PHASE I
WATERSHED ASSESSMENT
FINAL REPORT

LAKE COCHRANE/LAKE OLIVER
DEUEL COUNTY, SOUTH DAKOTA

South Dakota Watershed Protection Program
Division of Financial and Technical Assistance
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October, 2000

EXECUTIVE SUMMARY

Lake Cochrane and Lake Oliver are located within the same sub-basin of the Coteau de Prairie in eastern South Dakota. Lake Cochrane is has a surface area of 366 acres and a 800 acre watershed. Lake Oliver has a surface area of 180 acres and a watershed of 540 acres. Lake Oliver is actually within the Lake Cochrane basin, in essence increasing the Lake Cochrane watershed to 1,340 acres of land. Lake Oliver had spilled into Lake Cochrane for approximately 6 years before the start of this assessment. Prior to a recent wet cycle, it was approximately 20 years since Lake Oliver reached elevations that ran into Lake Cochrane. Lake Cochrane was listed on the 1998 303(d) list due to public beach closures which indicates fecal coliform standard violations. Lake Oliver was placed on the 1998 303(d) list for a high Trophic State Index due to excessive nutrients.

The majority of the water load for both lakes was from precipitation (Cochrane 66% and Oliver 62%). Thirteen percent of the water input to Lake Cochrane and 21% to Lake Oliver was estimated to come from outwash alluvium or adjacent gravel springs located near the shoreline. The vast majority of the lakes' output was to evaporation (Cochrane 82% and Oliver 75%).

The major tributary nutrient and sediment input to Lake Cochrane were from sites LCT-3 and LOO. The AGNPS run-off model targeted a majority of critical cells in the watershed above LCT-3. Both AGNPS and water quality monitoring found site LCT-2 to have the highest loading per acre. Sediment basins were installed at the major inlets to Lake Cochrane in 1975. Two of the basins lost approximately 1/3 of their capacity due to sedimentation. The sediment loading at Site LOO (outlet of Lake Oliver) was due to carp stirring up sediments at the inlet to Lake Cochrane. Even though sub-watersheds were compared against each other for targeting purposes, the loading to Lake Cochrane appears to be quite small compared to that of other lakes in the region.

The major tributary nutrient and sediment inputs into Lake Oliver were from site LOT-4 and LOT-2. Site LOT-4 was significant because it received run-off from 81% of the watershed. The watershed of site LOT-2 was approximately 11% of the total watershed area. LOT-2 was located downstream of a wetland and adjacent to a gravel road. Ammonia loads from decaying vegetation in the wetland and suspended solids from the gravel road were most likely responsible for the significance of LOT-2 contributions to Lake Oliver. LOT-2 also had the highest nutrient and sediment loads per acre of all the sites in the Lake Oliver watershed. Due to the large percentage of grass in the watershed, AGNPS did not find even one critical cell upstream of the sampling sites to Lake Oliver. The overall loading to Lake Oliver was far less than the loading to Lake Cochrane. Internal loading in Lake Oliver is largely responsible for its eutrophic condition.

Lake Cochrane is a deeper (26.5 feet maximum depth) macrophyte dominated lake and Lake Oliver is a shallower (12.5 feet maximum depth) algae dominated lake. Most of the nutrient parameters of concern were higher in Lake Oliver than Lake Cochrane. Secchi depth, total phosphorus, total dissolved phosphorus, and chlorophyll *a* concentrations were approximately twice as high in Lake Oliver as Lake Cochrane.

There were no significant changes in water quality trends in either lake. The more eutrophic waters of Lake Oliver have not resulted in higher TSI ratings in Lake Cochrane. However, Lake Cochrane received more nutrients and sediment than it released through the outlet. Whenever Lake Oliver discharged into Lake Cochrane, it was noted that carp stirred up sediments at the outlet structure. It was determined that the carp were responsible for elevated sediment and nutrient loads entering Lake Cochrane.

With reference to the 303(d) listing, fecal standards violations were not found in Lake Cochrane during the assessment. All but two water quality samples collected contained fecal coliform concentrations less than the detection limit. Water quality targets established for Lake Cochrane are to maintain a phosphorus TSI level around 50. Reaching this target should keep the overall lake within Carlson's mesotrophic category. The target could be attained by:

1) targeting critical cells for best management practices;
2) removing the influence of carp from the outlet of Lake Oliver;
3) cleaning out the sediment basins upstream of sites LCT-1, LCT-2 and LCT-3;
4) making improvements to basin structures, if needed;
5) dredging the west bay if assessment of the sediment finds the activity feasible; and
6) installing a trickle alum system on the sediment retention dams.

Again, with reference to the 303(d) listing, the mean and median TSI levels in Lake Oliver were 67.03 and 66.63, respectively. These TSI levels were slightly within the hyper-eutrophic range (< 65.0). The water quality goal for Lake Oliver is to reduce the inlake phosphorus concentration by 50%. A 50% inlake phosphorus reduction should bring chlorophyll TSI values below 60. This target should be met by switching the lake from algal dominance to macrophyte dominance. Steps needed to make this change should include:

1) installing an electronic fish barrier between Lake Cochrane and Lake Oliver;
2) removing a minimum of 2/3 of the rough fish population(whole lake treatment with rotenone would be most effective);
3) dredging the marginal depths (5-7 feet) two or three feet deeper to better sustain the alum treatment and create fish habitat (optional);
4) Alum treating all of Lake Oliver that has a water depth of 5 feet or greater;
5) encouraging macrophyte growth;
6) stocking fish in proper numbers to maintain the macrophyte dominant community; and
7) periodically assessing the community to ensure macrophyte dominance.

ACKNOWLEDGEMENTS

The cooperation of the following organizations and individuals was gratefully appreciated. The assessment of Lake Cochrane/Lake Oliver could not have been completed without their assistance.

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Deuel County
State Climatologist Al Bender

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INTRODUCTION

Lake Cochrane and Lake Oliver are located in southeast Deuel County in northeastern South Dakota, near the Minnesota boundary (Figure 1). The lakes are directly adjacent and are connected by an established high water mark at 1683.6 feet above mean sea level (msl). Despite recent high water, outflows rarely occur, causing the lakes to function as sinks for sediments and nutrients that enter from the watershed or shoreline areas. Due to a series of unusually wet years, Lakes Cochrane and Oliver have experienced problems due to flooding. The flooding has caused local resident concern about the future water quality of Lake Cochrane.

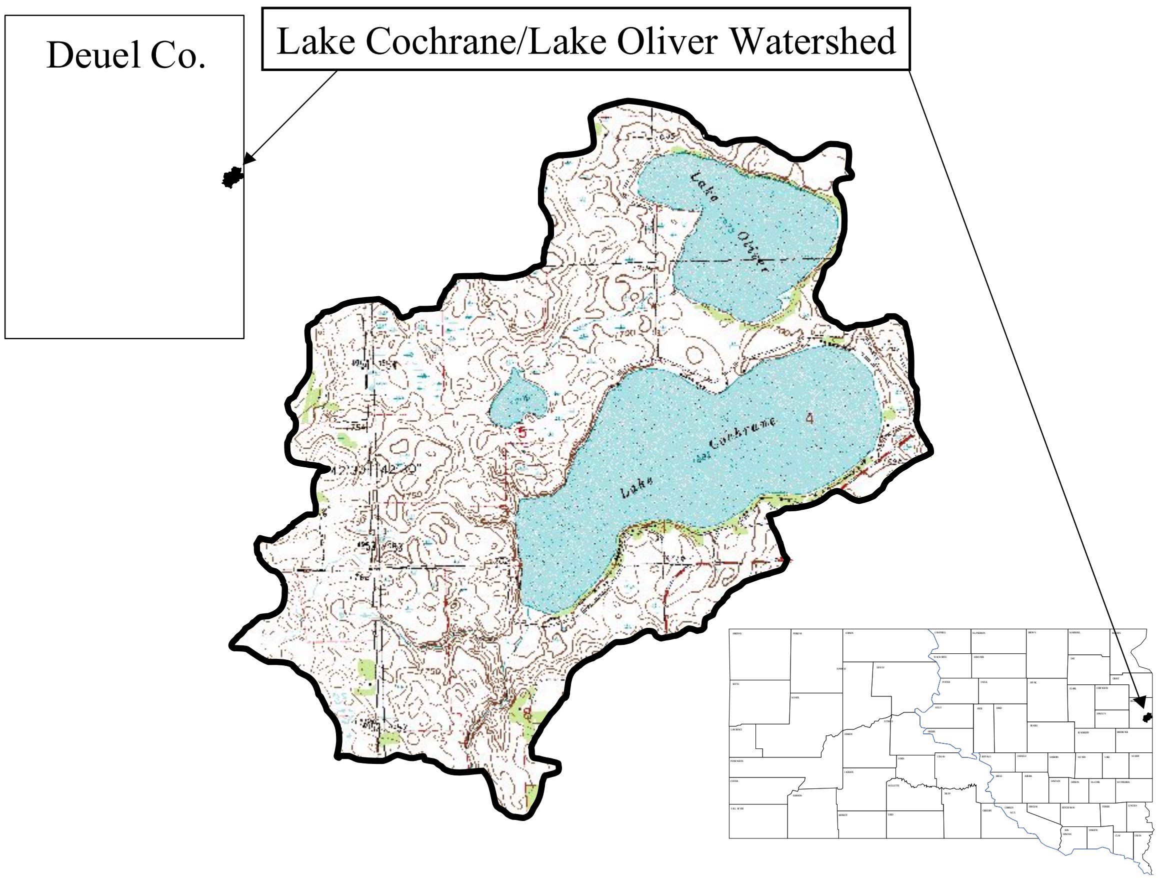


Figure 1. Location of Lake Cochrane/Lake Oliver Watershed.

Lake Cochrane is included in South Dakota's Lake Protection Strategy, a special Non-Point Source (NPS) program to preserve high quality lakes. With recent high water levels, concerns of how Lake Oliver may be affecting the water quality of Lake Cochrane were raised. Funding from federal (319) and local sources was received to assess both lakes and the encompassing watershed. Due to the small size of the watershed and its' intermittent tributaries, a one-year water quality assessment was initiated. This assessment began in March of 1999, and proceeded until March of 2000. The purpose of this Phase I assessment study was to document sources of nutrient and/or sediment pollution for the watershed and develop restoration alternatives to improve the water quality in both lakes. Lake Cochrane was listed on the 1998 South Dakota 303(d) Waterbody List as impaired by high fecal coliform concentrations. Lake Oliver was placed on the 1998 303(d) list for excessive Trophic State Index (TSI) values, a measure of eutrophy (SD DENR, 1998). The main components of the assessment consisted of inlake water quality monitoring, biological monitoring, tributary monitoring, and landuse assessment.

LAKE COCHRANE

Lake Cochrane is a natural lake of glacial origin with a surface area of 366 acres (148.1 ha), an average water depth of 11 ft. (3.4 m), and a maximum depth of 26.5 ft. (8.2 m). The lake is moderately eutrophic and is of better than average water quality compared to other lakes in the area. The lake has a small direct drainage of approximately 800 acres with a similarly sized, indirect drainage. Inflows occur from three main intermittent tributaries on the western side of the lake. Although there are no identified springs around the lake, shoreline residents used private wells prior to connecting with the rural water system. Reportedly, there are flowing wells on the north side of the lake.

The Lake Cochrane shoreline is highly developed, with several residences surrounding the lake. A small percentage of these residences have year-round occupancy. A centralized waste collection and treatment system was installed during the years 1987-1989. All shoreline residences are connected to the system. Prior to this system, residences used septic tanks and drainfields.

Lake Cochrane has excellent public access with a state recreational area on the north side of the lake and a public boat ramp on the west side. Limited access is also allowed from the Shady Beach Resort on the east side of the lake. Lake Cochrane experiences heavy use as it provides opportunities for camping, boating, swimming, fishing, sailing and diving.

In 1972, an outlet structure was installed at the east end of the lake to maintain the lake level. A standpipe structure, located off-shore, tunneled outflow by culvert to an open channel which then directed flow to Culver Lake across the Minnesota state boundary. During ice-off in the spring of 1995, ice destroyed the standpipe, which caused flood conditions to escalate and damage shoreline property on the northeast side of the lake. Natural processes were repairing the damaged shoreline. Installation of emergency culverts controlled outflow until a permanent outlet structure was installed in 1996 replacing the standpipe. The new outlet is a permanent concrete structure with an established normal high water mark of 1683.6 msl. Outflow is diverted by culvert to a downstream channel, which passes through a series of wetlands before ultimately entering Culver Lake.

In 1975, EPA provided a Clean Lakes grant to the East Dakota Conservancy Sub-District for installation of three sediment traps, in conjunction with the lake perimeter road system (complete report in Appendix A). The sediment traps were designed to pond inflow from the three main tributaries during run-off periods. It was thought these ponds would serve as retention basins for nutrients and sediment and would thereby improve the quality of the run-off into the lake. Following installation of these sediment traps, biologists from South Dakota State University (SDSU) evaluated their efficiency. Haertel (1980) suggested that the sediment traps, when functioning properly, reduced the nutrient and sediment input to the lake. Presently, only one sediment trap (LCT-1) appears to be functioning properly. One sediment trap (LCT-2) has a seepage problem and the other (LCT-3) has been altered.

Water Quality History

Lake Cochrane has been studied extensively by professionals from SDSU. The first documentation of an "algae bloom" was in 1971, which indicated that Lake Cochrane was revealing signs of eutrophication. Haertel (1976) documented a decline in water quality from 1970 to 1972 which she attributed to the careless construction of lakeshore homes. The lake has a high density of aquatic vegetation and receives a large biomass of leaves from shoreline trees. Under the right conditions, decomposition of this organic matter has been associated with the reduction of dissolved oxygen (anoxia) in portions of the lake. In addition to the breakdown of organic material, the lake experiences re-occurring algae blooms. Humic matter from the watershed, aquatic plants and diatom blooms may be associated with the water's periodic color of weak tea and loss of water clarity in the lake.

Lake Cochrane has little outflow and acts as a sediment and nutrient trap, making it susceptible to eutrophication. Lake Cochrane's water quality tends to be poorer during periods of high run-off as opposed to dryer periods of low run-off (Haertel, 1980). Minor fish kills are commonly reported by lake residents. Following ice-off in April of 1999, the local coordinator witnessed several dead fish (variable size and species) along the southwest shoreline. Dave German, from the Water Resource Institute (SDSU), investigated a summer fishkill in August, 1984 (unpublished, investigative report). Several possibilities for these conditions were researched, though no definite conclusions were reached as to the reason for the fish kills.

<u>LAKE OLIVER</u>

Lake Oliver is a natural glacial lake with a surface area of 180 acres (72.8 ha), a maximum water depth of 12.5 ft. (3.8 m) and a mean depth of 8.7 ft. (2.7 m). The lake has a direct drainage of approximately 540 acres. Inflow occurs from four intermittent tributaries on the west side of the lake. Outflow is regulated by an outlet structure that is a direct discharge to Lake Cochrane. Lake Oliver is, for the most part, undeveloped; however, there is a public boat ramp and approximately 100 acres of state land border the lakeshore. The lake is hyper-eutrophic and often experiences a heavy algae bloom during the summer months. Lake Oliver provides an opportunity for anglers, though it frequently experiences winterkill.

Controversy over the outflow of Lake Oliver to Lake Cochrane has existed between state entities and Lake Cochrane residents for several years. During a period of low water levels prior to 1993, Lake Oliver functioned as a sink for nutrients (phosphorus) that entered from the watershed. With infrequent flushing of these nutrients levels, Lake Oliver had a reputation of poor water quality due to frequent and intense algae blooms. Since development altered the original outlet, a tile was installed to regulate the water level in Lake Oliver, creating a direct link to Lake Cochrane. In 1993, above normal precipitation (a wet cycle) began to raise the water level in Lake Oliver. The tile failed to control the floodwaters and resulted in a diversion of water by culvert to wetlands created by the road system. In early spring of 1995, the wetlands and Lake Oliver began to threaten the integrity of the road, the State Recreation Area and Lake Cochrane residences. A twelve-inch polyurethane pipe was used to drain the excess water from the wetlands into Lake Cochrane. Lake Cochrane residents were skeptical of the water quality being discharged through the wetlands, since the water had been stagnant throughout the summer.

Despite spurious claims that Lake Oliver should be diverted around Lake Cochrane in the event of flooding, the state determined that the historic natural outflow of Lake Oliver was to Lake Cochrane. In 1998, a flood control structure and weir was installed to regulate Lake Oliver flow to Lake Cochrane. The outlet was designed to bypass the wetlands that diverted water straight from Lake Oliver to Lake Cochrane. The structure is open October 16^{th} through June 14^{th} of each year to allow Lake Oliver to maintain the established outlet elevation of 1,683.6 msl. During closure, Lake Oliver is allowed to store up to an elevation of 1685.0 msl. Whenever an elevation of 1685.0 msl occurs, water spills uncontrolled over the weir. If a precipitation event causes flow over the weir (1685.3 msl), the control structure is re-opened until Lake Oliver attains an elevation of 1684.3 msl. The South Dakota Department of Game, Fish and Parks (GF&P) regulates the outlet structure. The main purpose of this control structure is to restrict Lake Oliver water from entering Lake Cochrane during months when algal blooms are most likely to occur.

