples, with all exceedances occurring on Aug. 5, 2005. The highest value of 8.9 pH units was recorded on this day at 0.5 m. The Minimum pH Criteria for Drinking Water was also not met in 5/85 (or 6%) samples, and these exceedances occurred on May 12, 2005. The lowest pH value of 6.2 pH units was recorded on this date at 0.5 m.

Figure 10 showing PH values averaged with depth at Quamichan Lake, reveals the following:

- Values generally appear to be consistent with depth. Where differences exist, surface values tend to be higher than lower depth values. The greatest differences in pH through the water column are exhibited during the summer when the lake is stratified.

  Wetzel (2001) supports these findings by describing that the vertical pH distribution in lakes is strongly influenced by biological reactions. He provides that high surface pH values result from photosynthesis in the upper light penetrated waters, while respiration and decomposition processes decrease pH values in the lower waters. He also identifies that these vertical changes in pH are known to rapidly occur in eutrophic lakes, where under conditions of intensive photosynthesis by phytoplankton, the pH can undergo significant fluctuations within the course of a day.

Annual averages were reviewed for spring values prior to stratification, which is the period when pH is expected to be most stable (Appendix 2 Table 8). Results indicate that the annual averages fluctuate slightly around the lake's average of 7.3 pH units, with no increasing or decreasing trend apparent.

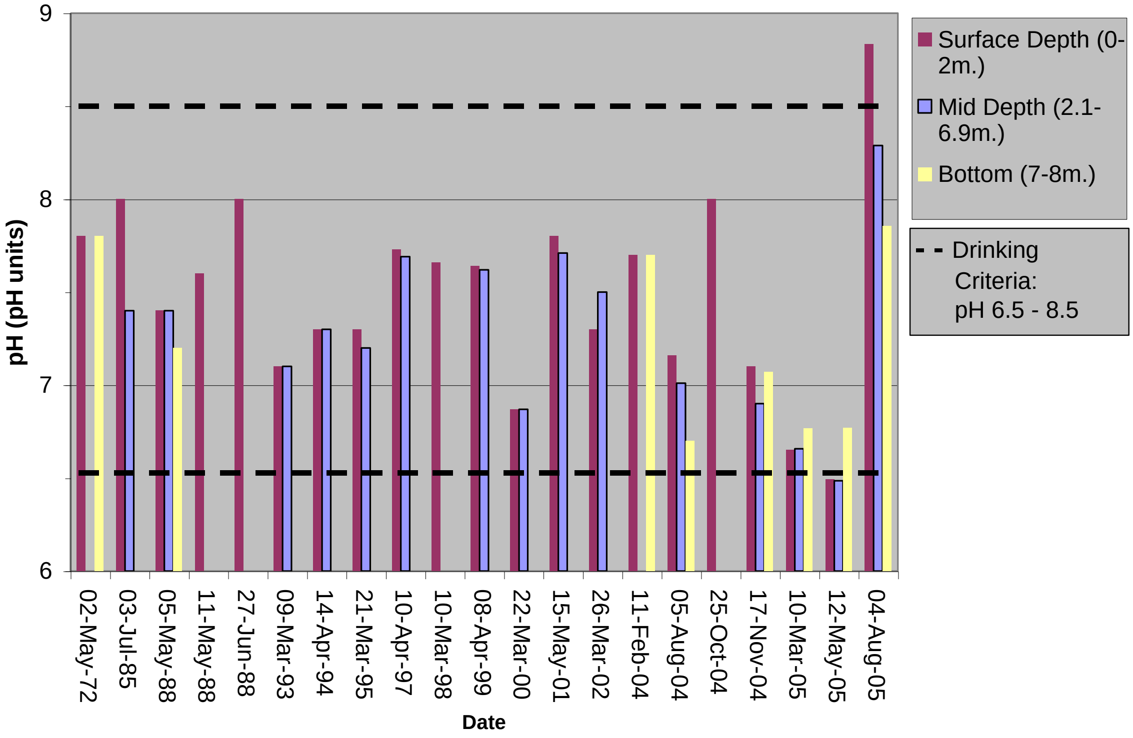


Figure 10. pH averaged with depth at the Quamichan Lake deep station site, for the period of 1972 – 2005.

7.5 Turbidity

> *Turbidity is a measure of suspended particulate matter in a water body. Silt, clay, organics or micro-organisms can contribute to turbidity. High turbidity results in a high surface area of suspended solids for bacteria to grow on. It reduces light penetration, impairing photosynthesis, which in turn may suppress fish productivity. Turbidity also interferes with drinking water disinfection and is aesthetically unpleasant. Anthropogenic sources can include: forest harvesting, road building, agriculture, urban developments, and sewage effluents.* (RIC 1998)

Turbidity data has been collected at Quamichan Lake in 1995, 1997 – 2000, 2004 – 2005. A review of all raw data indicates that turbidity values range from 0.9-8.1 NTU, and average 2.1 NTU. The CCME Drinking Water Criteria for health is 1 NTU max., and 5 NTU max. for aesthetics. The 1 NTU (health) Criteria was exceeded in 78% (18/23) of individual samples, and the 5 NTU (aesthetic) Criteria was exceeded in 17% (4/23) of samples.

Figure 11 shows the results of the turbidity data with depth, and reveals the following:

- The highest recorded values occurred in November 2004 and October 2005. These were the only two sample dates that had values exceeding the 5 NTU Drinking Water Criteria max. (aesthetics). As well, these fall values far exceeded the other samples collected, which were mostly from the spring. Although there are only two years of fall data available, these highs are likely typical during this period, resulting from soil erosion within the catchment basin entering the lake as run off during rain events. Wetzel (2001) confirms that soil erosion as well as resuspension of the bottom sediments are where turbidity usually originates. Bottom sediments becoming suspended (perhaps as a result of winds) may be evident through much of the spring data where bottom values are higher than surface values.

- Annual spring average values provided in Appendix 2 - Table 8 do not show a clear increasing or decreasing trend; however, 2004, 2005 values are amongst the highest.

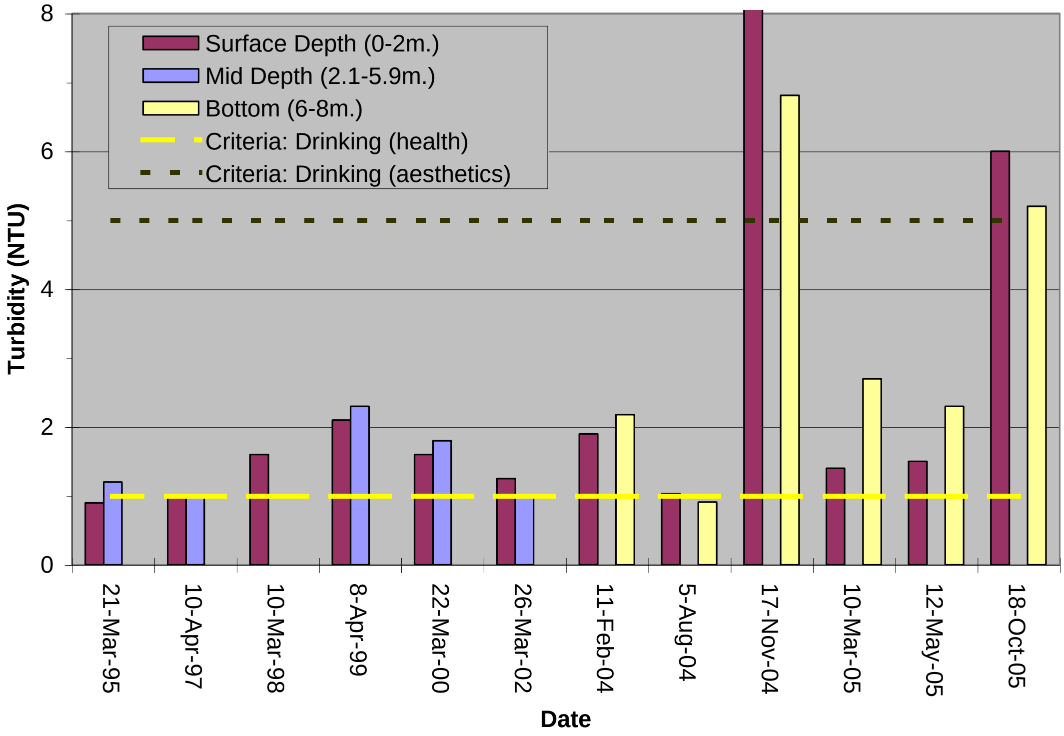


Figure 11. Turbidity with depth at the Quamichan Lake deep station site, for the period of 1995 - 2005

Nutrient Parameters

7.6 Carbon, Total Organic (TOC)

> *Total Organic Carbon is a measure of the dissolved and particulate organic carbon in water, which is mainly composed of humic substances and partly degraded plant and animal materials. Organic carbon is resistant to microbial degradation. Carbon is important because it is a nutrient required for biological processes. High levels of organic carbon coincide with a lowering of DO concentrations. Anthropogenic sources can include agriculture, and municipal and industrial waste discharge.* (RIC 1998)

TOC data has been collected at Quamichan Lake during the years of 1997 – 2002 and 2004 – 2005. A review of all raw data indicates that TOC values ranged from 3.0 - 7.3 mg/L, and averaged 4.8 mg/L. The Drinking Water Criteria for chlorinated water is 4 mg/L max. Levels above this value may lead to trihalomethane formation (a potential carcinogen), if the water is chlorinated (RIC 1998). The Criteria was exceeded in 88% (15/17) of samples. The two samples where Criteria exceedances did not occur were both in March of 1998 and 2005.

TOC data with depth (Figure 12) portrays that the highest values occurred in August 2004. Here the surface and mid depth values both were markedly higher than the Criteria, and higher than all the other available data (all of which was collected through the spring or winter, prior to stratification). The August 2004 TOC highs coincide with record DO lows (discussed in Section 7.2 DO) and are thus likely attributed to an algal bloom die-off. If more summer data was available, it is expected these types of high TOC levels would be typical.

A review of the calculated annual spring averages (Appendix 2 Table 8) indicates fluctuations over the years, with no increasing or decreasing trend apparent.

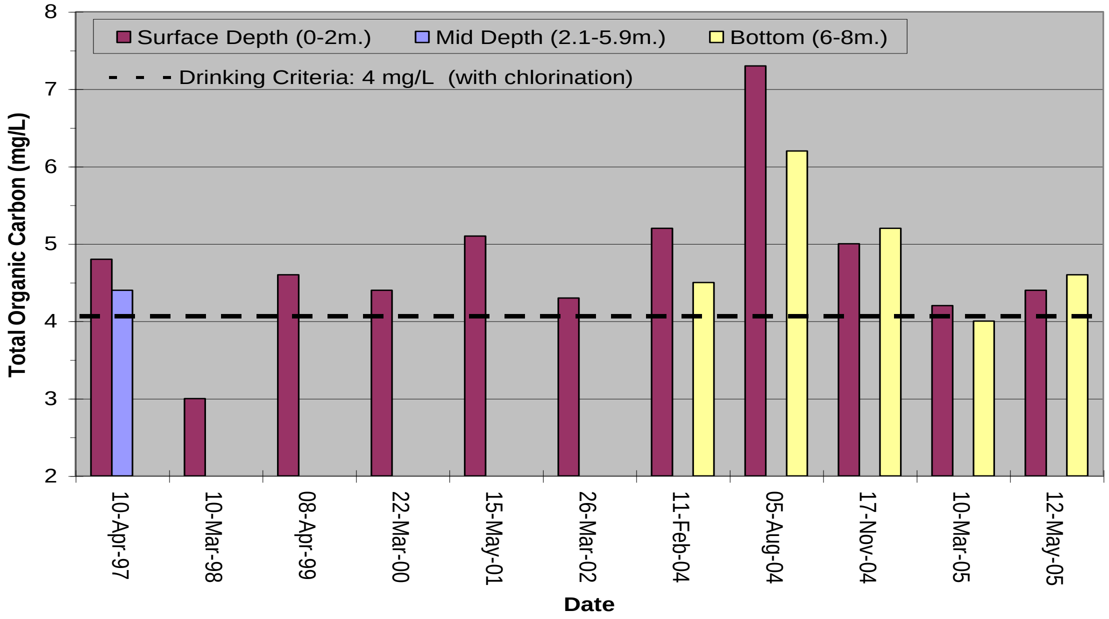


Figure 12. Total Organic Carbon with depth at the Quamichan Lake deep station site, for the period of 1997 – 2005.

7.7 Phosphorus, Total (TP)

The best approximation of bioavailable phosphorus in lakes is TP (Nordin 1985). The RIC manual (1998) summarizes the importance of phosphorus as follows:

> *Phosphorus is an essential plant nutrient and is often the most limiting nutrient to plant growth in fresh water. Because of this, its input to fresh water systems can cause extreme proliferations of algal growth. Inputs of phosphorus are the prime contributing factors to eutrophication in most freshwater systems. Anthropogenic sources can include sewage effluent, agriculture, urban developments (particularly from detergents) and industrial effluents*.

TP data was collected at Quamichan Lake during the period of 1985, 1988, 1992-1995, 1997-2002, 2004-2005. A review of all raw data provides that TP values ranged from 5-255 µg/L, and averaged 60 µg/L. The TP Criteria for Drinking Water and Recreation is 10 µg/L maximum, and this was exceeded in 90% (or 60/66) samples.

The Aquatic Life Criteria maximum, set to protect salmonids from oxygen depletion in the hypolimnion, is a range between 5 µg/L and 15 µg/L. Nordin (1985) describes that this range allows for the individual characteristics of lakes to be taken into account; with effects on fisheries and on salmonids in particular being the primary determiner of the maximum. At Quamichan Lake, the lower range of the Criteria (i.e. 5 - 10 µg/L) should most likely be considered as the maximum. This is because Quamichan Lake and its salmonid species have shown sensitivities to higher TP levels, including DO depletions in the hypolimnion and fish kills. The fact that the lake is not highly flushed, also contributes to its TP sensitivity. The 5 µg/L was exceeded in 98% (65/66) of samples, and the 15 µg/L was exceeded in 83% (55/66) of samples.

Spring overturn is the standard reference for gauging the supply of phosphorus to the lake over the following summer growing period (Nordin 1985). Figure 13 provides the results of spring overturn data for Quamichan Lake. This figure shows substantial fluctuations in values over the years, with 2004 having the highest value (38.4 µg/L), and 1998 having the lowest (6 µg/L). Of the 11 years of data, all but two years (1994 and 1998) exceeded the Drinking and Recreation Criteria. The Aquatic Life Upper Maximum was exceeded in seven of the years, and the Aquatic Life Lower Maximum was exceeded in all eleven years.

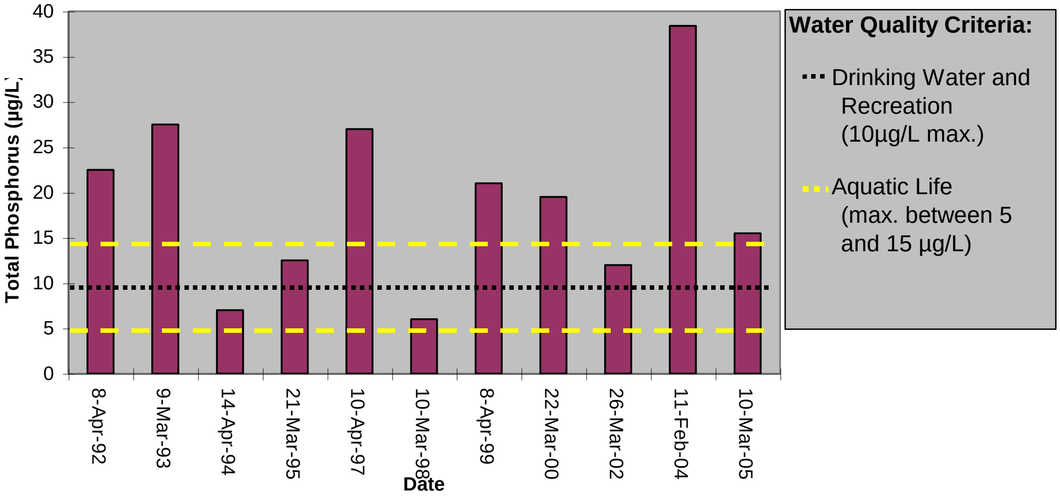


Figure 13. Average Total Phosphorus levels during spring overturn at the Quamichan Lake deep station site, for the period of 1992 – 2005.

