WATER QUALITY BRANCH
ENVIRONMENTAL PROTECTION DEPARTMENT
MINISTRY OF ENVIRONMENT, LANDS AND PARKS

Christina Lake
Water Quality Assessment and Objectives

Technical Appendix

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SUMMARY

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

There are numerous water licenses within the Christina Lake watershed that authorize withdrawals for drinking water, waterworks, irrigation and industrial purposes. The lake is also important for aquatic life and recreational activities.

Non-point sources of waste are the only major input of pollutants to the lake. These are potentially derived from agricultural activities, past logging operations, past mining activities and most significantly, poorly maintained and/or located septic tank or tile field systems.

The data collected over the past 20 years confirms that the lake is in an oligotrophic state and that the overall quality of the water is very good. The parameters assessed did not provided evidence of overall lake deterioration. Yet, there was concern expressed by the public that, in recent years, deterioration has occurred in the shallow areas of the lake. Some local residents perceive that there has been a decrease in water clarity, an increase in aquatic weed and algae production, and odour problems during summer months. Local physicians report increased incidence of ear, throat and eye infections. Lack of extensive sampling in the near-shore regions prevents definitive conclusions with regard to these matters. Some tributaries do have higher fecal bacteria concentrations than the lake. This presents an increased risk of contamination of drinking water drawn from the streams.

Ecosystem objectives were established for the phytoplankton, periphyton, and zooplankton communities. Ambient water objectives were set for dissolved oxygen, turbidity, nutrients, clarity, chlorophyll *a*, and coliform bacteria.

Future monitoring recommendations include: establishing more sample sites in the very near-shore littoral areas, more emphasis on microbiological analysis, measurement of thermocline water chemistry, and estimations of kokanee salmon

populations. Future analysis should involve correlations between deep station data (long-term trends) and results obtained at the near-shore stations, which would show more immediate changes and indications of possible sewage contamination. Recommendations for future studies included an inventory of the septic systems that are currently operating near the lake, and an assessment of the near-shore soil types so as to determine the suitability of continued development (septic installations). The residents were encouraged to prepare an official community plan and pursue incorporation of the area. For health considerations, it was recommended that all intakes that draw water for the purpose of human consumption be located at a depth below the thermocline.

A glossary of technical terms is included as an appendix to the report.

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1. INTRODUCTION AND BACKGROUND

Christina Lake and the surrounding region is an important, multi-use area of British Columbia. The drainage basin supplies water for the domestic needs, as well as the industrial and agricultural activities of the local communities. The lake is used extensively for recreation purposes and as a site for summer and permanent residences. Aesthetic attributes such as exceptional water clarity and thermal springs make this area unique. Additionally, by virtue of inaccessibility, much of the adjacent land provides ideal habitat for a diverse array of wildlife. Consequently, maintaining the quality of the water is vital to those who use the lake as a water source and recreation area, and to preserve the present level of aesthetic value it provides.

The residents of the region are concerned that increased development and recreation, in conjunction with inadequate waste disposal, are factors that are adversely modifying the ambient conditions of Christina Lake. Specific observations presented at a community meeting held on December 2, 1993, are:

1) Sewage disposal by septic tank-tile field is perceived to be contaminating the lake. Some of these systems are poorly maintained or were installed in soils that are unsuitable for the purpose of on-site waste disposal (Kerr Wood Leidal, 1990);

2) A local physician reported an increased occurrence of minor ear, throat and eye infections associated with swimming in the lake;

3) Various kinds of illnesses, including those associated with the parasite *Giardia*, are attributed to drinking untreated lake water;

4) There is a perceived deterioration in lake aesthetics such as, increased attached algae on docks and boat bottoms, increased weed production, decreased water clarity, odour problems in summer months, and surficial oily slicks and foaming during late autumn;

5) Long-term changes in wildlife (fish and waterfowl) community structure is regarded as a possible problem;

6) There is a potential for increased houseboat traffic on the lake, yet currently, there are no facilities for the disposal of wastes from the holding tanks;

7) Discrepancies in coliform bacteria sampling results that exist between the Ministries of Environment and Health and an independent analysis performed in Spokane, Washington, has caused much concern.

The efforts of the Christina Study Committee were instrumental in the initiation of a program that has resulted in the collection of much water quality data. The primary purpose of this report is to provide a review of this information, concentrating primarily on those data collected by BC Environment (BCE) . On the basis of this and other information, ambient water quality objectives are proposed to ensure that the future water quality is maintained at an acceptable level.

This assessment and subsequent setting of objectives is based on a comprehensive study involving data for 12 BCE sites. The most extensive data were collected at two deep water sites, one at the south end of the lake and the other, approximately one third up the lake (Figure 1). This component of the study has been ongoing since 1972 and 1976 for each of these two sites, respectively. As of 1991, ten additional sites were established: a deep site in the north basin of the lake, three shallow sites, and one site in each of six tributaries (Figure 1). Also, to ascertain the significant seasonal trends within the lake, the sampling schedule was increased from once or twice a year to monthly in 1991. The characteristics analyzed and a summary of the results for each site are listed in Tables 1-12. Results are discussed in detail in Section 3. This assessment also makes use of analyses conducted by other agencies that extend back to the mid 1960's. These include: Ministry of Health Sanitary Surveys in 1967, 1970, 1975 and 1985-93; Regional District of Kootenay Boundary Report (1975); Water Quality and Primary Productivity Report (Crozier, 1979); Fisheries and Wildlife data (covering several decades); Eurasian watermilfoil Reports (1986-1992);

Water Supply and Wastewater Disposal (Kerr Wood Leidal, 1990); and, Assessment of Water Quality Data (Sigma Engineering, 1991).

2. CHRISTINA LAKE AND TRIBUTARIES PROFILE

2.1 Morphology

Summaries of the morphological and hydrological characteristics of Christina Lake and its watershed are presented in Tables 13-16. Christina Lake watershed is located in south-central British Columbia within the Monashee Mountain Range of the Columbia Mountains physiographic province. The climatic conditions of the area are generally that of cool winters with moderate to heavy snowfall, and warm, dry to relatively moist summers. The basin's drainage area is 492 km^2 (Figure 2) and the elevation at the lake outlet is at approximately 450 m (Table 13). The lake drains through Christina Creek, at its south end, into the Kettle River which flows into the Roosevelt Reservoir on the Columbia River in Washington State (Sigma Engineering, 1991).

Christina Lake can be characterized as long and narrow with a steep, U-shaped, glacially-carved bottom. For a map of the bathymetry refer to the Kootenay Boundary Study (1975, p. 36). The lake volume is 9.295×10^5 dam^3 and its surface area is 25.1 km^2. Of this area, only 5% is occupied by a littoral zone (<6 m depth), the majority of which is located on the southeast shore of the lake (Northcote and Larkin, 1956). It is at this location where near shore depths are sufficiently shallow that macrophytes (aquatic plants) are able to establish themselves in significant numbers. The lake is strongly stratified during the summer months with the epilimnion (surface layer) extending to a depth of approximately 8-10 m and occupying a volume of nearly 2.0×10^5 dam^3 (21.5% of the lake volume). Surface water temperatures peak in early to mid August and reach a maximum of 25°C. Local residents have reported higher temperatures (to 30°C) in shallow waters. Summer hypolimnetic temperatures generally do not exceed 10°C and drop to below 6°C at depths exceeding 20 m.

2.2 Hydrology

There are 23 creeks that flow directly into Christina Lake, of which only a few such as McRae and Sutherland, consistently have year-round flows. All other creeks in the drainage basin have ephemeral flow patterns (Aquatic Studies Branch, 1980). Christina Creek, at the southern end of the lake, is the outlet. Approximately once every ten years this creek back flows into the lake when the Kettle River experiences periods of high flow (Maximenko, pers. comm., 1993). Based on limited discharge data for Christina Creek (Table 16) and an estimation of the evaporation rate, the total watershed runoff was calculated to be approximately 226,825 dam^3/yr. The flushing rate (lake volume + outflow) of the lake is estimated at 4.5 years, a value that is in relative agreement with previous estimates (Crozier, 1979; Sigma Engineering, 1991). A large percentage of the precipitation falls during the winter months as snow, consequently maximum lake water levels occur in May and June during the snow-melt freshet (Aquatic Studies Branch, M.O.E., 1980). Minimum levels occur during October and November.

2.3 Land Uses

2.3.1 Protected Areas Strategy

The Protected Areas Strategy for B.C. is a joint program of B.C. Parks and B.C. Forest Service developed to conserve and protect the natural heritage of the province. The goal is to protect 12% of the province through park or wilderness area designations by the year 2000. The Christina Lake watershed is one of the areas currently being considered in this process (Quesnel, pers. comm., 1993). Those portions of the watershed that will be allocated as study areas will be presented in a report prepared by the Kootenay Regional Protected Areas Team within one year (tentative title - Protected Areas Strategy, an assessment of candidate protected areas in

Kootenay region). The shoreline of the northern 60% of the lake and most of the drainages within this portion of the watershed will likely be identified as this study area (Quesnel, pers. comm., 1993). This and other study areas within the region will then be assessed until the year 2000, at which time, some will be designated as park or wilderness areas. During the interim, resource based industrial activities (e.g.logging and mining) within the study area will be suspended.

2.3.2 Residential Development

There are approximately 500 permanent dwellings in the Christina Lake watershed, the majority of which are located along the southeast shore of the lake from the township of Christina to Lavalley Point and at English Point (Maximenko, pers. comm., 1993). The permanent residents, of which 37% are retired, amount to a population of approximately 1,100 individuals.

A report produced by Sussex Consultants (1991, cited in Sigma Engineering) documented that there are almost as many seasonal dwellings (460) along the lake shore as there are permanent ones. The majority of these are located along the southern shore, while over 100 are located at the north end and are accessible only by boat. These dwellings, in conjunction with the campgrounds, resorts, motels and day-use visitors (Figure 3), account for a population increase of greater than 500% during the summer months. Estimates of the numbers of people visiting some of the popular facilities during the peak summer period are summarized in Table 17.

2.3.3 Agriculture

Due to rugged topography and poor soils, agricultural activity has been severely limited in the watershed. The majority of what little agriculture exists is located within the Agricultural Land Reserve of the Sutherland Creek valley (Sigma Engineering, 1991). In 1993, fifteen of twenty-three water withdrawal licenses designated for irrigation purposes were located along this creek (Table 18). The total 1993 quantity permitted for withdrawal for agricultural purposes was 517 dam^3 (419.5 acre/feet).

2.3.4 Forestry

At the present time, there is no commercial logging activity in the Christina Lake watershed (Thorpe, pers. comm., 1993). Sigma Engineering (1991) reported that between 1990 and 1994 there were three cutting permits issued to Pope and Talbot Ltd. which operates under Forest License A18969. In 1990, one of these areas was logged, a 16-ha block near the headwaters of Stewart Creek. The company has decided not to cut one of the remaining two sites, but does plan on logging the other, a 57-ha block near Coryell Creek which is a tributary to McRae Creek (Pope and Talbot Ltd., pers. comm., 1993).

There are parcels of land which are privately owned and likely to be logged within the next few decades. The location and size of each are not known.

2.3.5 Mining

Although there has been mining exploration and some development of small mines in the Christina Lake watershed, there is no active exploration and no mining at present (Brueckl, pers. comm., 1993). The Mehmal Gravel Pit is being expanded, but as it is located in the Christina Creek and Kettle River drainage, its potential to impact the lake would be limited to the rare occasions that Christina Creek backflows.

Donna Mine, northwest of Coryell Creek (a tributary to McRae Creek), operated prior to the 1980's (Sigma Engineering, 1991). However, since no metals data exist for the creeks, it is not currently possible to determine if leachates from the mine's tailings pit are reaching McRae Creek.

2.4 Water Uses

2.4.1 Licenses

As of June 1993, there were nine water licenses registered for direct withdrawal from Christina Lake (Table 18, Figure 4). Six of these were for domestic use and three for waterworks (one of which also withdraws for industrial purposes). These licenses account for a total potential withdrawal of 165.1 dam^3/year (0.08% of the lake outflow of 208 000 dam^3/year). There are an additional 148 licenses registered for withdrawal from within the Christina Lake drainage basin. Over half (77) are drawn from Sutherland Creek while the remainder are distributed throughout many smaller tributaries. Of these tributary licenses, 121 are domestic, 23 are for irrigation, 2 are waterworks and 2 are industrial. The two waterworks licenses are located near the mouth of Sutherland Creek (Figure 4) and account for a significant portion of the total withdrawal from the tributaries. In addition to licensed withdrawals, it is likely that there are a number of unlicensed withdrawals from both the lake and the creeks.

2.4.2 Recreation

Christina Lake is a very popular recreation area. During the summer months (mid June - mid September) the water temperature is well suited for body-contact recreation (swimming, water-skiing, wind surfing, etc.). The lake also offers very good water clarity and sandy beaches. Due to limited access within the watershed, most recreational activity is water-based as opposed to land-based. The access also limits the majority of the water-related activity to the southern half of the lake. Additionally, it is in this region that the topography of the shoreline is most suited to water sports. Swimming, boating and particularly water-skiing are very popular activities associated with the lake. Cottages and campgrounds (Figure 3) are restricted to the shoreline of the lake as the topography of the region limits construction and road building. Christina Lake has a moderate sports fishery with approximately 10 000 angler days per year (Smith, pers. comm., creel survey, 1993). The target species are smallmouth bass, rainbow trout and, perceived as high priority, kokanee salmon. Due to the low lake productivity, the growth rate of kokanee is reduced relative to more productive lakes in the region. Older rainbow trout caught in Christina Lake have been reported to exceed 5 kg (Matthews, pers. comm., 1993).

2.5 Aquatic Life And Wildlife

2.5.1 Macrophytes

The relatively wide littoral zone at the south end of lake, as well as the narrow littoral strips elsewhere, have historically supported a moderately dense and diverse native macrophyte community. At times, the density of some species has impeded recreational activity in the southern portion of the lake. Surveys conducted in the late 1970's for the Aquatic Plant Management Program (M.O.E.) has resulted in detailed documentation of the macrophyte species present in Christina Lake (Table 19). At that time Eurasian watermilfoil (*Myriophyllum spicatum*) was not present in the lake. In 1985, however, this nuisance species was inadvertently introduced and has since become successfully established. In order to confine this species, an intensive survey and control program has operated during the summer months since 1986. Despite these efforts, the plant has an increasing population (Table 20). Yearly reports have been produced by the Water Quality Branch to summarize the progress of the control program (Retzer and Haberstock, 1989-91 and 1993; Wallis, 1986; Wallis and Haberstock, 1988; Dale & Haberstock, 1992).

2.5.2 Fish

Extensive stocking programs during the first half of the century were designed to enhance the fishery of the lake (see Table 21 for a list of the release records). The native game species released were rainbow trout (*Oncorhynchus mykiss*) and a shore-spawning stock of kokanee salmon (*Oncorhynchus nerka kennerlyi*), while non-native (introduced) game species included a stream-spawning stock of kokanee, smallmouth bass (*Micropterus dolomieui*), largemouth bass (*M. salmoides*) and carp (*Cyprinus macrocheilus*) (B.C. Environment Fisheries Branch File). Non-sport species within the lake include: sunfish, catfish, suckers, squawfish, whitefish, sculpin, shiners and chub (Sigma Engineering, 1991). Within the last couple of years, walleye (*Stizostedion vitreum*) has made its way into Christina Lake by way of the Kettle river system (Smith, pers. comm.,

1993). This species is piscivorous and consequently, might have an impact on the kokanee and rainbow trout populations in the near future.
The life history pattern of the native kokanee involves several years of pelagic feeding followed, at maturity, by a return to those limited portions of the shoreline that are appropriate for spawning. The introduced stock of kokanee salmon and the rainbow trout exhibit similar life history patterns with the exception that they return to the streams to spawn. The Fish and Wildlife Branch has documented that McRae, Sutherland, and particularly Sandner creeks are currently active spawning habitats for these species (Sigma Engineering, 1991).

In the 1920's, 30's, and 40's, a commercial kokanee fishery was quite successful. The small size of the fish, timing of spawning runs, shoreline development, and market competition contributed to an economic decline of the fishery (Stringer, N.D.). Stringer proposed that the introduction of the new stock in 1940 was as attempt to produce a hybrid with greater genetic vigor at a time when the average size of the native strain was dropping. However, due to the different spawning habits of the two stocks, the native (shore-spawning) population may remain genetically isolated from the stream-spawning population. It is now likely that a combination of over exploitation, increased shoreline development at prime beach-spawning habitats, fish introductions and biological interactions are further hindering the recovery of the native shore-spawning kokanee. The competitive pressures for food from both the stream-spawning stock and an introduced species of freshwater shrimp (*Mysis relicta*) are likely factors. *Mysis* introductions in numerous other lakes has, in many cases, resulted in negative effects on kokanee populations (Lasenby, *et al.*, 1986).

2.5.3 Waterfowl

The Aquatic Studies Branch of the Ministry of Environment (1980) documented that the southern perimeter of the lake is the only location in the watershed where habitat is moderately suited to waterfowl production. Elsewhere, adverse topography, deep water, and lack of marshy habitat impose severe limitations to these wildlife.

2.5.4 Zooplankton

A concise pre-1991 summary of the zooplankton species present in Christina Lake can be obtained from Sigma Engineering (1991, Table A9). This documentation includes two genera of cladocerans, two genera of calanoid copepods, one genus of cyclopoid copepods, and three rotifers. Each of these groups has been represented in BCE zooplankton sampling to date (Tables 22 and 23). All the species documented in Christina Lake are common to other lakes of south-central British Columbia (Pinsent and Stockner, 1974). The cladoceran, *Bosmina longirostris*, and the rotifer, *Kellicotia longispina*, have been dominant in the lake throughout the period of study. The calanoid copepod, *Epischura nevadensis*, and the cyclopoid copepod, *Diacyclops bicuspidatus*, have become a dominant component of the zooplankton community structure in more recent years. In the summer of 1991 a species of rotifer (*Conochilus unicornus*) was present in high concentrations at only the northern region of the lake. The patchy distribution and relative abundance of this species are apparent when density per unit area is considered (Tables 24 and 25).

Approximately 90 000 *Mysis relicta* were released into the lake in 1966 in an attempt to stimulate the Kokanee population (Stringer, 1966). BCE sampling performed in 1975 and 1988 determined that a population of *Mysis* had become well established (Sigma Engineering, 1991). The province-wide *Mysis* introduction program has resulted in increased size classes of target fish species in half of the lakes recently studied. Yet, of 20 lakes tested, there have been poor results in fish population trends since the introductions (reduced abundance in 9 lakes, unknown effects in 9, and no effect in 2). For Christina Lake, the effect on kokanee abundance is unknown while there has been no change in the size classes (Lasenby *et. al.*, 1986).

2.5.5 Phytoplankton

Pre-1991 phytoplankton records are available in the report prepared by Sigma Engineering (1991, Table A8) for BCE. BC Environment (BCE) has collected additional data since that time. At the three deep sample sites, analysis of pelagic algal species continued as in previous years. Dominant diatom species present in the lake are considered typical of oligotrophic lakes (Wetzel, 1983). Additionally, according to Wetzel (1983), those members of the Dinoflagellates, Chloroccocales and Chrysophytes that are indicative of oligotrophic waters were regularly present, while those groups typical of eutrophy (the blue-greens and many greens) were uncommon (Tables 26 and 27). A community structure that regularly consists of diatoms (particularly *Melosira italica, Asterionella formosa, Fragilaria crotonensis*, and *Synedra acus*), the dinoflagellate *Peridinium*, various members of the Chlorococcales, the Cryptomonads and Ochromonadales (*Dinobryon* and *Mallomonas*) should be considered typical of pelagic algal species in Christina lake.

2.5.6 Periphyton

At the three shallow sample sites, analysis of attached algal species (periphyton) was conducted during the summer of 1991 (Table 28). The diatoms were the group most representative of this attached community. Relative to the pelagic samples, blue-green algae were present in greater numbers. This situation is indicative of elevated nutrient levels at the shallow sites relative to the deeper water. These nutrients are likely from natural sources as well as near-shore septic fields that are leaching into the lake via the sediments. Continued sampling of the attached algae is required to definitively determine its community structure. At present, the community can be characterized as being dominated by the pennate diatoms (particularly *Achnanthes minutissima* and *Fragilaria construens*) and regularly consists of some blue-greens.

Future alterations in these community structures, either through the elimination of a group, or a shift in dominance (such as towards the blue-green algae), would be representative of changing ambient conditions (likely through eutrophication). Any changes, therefore, may provide a sensitive indicator of the shallow water quality of the lake.

2.6 Waste Discharges

2.6.1 Point sources

There are no true direct discharges of domestic or industrial waste to either Christina Lake or its tributaries.

2.6.2 Non-Point Sources

Since there are no point sources, all waste reaching Christina Lake does so diffusely via groundwater, run-off (creeks), and to a lesser extent, into the water column from surface waters.

2.6.2.1 Commercial Non-Point Sources

There are several large sources of commercial wastewater being discharged into the soil near the water table (Figure 5 and Table 29). Invariably, much of this becomes a significant component of the non-point sources of contamination to the lake (see section 2.6.2). Table 29 lists all of the permitted discharges with the possible exception of a few of the gas stations or restaurants (1994 data). All of the treatment systems are septic tank and tile fields, each designed to be large enough to handle the commercial flows.

The commercial septic tank facilities, such as those that service the campgrounds, are inspected regularly by BC Environment or BC Health staff. In most cases the septic tanks are well maintained and pumped out every 2-3 years. Unfortunately though, many of the tile fields are likely close to, or even below, the water table. And, since the capacity of the soils to remove phosphorus from the wastewater is poor, there are likely to be large seasonal surges of this nutrient to the lake at sites adjacent to these disposal facilities.

The total annual phosphorus load to the ground from all commercial facilities is estimated in Table 29. The phosphorus data on which these estimates were based are derived from a study of septic tanks and phosphorus concentrations in the Okanagan (Cleal-Udell MS , 1993). Phosphorus concentrations in Okanagan septic tanks were variable throughout the summer months. Therefore, in order to estimate a generalized phosphorus concentration, the mean value for the entire summer was calculated. This mean value is 7.22 mg/L with a standard error of 0.5. The volumes of wastewater discharged in summer and winter were estimated by environmental health officers and waste management officers familiar with the permits and are reported as daily flows (Table 29). To estimate the maximum annual phosphorus load to ground, the summer volumes were assumed to be generated for 120 days per year (winter flows for 245 days). These estimates probably exceed the true quantity reaching the lake as a small percentage of phosphorus will be retained by the soil. The amount of phosphorus retention should be determined by a separate study.

2.6.2.2 Residential Non-Point Sources

It is possible that a significant input, in terms of Christina Lake, is groundwater contaminated with domestic waste from individual households or cottages.

All permanent and seasonal dwellings around Christina Lake use on-site waste disposal units. The vast majority of these are septic tank and tile field systems, most of which are not maintained in accordance with recommended practices. According to a survey conducted by Kerr Wood Leidal Associates (1990), half of the septic tanks have not been cleaned since installation, while one quarter have sludge removed infrequently (4 to 10 years). Only the remaining 25% of residents have sludge removed every 2 to 3 years, the frequency recommended for optimal performance of septic tanks. Consequently, it is very likely that the septic tanks are contributing more phosphorus to the groundwater than they would if they were operating according to design criteria.

The near-shore topography and soil conditions further compound this problem. Adverse topography has limited the size of many lake-shore lots. Consequently, many older septic systems were installed closer to the lake than the required distance of 30 m, a value later established under the Health Act. Also, much of the soil upon which these dwellings are built is unsuitable or marginal for the purpose of on-site wastewater disposal. Because of exposed and shallow bedrock, the soils do not sufficiently filter the contaminants (both nutrients and sewage pathogens) from the water before it reaches the lake. Previous zoning which allowed for very small lot size has also contributed to this problem.

A detailed assessment of groundwater quality and the quantity of wastewater moving from the commercial and residential sources needs to be done if a better understanding of wastewater effects on the lake water is to be gained.

Another potential source of nutrients to the lake is lawn fertilizers. Loss of fertilizer to ditches which drain to the lake, especially after rainfall, is a problem which has not been quantified. The best approach to this is probably public education.

2.6.2.3 Watershed Non-Point Sources (via run off)

Other sources of non-point pollution include agriculture and logging. The most intensive agricultural activity in the watershed occurs along Sutherland Creek. Crozier (1979) identified Sutherland Creek as the main source of nutrients to Christina Lake from this land based activity. Some of these nutrients undoubtedly originate from agriculture.

Logging has the potential to increase sediment phosphorus and nitrogen flowing into tributaries to the lake. Because of the steep terrain surrounding the lake, runoff from logging is a potential concern. Indeed, there are some examples of mud slides that apparently resulted from logging (Sigma Engineering, 1991). A recent slide (1993) into Sutherland creek apparently due to logging was the source of considerable sediment and was coincident with high coliform concentrations. Future logging on

Crown land will follow the new Forest Practices Code which is designed to prevent problems like this. However, private landowners may not bound by this code of practice.