Elevated water levels in Lake Oliver should eventually subside so exchange between Lake Oliver and Lake Cochrane will not occur. Due to the flushing effect in both lakes over a period of half a decade, the data in this report should serve as an indication of how Lake Oliver's water quality affected Lake Cochrane's water quality. Restoration efforts will focus on future high water occurrences and improving inlake conditions.

THE WATERSHED

The total watershed encompasses approximately 2000 acres and is located in the upper Minnesota River Basin (Figure 1). Topography involves fairly steep hillsides and flat bottom areas, part of which are marshy. The watershed is about 70% grassland/pasture, 20% cropland and 10% shoreline development. The major soil association found in the watershed is Forman-Aastad-Parnell. No major point sources of pollution were identified in the watershed. Two small feedlots are positioned at the western edge of the watershed. One has the potential to drain into Lake Cochrane, while the other drains to Lake Oliver. Many changes have occurred in the watershed over the past several years. Once predominately cropland, highly erodible slopes, especially near Lake Oliver, have been taken out of production. Many landowners have also contracted land in the watershed to Conservation Reserve Program (CRP). Modern conservation practices are popular in the watershed.

THREATENED AND ENDANGERED SPECIES

No federally designated threatened or endangered species exist in the Lake Cochrane/Lake Oliver watershed. Table 1 below shows the state threatened and endangered species listed for Lake Cochrane. No state study has been conducted on Lake Oliver. Since the lakes are hydrologically connected, listed species for Lake Cochrane would be expected for Lake Oliver as well.

Table 1. Rare, Threatened and Endangered Species.

Rare, Threatened or Endangered Species Documented
In Lake Cochrane, Deuel County, SD
SOUTH DAKOTA NATURAL HERITAGE DATABASE
As of June 7, 2000

Name	Township Range & Section	TRS Note	Last Observed	Federal Status	State Status	State Rank	Global Rank	General Notes
Central Mud Minnow *Umbra limi*	114N 047W 04	SEC. 5,8.	1978		SE	S1	G5	one individual
Banded Killi Fish *Fundulus diaphanus*	114N 047W 04	S05 S08	1991-08-00		SE	S1	G5	2 fish caught in trawl net in '83;one on S side of lake 300 yds W of resort at E end of lake; one on N side of lake 400 yd W of same resort. In 1991 seine haul CPUE of.38 in May, 2. 25 in June, 4.63 in July, and 1.5 in August
Log Perch *Percina caprodes*	114N 047W 04		1952-08-18			S3	G5	Specimens examined by Allum

SE = State Endangered
S1 = Critically imperiled because of extremely rarity (5 or fewer occurrences or very few remaining individuals) because of some factors making especially vulnerable to extinction.
S3 = Very rare and local throughout its range, or found locally (even abundantly at some of its locations) in a restricted range, or vulnerable to extinction throughout its range because of other factors; in the range of 21 to 100 occurrences.
G5 = Demonstrably secure, though it may be quite rare in parts of its range, especially at the periphery.

FISHERIES DATA

The following discussion summarizes the South Dakota Statewide Fisheries Survey for Lake Cochrane. South Dakota GF&P conducted the survey on June 23 - 25, 1998, and used standard gillnet sets to sample fish populations. The entire fisheries survey for Lake Cochrane is included in Appendix B. Fisheries data was not available for Lake Oliver.

Species detected in past and present surveys:

1. Walleye (WAE)
2. Largemouth Bass (LMB)
3. Bluegill (BLG)
4. Black Crappie (BLC)
5. Yellow Perch (YEP)
6. White Sucker (WHS)
7. Hybrid Sunfish (BGH)
8. Black Bullhead (BLB)
9. Common Carp (COC)
10. Green Sunfish (GSF)

Black Crappie, Bluegill, Green Sunfish and Bluegill X Green Sunfish (hybrid)

Beginning in 1994, officials from SDSU engaged in mechanical removal of overabundant panfish (including yellow perch) in Lake Cochrane (Table 2). The removal of yellow perch (<203 mm) and sunfish (<152 mm) continued until August, 1999. The removal was part of a study by SDSU to evaluate the effects of mechanical removal, in conjunction with high predator populations, on size structure of overly abundant panfish populations. Black crappies, not part of the study, were released regardless of size.

Table 2. Panfish (in kg) Removed from Lake Cochrane by SDSU, 1994-1998.

Species	1994	1995	1996	1997	1998	**Total**
YEP	504.6	1,969.2	702.3	118.3	242.7	3537.1
BLG	357.2	225.9	135.8	446.3	389.9	1555.1
BXG	667.2	855.1	403.4	424.7	765.5	3115.9
Total	**1,529**	**3,050.2**	**1,241.5**	**989.3**	**1398.1**	**8,208.1**

GF&P personnel used gillnets to survey Lake Cochrane in 1998. Though gillnets target a wide range of fish species, they are not the most optimal gear for species such as panfish. Frame nets used by SDSU, were ideal for recruiting panfish. Despite using gillnets, hybrid sunfish and black crappie comprised 3.2% of all fish sampled. The 23-fish sample had stock-to-quality length individuals that ranged in length from 17 to 23 cm. The relative weight values indicated good conditions for all sampled length groups.

Yellow Perch

Improvements in size structure were not apparent in gillnet samples, despite long-term removal efforts of yellow perch (<203 mm) by SDSU. Even though yellow perch >203 mm were released, gillnet catches of preferred length fish (200-250 mm) were low. The dominant size class of sampled yellow perch was at or near stock length (130-150mm).

The relative weight values suggest a decline in yellow perch as they surpass quality length (≥200 mm). This decline in condition can perhaps be attributed to the lack of appropriate forage for this size class, further explaining the absence of larger yellow perch in Lake Cochrane. The yellow perch population is moderate to moderate high density, though abundance has slightly declined from the surveys in 1994 and 1996.

Currently, yellow perch are not in a position to provide a satisfactory fishery. Perhaps information gained from the SDSU removal project will provide information that will aid in restructuring the yellow perch population.

Walleye

The walleye population had a moderate to moderate-high abundance. Larger fish dominated the population. Most of the walleye sampled were over the minimum length limit of 356 mm. Walleye growth was average, with fish reaching the minimum length limit during the fourth growing season. The larger walleye appear to be able to utilize the local forage base better than the smaller walleyes. The overabundance of panfish were likely competing with the smaller walleye for the same forage base.

Size structure and relative abundance suggest that angler harvest rates are low. Dense aquatic vegetation and nuisance panfish probably protect walleye from being caught. Natural reproduction is thought to be poor, though successful stocking has generated an exploitable population.

Northern Pike

Northern pike ranged in length from 45 to 87 cm. Although the number of fish are low, the condition and growth of the fish seemed adequate. According to stocking records, 24 juvenile northern pike were last stocked in Lake Cochrane in 1986. The ability of northern pike to reproduce in good numbers in every year class may be negatively affected by the high abundance of panfish. Given the high density of forage available, as well as submergent vegetation, catchability of northern pike by anglers may be low.

Black Bullhead

Black bullhead abundance has slightly increased since 1992 though abundance is still relatively low. The slight increase in abundance is attributed to the removal of panfish. Inter-specific competition with overly abundant panfish is likely effecting the abundance of black bullhead in Lake Cochrane.

Largemouth Bass

Because gillnets are generally ineffective sampling gear for largemouth bass, no samples were collected during the survey. Electrofishing techniques were used by SDSU to obtain data during the removal study. Speculation was that largemouth bass provide a satisfactory fishery in Lake Cochrane. Bass are more exploitable to anglers because angling techniques for bass often accommodate dense submergent vegetation. There is currently a minimum length limit of 38.1 cm for largemouth bass. Stocking efforts, totaling 65,500 fingerlings over three years, have likely helped maintain the population. It is highly probable that management of largemouth bass will be based on results from the panfish removal study.

Management Recommendations from the GF&P Study:

Black Crappie, Bluegill, Green Sunfish and Bluegill X Green Sunfish (hybrid)

1. After the SDSU removal project is completed (year 2000), incorporate frame nets into biennial surveys to monitor changes in population size structure, species composition and abundance.
2. Utilize SDSU data from removal project to establish panfish management plan.

Yellow Perch

1. Continue biennial surveys to monitor changes in population size structure and abundance.
2. Collect scale samples during next survey to gather age and growth information.
3. Utilize information gained from SDSU removal study to formulate panfish management plan.

Walleye

1. Continue surveys on biennial schedule to monitor population parameters.
2. Proceed with annual stocks of large fall walleye fingerlings (25/lb.) at 1.0 lb./ac.
3. Utilize conclusions of SDSU panfish removal study to modify stocking strategy if data warrants change.

Northern Pike, Black Bullhead, Largemouth Bass

1. Continue biennial surveys to monitor changes in population size structure and abundance.
2. Utilize SDSU data from removal project to monitor population trends in trap nets since 1994.

BIOLOGICAL MONITORING

Lake Cochrane Phytoplankton

Planktonic algae, collected monthly from April to November 1999 at three inlake sites in Lake Cochrane (Figure 2), consisted of 73 taxa (Appendix C – Table C-1a). Diatoms (*Bacillariophyceae*) were the most diverse group with 37 taxa (51%) distantly followed by green algae (*Chlorophyta*) with 14 taxa (including one motile species, *Chlamydomonas*), and blue-green algae (*Cyanophyta*) represented by 10 taxa. The remaining 11 identified taxa were evenly distributed among three phyla of motile (flagellated) algae: dinoflagellates (*Pyrrhophyta*), cryptomonads (*Cryptophyta*), and yellow-brown algae (*Chrysophyta*). Another commonly occurring group, the euglenoids (*Euglenophyta*) was not collected during this survey.

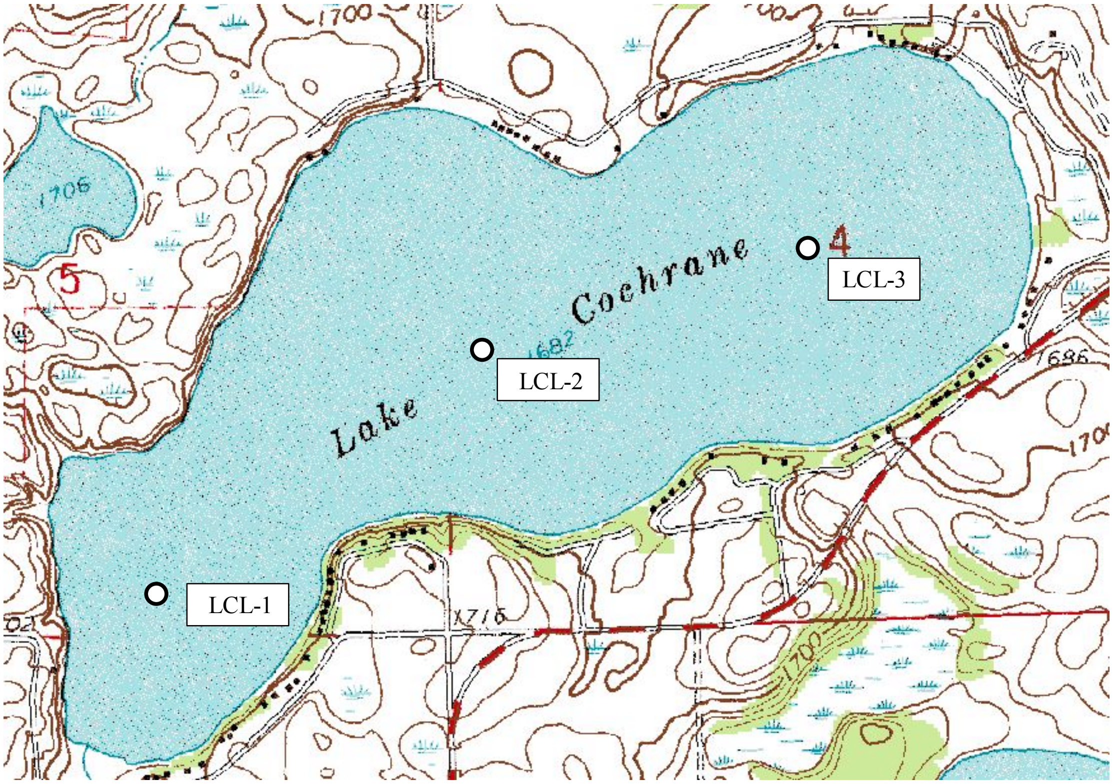


Figure 2. Location of Lake Cochrane Inlake Sites.

Blue-green algae numerically dominated the lake plankton for nearly all of the study period, except for May when both centric and pennate diatoms (*Cyclotella* sp. and *Synedra* sp.) increased to their spring and annual maximum (Figure 3). Because the abundant blue-greens consisted mostly of small species, mainly *Anacystis marina* (= *Aphanothece nidulans*), dominance in terms of biovolume was observed only from August to October 1999 (Figure 4).

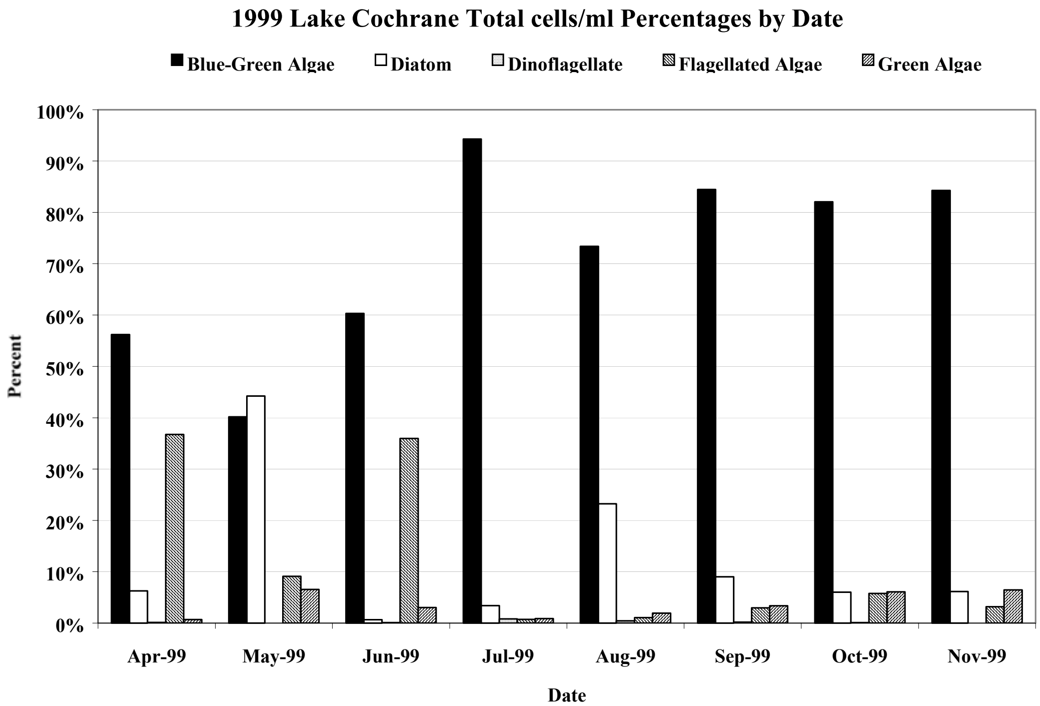


Figure 3. 1999 Lake Cochrane Total Cells/mL Percentages by Date.

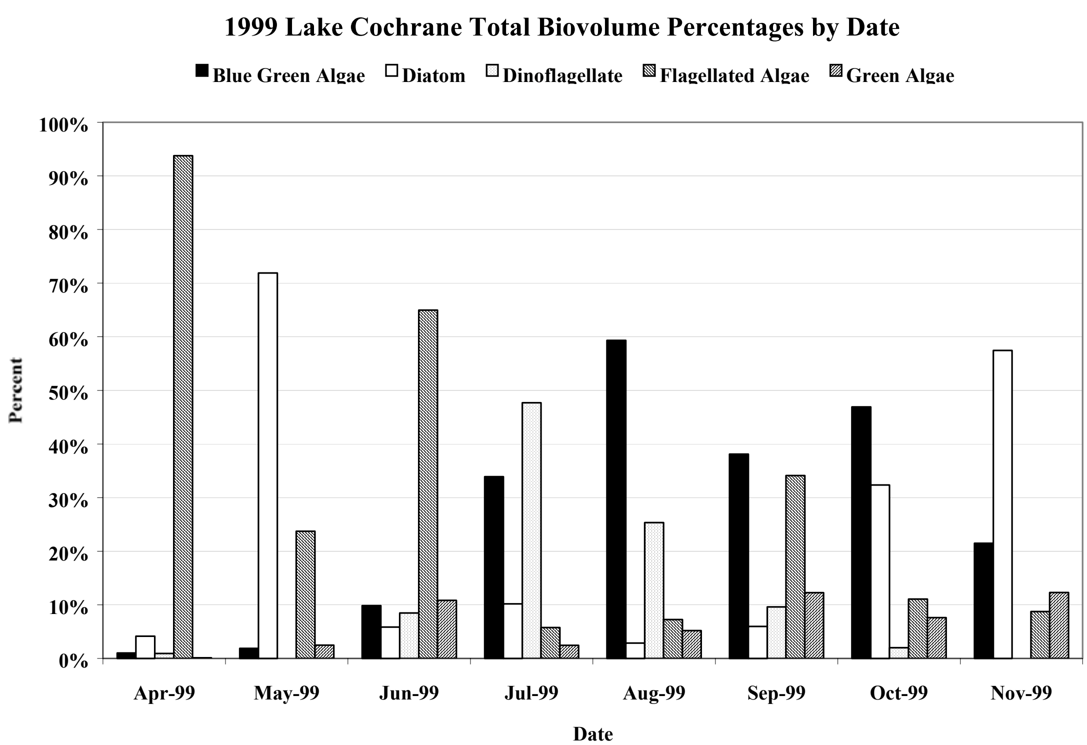


Figure 4. 1999 Lake Cochrane Total Biovolume Percentages by Date.