Figure 14 depicts all available TP data for Quamichan Lake. From this, the following conclusions can be drawn:

- TP levels are lowest during the winter and spring. Values get progressively higher through the summer months, peaking in September.
- The highest values were reported in September 1992, with 250 µg/L at the surface and 255 µg/L at the mid depth.
- Throughout the year and particularly during the summer, values at the lower depths were most often higher than those of the surface. This indicates that TP levels are being driven by activities/processes in the bottom depths.

Appendix 2 - Table 8 provides summer water column TP averages for Quamichan Lake going back to 1985. All averages were very high (above 100 µg/L) and no trend is apparent from the data available.

Phosphorus levels and phosphorus distribution in productive lakes such as Quamichan are determined by a number of factors including: run-off and turn over events in the fall, nutrient uptake by algae, settling of algae, and internal loading from the sediments during anoxic periods. These occurrences and their effects on productivity will be reviewed in greater detail in Section 8 - Trophic State and Algal Growth.

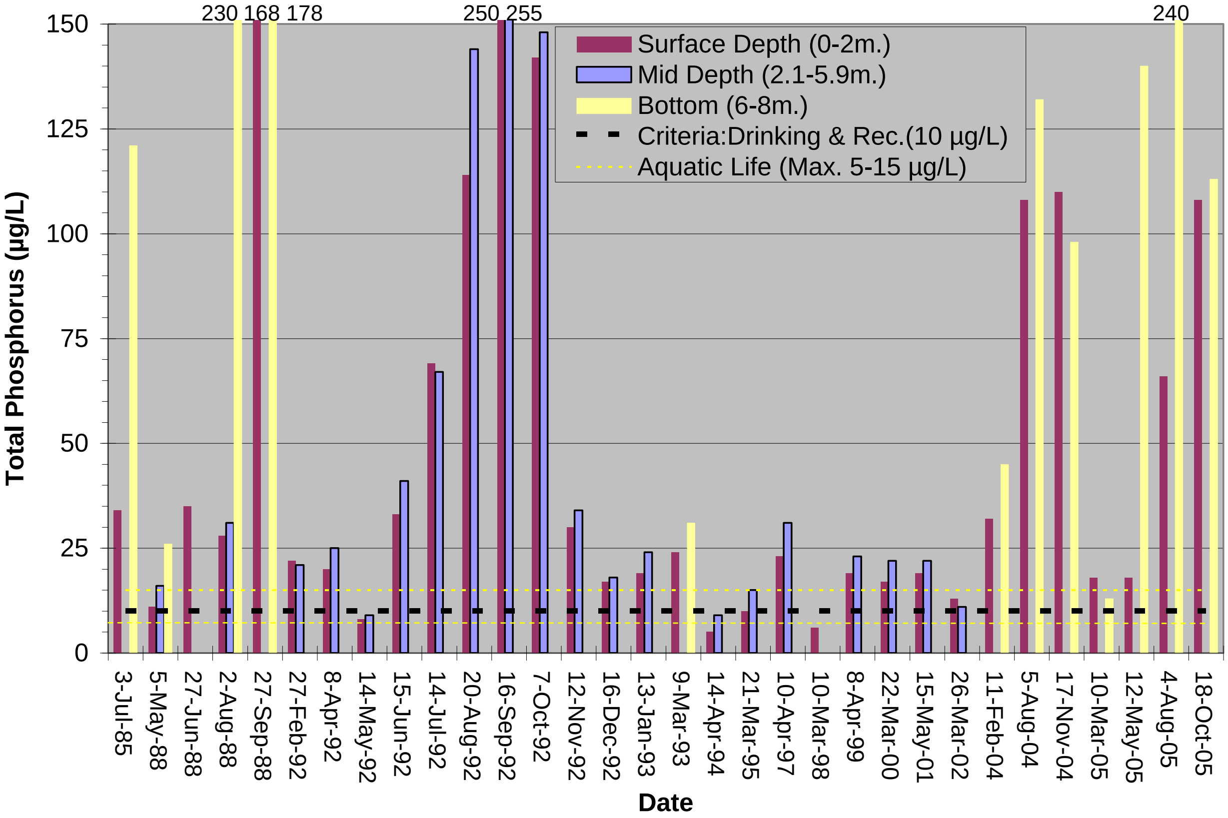


Figure 14. Total Phosphorus with depth at the Quamichan Lake deep station site, for the period of 1985 – 2005

7.8 Nitrogen (Dissolved Nitrate + Nitrite and Ammonia)

While none of the nitrogen forms exceeded the Water Quality Criteria, nitrogen will be reviewed because of its importance as a nutrient. Nordin (1985) provided that nitrogen is second to phosphorus, as a major nutrient required by algae. Nordin also identified that nitrogen limitation of freshwater algal growth is less common than phosphorus limitation because blue-green algae can fix atmospheric nitrogen. Of the nitrogen forms, dissolved nitrate + nitrite and dissolved ammonia will be reviewed because of their importance to plant growth. Summary information on these parameters is as follows):

> ***Nitrate*** *is particularly important because it is the most stable form of nitrogen in a water body, and it is the main nitrogen form used by plants as a nutrient to stimulate growth.* ***Nitrite*** *is an intermediate form of nitrogen, which is unstable and rapidly oxidizes to nitrate or is reduced to nitrogen gas.* ***Ammonia*** *is the most reduced inorganic form of nitrogen, and although it is only a small component of the nitrogen cycle, excess amounts can contribute to the eutrophication of water bodies, by causing prolific algae growth. The anthropogenic sources of these nitrogen forms include sewage treatment effluents, agriculture, urban developments, recreation, industrial effluents, and blasting residues (*RIC 1998).

Dissolved nitrate + nitrite and dissolved ammonia data was collected at Quamichan Lake in 1985, 1988, 1992-1995, 1997 (ammonia only), 1998-2002, 2004-2005. The dissolved nitrate + nitrite and dissolved ammonia results are depicted in Figures 15 and 16 respectively. Appendix 2 Table 8 provides annual averages for each parameter. The following conclusions can be drawn from these results:

<u>Nitrate + Nitrite</u>

- Nitrate + nitrite values ranged from <0.002 - 0.100 mg/L, and averaged 0.015 mg/L. The nitrate and nitrite parameters were reviewed individually against their respective Criteria and both had all values far lower than the Criteria (see Appendix 2 Table 7).
- Nitrate + nitrite levels are highest through the fall, peaking by November or December. This is most likely related to rain/runoff events, since Wetzel (2001) describes that a major source of nitrogen to streams and lakes is from surface land drainage. Values drop significantly throughout the spring and summer period, often to levels below detectable limits. These low values are likely due to assimilation by plankton and nitrate reduction by bacteria (Wetzel 2001).
- Values fluctuated between surface and mid/bottom depths, with deeper waters generally having the higher values.
- The highest value of 0.1 mg/L was reported in October 1992. A review of average values over the freshet or fall/winter period would be valuable to gauge if runoff events were contributing higher or lower amounts of nitrate + nitrite to the system over time. As Figure 15 and Appendix 2 - Table 8 provide, freshet data is limited and a trend cannot be determined.

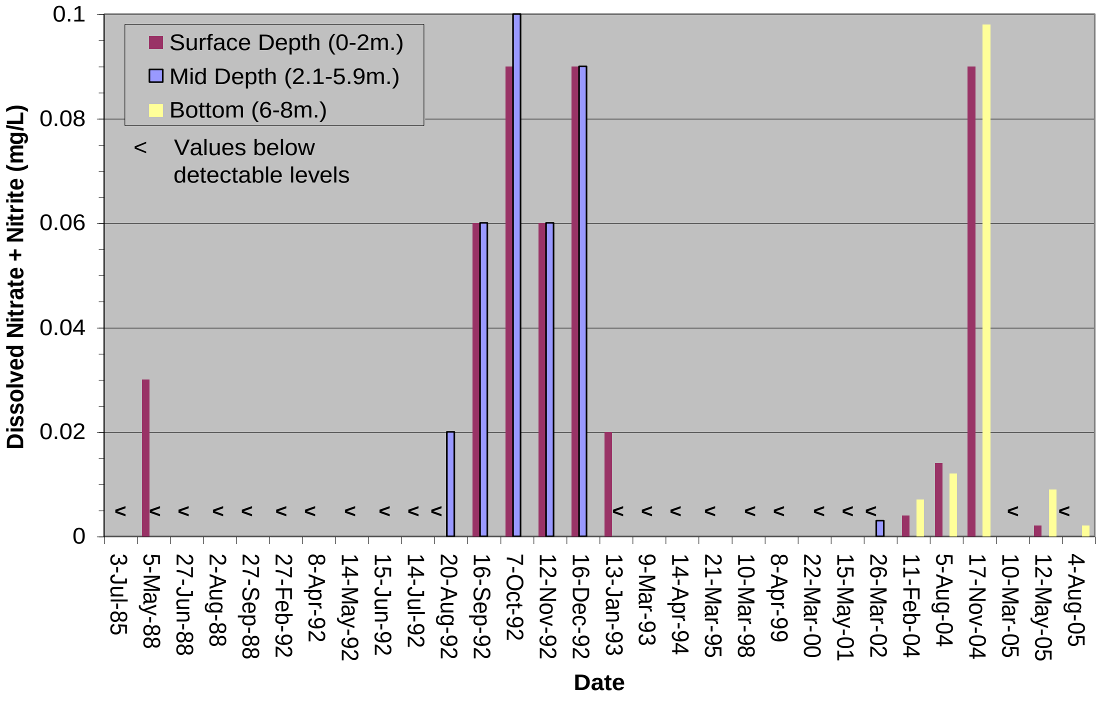


Figure 15. Dissolved Nitrate + Nitrite with depth at the Quamichan Lake deep station site, for the period of 1985 – 2005.

Dissolved Ammonia

- Ammonia values range from <0.005 – 0.900 mg/L, and averaged 0.080 mg/L. The ammonia Criteria is dependent on pH and temperature (MOE 1998), and during the periods of the highest temperatures and pH levels, ammonia values also at their highest, did not exceed the Criteria (see Appendix 2 Table 7).
- The highest ammonia levels occur during the summer months (July- September), with the mid and bottom depths most often having the highest values/influence on peaks. The elevated levels are likely the result of recent algal bloom die offs, since ammonia is the end product of bacterial decomposition of organic matter (Wetzel 2001). The highest ammonia values were recorded on August 5, 2004, with values of 0.8 and 0.9 respectively at the surface and at the bottom depths. These levels far exceeded any others on record.
- The lowest ammonia values tend to occur through the winter and spring, where they are often below detectable limits.

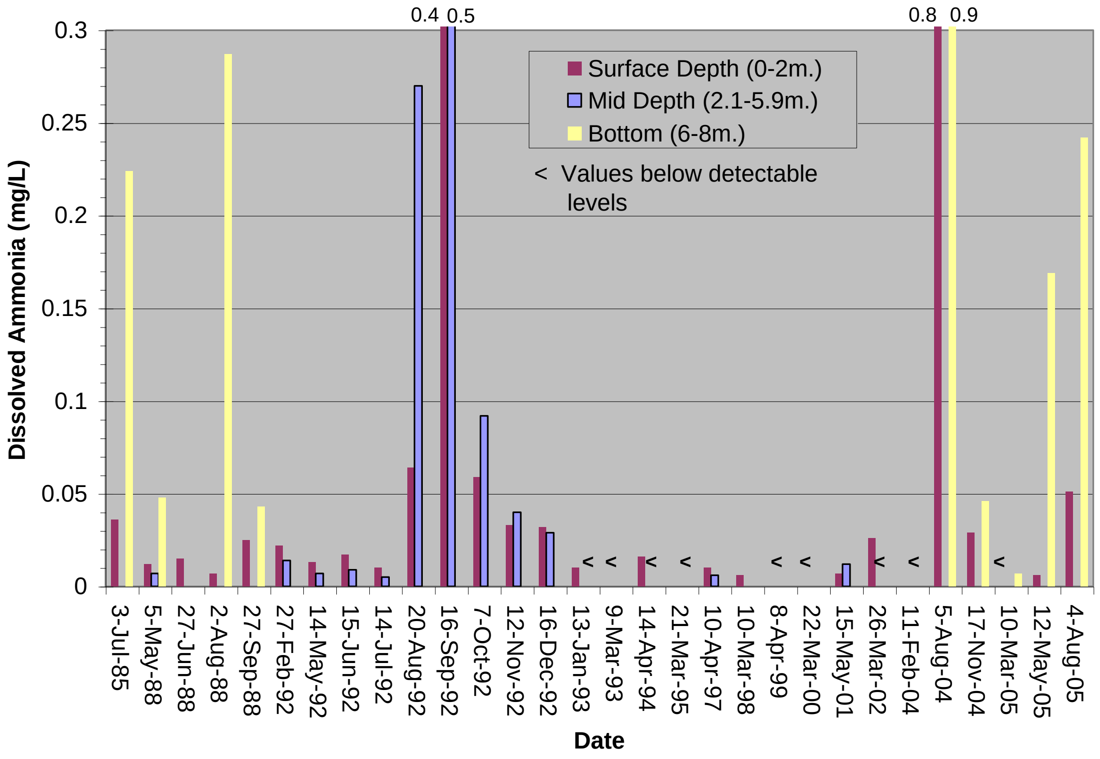


Figure 16. Dissolved Ammonia with depth at the Quamichan Lake deep station site, for the period of 1985 – 2005.

Biological Parameters

7.9 Chlorophyll a

> *Chlorophyll-a is a measure of phytoplankton (microscopic plants) or periphyton (microscopic plants on substrata) biomass in a body of water. High concentrations are a direct result of high nutrient inputs. Anthropogenic influences can include agriculture, sewage treatment effluent, forest harvesting, urban development, and recreation* (RIC 1998).

The availability of Chlorophyll a data at Quamichan Lake is limited to only four dates (three in 2004, and one in 2005). Values range from <0.5 to 81.9 µg/L, averaging 25.3 µg/L. The Drinking Water Criteria for chlorophyll a is 2-2.5 µg/L max. based on a summer average. All 2004 samples exceeded the Criteria, irrespective of season.

Figure 17 depicts the chlorophyll a results. Because the data set is small, conclusions regarding trends could not be determined. The data does indicate that phytoplankton and/or periphyton growth can remain high at Quamichan Lake even in the winter, where values peaked at 81.9 µg/L in November 2004.

The phytoplankton sampling results (see Section 8.2 Factors Controlling Algal Growth) substantiated the November 17, 2004 chlorophyll a peak, by showing very high levels of cyanobacteria. Turbidity values were also at peak levels on this day (see Section 6.5 Turbidity). Interestingly, other parameters expected to be associated with chlorophyll a (i.e. secchi depth and true colour) did not have corresponding high values for this date. Secchi depth and true colour values however, did show relationships with the chlorophyll a results on the other sample dates.