Sander Brothers sawmill once operated adjacent to Christina Creek, immediately downstream from the lake. During production, woodwaste was buried along the south-east shore of the lake, close to the outlet. It was here that the burner was located and much of the marshy shoreline was filled with woodwaste and soil. It is very likely that breakdown products and wood preservatives from this woodwaste continue to leach to the groundwater table, the lake and the creek.

2.6.2.4 Miscellaneous Non-Point Sources

At present, there is no facility for removal of wastewater from houseboats on Christina Lake. None of the marinas have a private pump-out facility. It is illegal to discharge wastewater from boats to any freshwater in B.C. Such discharge is a violation of the B.C. Litter Act. Citizens can report violations to a Conservation or RCMP Officer for enforcement.

Residents of Christina Lake expressed the desire to have the lake registered under the Canada Shipping Act, a status designated to Shuswap, Mara and Okanagan lakes. Such registration would require all boats to have locked holding tanks. Unfortunately, this Act can only be enforced by Canada Coast Guard Officers. A legislative change is required in order to allow enforcement by Conservation Officers. So far, the Federal Government has been unwilling to make this change.

2.7 Water Use Designations

On the basis of the aforementioned conditions the following designated water uses are identified for all areas of Christina Lake: drinking water, recreation, irrigation, livestock watering, industrial use, wildlife watering and protection of aquatic life. Water use designations for creeks within the watershed are as above with the exception of recreation.

3. WATER QUALITY ASSESSMENT AND OBJECTIVES

3.1 Water Quality Assessment

3.1.1 Temperature

Christina Lake is a typical interior lake in terms of seasonal temperature stratification patterns. Although extensive temperature data only exist for the spring, summer and fall months, these data suggest that Christina is a dimictic lake (i.e., that the lake has two yearly periods when it mixes completely from top to bottom). The first brief period of circulation probably occurs in early April while the second occurs in early November. However, on the increasingly more frequent occasions that winter temperatures are not sufficiently cold, the lake does not freeze over. Under these circumstances the lake goes through a monomictic cycle (it mixes once, throughout the November - April period). Surface water temperatures regularly approach 25°C in August. During the summer months a distinct thermocline is present at a depth of 8-10 m (Figures 6-9, 13 & 14). Hypolimnetic temperatures range from 10°C at its upper depth limit to below 6°C at depths exceeding 20 m. These cooler temperatures at depth are significant since it is the hypolimnion that provides a thermal refuge for kokanee and rainbow trout during this warmer period.

3.1.2 Dissolved Oxygen

For the months of record (May through October), the 1991 and 1992 dissolved oxygen concentrations throughout the water column ranged from very high to supersaturated (Figures 10-12). Supersaturation results from photosynthetic activity in excess of losses to the atmosphere (Wetzel, 1983). The minimum absolute concentration recorded at site 0200078 during this period was 8.7 mg/L. This value occurred at the surface in early August when the water temperature was 25°C (107% saturated). Consequently, all readings significantly surpassed the provincial working criterion of 5 mg/L which is the level below which salmonids begin to experience oxygen stress (Nagpal and Pommen, 1994). Additionally, the minimum value observed during 1991-92 exceeds the minimum recorded for the previous ten years by 0.7 mg/L.

Oxygen profiles in Christina Lake (Figures 13 & 14) are typical of oligotrophic lakes (Wetzel, 1983). The increase in the metalimnetic (thermocline) oxygen concentrations noted in previous documentation (Crozier, 1979; and Sigma Engineering, 1991) is the result of phytoplankton production in this strata. Photosynthetic oxygen production is elevated in this zone due to the fact that, although low, nutrient concentrations are usually higher in the thermocline than in the epilimnion (Wetzel, 1983).

Relative areal hypolimnetic oxygen depletion rates (Tables 30 & 31) are used as an approximate index of the productivity of stratified lakes. The method assumes that the organic production of the trophogenic zone (surface waters) is reflected in the oxygen consumption that occurs in the hypolimnion (Wetzel, 1983). Historically, there has been no appreciable oxygen depletion in the hypolimnion of Christina Lake (Crozier, 1979). Depletion rates calculated for the summers of 1981 and 1991 support Crozier's observation (0.022 mg/cm^2/day and 0.010 mg/cm^2/day for the two years, respectively). These values are by no means definitive as dissolved oxygen data for the entire hypolimnion were not collected. Nevertheless, the analysis lends support to the current trophic classification of Christina Lake. Oligotrophic lakes are reported to have oxygen depletion rates less than 0.025 mg/cm^2/day while eutrophic lakes are expected to exceed 0.055 mg/cm^2/day (Wetzel, 1983). Both years, particularly 1991, were within the oligotrophic range.

3.1.3 Turbidity

Turbidity in Christina Lake remains very low. The recent values obtained for the south end deep site (0200078) are an improvement from those prior to the last documentation (Sigma Engineering, 1991) (mean value pre-1991 = 0.4 NTU relative to 0.29 NTU for the period 1991-1993). The maximum value obtained at any of the deep sites was 1 NTU and the minimum value was 0.1 NTU. Turbidity at the shallow sites was slightly higher (maximum = 2.1 at E215959 on September 2 1992), but this was likely the result of wave-induced suspended inorganics. Suspended sediment would also be the cause of elevated turbidity values in the tributary systems (maximum = 3.0 NTU at 0200079 on April 27, 1993). In no case did the mean value at any site exceed 1 NTU and since this is the Canadian drinking water guideline, Christina Lake easily meets this criterion.

3.1.4 Extinction Depth

Secchi depth values for the lake also demonstrate that the clarity is exceptional. The mean measurement at all three deep sites exceeded 10 m. The maximum was 16 m while the minimum was 3.2 m. An apparent long-term trend of increasing clarity is evident in Figure 15, which presents a plot of best-fit analysis of Secchi depth over time.

3.1.5 Nutrients

3.1.5.1 Spring Overturn Phosphorus

Spring overturn is the period prior to the formation of a summer thermocline, and is important for estimating the potential summer algal biomass and trophic state of a lake (McKean, 1992). Sampling during this period, when the lake is homogeneously mixed, provides an index for evaluating the lake state. Between the years 1973 and 1993, the spring overturn total phosphorus concentrations for Christina Lake ranged from 3 (analytical detection limit) to 16 µg/L (Table 32). It should be noted however, that the maximum values (all obtained during the mid 1980's) are higher than might be expected for other related lake conditions (chlorophyll, water clarity). Despite this period of implausible data, the mean spring overturn phosphorus concentration for the period of record was 6.5 µg/L, a value that is at the low end of the oligo-mesotrophic range of 5-10 µg/L (Wetzel, 1983).

Aside from the period of high results (1983, '84 and '86), the remainder of the data illustrate no strong trend in spring overturn phosphorus concentrations with respect to time (Figure 16). There appears to be a slight reduction in phosphorus concentrations in recent years with the exception of an anomalous value at site 0200520 (11 µg/L) in April of 1993. Continued sampling will substantiate the validity of this apparent trend. Regardless of temporal trends, overturn phosphorus levels for the entire 20-year period are low, generally in the range of 3 µg/L (the minimum detectable concentration) to 8 µg/L. The overall mean for phosphorus is 6.5 µg/L. When the 1983-86 data are excluded, the mean spring overturn phosphorus drops to 5.6 µg/L.

3.1.5.2 Phosphorus Loading

With a mean spring overturn concentration of 6.5 µg/L, the total load of phosphorus to the lake is estimated to be 4656 kg/yr (likely within the range of 3478 - 6435 kg/yr) (Appendix 1). The majority of this is derived from allochthonous (or external) inputs. The tributaries to the lake had phosphorus concentrations above lake concentrations (particularly Sutherland Creek) and seepage to the lake from septic fields most certainly adds to the streamflow concentrations. Relative to the other tributaries, Sutherland Creek is responsible for the greatest phosphorus load to Christina Lake. This is due to greater discharge volumes (except McRae Creek) and more concentrated agricultural activity. The summer hydrograph for Sutherland Creek (Figure 17, derived from mean stream flow data compiled by the Water Survey of Canada, 1991) allows for a rough estimation of the timing and quantity of the phosphorus load to the lake from this particular system (Table 33). Greater than 50% of the summer load occurs in the month of May. This is significant as the quantity of nutrients available in the early summer will directly influence the degree of algal production during the growing season.

On the basis of the calculated loading from Sutherland Creek (total phosphorus ≈ 460 kg/year, Table 33), estimated inputs from the other areas of the watershed (via creeks) can also be made. Sutherland Creek's watershed is about 18% (88 km^2) of the Christina Lake drainage and on an areal basis provides about 5.2 kg P/km^2/yr. The largest tributary watershed within the lake's drainage is McRae Creek (115 km^2), but it is less developed than Sutherland Creek. If a total phosphorus export of 3.9 kg/km^2/yr is used (75% of Sutherland's), then McRae Creek would supply a yearly average of 450 kg of total phosphorus to the lake. The remainder of the watershed (60%, 290 km^2) has much less development and consequently a lower export coefficient. If a value of 3.1 kg/km^2/yr is used (60% of Sutherland's) a total phosphorus supply of 900 kg/yr is obtained. These export values are lower than those cited in another study of the Pacific Northwest (Reckhow *et al*, 1980). Reckhow established that export coefficients averaged 8 kg/km^2/yr of dissolved phosphorus and 18 - 68 kg/km^2/yr of total phosphorus. Many of the data on which these estimates were based were obtained from logged watersheds and therefore the values are expected to be considerably higher than for a relatively undisturbed watershed such as Christina Lake.

Atmospheric deposition of phosphorus from dustfall and precipitation can be a significant source to a lake. For coastal areas (i.e., Puget Sound) an estimate of 20 kg P/km^2/yr has been used (Gilliom, 1980). Data for the Okanagan Valley were gathered in 1971-72 and reported in Haughton *et al* (1974). Using the median data for 8 basins, a value of 32 kg/km^2/yr is calculated. Based on this estimate, 800 kg of phosphorus would enter the lake each year from this source.

Dustfall data for the Christina basin were collected at 3 sites during 1991-93. It was intended that these data would provide actual dustfall loading information for the lake, rather than having to depend on data from other areas for this component of the phosphorus budget. After compiling and evaluating the Christina data, we concluded that there was some error in the results (i.e., these data suggested that there was more phosphorus input from this one component than there was in the entire lake) and consequently, they are not included here.

It is unlikely that there is significant internal loading of phosphorus to the lake. Since the lake maintains high dissolved oxygen concentrations throughout the year, phosphorus released from the deep sediments would be negligible. A well-oxidized sediment-water interface acts as a barrier to phosphorus release to the water column (Wetzel, 1983).

To better understand the relative contributions of phosphorus to the lake, a very simple budget is provided below to illustrate the importance of each component. The values given above present estimates for the phosphorus supply to the lake from streams (which would incorporate logging and agriculture). The sum for these is 1810 kg (460 + 450 + 900). The atmospheric deposition is probably about 800 kg/yr.

The other significant source of phosphorus to Christina Lake is probably from dwellings. The estimate of phosphorus from the large septic tank systems (commercial operations) is potentially up to 674 kg per year. Contributions from residential septic systems is more difficult to estimate. Vollenweider (1971, Table 5.11) used an average of 2.25 g P/person/day. Therefore, with a population of 1,100 people, potentially 900 kg/yr of phosphorus would be discharged to ground near Christina Lake. Reckhow *et al* (1980, p. 89) use an estimate of 1.5 kg/person/yr (or about 1650 kg P/yr in close proximity to the lake). However, not all phosphorus would reach the lake as some would be bound to soil particles or metabolized by soil biota. It is likely that, since the soil conditions are poor, the true loading to the lake is a high percentage of that which is loaded to ground (≈600+ kg per year).

The sum of the watershed (1800), atmospheric (800), commercial septic (675), and residential septic (600) values agrees fairly well (3875 kg/yr) with the total load to the lake estimated by the lake concentration (4656 kg/yr). The most important point to consider here is that sewage is a significant fraction of the phosphorus input to the lake (1275 kg of 3875 kg - or approximately one third).

3.1.5.3 Nitrogen

In 1979, Crozier reported that nitrogen concentrations in Christina Lake were low enough that the lake would be considered ultra-oligotrophic according to the classifications established by Wetzel in 1975. The mean values for all forms of nitrogen obtained to date concur with those reported by Crozier. Consequently, no trend in nitrogen concentration over time is discernible (Figure 18). Additionally, during the summer months (1991-92) the mean Kjeldahl values did not vary between sample sites within the drainage basin ($P < 0.05$, Appendix 2) hence, it is likely that there is no isolated area of the watershed that is exposed to significantly elevated inputs of nitrogen.

The ratio of total nitrogen to total phosphorus at spring overturn is often used as an indicator of the relative importance of these two major nutrients. In general, phosphorus is the limiting nutrient in most lakes and this appears to be the case in Christina Lake (Table 32). N:P ratios for Christina Lake range from 7:1 to 39:1 (ratios of 15:1 or higher are indicative of phosphorus limitation, 5-15:1 suggests co-limitation, and ≤5:1 is nitrogen limited, Nordin 1985).

3.1.5.4 Fate of Summer Nutrients Entering the Lake

The dispersion of tributary water once it enters a lake is dependent on its density relative to that of the lake. Density is primarily dictated by the temperature of the water and, to a lesser extent, by the salinity (Wetzel, 1983). Figure 19 depicts the mean monthly summer densities of the water entering Christina Lake from Sutherland Creek. As Christina Lake stratifies throughout the summer the density of the water at the surface decreases (as temperature increases). Therefore, the strata of water that exhibits a density (temperature) equivalent to that of the creek is the depth to which the tributary water will immediately sink and disperse (Table 34). In early spring the lake is homogeneously mixed at a temperature that is approximately the same as the incoming creek; consequently, tributary nutrients are diluted throughout the water column. Yet by May, stratification of the lake results in a situation where the density of the thermocline is equal to that of the incoming tributaries. In this case the elevated levels of nutrients discharged to the lake at this time of the year (Table 33) remain relatively concentrated at a depth that is within the photic zone. The increase in the dissolved oxygen concentration, reflecting increased algal photosynthesis (Figures 13 &14; also see section 3.1.2), at the thermocline during summer months supports this observation. Furthermore, there was no appreciable difference between deep (hypolimnetic) and surface (epilimnetic) phosphorus concentrations during summer stratification periods. This is the case because the stream nutrients are entering the lake at a depth of 8-16 m for the majority of the summer. Analysis of nutrient profiles throughout this portion of the water column would probably verify this (the present Christina Lake database does not include nutrient analysis from within the thermocline).

3.1.6 Chlorophyll *a*

Chlorophyll *a* concentrations provide a measure of the phytoplankton biomass of a lake. Wetzel (1983) reported that chlorophyll *a* concentrations in the range of 0.3 - 3.0 µg/L are indicative of oligotrophic lakes. Of the values obtained for Christina Lake since 1980, 90% fall within this range (Table 35). In recent years, extensive analysis for planktonic chlorophyll *a* has been conducted at the southern and northern deep stations only. In 1991, the mean summer values for these sites were 1.2 and 1.6 µg/L, respectively. In 1992, the algal biomass at these two sites was somewhat higher (2.0 and 2.3, respectively). An extreme value of 7.8 µg/L at the southern station on October 28, 1992 was excluded from the calculation of the mean as it was assumed to be an anomaly (total phosphorus measurements, which includes that which is bound up in the phytoplankton, were below detection limits on that day). It is possible that the weather conditions of the preceding winter contributed to the increase in algal production during the summer of 1992. The 1991-92 winter was reported to be unusually mild, and for the first time in years the lake did not freeze over (Retzer and Haberstock, 1993). Relative to previous years, a lighter snow pack caused a lower lake level during the subsequent summer months.

A slight difference between the means of the southern and northern stations can be observed. The northern site had a slightly higher phytoplankton biomass during each of the two summers. This situation is the opposite of what would be expected as most nutrient loading occurs in the southern portion of the lake. With only two years of extensive summer data, the significance of this situation is unclear. Perhaps further studies that incorporate the remaining deep site (0200520 - English Point) are warranted.

Chlorophyll *a* concentrations for periphyton provide a measure of the biomass of the attached species of algae. At all sites where periphyton analysis was conducted (both lake and tributary, 1991-92), the chlorophyll *a* concentrations were exceptionally low. The maximum value recorded (7.3 mg/m^2 at site E215959 on September 17, 1991) is far less than the provincial criterion for this parameter (50 mg/m^2 Nordin, 1985). At the three shallow sites, the chlorophyll *a* averaged 1.56 mg/m^2.

3.1.7 Metals

Metal concentrations in Christina Lake (Tables 1-3) are below the criteria set for aquatic life and drinking water (Nagpal & Pommen, 1994). In some instances, the analytical technique employed to assess metal concentrations had detection limits greater than the value established for the criteria (poor sensitivity).In these cases the mean value is artificially skewed towards a higher value.

3.1.8 Microbiological Indicators

Coliform analysis is the primary method used to assess the degree of bacterial contamination of a body of water. The coliform bacteria (total and fecal) occur naturally in the digestive tract of warm-blooded animals and most are not pathogenic unless present in extreme numbers. The bacteria enumerated as total coliforms are part of the natural microbial flora since they decompose wood and vegetation. Fecal coliforms do, however, demonstrate that fecal waste has entered the water directly. Beyond the obvious aesthetic issue, there is the health concern that the transmission of other, more pathogenic organisms is more likely when levels of fecal waste is high, particularly in water that is used for drinking and/or recreation. The criterion established for raw lake water that is to be chlorinated for drinking purposes is a maximum of 10 fecal coliforms per 100 mL of water (90th percentile, minimum of 10 samples; Warrington, 1988). Water at the tap should have zero fecal coliforms according to Ministry of Health drinking water regulations. All BC Environment sites within the lake have had very low concentrations of coliform bacteria throughout the entire 20-year study period (maximum = 3 bacteria per 100 mL; Tables 1-6). Most of these samples were collected from the deep water sites.

Since the late 1960's the Central Kootenay Health Unit (formerly West Kootenay Health Unit) of the Ministry of Health has conducted seasonal coliform analyses at four recreational beach sites on the southern portion of the lake. At these heavily used areas, the summer fecal coliform levels have remained consistently very low (generally less than 10/100 mL) throughout this 25-year period (Table 36). In 1994, the health unit will commence coliform sampling of raw water at the Christina Works intake.

The tributaries to the lake have had elevated coliform counts since testing commenced in 1991 (see Table 37). Because some of these creeks serve as major sources of drinking water, the raw water 90th percentile values exceeding 10/100 mL for Christina, McRae and Sutherland are cause for concern. The likely reason for the elevated coliform levels is livestock and wildlife activity in close proximity to the creeks but human input from hikers or other recreationalists and from logging activities is also a possibility. Because these coliforms are not likely from human sources, the likelihood of disease transmittance is reduced, yet regardless of this fact, the coliform values exceed the criterion established for drinking water that is treated only through disinfection.

All sites, including the tributaries, were well within the guidelines established for recreational activity (the geometric mean of no less than 5 samples per 30 day period should not exceed 200 fecal coliform bacteria/100 mL).

An independent analysis of samples collected by Christina Lake Study Community members was conducted by the Spokane County Health Unit (October 12, 1992). This was a qualitative analysis that assessed the presence or absence of microbiological indicators. Of eight samples submitted, only one was positive for *Escherishia coli*, a fecal coliform. In each case the laboratory reported that the water was unsatisfactory for drinking. This assessment was based on the presence of coliform (total) bacteria in water that would be ready to drink, whereas surface waters in B.C and Washington must be disinfected before use. The presence of total coliform bacteria in surface waters is not surprising as these organisms occur naturally in the aquatic environment (they break down vegetation and other organic matter). The Spokane lab routinely assesses drinking water from wells, where the presence of coliform bacteria is much more of a concern than in surface waters. In British Columbia, as well as in Washington state, drinking water from wells is not generally disinfected, whereas water drawn from streams and lakes is required to be. Both the Spokane data and the Ministry of Health data demonstrate that there is a low level of bacterial contamination of the lake, but it varies considerably from place to place and time of the year.

3.2 Water Quality Objectives

In the province of British Columbia, water quality objectives are mainly based on approved or working water quality criteria (Nagpal & Pommen, 1994). These criteria were established to prevent specified detrimental effects from occurring with respect to a designated water use. In this case, we wish to recognize the provincial significance and value of the oligotrophic nature of Christina Lake, where the levels of certain characteristics are well below criteria. Identified water uses that are sensitive and should be protected include drinking water, body-contact recreation and aquatic life. The following are the ambient water quality objectives for Christina Lake (they are also summarized in Table 38). There has been a major effort in the past few years to establish what are presently called "ecosystem objectives". These objectives are designed to augment present water quality objectives which are primarily concerned with chemical constituents of the environment. There has been no clear consensus as to what ecosystem objectives should include. For Christina Lake an effort is made to include biologically-based objectives to augment the conventional water chemistry objectives. Ecosystem objectives should perhaps, in the future, also include social or economic objectives to fit the wider concept of ecosystem. These might include such things as population objectives or administrative structures to protect ecological integrity. The scope of this study is too narrow to consider these wide-ranging items and many other agencies and considerations would have to be included in such objectives.

1. **Phytoplankton - Objective → A phytoplankton community numerically dominated by taxa typical of an oligotrophic lake system.** The goal is to maintain a community that is similar to the one that presently exists, consisting of species of diatoms such as *Melosira italica, Asterionella formosa, Fragilaria crotonensis* and *Synedra acus*, the dinoflagellate *Peridinium* and other oligotrophic genera such as *Dinobryon* and *Mallomonas*. These genera should be the dominant taxa in any sample (dominant species are considered to be any that account for >10% of the cells counted). A shift to another species mix,

especially a community dominated (>10% of cells counted) by species indicative of nutrient inputs (such as the blue-green algae) would not meet this objective.

Due to the acute sensitivity of many algal species, an observable shift in species composition at any time of year may precede detectable changes in water chemistry and therefore, will serve as an early warning of deterioration in water quality. Quantitative objectives for phytoplankton biomass are to be measured as chlorophyll *a* (see #9 below).

2. **Periphyton - Objective → A stable community structure, primarily dominated by pennate diatoms .**

   Due to their proximity to non-point shoreline inputs, these attached species may provide the earliest warning of changing ambient conditions. In this case, dominance means greater than 50% (absolute numbers). Quantitative objectives for periphyton biomass are to be measured as chlorophyll *a* (see #9 below).

3. **Zooplankton - Objective → A stable community structure dominated (10% or greater of the total numbers of crustacean zooplankters) by the cladoceran *Bosmina longirostris* and the calanoid copepod *Epischura nevadensis*. Collected with a 150 μm mesh size net.**

   The zooplankton of the lake provide a sensitive indicator. In addition to the two species of crustacean zooplankton above, the rotifer *Kellicotia longispina* is also a dominant species and an indicator of present conditions.

   Standing crop of crustacean zooplankton (copepods and cladocerans) should be comparable to present estimates of standing crop (total of 1-5 animals/cm^2, minimum 10-20 animals/cm^2 peak standing crop, April - Oct.).

   Changes in the zooplankton species composition or numbers can be affected by higher and/or lower trophic levels. If the algal community structure upon which the zooplankton are dependent for food should change, then zooplankton species composition is affected by a lower trophic level. Conversely, if the fish species composition changes dramatically (which might occur with the introduction of Walleye to the ecosystem), then the zooplankton species composition is affected by a higher trophic level.

4. **Dissolved oxygen - Objective → A minimum concentration of 8 mg/L.**
   The minimum provincial working criteria of 5 mg/L was established to protect salmonids, yet since Christina Lake currently has dissolved oxygen concentrations that significantly surpass this value, a more stringent value has been set to reflect these present conditions and ensure they do not deteriorate. The objective is to apply at any depth.

5. **Turbidity - Objective → A mean monthly open water value that does not exceed 1 NTU. A maximum of 5 NTU.**

6. **Secchi depth - Objective → (i) A minimum of 3 m. (ii) An annual mean greater than 10 m.**

7. **Phosphorus - Objective → Mean spring overturn total phosphorus concentrations less than 7 µg/L (water column mean for the 3 deep water stations).**
   The provincial criteria for both untreated drinking water and recreation is a maximum mean of 10 µg/L.

8. **Nitrogen - Objective → Mean spring overturn total nitrogen concentrations less than 200 µg/L.**
   This objective in conjunction with the value set for phosphorus will ensure that Christina Lake remains oligotrophic. Since nitrogen is not typically the limiting nutrient in oligotrophic lakes, increases in concentrations would not likely result in algal blooms. Yet, due to the fact that nitrogen concentrations are easily modified (generally increased) when land based disturbances occur, it is useful as an indicator of the watershed status.

9. **Chlorophyll *a* - Objective → A monthly photic zone (within 2.5 x Secchi) summer (Apr.-Oct.) average of less than 2.5 μg/L for phytoplankton and less than 10 mg/m^2 for littoral lake and tributary periphyton.**
   The objective is intended to ensure maintenance of the background oligotrophic conditions that currently exist.