In April and June, flagellated algae, primarily *Dinobryon* and *Ochromonas* sp., exceeded blue-greens in volume. In July, dinoflagellates, mainly *Gymnodinium* sp.(probably *Peridinium willei*) at site LCL-1, comprised a greater average biovolume than blue-greens. Lastly, during November, a fall pulse of primarily centric diatoms, *Cyclotella* spp., comprised 55% of total algal biovolume (Figure 4).

Total phytoplankton mean densities and biovolumes ranged from 11,569 cells/mL and 0.646 µl/L (= 646,000 μm^3/mL x 10^{-6}) in November and June, to 34,131cells/mL and 10.80 µl/L in August and April, respectively. The latter disparity between maximum algal density and volume was due to high numbers of larger-sized flagellates and larger species of blue-greens present in April. Differences in algal densities between monitoring sites did not display a consistent pattern during this survey. The site with the largest or smallest algae density varied month by month (Appendix C - Table 2).

The initial samples for this survey were collected in the spring on April 20, 1999, approximately one month after the breakup of ice cover. Sample analysis for the three lake sites indicated a mean algae population of 21,475 cells/mL. Individual site densities ranged from 14,758 cells/mL at site LCL-2 to 30,805 cells/mL at site LCL-3. During this 8-month assessment, the maximum cell density for monthly 3-site averages was three times the minimum density (Appendix C - Table 2). Most of the plankton density and biovolume in April was provided by a bloom of the yellow-brown colonial flagellate, *Dinobryon sertularia,* at a mean density of 12,529 cells/mL. Centric and pennate diatoms at 1,931 cells/mL, comprised only 6% of the total plankton. This is a rather low density for late April considering this is when many other state lakes experience their spring diatom bloom. Possibly the slower warming of the waters of Lake Cochrane, due to its greater average depth, may have been a causative factor that delayed the spring diatom maximum. The main diatom species involved, *Cyclotella michiganiana,* does not usually become abundant ('bloom') until spring water temperatures reach approximately 14 or 15 ^{o}C, which did not occur until May in Lake Cochrane (University of Michigan, 2000). Blue-green algae, primarily *Anacystis, Aphanizomenon,* and *Oscillatoria,* were more prominent in the April plankton than expected this early in the season (Appendix C - Table 2).

The next series of samples, taken on May 18, disclosed the presence of a belated spring diatom bloom composed mainly of *Cyclotella michiganiana* and *Synedra radians* at a mean density of 9,190 cells/mL of which *C. michiganiana* comprised 5,895 cells/mL. However, total algae densities declined by nearly 19% in May to 17,471 cells/mL due primarily to the collapse of the April *Dinobryon* bloom. *Dinobryon* numbers fell sharply to a mean density of 663 cells/mL. Blue-green algae also declined to less than half the density recorded in April.

By mid-June, lake algae populations had undergone a moderate increase to 25,109 cells/mL owing to larger numbers of blue-greens, primarily *Anacystis marina* (14,439 cells/mL) and a sizeable increase in numbers of a unidentified flagellate species (8,867 cells/mL), possibly *Ochromonas* sp. (Appendix C - Table 2). These two taxa comprised nearly 89% of the June algae. Diatoms decreased sharply to 166 cells/mL over the same period. Increases in blue-green algae and a decline in diatoms by late spring are typical for these algal groups (Hutchinson, 1967).

Highest annual algae densities in Lake Cochrane were recorded in summer from July through September with a poorly-defined population peak on August 23, 1999 (Figure 5). The summer algae community was composed almost entirely of coccoid colonial blue-green algae (Figure 6).

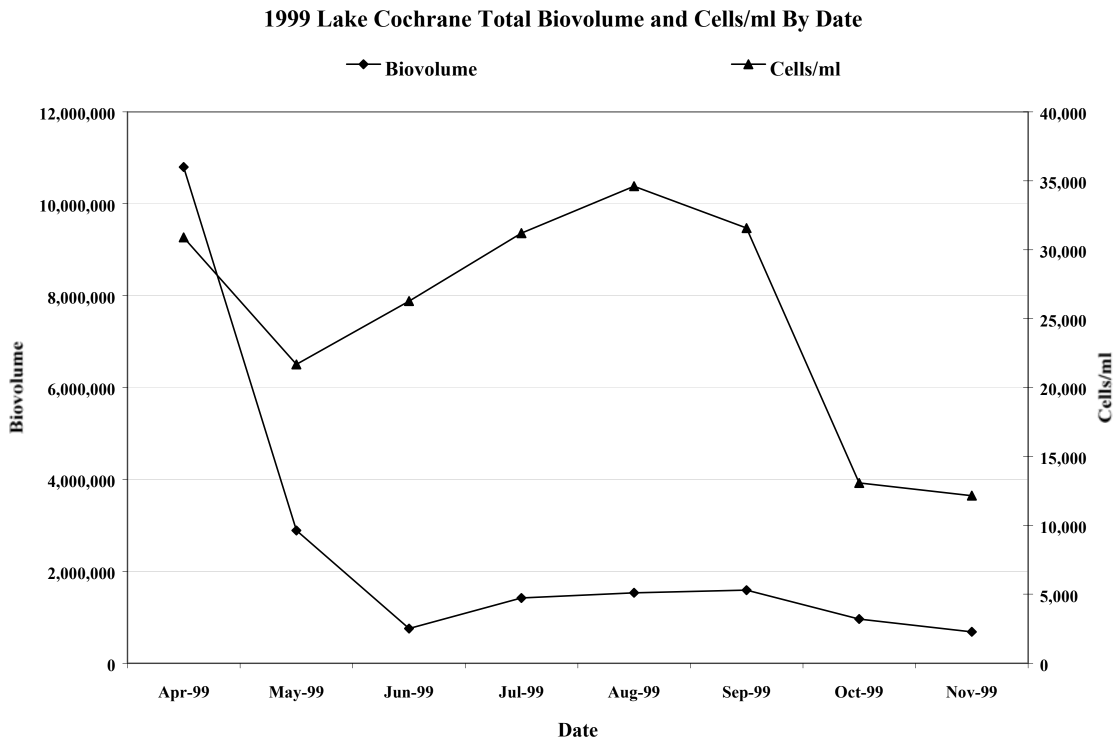


Figure 5. 1999 Lake Cochrane Total Biovolume and Cells/mL Percentages by Date.

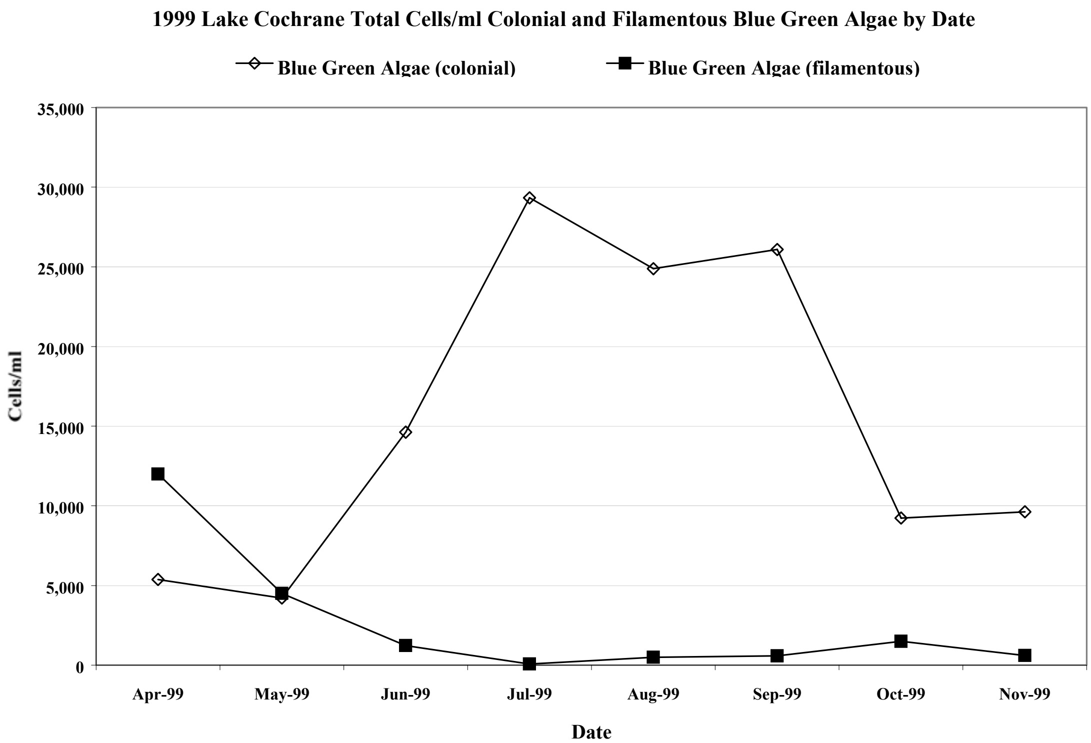


Figure 6. 1999 Lake Cochrane Total Cell/mL Colonial and Filamentous Blue-Green Algae by Date.

Anacystis marina, in combination with several less abundant blue-green species, notably *Gomphosphaeria lacustris* and *Microcystis aeruginosa,* comprised between 92% to 97% of the total phytoplankton. *Anacystis* mean densities remained fairly uniform from month to month and ranged from 15,327 cells/mL in August to 24,209 cells/mL in July. September *Anacystis* densities had increased slightly over August levels to 17,734 cells/mL. In addition, *Dinobryon* became a major species collected in September. Although present at a mean density of only 608 cells/mL, this large-sized colonial flagellate comprised a large percentage of the algal biovolume for the month. Summer diatom populations remained small, averaging less than 200 cells/mL (Appendix C - Table 2).

Decreasing seasonal water temperatures and light intensity during autumn probably resulted in a significant decline in the Lake Cochrane algae population in late October and November 1999. Total algae declined from approximately 31,000 cells/mL in September to a mean of 11,600 cells/mL in October and November. This decrease was due to a decline in blue-greens, particularly *Anacystis,* which represented the dominant species in the summer algae population. Blue-greens are usually abundant only during the warm months of the year (Smith, 1950). However, numerically this group still comprised 82% and 84% of total algae in October and November, despite moderate increases in the numbers of diatoms and green algae which maintained their summer levels of abundance and only a slight decline in densities of flagellated algae. The modest increase in autumn diatoms amounted to a mean of 766 cells/mL for both months and was composed mainly of *Cyclotella* spp. accompanied by several less common pennate and centric diatom taxa.

Lake Oliver Phytoplankton

Planktonic algae, identified from two monitoring sites in Lake Oliver (Figure 7) and sampled monthly from April to November 1999, consisted of 49 taxa (Appendix C - Table 1b). Diatoms (Bacillariophyceae) were the most diverse group with 20 taxa (41%) followed distantly by green and blue-green algae with 9 taxa each. The remaining 10 identified taxa were distributed among three phyla of motile algae: yellow-brown algae (Chrysophyta), dinoflagellates (Pyrrhophyta), and cryptomonads (Cryptophyta), listed in order of importance. Euglenoids (e.g., *Euglena*) were not collected from Lake Oliver during this assessment.

Similar to Lake Cochrane, blue-green algae were also numerically dominant in Lake Oliver for most (75%) of the study period. However, blue-green algae in Oliver were predominant over a longer time span (from June through October) in terms of biovolume due to the abundance of larger-sized taxa (Figures 8 and 9). In April, the pennate diatom species *Nitzschia paleacea* predominated both in density and biovolume while in November, the cryptomonad flagellates, *Rhodomonas minuta* and *Cryptomonas erosa*, represented the most abundant taxa in a relatively small late autumn plankton population.

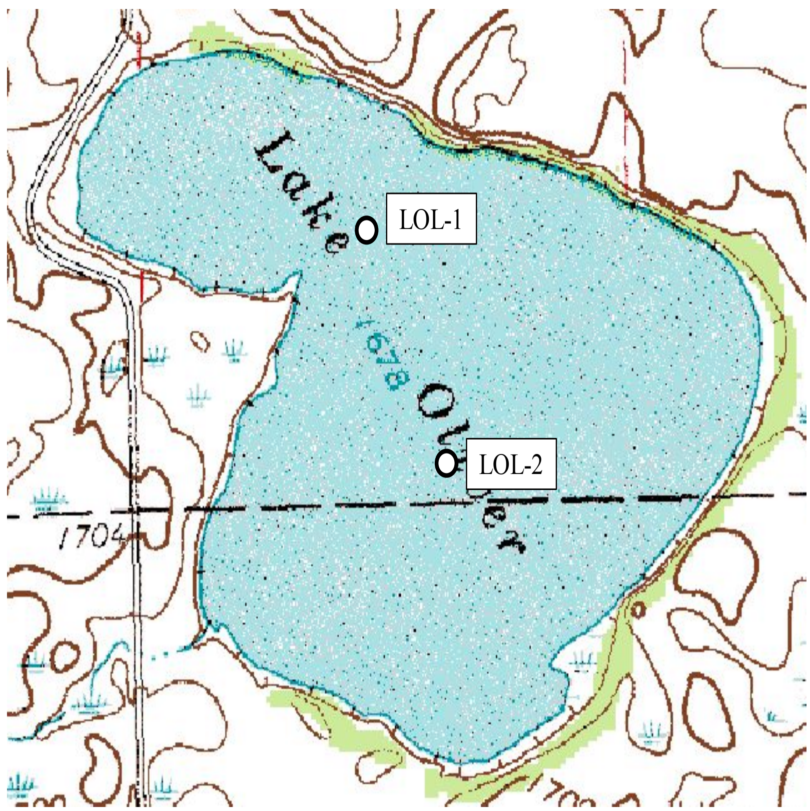


Figure 7. Location of Lake Oliver Inlake Sampling Sites.

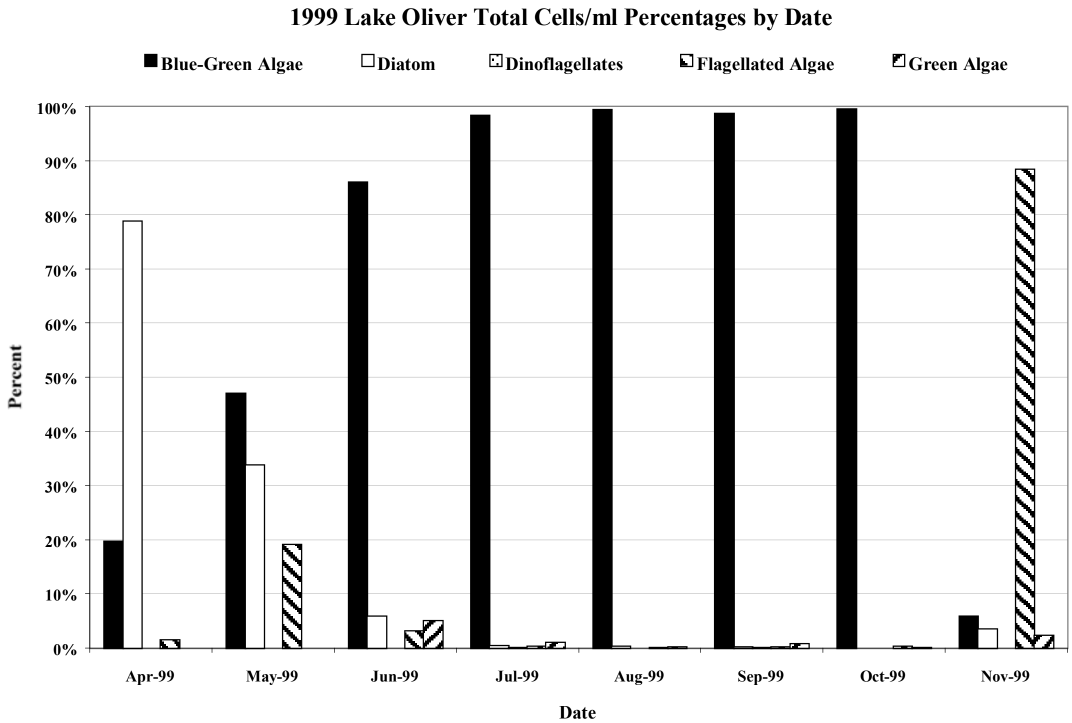


Figure 8. 1999 Lake Oliver Total Cell/mL Percentages by Date.