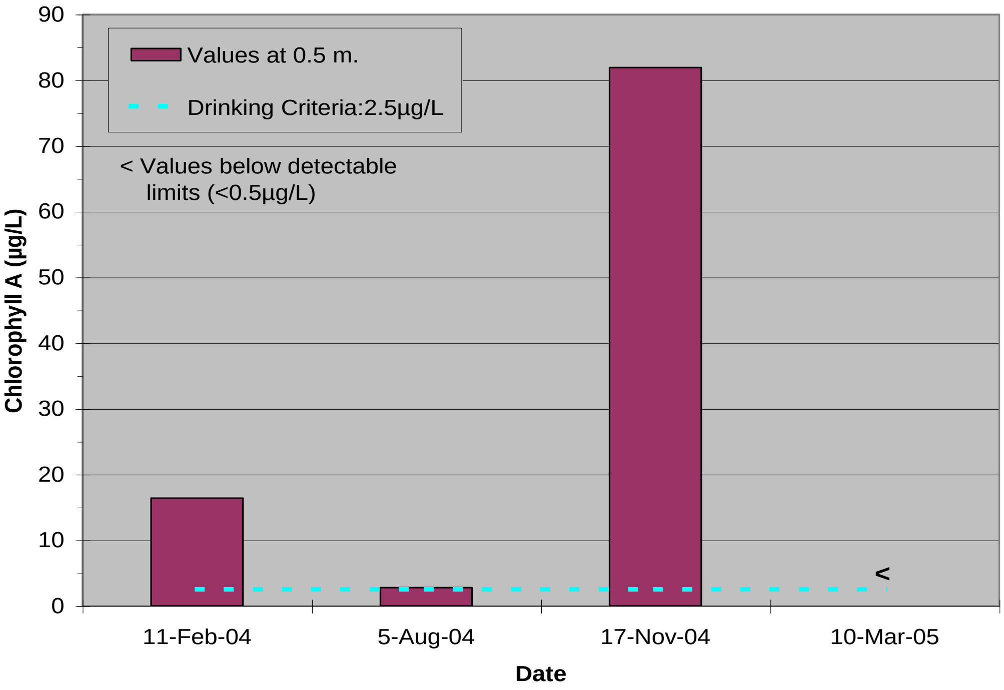


Figure 17. Chlorophyll a values at the Quamichan Lake deep station site, for the period of 2004 – 2005.

7.10 Secchi (Extinction) Depth

> *The Secchi disk transparency is the depth where a weighted white disk remains visible in the water. Secchi disk transparency is a function of reflection of light from its surface, and is affected by dissolved organic matter and suspended particulates. In productive lakes, secchi depth is a way to estimate the approximate density of phytoplankton populations* (Wetzel 2001).

Quamichan Lake Secchi depth data is available for the years of 1951, 1972, 1985, 1987-1988, 1990, 1994, 1997, and 2004-2005. A review of raw data indicates that values ranged from 0.5 – 4.5 m and averaged 1.9 m. The Recreation Criteria for secchi depth is 1.2 m (minimum). The Criteria was exceeded in 25% (8/32) of samples. Each of the instances where the Criteria was not met happened during June and July, and with 2004 having almost all of the June/July data on record, 2004 showed the poorest conditions overall.

The results of secchi depth monitoring are portrayed in Figure 18, and are summarized as follows:

- Quamichan Lake secchi values appear to fluctuate significantly throughout the year. Even within a month such as July or August, values can be below the Criteria one week and the following week be well above. Because of the highly productive nature of the lake, these fluctuations are most likely the result of phytoplankton population blooms and die-offs. Weather conditions such as rain and cloud cover can also effect sechhi readings (Epps 2005).
- The 2004 weekly data set is valuable in portraying summer conditions. This data shows that secchi depth was lowest (indicating algal blooms) in June and July, with record lows of 0.5 m. This was likely the result of optimal algal growing conditions in terms of light, temperature and nutrients. By August secchi values increased, which is likely due to the algae dying off and sinking to the bottom as a result of depleted nutrient and habitat conditions. Secchi values then declined again by the end of August and in October, indicating algal blooms. The August blooms were likely due to increased TP levels resulting from internal loading (see Section 8.2.2 Phosphorus Cycle and Algal Growth). The October blooms were likely the result of fall turnover improving nutrient conditions in the water column fuelling algal growth. Historic data shows that Secchi values then gradually increase through the winter (with a maximum of 4.5 m recorded in February 1988), until the spring/summer when growth conditions were once again optimal.

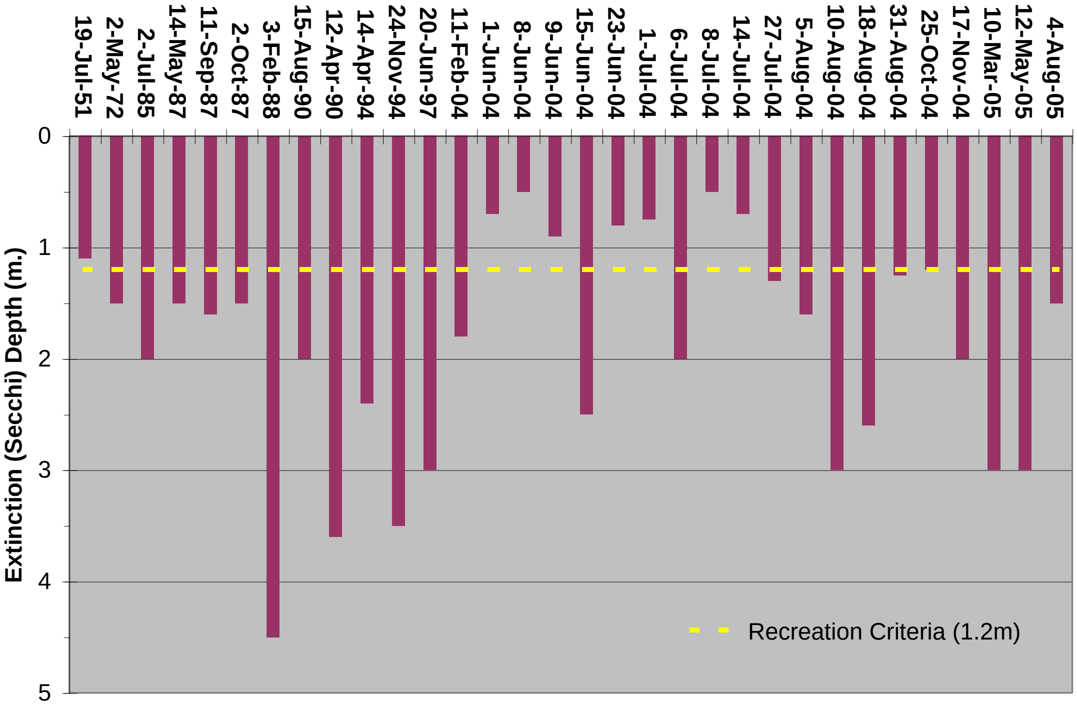


Figure 18. Secchi Depth at the Quamichan Lake deep station site, for the period of 1951 – 2005.

7.11 Microbiological Indicators (Fecal Coliform and Escherichia coli)

> *Fecal coliform estimates the degree of fecal contamination from human and animal wastes. Fecal coliforms are common to the intestinal tracts of humans and warm blooded animals, and are distinct from the non-fecal coliforms which are found naturally in soils and on vegetation. Fecal coliform bacteria are used as an indicator organism; whereby, its presence may indicate the occurrence of pathogenic organisms. Sources can include sewage treatment plants, recreation areas, pulp and paper mills, livestock, and urban runoff.* (RIC 1998).
>
> *Escherichia coli (E. coli), like Fecal coliform, is an indicator of pathogenic organisms. E. coli however, is known to have higher correlations with specific types of disease (i.e. gastrointestinal disease) under specified conditions than fecal coliform.* (Warrington 1988)

The Criteria for raw untreated water for drinking, livestock, and industrial purposes is 0/100 mL maximum for both fecal coliform and *E. coli*. As is evident in Figure 19 below, the data available to this study for these parameters is limited to only two days, one in March 2002 and one in November 2004. All values for both parameters exceed the Criteria. The March data was higher for both parameters at 52 and 42 CFU/100mL respectively for fecal coliforms and *E. coli*.

More data would be necessary to identify trends and to confirm risks to users; however, given the data available, water should be treated prior to consumption.

Additional fecal coliform and *E. coli* data could be attained through the Ministry of Health or the local Health Authority, with regards to the local beaches (i.e. Art Mann Park Beach).

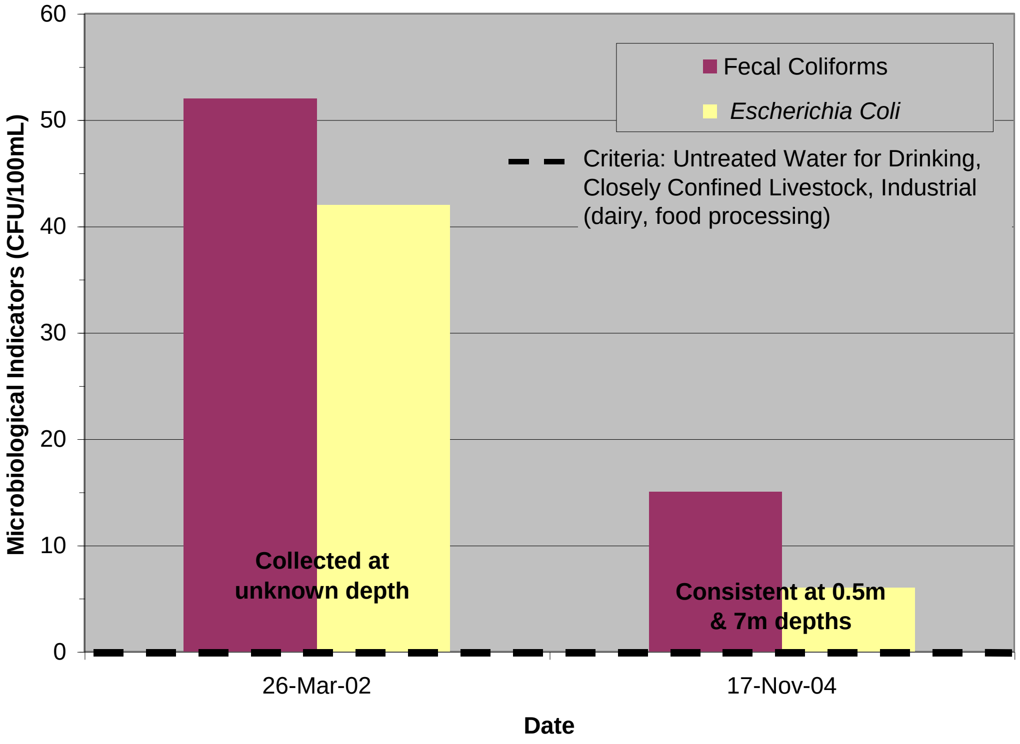


Figure 19. Pathogenic organisms (Fecal Coliforms and *Escherichia coli)* at the Quamichan Lake deep station site, for the period of 2002 and 2004.

Metal Parameters

7.12 Copper, Total

> *Copper is an essential micronutrient for all plant and animal nutrition. Increased quantities of copper make water distasteful to drink and very large prolonged doses may result in liver damage. Copper is acutely toxic to most forms of aquatic life at relatively low concentrations. In the presence of excess quantities of molybdenum in forage crops, copper can ameliorate molybdenum toxicity and prevent the onset of molybdenosis in cattle and other ruminants. Anthropogenic sources can include industrial effluents (may enter aerially through the atmosphere), mining and urban developments (plumbing)* (RIC 1998).

Total Copper data at Quamichan Lake is available for the years 1992 – 1995, 1997-2002, and 2004-2005. Calculations from all raw data indicate that values ranged from 0 to 6µg/L, and averaged 1 µg/L. The Provincial Criteria of 500 µg/L for Drinking Water, and 6 µg/L for Aquatic Life were not exceeded. The Aquatic Life Criteria established by the CCME ranges with a maximum between 2 and 4 µg/L. This CCME Criteria was exceeded with 28% (12/43) of samples recorded to be 2 µg/L or higher, and 5% (2/43) of samples 4µg/L or higher.

Figure 20 illustrates the Total Copper results with depth at Quamichan Lake and depicts that all Criteria exceedances occurred in 1992. The 1992 values were also the highest overall peaking at 6 µg/L in the bottom depths in May. The high bottom values in May and June of 1992 may be a result of settling organic detritus following an algal bloom, as this is known to be what primarily drives the copper cycle (Bacini 1976). The high bottom Copper value in December of 1992 may be caused by increases typically experienced during fall circulation and winter, where oxygenation enhances the release of Copper from organic matter (Xue *et al*. 1997).

Data collected after 1992 is considerably lower, with no Criteria exceedances. The accuracy of the data collected between 1993 and 2002, which was all below detectable limits, is uncertain. This is because the minimum limits of detection ranged between 2 and 6 µg/L for this period. These detection limits were at or higher than Criteria, and were also significantly higher than the 0.05µg/L detection limit for 2004 and 2005 data.

In terms of current copper conditions, the 2004 and 2005 results averaged 0.5 and 0.4 µg/L respectively, and peaked at 0.8 µg/L (March 2005). These values are much lower than the Criteria, and therefore do not indicate that Copper is currently a parameter of concern in Quamichan Lake. Capturing future data during times of expected peaks (i.e. following spring or early summer algal blooms and during the winter) would help to confirm this.

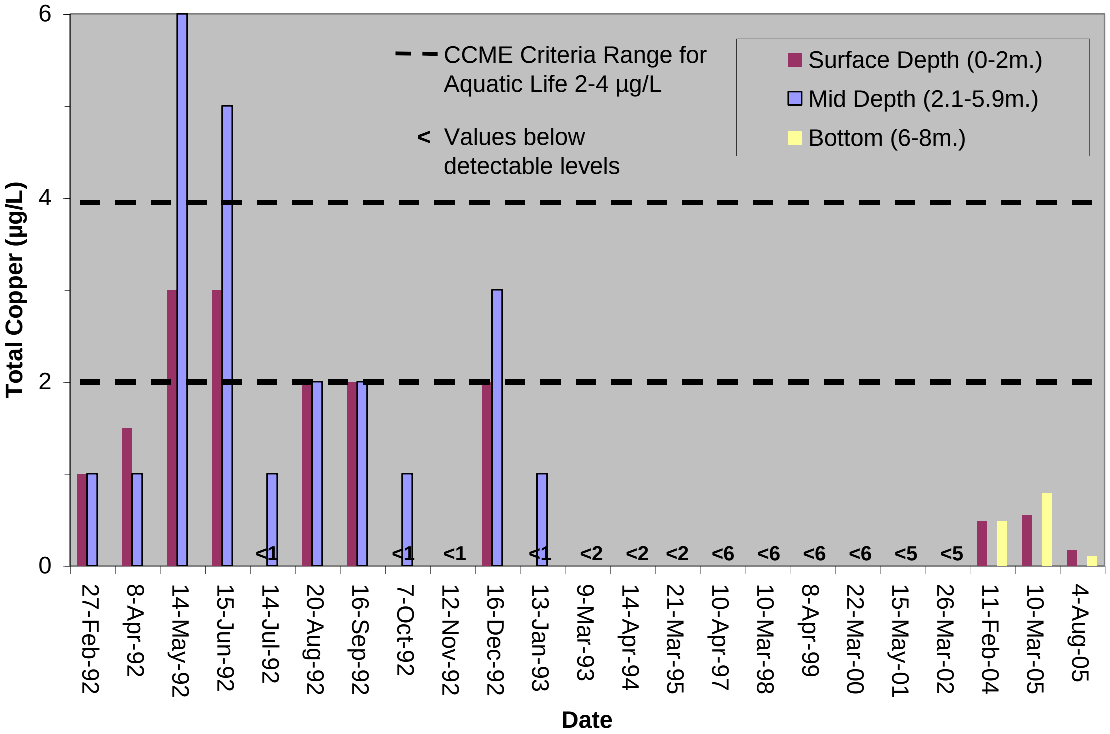


Figure 20. Total Copper with depth at the Quamichan Lake deep station site, for the period of 1992 – 2005.

7.13 *Iron, Total*

> *Iron is an essential micronutrient of microflora, plants and animals, but in very high concentrations it can be toxic. Ingestion of heavy metals with iron-oxides can also increase the dietary supply of metals to toxic concentrations in the food web* (Wetzel 2001).

Total Iron data is available for Quamichan Lake from 1992 – 2002 (excluding 1996). Calculations from all raw data indicate that values ranged from <0.05 to 0.85 mg/L and averaged 0.14 mg/L. The Criteria for Drinking Water (aesthetics) and Aquatic Life is less than or equal to 0.3 mg/L. The Criteria was exceeded in 16% (6/37) of samples. The graph of Total Iron data depicted with depth (Figure 21) reveals that the exceedances all occurred in 1992, where a maximum value of 0.85 mg/L was reached in December.