10. **Coliform bacteria - Objective → Less than 10 fecal coliform bacteria per 100 mL of water (90th percentile).**
    This objective is based on criteria established for drinking water which will be subject to disinfection (chlorination). The objective applies to all areas where drinking water is withdrawn.
    New sites need to be established for a number of near-shore locations. The locations can be determined by a citizens group (perhaps the Christina Lake Study Committee if they are agreeable), the Health Unit and BC Environment staff.

4. MONITORING RECOMMENDATIONS

Through issues raised at the community meeting on December 2, 1993, it appears that the current Ministry sampling does not fully address all questions that were posed. A focus of the citizens' concerns is microbiological quality of the very near-shore littoral area and, until recently, the vast majority of the sampling has been conducted in the deep areas of the lake. Therefore, additional near-shore sites should be established in heavy use areas as well as areas suspected of sewage contamination, and microbiological analyses should be a major focus at these sites. Additionally, analysis for other pathogenic organisms such as *Giardia* should be conducted during peak use periods for areas where waterworks intakes are located.

The proposed sampling regime is sufficiently rigorous that open-water and near-shore temporal and spatial trends will become readily apparent. Trends which may be developing and therefore require special attention in the future are: increased clarity, decreased phosphorus concentrations at deep sites, fish species composition, spatial distribution of chlorophyll *a* (algal biomass), and zooplankton / phytoplankton species composition (both in terms of community structure and spatial distribution).

Sampling of water chemistry in the water column at the deep stations should be altered to include analysis in the thermocline. Currently, composite samples of the epilimnion and hypolimnion are assessed. It is possible that the majority of the nutrients that enter the lake in the summer months are concentrated in the thermocline and are, therefore, not being detected. Discrete samples of the epilimnion, thermocline and hypolimnion are recommended.

An analysis of the tributaries for heavy metals should be conducted to determine if past mining operations are affecting the water quality of these systems (particularly McRae Creek). If mining activity should commence in the future, then heavy metal analysis in the tributaries should become a regular component of the sampling program.

Site 0200520 (Deep station at English Point) should be included in the chlorophyll *a* analysis in order to better understand spatial trends within the lake.

A preliminary assessment should be made of the groundwater and near-shore surface water adjacent to the old Sander Brothers sawmill site. This would determine if leachates from the woodwaste (organics such as chlorophenols and creosote) are contributing to perceived water quality problems (surface slicks, etc.).

The fish community is a particularly important component of the lake ecosystem. An objective for fish production, numbers and community composition was considered and judged to be desirable, but insufficient data were available to propose one. An objective identifying one or more key species and specifying goals for numbers of each species should be pursued. We recommend that a survey of at least the kokanee population be conducted to determine the present numbers of this key species. Monitoring of numbers of this species on a regular basis would provide an additional index of the biological structure of the lake ecosystem.

A suggested monitoring schedule for 1994 is outlined in Table 39. Execution of this program will depend on the availability of monitoring funds.

5. A DISCUSSION OF FUTURE DIRECTIONS

As with many environmental problems, there is a combination of technical and social aspects to consider. The citizens who attended the December 2nd, 1993, meeting expressed the view that sewage disposal was probably their major concern. The standard technical approach to dealing with sewage problems is with a sewer system. However, a sewer system in a rural area that has very rocky topography would be very costly (7-13 million dollars, Kerr Wood Leidal, 1990). This initiative would require significantly elevated taxes. Many of the permanent as well as summer residents are retired and appear unwilling or unable to pay the present costs for benefits that would be realized in the future. Although this is understandable in the short term, some investment in the future well-being of the lake and watershed is necessary. Given the present trends in population and development, and the unsatisfactory systems of sewage disposal, the future quality of the water may be jeopardized. Although a sewer system <u>might</u> solve the problem of lake contamination, there are other less costly means of dealing with sewage disposal.

It would appear that the community must take some action to control future activities around the lake. The most obvious route to local empowerment will probably require two actions. The first would be to have an official community plan drawn up. This could provide a way to control density and zoning. The second action would be incorporation of the area such that funding which would benefit the local population could be more easily obtained. There are a number of potential initiatives to deal with the sewage problem that will require the structure of a municipality in order that they may be carried out effectively. Major projects, or even the studies that precede them, are extremely unlikely to proceed if the community remains as a designated area of the regional district.

Once community status is established, application for some protection as a special status watershed, such as was received by the Okanagan valley, could be pursued. In the Okanagan, the status of being "an environmentally sensitive area" allowed the funding of many water quality projects that would not otherwise have been possible. It would seem advantageous to include the whole watershed for protection since the lake water quality is directly linked to what happens in the watershed. The Protected Area Strategy is one potential way of achieving this.

One of the gaps in assessing the needs for alternative sewage disposal options is the absence of an intensive study that addresses the extent and number of faulty septic tank/tile field systems. A septic study should be a high priority and include the following:

- an inventory of the type, location and age of all the septic systems within 100 m of the lake or any of the inflow streams;
- the elevation of the tanks relative to groundwater level during the spring high water period;
- a ranking of the likelihood of bacterial contamination or nutrients reaching the lake by considering soil type and other factors;
- a soil map of the near-lake areas with a ranking as to the suitability for septic tanks (this could be used as a basis for zoning in the community plan or identification of areas that should not be built on).

At the community meeting there was concern expressed about prior methods of approval of septic systems. There are many older units that were installed when very primitive systems (such as rock pits) were acceptable. Small cottages on these older units now accommodate many more people than in previous years, yet many of the sewage disposal units have not been upgraded. It may be that a system of mandatory pump-out and maintenance (paid out of a special levy on residents) could be a way of reducing the contamination to the lake. In any case, a closer involvement and cooperation with the Ministry of Health and the local Health Unit will be necessary.

The concern with sewage related health issues is generally not borne out by the coliform monitoring data. Neither BC Environment nor the Health Unit data demonstrate much evidence of contamination. This may be the result of inappropriate site selection or insufficient sampling, but there is little evidence of severe fecal inputs. If this is the case, an extensive sewer system would have a negligible effect on recreational and drinking water quality.

The additional sampling recommended should verify the severity of sewage contamination.

Involvement of the community in conducting the monitoring program is strongly recommended. Reductions in government funds available for environmental monitoring means that it may not be possible for ministry staff to conduct all components of this, more extensive, sampling program. If volunteers were available to collect samples, (after being equipped and trained by BC Environment and Ministry of Health staff) it is more likely that the new monitoring program would be carried out to its fullest.

There are a number of specialized sampling techniques (i.e., *Giardia*, surface film sampling, groundwater sampling) which will require special arrangements and high costs. These need to be carefully assessed and arranged.

With regard to health considerations, the risk of consuming contaminated water can be reduced by locating the domestic intakes much deeper than where most are presently placed. From the data, it is apparent that in the summer, the lake stratification provides a barrier between the surface mixed layer (epilimnion) and the colder deep hypolimnetic water. It is in this surface layer that any pathogenic organisms which have entered the lake via surface runoff or septic tanks would be concentrated. By ensuring that the intakes are at least 15 m deep and at least a meter off the bottom, the risk of infection from drinking waterborne pathogens would be low. To further reduce this risk, some form of disinfection is also necessary. This is required by the Ministry of Health as per health regulations, for any waterworks or utilities using the lake as a source of supply. One of the present licenses draws water from an area of the lake close to a high use provincial park and near the mouth of Sutherland Creek. Since this creek does convey a significant number of coliform bacteria to the lake, the location of the intake, both in terms of depth and horizontal distance from the creek, is a very important consideration.

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TABLE 1
AMBIENT WATER QUALITY DATA SUMMARY 0F SITE 0200078 - DEEP SAMPLE SITE AT CHRISTINA (1972-92)

CHARACTERISTICS	# VALUES	MINIMUM	MAXIMUM	MEAN	STD DEV.
GENERAL					
Acidity: 8.3 (mg/L)	11	2	5	2.9909	0.98737
Alkalinity: Total4.5 (mg/L)	54	27.5	35.6	32.3019	1.54303
Organic carbon (µg/L)	35	<1000	6000	<2.17143	1.24819
Chlorophyll *a* (µg/L)	18	<0.5	7.8	<1.96111	1.79776
Coliform (CFU/cL)	17	1	<2	<1.94118	0.24253
Coliform (MPN/cL)	6	<2	<2	<2	0.0
Color (true) (col. units)	26	<5	10	<5.38462	1.35873
Dissolved oxygen (mg/L)	362	7	14.6	10.6559	1.58572
Hardness (mg/L)	34	27.1	35.6	30.9559	1.65569
ORP (mV)	56	150	390	277.232	49.176
pH (pH units)	345	5.6	8.9	7.28009	0.48140
Total residue (mg/L)	35	52	64	57.9143	3.31105
Filterable residue (mg/L)	28	48	62	55.7857	3.70542
Non-filterable res (mg/L)	9	<1	2	1.22222	0.44095
Secchi depth (m)	47	3.2	16	10.7995	2.32606
Specific cond (µS/cm)	165	55	101	76.945	10.25
Temperature (°C)	365	4	25	11.2173	5.94342
Turbidity (NTU)	54	0.1	1	0.38407	0.20842
METALS (µg/L)					
Aluminum	10	<20	130	<42	40.222
Arsenic	12	<5	<250	<80.833	103.217
Boron	5	<10	40	<28	13.038
Cadmium	15	0.0	<10	<3.5	4.762
Calcium (dissolved)	34	8700	10900	9908.82	384.05
Calcium (total)	11	7490	10749.1	1911.81	576.432
Chromium	15	0.0	<10	<5.333	4.419
Cobalt	11	0.0	<100	<54.545	52.223
Copper (dissolved)	16	<1	2	<1.063	0.25
Copper (total)	23	0.0	<10	<3.217	4.145
Iron (dissolved)	16	<40	<100	<62.5	30.0
Iron (total)	16	0.0	200	66.875	49.762
Lead	16	<1	<3	<1.375	0.806
Magnesium (dissolved)	33	1250	1600	1422.42	89.199
Magnesium (total)	11	1390	3080	1730	469.106
Manganese (dissolved)	16	<10	<20	<13.75	5.0
Manganese (total)	21	0.0	<20	<12.831	8.309
Molybdenum	11	0.0	10	6.364	5.045
Nickel	11	<10	<50	<31.818	20.889
Potassium (dissolved)	33	600	1200	718.182	104.447
Potassium (total)	3	<400	700	<600	173.205
Silica	55	10700	15000	12072.7	819.768
Silicon	5	4500	5800	5260	472.229
Sodium (dissolved)	33	1700	2500	2000	171.391
Sodium (total)	3	2030	2080	2053.33	25.166
Tin	5	0.0	200	40	89.443
Zinc	14	<5	17	<7.429	4.398
NUTRIENTS (µg/L)					
N - ammonia	5	5	16	6.014	2.33
N - nitrate	17	<20	30	<20.588	2.425
N - nitrite	59	<5	17	<5.203	1.562
N - nitrate + nitrite	67	<20	80	<22.239	10.563
N - total organic	46	<10	900	<109.565	128.65
N - Kjeldahl	68	10	260	90	42.285
N - Total	16	40	900	158.125	201.568
P - ortho dissolved	34	<3	6	<3.088	0.514
P - dissolved	51	<3	8	<3.549	1.17
P - total	84	<3	16	<5.392	2.776
Low Level nitrate + nitrite	12	<5	70	<11.833	18.512
Low Level nitrite	12	<1	3	<1.333	0.651
Low Level phosphorus (ortho)	12	<1	<1	<1	0.0

TABLE 2
AMBIENT WATER QUALITY DATA SUMMARY OF SITE 0200520 DEEP SAMPLE SITE AT ENGLISH POINT, CHRISTINA LAKE (1976-92)

CHARACTERISTICS	# VALUES	MINIMUM	MAXIMUM	MEAN	STD DEV.
GENERAL					
Acidity: 4.5 (mg/L)	6	<0.5	<0.5	<0.5	0.0
Acidity: 8.3 (mg/L)	14	2.1	5	2.87857	.81635
Carbon (organic) (µg/L)	18	<1000	4000	<1888.89	900.254
Chlorophyll *a* (µg/L)	25	<0.5	4	<1.6	1.067
Coliform (CFU/cL)	8	<2	<2	<2	0.0
Coliform (MPN/cL)	6	<2	<2	<2	0.0
Color (true) (col. units)	10	<5	5	<5	0.0
Dissolved oxygen (mg/L)	223	7.02	12.2	9.74202	1.35493
Hardness (mg/L)	1	29.5	29.5	29.5	0.0
ORP (mV)	63	122	375	270.825	57.76
pH (pH units)	173	6.3	8.3	7.37815	0.415078
Total residue (mg/L)	18	51	62	56.0556	3.47211
Filterable residue (mg/L)	12	50	60	53.5	2.84445
Non-filterable res (mg/L)	10	<1	2	<1.2	0.42163
Secchi depth (m)	26	6.4	15.8	11.12307	2.440378
Specific cond (µS/cm)	155	35	100	76.0581	14.0372
Temperature (°C)	215	1.3	21.7	8.85209	5.50643
Turbidity (NTU)	21	0.1	0.5	0.29047	0.12208
METALS (µg/L)					
Aluminum	4	<20	100	<47.5	37.749
Arsenic	7	<5	<250	<110	130.958
Barium	1	10	10	10	0.0
Cadmium	9	<0.5	<10	<5.778	5.007
Calcium (dissolved)	18	8800	10700	9905.56	548.229
Calcium (total)	5	7560	11400	9554	1396.7
Carbon (inorganic)	1	8000	8000	8000	0.0
Chromium	9	<5	<10	<7.778	2.635
Chloride (dissolved)	17	500	1300	805.882	188.648
Cobalt	5	<100	<100	<100	0.0
Copper (total)	17	<1	70	<7.176	16.652
Fluoride (dissolved)	18	<100	120	<101.111	4.714
Iron (total)	17	<10	200	<85.882	45.285
Lead	17	<1	100	<30.118	46.497
Magnesium (dissolved)	18	1100	1500	1383.33	104.318
Magnesium (total)	5	1320	1710	1538	1583.35
Manganese (total)	13	<10	<20	<16.154	5.064
Mercury	1	<0.05	<0.05	<0.05	0.0
Molybdenum	5	<10	20	<12	4.472
Potassium	17	600	800	700	50
Silica	29	10700	12900	11886.2	491.153
Sodium	16	1800	2300	2018.75	175.95
Sulfate	16	4200	<5000	4768.75	326.024
Zinc	17	<5	20	<7.059	3.976
NUTRIENTS (µg/L)					
N - ammonia	49	<5	17	<6.224	2.771
N - nitrate	13	<20	40	<21.538	5.547
N - nitrite	33	<5	<5	<5	0.0
N - nitrate + nitrite	49	<20	70	<22.449	10.314
N - total organic	29	20	200	99.655	42.383
N - Kjeldahl	49	30	200	98.98	114.615
N - total	13	60	150	114.615	28.756
P - ortho dissolved	16	<3	<3	<3	0.0
P - dissolved	35	<3	7	<3.57	1.065
P - total	51	3	23	5.92	3.741

TABLE 3
AMBIENT WATER QUALITY DATA SUMMARY OF
SITE E215758 - DEEP SAMPLE SITE AT NORTH BASIN, CHRISTINA LAKE (1991-92)

CHARACTERISTICS	# OF VALUES	MINIMUM	MAXIMUM	MEAN	STD DEV.
GENERAL					
Acidity T4.5 (mg/L)	13	30.9	34.1	32.6923	1.23184
Acidity P8.3 (mg/L)	13	<0.5	<0.5	<0.5	0.0
Coliform (CFU/cL)	14	1	2	1.9285	0.26726
Color (true) (col. units)	1	<5	<5	<5	
Chlorophyll *a* (µg/L)	14	0.6	3.3	1.9071	0.89224
Dissolved oxygen (mg/L)	229	4.13	15.56	11.3185	1.827
pH (pH units)	237	5.95	7.9	6.90101	0.42637
Secchi depth (m)	15	8.7	16	13.0433	1.93362
Specific cond (µS/cm)	9	72	79	74.555	2.408
Temperature (°C)	234	4	25	9.47829	5.99845
Turbidity (NTU)	17	0.1	0.9	0.32941	0.20237
METALS (µg/L)					
Aluminum	7	<20	<100	<31.43	30.23
Arsenic	6	<40	<40	<40	0.0
Barium	7	0.0	10	8.571	3.78
Bismuth	6	<20	<20	<20	0.0
Boron	6	<10	40	<20	10.95
Cadmium	7	0	<.5	<0.07	0.19
Calcium	7	8750	12100	10578	1139
Chromium	7	0.0	10	1.429	3.78
Cobalt	7	0	<100	<14.286	37.796
Copper	7	0.0	2	0.286	0.756
Iron	7	0	20	14.3	7.87
Lead	7	0	<1	<0.37	0.14
Magnesium	7	1290	2010	1608.57	226.821
Manganese	7	0	<10	<1.4	3.8
Nickel	7	<10	<50	<15.71	15.12
Molybdenum	7	0	10	2.8	4.9
Potassium	4	<400	600	<550	100
Silica (dissolved)	13	11100	13400	12553.8	570.987
Silicon	6	4700	5500	5183.33	278.687
Silver	6	<10	<10	<10	0.0
Sodium	4	1750	2100	2000	168.32
Sulfur	4	1100	1400	1275	125.83
Vanadium	7	0.0	<10	<1.429	3.78
Zinc	7	0.0	10	5	5
NUTRIENTS (µg/L)					
N - ammonia	27	<5	8	<5.22	0.69
N - nitrite	15	<5	<5	<5	0.0
N - nitrate + nitrite	27	<20	30	<20.74	2.66
N - Kjeldahl	21	<10	150	<81.905	31.878
P - ortho dissolved	1	<3	<3	<3	0.0
P - dissolved	27	<3	3	<3	0.0
P - total	27	<3	5	<3.333	0.62
Low Level nitrate + nitrite	13	<5	105	<18.53	32.18
Low Level nitrite	13	<1	15	<3.31	5
Low Level phosphorus (ortho)	13	<1	<1	<1	0.0

TABLE 4
AMBIENT WATER QUALITY DATA SUMMARY OF SITE E215960
SHALLOW SAMPLE SITE AT NORTH END OF D'APPOLONIA'S DOCK,
CHRISTINA LAKE (1991-92)

CHARACTERISTICS	# VALUES	MINIMUM	MAXIMUM	MEAN	STD DEV.
GENERAL					
Chlorophyll *a* (µg/L)	1	0.7	0.7	0.7	0.0
Chlorophyll *a* (mg/m^2)	10	0.4	2.1	1.13	0.5851
Coliform (CFU/cL)	13	1	2	1.9230	0.27735
Phaeophytin *a* (mg/m^2)	6	<0.3	0.4	<0.3166	0.0408
pH (pH units)	1	7.8	7.8	7.8	0.0
Specific cond (µS/cm)	1	78	78	78	0.0
Temperature (°C)	7	10.5	23.5	16.2857	4.5812
Turbidity (NTU)	5	0.2	1.1	0.42	0.3834
NUTRIENTS (µg/L)					
N - ammonia	6	<5	8	<6	1.549
N - nitrite	7	<5	20	<7.143	5.669
N - nitrate + nitrite	13	<20	<20	<20	0.0
N - Kjeldahl	13	30	130	88.462	37.382
P - dissolved	7	<3	7	<3.571	1.512
P - total	13	<3	9	<3.846	1.625
Low Level nitrate + nitrite	7	<5	48	<18.714	14.186
Low Level nitrite	7	<1	8	<4	3.162
Low Level phosphorus (ortho)	7	<1	<1	<1	0.0

TABLE 5
AMBIENT WATER QUALITY DATA SUMMARY OF SITE E215959
SHALLOW SAMPLE SITE AT NORTH END OF DR. MERRY'S DOCK,
CHRISTINA LAKE (1991-92)

CHARACTERISTICS	# VALUES	MINIMUM	MAXIMUM	MEAN	STD DEV.
GENERAL					
Chlorophyll *a* (µg/L)	1	0.8	0.8	0.8	0.0
Chlorophyll *a* (mg/m^2)	9	1.2	7.3	2.3777	2.019
Coliform (CFU/cL)	13	1	3	2	0.4082
Phaeophytin *a* (mg/m^2)	6	<0.3	0.5	<0.3666	0.103
pH (pH units)	1	7.7	7.7	7.7	0.0
Temperature (°C)	7	10.0	23.5	15.8571	4.5158
Turbidity (NTU)	7	0.2	2.1	0.5857	0.6914
NUTRIENTS (µg/L)					
N - ammonia	6	<5	13	<6.667	3.204
N - nitrite	7	<5	20	<7.143	5.669
N - nitrate + nitrite	13	<20	<20	<20	0.0
N - Kjeldahl	13	<10	170	<91.538	42.592
P - dissolved	7	<3	7	<3.571	1.512
P - total	13	<3	9	<3.692	1.702
Low Level nitrate + nitrite	7	<5	75	<27	28.548
Low Level nitrite	7	<1	14	<3.857	4.811
Low Level phosphorus (ortho)	7	<1	2	<1.143	0.378

TABLE 6
AMBIENT WATER QUALITY DATA SUMMARY OF SITE E215961
SHALLOW SAMPLE SITE AT NORTH END OF
CHRISTINA LAKE (1991-92)

CHARACTERISTICS	# VALUES	MINIMUM	MAXIMUM	MEAN	STD DEV.
GENERAL					
Chlorophyll *a* (mg/m^2)	9	0.4	4.9	1.233	1.393
Coliform (CFU/cL)	13	1	<2	<1.8461	0.3755
Phaeophytin *a* (mg/m^2)	5	<0.3	<0.3	<0.3	0.0
pH (pH units)	2	7.4	7.8	7.6	
Specific cond (µS/cm)	1	72	72	72	0.0
Temperature (°C)	9	8.0	25.0	16.055	5.5365
Turbidity (NTU)	5	0.2	0.9	0.44	0.2792
NUTRIENTS (µg/L)					
N - ammonia	6	<5	14	<6.833	3.601
N - nitrite	7	<5	19	<7	5.292
N - nitrate + nitrite	13	<20	<20	<20	0.0
N - Kjeldahl	13	<10	180	<97.692	46.575
P - dissolved	7	<3	3	<3	0.0
P - total	11	<3	4	<3.364	0.505
Low Level nitrate + nitrite	7	<5	25	<11.857	7.798
Low Level nitrite	7	<1	9	<3.286	3.302
Low Level phosphorus (ortho)	7	<1	<1	<1	0.0

TABLE 7
AMBIENT WATER QUALITY DATA SUMMARY OF
SITE 0200079 - SUTHERLAND CREEK (1991-92)

CHARACTERISTICS	# VALUES	MINIMUM	MAXIMUM	MEAN	STD DEV.
GENERAL					
Acidity: 4.5 (mg/L)	13	28.9	72.3	56.5	16.8003
Chlorophyll *a* (mg/m^2)	1	1.2	1.2	1.2	0.0
Coliform (CFU/cL)	31	1	226	18.3226	41.6392
Dissolved oxygen (mg/L)	2	16	17	16.5	
Flow rate (m^3/s W)	7	0.1	8.3	1.5585	3.0043
pH (pH units)	32	7.4	8.0	7.725	0.20160
Specific cond (µS/cm)	16	47	165	112.75	42.9146
Temperature (°C)	19	0.5	18.5	9.1478	5.9256
Turbidity (NTU)	33	0.1	3.0	0.5636	5.888
NUTRIENTS (µg/L)					
N - ammonia	18	<5	21	<8	5.358
N - nitrite	18	<5	5	<5	0.0
N - nitrate + nitrite	18	<20	60	<26.111	11.95
N - Kjeldahl	18	50	240	98.333	47.682
P - dissolved	18	12	29	20.278	5.799
P - total	33	15	57	25.364	9.01

TABLE 8
AMBIENT WATER QUALITY DATA SUMMARY OF
SITE 0200517 - MCRAE CREEK (1991-92)

CHARACTERISTICS	# VALUES	MINIMUM	MAXIMUM	MEAN	STD DEV.
GENERAL					
Acidity: 4.5 (mg/L)	13	46.5	93.6	75.0154	17.335
Chlorophyll *a* (mg/m^2)	1	0.9	0.9	0.9	0.0
Chloride (mg/L)	1	47	47	47	0.0
Coliform (CFU/cL)	23	1	52	5.3913	10.8868
Dissolved oxygen (mg/L)	2	16.5	16.9	16.7	0.0
Flow rate (m^3/s W)	7	0.12	1.9	0.89	0.7098
pH (pH units)	23	7.4	8.2	7.9348	0.2102
Specific cond (µS/cm)	16	81	272	179.813	67.3718
Temperature (°C)	19	0	19	8.3105	5.7187
Turbidity (NTU)	23	<0.1	2.1	<0.6174	0.5556
NUTRIENTS (µg/L)					
N - ammonia	18	<5	7	<5.111	4.71
N - nitrite	18	<5	8	<5.167	0.707
N - nitrate + nitrite	18	<20	50	<22.778	8.264
N - Kjeldahl	16	10	380	82.5	84.971
P - dissolved	15	<3	7	<3.267	1.033
P - total	21	<3	53	<7.714	11.069