Total phytoplankton monthly densities and biovolumes ranged from 9,655 cells/mL and 1.561 ul/L in November to 362,751 cells/mL and 42.420 ul/L in October (Appendix C Table 3). Algal densities were roughly similar at both stations on most sampling dates, with those at site LOL-1 being somewhat higher than at LOL-2 (Appendix C Table 3). Species compositions were generally similar between the two sites, except that in May, the chrysophyte flagellate *Chrysochromulina* was more abundant at site LOL-2 than at site LOL-1. Algal biovolumes were highly similar between locations as indicated by a trophic state index developed by Sweet (1986).

The initial samples for the Lake Oliver algal survey were collected on April 20, 1999, at the same time as Lake Cochrane. Sample analysis for the two sites indicated a mean algae density of 92,986 cells/mL. Individual site algal densities amounted to 107,698 cells/mL for site LOL-1 and 78,273 cells/mL for site LOL-2. Slightly more than 73% of the plankton numbers and nearly 75% of the biovolume in April was contributed by a bloom of a pennate diatom *Nitzschia paleacea,* which was present at a mean density of 68,284 cells/mL. This is the first record of a bloom of *N. paleacea* in a state lake. However, previous instances of spring blooms of *Nitzschia acicularis* were recorded for Lake Alvin, Clear Lake (Deuel Co.), and Lake St. John in recent years. Motile pennate diatom genera such as *Nitzschia* and *Navicula* are known to actively grow on sediments of rivers and littoral substrates of lakes and usually occur only incidentally in the plankton (Patrick and Reimer, 1966; Hutchinson, 1967). Blooms of these diatom types in the water column of some lakes may be indicative of shallow, as well as eutrophic waterbodies (Palmer, 1969).

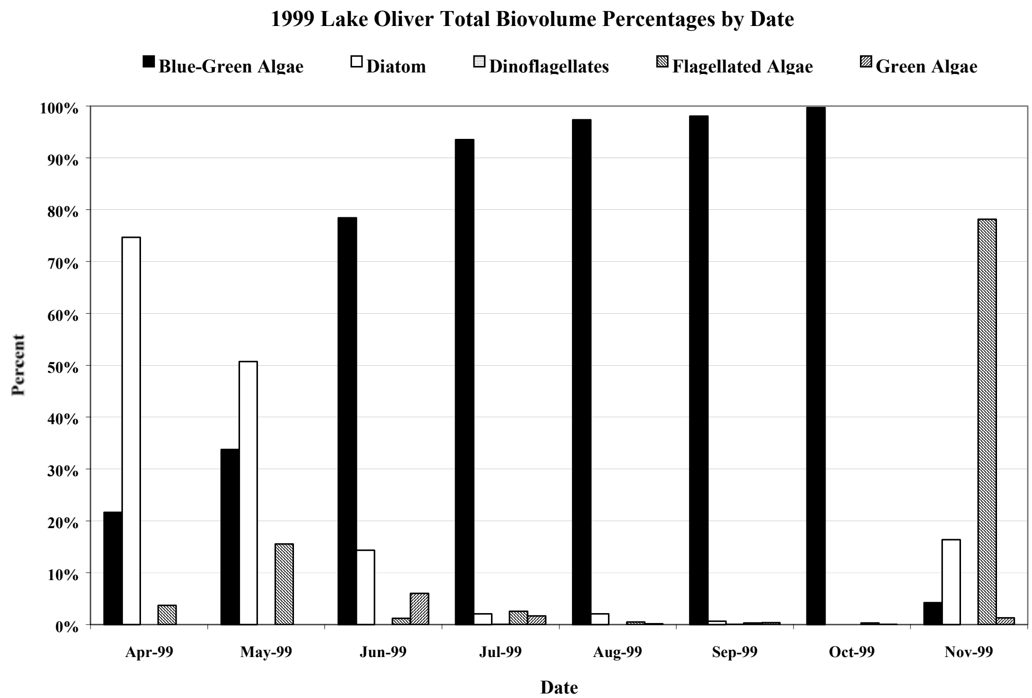


Figure 9. 1999 Lake Oliver Total Biovolume Percentages by Date.

The following samples, taken on May 18 and June 16, indicated a steep drop in late spring algal densities from 92,986 cells/mL in April to 15,857 cells/mL in May and a partial recovery to 31,285 cells/mL by the middle of June. A similar late spring decline in algae populations was previously observed in several other eutrophic state lakes and may be a fairly common phenomenon in these types of waterbodies. The decline in algae is often noticeable as a significant, albeit temporary, improvement in lake water transparency for several weeks from late May to mid-June in otherwise, turbid lakes. The algal decrease in the present assessment can be attributed to the collapse of the spring diatom bloom and lack of sufficient replacement of algal numbers by other algal groups such as greens or blue-greens at this time. The smaller algae communities in May and June were primarily comprised of *Aphanizomenon flos-aquae,* the pennate diatoms *Asterionella formosa* and *Nitzschia paleacea*, and flagellated algae *Chrysochromulina* sp. and *Rhodomonas minuta* in approximate order of importance. This period also saw the increase in the importance of blue-green algae, mainly *Aphanizomenon flos-aquae*, in the plankton from 7,465 cells/mL in May to 26,921 cells/mL in June.

Algae densities had increased more than threefold to 98,982 cells/mL by late July due entirely to larger populations of blue-greens which developed during early summer. *Aphanizomenon flos-aquae* and *Gomphosphaeria lacustris* in combination with several lesser abundant blue-green species, notably *G. aponina, Microcystis aeruginosa,* and

Anacystis marina, comprised 98% of the total phytoplankton density and nearly 94% of the biovolume in July. This level of dominance by blue-greens was maintained through October,1999 (Appendix C, Table 3). The blue-green population continued to increase in size from 185,560 cells/mL in August to 361,335 cells/mL in late October with a corresponding increase in biovolume (Appendix C, Table 4). In late August, *Gomphosphaeria lacustris* attained its annual maximum of 113,784 cells/mL and comprised 89% of the algal population. The following month this bloom collapsed and was replaced by a dense bloom of *Aphanizomenon flos-aquae* (mean: 312,878 cells/mL) which persisted through October.

Densities of other algal groups in Lake Oliver (diatoms, flagellated algae, dinoflagellates, and green algae) were low, relative to blue-greens from July to October. Densities for each group generally averaged less than 1,000 cells/mL for each month, with the exception of the green alga *Oocystis pusilla,* which reached a mean density of 2,548 cells/mL in September.

Autumn algae populations declined sharply from an annual peak of 362,751 cells/mL in October to 9,655 cells/mL in late November due to the collapse of the *Aphanizomenon* bloom. The rapid decay of a summer or early fall blue-green bloom is usually caused by the sharp drop in late season water temperatures. The small November algae population consisted primarily of flagellated forms, *Rhodomonas minuta* and *Cryptomonas erosa.* Those motile algae increased in abundance from 1,173 cells/mL in September to 8,540 cells/mL in November when they constituted nearly 94% of the plankton community (9,130 cells/mL) in Lake Oliver.

Comparison of Algae Communities in Lakes Cochrane and Oliver

The algae communities of Lake Cochrane and Lake Oliver were very different in most respects with regard to major species present, total annual biovolume, and seasonal distribution of the respective phytoplankton populations. The same conclusion was reached following a limited comparative survey of the two adjacent lakes by the SD DENR in 1995. Literature indicates that even closely spaced lakes of comparable morphology and water chemistry may often be dissimilar in the composition and seasonal dynamics of their phytoplankton communities. The reasons for this commonly observed phenomenon are not completely understood at this time (Hutchinson, 1967).

The algae population in Lake Oliver monitored from April to November, 1999, was approximately six times larger than that of Lake Cochrane, both in terms of algal density (cells per milliliter) and biovolume (microliters per liter) (Figures 10 and 11). The Lake Oliver mean monthly algal density was calculated as 139,873 cells/mL, which had a biovolume of 14.777 µl/L, compared to 22,944 cells/mL and 2.531 µl/L for Lake Cochrane. The blue-green algae population in Lake Cochrane was composed primarily of colonial coccoid species while that of Lake Oliver consisted predominantly of filamentous taxa (Figures 6 and 12). The same results were obtained in the 1995 DENR algal survey.

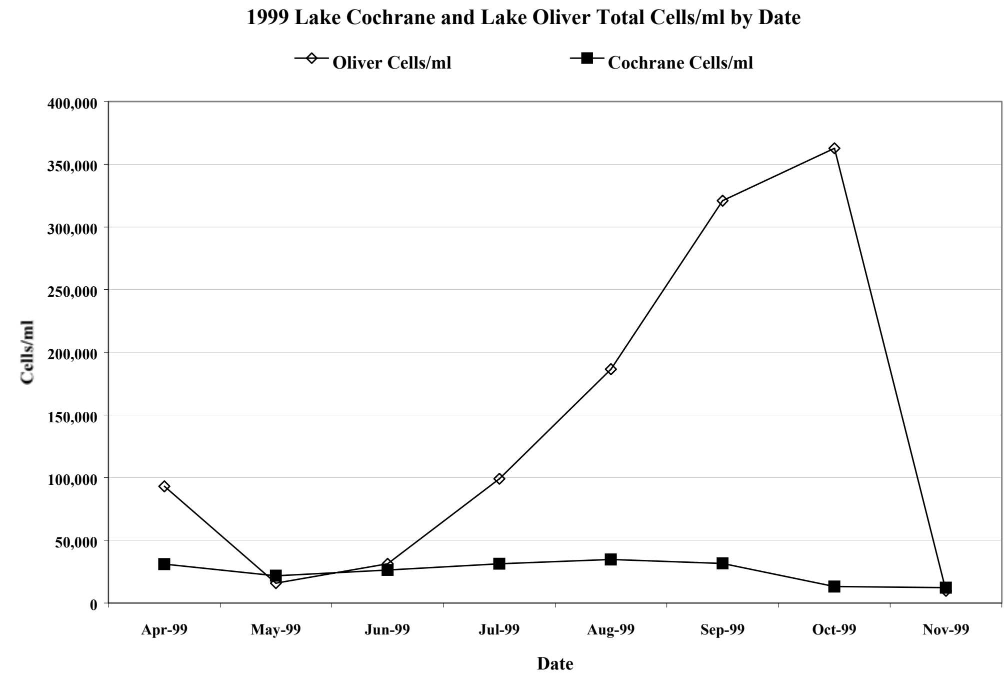


Figure 10. 1999 Lake Cochrane and Lake Oliver Total Cells/mL by Date.

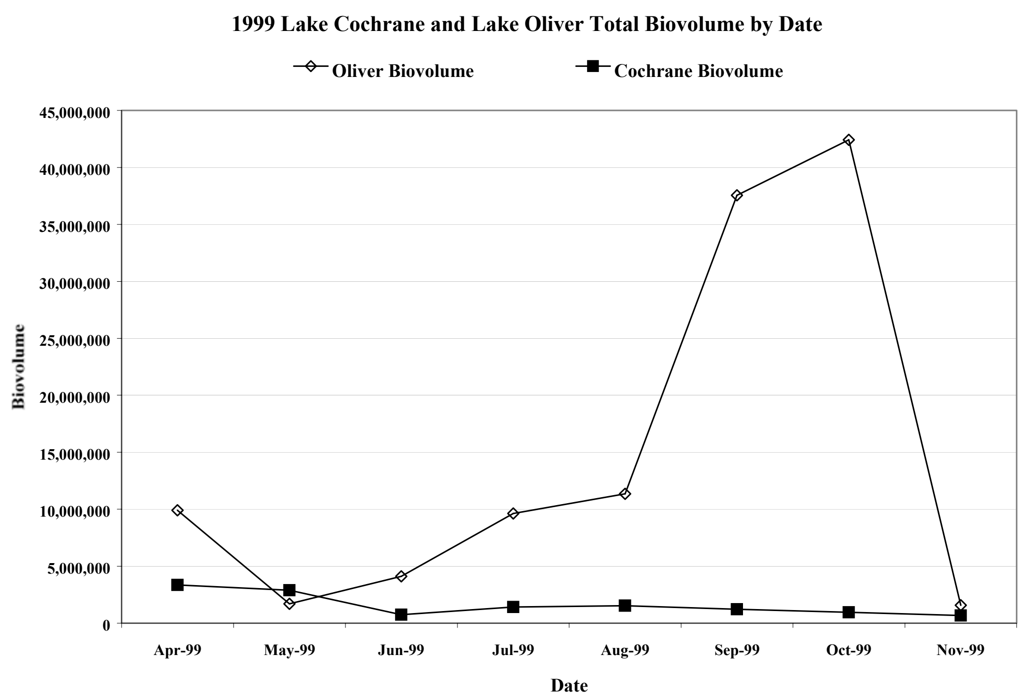


Figure 11. 1999 Lake Cochrane and Lake Oliver Total Biovolume by Date.

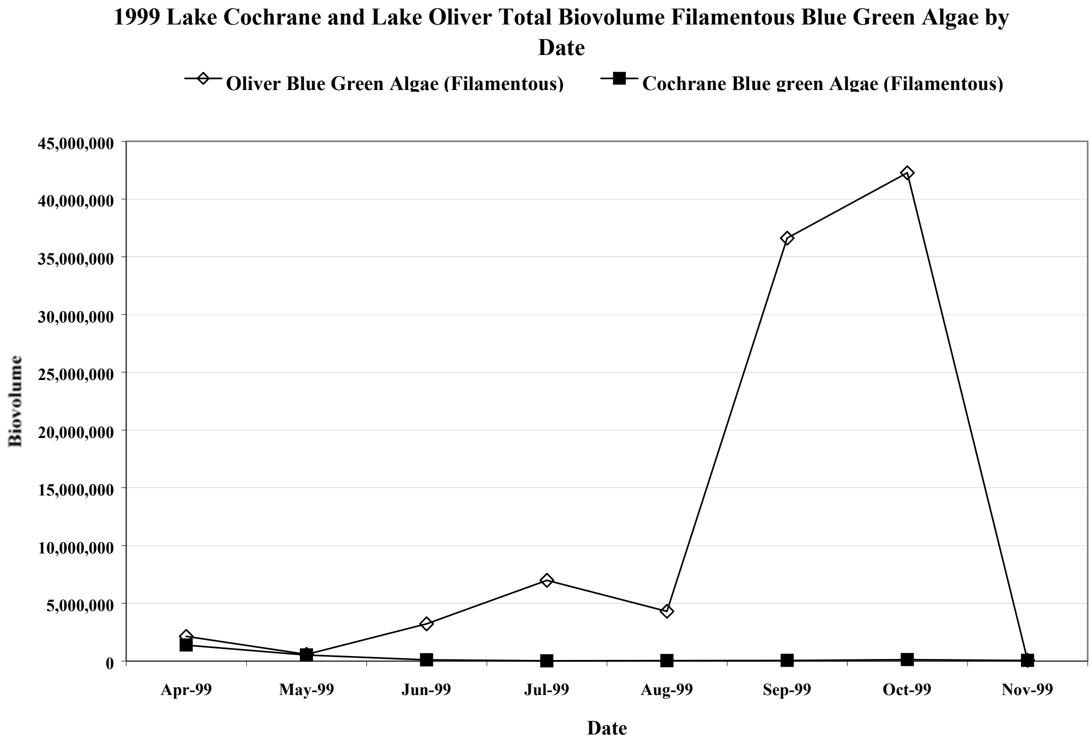


Figure 12. 1999 Lake Cochrane and Lake Oliver Biovolume Filamentous Blue-Green Algae by Date.

Seasonal patterns of algal abundance and biovolume levels at Lake Oliver were characterized by congruent peaks in October followed by a steep drop in the values of both parameters in November (Figure 13) due to the collapse of an autumn *Aphanizomenon* bloom. In sharp contrast, a similar graph plotted for Lake Cochrane indicated a temporal divergence in the peaks for biovolume and algal numbers between spring and summer, and a weak positive correlation coefficient (R=0.33) between the seasonal trends of the two parameters (Figure 5). The April maximum in biovolume was contributed mostly by a bloom of a large-sized colonial flagellate *Dinobryon*; whereas several taxa of small-sized blue-greens (*Anacystis, Gomphosphaeria)* which became abundant in summer were mainly responsible for the August peak in algal density, although their combined biovolume was not closely proportional to the number of cells.