These results do not confirm that criteria exceedances occurred only in 1992, although it was the only year where exceedances were recorded. This is because summer/early fall data was only collected in 1992, and only winter or spring data is available for the other years. Capturing data during the period when the water column is stratified and DO conditions in the bottom depths are lowest (i.e. May – October as depicted in Figure 7) is significant because Iron is released from the sediments when the DO content of the water declines (Mortimer 1971). The fact that most of the 1992 mid depth values were higher than the surface values, and that Total Iron values were highest during the May – October period (as well as in December), substantiates that reactions at the sediment-water interface during low DO periods are likely driving water column Total Iron levels. It is uncertain what caused the December 1992 peak.

Future data collection during periods of expected peaks (during the growing season, when hypolimnetic DO levels are low) would confirm if the current conditions were below the Criteria.

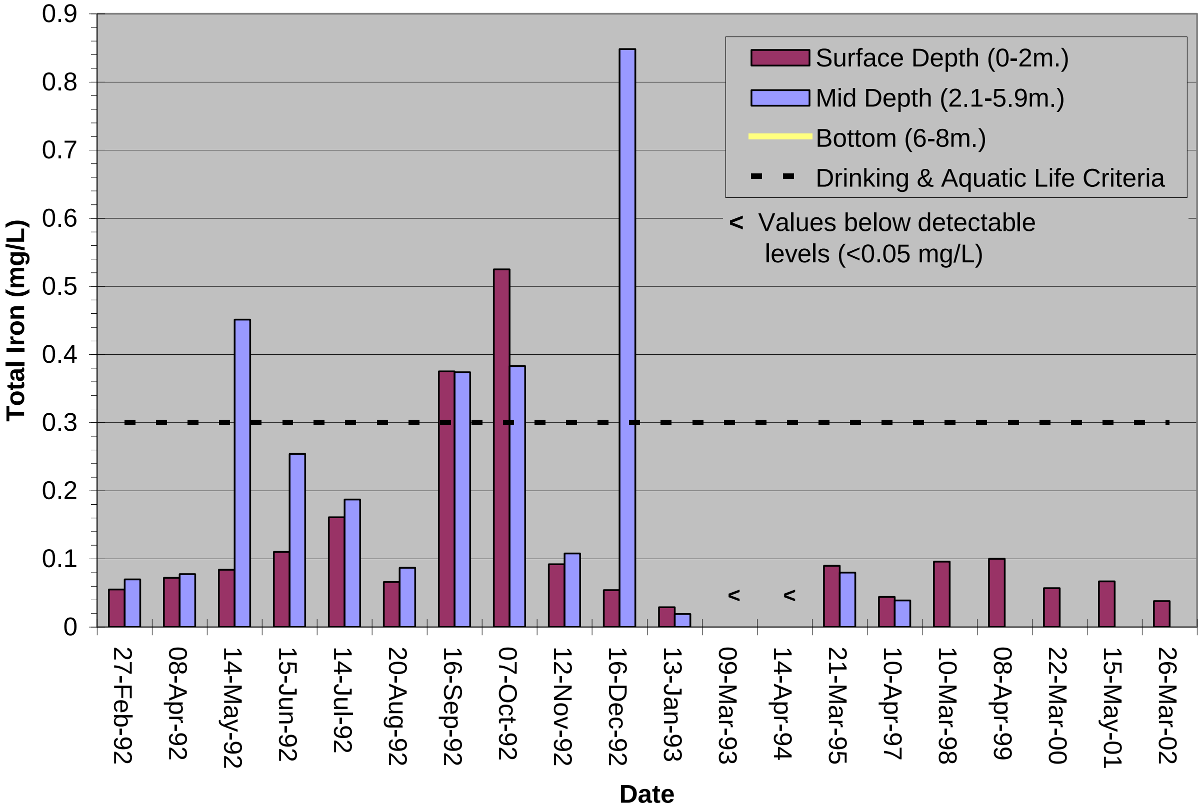


Figure 21. Total Iron with depth at the Quamichan Lake deep station site, for the period of 1992 – 2002.

7.14 Manganese, Total

> *Manganese is an essential element in trace amounts, for plants and animals. In aquatic environments, manganese toxicity is slight to moderate and is influenced by several factors such as water hardness, salinity, pH, and the presence of other contaminants. It often reduces the hazard posed by other metals. Anthropogenic sources include mining effluents, municipal sewage and sludge, and landfills. The primary concerns to drinking water are its taste and its capacity to stain plumbing and laundry* (Nagpal 2001).

Shapiro and Glass (1975) also report that a synergistic effect occurs when waters are enriched with both phosphorus and manganese. Together these nutrients enhance the rate of photosynthesis increasing algae population growth.

Total Manganese results at Quamichan Lake are depicted in Figure 22. Data is available from 1992 – 2005 (excluding 1996 & 2003). A review of all raw data indicates that values ranged from 6 - 633 µg/L and averaged 71 µg/L. The Drinking Water Criteria (aesthetics) for Total Manganese is less than or equal to 50 µg/L, the Irrigation Criteria is 200 µg/L, and the Aquatic Life Criteria is 1100 µg/L (based on a water hardness of 50 mg/L). Quamichan Lake's data indicated that the Drinking Criteria was exceeded in 35% (15/43) of samples, with all exceedances occurring in 1992. The Irrigation Criteria was exceeded in 9% (4/43) of samples, with all exceedances occurring in 1992 other than one (in 2005). The Aquatic Life Criteria was not exceeded. The highest value of 633 µg/L was recorded in August 2005 at the 6 m depth.

Total Manganese peaks occurred in 1992 and 2005 in the late summer/early fall, and they appeared to be driven by bottom conditions. Other than these highs, values have remained low and below the Criteria from November 1992 to March 2005.

These results, much like those of Total Iron, do not confirm that Criteria exceedances occurred only in 1992 and 2005, although they are the only years where exceedances are recorded. This is because data during the summer/early fall is limited to these 2 years, and all of the other years only have winter or spring data. Capturing data during the period when the water column is stratified and DO conditions in the bottom depths are lowest (i.e. May – October as depicted in Figure 7) is significant because Manganese is released from the sediments when the DO content of the water declines (Mortimer 1971). The facts that most of the mid and bottom depth values were higher than those of the surface, and that Total Manganese values were highest during the late summer/early fall, substantiates that reactions at the sediment–water interface during low DO periods are likely driving water column Manganese levels.

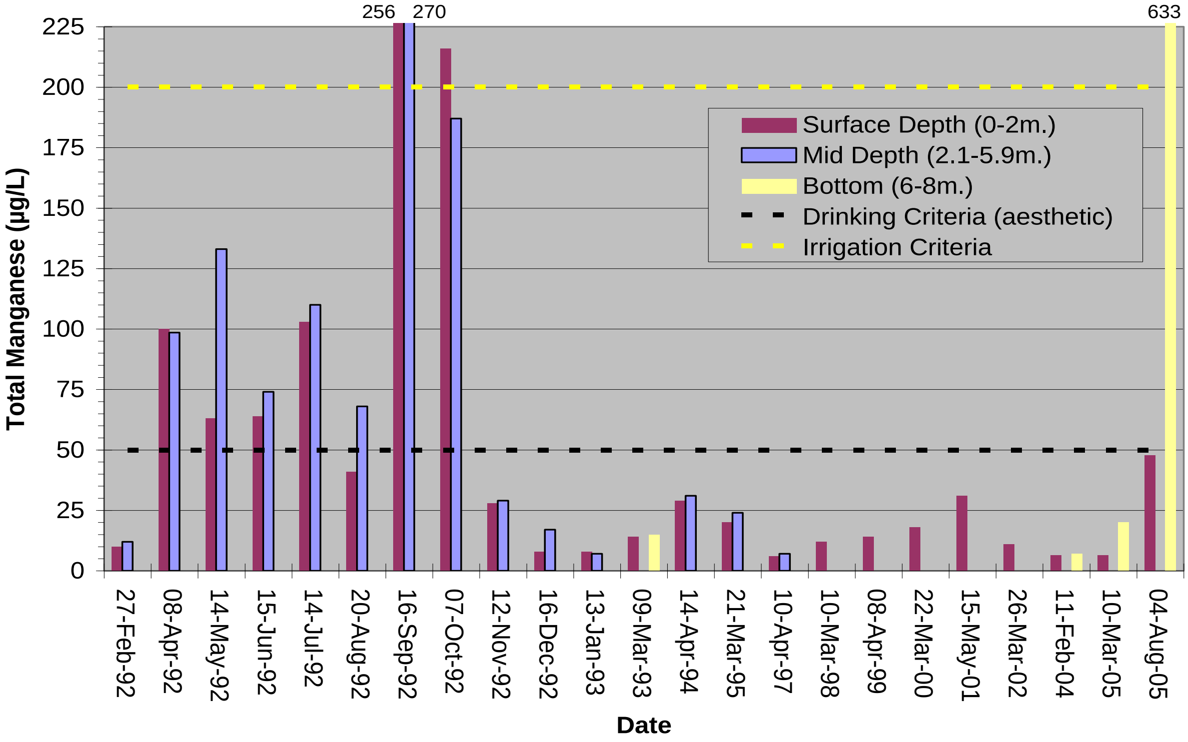


Figure 22. Total Manganese with depth at the Quamichan Lake deep station site, for the period of 1992 – 2005

7.15 Thallium, Total

Thallium is an inorganic element. Thallium that enters the aquatic environment naturally (i.e. by weathering processes), is usually not a concern toxicologically (CCME 1999). Anthropogenic sources come from activities such as mining and smelting (McNeely et al. 1979); and the combustion of coal and oil (NRCC 1982). High levels of thallium have been found to be toxic to both plants and animals (CCME 1999).

Total Thallium data at Quamichan Lake is available for the years of 1992 – 1995, 2002, 2004, and 2005. Calculations from all raw data indicate that values averaged 2.080 µg/L, and ranged from <0.002 – 20.000 µg/L. The CCME Aquatic Life Criteria is 0.8 µg/L. This was exceeded in 19% (7/37) of samples. All of these exceedances occurred in 1992, with the highest value of 20 µg/L reported in November 1992 at 0.5 and 3 m depths.

Figure 23 depicts the results of Total Thallium data at Quamichan Lake. This figure indicates that all data collected after 1992 is below detectable limits. The accuracy of the data collected between 1992 and 2002, however is uncertain. This is because the minimum limits of detection ranged between 3 and 30 µg/L for this period. These detection limits were substantially higher than Criteria, making it unclear as to whether or not exceedances actually occurred.

Technologies of recent years appear to have become more precise with 2004 and 2005 detection limits being 0.002 µg/L. As indicated by the 2004 and 2005 results, which were below detectable levels and substantially lower than the Criteria, current conditions do not appear to indicate that Thallium is a parameter of concern in Quamichan Lake. The collection of future data during November (i.e. the period when the 1992 peak occurred), may help to confirm this.

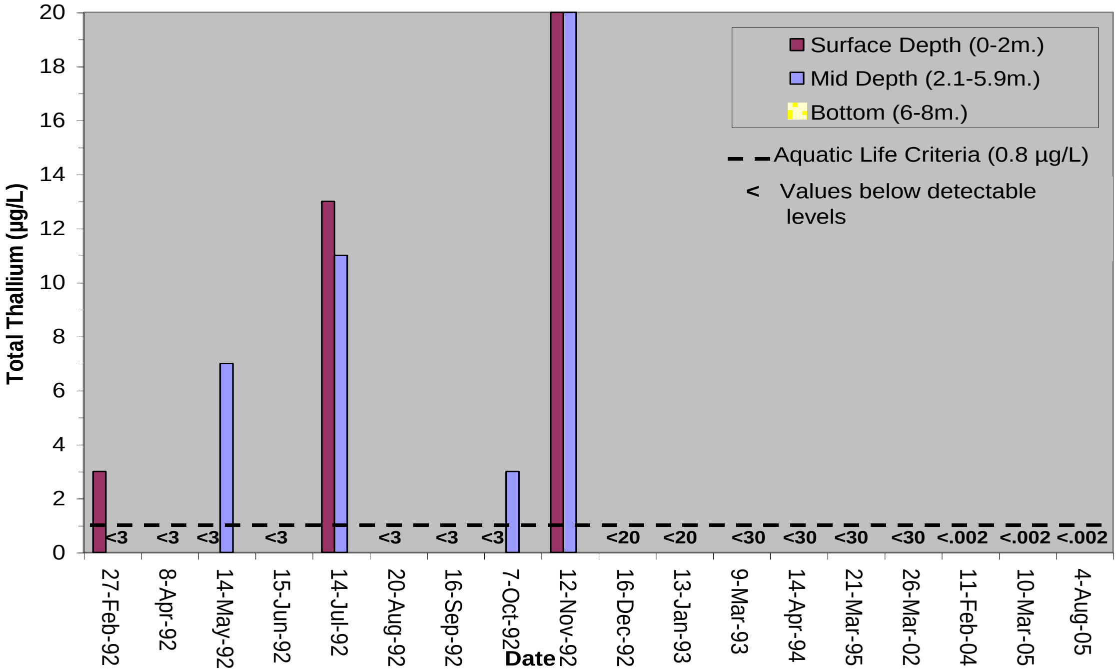


Figure 23. Total Thallium with depth at the Quamichan Lake deep station site, for the period of 1992 – 2005.

7.16 *Zinc, Total*

> *Zinc is a micronutrient required for the nutrition of plants and many animals. The cycling of zinc in lakes is similar to copper, with it accumulating in the hypolimnion during stratification as a result of sedimenting organic detritus. Increases in water column zinc values also often occur during fall circulation as a result of hypolimnetic oxygenation* (Wetzel 2001).

Total Zinc data has been collected at Quamichan Lake between 1992 and 2005 (excluding 1993 and 2003). Raw data calculations indicate that values ranged from 0 – 31 µg/L and averaged 7 µg/L over the period of study. The CCME Aquatic Life Criteria of 30 µg/L was exceeded by 2% (1/43) of samples. These exceedances occurred in July 1992, where values reached 31 µg/L at 3 m.

Figure 24 shows the results of Total Zinc data graphed with depth at Quamichan Lake. These results indicate that data collected after 1992 is considerably lower. The most recent years' data (2004 and 2005 results), further reveal values substantially lower than the Criteria, indicating that that Total Zinc does not appear to currently be a parameter of concern in Quamichan Lake. The collection of future data during June and July (i.e. the months when the 1992 peaks occured), and following fall turnover, would help to confirm this.