TABLE 9
AMBIENT WATER QUALITY DATA SUMMARY OF
SITE 0200518 - SANDNER CREEK (1991-92)

CHARACTERISTICS	# VALUES	MINIMUM	MAXIMUM	MEAN	STD DEV.
GENERAL					
Acidity: 4.5 (mg/L)	6	14.9	43	29.733	11.1633
Chlorophyll *a* (mg/m^2)	1	2.8	2.8	2.8	0.0
Coliform (CFU/cL)	14	1	9	2.8571	2.4763
pH (pH units)	14	7.1	7.8	7.5143	0.1995
Specific cond (µS/cm)	7	27	95	57	29.6929
Temperature (°C)	11	5	12	7.6363	2.4504
Turbidity (NTU)	14	<0.1	0.8	<0.2928	0.1940
Water level (m)	11	0.01	0.5	0.1321	0.1542
NUTRIENTS (µg/L)					
N - ammonia	8	<5	30	<8.375	8.766
N - nitrite	8	<5	20	<6.875	5.303
N - nitrate + nitrite	8	<20	50	<23.75	10.607
N - Kjeldahl	8	<10	210	<68.75	60.104
P - dissolved	8	<3	7	<4	1.852
P - total	14	<3	12	<4.714	3.148

TABLE 10
AMBIENT WATER QUALITY DATA SUMMARY OF
SITE 0200538 - STEWART CREEK (1991-92)

CHARACTERISTICS	# VALUES	MINIMUM	MAXIMUM	MEAN	STD DEV.
GENERAL					
Acidity: 4.5 (mg/L)	5	27.6	44.9	37.68	8.8694
Chlorophyll *a* (mg/m^2)	1	3.5	3.5	3.5	0.0
Coliform (CFU/cL)	13	1	12	2.7692	2.8912
Flow rate (m^3/s W)	6	0.06	0.56	0.26167	0.2156
pH (pH units)	13	7.1	8	7.7077	0.2431
Specific cond (µS/cm)	6	47	98	74.5	23.0716
Temperature (°C)	10	4.5	14	10.1	3.0166
Turbidity (NTU)	13	0.1	1.3	0.4769	0.3345
NUTRIENTS (µg/L)					
N - ammonia	7	<5	<5	<5	0.0
N - nitrite	7	<5	19	<7	05.292
N - nitrate + nitrite	7	<20	<20	<20	0.0
N - Kjeldahl	7	20	110	77.143	34.017
P - dissolved	7	4	10	6.714	2.215
P - total	13	5	13	8.692	2.594

TABLE 11
AMBIENT WATER QUALITY DATA SUMMARY 0F
SITE 0200077 - CHRISTINA CREEK (1991-92)

CHARACTERISTICS	# VALUES	MINIMUM	MAXIMUM	MEAN	STD DEV.
GENERAL					
Acidity: 4.5 (mg/L)	13	31.4	41.7	35.3077	3.5973
Coliform (CFU/cL)	22	1	1130	57.9545	239.583
Chloride (µg/L)	1	1200	1200	1200	0.0
Dissolved oxygen (mg/L)	2	15	16	15.5	
pH (pH units)	23	7.1	8.1	7.5696	0.2530
Specific cond (µS/cm)	16	73	99	81.9375	9.7123
Temperature (°C)	18	2	24	13.1667	7.5401
Turbidity (NTU)	24	0.2	1.5	0.6333	0.3619
Water level (m)	7	3.3	6.01	4.1757	0.9963
NUTRIENTS (µg/L)					
N - ammonia	18	<5	10	<5.278	1.179
N - nitrite	18	<5	<5	<5	0.0
N - nitrate + nitrite	18	<20	20	<20	0.0
N - Kjeldahl	18	50	140	87.222	24.688
P - dissolved	17	<3	8	<3.294	1.213
P - total	23	<3	10	<4.696	1.743

TABLE 12
AMBIENT WATER QUALITY DATA SUMMARY 0F
SITE 0200547 - MOODY CREEK (1991-92)

CHARACTERISTICS	# VALUES	MINIMUM	MAXIMUM	MEAN	STD DEV.
GENERAL					
Acidity: 4.5 (mg/L)	3	54.4	66.5	60.3	6.0555
Coliform (CFU/cL)	5	<2	50	<18.4	22.289
Dissolved oxygen (mg/L)	2	15.8	16	15.9	
pH (pH units)	3	7.8	7.9	7.8333	0.05773
Filterable residue (mg/L)	2	98	104	101	
Specific cond (µS/cm)	5	109	140	122.8	11.7346
Temperature (°C)	3	6	10.5	7.8333	2.3629
Turbidity (NTU)	1	1.2	1.2	1.2	0.0
NUTRIENTS (µg/L)					
N - ammonia	1	<5	<5	<5	0.0
N - nitrite	1	<5	<5	<5	0.0
N - nitrate + nitrite	1	<20	<20	<20	0.0
N - Kjeldahl	1	200	200	200	0.0
P - dissolved	5	5	13	8.6	2.881
P - total	5	12	18	14.2	2.28

TABLE 13
LIST OF MORPHOMETRIC DATA FOR CHRISTINA LAKE

ELEVATION AT LAKE OUTLET	450 m
DRAINAGE BASIN AREA ($A_{d.b.}$)	492 km^2
SURFACE AREA (A)	25.1 km^2
VOLUME (V)	$9.295x10^5$ dam^3
VOLUME OF EPILIMNION (V_e) (0-8 m)	$1.972x10^5$ dam^3
VOLUME OF HYPOLIMNION (V_h) (9-54 m)	$7.323x10^5$ dam^3
MEAN DEPTH (z)	37.0 m
MAXIMUM DEPTH (z_m)	54.0 m
FETCH - UNOBSTRUCTED LENGTH (l)	18.7 km
LITTORAL AREA (% of total surface area)	5%

TABLE 14
LIST OF HYDROLOGIC DATA FOR CHRISTINA LAKE

EVAPORATION RATE (assume 75 cm evaporated from surface/yr)	18825 dam^3/yr
OUTFLOW VOLUME	208000 dam^3/yr
INFLOW VOLUME (evap. rate + outflow vol.)	226825 dam^3/yr
DRAINAGE BASIN WATER YIELD	461 dam^3/km^2
FLUSHING TIME	4.5 years
WATER YIELDS OF ADJACENT SYSTEMS	
Moody Creek	333 dam^3/km^2
Kettle River at Cascade	250 dam^3/km^2
Granby River at Grand Forks	471 dam^3/km^2

TABLE 15
SURFACE AREAS AND VOLUMES OF 2-METER INTERVAL STRATA OF CHRISTINA LAKE

DEPTH RANGE (M)	AREA OF UPPER LIMIT (M^2) (*10^7)	VOLUME OF STRATA (M^3) (*10^7)
0-2	2.51	5.02
2-4	2.48	4.96
4-6	2.45	4.9
6-8	2.42	4.84
8-10	2.375	4.75
10-12	2.33	4.66
12-14	2.28	4.56
14-16	2.25	4.5
16-18	2.21	4.42
18-20	2.17	4.34
20-22	2.125	4.25
22-24	2.075	4.15
24-26	2.0	4.0
26-28	1.95	3.9
28-30	1.9	3.8
30-32	1.85	3.7
32-34	1.775	3.55
34-36	1.675	3.35
36-38	1.575	3.15
38-40	1.475	2.95
40-42	1.35	2.7
42-44	1.2	2.4
44-46	0.975	1.95
46-48	0.625	1.25
48-50	0.275	0.55
50-52	0.15	0.3
52-54	0.025	0.05
	Total volume =	$9.295*10^8$ m^3

TABLE 16
STREAM DISCHARGE SUMMARY DATA
(Water Survey of Canada, 1991)

SYSTEM	STATION	MEAN FLOW m^3/s	MIN FLOW m^3/s	MAX FLOW m^3/s	PERIOD OF RECORD
Christina	08NN014	6.58	0.255	53.5	1945-46
Moody	08NN021	0.142	0.007	2.72	1971-84
Sutherland	08NN016		0.028	6.91	Apr.-Sept. 1960-73
Kettle	08NN006 at Cascade	71.1	1.7	830	1916-34
	08NN013 near ferry	43.1	0.425	575	1928-90

TABLE 17
SOME CAMP AND RESORT FACILITIES ON CHRISTINA LAKE
WITH ESTIMATES OF THE NUMBERS OF TRANSIENT VISITORS DURING THE SUMMER PERIOD
(Apr. - Oct)

Campsite/Resort	# Campsites (at 3.2 persons per site)	Estimated # visitors per day (peak period, campground full ^ July - Aug.)	Estimated number of visitors per year
Christina Sands	42	135	3800
Kiana by the lake	168	540	15250
Schulli's	23	75	2085
Skands	84	270	7620
Texas Pt. Prov. Park	33	106	•2994
Willow Beach	71	230	6440

Estimates at the private facilities are based on figures provided by B.C. Parks for Texas Point Provincial Park for 1993 (2994 total registered visitors with an average of 3.2 visitors/site).

• Up 19% from 1992.

The 460 seasonal dwellings (4 persons per day) account for an additional 1840 summer visitors per day during peak period (July - August).

TABLE 18
SUMMARY OF WATER LICENSES
ISSUED IN THE CHRISTINA LAKE WATERSHED

SOURCE	LICENSE #	USE	QUANTITY
ANN SPR.	F039826	DOMESTIC	500 gal/day
ANN SPR.	F039827	DOMESTIC	500 gal/day
AQUARIUS BR.	C040756	IRRIGATION	40.0 acre feet
BAKER CR.	C022856	DOMESTIC	2000 gal/day
BART CR.	C047158	DOMESTIC	500 gal/day
CHRISTINA LK.	C040308	DOMESTIC	500 gal/day
CHRISTINA LK.	C072240	WATERWORKS	17520000 gal/yr
		INDUSTRIAL	17.7 acre feet
CHRISTINA LK.	C052493	DOMESTIC	500 gal/day
CHRISTINA LK.	C072241	WATERWORKS	8212500 gal/yr
CHRISTINA LK.	C059373	DOMESTIC	1500 gal/day
CHRISTINA LK.	C062855	DOMESTIC	500 gal/day
CHRISTINA LK.	C103754	DOMESTIC	500 gal/day
CHRISTINA LK.	C066604	WATERWORKS	9125000 gal/yr
CHRISTINA LK.	C070135	DOMESTIC	500 gal/day
COPPER CR.	C046150	DOMESTIC	500 gal/day
		IRRIGATION	25.0 acre feet
COPPER CR.	F066253	DOMESTIC	1000 gal/day
CORYELL CR.	F003275	DOMESTIC	500 gal/day
DYSON SPR.	C026701	DOMESTIC	500 gal/day
DYSON SPR.	C044357	DOMESTIC	500 gal/day
DYSON SPR.	C066416	DOMESTIC	500 gal/day
DYSON SPR.	C066417	DOMESTIC	500 gal/day
DYSON SPR.	F039726	DOMESTIC	500 gal/day
DYSON SPR.	F039728	DOMESTIC	500 gal/day
DYSON SPR.	F041114	DOMESTIC	500 gal/day
EARHART CR.	C053779	DOMESTIC	500 gal/day
EARHART CR.	C059416	DOMESTIC	500 gal/day
FERRARO SPR.	C064204	DOMESTIC	500 gal/day
GILL CR.	C023680	DOMESTIC	1500 gal/day
GILL CR.	C025442	DOMESTIC	500 gal/day
GILL CR.	C041542	DOMESTIC	500 gal/day
GILL CR.	C045607	DOMESTIC	1000 gal/day
GILL CR.	C066418	DOMESTIC	500 gal/day
GILL CR.	C066419	DOMESTIC	500 gal/day
HOFER CR.	C058081	DOMESTIC	500 gal/day
ITALY CR.	C042709	DOMESTIC	500 gal/day
LIGHTHOUSE CR.	F018168	DOMESTIC	500 gal/day
MAIDA CR.	F004583	IRRIGATION	20.0 acre feet
MAIDA CR.	F039946	DOMESTIC	500 gal/day
MAIDA CR.	C059374	DOMESTIC	1000 gal/day
		IRRIGATION	10.0 acre feet
MCRAE CR.	C033682	DOMESTIC	1000 gal/day
		IRRIGATION	4.0 acre feet
MCRAE CR.	C033683	DOMESTIC	1000 gal/day
MCRAE CR.	C064235	DOMESTIC	500 gal/day
		IRRIGATION	50.0 acre feet

TABLE 18 CONT.

MCRAE CR.	C06660	INDUSTRIAL	0.001 FEET^3/SEC
MURPHY SPR.	C039658	DOMESTIC	1000 gal/day
PALMA SPR.	C059446	DOMESTIC	1500 gal/day
PARSON CR.	C039990	DOMESTIC	500 gal/day
PARSON CR.	C047785	DOMESTIC	500 gal/day
RED OCHRE CR.	C043497	DOMESTIC	500 gal/day
ROBINSON SPR.	C044349	DOMESTIC	1000 gal/day
SPOONER CR.	C049757	DOMESTIC	500 gal/day
SPOONER CR.	F015282	DOMESTIC	1000 gal/day
SPOONER CR.	F019573	DOMESTIC	1000 gal/day
STEPKINSON BR.	F017838	DOMESTIC	500 gal/day
STEPKINSON BR.	F017972	DOMESTIC	500 gal/day
STEPKINSON BR.	F019539	DOMESTIC	500 gal/day
STEPKINSON BR.	F019707	DOMESTIC	500 gal/day
STEPKINSON BR.	F061827	DOMESTIC	1000 gal/day
STEWART CR.	C024431	DOMESTIC	500 gal/day
STEWART CR.	C031939	DOMESTIC	500 gal/day
STEWART CR.	C032012	DOMESTIC	500 gal/day
STEWART CR.	C039900	DOMESTIC	500 gal/day
STEWART CR.	C043333	DOMESTIC	500 gal/day
STEWART CR.	C052996	DOMESTIC	500 gal/day
STEWART CR.	C060475	DOMESTIC	500 gal/day
STEWART CR.	C062151	DOMESTIC	500 gal/day
STEWART CR.	F018307	DOMESTIC	500 gal/day
STEWART CR.	F019120	DOMESTIC	500 gal/day
STEWART CR.	F067373	DOMESTIC	500 gal/day
STEWART CR.	F067374	DOMESTIC	500 gal/day
SUTHERLAND CR.	C045606	WATERWORKS	27375000 gal/yr
SUTHERLAND CR.	C056462	DOMESTIC	500 gal/day
SUTHERLAND CR.	C057723	DOMESTIC	500 gal/day
SUTHERLAND CR.	C057724	DOMESTIC	500 gal/day
SUTHERLAND CR.	C058667	DOMESTIC	500 gal/day
SUTHERLAND CR.	C058668	DOMESTIC	500 gal/day
SUTHERLAND CR.	C058669	IRRIGATION	3.0 acre feet
SUTHERLAND CR.	C058670	DOMESTIC	1000 gal/day
SUTHERLAND CR.	C058671	IRRIGATION	17.5 acre feet
SUTHERLAND CR.	C058672	IRRIGATION	3.0 acre feet
SUTHERLAND CR.	C058673	DOMESTIC	500 gal/day
SUTHERLAND CR.	C059200	DOMESTIC	500 gal/day
		IRRIGATION	17.5 acre feet
SUTHERLAND CR.	C059201	IRRIGATION	12.5 acre feet
SUTHERLAND CR.	C059202	IRRIGATION	31.25 acre feet
SUTHERLAND CR.	C060449	DOMESTIC	500 gal/day
		IRRIGATION	7.5 acre feet
SUTHERLAND CR.	C060450	DOMESTIC	500 gal/day
		IRRIGATION	30.0 acre feet
SUTHERLAND CR.	C060451	DOMESTIC	500 gal/day
		IRRIGATION	7.5 acre feet
SUTHERLAND CR.	C060452	DOMESTIC	500 gal/day
SUTHERLAND CR.	C060453	DOMESTIC	500 gal/day
		IRRIGATION	25.0 acre feet
SUTHERLAND CR.	C060454	IRRIGATION	10.0 acre feet

TABLE 18 CONT.

SUTHERLAND CR.	C060456	DOMESTIC	500 gal/day
		IRRIGATION	2.5 acre feet
SUTHERLAND CR.	C060457	DOMESTIC	500 gal/day
		IRRIGATION	2.5 acre feet
SUTHERLAND CR.	C060473	WATERWORKS	27375000 gal/yr
SUTHERLAND CR.	C062261	DOMESTIC	500 gal/day
SUTHERLAND CR.	C066372	DOMESTIC	500 gal/day
SUTHERLAND CR.	F017756	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	C046151	DOMESTIC	2000 gal/day
STHLD CR.S. OUT.	C046152	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	C046153	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	C049285	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	C049384	INDUSTRIAL	500 gal/day
STHLD CR.S. OUT.	C049385	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F007828	DOMESTIC	500 gal/day
		IRRIGATION	11.0 acre feet
STHLD CR.S. OUT.	F010388	DOMESTIC	250 gal/day
		IRRIGATION	15.25 acre feet
STHLD CR.S. OUT.	F010941	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F010942	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F011774	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F013331	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F013332	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F013333	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F013334	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F013335	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F013533	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F013534	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F013606	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F013607	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F016484	DOMESTIC	1000 gal/day
STHLD CR.S. OUT.	F016535	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F016536	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F016537	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F016705	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F016706	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F016707	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F016708	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F017086	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F017087	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F017141	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F017167	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F017330	DOMESTIC	1000 gal/day
STHLD CR.S. OUT.	F017331	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F019082	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F019325	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F019326	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F019327	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F019328	DOMESTIC	1000 gal/day
STHLD CR.S. OUT.	F019360	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F019579	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F019768	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F021108	DOMESTIC	500 gal/day

TABLE 18 CONT.

STHLD CR.S. OUT.	F021109	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F021110	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F021111	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F045779	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F045780	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F045781	DOMESTIC	500 gal/day
STHLD CR.S. OUT..	F046070	DOMESTIC	500 gal/day
STHLD CR.S. OUT.	F046485	DOMESTIC	500 gal/day
SWETLAND SPR.	C040567	DOMESTIC	1000 gal/day
		IRRIGATION	40.0 acre feet
SZIMMER SLOUGH	C024548	IRRIGATION	42.0 acre feet
TEXAS CR.	F013311	DOMESTIC	1000 gal/day
TEXAS CR.	F015276	DOMESTIC	1000 gal/day
TEXAS CR.	F019080	DOMESTIC	1000 gal/day
TREADMILL CR.	C029391	DOMESTIC	500 gal/day
WALKER CR.	C039901	DOMESTIC	500 gal/day
WOODLEY CR.	C036605	DOMESTIC	500 gal/day
WOODLEY CR.	C047157	DOMESTIC	500 gal/day
WOODLEY CR.	C047455	DOMESTIC	500 gal/day

The water license records used to compile this table listed the water volumes in english units. In order to avoid mistakes with unit conversions, the numbers have been left in those units. The conversions to metric units are given below.

Gal/day = 0.004546 M^3/DAY, ACRE FOOT = 1.23348 DAM^3, $FOOT^3$/S (cfs) = 0.0283 M^3/S

TABLE 19
AQUATIC PLANT SPECIES IDENTIFIED IN CHRISTINA LAKE

Myriophyllum sibiricum **	*Nuphar polysepalum*
Myriophyllum verticillatum	*Scirpus lacustris*
Myriophyllum spicatum	*Scirpus subterminalis*
Potamogeton amplifolius ***	*Typha* spp.
Potamogeton berchtoldii	*Najas flexilis* *
Potamogeton gramineus	*Vallisneria spiralis* *
Potamogeton illinoensis	*Utricularia vulgaris*
Potamogeton zosteriformis **	*Hippuris vulgaris*
Potamogeton robinsii **	*Polgonum amphibium*
Potamogeton natans	*Sagittaria cuneata*
Potamogeton alpinus	*Lemna minor*
Potamogeton richardsonii	*Myosotis* spp.
Potamogeton pectinatus	*Nymphaea alba*
Potamogeton praelongus	*Nymphaea odorata*
Potamogeton epihydrus	*Heteranthea dubia*
Potamogeton foliosus	*Callitriche* spp.
Elodia canadensis **	*Equisetum fluviatile*
Isoetes sp. *	*Equisetum palustre*
Ranunculus aquatilis	*A lisma plantago-aquatica*
Ranunculus flabellaris	*Dulichium arundinaceum*
Ranunculus flammula	*Eleocharis palustris*
Brasenia schreberi	*Eleocharis acicularis*
Bidens beckii	*Nitella* spp.
Ceratophyllum demersum **	
Sparganium spp.	
Potentilla palustris	
Ricciocarpus natans	
Sium sauve	
Typha latifolia	

*** Dominant species (by number and biomass).
** Species which are common throughout the lake and account for a high percentage of the lake's plant biomass.
* Species which are common throughout the lake, but contribute little to the total plant biomass .

TABLE 20
EURASIAN WATER MILFOIL RECORDS
FOR CHRISTINA LAKE

Year	# sites *M. spicatum* found	# M. spicatum stems removed
1986	2	14000
1987	21	1617
1988	32	2184
1989	38	4553
1990	46	6380
1991	39	15138
1992	48	17382
1993	62	27443

Data from files at the Water Quality Branch, 765 Broughton St. Victoria

TABLE 21
FISHERIES RELEASE RECORDS FOR CHRISTINA LAKE, BRITISH COLUMBIA

YEAR	SPECIES	QUANTITY	STAGE
1901	Bass	500	fry
1914	Rainbow trout	13,300	fry
1915	Rainbow trout	30,000	fry
1916	Rainbow trout	25,000	fry
1919	Rainbow trout	12,000	fry
1920	Rainbow trout	18,000	fry
1923	Rainbow trout	30,000	fry
1925	Rainbow trout	5,000	fry
1927	Rainbow trout	20,000	fry
1928	Rainbow trout	15,000	eyed egg
1929	Rainbow trout	40,000	eyed egg
1930	Rainbow trout	30,000	fry
1931	Kokanee salmon	20,000	eyed egg
1931	Rainbow trout	25,000	eyed egg
1932	Kokanee salmon	50,000	eyed egg
1932	Rainbow trout	25,000	eyed egg
1933	Kokanee salmon	150,000	eyed egg
1934	Rainbow trout	35,000	eyed egg
1935	Rainbow trout	30,000	eyed egg
1936	Rainbow trout	40,000	eyed egg
1937	Rainbow trout	40,000	eyed egg
1938	Rainbow trout	40,000	eyed egg
1939	Rainbow trout	60,000	eyed egg
1940	Kokanee salmon*	150,000	eyed egg
1940	Rainbow trout	200,000	eyed egg
1941	Rainbow trout	200,000	eyed egg
1942	Rainbow trout	200,000	eyed egg
1943	Rainbow trout	195,200	eyed egg
1944	Rainbow trout	180,000	eyed egg
1945	Rainbow trout	95,000	eyed egg
1946	Rainbow trout	145,680	eyed egg
1947	Rainbow trout	130,000	eyed egg
1948	Rainbow trout	50,000	fry
1949	Rainbow trout	30,000	fry
1949	Rainbow trout	70,000	eyed egg
1950	Rainbow trout	48,768	fingerling
1951	Rainbow trout	6,000	fingerling
1951	Rainbow trout	25,000	fry
1952	Rainbow trout	45,225	fingerling
1953	Rainbow trout	46,000	fingerling
1953	Rainbow trout	25,533	unknown
1954	Rainbow trout	24,990	unknown
1956	Rainbow trout	26,000	fingerling
1957	Rainbow trout	10,750	fingerling
1957	Rainbow trout	10,750	fingerling
1958	Rainbow trout	26,000	fingerling
1959	Rainbow trout	26,000	fingerling
1960	Rainbow trout	26,000	fingerling
1961	Rainbow trout	26,000	fingerling
1962	Rainbow trout	9,000	yearling
1963	Rainbow trout	26,000	fingerling

* stream spawning stock

TABLE 22
1991 AND 1992 ZOOPLANKTON SUMMARY FOR SITE 0200078 (AT CHRISTINA)

● = dominant, • = not dominant

Taxonomic Identification	91/04/11	91/04/14	91/07/17	92/05/05	92/06/03	92/07/08	92/08/04	92/09/02	92/10/01	92/10/28
Sub-class: Cladocera										
Bosmina longirostris	•	●	●	•	●	●	●	•	•	●
Holopedium sp.					•	•	●	•		•
Diaphanosoma sp.									•	
Sub-class: Copepoda										
Nauplii	•			•	•	•	•	•	●	●
Order: Calanoida										
Diaptomus ashlandi	•									
Epischura nevadensis		•	•	●	●	•	●	●	●	●
Order: Cyclopodia										
Diacyclops sp.	•			•		•	●	•	●	•
Rotifers:										
Keratella	•									
Kellicotia longispina	●	•	•	●	●	•	●	●	•	•
Conochilus sp.									•	