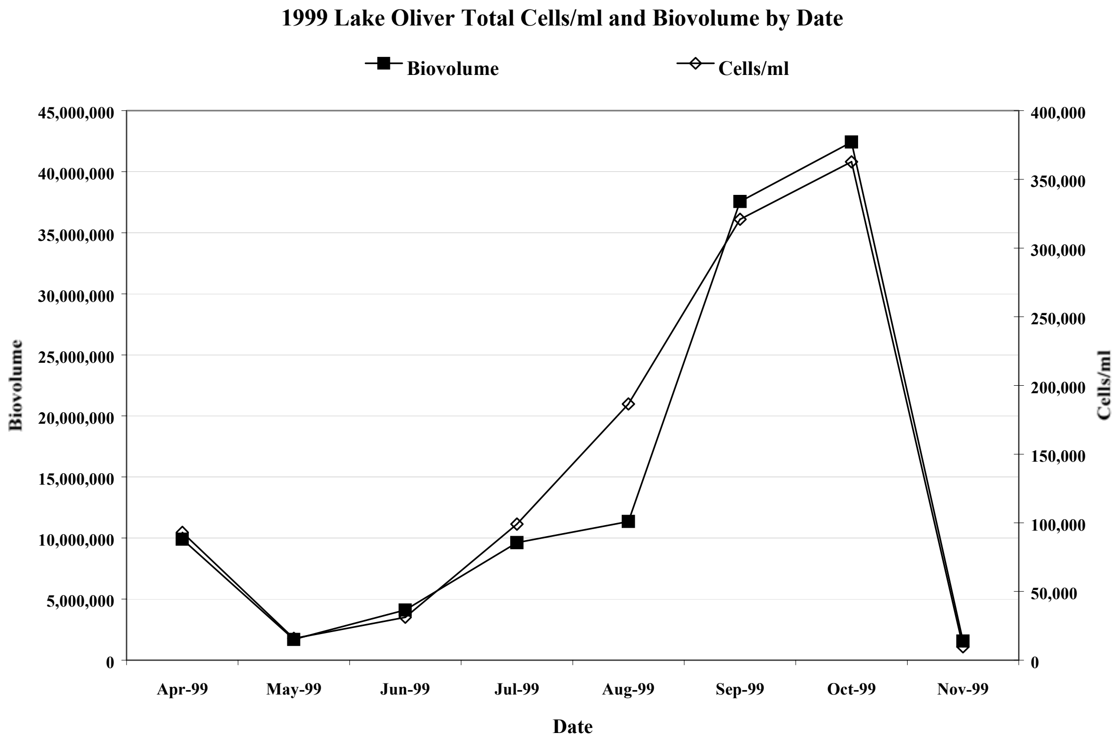


Figure 13. 1999 Lake Oliver Total Cells/mL and Biovolume by Date.

Blue-green algae were much more prominent in Lake Oliver than in Lake Cochrane during 1999. Blue-green algae contributed 9.753 µl/L, or 66%, to the biovolume in Lake Oliver, but only 0.785 µl/L, or 31%, in Lake Cochrane. The biovolume or 'biomass' of blue-greens in Lake Oliver was more than 12 times greater than in Lake Cochrane. Blue-greens remained predominant in terms of biovolume for five months in Lake Oliver from June through October. In Lake Cochrane, blue-green biovolume was dominant for two months and co-dominant with flagellated algae for one month (Tables C-2 and C-3).

The two lakes also differed widely as to the number of algal taxa collected in each lake during this study, and the seasonal and monthly succession of algal dominants. Lake Cochrane proved to be more diverse (73 taxa) than Lake Oliver (49 taxa). This may have been expected since the former is less eutrophic than Lake Oliver.

Lake Cochrane had a large variety of algae dominant, with diatoms occurring in the spring and fall, and small-celled colonial blue-greens abundant during the summer months. Interestingly, *Dinobryon sertularia* was dominant in April and co-dominant in September.

Lake Oliver had the pennate diatom *Nitzschia paleacea* dominant in spring, with *Aphanizomenon flos-aquae* dominating from June through September, except during August when *Gomphosphaeria lacustris* was most abundant. *Rhodomonas minuta* was most dominant during November.

The following table summarizes the monthly succession of the most dominant species (by density and/or biovolume) for the two adjacent lakes.

Table 3. Most Dominate Algal Species by Month.

LAKE	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
Cochrane	DBST	CCKT	ANMR MXFG	GNXX ANMR	ANMR GMLC	DBST ANMR	CCKT RDMN	CCCO ANMR
Oliver	NZPC	NZPC KKXX	APFA	APFA	GMLC	APFA	APFA	RDMN

Codes:

ANMR = Anacystis marina (Aphanothece nidulans)
APFA = Aphanizomenon flos-aquae
CCCO = Cyclotella comta
CCKT = Cyclotella kuetzingiana (probably Cyclotella michiganiana)
DBST = Dinobryon sertularia
KKXX = Chrysochromulina sp.
GMLC = Gomphosphaeria lacustris
GNXX = Gymnodinium sp. (probably Peridinium willei)
MXFG = unidentified flagellate (probably Ochromonas sp.)
NZPC = Nitzschia paleacea
RDMN = Rhodomonas minuta

Historical Occurrence of Nuisance Algae

Usually one of the first obvious signs of deteriorating water quality in state lakes is the appearance of a massive blue-green algae bloom. The nuisance blue-green taxa involved in local waterbodies are commonly *Aphanizomenon, Microcystis aeruginosa, Anabaena spp.,* and *Oscillatoria spp.* Those relatively large-sized species can build up to a correspondingly large biomass during the summer months, producing the highly visible and unsightly floating mats, and the large masses that collect on lake shorelines.

There has been no recent history of such blooms in Lake Cochrane that can be determined from rather limited past monitoring. The current assessment also did not indicate the presence of such a bloom. The most common blue-green in 1999 was a small-sized colonial species *Anacystis marina (Aphanothece nidulans)* aggregations of which are not noticeable to the eye unless, perhaps, it becomes extremely abundant. Densities of *Oscillatoria* (tentatively identified as mostly *O. tenuis*) in Lake Cochrane have been low to moderate, so far. In this assessment *Oscillatoria* density ranged from 125 cells/mL in July to 4,625 cells/mL in April. Sample analysis has erroneously identified *Aphanizomenon* as occurring in Lake Cochrane during 1999. The filamentous species found in the samples is probably referable to *Oscillatoria.* To the best of our knowledge, *Aphanizomenon* has not been reported from this lake to date.

Maximum monthly density of *Microcystis aeruginosa* reported from limited sampling in Lake Cochrane over the past two decades was 1,299 cells/mL, a low density recorded for August 1979. The maximum density recorded during this survey was 12,684 cells/mL at site LCL-3 on August 1999 (3-site mean: 7,934 cells/mL). Those are still considered moderate densities. It is possible, however, that this species has been increasing in recent years, although more frequent sampling in 1999 may have skewed the data.

Limited sampling during the past 25 years indicated *Anabaena* sp. (probably mostly *A. flos-aquae*) was present in Lake Cochrane as 1,559 cells/mL in August 1979 and again in July and August 1998 as 769 cells/mL and 917 cells/mL, respectively. It was absent in the 1974 (EPA), 1989 (DENR) and 1995 (DENR) surveys. In the present survey, it was found only in October at a mean density of 422 cells/mL. *Anabaena* is, apparently, not an important constituent in the plankton of Lake Cochrane at the present time.

Lake Oliver was first sampled for phytoplankton in June and August 1995 by DENR, followed by other DENR surveys in July and August 1998, and the present assessment (April to November 1999). Analysis of samples from the previous and present surveys indicated that this lake regularly develops dense summer and autumn blooms of blue-green algae consisting mainly of *Oscillatoria agardhii, Aphanizomenon flos-aquae, Gomphosphaeria, Microcystis,* and sometimes *Anabaena* spp. Lake Oliver shows the characteristics of a highly eutrophic waterbody by these regularly occurring annual blooms.

Macrophyte Survey

A macrophyte survey was conducted in the early summer of 1999. Results of the survey found Lake Cochrane to have a relatively dense macrophyte population. *Chara* sp., a large type of algae that has the appearance of a macrophyte, dominated the macrophyte community. *Chara* sp. was found at depths from near 0 ft. to 8-10 ft., depending on water clarity. *Potamogeton pectinatus* (sago pondweed) and *Ceratophyllum desmersum* (coontail) were also quite prevalent in Lake Cochrane. Both species were found at depths from the shoreline to 15+ feet of water. Less frequent, but also found in the survey, was *Ruppia* sp. (widgeon grass). *Ruppia* sp. are usually found in saline waters and estuaries and are rare inland (Fassett, 1957). The high dissolved solids due to the high residence time and large water loss to evaporation most likely make conditions favorable for *Ruppia* sp. *Ruppia* sp. was found only in the deeper areas of Lake Cochrane.

The macrophyte species found in Lake Oliver were less abundant than those found in Lake Cochrane. *Potamogeton pectinatus* (sago pondweed) was found around most of the shoreline. *Potamogeton richarsonii* (clasping-leaf pondweed) was also found in clumps with varying densities along the shoreline. *Potamogeton richarsonii* was not as common as *Potamogeton pectinatus*. The macrophytes in Lake Oliver were found in much shallower water (from the shoreline to 4 feet) than those in Lake Cochrane.

SEDIMENTATION

Lake Cochrane Sediment Basins

In 1975, a locally supported EPA Clean Lake Project was initiated to reduce sediment entering Lake Cochrane. Approximately $20,000 was expended to construct 3 sediment traps on the main tributaries entering the lake. The sediment traps were incorporated into the perimeter road system. Approximately 2,700 feet of gravel road and a new boat access was constructed for approximately $34,700. A study conducted for EPA, published in April of 1979, suggested that sediment basins had good initial sediment removal but relatively low nutrient reduction (US EPA 1979). The location of the sediment basins corresponded to the location of the tributary sampling sites chosen for the project. Site LCT-1 was the basin located in the northwest corner of Lake Cochrane. Site LCT-2 was located downstream of the basin on the west side of the lake and site LCT-3 was located downstream of the basin on the southwest corner of the lake (Figure 14).

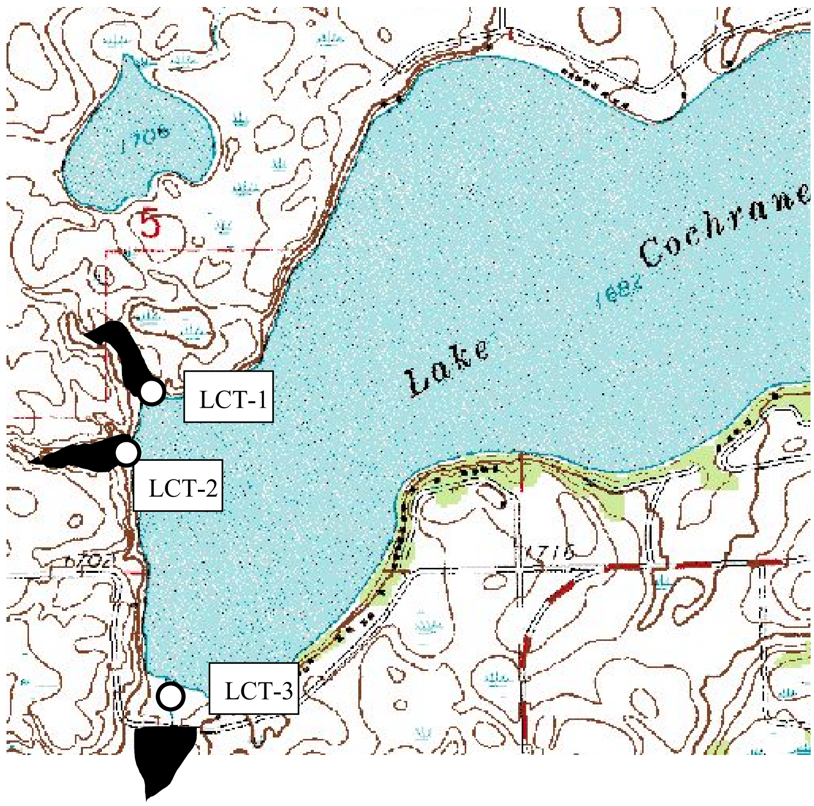


Figure 14. Location of Sediment Basins and Corresponding Monitoring Sites

A sediment survey was conducted on the northwest and west ponds in the winter of 2000. Results of the sediment survey showed the pond on the northwest tributary lost approximately 35% percent of its initial capacity. Figure 15 shows the current water depth compared to Figure 16 which shows its estimated original depth.

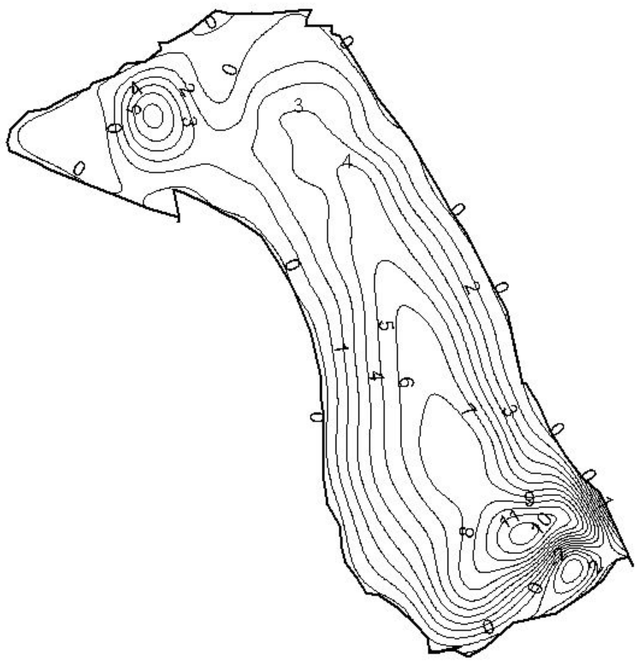


Figure 15. Current Water Depth of Pond LCT-1.

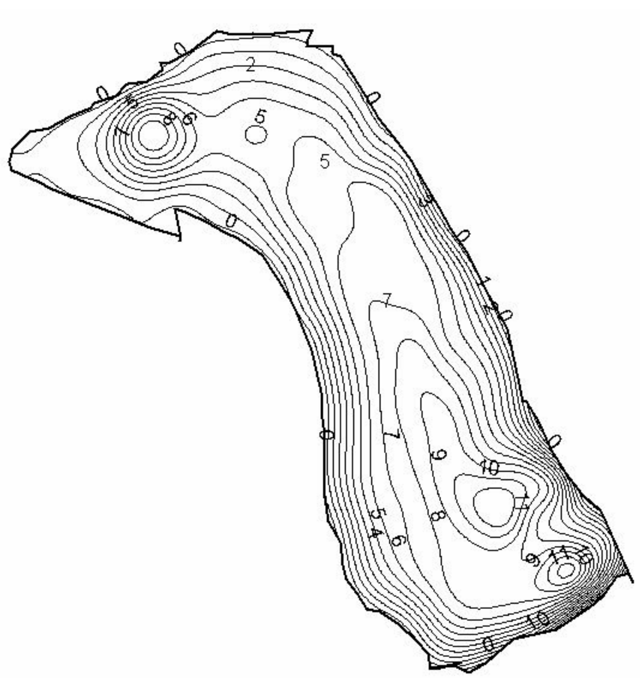


Figure 16. Estimated original depth of Pond LCT-1.

Results of the survey at the pond upstream of LCT-2 showed approximately 31% of its original capacity was lost due to sedimentation. Figure 17 shows the current water depth of the second sediment pond. Figure 18 shows the estimated depth of the original bottom.

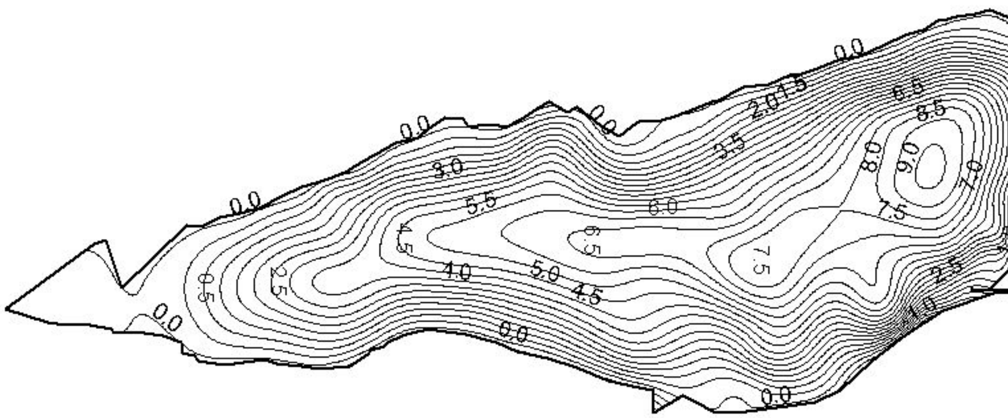


Figure 17 . Current Water Depth of Pond LCT-2.

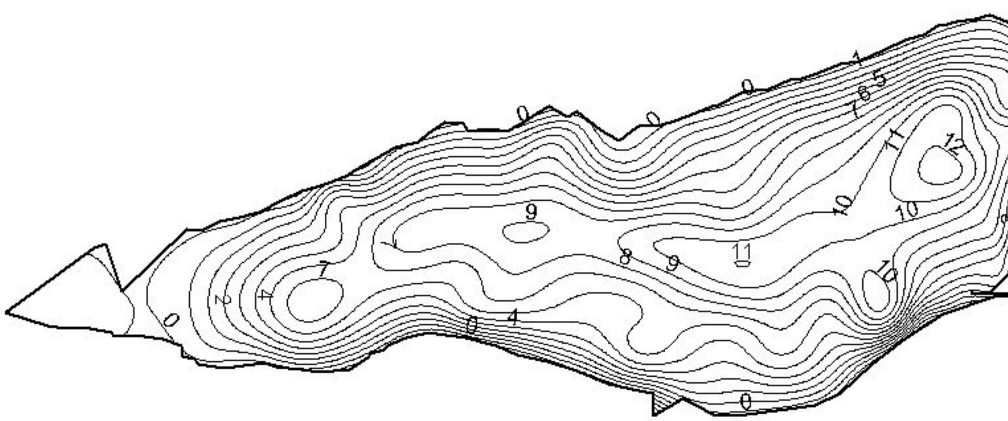


Figure 18. Estimated Original Depth of Pond LCT-2

As sediment enters the ponds, the ponds loose ability to remove sediment from the water column. The subwatershed above site LCT-1 was mostly grass at the time of the study so the sediment rate entering the lake was as low as could be expected. The watershed that drained into site LCT-2 had more cropland. The water quality sampling showed site LCT-2 to have a low overall sedimentation rate, however, the watershed above site LCT-2 had a higher sediment or soil loss per acre than the other tributary sites. The sediment ponds at sites LCT-1 and LCT-2 are different from the southwest pond LCT-3 in that ponds LCT-1 and LCT-2 were designed with controlled drawdown tubes. The tubes may need to be inspected to see if they are functional. There was a constant trickle of water coming from site LCT-2 even when no water was going over the top of the tube. It was difficult to tell if there was any run-off at site LCT-1 because the tube into the lake was partially underwater throughout the project period. Cleaning out these two dams would insure the functionality of the drawdown tubes and improve the trapping efficiency of the two northern-most ponds. Maps of the sediment depths and survey points are shown in Appendix D.