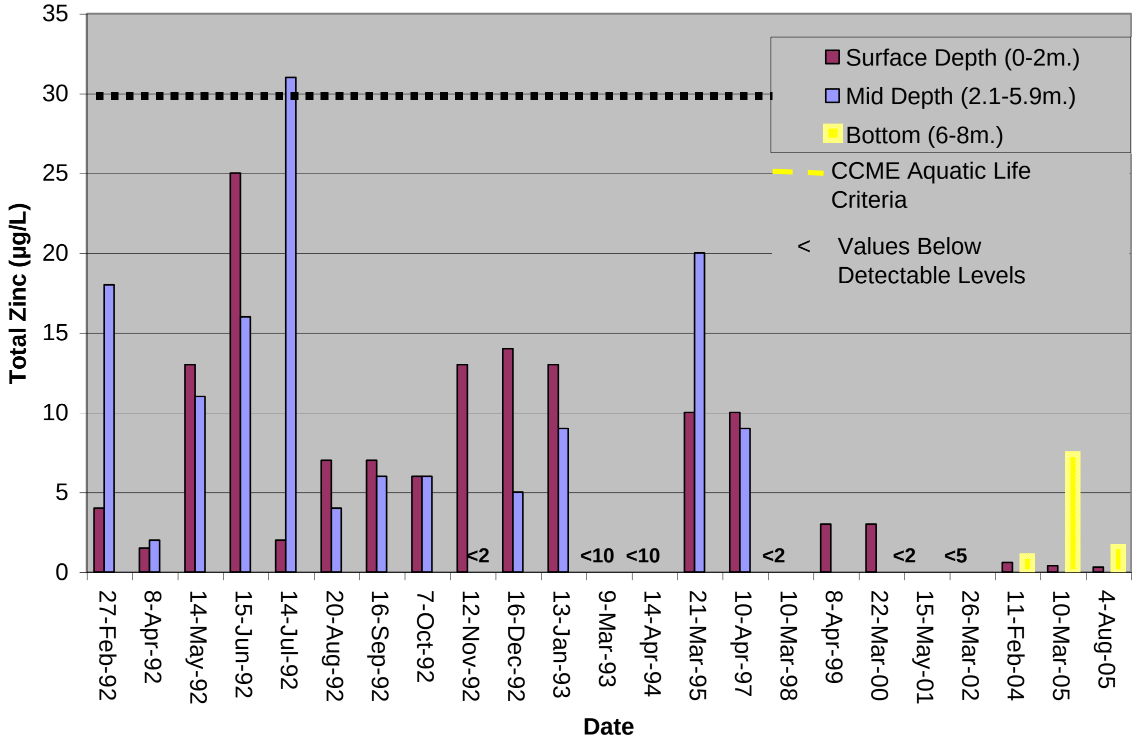


Figure 24. Total Zinc with depth at the Quamichan Lake deep station site, for the period of 1992 – 2005.

8.0 Trophic State and Algal Growth in Quamichan Lake

There are a variety of parameters that can be used to gain an understanding of the characteristics of algal species or algal communities. Generally, no one indicator should be used by itself to provide an answer, but rather a number of indicators should be considered together, to provide the best information for an interpretation of growth rates, relative state of health, limiting nutrients, etc. (Nordin 1985).

In attempts to understand why there is an algae growth issue at Quamichan Lake, this section will complete the following components:

1. Identify the current trophic state,
2. Review nitrogen to phosphorus ratios,
3. Correlate water quality results with algal requirements,

8.1 Trophic Classification of Quamichan Lake

Nordin (1985) described that the concept of lake trophic levels is based on grouping a lake into a category of oligotrophy, mesotrophy or eutrophy, depending on its level of biological production. Nordin further provided a variety of ways that trophic levels could be characterized. Table 4 below, presents characterization ranges for nutrient and phytoplankton parameters available to the Quamichan Lake data set.

Data collected during the ‘90s and the ‘00s have been incorporated into the table for trophic level determination. TP and Total Nitrogen (TN) spring overturn values were determined by averaging all data available during the period of February –April (and May for 2001 only). For TP, data was available for these months for the years of 1992 – 1995, 1997- 2002, and 2004 - 2005. For TN, data was available for these months in 1992, 1997-2002, 2004 - 2005. Secchi values were determined by averaging all available data (see Section 7.10, Figure 18), since the growing season can be year round at Quamichan Lake.

The Trophic Status results indicate that Quamichan Lake is mesotrophic-eutrophic. Values are in the upper end of the mesotrophic range for phosphorus and nitrogen and eutrophic in terms of secchi depth. A comparison of the results in the 1990s and the 2000's indicates that the lake may be becoming more eutrophic with time.

Table 4. Determination of Quamichan Lake's Trophic Status, Through Comparison to Standard Ranges of Select Parameters (adapted from Nordin 1985).

		Total Phosphorus (µg/L) spring overturn*	Total Nitrogen (µg/L) spring overturn*	Secchi Depth (m) growing season mean**
Oligotrophic		1-10	<100	>6
Mesotrophic		10-30	100-500	3-6
Eutrophic		>30	500-1000	<3
Quamichan Lake	1990 -1999	19	374	2.9
	2000 - 2005	21	430	1.6

*TP and TN spring overturn values were determined by averaging all data available during the period of February –April (and May for 2001 only).
** Secchi values were determined by averaging all annual data available.

WOW (2004), identifies that eutrophication is essentially excessive plant growth caused by excess fertility. WOW further provides that this leads to a number of associated water quality impacts; many of which have been reported at Quamichan Lake including:

- noxious algal growth resulting in scums; blue-green algae; and taste, odor and visual concerns;
- macrophyte growth, resulting in loss of open water
- lowered water clarity;
- low dissolved oxygen, affecting fish habitat and food;
- excessive organic matter production, resulting in smothered eggs and insects;
- toxic gases (ammonia, H_2S) in bottom water, resulting in fish habitat loss;
- possible toxins from some species of blue-green algae;
- reduced food chain efficiency due to blue-green algae being inedible by some zooplankton.

Water is often chemically treated in order to address the drinking water concerns. These processes can lead to further deleterious effects such as the production of disinfection by-products, or carcinogens such as chloroform (when organic matter reacts with disinfectants like chlorine) (WOW 2004).

Quamichan Lake is likely experiencing eutrophication because of the following conditions:

- Nutrient supply to the lake is increasing with time, with sources likely including agricultural activities, bordering pasture areas, urban growth (i.e. lawn fertilization) and internal loading.
- Climatic conditions are warm with high summer temperatures.
- The lake does not get flushed adequately during the growing season (i.e. there is little flow from the inlet stream).

- The morphometry of the lake is shallow. Because of this the lake does not adequately stratify, allowing nutrients to remain in circulation (WOW 2004).

8.2 Factors Controlling Algal Growth in Quamichan Lake

MOE collected phytoplankton data during the period of 2004 and 2005 at Quamichan Lake (Epps 2005). The results of phytoplanton counts are provided in Appendix 2 Table 9, and a summary of dominant species and algal types is provided in Table 5. From this data it is apparent that either diatoms or cyanobacteria (a.k.a. blue green algae) tend to dominate the phytoplankton/algae community. Wetzel (2001) provides that these algae types are typical in eutrophic lakes where there is nutrient enrichment, with cyanobacteria typically dominating during warmer periods. Phytoplankton results also show extremely high concentrations of cyanobacteria on November 2004, with 127,968 cells counted/mL of water. This likely coincides with optimal habitat conditions (i.e. temperature, DO, and TP) at the surface, following fall turnover. Lowest total counts of phytoplankton were evident in August 2005, with 1423 cells counted/ml water

The prevalence of cyanobacteria in particular at Quamichan Lake has been an issue for some time. Cyanobacteria has received much attention in the literature because it causes many problems including: creating surface scums, taste and odour problems (Pick and Lean 1987); being potentially toxic to fish, livestock and even humans (Carmichael 1981); and in small shallow lakes, reducing oxygen levels upon decomposition which can lead to fish kills (Barica 1975). These are all significant concerns at Quamichan Lake.

Table 5. Dominant algae populations collected during 2004 and 2005 sampling at Quamichan Lake.

Date	Algae-largest population	cells / mL	% of total	Algae-2nd largest population	cells / mL	% of total
Feb. 11, 2004	*Cyclotella glomeratta* (Diatoms)	5,295	79%	*Melosira cf italica* (Diatoms)	410	6%
Aug. 5, 2004	Unidentified unicellular cells	1,075	76%	*Cryptomonas ovata/erosa* (Cryptophyte)	238	17%
Nov. 17, 2004	*Aphanizomenon flos-aquae* (Cyanobacteria)	64,240	50%	*Anacystis cf aeruginosa* (Cyanobacteria)	63,728	49%
March 10, 2005	*Melosira cf italica* (Diatoms)	1,148	77%	*Chroomonas acuta* (Cryptophyte)	112	7%
May 12, 2005	*Anabeana flos-aquae* (Cyanobacteria)	1,344	48%	*Anabaena cf circinalis* (Cyanobacteria)	899	32%

Toxicity is one important issue that does not appear to have been given a lot of attention in the past documentation on Quamichan Lake. From the 2004 and 2005 findings (Appendix 2 Table 9), it is apparent that all reported species of cyanobacteria are known to contain toxic compounds (Cyanosite 2005). During times of blooms, the scum that forms on the water's surface should be considered potentially dangerous to animals and humans (Cyanosite 2005). Lethal dosage limits and concentrations that would be a cause for concern should be given further review.

Cyanobacteria have several competitive advantages over other algae, making them so successful. Some of these strategies include: occurring in large colonies, ability to fix nitrogen under aerobic conditions, tolerance to higher temperatures, mucilage sheaths and gas vacuoles to reduce their sinking rate allowing them to remain in the photic zone, and, with their gas vacuoles, the ability to regulate their buoyancy so they can position themselves in the most favourable chemical and physical gradients (Wetzel 2001).

There are several important factors regulating algal biomass, production, and community structure in lakes including: light and temperature, the ability to remain in the photic zone, inorganic nutrients, organic micronutrients, interactions of organic compounds with inorganic nutrient availability, and biological factors of competition (Wetzel 2001). Due to their overriding significance to algal growth, nitrogen and phosphorus levels and interrelationships affecting their availability (including oxygen availability) at Quamichan Lake will be reviewed in greater detail.

8.2.1 Nitrogen to Phosphorus Ratio

Nordin (1985) summarizes that algae require nitrogen and phosphorus in specific proportions to meet their metabolic needs, and that the ratio of these two nutrients (N:P ratio) is used to provide an indication of their relative availability. Nordin further states that an N:P ratio less than 5:1 is indicative of nitrogen limitation, and a ratio greater than 15:1 indicates phosphorus limitation.

Typically, TN and TP values are used for calculating the ratio. Here, the ratio of Ammonia, Nitrate+Nitrite to TP was also reviewed, because these nitrogen parameters represent those that would be immediately available for plant uptake (or bio-available) (Deniseger 2004). The ratios were calculated by averaging epilimnetic (or surface waters 0-2 m) values for each of the parameters. Results are depicted in Figures 25 and 26 and are summarized as follows:

- The TN:TP results of Figure 25 indicate that Quamichan Lake's values range from 10 – 68 and average 25. 12/15 (80%) samples indicate a Phosphorus limitation. TN:TP appears to be highest during the spring, and lowest during the winter. The spring results likely reflect high algal biomass reducing phosphorus availability; and conversely the winter values would indicate low algal biomass and thus heightened phosphorus availability.
- When the N:P ratio considers only bio-available nitrogen (Figure 26), values are much lower, ranging from 0-7.5 and averaging 1.5. These low ratios indicate that nitrogen is the limiting factor for plant growth in 28/30 or 93% of samples. This means that phosphorus is generally plentiful and does not limit plant growth.

The bio-available nitrogen results (Figure 26), likely more specifically describe nutrient availability for algal growth at Quamichan Lake. The extent that nitrogen is limiting supports the Quamichan Lake findings of cyanobacteria often dominating the algal community. This is because cyanobacteria can thrive in environments where bio-available nitrogen levels are low, due to their unique ability to fix atmospheric nitrogen (WOW 2004). Pick and Lean (1987) also confirm that cyanobacterial growth is favoured in temperate lakes with low TN:TP ratios in surface waters because the low ratios usually accompany elevated TP levels.

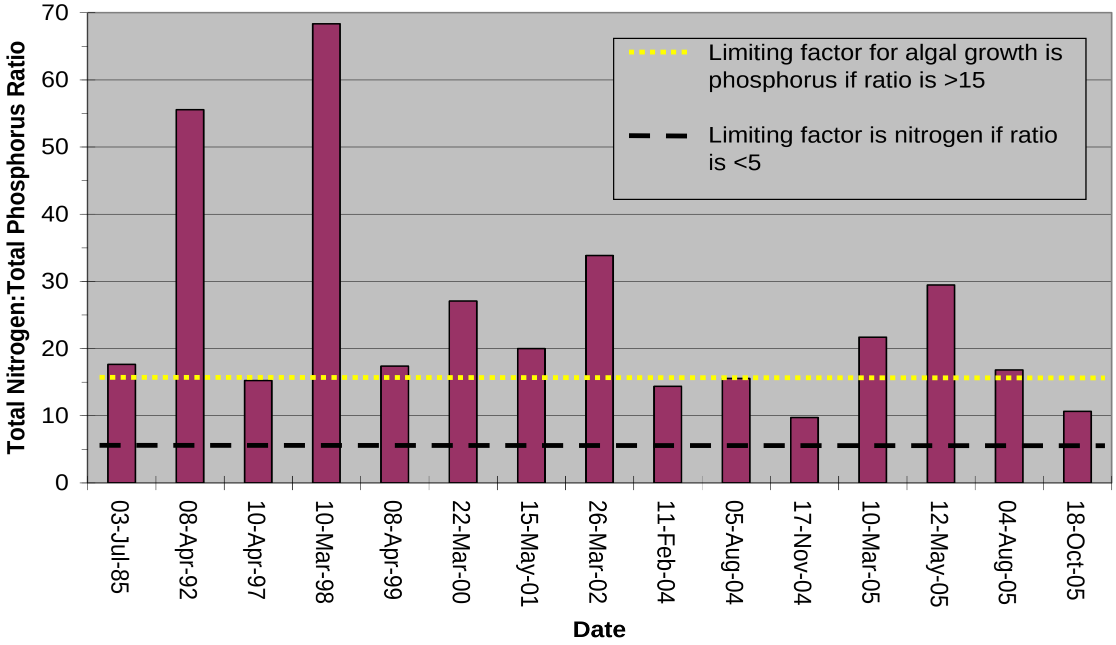


Figure 25. Epilimnetic Total Nitrogen: Total Phosphorus ratios at the Quamichan Lake deep station site, calculated for the period 1985 – 2005.

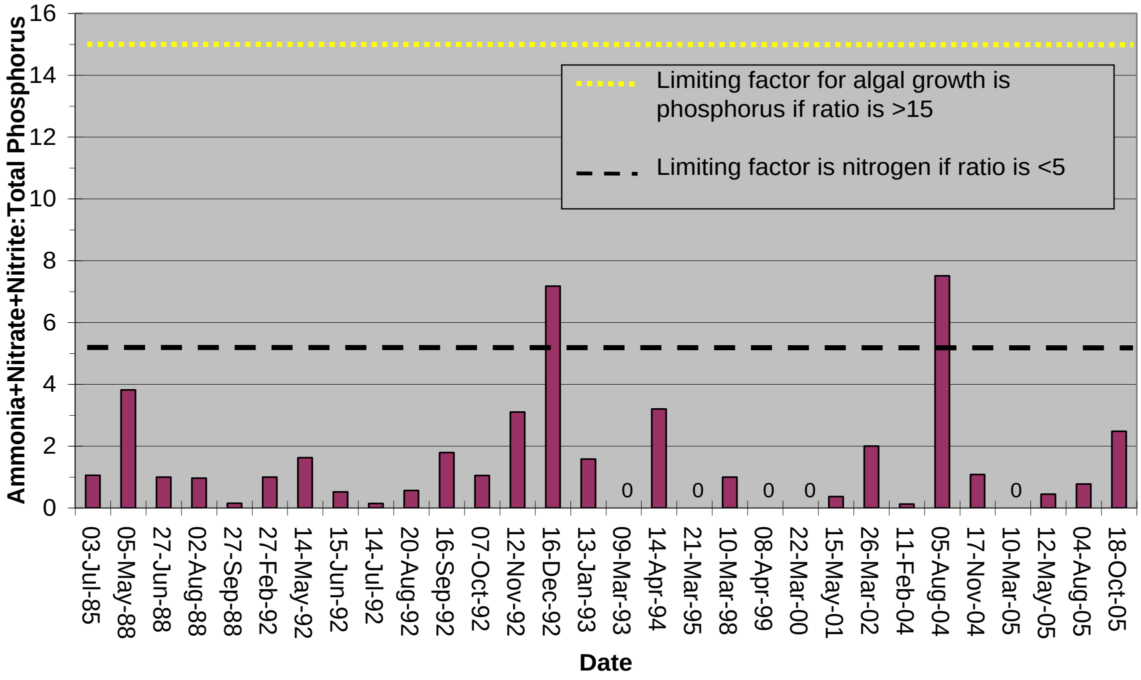


Figure 26. Epilimnetic Bio-Available Nitrogen: Total Phosphorus ratios at the Quamichan Lake deep station site, calculated for the period of 1985 – 2005.