TABLE 23
1991 AND 1992 ZOOPLANKTON SUMMARY FOR SITE E215758 (NORTH BASIN DEEP CENTER)

● = dominant, • = not dominant

Taxonomic Identification	91/08/14	91/09/16	91/10/15	92/05/05	92/06/03	92/07/08	92/08/04	92/09/02	92/10/01	92/10/28
Sub-class: Cladocera										
Bosmina longirostris	•	•		•	●	●	•		•	•
Holopedium sp.		•				•	•	•	•	
Sub-class: Copepoda										
Nauplii			•	•	•	•	•	•	•	•
Order: Calanoida										
Epischura nevadensis	•	●	•	●	●	●	●	●	●	●
Order: Cyclopodia										
Diacyclops sp.				•	•	•	●	●	●	●
Rotifers:										
Keratella			•				•	•	•	
Kellicotia longispina			•	●	●	•	●	●	•	•
Conochilus sp.	●	●	●	●					●	

TABLE 24
NUMBER PER cm^2 OF ZOOPLANKTON SPECIES AT SITE 0200078 (AT CHRISTINA) FOR THE PERIOD 1991-92

Taxonomic Identification	91-04-11	91-04-14	91-07-17	92-05-05	92-06-03	92-07-08	92-08-04	92-09-02	92-10-01	92-10-28
Bosmina longirostris	.0006	2.054	.734	.146	.768	17.23	.582	.004	.042	.426
Holopedium gibberum					.008	.83	.478	.026		.051
Diaphanosoma sp.									.14	
Diaptomus ashlandi	.001									
Epischura nevadensis		.004	.006	3.58	.792	1.58	.284	1.124	.75	2.40
Diacyclops sp.	.001			.098		.07	.656	.184	.416	.212
Nauplii	.156			.09	.148	.19	.03	.054	.316	.566
Keratella	.352									
Kellicotia longispina	5.56	.046	.026	4.244	1.31	.38	.312	.586	.03	.144
Conochilus unicornis									.138	

TABLE 25
NUMBER PER cm^2 OF ZOOPLANKTON SPECIES AT SITE E215758 (NORTH BASIN DEEP CENTER) FOR THE PERIOD 1991-92

Taxonomic Identification	91-08-14	91-09-16	91-10-15	92-05-05	92-06-03	92-07-08	92-08-04	92-09-02	92-10-01	92-10-28
Bosmina longirostris	3.088	.694		.051	.882	11.30	.178		.032	.232
Holopedium gibberum		.001				.176	.178	.074		
Diaphanosoma sp.										
Diaptomus ashlandi										
Epischura nevadensis	.206	2.698	2.368	4.674	1.46	1.566	.606	.922	.672	.976
Diacyclops sp.				.174	.122	.176	.664	.624	1.114	1.966
Nauplii			.126	.044	.244	.186	.118	.074	.408	1.03
Keratella			.008				.01	.006	.022	
Kellicotia longispina			.06	5.194	2.554	.572	.784	.278	.22	.398
Conochilus unicornis	29.83	22.91	26.99	3.146					.66	

TABLE 26
1991 AND 1992 PHYTOPLANKTON SUMMARY FOR SITE 0200078 (AT CHRISTINA)

● = dominant, • = not dominant

Taxonomic Identification	91/04/11	91/05/23	91/06/20	91/08/15	91/09/17	91/10/15	92/05/05	92/06/03	92/07/08	92/08/04	92/09/02	92/10/01	92/10/28
GREENS													
Order: Chlorococcales													
Ankistrodesmus				•	•	•	•	•	•	•	•	•	
Botryococcus								●		•			
Crucigenia tatrapedia					•				•	•	•		
Elakotothrix gelatinosa					•	•	•	•	•	•	•	•	
Oocystis									•	•		•	
Nephrocytium limneticum							•	•	●	•	●	•	●
Pediastrum tetras									•		•	•	
Sphaerocustis schroeteri							●	•	•	•	•		
Order: Zygnematales													
Spondylosium planum										●	●	•	
BLUE-GREENS													
Order: Nostocales													
Ababaena affinis		•			•			•					
Order: Oscillatoriales													
Lyngyba subtilis	●	●	●					•			•		
CHRYPTOPHYTES													
Order: Cryptomonadales													
Chroomonas acuta		•	•	•	•	•	•	•	•	•	•	●	
Cryptomonas ovata		•	•			•		•	•	•	•	•	
CHRYSOPHYTES													
Order: Ochromonadales													
Dinobryon divergens		•	•	•	●		●	•	•	•	•	●	
Dinobryon bavaricum	•	●	●	•			•	●	•	•		•	
Mallomonas							•	•	•	•	•	•	
Order: Dinokontae													
Peridinium		•	•	•			•	•	•	•	•	•	
DIATOMS													
Order: Centrales													
Cyclotella	•						•						
Melosira italica	•		•	●	●	●	●	•	●	●	●	●	●
Order: Pennales													
Achnanthes				•	•	•	•	•				•	
Amphora								•					
Asterionella formosa	•	•	•	•			●	•	•	•		•	
Cocconeis						•	•	•		•	•		
Cymbella					•		•						
Fragilaria crotonensis	•		•		•	•	•	•	•	•	•	•	●
Gomphonema		•			•		•		•	•			
Navicula						•	•	•		•	•	•	
Nitzschia				•	•	•		•		•	•	•	
Synedra acus	•	•	•		•		•	•	•	•	•		
Tabellaria			•				•	•					

TABLE 27
1991 AND 1992 PHYTOPLANKTON SUMMARY FOR SITE E215758 (NORTH BASIN DEEP CENTER)

● = dominant, • = not dominant

Taxonomic Identification	92/05/05	92/06/03	92/07/08	92/08/04	92/09/02	92/10/01	92/10/28
GREENS							
Order: Chlorococcales							
Ankistrodesmus falcatus	•	•	•	•	•	●	●
Botryococcus braunii		●	•				●
Crucigenia tatrapedia	•		•		•		
Elakotothrix gelatinosa	•	•	•	•	•	•	•
Oocystis		•	•	•		•	•
Nephrocytium limneticum	●	•	●		●	●	•
Pediastrum tetras			•	•	•	•	•
Sphaerocustis schroeteri	•		•		•	•	
Order: Zygnematales							
Mougeotia	•	•			•		
Spondylosium planum			●	●	●		
BLUE-GREENS							
Osrder: Chroococcales							
Anacystis				•			
Order: Oscillatoriales							
Lyngbya subtilis	●						
CHRYPTOPHYTES							
Order: Cryptomonadales							
Chroomonas acuta	•	●	•	•	●	•	●
Cryptomonas ovata	•	•	•	•	•	•	●
CHRYSOPHYTES							
Order: Ochromonadales							
Dinobryon divergens	•	•	•	•	•	●	•
Dinobryon bavaricum	•	•	•	•	•	•	•
Mallomonas	•	•	•	•	•	•	•
Order: Dinokontae							
Peridinium		•	•	•	•	•	•
DIATOMS							
Order: Centrales							
Cyclotella				•			
Melosira italica	●	•	●	●	●	●	•
Order: Pennales							
Achnanthes	•		•		•		
Amphora		•			•	•	
Asterionella formosa	•	•	•	•	•		•
Cymbella							•
Fragilaria crotonensis		•				•	
Gomphonema	•						
Navicula	•	•				•	
Nitzschia					•		
Synedra acus	•	•	•		•	•	
Tabellaria	•						

TABLE 28
SUMMARY OF PERIPHYTON SPECIES COMPOSITION AT SHALLOW SITES ON CHRISTINA LAKE

● = dominant, • = not dominant

Taxonomic Identification	Site E215959 91/07/17	Site E215959 91/09/07	Site E215959 91/10/16	Site E215960 91/07/17	Site E215960 91/08/15	Site E215960 91/09/17	Site E215960 91/10/16	Site E215961 91/08/15	Site E215961 91/09/17	Site E215961 91/10/16
GREENS										
Order: Oedogonium										
Bulbochaete	•									
Oedogonium	•			•	•					
Order : Chaetophorales										
Stigeoclonium						•				
Order: Chlorococcales										
Ankistrodesmus			•						•	
Crucigenia tatrapedia		•								•
Oocystis	•									
Order: Zygnematales										
Spirogyra	•									
Mougeotia	•	●	•	•	•	•		●	•	●
Zygnema	•									•
BLUE-GREENS										
Chroococcales										
Microcystis aeruginosa	•			●						
Order: Oscillatoriales										
Lyngyba subtilis	●		●	●				●		●
Order: Nostocales										
Anabaena affinis	●	●	•		●			●	●	•
CHRYSOPHYTES										
Order: Ochromonadales										
Dinobryon divergens		•	•						•	•
Dinobryon bavaricum				•						
DIATOMS										
Order: Centrales										
Cyclotella glomerata		•	•						•	●
Melosira italica	•	•	●				●	•	●	●
Order: Pennales										
Achnanthes minutissima	●	●	•	•	●	●	●	●	●	●
Achnanthes microcephala					•	●	●	•		
Achnanthes spp.	•	•	•	•	•	•	•	•	•	•
Amphipleura pellucida				•			•	•	•	•
Amphora ovalis	•									
Asterionella formosa							•	•		
Ceratoneis arcus		•							•	
Cocconeis placentula		•	•	•	•		•			

continued on next page

Table 28 continued

Taxonomic Identification	Site E215959			Site E215960				Site E215961		
	91/07/17	91/09/07	91/10/16	91/07/17	91/08/15	91/09/17	91/10/16	91/08/15	91/09/17	91/10/16
Cymbella microcephala	•	•	•			•				
Cymbella spp.	•	•		•	•	•	•			
Diploneis			•	•						
Epithemia sorex		•		•	•		•	•		
Epithemia turgida	•		•	•	•	•	•	•		
Fragilaria construens	●	●	●	●	•	●	•	•	•	•
Fragilaria pinnata		●	•	•			●			
Fragilaria capucina	•									
Fragilaria intermedia	•									
Gomphonema	•		•	•					•	•
Navicula	•	•	•	•	•	•		•	•	•
Navicula acicularis	•									
Navicula filiformis	•									
Nitzschia spp.				•	•		•	•	•	
Nitzschia amphibia		•				•	•	•		•
Nitzschia acicularis		•	•		●	•	•	•	●	
Nitzschia dissipata			•							
Rhopalodia gibba	•	•	•	•	•	•		•	•	•
Synedra ulna	•			•						
Synedra	•	•	•	•		•	•	•	•	•
Tabellaria fenestrata	•	•		•						

TABLE 29
COMMERCIAL DISCHARGES OF DOMESTIC WASTEWATER IN THE CHRISTINA LAKE DRAINAGE

# on map (fig. 5)	Source (commercial establishment)	Summer flow (m^3/day)	Winter flow (m^3/day)	Annual phosphorus load (kg)
	Campsites and Trailer Parks			
2	Camp Beverly Hills	13.6	2.3	15.8
26	Christina Pines Tent & Trailer Park	22.7	0.0	19.7
18	Christina Sands	38.3	3.8	39.9
15	Kiana Resort by the lake	18.2	2.3	19.8
7	Kingsley's Trailer Park	3.9	1.4	5.8
14	Shulli Resort	22.7	2.3	23.7
30	Silver Birch Family Camping	9.1	3.6	14.3
13	Skand's Campsite Tent & Trailer	18.2	1.1	17.8
6	Totem Motel and Resort	18.2	6.8	27.8
25	Village Service	22.7	2.2	23.6
33	Willow Beach	22.7	1.1	21.7
16	Wilson Beach Resort	18.2	2.3	19.8
	Motels & Lodging			
31	Alpine Inn Lodge	31.4	9.1	43.3
8	Blue Mountain Lodge	4.5	0.9	5.5
25	Christina Motor Inn	7.6	2.3	10.6
21	Lake View Motel	2.3	0.9	3.6
1	New Horizon Motel	13.6	9.1	27.9
5	Parklane Motel	9.1	2.3	11.9
28	The Greenhouse (Bed & Breakfast)	6.8	1.8	9.1
	Miscellaneous			
12	Anne's Bakery	4.5	0.0	3.9
11	Butcher's Block	3.4	3.4	9.0
29	Christina Lake Community Club	2.3	2.3	6.0
24	Christina Sports & Marine	2.3	0.2	2.4
4	Country Kitchen	22.7	1.8	22.9
27	Durand's Nursery	1.1	0.2	1.4
9	Firehall	1.1	1.1	3.0
25	Grey Fox Development (laundry)	10.9	3.0	14.8
25	Henessey's Restaurant	22.7	18.2	51.9
3	Kool Treat	22.7	0.0	19.7
20	Mama Mitri's Restaurant	22.7	0.2	20.1
22	Movie Rentals / Souvenirs	0.9	0.2	1.2
25	Red Wagon Lounge	22.7	22.7	59.9
32	RV & Ministorage	2.0	2.0	5.4
25	Stop & Shop Food Market	9.1	4.5	15.9
17	Tempo Gas	6.8	3.4	11.9
23	Thrifty Gas	1.4	1.4	3.6
19	Time & Place Pub & Restaurant	22.7	18.2	51.9
10	Wild Ways - Adventure Sports	4.5	2.3	8.0
			Total	674.5

TABLE 30
AREAL HYPOLIMNETIC OXYGEN DEPLETION RATES FOR THE SUMMER OF 1981 AT SITE 0200078 - DEEP STATION AT SOUTH END OF CHRISTINA LAKE

DATE	DEPTH	D.O. (mg/L)	VOLUME (m^3)	MASS O_2 (g)	DATE	D.O. (mg/L)	MASS O_2 (g)
Apr	8-10	11.8	47500000	560500000	Sept	10.4	494000000
28/81	10-12	11.8	46600000	549880000	2/81	10.1	470660000
	12-14	11.7	45600000	533520000		9.6	437760000
	14-16	11.6	45000000	522000000		9.4	423000000
	16-18	11.5	44200000	508300000		9.0	397800000
	18-20	11.3	43400000	490420000		8.8	381920000
	20-22	11.0	42500000	467500000		8.1	344250000
*							
			Total =	3632120000		Total =	2949390000

* note that data does not include entire hypolimnion

Overall consumption = 3632120000 - 2949390000 = 682730000 g
= 682730000000 mg

Surface area of lake at 8 m = 237500000000 cm^2

Consumption per day = $\frac{682730000000}{237500000000}$ ÷ 128 days = 0.022 $mg/cm^2/day$

TABLE 31
AREAL HYPOLIMNETIC OXYGEN DEPLETION RATES FOR THE SUMMER OF 1991 AT SITE 0200078 - DEEP STATION AT SOUTH END OF CHRISTINA LAKE

DATE	DEPTH	D.O. (mg/L)	VOLUME (m^3)	MASS O_2 (g)	DATE	D.O. (mg/L)	MASS O_2 (g)
May	8-10	12.3	47500000	584250000	Oct	10.4	494000000
23/91	10-12	12.4	46600000	577840000	10/91	11.6	540560000
	12-14	12.4	45600000	565440000		12.1	551760000
	14-16	12.5	45000000	562500000		11.9	535500000
	16-18	12.4	44200000	548080000		11.6	512720000
	18-20	12.3	43400000	533820000		10.9	473060000
	20-22	12.2	42500000	518500000		10.4	442000000
			Total =	3890430000		Total =	3549600000

Overall consumption = 3890430000 - 3549600000 = 340830000 g
= 340830000000 mg

Surface area of lake at 8 m = 237500000000 cm^2

Consumption per day = $\frac{340830000000}{237500000000}$ ÷ 141 days = 0.010 $mg/cm^2/day$

TABLE 32
MEAN SPRING OVERTURN NUTRIENT CONCENTRATIONS (µg/L) AT DEEP SITES ON CHRISTINA LAKE

(no entry = no data)

SITE	YEAR	MONTH	T.P.	T.D.P.	T.N.	K.N.	NO_3	NH_3	N:P
0200078 at Christina	1973	May	6					<10	
	1978	April	6	<3		95		8	16:1
	1981	April	8	5.5	55	55		16	7:1
	1983	March	9.5	5	140	140		<5	15:1
	1984	April	10.5	5	120	70	<20	<5	11:1
	1986	April	8	3		70		<5	9:1
	1988	April	7.5	3.5		105		<5	14:1
	1990	March	3	<3		90		<5	30:1
	1991	April	4	<3		95		<5	24:1
	1991	May	4	<3	55	50		<5	13:1
	1992	April	3.5	<3		135		6.5	39:1
	1992	May	4	<3	95	90		5	23:1
0200520 English Point	1978	April	5.5			120		8.5	22:1
	1981	April	8	5	85	85	<20	16	11:1
	1983	March	9	5.5	130	110	40	9	14:1
	1984	April	16	3	115	115	<20	<5	7:1
	1986	April	9	3		70	<20	<5	8:1
	1988	April	5	3		70	<20	<5	14:1
	1990	March	3	<3		90	<20	<5	30:1
	1991	April	4.33	<3		95	<20	<5	22:1
	1992	April	6.5	<3		85	<20	<5	13:1
	1993	April	11	4		95	<20	<5	9:1
E215758 North Basin	1991	May	3.5	<3		55	<5	5.5	16:1
	1992	April	4	<3		80		<5	20:1
	1992	May	4	<3		50	<4	<5	13:1

T.P. = Total phosphorus
T.D.P. = Total dissolved phosphorus
T.N. = Total nitrogen
K.N. = Kjeldahl nitrogen
NO_3 = Nitrate
NH_3 = Ammonia
N:P = Nitrogen to phosphorus ratio

TABLE 33
ESTIMATED MONTHLY PHOSPHORUS LOAD TO CHRISTINA LAKE FROM SUTHERLAND CREEK

Month	Volume entering lake (L)	Approximate mean phosphorus concentration (µg/L)	Total phosphorus load to lake (kg)
April	1.9232×10^9	35	67.31
May	6.9102×10^9	40	276.41
June	4.3027×10^9	20	86.05
July	0.9454×10^9	20	18.91
August	0.3240×10^9	20	6.48
September	0.2357×10^9	20	4.71
			total = ~460 kg

TABLE 34
ESTIMATED SEASONAL WATER DENSITIES OF SUTHERLAND CREEK
(determination of generalized dispersion patterns of input water to the lake)

Month	Mean monthly water Temp. (°C)	Mean Specific conduc-tance (µS/cm)	Total dissolved solids (mg/L) *	Water density (g/mL)	Mean lake total dissolved solids (mg/L)	Likely lake depth with same density (meters)
April	4.40	80.0	56.00	1.000052	52.5	** see below
May	5.62	56.5	39.55	1.000024	52.5	14-16
June	8.91	57.5	40.25	0.999849	52.5	8-12
July	13.15	87.3	61.11	0.999467	52.5	8-12
August	13.87	122.3	85.61	0.999375	52.5	8-12
September	10.67	142.0	99.40	0.999764	52.5	10-14

* conversion factor (Specific conductivity x 0.7) to obtain approximate Total Dissolved Solids.

** In early April the water column is homogeneously mixed (~ 4.5 °C), therefore the Sutherland Creek water would mix evenly throughout the water column

TABLE 35
EPILIMNETIC CHLOROPYLL *a* CONCENTRATIONS FOR CHRISTINA LAKE
(composite samples of the top 10 meters)

Date	Site 0200078 (µg/L)	Site 0200520 (µg/L)	Site E215758 (µg/L)
October 10 1980	0.6	0.7	-
April 28 1981	0.6	0.9	-
March 16 1983	1.8	1.7	-
September 21 1983	0.6	-	-
April 17 1984	0.9	0.8	-
October 2 1984	0.8	0.7	-
April 16 1986	1.3	1.8	-
October 11 1986	0.6	0.7	-
April 14 1988	0.5	1.5	-
Sept 29 1988	0.6	0.7	-
March 22 1990	4.6	4.8	-
October 11 1990	1.3	1.5	-
April 11 1991	1.6	2.0	-
May 23 1991	2.5	-	1.5
June 20 1991	1.7	-	3.2
July 18 1991	0.8	-	2.1
August 15 1991	1.3	-	1.2
September 17 1991	1.1	1.4	1.0
October 15 1991	0.7	-	0.6
April 1 1992	1.0	1.0	1.3
May 5 1992	1.6	-	1.5
June 3 1992	1.8	-	2.4
July 8 1992	3.7	-	2.5
August 5 1992	-		2.8
September 2 1992	1.3	1.0	0.8
October 1 1992	1.4	-	3.3
October 28 1992	7.8*	-	2.5
Mean 1991 summer conc. (May-Oct)	1.157	-	1.6
Mean 1992 summer conc. (May-Oct)	2.95 (1.96)	-	2.26

*Mean value for summer of 1992 drops to 1.96 when anomalous value of Oct 28 is excluded

TABLE 36
MINISTRY OF HEALTH BEACH DATA FOR FECAL COLIFORM BACTERIA
(expressed as summer geometric means of most probable number per 100 mL of water)

Year	Alpine Inn	Skands campsite	Schulli Campsite	Provincial beach
1967 (median)	3.3	2.0	--	6.8
1971 (median)	4.0	0.0	--	0.0
1972 (median)	4.0	9.0	--	4.0
1973 (median)	6.0	0.0	--	0.0
1974 (median)	0.0	4.0	0.0	9.0
1985 (log mean)	5.1	8.0	5.5	14.7
1986 (log mean)	6.0	10.0	4.0	10.0
1987 (log mean)	<1.0	<1.0	1.1	1.1
1988 (log mean)	3.1	3.0	3.3	5.9
1989 (log mean)	5.0	5.0	5.0	6.5
1990 (log mean)	4.0	<1.0	2.0	4.0
1991 (log mean)	<1.0	1.0	2.0	2.0
1992 (log mean)	2.0	2.0	2.0	6.0

TABLE 37
FECAL COLIFORM DATA FOR TRIBUTARIES TO CHRISTINA LAKE FOR THE PERIOD 1991-92
(expressed as 90th percentile)

Tributary	Value
Christina Creek	31.0
McCrae Creek	14.8
Sandner Creek	8.5
Stewart Creek	8.8
Sutherland Creek	53.2

TABLE 38
AMBIENT WATER QUALITY
OBJECTIVES FOR CHRISTINA LAKE
(April through October)

PARAMETER	OBJECTIVE
Phytoplankton (pelagic)	stable community structure, not dominated by blue-greens(<10% of cells in any sample). Dominant genera (>10% of cells) should include *Melosira, Asterionella, Fragilaria, Synedra, Peridinium, Dinobryon,* and *Mallomonas.*
Periphyton	stable community structure, dominated (>50% of cells) primarily by pennate diatoms
Zooplankton	stable community structure, dominated (>10% of cells) primarily by *Bosmina longirostris*, *Epischura nevadensis* and *Kellicotia longispina*
Dissolved oxygen	8 mg/L minimum at any site and depth
Turbidity	mean value ≤ 1 NTU, ≤ 5 NTU maximum
Secchi depth	3 m minimum at any time (annual mean >10 m)
Total Phosphorus	<7 µg/L
Total Nitrogen	≤ 200 µg/L
Chlorophyll *a*	≤ 2.5 µg/L for phytoplankton, monthly mean (in photic zone - 2.5x Secchi) ≤ 10 mg/m2 for periphyton, monthly mean
Coliforms	≤ 10 fecal coliforms per 100 mL of water (90th percentile)

TABLE 39
CHRISTINA LAKE SUGGESTED OBJECTIVES MONITORING SCHEDULE

Location	Frequency	Date	Parameter
deep stations	monthly	Apr-Oct	Phytoplankton (1) Zooplankton (2) D.O. (profile) Temperature (profile) Secchi depth M F Fecal Chlorophyll *a* Turbidity
deep stations 3 depths per station (3)	monthly	Apr-Oct	T. Phosphorus T.D.P. NO_2 / NO_3 NH_3 Organic N
6 shallow stations	weekly	July-Aug	M F Fecal
6 tributaries	monthly	Apr-Oct	M F Fecal
6 shallow stations	monthly	Apr-Oct	Periphyton (4)
6 tributaries & 6 shallow stations	monthly	Apr-Oct	D.O. Temperature T. Phosphorus T.D.P. NO_2 / NO_3 NH_3 Organic N Turbidity

1. Surface (0.5 m) unconcentrated 1 L sample preserved with Lugol's solution.
2. Vertical haul from 50 m to surface. Preserved in 10% formalin. Mouth size of net must be recorded.
3. At least three depths in water column (epilimnion, thermocline and hypolimnion).
4. Periphyton taxonomy and chlorophyll *a* from natural substrates (chlorophyll *a* to be a composite of 6 sub-samples at each site).