The southwest pond that drains into site LCT-3 is different in design from the more northern ponds in that it was built on an existing road without a controlled drawdown tube. The sediment load out of LCT-3 was greater than the sediment load from any other site. Working with land owners to reduce sediment run-off in the watershed would help reduce the sediment load to Lake Cochrane. Also, the standpipe is approximately one to two feet shorter than the initial design. Because the pond is relatively shallow, the volume of water reduced with a foot less of storage may be significant. The more water in the sediment retention pond, the better the ability of the pond to reduce sediment loads to Lake Cochrane.

Lake Oliver Sedimentation

During the winter of 1999–2000, water and sediment depth measurements were collected in Lake Oliver. The data was collected to measure how much lake volume was lost to sediment. The sediment and water depths were measured by probing to the bottom of the sediment layer with re-bar at various points in the lake. The location of the data points (ice holes) were gathered by use of a GPS unit. The points were then differentially corrected and plotted with ArcView. Contour lines were calculated by using the program, 3-D Analyst.

The sediment survey showed that Lake Oliver had lost 27% of its original depth. Figure 19 is a map of the top of the current sediment depths and Figure 20 is a map of the original bottom as measured during the 1999-2000 survey. The area with the most accumulated sediment appeared to be the northern bay where the majority of the tributaries enter. Landuse within these tributaries has been converted to grass and the sediment load to Lake Oliver has been all but eliminated. Input from the site that parallels the gravel road (LOT-2) was the only input identified that could be reduced. The deeper "holes" have accumulated deeper sediment depths. As sediment fills in, it typically makes the bottom of a lake more uniform in depth and slope. The deepest depths are typically filled in first.

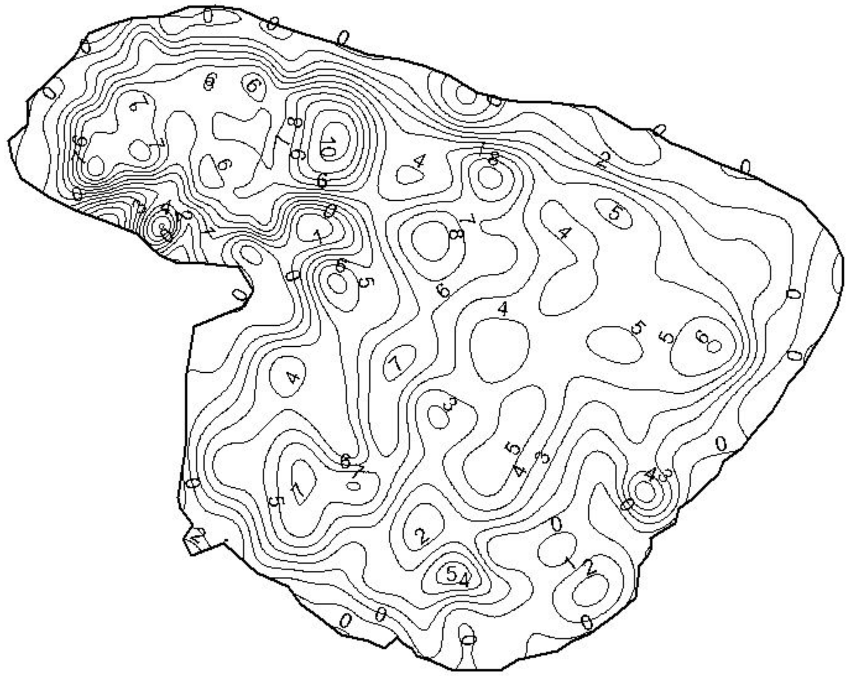


Figure 19. Current Sediment Depths of Lake Oliver.

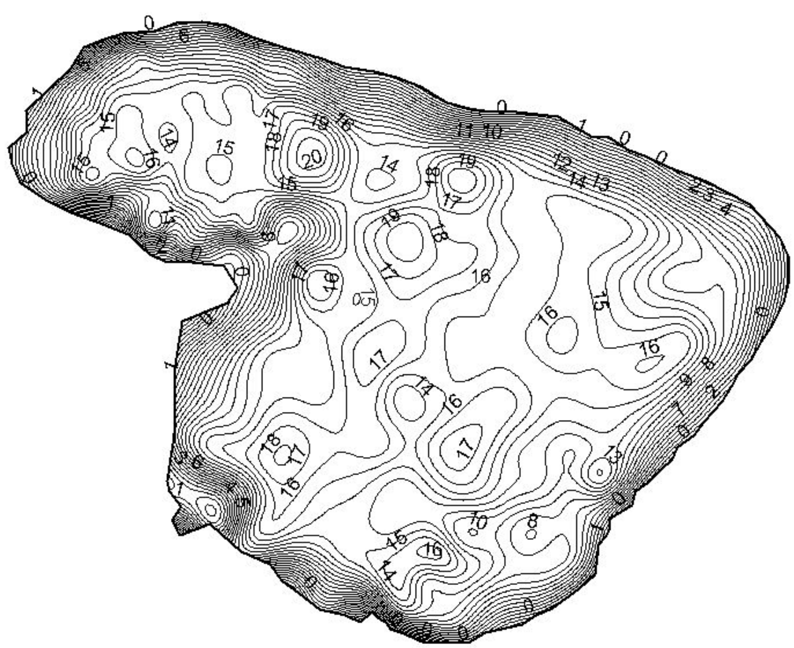


Figure 20. Estimated Original Depth of Lake Cochrane.

At the current rate of sedimentation, it appears the majority of sediment entered Lake Oliver in the past. The current rate of sedimentation is almost non-detectable when looking at the lake as a whole. As stated earlier, any work to eliminate the sediment from the gravel road will benefit the lake.

The estimated volume of the sediment layer in Lake Oliver is 690,324 cubic meters. Although more concentrated in some places than others, the volume of sediment equals approximately 1 meter of sediment over the entire 180 surface acres of the lake. The maximum sediment depths in the deeper areas of Lake Oliver were 8 to 9 feet. Maps of the survey points and the current sediment depths are shown in Appendix D.

METHODS AND MATERIALS

Hydrologic Data

Nine tributary locations and both outlets were chosen for collecting hydrologic and nutrient information from the combined Lake Cochrane (5) and Lake Oliver (4) watersheds (Figure 21). Monitoring was conducted from March 2 through November 2, 1999. Because the perimeter road system acts as a barrier for inflow, all possible culverts were chosen for investigation.

Stevens Type F paper graph recorders were installed at two tributary sites and both outlets to record continuous stage. An average daily stage was calculated from these graphs to the nearest 1/100th of a foot.

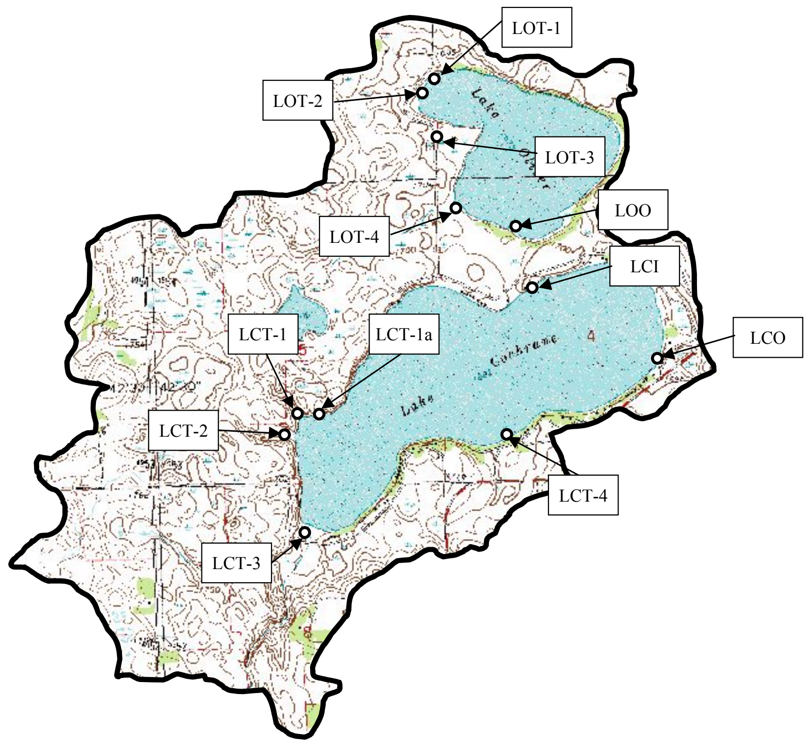


Figure 21. Location of Tributary Inlet Monitoring Sites.

Supplemental stage markers were installed at each outlet to provide a basis for interpreting the stages relevant to outflow. The remaining tributaries were gauged periodically with a depth rod in increments to the nearest 1/10th of a foot. Each site had an established staging location. Water heights were averaged between days to determine the daily stage. A Marsh-McBirney flow meter was used to take periodic velocity measurements at different stage heights. Stage and flow measurements were taken during run-off events and base flow periods to assure a representative stage/flow relationship. The stage and flow measurements were used to develop a stage/discharge table that was used to calculate an average daily loading for each site. Site LCT-2 flow was calculated by taking the time required to fill a known volume of water and converting it to cubic feet per second (cfs). The flows were averaged between days to calculate daily load.

In order to monitor storm events and fluctuating base flows; continuous monitoring equipment was installed at six tributary sites beginning in June (Figure 21) ISCO 4230 flow meters connected to GLS auto-samplers and 6700 auto-samplers containing 730 flow modules were utilized to complete the task. Both units function in a similar manner and are powered with deep cycle marine batteries. The machines were housed in metal boxes or barrels to prevent tampering. Data was downloaded to a laptop computer (FLOWLINK) and the batteries were changed on a monthly basis.

The flow meters were programmed to record stream level every five minutes. These levels were averaged per day to calculate an average daily stage. In most instances, a 90-degree V-notch weir was installed in a culvert and a conversion equation applied to the level data to calculate discharge. The average daily discharge was used to calculate a daily loading for each site. A Parshall flume with a 12-inch throat was used at LCT-3 in place of the weir to obtain similar data. All daily loadings were combined to calculate an annual load for each site.

Because storm event run-off was often of a short duration, auto-samplers were utilized where possible to capture representative water samples for a given event. The samplers were directly connected to the flow meters and preprogrammed to follow the desired sampling program. For instance, if a desired stage was reached in the stream, the auto-sampler would collect a certain volume of water until the desired stage receded. The auto-samplers are equipped with a suction tube that is placed in the stream channel and a 2.5 gallon collection bottle located internally within the machine. Following a storm event the collection bottle was retrieved and sampling procedures were conducted using the EPA approved Standard Operating Procedures for Field Samplers (Stueven, et al., 2000).

Evaporation

A lake evaporation rate, inflow/outflow, precipitation, and lake level data was needed in order to estimate the total hydrologic budget. An evaporation station was set up to record the pan evaporation within the watershed. The station consisted of an alloy pan 4 feet in diameter and 10 inches deep with an attached stilling well, an anemometer with a counter and a rain gage. The pan was filled 3 inches from the top and measured daily to the nearest $1/16^{th}$ of an inch. The pan was refilled when the water level measured 3 inches from the bottom. Also on a daily basis, precipitation and the anemometer reading were recorded. A 6-foot tall fence was built around the station to prevent animals from altering the pan level. The state climatologist, Al Bender, provided materials, data collection and strategy. Even though the information was collected, analysis of the data was not completed in time for this publication. State average evaporation data was used in absence of the measure pan evaporation data (Spuhler, 1971).

Tributary Water Quality

Due to the small size of the direct watershed for both lakes, precipitation events were distributed evenly. Tributary sampling was conducted after a storm event depending on size and duration. Base flow was sampled twice a week during spring run-off and event-based, thereafter. If no run-off event occurred within a three to four week period, a base flow sample was collected. Sampling was based on opportunity, as not all tributaries experienced definite base flows. Outlets were sampled after rain events and periodically to cover high and low flow periods. All nutrient and solid parameters were sampled using the approved methods documented in South Dakota's EPA-approved *Standard Operating Procedures for Field Samplers.* The South Dakota State Health Laboratory in Pierre, SD analyzed all samples. The purpose of these samples was to develop nutrient and sediment loadings and to determine critical pollution areas in the watershed. The outlets were sampled to develop nutrient and sediment budgets for each lake. The outputs from Lake Oliver were also treated as a tributary to Lake Cochrane.

The standard water quality parameters analyzed by the State Health Laboratory were:

Total Alkalinity	Total Solids	Total Suspended Solids
Ammonia	Nitrate-Nitrite	Total Kjeldahl Nitrogen
Fecal Coliform	Total Phosphorus	Total Dissolved Phosphorus
Total Volatile Suspended Solids		

Water quality parameters that were calculated from the above parameters were:

Un-ionized Ammonia	Organic Nitrogen	Fixed solids
Total Dissolved Solids	Total Nitrogen	

In addition to the chemical water quality data above, physical parameters were also collected. The following is a list of field parameters collected:

Water Temperature	Air Temperature
Dissolved Oxygen	Field pH

Biological sampling included:

Algae counts	Chlorophyll a
Algae identification	Macrophyte survey

Definition of Water Quality Parameters

A ***total phosphorus*** sample consists of both particulate and dissolved forms of phosphorus. ***Dissolved phosphorus*** is a measure of the phosphorus not attached or bound to any particle larger than a 0.45 microns. ***Particulate phosphorus*** is attached to suspended particles.

Dissolved phosphorus is not attached to sediment particles and is the form of phosphorus most available for immediate uptake by plants and algae. Sources can be fertilizer, animal waste run-off, and phosphorus detergents. The quantities of phosphorus entering streams through land run-off vary greatly and are dependant upon soils, vegetation, quantity of run-off and pollution (Wetzel, 1983).

Suspended solids are those solids transported in the water column downstream to the receiving body of water. Suspended solids concentrations are an estimate of the sediment transported in the stream.

Fecal coliform bacteria are found in the intestine of warm blooded animals and can be an indicator of pathogens in a water supply. Fecal coliform concentrations usually indicate the presence of human, livestock or wildlife wastes.

Nitrogen exists in many forms, both inorganic and organic, in the environment. Nitrate-nitrite (NO3+2) and ammonia (NH4+) can be indicators of excessive nitrogen inputs associated with fertilizers, animal wastes, and natural decay of vegetation. ***Ammonia*** is a breakdown product of the biodegradation of vegetation and other organic matter, such as animal wastes. ***Unionized ammonia*** is highly toxic to many organisms, especially fish, and is subject to South Dakota water quality standards. The concentration of unionized ammonia is dependent upon the temperature and pH of the water.

Total nitrogen is calculated by summing Total Kjeldahl Nitrogen (TKN) and the nitrate-nitrite as nitrogen concentrations.

Organic nitrogen estimates the amount of nitrogen tied up in vegetation or animal biomass. To estimate organic nitrogen, ammonia is subtracted from TKN concentrations.

Alkalinity is the buffering capacity of water. The higher the alkalinity, the more stable the pH of the water. Natural alkalinity can vary between 20 – 200 mg/L, or more, and is largely dependant of the geology of the area (Lind, 1985).

Quality Assurance and Quality Control

Quality Assurance/Quality Control samples were collected on 10% of the samples in accordance with the South Dakota's EPA approved *Clean Lakes Quality Assurance/ Quality Control Plan.* Data analyses and a description of sampling errors are included as Appendix E of this report. The Quality Assurance Project Plan can be referenced by contacting the South Dakota Department of Environment and Natural Resources at (605) 773-4254.

Agricultural Non-Point Source Model (AGNPS)

In addition to water quality monitoring, information was collected to complete a comprehensive watershed landuse model. The model entitled AGNPS was used and is a computer simulation model developed by United States Department of Agriculture (Young, et al., 1986) to comparatively evaluate the quality of the run-off from agricultural watersheds. The model works on a cell basis. These cells are uniform square areas, which divide up the watershed. Ten-acre cells were used for this project to best represent individual details within the watershed. The model predicts run-off volume and peak rate, eroded and delivered sediment, nitrogen, phosphorus, and chemical oxygen demand (COD) concentrations in the run-off and the sediment for a single storm event for all points in the watershed. The model can also predict the response of water quality following the implementation of Best Management Practices (BMPs). Twenty-one parameters were collected for every ten-acre cell in the watershed.