8.2.2 Phosphorus Cycle and Algae Growth

The N:P ratio review confirmed that TP is particularly significant to the growth of cyanobacteria. TP levels throughout the year at Quamichan Lake will thus be reviewed in detail to better understand possible sources.

Bio-available forms of phosphorus typically increase during turnover events when accumulated bottom nutrients mix into upper waters and during runoff periods (WOW 2004). At Quamichan Lake fall turnover typically occurs by October (see Temperature Section 7.3). This coincides with the start of the rainy period. TP results at Quamichan Lake indicate that TP levels increase during the early fall period (see Section 7.7 Figure 14), with peaks exhibited on September 27th 1988, September 16th 1992, October 7th 1992 and October 18th 2005. Without knowing the actual days when the fall rain events and fall turnover occurred, it is not possible to accurately discern whether runoff or turnover had the greater influence on these TP peaks. Bottom TP values however, were somewhat higher on these dates, indicating that fall turnover possible was a greater influence.

WOW (2004) also states that *nutrient concentrations typically decrease in the epilimnion during stratification as nutrients are taken up by algae and are eventually transported to the hypolimnion when the algae die and settle out*. This is evident at Quamichan Lake, where during the spring, lowest phosphorus values were observed at the surface.

Following the spring lows, Total Phosphorus values at Quamichan Lake got progressively higher throughout the summer, with the highest values (i.e. greatest influences) evident at the lower depths. These summer highs are most likely attributed to the release of phosphorus from the sediments; a reaction that occurs when conditions become anoxic.

8.2.3 Oxygen's Influence on the Release of Phosphorus from the Sediments

The release of phosphorus from the sediments into the overlying water is a major outcome of DO depletion (Wetzel 2001). This process is significant to nutrient cycling because lake sediments contain much higher concentrations of phosphorus than the water (Wetzel 2001). This chemical process is known to occur at the sediment-water interface when the DO levels drop below 1 mg 0_2/L (WOW 2004).

The annual DO cycle for Quamichan Lake (see Section 7.2 DO), indicates that summer DO depletions are experienced annually in the bottom waters. More specifically, the raw data provides that bottom DO values dropped to 1 mg 0_2/L or less in almost every sample collected (13 /17) during the summer period (June – September); with one spring sample (May 12th, 2005) even showing depleted DO conditions. Table 6 provides further details on these low oxygen levels by indicating the dates and extent of depletions. Table 6 also provides the results of a cross-reference with TP raw data values for these dates. Unfortunately TP data was not available for many of the dates that DO depletions were noted. For all three dates that both DO and TP data was available, results reveal high bottom TP levels when DO values were low, indicating that phosphorus was likely being released from the sediments.

Figure 14 (see Section 7.7 TP) indicates that there were eight additional summer dates (July 1985; June, August & September 1988; and June, July, August & September 1992) where TP data was collected but where DO was not sampled. All these dates had elevated bottom TP values. These high values were also very likely the result of phosphorus being released from the sediments due to low DO conditions.

Figure 14 also reveals that TP values appear to get progressively higher (with the bottom depths appearing to have the greatest influence/highest values) as the summer progresses. This is particularly evident in the 1992 results, where samples were collected monthly. This is likely the result of bottom conditions becoming more anoxic as the summer progresses.

Typically in the fall when the lake mixes, the TP that has built up at lower depths is redistributed to the upper waters fuelling algal growth (WOW 2004). Although Quamichan Lake experiences these high TP values throughout the water column during the fall, TP data and reports of algal blooms/fish kills also indicate that mixing of nutrients from the bottom depths occurs during the summer. This summer mixing is likely due to the shallowness of the lake and thus its inability to become fully stratified.

Table 6. History of DO levels falling below 1 mg/L and associated Total Phosphorus levels at Quamichan Lake

Date	**Depths (m) where DO values were 1mg/L or lower**	**Average DO values (mg/L) for these depths**	**Associated Bottom TP Values (µg/L)**
September 11, 1987	5, 6,7	0.4	No data
August 15, 1990	7,8	0.6	No data
June 20, 1997	6,7,8	0.5	No data
June 9, 2004	7,8	0.7	No data
June 15, 2004	8	0.4	No data
June 23, 2004	6,7,8	0.8	No data
July 1, 2004	4,5,6,7,8	0.6	No data
July 8, 2004	5,6,7,8	0.42	No data
July 27, 2004	5	5	No data
August 5, 2004	5,6,7	0.26	132
August 10, 2004	6,7	0.45	No data
August 18, 2004	4,5	0.42	No data
May 12, 2005	7,8	.65	140
August 4, 2005	6,7,7.5	0.28	240

9.0 Conclusions

An examination of Quamichan Lake’s water quality results from 1951 to 2005 indicate that the lake is quite productive, with generally poor conditions, that appear to be deteriorating with time. This is evidenced by several parameters exceeding the water quality criteria, with poorest instantaneous conditions often being recorded in recent years, and with productivity measures showing an increase between the 1990s and the 2000s. Several factors such as high ambient temperatures, shallow lake morphometry, and low flushing rate contribute to conditions being particularly poor during the summer and fall. During this time, a cycle of algal growth, diminished DO levels, and phosphorus inputs (particularly from internal sources) perpetuates itself. These conditions have negative effects on aquatic life (i.e. result in fish kills), drinking water quality and recreation activities. Summary details on Quamichan Lake’s water quality results are as follows:

1. When compared against the Water Quality Criteria, the water quality of the lake was generally poor, with several (16/42) parameters exceeding the Criteria at some point throughout the period of study.
2. A review of instantaneous results indicates that nearly half of the parameters reviewed in detail (8/18), exhibited their poorest condition (i.e. peak value, or for DO and secchi- lowest values) in the recent years of 2004 or 2005. These included:

   2004
   - temperature
   - turbidity
   - total organic carbon
   - ammonia
   - secchi depth

   2005
   - DO
   - pH
   - total manganese
3. Generally the water chemistry in the lake is at its poorest during the growing season and particularly in the summer months. This is when many parameters often exceed both the Drinking Water and Aquatic Life Criteria. A number of critical parameters are affected during this period, and in many cases their combined effects act to further drive water quality conditions down. Some of the important occurrences during the summer include: high temperatures; low dissolved oxygen with depth; pH values that fluctuate between the extremes; high nutrient levels including total organic carbon, total phosphorus and ammonia; and low secchi readings. The shallow morphometry and low flushing rate of the lake in the summer make it particularly sensitive to these conditions. As a result, algal blooms are frequent and fish kills occur periodically.
4. Fall is also an important time at Quamichan Lake. During the fall turnover, nutrients (particularly phosphorus) are circulated from the bottom throughout the water column, further fuelling algal growth conditions. Runoff during the rainy period (fall and winter) also likely effects water quality, leading to elevated turbidity levels and nutrient inputs into the lake from neighboring lands (including nitrate+nitrite, and phosphorus).
5. In terms of trophic status or productivity, Quamichan Lake is mesotrophic-eutrophic, indicating that it is quite productive. Based on a comparison of productivity measures between the 1990s and the 2000s, the lake appears to be getting more productive with time.

6. Diatoms and cyanobacteria exemplify the productive state of the lake by being the prevalent algae types found during sampling in 2004 and 2005. The cyanobacteria in particular are known to cause several water quality problems, especially during periods of blooms. Of particular note, all the cyanobacteria species identified at the lake are known to contain toxic compounds. This is an issue which should be given further attention (i.e. determine if levels of toxins during blooms are a concern for livestock or humans). The prevalence of cyanobacteria in Quamichan Lake appears to be related to the low bio-available nitrogen to TP ratios. The low ratios favour this algal group not only because they accompany high TP levels, but also because the low nitrogen levels give the cyanobacteria a competitive advantage over other algal groups which can not fix atmospheric nitrogen.
7. Although phosphorus likely enters the lake from external sources (i.e. nutrient transport following fall rain events), internal loading of phosphorus from the sediments during periods of low DO appears to be a greater influence. Bottom water DO values typically drop to levels of 1mg O_2/L or less during the summer period (June – September), resulting in the release of phosphorus from the sediments. This phosphorus mixes throughout the water column during the summer and fall, fuelling algal blooms. The heightened algal biomass perpetuates the cycle by contributing phosphorus to the deeper waters (as the algae dies off), which results in low DO levels at the bottom of the lake.

This situation can be improved with time, for as Wetzel (2001) provides, a relatively rapid decline of the productive capacity of the lake system occurs when the phosphorus inputs are reduced.

10.0 Recommendations

Quamichan Lake is set amid rural residential and agricultural lands. This lake is an important water source (particularly for irrigation), and is also a valued location in the central Vancouver Island area for recreational activities including fishing and water sports. The combination of Quamichan Lake's natural morphometry and of the local land-use practices appear to have led to the decline of the lake's water quality conditions. Algal blooms frequently occur as a result of a series of chemical and ambient events including high internal loading of phosphorus, low oxygen conditions and warm temperatures. These algal blooms have been known to cause fish kills, and to further impair water quality by perpetuating negative conditions. The situation does not appear to be stabilizing; rather, the lake appears to be becoming more productive with time and will likely continue to do so as a result of ongoing growth and development pressures. In order to address these issues, it is recommended that Quamichan Lake continue to receive attention aimed at planning, protecting, improving and monitoring. The following actions are recommended:

10.1 Information Dissemination and Committee Formalization

Continued effort from local government agencies, landowners and water users is necessary if any improvements to the current conditions are to occur. Informing and educating these parties on the current water quality status and issues as identified in this report, should be the first step. Defining and acting on measures to improve and protect the water quality of the lake should follow.

A Lake Stewardship Committee made up of local residents and stakeholders, such as that of Cusheon Lake on Saltspring Island (which has similar issues), should be formalized to lead the planning and implementation of future improvements. This group may wish to join the BC Lakes Stewardship Society, which provides support and helpful information.

10.2 Improvement Planning

In order to improve water quality, the planning action items as identified at the June 2005 multi-agency meeting should be followed up on (Haddow 2005). These include:

- Developing a Watershed Management Plan for the Quamichan Watershed, which outlines longer range planning needs. In order to initiate this, it is important to identify a party to lead this process - the District of North Cowichan was suggested as being the most appropriate.
- Incorporating Quamichan Lake in the Cowichan River Planning Process that is currently underway.

There have been many recommendations for improvement made in the past (Ashley 1990, Burns 2002, Haddow 2005, and Nordin 1990). The Watershed Management Plan should revisit, prioritize, and put plans in place to act on these recommendations (including seeking out funding sources). A list of these recommendations include:

<u>To reduce nutrient flows into the lake:</u>

- Educate land-owners (including golf courses) on appropriate lawn and landscape management practices.

- Have farmers follow a Nutrient Management Plan that assures crops take up all nutrients applied.
- Maintain drainage systems to reduce flooding.
- Fence livestock away from the lake.
- Decrease waterfowl populations.
- Check septic system function and conduct maintenance/upgrading.
- Check storm drains for possible cross connections with sewer lines.
- Improve storm water management by infiltrating or storing road surface and roof top water.
- Protect the Quamichan Lake shoreline.
- Acquire more green space / public land in the Quamichan Basin, including the Quamichan Lake shoreline.

<u>To directly address cyanobacteria growth:</u>

- Reduce pH by adding acid or circulating the lake with compressed air. The addition of acid would first require testing in a large experimental enclosure.

<u>To reduce internal phosphorus loading from the sediments:</u>

- Reduce phosphorus supply from the sediments by chemically binding (with aluminum or iron) or with sediment oxidation / consolidation processes. Oxidants such as nitrate could also be considered. Experimentation to determine doses would be required.
- Increase phosphorus export from the lake by increasing water flow. Water could be obtained from the water pipeline supplying the Crofton Pulp mill, which passes within 5 km of the lake. This is considered the most certain option for improving the conditions, however it would require the most cost and effort.
- Withdraw select sediments of concern from the hypolimnion, with a siphoning system.
- Construct a lake aeration system, to increase water oxygen levels.
- Release salvaged Coho fry into Quamichan Lake, to take up nutrients from the lake. This would require improving the outlet or building a weir.

<u>To address fish habitat and/or flooding issues in Quamichan Creek (as they pertain to Quamichan Lake):</u>

- Construct a low-lying weir at the Quamichan Lake outlet to increase flows out of the lake during the spring and summer period. This would require the following:
    - Completing a survey of elevations on lowlands and stream bottoms of Quamichan and McIntyre Creeks and the adjacent lowland areas,
    - Obtaining Environment Canada’s water level information for the stream gauge on Upper Quamichan Creek.
    - Conducting public consultation – for people whose land may be affected by the change in water levels.
- Restrict further consumptive water use unless storage is possible.

10.3 Continued Water Quality Monitoring

Water quality monitoring should continue to be conducted at the deep station site (E207465) in order to track future conditions. General, nutrient, biological and metal parameter water quality data should continue to be collected at multiple depths. Representative samples should also be collected throughout the year including during spring overturn, summer, and fall freshet periods (as has been done in 2004 and 2005). A higher frequency of sampling should also be conducted during the summer (i.e. monthly, or weekly as was conducted in 2004), to capture data during the period when Criteria exceedances are highest, and when the drinking water, aquatic life, and recreation values are the most vulnerable.

Local stream stewards could also contribute to monitoring by continuing to conduct water quality sampling, as they did in the summer 2004. (i.e. secchi disc, dissolved oxygen and temperature data).

10.4 Microbiological Sampling

Ensure that the Ministry of Health is conducting appropriate microbiological (*E. coli* and fecal coliform) monitoring that checks the safety of all the licenced water uses (i.e. domestic, irrigation and stock watering) and recreation activities. This would include ensuring that the following monitoring is conducted:

- If there is any drinking water that is not treated, levels are to be 0/100mL maximum.
- If there is livestock watering for general use, levels are to be 200/100ml max. If the livestock are closely confined and not treated, a maximum of 0/100mL is to be met.
- If there is any water that is treated and used for human consumption or livestock watering, 10 bacteriological samples are to be collected during a 30 day period. The 90th percentile value is to be calculated. The microbiological limits are dependant on the level of treatment.
- To review if the irrigation and recreation Criteria are met, 5 samples are to be collected over a 30 day period. The geometric mean is to be calculated. The microbiological limits are 200/100mL for recreation activities, and for irrigation the limits are dependant on the use.

10.5 Phytoplankton

Lethal dosage limits for toxin producing phytoplankton species should be reviewed. Results should be compared to species numbers found at Quamichan Lake during blooms, to determine if concentrations are a cause for concern to livestock and humans.

References

Anonymous. 1989 & 1990. Quamichan Lake Gill Net File Notes from June 23, 1989 and April 12, 1990. Quamichan Lake File, Ministry of Environment, Nanaimo.

A.F.H. and W.F. 1960. File Note: Fisheries Reconnaissance Findings. Quamichan Lake File, Ministry of Environment, Nanaimo.

Ashley, K. 1990. Memorandum To Fisheries Program (P. Law) Re: Quamichan Lake Water Quality. Quamichan Lake File, Ministry of Environment, Nanaimo.

Baccini, P. 1976. Untersuchungen über den Schwermetallhaushalt in Seen. Schweiz.Z. Hydrol. 38:121-158. *In* Wetzel 2001.

Baraclough, J. 1997. Quamichan Lake File Note. Quamichan Lake File, Ministry of Environment, Nanaimo.

Barica, J. 1975. Collapses of Algal Blooms in Prairie Pothole Lakes: Their Mechanisms and Ecological Impact. Verhandlungen der internationalen Vereinigung fur theoretosche und anfewandte Limnologie. 19:606-615. *In* Pick and Lean 1987.

BC Fisheries. 2005. Fisheries Inventory Stocking Report. Fish Inventory Summary System (FISS). Ministry of Sustainable Resource Management. Website address: http://www.bcfisheries.gov.bc.ca

BC Lakes Stewardship Society. 2003. BC Volunteer Lake Monitoring Program: Fraser Lake 2000 – 2002. Summary Document.