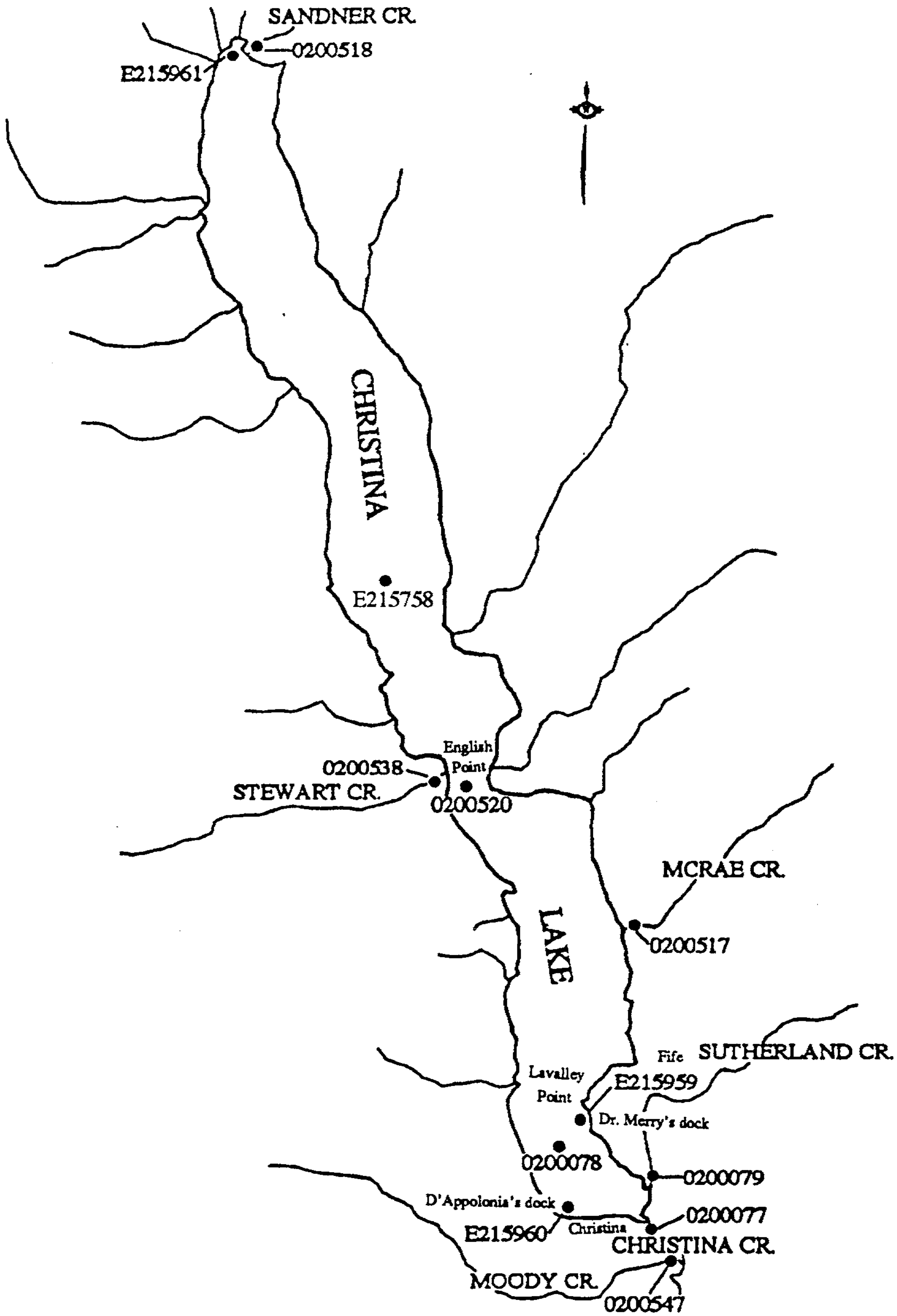


FIGURE 1. CHRISTINA LAKE WITH BC ENVIRONMENT SAMPLE SITES

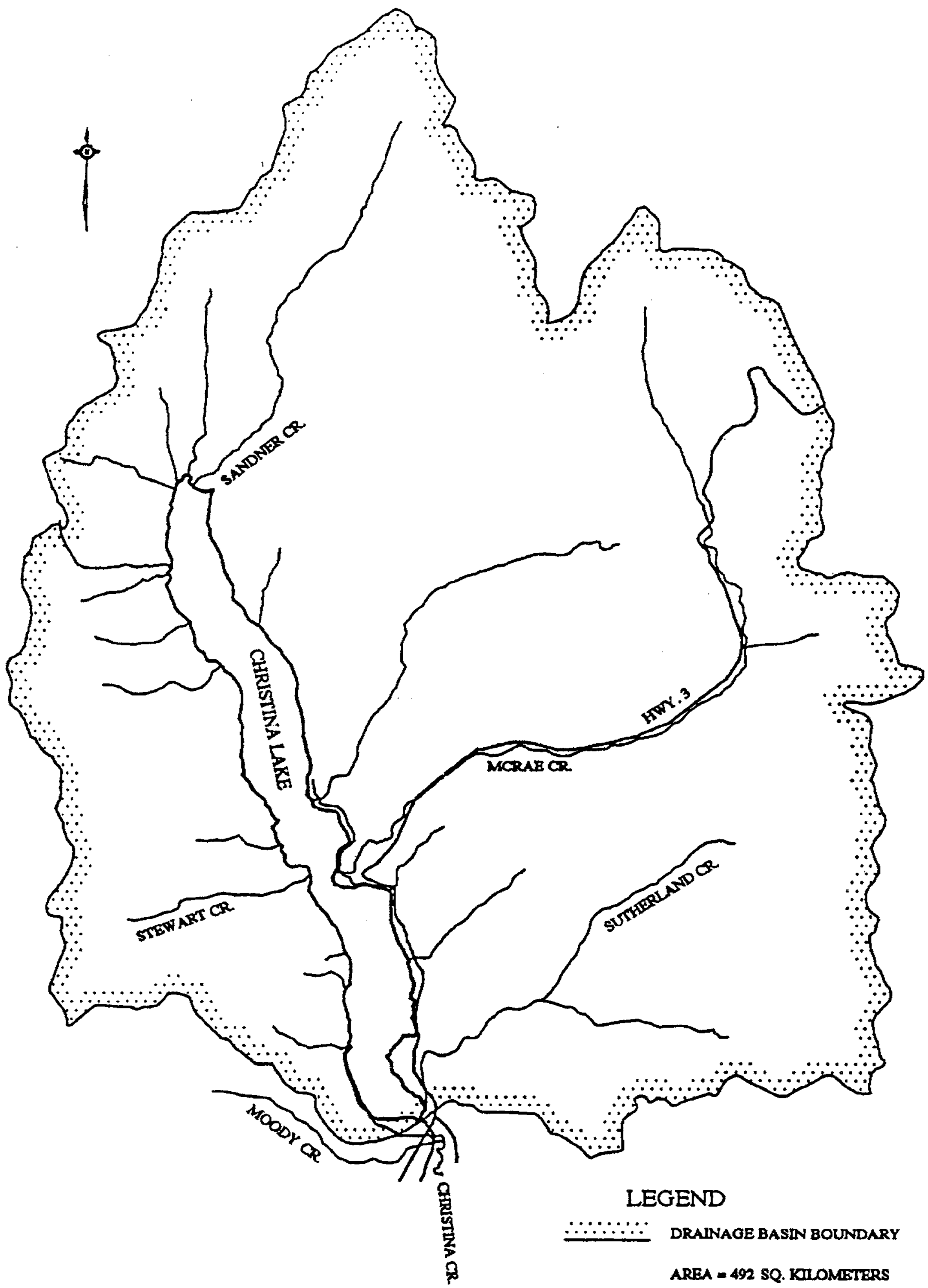


FIGURE 2. CHRISTINA LAKE DRAINAGE BASIN

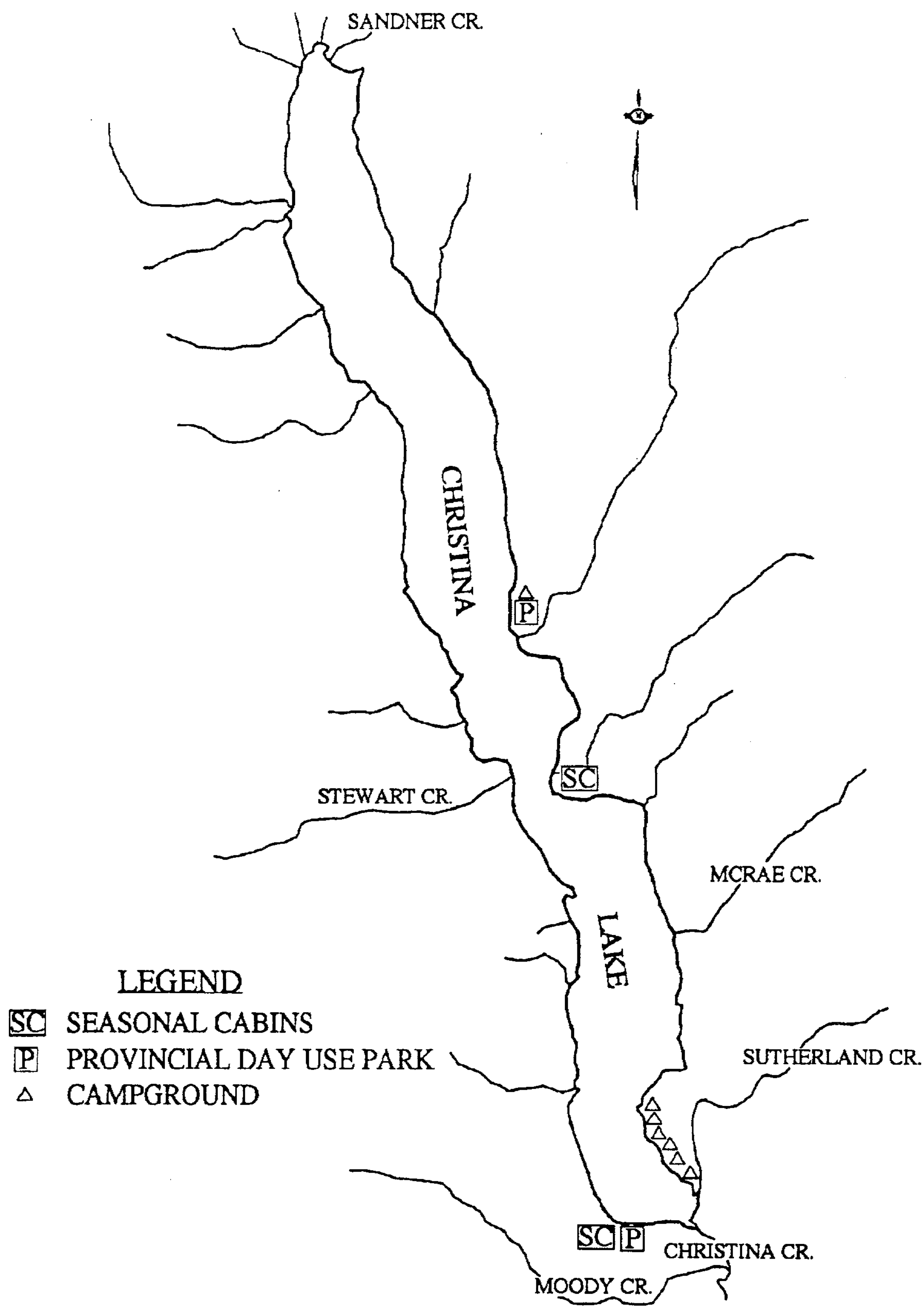


FIGURE 3. CHRISTINA LAKE RECREATION FACILITIES

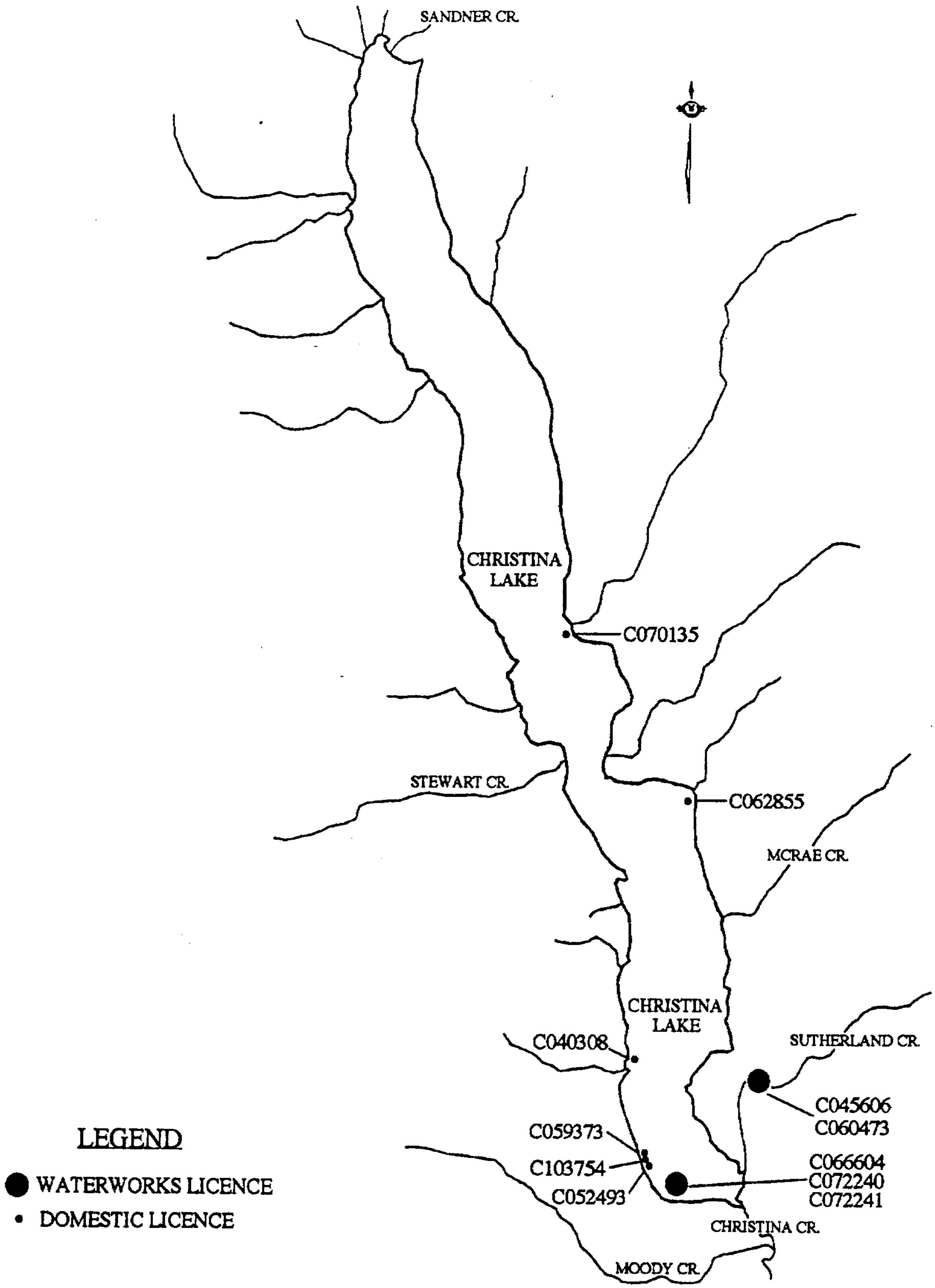


FIGURE 4. CHRISTINA LAKE WATER LICENCES

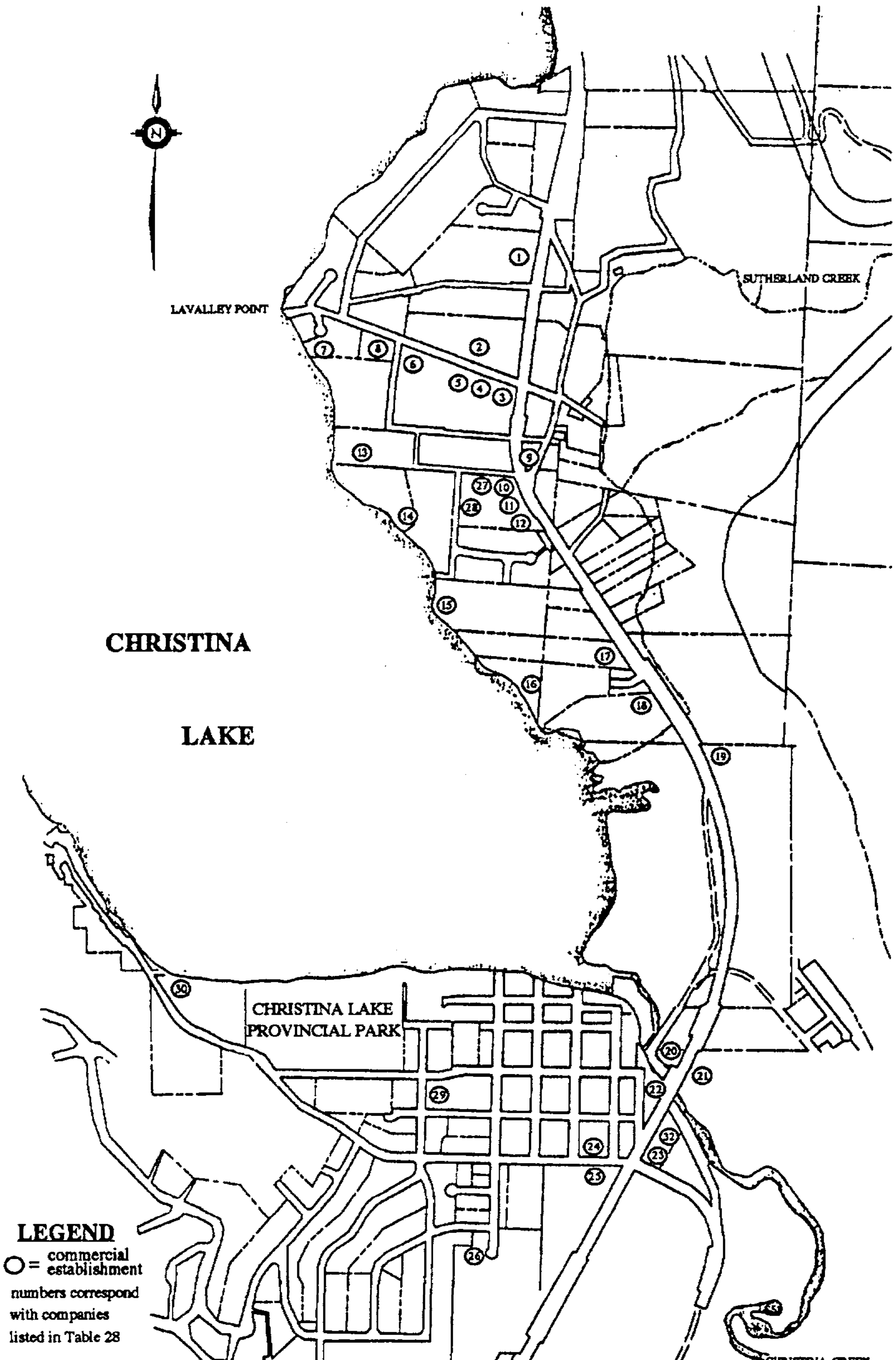


FIGURE 5. LOCATIONS OF COMMERCIAL WASTEWATERS DISCHARGED TO GROUND NEAR CHRISTINA LAKE

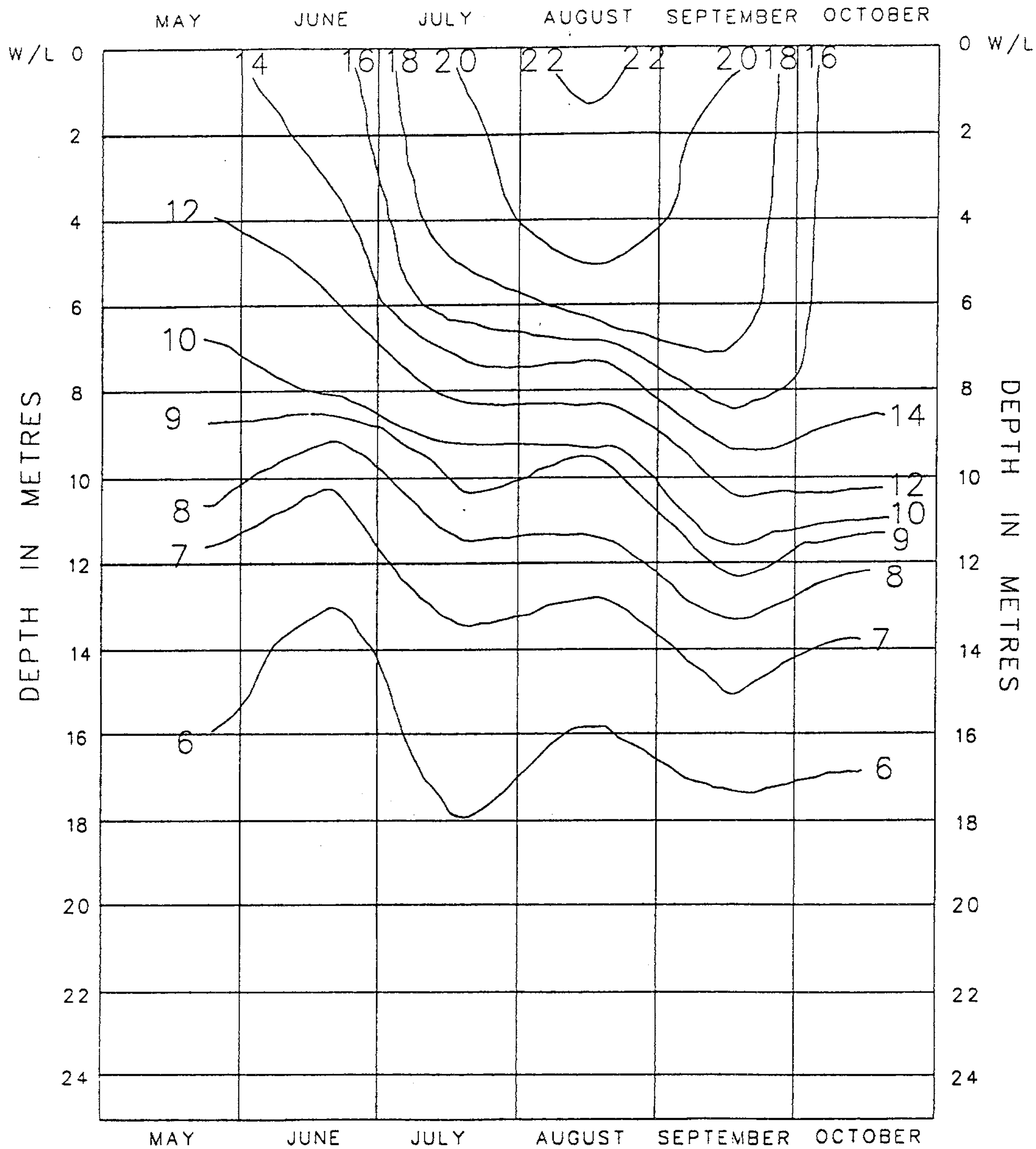


Figure 6. Time - Depth diagram of isotherms (°C) as site 0200078 (south end of Christina Lake) for 1991.

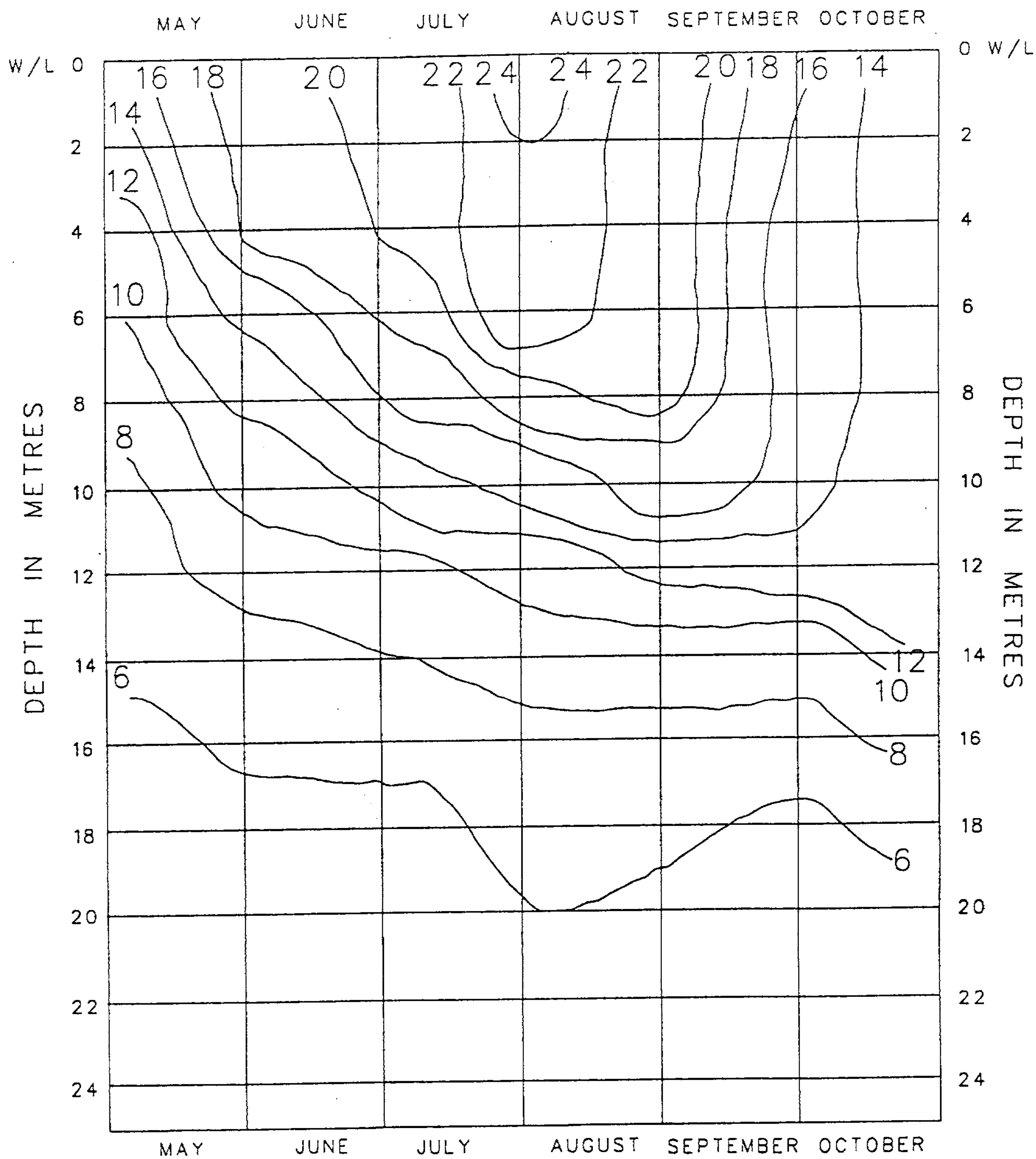


Figure 7. Time - Depth diagram of isotherms (°C) as site 0200078 (south end of Christina Lake) for 1992.