The twenty-one parameters included:

1) Cell Number	2) Receiving Cell	3) Aspect Ratio
4) NRCS Curve #	5) Land Slope	6) Slope Length
7) Slope Shape	8) Manning's Coeff.	9) Soil Erodibility
10) Cropping Factor	11) Practice Factor	12) Surface Constant
13) Soil Texture	14) Fertilizer Level	15) Available Fertilizer
16) Point Source	17) Gully Source	18) COD Factor
19) Impoundment	20) Channel Indicator	21) Channel Slope

Findings from the AGNPS report can be found throughout the water quality discussion. The conclusions and recommendations found in this report heavily rely on the AGNPS findings. The entire AGNPS report is included as Appendix F.

South Dakota Water Quality Standards for tributary samples

Intermittent tributaries to Lake Cochrane and Lake Oliver have been assigned the following water quality beneficial uses:

(9) Fish and Wildlife Propagation, Recreation and Stock Watering*; and
(10) Irrigation Waters.

When two or more standard limits exist for the same parameter, the most stringent standard is applied. Table 4 indicates the most stringent standard limits for tributaries to Lake Cochrane and Lake Oliver.

Table 4. Lakes Cochrane and Oliver Tributary Water Quality Standard Limits.

Parameter	Limits
pH	> 6.0 and < 9.5 su
Total Dissolved Solids	< 2500 mg/L
Alkalinity	< 750 mg/L
Nitrates	< 50 mg/L

*Note: 74:51:03:01. **Beneficial uses of South Dakota streams to include irrigation and fish and wildlife propagation, recreation, and stock watering.** All streams in South Dakota are assigned the beneficial uses of irrigation and fish and wildlife propagation, recreation, and stock watering. The classifications only designate the quality at which the waters are to be maintained and protected.

A total of 88 samples were collected from the combined Lake Cochrane and Lake Oliver tributaries, including both outlets. Of the 88 samples, no exceedances of the water quality standards were observed.

Lake Cochrane Tributary Seasonal Water Quality

Different seasons of the year can yield differences in water quality due to changes in precipitation and landuse practices. To discuss seasonal differences, Lake Cochrane tributary samples were separated into seasons: spring (March 3 – May 31, 1999), summer (June 1 – August 31, 1999), and fall (September 1 – November 2, 1999). The Lake Cochrane watershed received an average amount of precipitation over the course of the study. The majority of precipitation occurred in the spring and early summer (June). Spring events were light and frequent, while summer events were heavier and less frequent. Dry conditions began to prevail in mid-summer and became especially dry in the fall. In general, surface run-off occurred rapidly in the watershed, especially in the tributaries with small sub-watersheds. Despite evenly distributed storm events in the small watershed, not all tributaries were sampled at the same time due to intermittent flow. Of the 56 total tributary samples, 32 were collected in spring, 19 were collected in summer and 5 were collected in fall. Lake Oliver discharged to Lake Cochrane from April 9, 1999, until the outlet was mechanically closed June 15, 1999. Because of the hydrological connection between the lakes, the outlet of Lake Oliver was treated as a Lake Cochrane tributary. A total of nine samples were collected from the Lake Oliver outlet; 5 samples were collected in the spring and 4 were collected in the summer.

Flow
During the 1999 study, it was estimated that 71% of the total discharge to Lake Cochrane occurred during the spring. Approximately 25% of the input occurred in the summer and the remaining 4% occurred in the fall. The average and median concentrations of different parameters changed throughout the seasons as shown in the following table.

Table 5. Seasonal Mean and Median Lake Cochrane Tributary Concentrations.

Parameter	Spring			Summer			Fall		
	Count	Mean	Median	Count	Mean	Median	Count	Mean	Median
Diss. Oxygen	32	11.6	11.4	19	7.9	8.1	5	8.5	9.2
Field pH (*su*)	32	8.18	8.16	19	8.1	8.0	5	8.1	8.2
Alkalinity	31	268.6	274	19	211.3	223	5	163	162
Total Solids	31	984.7	985	19	989.3	1021	5	912.8	1013
Susp. Solids	31	13.4	5.0	19	10.6	9.0	5	29.4	10
Diss. Solids	31	971.4	981	19	978.6	999	5	883.4	984
Ammonia	32	0.09	0.01	19	0.02	0.01	5	0.3	0.3
Nitrate-Nitrite	32	0.67	0.10	19	0.10	0.10	5	0.20	0.10
Total Kjeldahl- N	32	1.54	1.41	19	1.58	1.41	5	1.5	1.5
Total Phosphorus	32	0.11	0.07	19	0.10	0.10	5	0.20	0.20
Total Dissolved Phosphorus	32	0.05	0.02	18	0.04	0.04	5	0.03	0.03
Fecal Coliform	28	43.2	7.5	19	734.5	280	3	15	10

- Highlighted areas are the seasons that recorded the highest concentrations for a given parameter.
- Unless specifically noted, the concentrations are expressed in *mg/L* except for fecal coliform which is in *colonies/100mL*

Dissolved Oxygen
Dissolved oxygen concentrations are highest in the spring. This is most likely due to the heavier flow of water becoming aerated as it moves along a stream. Cooler water temperatures experienced in the spring allowed for higher oxygen holding (saturation) capacity of the water . The lower oxygen concentrations in the summer are probably due to warm water temperatures, lower flows, and decomposition of organic material.

Alkalinity
The higher alkalinity in the spring suggests that groundwater was likely contributing to surface run-off. Groundwater typically has higher alkalinity than rainwater because of the dissolved minerals from constant contact with the soil. Alkalinity decreased from spring to fall. This may potentially be due to subsiding ground water levels.

Solids
Average and median dissolved solid concentrations differed slightly between seasons. Dissolved solids, like alkalinity, are associated with influence from ground water, although a certain amount is transported in surface run-off. Dissolved solid concentrations varied considerably between sites. The spring samples ranged between a minimum concentration of 336.5 mg/L (LCT-3) to a maximum of 1965 mg/L (LCT-4). Summer samples ranged between a minimum concentration of 443 mg/L (LCT-3) to a

maximum of 1621 mg/L (LCT-4). Fall samples also varied, ranging between 466 mg/L (LCT-3) and 1041 mg/L (LCT-2). Site-specific landuse characteristics, sub-watershed size and ground water input likely dictated the dissolved solid concentrations.

During the project, the local coordinator made detailed notes during sampling periods. These notes were often referred to if a concentration appeared questionable. For example, the median suspended solids concentrations were lower than the average concentrations for both spring and fall samples. Two samples with high suspended solids concentrations were collected from LOO (41 mg/L and 182 mg/L) during the spring sampling period. The sampler indicated that rough fish (carp) were often witnessed routing in the bottom substrate near the outlet causing sediment to enter into suspension. When the two values were removed, the average returned closer to the median (average: 6.64 mg/L, median: 5 mg/L). Again in the fall, the average concentration was skewed from the median. On 10/19/99, a suspended solids concentration of 106 mg/L was obtained from site LCT-2. This high concentration was attributed to sediment that deposited on the upstream side of a weir that had been installed in late May. When this value was removed, the average became 10.3 mg/L (median: 10 mg/L). When the outstanding values were removed, the average seasonal concentrations of suspended solids were slightly higher in the summer than the fall. Heavier storm events in the summer were most likely responsible for transporting the higher suspended solids. Focusing management efforts on improving the sediment pond at LCT-2 and removing rough fish at LOO may potentially reduce undesired sediment loads to Lake Cochrane.

Nitrogen

The highest tributary ammonia concentration was 1.2 mg/L (LCT-2) collected in the spring. This value increased the mean from the median by a factor of 4. Despite this anomaly, the fall had the highest average and median concentrations. The highest fall concentration was 0.91 mg/L collected from a composite sample on 11/1/99 at site LCT-2. Summer ammonia concentrations were all below the detectable level (0.02 mg/L), except for two sample concentrations (0.06 mg/L and 0.08 mg/L). In general, LCT-2 had the highest and most frequent concentrations of ammonia which accounted for the variability in spring samples.

The spring nitrate-nitrite average concentrations appeared to be the highest values despite the variability from the median. Again LCT-2 concentrations were respectively higher than the other tributaries (including LOO). The maximum concentration in spring samples was 2.8 mg/L while the summer and fall maximum concentrations were 0.1 mg/L and 0.5 mg/L, respectively. Not as much variability was seen in the summer and fall as indicated by the medians.

Average and median TKN concentrations showed little variation seasonally, despite higher concentrations at LCT-2. The highest TKN concentration (5.70 mg/L) was seen at LCT-2 in the spring. As with the other nitrogen parameters, relatively moderate concentrations of TKN were observed in the tributaries, while concentrations elevated from the mean consistently at site LCT-2.

In conclusion, sources of nitrogen can be from animal feeding areas, decomposition of organic material, or run-off from applied fertilizer. Consistently elevated concentrations of nitrogen at LCT-2 may be due to agricultural influence. LCT-2 drains approximately 100 acres of cropland that may have included run-off from a feedlot. Feedlot runoff was highly unlikely during the study due to the amount of precipitation needed to create direct flow. Manure may have accumulated in the sub-watershed from previous land applications. In any case, whether nitrogen was from organic or inorganic sources, it is an added non-point source of pollution that contributes to the eutrophication of Lake Cochrane.

Phosphorus
Average total phosphorus was highest in the fall, while average dissolved phosphorus concentrations were highest in the spring. Some sample variation existed in spring samples, but summer and fall averages were consistent with the medians for both parameters. Total phosphorus ranged between 0.055 mg/L to 0.372 mg/L and dissolved phosphorus ranged between 0.024 mg/L to 0.071 mg/L. For the most part, higher phosphorus concentrations appear to coincide with higher suspended sediment concentrations, especially in the spring and fall. However, the highest total and dissolved phosphorus concentrations were seen in the summer at LCT-3 when fecal coliform concentrations were also elevated. Prior to the presence of cattle, LCT-3 phosphorus concentrations were also related to suspended solids.

Bacteria
Fecal coliform concentrations were considerably higher in summer despite the lower nutrient concentrations. The lowest summer mean of fecal coliform (89 colonies/100mL) was observed at LCT-2, despite this site having the highest nutrient concentrations. Summer fecal concentrations were highest ranging from non-detectable to 2900 colonies/100mL. Spring samples ranged from non-detectable to 420 colonies/100mL and fall samples ranged from non-detectable to 30 colonies/100mL. Average spring and summer concentrations displayed considerable variation from the median. This is likely due to site-specific landuse characteristics. In most instances, elevated fecal concentrations were found at sites with no livestock influence. The only exception was the active summer pasture drained by LCT-3. LCT-3 ranked only 3 out of five for the highest mean fecal concentrations (1104 colonies/100mL). Fecal concentrations at this site may definitely be related to livestock waste. Animal waste at the remaining sites can most likely be attributed to wildlife and domestic pets.

Loadings
Loadings are defined as discharge multiplied by concentration. Lake Cochrane tributary seasonal loads are summarized below in Table 6.

Table 6. Comparison of Total Seasonal Loads.

Parameter	Spring	Summer	Fall
Discharge	71.3%	25%	3.7%
Alkalinity	77.2%	20.6%	2.2%
Total Solids	76%	21.2%	2.8%
Susp. Solids	84.9%	12.5%	2.5%
Diss. Solids	75.8%	21.4%	2.8%
Ammonia	82.1%	5.6%	12.3%
Nitrate-Nitrite	91%	7.6%	1.4%
Total Kjeldahl – N	68.7%	27%	4.3%
Total Phosphorus	67.7%	24.2%	8.1%
Total Diss. Phosphorus	66.4%	28.5%	5.1%
Fecal Coliform	3.9%	95.7%	0.3 %

Despite seasonal concentrations, the majority of the nutrient and sediment loadings to Lake Cochrane occurred during the spring run-off period (except for fecal coliform). Due to lower flows in the summer and fall, the higher nutrient concentrations were negligible compared to the total loadings produced in the spring. The lack of summer and fall precipitation reduced the potential of nutrient transportation through the watershed.

In conclusion, the sub-watersheds with the highest agricultural influence are most vulnerable to nutrient and sediment loss, especially in the spring when runoff was the greatest. Nevertheless, agricultural practices in the summer and fall cannot be ignored. With proper grazing, cropping, and nutrient management practices used in the summer and fall, some of the nutrients and sediment would not be available for spring runoff.

Lake Oliver Seasonal Water Quality Discussion

With regards to the Lake Oliver watershed, seasonal water quality was subject to changes in precipitation and vegetation growth. To gain an understanding of how the tributary water quality changed seasonally, samples were separated into spring (March 2 – May 31, 1999), summer (June 1, - August 31, 1999), and fall (September 1 – September 19, 1999). The Lake Oliver watershed received the majority of precipitation in the spring and early summer (June). Spring events were light and frequent, while summer events were heavier and less frequent. During the 1999 monitoring season, 20 samples were collected in the spring and 7 samples were collected in the summer. Only one sample was collected in the fall. Infiltration by the dense vegetation, which covers the majority of the watershed, was most likely a contributing factor to the lack of runoff experienced during summer and fall storm events. Despite occasional storm events, dry conditions prevailed in mid-summer and became especially dry in the fall. Due to relatively small drainage areas and intermittent flows, tributaries were sampled on the basis of opportunity.

Flow

In 1999, it was estimated that 85% of the total discharge to Lake Oliver occurred in the spring. Slightly less than 14% occurred in the summer and less than 1% of the total discharge to Lake Oliver occurred in the fall. The average and median (except fall) concentrations of various parameters changed throughout the seasons as shown below in Table 7.

Table 7. Seasonal Mean and Median Lake Oliver Tributary Concentrations.

Parameter	**Spring**			**Summer**			**Fall**		
	Count	Mean	Median	Count	Mean	Median	Count	**Actual**	LOT-4
Diss. Oxygen	20	11.5	11.1	7	7.93	8.1	1	7.4	
Field pH (su)	20	8.02	7.98	7	8.01	7.91	1	7.69	
Alkalinity	19	231.2	244	7	227.3	233	1	216	
Total Solids	19	1200	1228	7	1108	1042	1	2253	
Susp. Solids	19	19.9	3	7	6.29	4	1	2	
Diss. Solids	20	1121	1174	7	1102	1040	1	2251	
Ammonia	20	0.078	0.01	7	0.01	0.01	1	0.01	
Nitrate-Nitrite	20	0.22	0.06	7	0.06	0.05	1	0.1	
Total Kjeldahl – N	20	1.17	0.89	7	1.17	1.16	1	1.41	
Total Phosphorus	20	0.086	0.057	7	0.090	0.078	1	0.098	
Total Diss. Phosphorus	20	0.080	0.030	7	0.060	0.040	1	0.034	
Fecal Coliform	19	55	10	7	2001	1300	0	0	

- Highlighted areas are the seasons that recorded the highest concentrations for a given parameter.
- Unless specifically noted, the concentrations are expressed in *mg/L* except for fecal coliform bacteria which is in *colonies/100mL*.

Dissolved Oxygen
Dissolved oxygen concentrations are highest in the spring. This is most likely due to the heavier flow of water becoming aerated as it moves along a stream. Cooler water temperatures experienced in the spring allowed for higher oxygen holding (saturation) capacity of the water . The lower oxygen concentrations in the summer are probably due to warm water temperatures, lower flows, and decomposition of organic material.

Alkalinity
The higher alkalinity in the spring suggests that ground water was likely contributing to surface run-off. Ground water typically has higher alkalinity than rainwater because of the dissolved minerals from constant contact with the soil. Alkalinity decreased from spring to fall most likely from ground water levels subsiding.

Solids
Higher fall total and dissolved phosphorus samples were miss leading because of only one sample collected. Spring samples are slightly higher than summer samples due to the

influence of surfical springs running through the sites. By summer, the springs were no longer running. Suspended solids were highest in the spring due to increased flow carrying more solids from the watershed. The spring sample also included the one high 286 mg/L concentration from site LOT-2. This sample was over 20 times greater than the majority of samples collected.

Nitrogen

The highest tributary ammonia concentration was 0.92 mg/L (LOT-2) collected in the spring. Spring samples were the only samples with detectable levels of ammonia. The ammonia may have been available because no plants were using the nutrients at that time or from run-off carrying the product of winter decay.

Site LOT-2 was also largely responsible for increasing the seasonal mean of nitrate-nitrite. The maximum tributary nitrate sample (2.4 mg/L) was collected the same day the maximum ammonia sample was collected (March 15, 1999).

There was no variation in the mean TKN concentration although the median TKN concentration was varied by quite a large margin (0.27 mg/L). Reason for the summer median increase was due to less samples taken. Early spring samples collected were quite high. As the stream flushed themselves out the concentrations diminished. Samples collected in the summer were most likely collected from storm events moving material that accumulated since the last event.

Phosphorus

Like the TKN or organic nitrogen, the median samples of total phosphorus were greater in the summer by quite a margin of 0.021 mg/L. The accumulation of sediment and organic matter between storm events was the most likely reason for the summer increase in total phosphorus concentrations. The one sample in the fall was slightly greater than the summer or spring averages, however the single sample is not representative when comparing it to 20 spring samples and 7 summer samples. Average total dissolved phosphorus was highest in the spring, while the median was again highest in the summer. Early spring samples again raised the average while the later spring samples were quite lower. One relatively high summer concentration (0.170 mg/L) collected at site LOT-3 was responsible for increasing the summer average. That sample was approximately twice as large as the next highest summer concentration (0.086 mg/L).