Brams, R.A. 1987. Letter to S. Pollack Re: Coho Research on Quamichan Lake. Scientist i/c Coho Colonization, Pacific Biological Station. *In* Polack 1988.

BritishColumbia.com. 2005. British Columbia Population Statistics. http://www.britishcolumbia.com

Burns, T. 2005. File Note: Quamichan Creek Beavers June 6, 2005. Appendix 1 Quamichan File From Production Plan. Fishery Officer Narrative. Quamichan Lake File, Ministry of Environment, Nanaimo.

Burns, T. 2002. A Salmonid Protection and Production Plan For the Cowichan Valley Regional District. Completed for Cowichan Fish and Habitat Renewal. *In* Burns 2005.

Canadian Council of Ministers of the Environment (CCME). 2003. Canadian Environmental Quality Guidelines Summary Table. Canadian Council of Ministers of the Environment, Winnipeg.

CCME. 1999. Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment, Winnipeg.

Carmicheal, W.W. 1981. The Water Environment: Algal Toxins and Health. New York, Plenum Press. *In* Pick and Lean 1987.

Chan, F. and McCulloch, M. 1994. Stock Assessment of Quamichan Lake. Ministry of Environment Lands and Parks.

Corley-Smith and Associates. 1989. Quamichan Lake March 16, 1989 Sampling Data. Unpublished data submitted to Fisheries Branch, Ministry of Environment.

Corley-Smith and Associates. 1988. Quamichan Lake May 11, 1988 Sampling Data. Unpublished data submitted to Fisheries Branch, Ministry of Environment.

Corley-Smith and Associates. 1988. Assessment of Impact on the Cutthroat Trout Population of Quamichan Lake From Stocking the Lake with Coho Juveniles. Report for Department of Fisheries and Oceans, Nanaimo B.C. and Ministry of Environment and Parks, Nanaimo B.C.

Corporation of the District of North Cowichan. 2002. Official Community Plan. Website address http://www.northcowichan.bc.ca

Corporation of the District of North Cowichan. 1988. Letter to Dr. Polack Re: Quamichan Lake-Water Quality Study. Quamichan Lake File, Ministry of Environment, Nanaimo.

Cyanosite. 2005. A Webserver for Cyanobacteria Research. Department of Biological Sciences, Purdue University. http://www-cyanosite.bio.purdue.edu

Deniseger, J. 2004. Personal Communications. Ministry of Environment, Nanaimo Regional Office, Water Quality Section. *In* Fosker and Philp 2004.

DVG Engineering Services. 1987. Water Storage Feasibility Study. Somenos Lake, Quamichan Lake, Crofton Lake, Wowo Lake. Report for Ministry of Environment and Parks, Nanaimo B.C.

Environmental Monitoring System (EMS). 2004. Provincial Water Quality Data Base. Ministry of Water Land and Air Protection, Victoria B.C.

Epps, D. 2005. Personal Communications. Environmental Impact Assessment Biologist, Ministry of Environment, Nanaimo.

Fisheries and Oceans Canada. 2005. Mapster (v. 2.0) OGC Data Viewer. Website address: http://www-heb.pac.dfo-mpo.gc.ca

Fosker G. and Phlip, L. 2004. Quamichan Lake Stocking Assessment. Region 1, Ministry of Water Land and Air Protection, Nanaimo.

Haddow W. 2005. August 12, 2005 Letter to District of North Cowichan Re: Quamichan Watershed Management Plan. Regional Agrologist, BC Ministry of Agriculture, Food and Fisheries. Quamichan Lake File, Ministry of Environment, Nanaimo.

Haddow W. 2005. Quamichan Watershed June 2, 2005 Draft Meeting Minutes. Regional Agrologist, BC Ministry of Agriculture, Food and Fisheries. Quamichan Lake File, Ministry of Environment, Nanaimo.

Holms, G.B. 1996. State of Water Quality of Quamichan Lake 1988-1995. Report completed under the Canada-British Columbia Water Quality Agreement. Water Management Branch, Ministry of Environment, Lands and Parks.

Klein & Heathman. 1972. Lake Survey Data. Quamichan Lake File, Ministry of Environment, Nanaimo.

Land and Water British Columbia Incorporated. 2005. Water License Listings. Website address: http://www.elp.gov.bc.ca

McNeely R.N., Neimanis V.P., Dwyer L. 1979. Water Quality Sourcebook. A guide to water quality parameters. Environment Canada, Inland Waters Directorate, Water Quality Branch, Ottawa. *In* CCME 1999.

Ministry of Environment. 2004. Quamichan Lake Summer 2004 Lake Sampling Data. Collected by local volunteers/stream keepers at the deep station site (EMS number E207465). Water Quality Section (c/o D. Epps), Ministry of Environment, Nanaimo.

Ministry of Environment. 1998. Approved Water Quality Guidelines (Criteria), 1998 Edition. Updated August 24, 2001. Website address: http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/approved.html

Ministry of Environment and Parks. 1986. Cowichan - Koksilah Water Management Plan. Vancouver Island Region, Planning and Assessment Branch.

Mortimer, C.H. 1971. Chemical Exchanges Between Sediments and Water in the Great Lakes – Speculations on Probable Regulatory Mechanisms. Limnol. Oceanogr. 16:387-404. *In* Wetzel 2001.

Municipality of North Cowichan. 2005. Parks Directory: Art Mann Park. Website address: http://www.northcowichan.bc.ca

Nagpal, N. K. 2001. Ambient Water Quality Guidelines for Manganese. Overview Report. Water Management Branch, Environment and Resource Division, Ministry of Environment, Lands and Parks.

Newroth, P.R. 1987. Letter to Dr. Polack Re: Quamichan Lake Weeds. Littoral Resources Unit, Ministry of Environment. *In* Polack 1988.

Nordin, R. N. 2001. Water Quality Criteria for Nutrients and Algae. Overview Report. Resource Quality Section Water Management Branch. Ministry of Environment Lands and Parks.

Nordin, R. N. 1990. Memorandum Re: Quamichan Lake to P. Law of Fisheries Program. Quamichan Lake File, Ministry of Environment, Nanaimo.

Nordin, R. N. 1987. Letter to Dr. Polack Re: Quamichan Lake Algae Issues. Water Management Branch, Resource Quality Section, Ministry of Environment. *In* Polack 1988.

Nordin, R. N. 1985. Water Quality Criteria For Nutrients and Algae. Technical Appendix. Resource Quality Section Water Management Branch, Victoria BC. Ministry of Environment.

National Research Council of Canada (NRCC). 1982. Data sheets on selected toxic elements. Associate Committee on Scientific Criteria for Environmental Quality, Ottawa. *In* CCME 1999.

Oliver D.J. 1990. File Note: Re: Temperature and Oxygen Profile on Quamichan Lake. Quamichan Lake File, Ministry of Environment, Nanaimo.

Pick F. R., and Lean, D. R. 1987. The Role of Macronutrients (C, N, P) in Controlling Cyanobacteria Dominance in Temperate Lakes. *New Zealand Journal of Marine and Freshwater Research*. Vol. 21: 425-434.

Polack, S. 1988. Quamichan Lake Report. A Compilation of Information Relevant to the Problems of and Possible Solutions for Quamichan Lake. Resident and Quamichan Lake Committee Member. Quamichan Lake File, Ministry of Environment, Nanaimo.

Ptolemy, R. 1985. Personal Communications. Standards/Guidelines Specialist, Aquatic Ecosystem Science Section. Ministry of Environment, Victoria BC. *In* Yaworsky 1985.

Quamichan Lake Residents. 1987. Quamichan Lake Public Meeting Agenda. Quamichan Lake File, Ministry of Environment, Nanaimo.

Reid, G. 1989. Memorandum to P. Law Regarding Quamichan Lake. Quamichan Lake File, Ministry of Environment, Nanaimo.

Resource Inventory Committee (RIC). 1998. Guidelines for Interpreting Water Quality Data. Version 1.0. Prepared by Ministry of Environment, Lands and Parks, Land Data BC, Geographic Data BC.

Resource Inventory Committee. 1997. Ambient Fresh Water and Effluent Sampling Manual. Resource Information Standards Committee, BC Integrated Land Management Bureau

Resource Inventory Committee. 1997. Freshwater Biological Sampling Manual. Resource Information Standards Committee, BC Integrated Land Management Bureau

Scholten, G.H. 1987. File Note Re: Reported Fish Kill Follow-up. Recreational Fisheries Program. Quamichan Lake File, Ministry of Environment, Nanaimo.

Shapiro and Glass. 1975. Synergistic Effects of Phosphate and Manganese on Growth of Lake Superior Algae. Verh. Internat. Verein. Limnol. 19:395-404. *In* Wetzel 2001.

Tutty, B.D. 1988. Letter to The Corporation of the District of North Cowichan Re: Quamichan Lake. South Coast Division, Fisheries and Oceans, Government of Canada. Quamichan Lake File, Ministry of Environment, Nanaimo.

Vernon, E.H. 1951. Quamichan Lake Survey Data. Quamichan Lake File, Ministry of Environment, Nanaimo.

Warrington, P.D. 1988. Water Quality Criteria for Microbiological Indicators. Overview Report. Water Management Branch, Ministry of Water Land and Air Protection. Website address: http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/microbiology.html.

Wetzel, R.G. 2001. Limnology, Lake and River Ecosystems. 3rd Edition. Academic Press.

Willis, Cunliffe, Tait and Company. 1974. Quamichan Lake Study. Report for the Municipality of the District of North Cowichan. *In* Polack 1988.

Willis, Cunliffe, Tait and Company. 1979. Drainage Feasibility Study, Quamichan Lake, Preliminary Report and Benefit-Cost Analysis. Report completed for Water Investigations Branch, Ministry of Environment. *In* Polack 1988.

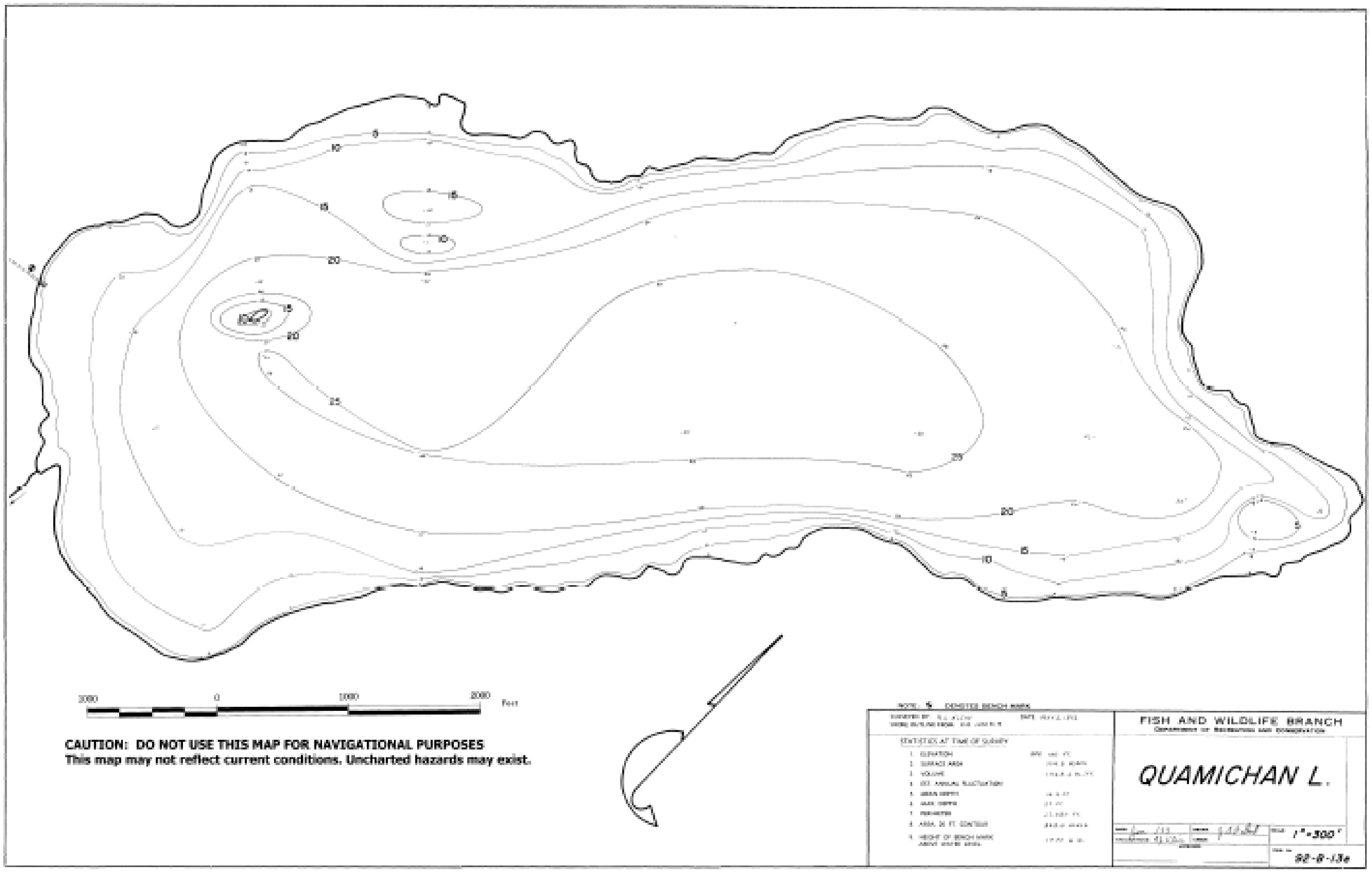
Water on the Web (WOW). 2004. Water on the Web - Monitoring Minnesota Lakes on the Internet and Training Water Science Technicians for the Future - a National On-line Curriculum Using Advanced Technologies and Real-time Data. University of Minnesota-Duluth. Website address: http://waterontheweb.org/

Xue, Gachter, and Sigg. 1997. Comparison of Cu and Zn Cycling in Eutrophic Lakes with Oxic and Anoxic Hypolimnion. Aquat. Sci. 59:176-189. *In* Wetzel 2001.

Yaworsky, B.A. 1985. Small Lake Enhancement Feasibility Study, Quamichan Lake. Fisheries Improvement Unit, Fisheries Branch, Ministry of Environment. Victoria, BC.

Appendix 1 Quamichan Lake Bathymetric Map

(BC Fisheries, 2005)



Appendix 2. Quamichan Lake Water Quality Data Summaries (Tables 7, 8, 9)

Table 7. Summary Comparing Quamichan Lake Parameters (Site E207465) to the Water Quality Criteria.

Parameter	Water Quality Criteria[1] (Criteria within range of the data are shown)	Data Range	Results of Quamichan Lake Data Compared to Water Quality Criteria
Aluminum Total	**Drinking Water:** 0.2mg/L (dissolved aluminum) **Aquatic Life**: 0.1mg/L (dissolved aluminum, with pH greater than 6.5) **Wildlife/Livestock/Irrigation:** 5 mg/L	0.0061 – 0.22 mg/L	Only total aluminum, (no dissolved aluminum) values were collected, thus only wildlife/livestock irrigation values were compared to Criteria. No exceedances were recorded.
Antimony Total	**Drinking**: 6 µg/L proposed interim max.	0 – 0.056 µg/L	No exceedances were recorded. Limits of detection (at <15 - <60 µg/L) were however, higher than the Criteria between 1992 and 2002.
Arsenic Total	**Drinking**: 25µg/L interim max. **Aquatic Life:** 5 µg/L	0.3 – 1.6 µg/L	No exceedances were recorded. Limits of detection (at <40 - <60 µg/L) were however, higher than the Criteria between 1992 and 2002.
Barium Total	**Drinking**: 1mg/L max.	0.0034 – 0.17 mg/L	No exceedances were recorded.
Boron Total	**Drinking**: 5mg/L max.	<0.008 – 0.211 mg/L	No exceedances were recorded.
Cadmium Total	**Drinking**: 5 µg/L max. **Aquatic Life**: 0.017µg/L	< 0.01 – 6 µg/L	No exceedances were recorded. Limits of detection (at <2 - <6 µg/L) were however, higher than the Criteria between 1992 and 2002.
Carbon Total Organic	**Drinking** (with chlorination): 4 mg/L source water.	3 – 7.3 mg/L	88% (15/17) of samples exceeded the Criteria.
Chloride Dissolved	**Drinking**: less than or equal to 250mg/L (aesthetic objective).	<0.1 – 13.4	No exceedances were recorded.
Chlorophyll A	**Drinking**: 2-2.5 µg/L (summer average).	<0.5 – 81.9 µg/L	75% (3/4) of samples exceeded the Criteria.