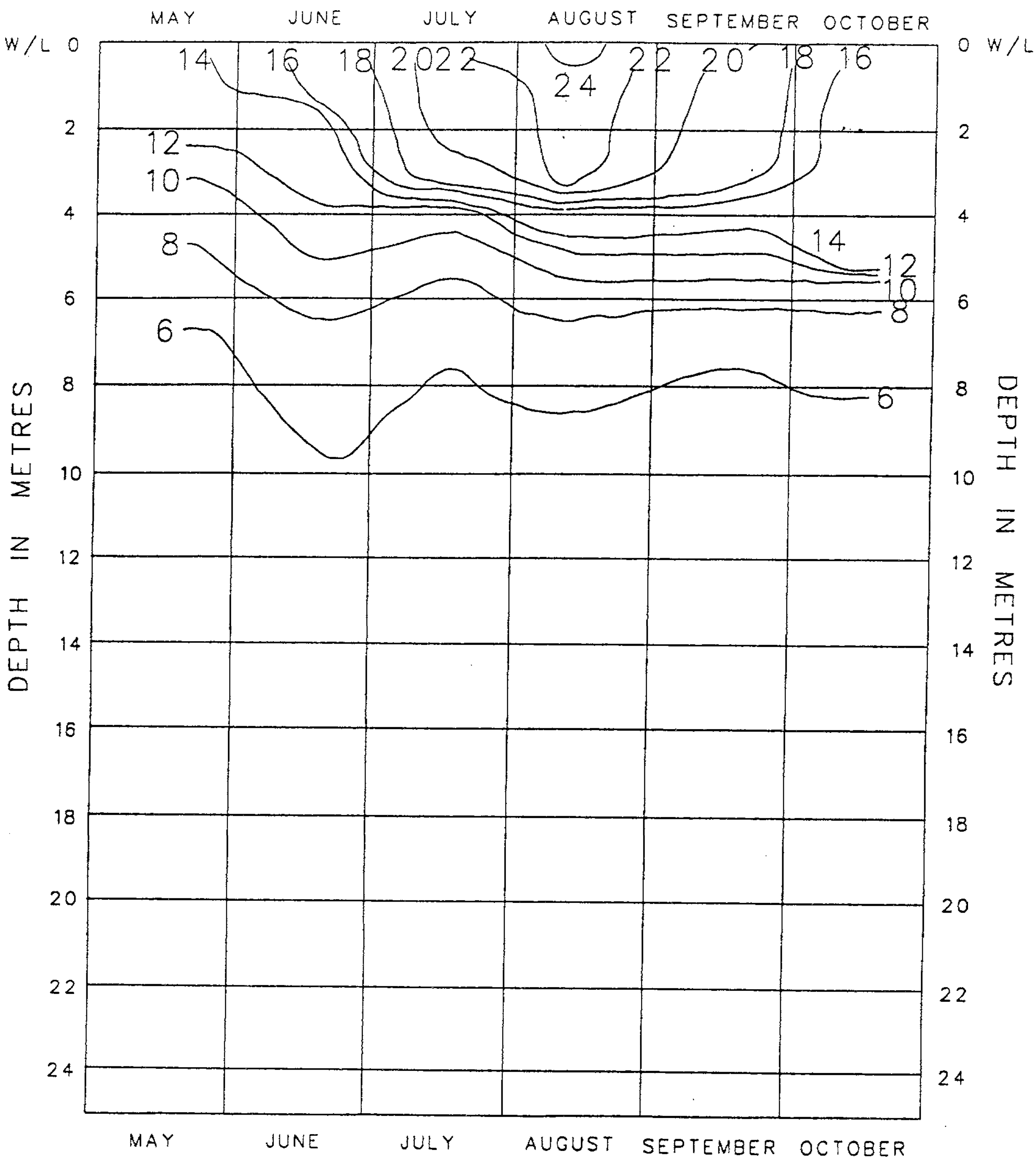


Figure 8. Time - Depth diagram of isotherms (°C) as site E215758 (north basin deep center) for 1991.

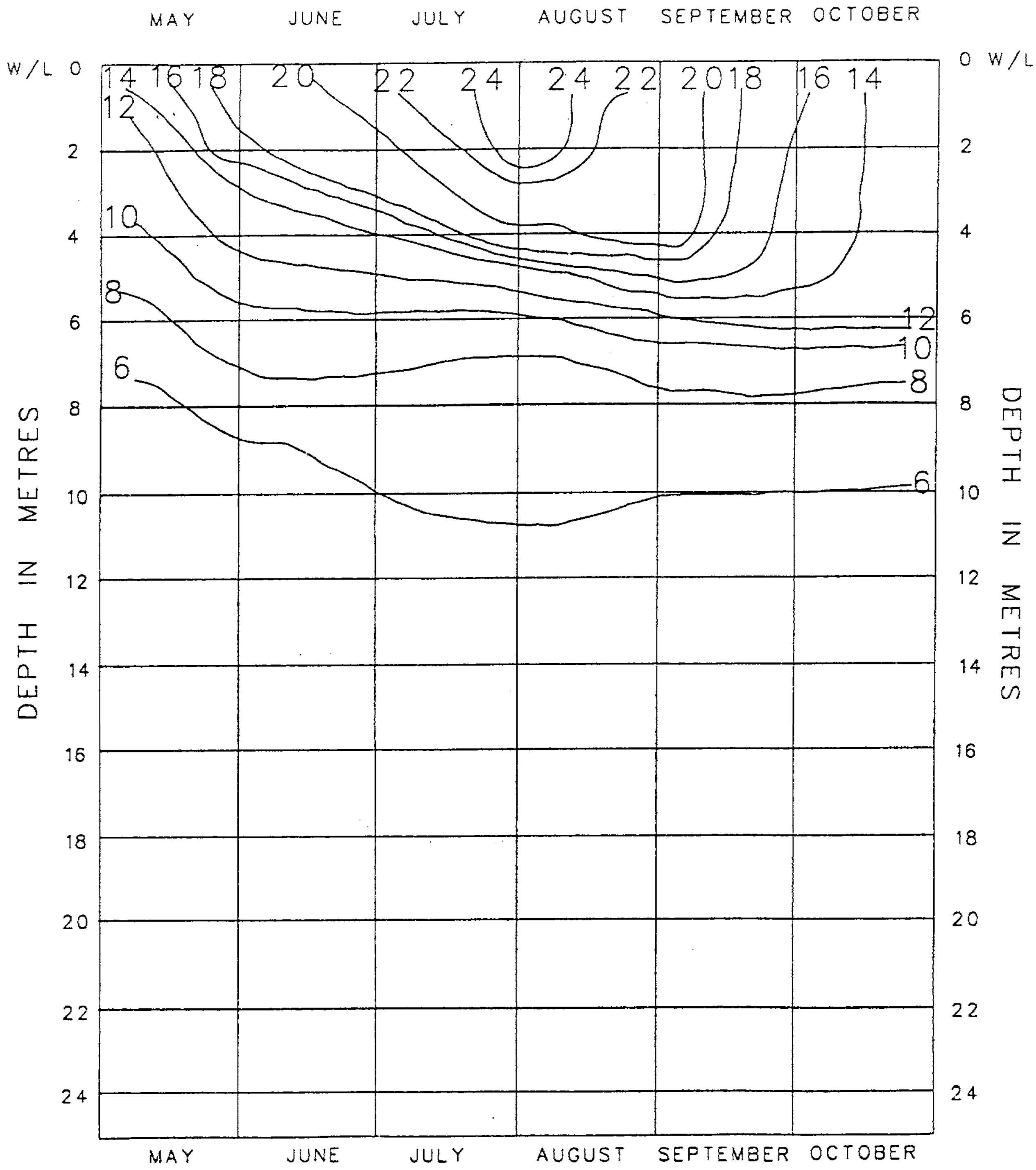


Figure 9. Time - Depth diagram of isotherms (°C) as site E215758 (north basin deep center) for 1992.

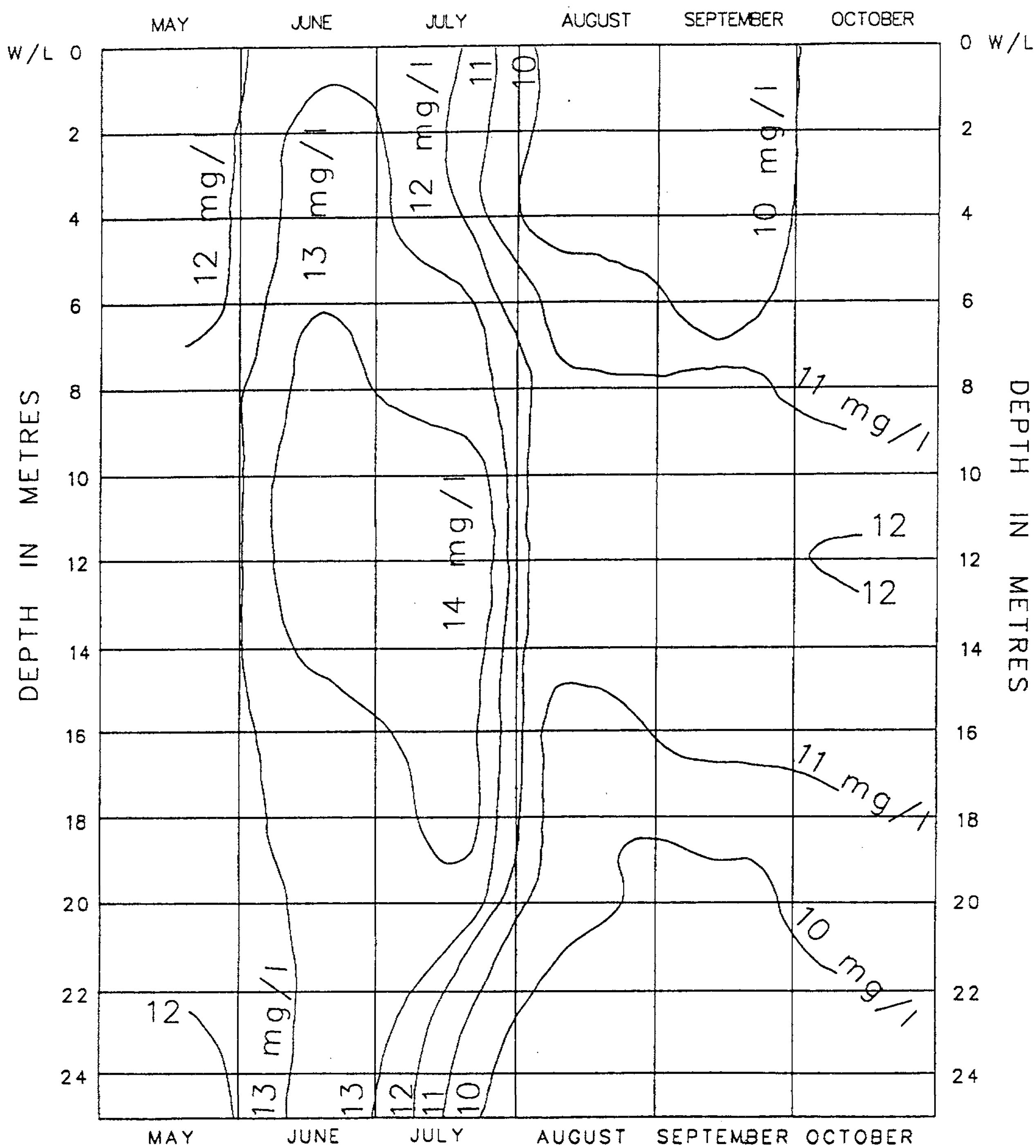


Figure 10. Time - Depth diagram of dissolved oxygen (mg/L) as site 0200078 (south end of Christina Lake) for 1991.

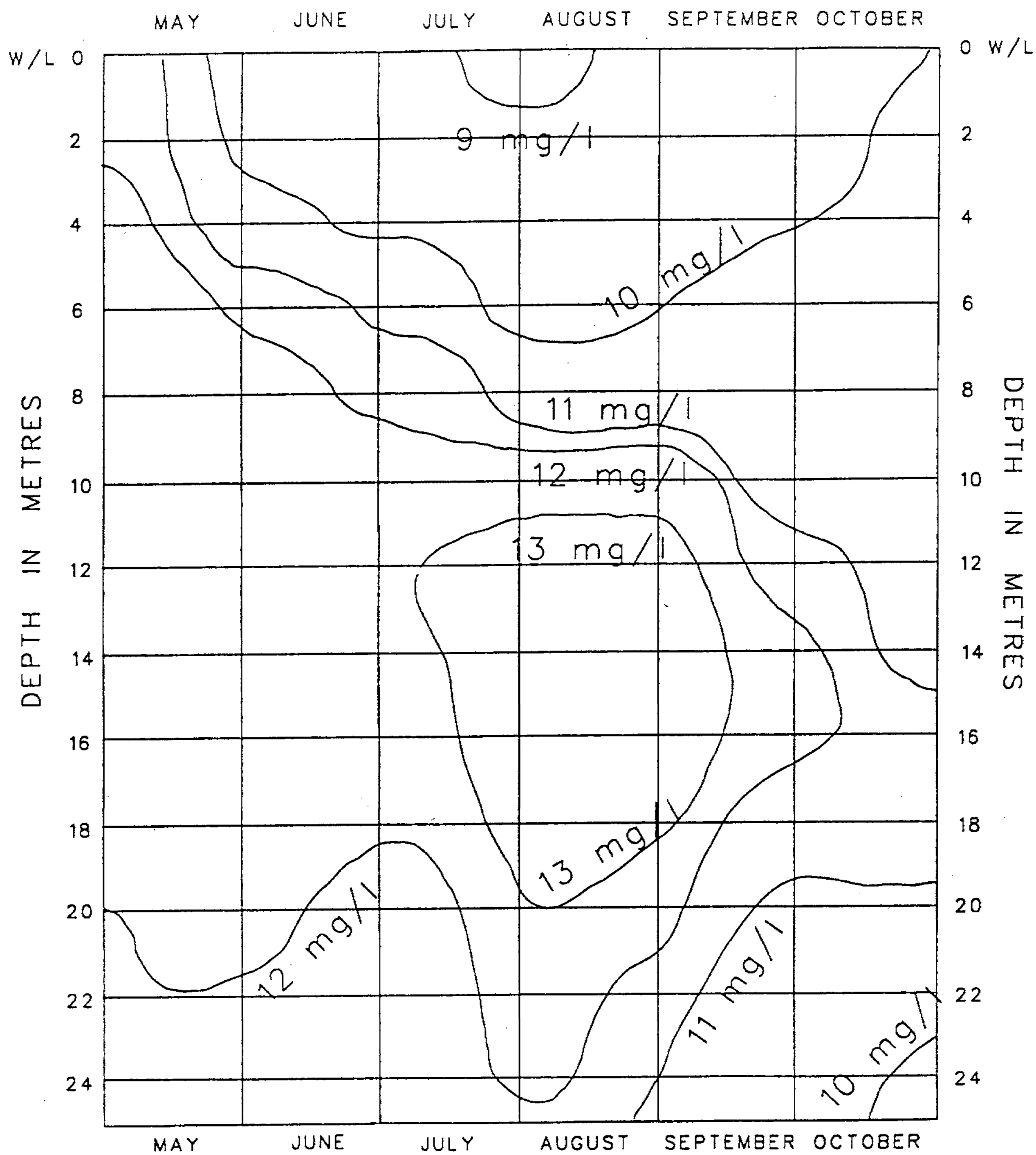


Figure 11. Time - Depth diagram of dissolved oxygen (mg/L) as site 0200078 (south end of Christina Lake) for 1992.

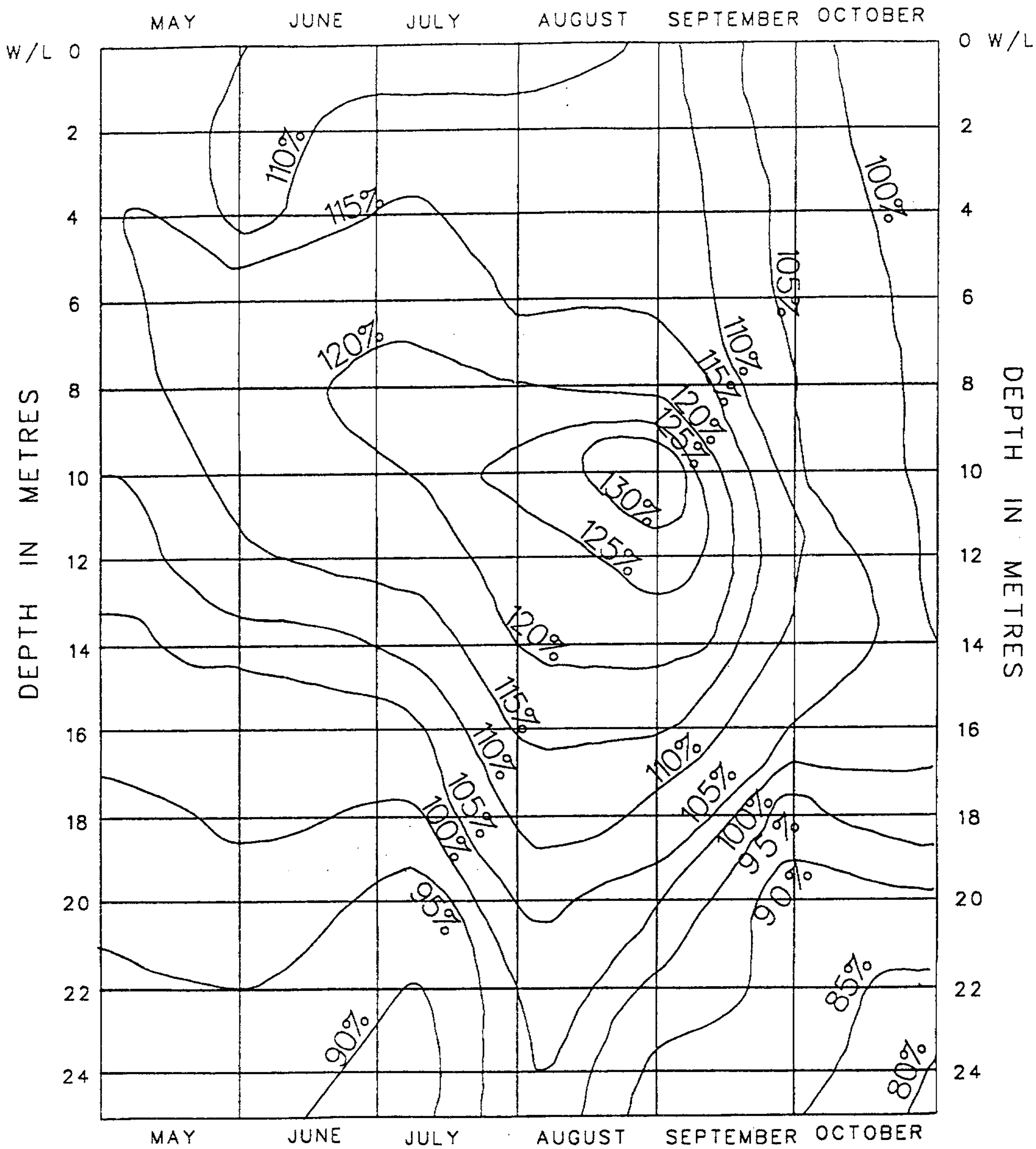
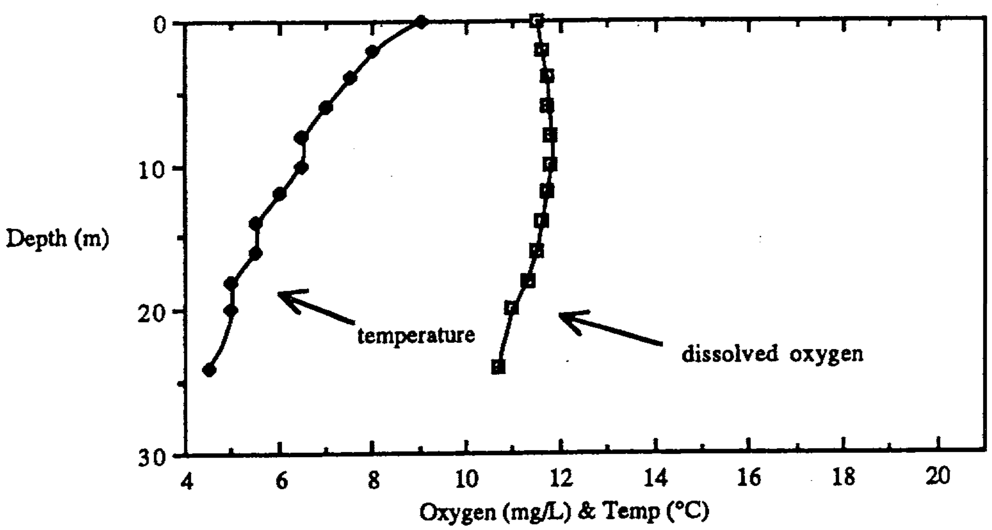
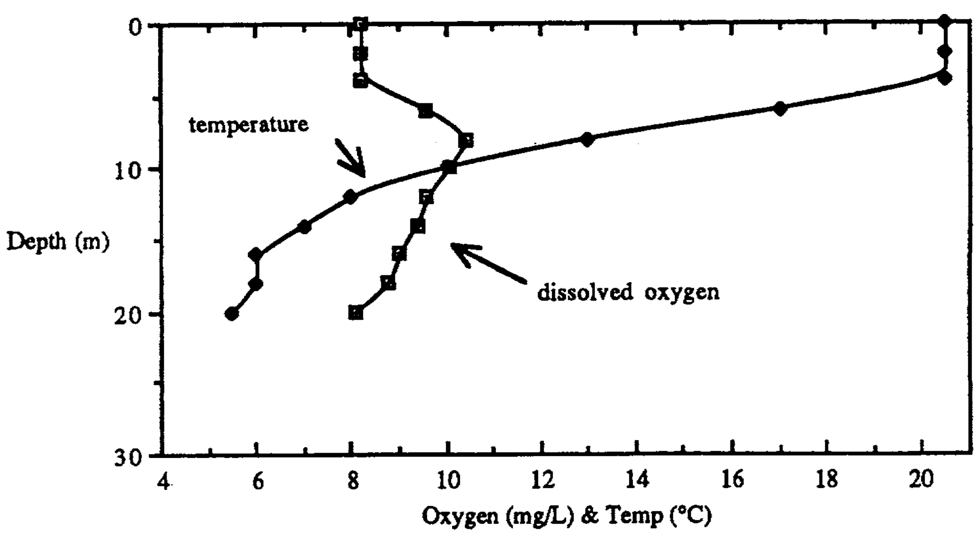


Figure 12. Time - Depth diagram of dissolved oxygen (% saturation) as site 0200078 (south end of Christina Lake) for 1992.