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[1] Denotes Provincial Water Quality Criteria, unless otherwise identified

Parameter	Water Quality Criteria[1] (Criteria within range of the data are shown)	Data Range	Results of Quamichan Lake Data Compared to Water Quality Criteria
Chromium Total	**Drinking**: 50 µg/L max.	0 – 25 µg/L	No exceedances were recorded.
Cobalt Total	**Irrigation:** 50 µg/L	0 – 0.084 µg/L	No exceedances were recorded.
Coliforms Fecal	**Untreated Drinking, Livestock, Industrial Use:** 0/100 mL max.	15 – 52 CFU/100mL	100% (3/3) of samples exceeded the Criteria.
Color True	**Drinking** (aesthetics): less than or equal to 15 TCU.	<5 – 20 TCU	13% (7/54) of samples exceeded the Criteria.
Conductance (specific)	**Drinking**: 700 µs/cm max.	50 – 388 µs/cm	No exceedances were recorded.
Copper Total	<u>Provincial Criteria</u>: **Drinking:** 500 µg/L. **Aquatic Life:** 6 µg/L (based on minimum hardness of 42.3 mg/L) <u>CCME Criteria:</u> **Aquatic Life** 2-4 µg/L.	0-6 µg/L	Provincial Criteria were not exceeded. 28% (12/43) of samples were recorded to be 2µg/L or higher, exceeding the CCME Aquatic Life Criteria. The limits of detection (at <2 - <6 µg/L) were however, higher than the Criteria between 1993 and 2002
Dissolved Oxygen	**Aquatic Life (water column, instantaneous minimum):** All life stages other than buried embryo/alevin): 5 mg/L.	0.04 – 20 mg/L	26% (29/113) of samples exceeded the Criteria.
Escherichia coli	**Untreated Drinking, Livestock, Industrial Use:** 0 CFU / 100 mL max.	6 – 42 CFU/100mL	100% (3/3) of samples exceeded the Criteria.
Extinction Depth	**Recreation**: 1.2 m minimum	0.5 – 4.5 m	25% (8/32) of samples did not meet the minimum Criteria.
Hardness (total dissolved)	**Drinking**: 80-100 mg/L acceptable; > 200 mg/L poor; > 500 mg/L unacceptable.	42.3 – 55.9 mg/L	No samples exceeded the Criteria for acceptable drinking water quality.

Parameter	Water Quality Criteria[1] (Criteria within range of the data are shown)	Data Range	Results of Quamichan Lake Data Compared to Water Quality Criteria
Iron Total	**Drinking** (aesthetics) **and Aquatic Life**:Less than or equal to 0.3 mg/L .	<0.05 – 0.848 mg/L	16% (6/37) of samples exceeded the Criteria.
Lead Total	Provincial Criteria: **Drinking:** 50 µg/L max. **Aquatic Life:** 34 µg/L maximum (based on hardness less than or equal to 50 mg/L). CCME Criteria **Drinking**: 10µg/L. **Aquatic Life** 1-7 µg/L	0 - 0.09 µg/L	No samples exceeded the Criteria. The limits of detection (at <20 - <60 µg/L) were however, higher than the Criteria between 1992 and 2002.
Lithium Total	**Irrigation** (CCME): 2500 µg/L	0.29 – 0.66 µg/L	No samples exceeded the Criteria.
Magnesium Dissolved	**Drinking** (taste threshold): 100 mg/L (sensitive people).	3.3 – 4.54 mg/L	Total Magnesium data was only available. No samples exceeded the Criteria
Manganese Total	**Drinking** (aesthetic): less than or equal to 50 µg/L. **Aquatic Life**: 1100 µg/L max. (total hardness at 50 mg/L). **Irrigation** (CCME**)**: 200 µg/L	6 – 633 µg/L	35% (15/43) of samples exceeded the Drinking Criteria. 9% (4/43) of samples exceeded the Irrigation Criteria. The Aquatic Life Criteria was not exceeded.
Molybdenum Total	**Drinking** (untreated): 0.25 mg/L. **Aquatic Life:** 2 mg/L. **Wildlife/Irrigation**: 0.05 mg/L **Aquatic Life** (CCME Criteria): 73 µg/L.	0 - 0.00028 mg/L	No samples exceeded the Criteria.
Nickel Total	**Aquatic Life** (CCME): 25-150 µg/L.	<8 - 0.12 µg/L	No samples exceeded the Criteria. The limits of detection (at <10 -<20 µg/L) were however, higher than the Criteria between 1992 and 2002.
Nitrogen - Ammonia	**Aquatic Life:** Max. based on highest temp and pH = 2.36 mg/L	<0.005 - 0.897 mg/L	No samples exceeded the Criteria

Parameter	**Water Quality Criteria[1] (Criteria within range of the data are shown)**	**Data Range**	**Results of Quamichan Lake Data Compared to Water Quality Criteria**
Nitrogen - Nitrate Dissolved	**Drinking/Recreation**: 10mg/L.	0 – 0.065 mg/L	No samples exceeded the Criteria.
Nitrogen-Nitrite Dissolved	**Drinking**: 1 mg/L. **Aquatic Life**: 0.06 mg/L when chloride is less than 2 mg/L.	<0.002 – 0.006 mg/L	No samples exceeded the Criteria.
pH	**Drinking**: pH 6.5-8.5. **Recreation / Irrigation**: pH 5-9.	6.2 – 8.9 pH Units	PH values fell below the Drinking Criteria minimum a total of 5/85 times (6%), and values were higher than the Drinking Criteria 5/85 times (6%).
Phosphorus Total	**Drinking & Recreation**: 10 µg/L max. **Aquatic Life:** 5-15µg/L.	5 - 255 µg/L	Drinking & Recreation Criteria were exceeded in 90% (60/66) of samples. Within the Aquatic Life range for a maximum, the 5µg/L value was exceeded in 98% (65/66) of samples, and the 15µg/L was exceeded in 83% (55/66) of samples.
Residue Filterable 1.0u (Total Dissolved Solids)	**Drinking** (aesthetics): 500 mg/L max.	44 – 120 mg/L	No samples exceeded the Criteria.
Selenium Total	**Drinking/ Irrigation**: 10 µg/L **Aquatic Life**: 2.0 µg/L. **Aquatic Life** (CCME): 1 µg/L **Wildlife**: 4.0 µg/L.	0 – 0.5 µg/L	No samples exceeded the Criteria. The limits of detection (at <30 -<60 µg/L) were however, higher than the Criteria between 1992 and 2002.
Silver Total	**Aquatic Life**: 0.1 µg/L (hardness is less than 100 mg/L)	<0.02 - <30 µg/L	No samples exceeded the Criteria. The limits of detection (at <10 -<30 µg/L) were however, higher than the Criteria between 1992 and 2002.
Sodium Total	**Drinking**: Less than or equal to 200 mg/L (aesthetics), 20 mg/L alert for people on sodium restricted diets.	6.3 – 8.6 mg/L	No samples exceeded the Criteria.

Parameter	**Water Quality Criteria[1] (Criteria within range of the data are shown)**	**Data Range**	**Results of Quamichan Lake Data Compared to Water Quality Criteria**
Sulfate Dissolved	**Drinking** (aesthetics): 500 mg/L max. **Aquatic Life**: 50 mg/L alert level, 100 mg/L max.	<.05 – 19.1	No samples exceeded the Criteria.
Temperature	**Drinking** (aesthetics): 15 °C. **Rainbow trout optimal rearing max.:** 18 °C. **Recreation & Aesthetics**: 30°C.	4.8 - 264 °C	The Drinking Criteria was exceeded in 46% (60/130) of samples. The Rainbow Trout rearing maximum was exceeded in 35% (45/130) of samples. Recreation & aesthetics were not exceeded.
Thallium Total	**Aquatic Life** (CCME**):** 0.8 µg/L	<0.002 – 20 µg/L	The Criteria was exceeded in 19% (7/37) of samples. These exceedances all occurred during the period of 1992. The limits of detection (at <3 - <30 µg/L) were however, higher than the Criteria between 1992 and 2002.
Turbidity	**Recreation**: 50 NTU max. **CCME Drinking:** **Health**: 1 NTU max.; **Aesthetics:** 5 NTU.	0.9 – 8.09 NTU	The Drinking (health) Criteria was exceeded in 78% (16/23) of samples. The Drinking (aesthetic) Criteria was exceeded in 17% (4/23) of samples.
Uranium Total	**Drinking**: 100 µg/L max. **Drinking (**CCME): 20 µg/L (interim maximum)	<0.002 – 0.016 µg/L	No samples exceeded the Criteria.
Vanadium Total	**Irrigation/Livestock** (CCME): 100 µg/L	0 – 7 µg/L	No samples exceeded the Criteria.
Zinc Total	**Drinking, Recreation/ Aesthetics**: Less than or equal to 5000 µg/L. **Aquatic Life**: 33 µg/L (based on water hardness less than 90 mg/L). **Aquatic Life** (CCME): 30 µg/L	0 – 31 µg/L	1 sample out of 43 (collected on July 14, 1992) exceeded the CCME Aquatic Life Criteria.

Table 8. Annual averages of significance for Quamichan Lake's water quality parameters reviewed in detail

	Year														
Parameter	**'85-'89**	**'90**	**'92**	**'93**	**'94**	**'95**	**97**	**'98**	**'99**	**00**	**'01**	**'02**	**'04**	**'05**	**Data Used/ Comments**
General															
Colour, True (TCU)			12	5	5	5	8.5	15	18	14		20	0	5	Spring Average (Feb – Apr.)
Dissolved Oxygen (mg/L)		0.6											1.2	0.2	Summer (Jul.-Aug) Average.@ Bottom Depths
PH (pH units)				7.1	7.3	7.2	7.7	7.7	7.6	6.9		7.4	7.7	6.7	Spring Average (Feb – Apr.)
Temperature (^{O}C)		22.3 19											21 18.2	21.5 18.3	Summer (Jul. – Aug.) Column Avg. Summer Avg. @ Bottom
Turbidity (NTU)						1.0	1.0	1.6	2.2	1.7		1.2	2.0	2.1	Spring Average (Feb – Apr.)
Nutrients															
Ammonia (mg/L)	0.09	0.2											0.85	0.15	Summer (Jul. – Sept.) Column Avg.
Carbon, Total Organic (mg/L)							4.6		3	4.4	5.1	4.3	4.8	4.1	Spring Average (Feb. – Apr.)

Parameter	**Year**														**Data Used/ Comments**
	‘85- ‘89	**‘90**	**‘92**	**‘93**	**‘94**	**‘95**	**97**	**‘98**	**‘99**	**00**	**‘01**	**‘02**	**‘04**	**‘05**	
Total Phosphorus (µg/L)	113		150										120	153	Summer (Jul. – Sept.) Column Avg.
Nitrate + Nitrite, Dissolved (mg/L)			0.08										0.09		Fall/Winter Average (Sept – Dec)
Biological															
Chlorphyll A (µg/L)													33.7	0	Annual Average
Coliforms, Fecal (CFU/100mL)												52	15		Actual data collected
E. Coli (CFU/100mL)												42	16		Actual data collected
Secchi (Extintion) Depth (m)	2.2	2.8			3		3						1.4	2.5	Annual Average
Metals															
Copper Total (µg/L)			1.8	<1	<2	<2	<6	<6	<6	<6	<6	<5	0.5	0.4	Annual Average
Iron Total (mg/L)			0.21	0.01	0	0.08	0.04	0.1	0.1	0.06	0.07	0.04			Annual Average

Parameter	Year														Data Used/ Comments
	‘85- ‘89	‘90	‘92	‘93	‘94	‘95	97	‘98	‘99	00	‘01	‘02	‘04	‘05	
Manganese, Total (µg/L)			94.8	11	30	22	6.5	12	14	18	31	11	6.8	177	Annual Average
Thallium, Total (µg/L)			3.5	<30	<30	<30						<3	<.002	<.002	Annual Average
Zinc, Total (µg/L)			9	5.5	<10	15	9.5	<2	3	3	<2	<5	.8	2.4	Annual Average

Table 9. Phytoplankton species counts (cells/mL) at Quamichan Lake in 2004 and 2005.

Order	Species *toxins produced[1]	Feb. 11 2004	Aug. 5 2004	Nov. 17 2004	Mar. 10 2005	May 12 2005
Centrales	*Cyclotella bodanica*	17				
(Diatoms)	*Cyclotella glomerata*	5,295				
	Cyclotella sp.					
	Melosira cf italica	410		284	1,148	25
	Melosira sp.	11				
	Stephanodiscus cf Niagarae	46		228		
	Percent of Total	**86.3%**		**0.4%**	**76.7%**	**0.9%**
Chlorococcales	*Ankistrodesmus cf falcatus*	17				
(Greens)	*Ankistrodesmus sp.*				6	3
	Crucigenia quadrata	23				
	Elakatothrix gelatinosa				14	
	Oocystis spp.		6		11	
	Pediastrum sp.	114				
	Scenedemus quadricauda	23		228	11	
	Schroederia Judayi					11
	Schroederia setigera				3	3
	Schroederia sp.		14			
	Sphaerocystis schroeteri	46				134
	Percent of Total	**3.3%**	**1.4%**	**0.0%**	**3.0%**	**5.5%**
Chroococcales	*Anacystis cf aeruginosa**			63,728		
(Cyanobacteria)	**Percent of Total**			**49.3%**		
Cryptomonadales	*Chroomonas acuta*	17			112	148
(Cryptophytes)	*Cryptomonas ovata / erosa*	6	238	171	34	70
	Cryptomonas sp.			284	3	17
	Percent of Total	**0.3%**	**16.7%**	**0.4%**	**10.0%**	**8.6%**
Dinokontae	*Peridinium / Glenodinium*					3
(Dinoflagellates)	**Percent of Total**					**0.1%**
Euglenales	*Trachelomonas sp.*	6				
	Percent of Total	**0.1%**				
Nostcocales	*Anabaena cf circinalis**					899
(Cyanobacteria)	*Anabaena flos-aquae**					1344
	*Aphanizomenon flos-aquae**			64,240		
	Percent of Total			**49.7%**		**82.6%**
Ochromonadales	*Dinobryon sertularia*	91			14	6

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[1] Cyanosite 2005

Order	**Species** ***toxins produced**[1]	**Feb. 11 2004**	**Aug. 5 2004**	**Nov. 17 2004**	**Mar. 10 2005**	**May 12 2005**
(Golden-browns)	*Dinobryon sp.*					6
	Mallomonas akrokomos					48
	Percent of Total	**1.3%**			**0.9%**	**2.2%**
Oscillatoriales (Cyanobacteria)	*Lyngbya limnetica**	86	90			
	Percent of Total	**1.2%**	**6.3%**			
Pennales (Diatoms)	*Asterionella formosa*	268			78	39
	Fragilaria crotonensis	188			53	17
	Fragilaria spp.				3	
	Gomphonema spp.	11				
	Navicula spp.	11				
	Nitzschia spp.				3	
	Synedra ulna			57		
	Percent of Total	**7.1%**		**0%**	**9.2%**	**2.1%**
Zygnematales	*Staurastrum cf paradoxum*	6				
	Percent of Total	**0.1%**				
Unidentified cells			1,075		3	
	Percent of Total		**75.5%**		**0.2%**	
	TOTAL CELLS COUNTED	**6,692**	**1,423**	**129,220**	**1,496**	**2,773**