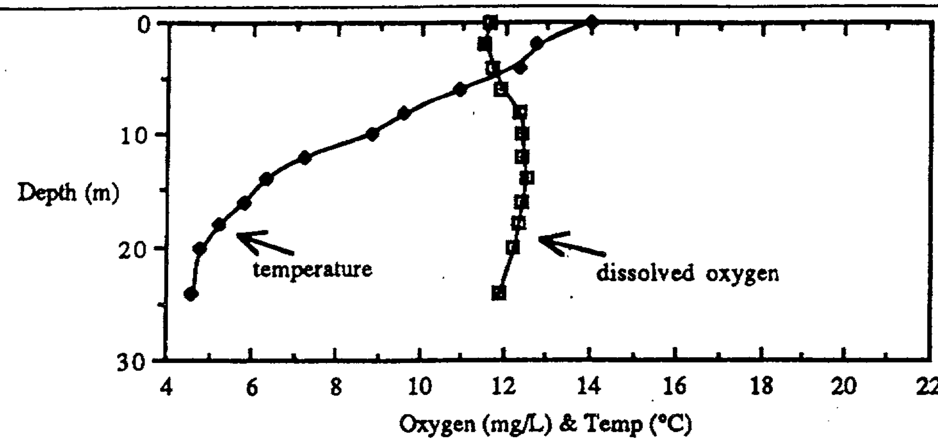


April 28

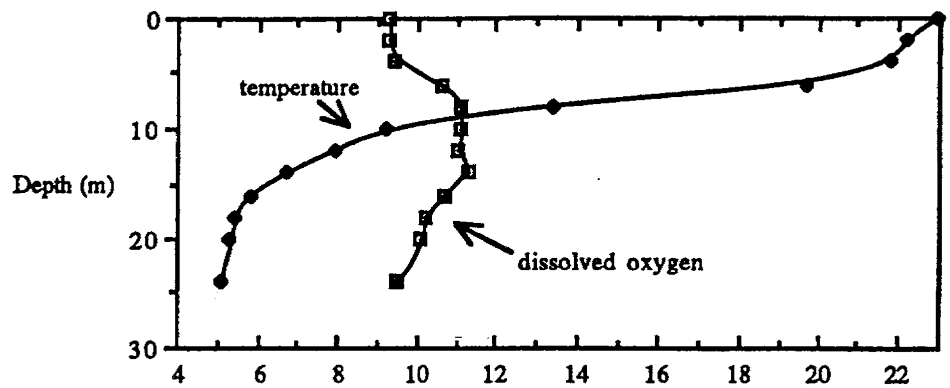


September 2

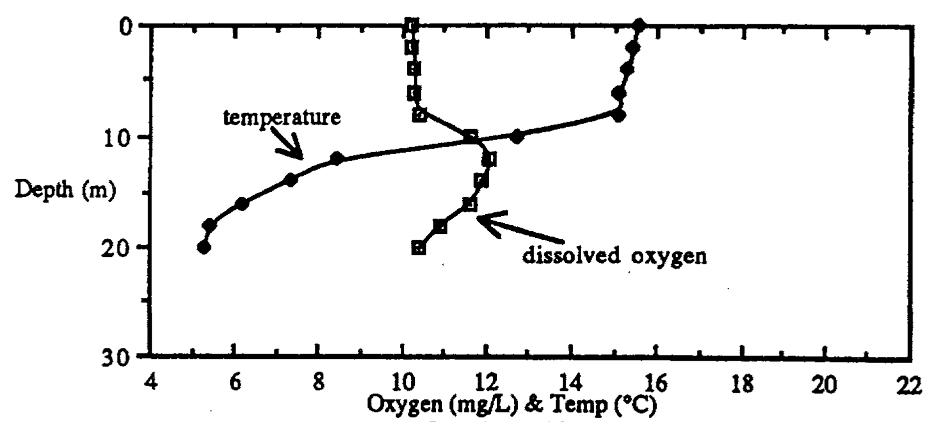
Figure 13. Depth profiles of dissolved oxygen and temperature at site 0200078 (Christina) during the summer of 1981



May 23



August 14



October 10

Figure 14. Depth profiles of dissolved oxygen and temperature at site 0200078 (Christina) during the summer of 1991

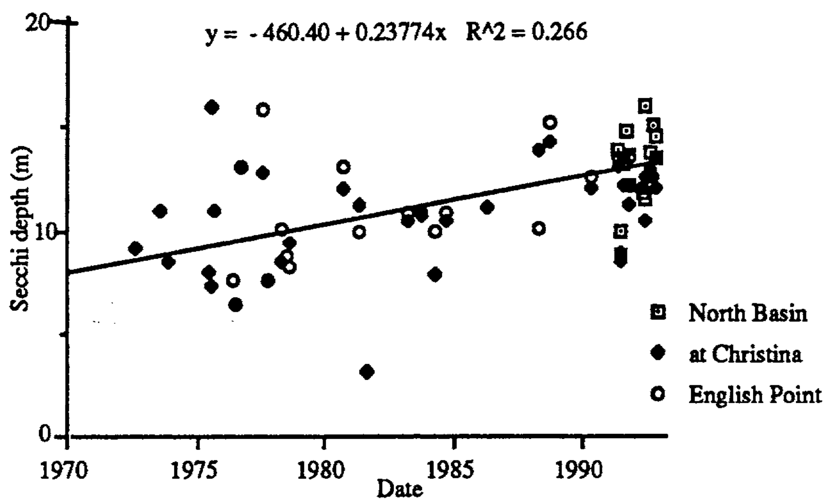


Figure 15. Christina Lake water clarity

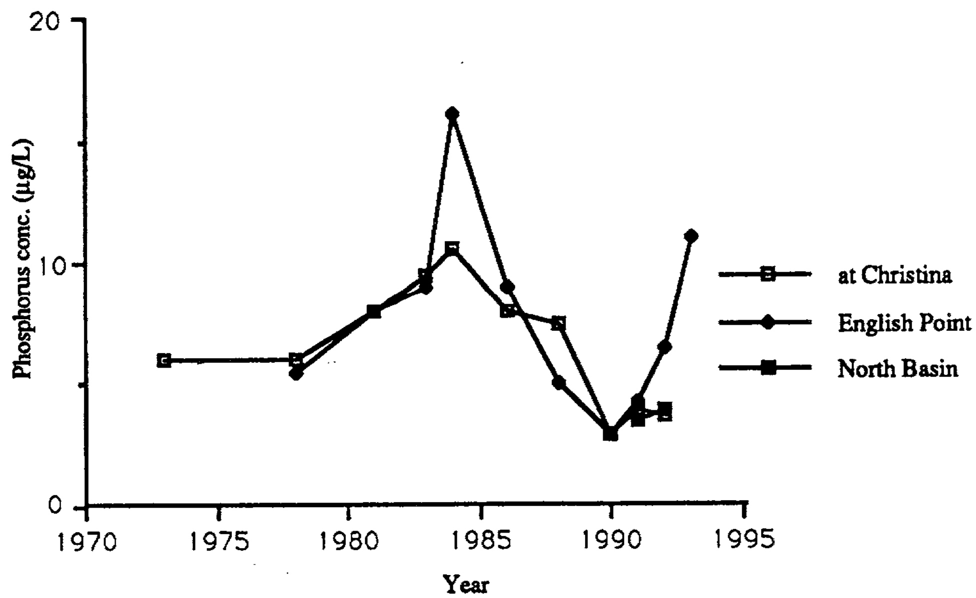


Figure 16. Mean spring overturn phosphorus concentrations for Christina Lake.

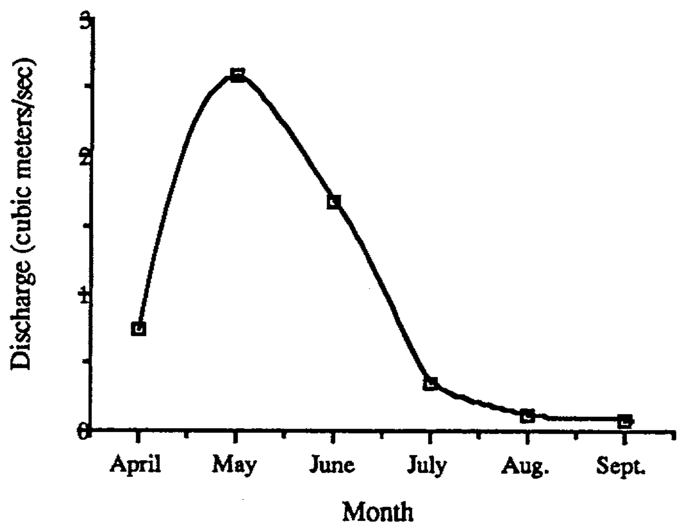


Figure 17. Summer hydrograph for Sutherland Creek near Fife

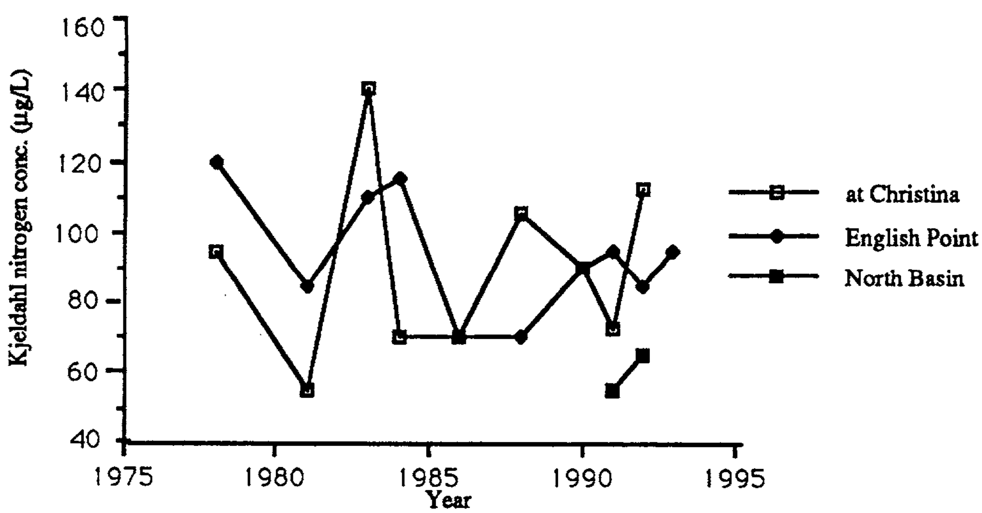
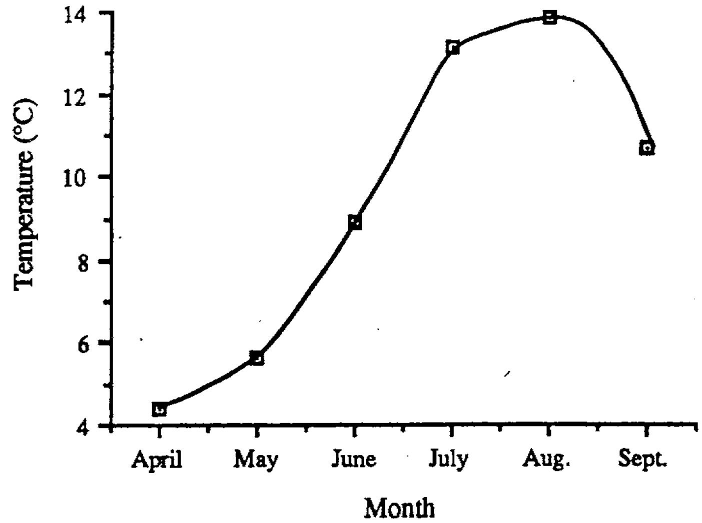


Figure 18. Mean spring overturn Kjeldahl nitrogen concentrations for Christina Lake



Mean summer temperatures of Sutherland Creek near Fife

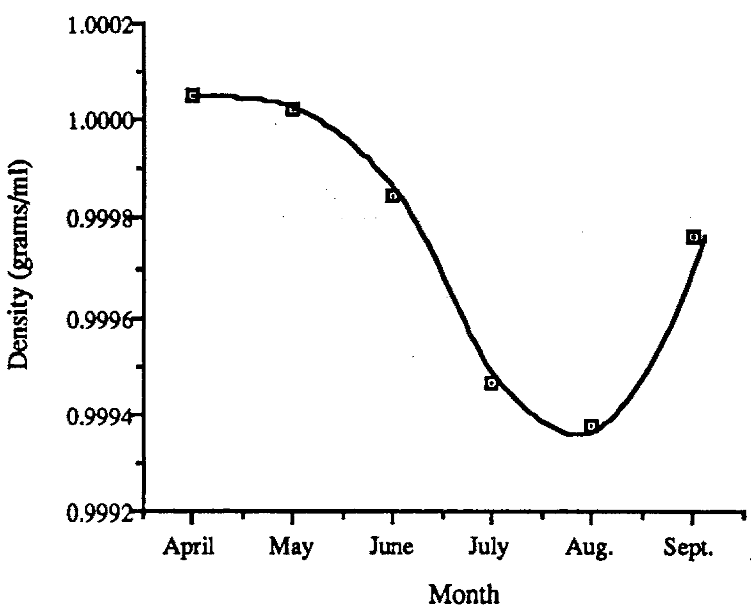


Figure 19. Summer water densities for Sutherland Creek near Fife derived from seasonal temperatures

APPENDIX 1.
LOADING CALCULATIONS FROM SPRING OVERTURN PHOSPHORUS

$$P = \frac{L}{(\sigma + \rho)\ Z}$$

where P is the mean concentration in g/m^3 of total phosphorus
L is the phosphorus loading in $g/m^2/yr$
Z is lake mean depth in m
σ is the sedimentation rate coefficient*
ρ is the replenishment coefficient (1 year + flushing rate of 4.5)

* an approximation based on Dillon and Rigler (1975) with modifactions incorporating flushing rate (Nordin, 1993)

For Christina Lake
- mean spring overturn P = 6.51 µg/L (0.00651 g/m^3)**
- Z = 37 m
- $\sigma = 0.55$
- $\rho = 0.22$

**Phosphorus load calculations are based on a range of 5-9 µg/L

Phosphorus loading

Low end of range: $0.005 = \frac{L}{(0.55 + 0.22)\ 37}$

$L = 0.1386\ g/m^2/yr$

Therefore, with a surface area of $2.51*10^7\ m^2$ and spring overturn phosphorus concentrations of 5 µg/L the total loading would be 3478 kg/yr

Mean value: $0.00651 = \frac{L}{(0.55 + 0.22)\ 37}$

$L = 0.1855\ g/m^2/yr$

Therefore, with spring overturn concentrations of 6.51 µg/L the total loading would be 4656 kg/yr

High end of range: $0.009 = \frac{L}{(0.55 + 0.22)\ 37}$

$L = 0.25641\ g/m^2/yr$

Therefore, with spring overturn concentrations of 9 µg/L the total loading would be 6435 kg/yr

APPENDIX 2.
TEST DIFFERENCE BETWEEN SAMPLE SITE MEANS FOR KJELDAHL NITROGEN

Step 1: Test diffence between "most heavily impacted" tributary (Sutherland Creek) and "least impacted" tributary (Sandner Creek) when the Kjeldahl data for the two sites were collected within 24 hours: A two-sample *t* test for the following two-tailed hypothesis:

H_o: $\mu_1 = \mu_2$
H_A: $\mu_1 \neq \mu_2$

Date	Sutherland	Date	Sandner
910522	130μg/L	910523	50μg/L
910619	50	910619	50
910717	70	910718	10
910814	50	910815	50
910916	50	910917	80
911015	100	911016	50
920331	140	920401	50
	Σ590		Σ340

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S_{\bar{X}_1 - \bar{X}_2}}$$

$n_1 = 7$ $\quad$ $n_2 = 7$
$v_1 = 6$ $\quad$ $v_2 = 6$

$\bar{X}_1 = 84.28$ $\quad$ $\bar{X}_2 = 48.57$
$SS_1 = 9171.42$ $\quad$ $SS_2 = 2485.7$

$$S^2p = \frac{SS_1 + SS_2}{v_1 + v_2} = \frac{9171.42 + 2485.7}{6 + 6} = 971.42$$

$$S_{\bar{X}_1 - \bar{X}_2} = \sqrt{\frac{S^2p + S^2p}{n_1 + n_2}} = 16.659$$

$$t = \frac{84.28 - 48.57}{16.659} = 2.1439$$

$t_{0.05(2),12} = 2.179$

Therefore, accept H_o

There is no difference in the mean Kjeldahl nitrogen values between these two creeks. Then assume that since these two creeks were "most" and "least" impacted then both McRae Creek (x = 82.5 μg/L) and Stewart Creek (x = 77.148 μg/L) values did not differ.

Appendix 2 cont.

Step 2: Test difference between "worst case" tributary and "best case" lake site (deep north basin) when data were collected within 24 hours of the other site.

H_o: $\mu_1 = \mu_2$
H_A: $\mu_1 \neq \mu_2$

Date	Sutherland cr.	Date	Deep north basin
910522	130μg/L	910523	70μg/L
910619	50	910620	110
910717	70	910718	70
910814	50	910815	40
910916	50	910917	70
911015	100	911015	100
920331	140	920401	90
920504	140	920505	50
	Σ730		Σ600

$\bar{X}_1 = 91.25$
$SS_1 = 11887.5$

$\bar{X}_2 = 75.00$
$SS_2 = 4000$

$S^2p = 1134.82$

$S_{\bar{X}_1 - \bar{X}_2} = 16.84$

$t = 0.9649$
$t_{0.05(2),14} = 2.145$
Therefore, accept H_o
There is no difference in mean Kjeldahl nitrogen values between the tributaries and the lake.

APPENDIX 3
GLOSSARY

Algae	Simple photosynthetic non-vascular plants, mostly aquatic. Most are microscopic; some reach large sizes. (see **Phytoplankton**)
Aquatic Life, Aquatic Organism	Organism which spends a critical part or all of its life cycle in water, and relies on a particular aquatic habitat for its survival.
Bathymetry	The measurement of depths in a water body. Bathymetric maps depict the bottom contours of a water body.
Biomass	The mass of all living material in a unit area at a given instant in time.
Chlorophyll	Green pigment, essential for photosynthesis, found in cells of most higher plants. Used as a measure of productivity.
Chlorination	The use of chlorine as a disinfectant of water that is to be used for drinking purposes.
Cladocera	a group of microscopic aquatic animals, often part of the zooplankton. Commonly called "water fleas". *Daphnia* is a typical example
Coliform Bacteria	A group of micro-organisms normally found in the intestines of humans and other warm-blooded animals. Their presence in water may indicate contamination from human or animal wastes, hence various types are used as indicators of sanitary quality for certain water uses. (see **Enterococci, *Escherichia coli*, Fecal Coliform, Microbiological Indicator**)
Copepods	a group of microscopic aquatic animals, often part of the zooplankton. No common name. *Cyclops* is a typical example
dam^3	cubic decametre (1000 m^3)

Designated Water Use	A water use that is to be protected at a specific location. Designated water uses for the purposes of setting water quality criteria and water quality objectives in British Columbia include: drinking, public water supply and food processing; aquatic life and wildlife; agriculture (irrigation, livestock watering); recreation and aesthetics; and industrial water supply.
Detection Limit	The smallest concentration of a substance which can be measured to a specified degree of certainty by a particular analytical method. Instrumental and analytical detection limits also need to be known.
Disinfection	The destruction of microorganisms by the use of a chemical agent (disinfectant) such as chlorine. (cf. **Chlorination**) or through physical means such as ultra-violet irradiation.
Dissolved Metals	Metals in solution, as opposed to total metals. Metals which pass through a filter with a specified pore size are assumed for environmental purposes to be dissolved.
Dissolved Oxygen	Oxygen dissolved in water, essential for respiration by most aquatic organisms.
Ecosystem	A natural community of organisms occupying a given area. An ecosystem is the sum of many physical, chemical and biological characteristics, including all of the interactions between the organisms and their environment.
Effluent	Liquid waste that is discharged into the environment as a by-product of human activity. Often a complex mixture of contaminants which are potential pollutants. Under the B.C. *Waste Management Act*, effluent is defined as "a deleterious material flowing in or out of works".
Elevated Level	Levels which are significantly higher statistically than those which occur naturally.
Epilimnion	The surface layer of a thermally stratified lake
Escherichia coli (*E. coli*)	A type of **coliform bacteria**. An **microbiological indicator** of sanitary quality and a potential pathogen.

Eutrophic	A water body which has elevated nutrient input or cycling, resulting in high levels of **biomass** production. (cf. **Oligotrophic, Productivity**).
Eutrophication	Increasing **nutrient** content within a water body over time. This natural process may be accelerated by nutrient-rich discharges from agriculture or sewage, resulting in **algal** blooms, excessive growth of **macrophytes**, or undesirable changes in water quality.
Fecal Coliform	A type of **coliform bacteria** normally found in the intestines of humans and other warm-blooded animals, and a potential pathogen. Their presence in water may indicate fecal contamination, so they are useful as an **microbiological indicator** of sanitary quality. (see **Coliform Bacteria, Enterococci, *Escherichia coli***)
Freshet	A suddenly increased period of flow in a river as a result of spring snowmelt or heavy rainfall.
Giardiasis	An intestinal disease, also called beaver fever, caused by the parasite *Giardia lamblia*, which may be present in untreated water used for drinking or preparing food. This parasite can survive normal chlorination and can be removed from the water by filtration.
Hypolimnion	The cooler, deeper waters of a thermally stratified lake.
Limnology	The study of fresh water bodies including biological, geological, physical and chemical aspects.
Littoral, Littoral Zone	The shallow shoreward region of a water body. It usually has light penetration to the bottom and is often occupied by rooted **macrophytes**.
Loading	The amount of a substance added to a water body per unit area per unit time.
Macrophyte	The larger aquatic plants, including aquatic mosses, liverworts, larger algae and vascular plants.
Microbiological indicator	Microscopic organisms that when present in water, are indicative of pollutant inputs (generally sanitary pollution).

Micrograms per litre (µg/L)	One unit of a substance per 1,000,000,000 units of water. 1 µg/L = 1 ppb (part per billion).
Milligrams per litre (mg/L)	One unit of a substance per 1,000,000 units of water. 1 mg/L = 1 ppm (part per million).
Monitoring	Continued observation, measurement, and evaluation, with appropriate controls, to examine changes over a period of time. For example, water quality in a water body is monitored to ensure that water quality objectives are not exceeded.
Mysis	A group of small (1 cm.) crustacean animals living in the deep waters of some lakes. Commonly but incorrectly called "shrimp"
Nearshore	The zone extending out from the shore to a distance where the water column is no longer influenced by conditions on or drainage from the land.
Nitrogen (total)	A nutrient that plays a significant role in biological metabolism. Total nitrogen refers to all forms of nitrogen in the water column (both organic and inorganic).
Nitrogen (Kjeldahl)	A measure of both the organic and ammonia portions of nitrogen in the water column.
Non-filterable Residue	see **Suspended Solids**
Non-point Source Pollution	Pollution that comes from diffuse sources, carried into water bodies by various forms of runoff. It includes micro-organisms, pesticides, fertilizers and other deleterious materials from fields, urban and suburban land and forests.
Not Detectable	Below the detection limit of a specified method of analysis.
Nutrient	Organic and inorganic substances necessary for the growth and development of plants and animals. More narrowly, a substance containing phosphorus, nitrogen or potassium, which are essential to plants.
Objective	A guideline against which environmental quality at a particular location can be measured. Often used to guide environmental management decisions and practices to protect users, and the environment. They do not have legal standing.

Oligotrophic	A water body which has limited nutrient input or cycling, resulting in low levels of **biomass** production. (cf. **Eutrophic**).
Periphyton	**Algae** attached to submerged surfaces (plants, rocks, etc.).
Permit	Written authorization (e.g., Waste Permit issued under section 8 of the B.C. *Waste Management Act*) to perform an action which would otherwise be unlawful.
Phosphorus (total)	A nutrient that plays a major role in biological metabolism. It is often the most significant nutrient with respect to primary **productivity** in fresh water systems. Total phosphorus refers to all forms (inorganic and organic).
Phosphorus (total dissolved) or TDP	The soluble component of both inorganic and organic phosphorus.
Phytoplankton	An assemblage of small plants that are suspended in the water column, that have no or very limited powers of locomotion.
Pisciverous	Fish eating animals.
Productivity	The rate of formation of organic matter averaged over a defined period of time.
Primary-contact Recreation	Activities like swimming and water sports where a person has or risks direct contact with water through immersion or ingestion.
Rotifer	a group of microscopic animals, often part of the **zooplankton**
Secondary-contact Recreation	Activities like boating or fishing where a person has limited direct contact with water, and little risk of immersion or ingestion. (cf. **Primary-contact Recreation**)
Stratification	Water layers which form in a water body due to differences in density or temperature within the **water column**. Most pronounced when there is little mixing or turbulence within the water body. Profoundly affects other water quality conditions. (cf. **Halocline, Thermocline**)
Streamflow	The rate at which water passes a given point in a stream, usually expressed in cubic metres per second.

Suspended solids	Particulate matter that is suspended within the water column.
Thermocline	A well-defined vertical temperature change or boundary; often associated with **stratification** in lakes.
Water column	The vertical axis within a body of water (associated with depth).
Zooplankton	Small animals suspended in the water column.