Bacteria

Fecal coliform concentrations were considerably higher in summer. The lowest summer fecal coliform concentration was(460 colonies/100mL) collected at LOT-2. The highest spring concentration collected was 360 colonies/100mL. Summer fecal concentrations ranged from 460 colonies/100 mL to 4,300 colonies/100mL. Because no cattle are evident in the watershed, the fecal coliform were most likely from wild animals or domestic pets.

Loadings

Seasonal loadings for Lake Oliver tributaries are summarized below in Table 8.

Table 8. Comparison of Total Seasonal Loads.

Parameter	Spring	Summer	Fall
Discharge	85.4%	13.9%	0.7%
Alkalinity	85%	14.3%	0.6%
Total Solids	84.4%	14.5%	1%
Susp. Solids	94.9%	4.8%	0.3%
Diss. Solids	84.3%	14.7%	1%
Ammonia	93.9%	5.8%	0.29%
Nitrate-Nitrite	87.9%	11.5%	0.6%
Total Kjeldahl – N	83%	16.1%	0.9%
Total Phosphorus	83.6%	14.9%	1.5%
Total Diss. Phosphorus	83.1%	15.4%	1.5%
Fecal Coliform	7%	93%	0%

With the exception of fecal coliform, the majority of the discharge, and nutrient and solids loadings were in the spring. There was very little runoff in the summer and fall of 1999. Since Lake Oliver's watershed is mostly in grass, and the inlets are protected by wetlands, the source for the elevated summer fecal coliform concentrations mostly resulted from native wildlife active at the sample sites.

Loadings were mostly dependant on volume of water. The nutrients present during the spring were most likely from decayed vegetation in the grasslands and wetlands surrounding the inlets. Native wildlife increased fecal coliform concentrations in the summer.

TRIBUTARY DATA

Water Quality Lake Cochrane

Table 9 below shows the location of the Lake Cochrane water quality sites and the duration of the measured flow.

Table 9. Latitude and Longitude of Lake Cochrane Tributary Sites.

Site	Latitude	Longitude	Duration of Run-off During 1999
LCT-1A	-96.4864704	44.7084471	April 11 -- July 11
LCT-1	-96.4886631	44.7067394	April 3 -- July 7
LCT-2	-96.4906003	44.7056386	March 3 -- November 2
LCT-3	-96.4890281	44.7009486	March 22 -- October 28
LCT-4	-96.4750564	44.7049282	March 22 -- July 10*
LOO	-96.4759091	44.7156054	April 8 – June 15

* Intermittent flow sporadically throughout the summer.

Site LCT-1A is located at the base of a small wetland with a fairly large culvert under the road (Figure 22). Although there was measurable flow through site LCT-1A, by the time the flow reached the lake there was not enough water to sample the flow as it entered the lake. Samples were collected at the road approximately 150 feet from the inlet.

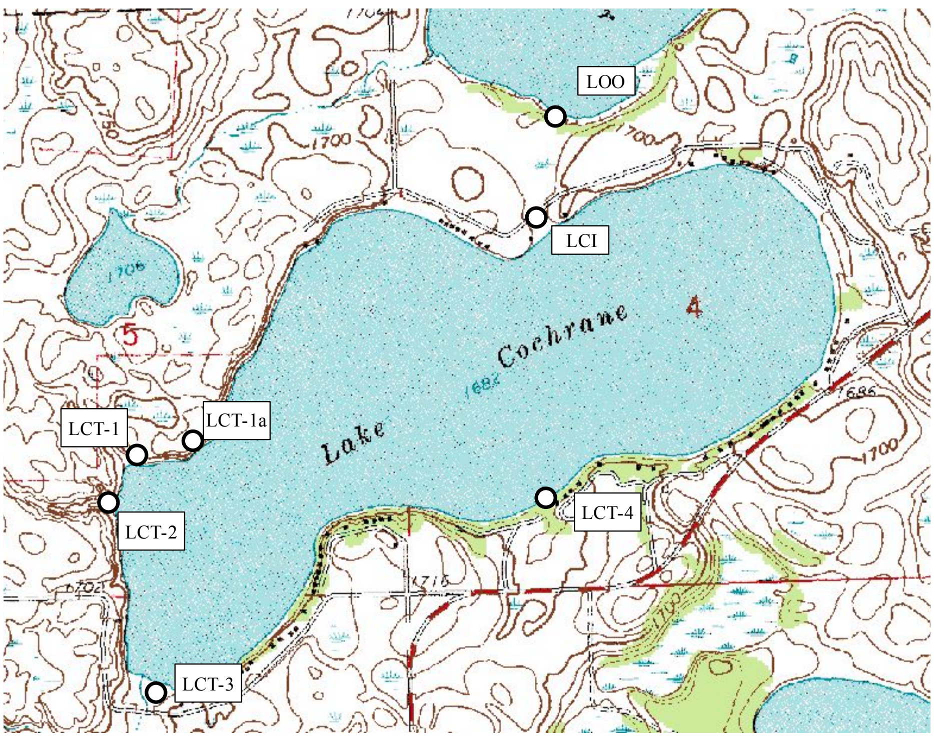


Figure 22. Location of Lake Cochrane Tributary Sites.

Sites LCT-1, LCT-2 and LCT-3 were downstream of constructed sediment retention ponds around the lake (Figure 22). The inlet to Lake Cochrane from Site LCT-1 was located below the lake level during the project, so the typical discharge calculation was not possible due to the influence of the backwater. Flows at Site LCT-1 were estimated by calculating the volume of water going over the standpipe. A weir was placed at site LCT-2 and a flume was placed at site LCT-3 to measure the exact amount of water passing through the site. Flow was present at Site LCT-2 for most of the summer due to an apparent spring in the drainage directly above the site. Site LCT-3 also ran most of the year.

Site LCT-4 was located on a small drainage mostly fed by ground water. The water passed through a wetland and then over a residential lawn before entering the lake. The samples were collected below the wetland and above the lawn.

Samples for site LOO were collected from both the outlet of Lake Oliver and the inlet to Lake Cochrane. The water passes through a concrete culvert between these two lakes. The water flow is controlled by GF&P according to an approved water plan. The control structure was opened in early April and was closed in mid June. Fish were observed in the culvert. These fish stirred the sediment, changing the water quality with their activity.

Fecal Coliform

Table 10 below lists the average, median, minimum, and maximum fecal coliform concentration by site.

Table 10. Summary of Lake Cochrane Fecal Coliform Tributary Concentrations.

Site	Number of Samples	Average	Median	Maximum	Minimum
LCT-1A	2	1250	1250	1400	1100
LCT-1	--	--	--	--	--
LCT-2	17	64.7	10	420	5
LCT-3	17	353	10	2200	5
LCT-4	6	842.5	220	2900	5
LOO	8	96.9	25	400	5

The presence of fecal coliform bacteria typically indicates contamination from waste of warm blooded animals. During the spring, little to no fecal coliform bacteria were found. However, in the summer and fall, fecal coliform concentrations increased dramatically. The only site in the drainage that had livestock present during the summer months was Site LCT-3. Fecal coliform concentrations at LCT-3 were most likely from the livestock, while fecal coliform concentrations at the other sites were most likely from wildlife.

Total Solids

The average total solids and total dissolved solids concentrations for the Lake Cochrane tributaries sampled are presented below in Table 11.

Table 11. Summary of Lake Cochrane Total and Total Dissolved Solids Tributary Concentrations.

Site	Average Total Solids Concentration	Average Dissolved Solids Concentration	% Dissolved Solids
LCT-1A	477.5 mg/L	475 mg/L	99.3 %
LCT-2	987.3 mg/L	970.9 mg/L	98.6 %
LCT-3	642.6 mg/L	602.6 mg/L	98.9 %
LCT-4	1529.5 mg/L	1525.3 mg/L	99.7%
LOO	1382.5 mg/L	1350.2 mg/L	95.4 %

Tributary runoff, consisting of ground water and water from shallow wetlands, typically has higher total dissolved solids concentrations than samples consisting mainly of surface water runoff. Sites LCT-1A and LCT-3 had lower total solids and total dissolved solids concentrations. These sites were most likely fed by surface run-off rather than ground water springs. Higher dissolved solids concentrations at Site LCT-2 were most likely from evaporation concentrating water or from ground water. During run-off events the concentrations at site LCT-2 were lower, showing influence of surface run-off. Site LCT-4 appeared to be fed by ground water springs.

Site LOO had high total solids and total dissolved solids concentrations. These higher concentrations were most likely due to a combination of ground water entering Lake Oliver and the evaporation of water that concentrated dissolved solids in the lake.

Suspended Solids

Suspended materials can decrease lake volume and increase eutrophication in lake systems. The total load of suspended solids delivered to Lake Cochrane was 6,327.52 kg. Table 12 below shows the total load, percent, and per acre suspended solids load to Lake Cochrane from each sampled subwatershed.

Table 12. Summary of Lake Cochrane Suspended Solids Tributary Information.

Site	Percent Watershed	Total Load (kg)	Percent Load` (%)	Load/Acre (kg/Acre)
LCT-1A	0.1%	1.48	0.02%	1.47
LCT-1	3.2%	35.4*	0.56%	
LCT-2	6.4%	353.85	5.59%	3.54
LCT-3	29.6%	820.45	12.97%	1.78
LCT-4	4.5%	31.78	0.50%	0.45
LOO	45.9%	**5,119.96**	80.93%	**9.48**
TOTAL	**88.47%**	**6,326.04**	**100%**	

The lowest suspended solids were delivered from LCT-1A and LCT-4. These relatively small drainages originate from small wetlands surrounded by riparian vegetation. The small size of the drainage area, plus the settling efficiency of the wetlands, combine to lower the suspended solids loads from these sites. The two constructed sediment traps (LCT-2 and LCT-3) contributed 1,174.3 kg of solids to Lake Cochrane. Lack of riparian vegetation around the sediment pond at LCT-3 allowed sediment to wash into the pond. After 25 years of sedimentation, it was difficult to determine if the sediment was coming from the watershed or internally from the sediment pond and livestock activity.

The loading from site LOO was nearly 81% of the total load to Lake Cochrane. From the volatile suspended solids samples collected, it was determined that the majority (88.6%) of the particles in the sample were inorganic or sediment. Carp stirring sediment at the outlet structure were responsible for the majority of the sediment load. If the samples from the dates when carp were present at the outlet were removed from the database, the volume of sediment estimated entering Lake Cochrane would be reduced by 89%. The estimated suspended solids load without the influence of the carp would be 588 kg for the project period. Site LOO would actually have less suspended solids than site LCT-3 if the carp were not stirring up sediments at the Lake Oliver outlet.

Because the AGNPS model could not process the effect of the carp at the outlet of Lake Oliver, the relative load at site LOO was estimated much lower in the model (2%) than the water quality sampling results (81%). The AGNPS model agreed with the other water quality sampling sites in that site LCT-3 and site LCT-2 had the highest loadings per acre (505.2 and 1612.8 lbs./acre, respectively). Sites LCT-1 and LCT-4 had very low overall loads and a relatively low loading per acre.

Sedimentation from the western tributary sites before the sediment basins were installed in 1975 may be the cause of the shallow depths at that end of the lake. Actions of lake shore owners in removing protective vegetation may have also increased sedimentation along the shorelines. Land owners have complained about insufficient water depth for recreational activities in this portion of the lake. From the water quality sampling, it appears that the sediment loads have been controlled. If sufficient sedimentation is found, after surveying the west bay, dredging could be used to increase beneficial use of that area. Dredging to a greater depth would also reduce the disturbance of bottom sediments, thus increasing overall water quality.

Ammonia

The total ammonia load to Lake Cochrane from tributary samples was 11.33 kg. Table 13 below shows the total load, percent, and per acre ammonia load to Lake Cochrane from each sampled subwatershed.

Table 13. Summary of Lake Cochrane Ammonia Tributary Information.

Site	Percent Watershed	Total Load (kg)	Percent Load` (%)	Load/Acre (kg/Acre)
LCT-1A	0.07%	0.004	0.04%	0.00437
LCT-2	7.25%	2.28	20.2%	**0.02283**
LCT-3	**33.33**%	2.61	**23.0%**	0.00567
LCT-4	5.07%	0.08	0.7%	0.00116
LOO	**39.13%**	**6.35**	**56.1%**	0.01176
TOTAL	**88.47%**	**11.33**	**100%**	

Less than one percent of the total ammonia loading occurred at LCT-1A and LCT-4, respectively. Both sites originate from small wetlands surrounded by riparian vegetation. Dense vegetation likely utilizes most of the available ammonia upstream of the lake. Just over half of the total ammonia load to Lake Cochrane was recorded at LOO. The outlet of Oliver drains the largest area and produced 33.4% of the total hydrologic discharge. Lake processes or decaying vegetation in the wetland near the outlet were the most likely contributor of ammonia from LOO. However, on a per acre basis, nearly twice the ammonia load was produced from LCT-2.

Similar ammonia loads were calculated for LCT-2 and LCT-3, despite the difference in subwatershed size. LCT-2 produced approximately four times the ammonia per acre than LCT-3. Ammonia from LCT-2 could have originated from two sources, fertilizer application in the subwatershed or decay of organic matter in the sediment pond. Ammonia-laden water may be entering the lake through site LCT-2 due to a faulty shut-off value. Despite having the highest discharge (51.1%), LCT-3 contributed only 23% of the load of ammonia to Lake Cochrane. One-half of the health lab detection limit (0.01 mg/L) was used as the concentration for calculating the loads to the lake. Site LCT-3 had only 4 of 19 samples above the detection limit. The large volume of water passing through the site raised the subwatershed ammonia load. Contributing sources of ammonia at LCT-3 could be from native wildlife, livestock manure, applied fertilizer, and suspended solids present in the sediment pond. Bacteria in the sediment pond may break down organic nitrogen, making it more readily available for plants. Cleaning and repairing all the sediment ponds would be beneficial in reducing nutrients and sediment from the watershed.

Nitrate-Nitrite

The total nitrate-nitrite loading to Lake Cochrane from tributary samples collected was 49.90 kg. Table 14 below shows the total load, percent, and per/acre nitrate-nitrite loads to Lake Cochrane from each sampled subwatershed.

Table 14. Summary of Lake Cochrane Nitrate-Nitrite Tributary Information.

Site	Percent Watershed	Total Load (kg)	Percent Load (%)	Load/Acre (kg/Acre)
LCT-1A	0.07%	0.02	0.04%	0.02183
LCT-2	7.25%	**33.11**	**66.4%**	**0.33113**
LCT-3	**33.33%**	12.11	24.3%	0.02632
LCT-4	5.07%	0.54	1.1%	0.00774
LOO	**39.13%**	4.11	8.2%	0.00762
TOTAL	**88.47%**	**49.90**	**100%**	

As with ammonia, nitrate-nitrite is an inorganic form of nitrogen that can increase productivity within a lake system. The greatest load and load per acre occurred from LCT-2. The average LCT-2 nitrate-nitrite concentration (0.99 mg/L) was over 7 times higher than any of the other average concentrations. Sources of nitrate-nitrite were similar to those discussed in the ammonia section.

Site LCT-2 had 15 out of 20 samples with nitrate limits over the detection limit. Site LCT-3 had 9 out of 19 samples with nitrate samples above the detection limit. Site LCT-4 had 2 out of 6 samples with nitrate detection, while LCT-1A and LOO did not have any nitrate detection in samples collected.

Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) loadings and loads per acre are shown in Table 15 below.

Table 15. Summary of Lake Cochrane TKN Tributary Information.

Site	Percent Watershed	Total Load (kg)	Percent Load` (%)	Load/Acre (kg/Acre)
LCT-1A	0.07%	0.73	0.2%	**0.73**
LCT-2	7.25%	54.13	16.5%	0.54
LCT-3	**33.33%**	**133.39**	**40.8%**	0.29
LCT-4	5.07%	9.24	2.8%	0.13
LOO	**39.13%**	**130.24**	**39.7%**	0.24
TOTAL	**88.47%**	**327.73**	**100%**	**Mean – 0.39**

TKN consists of both organic nitrogen and ammonia nitrogen. In all but one site, the amount of organic nitrogen in TKN was greater than 90%. In site LCT-2, the percent organic was only 59%. The comparatively low percentage of organic nitrogen in the TKN concentrations at site LCT-2 gave further evidence that the high inorganic loadings were coming from sediment within the basin upstream of site LCT-2. Bacteria in the sediments appear to be converting organic nitrogen to readily available inorganic nitrogen within the basin.

The relatively higher loadings at site LCT-3 were most likely due to sources from within the watershed and algae produced in the sediment retention dam. Livestock around the drop structure were also a likely source at site LCT-3. The higher TKN loadings from site LOO were most likely due to algae or aquatic vegetation surrounding the area adjacent to the outlet of Lake Oliver.

The high loadings per acre at site LCT-1A were most likely due to the breakdown of organic matter in the one-acre watershed that is the entire drainage for this site. Since the overall loading at site LCT-1A was so low the higher per acre load was insignificant.

Total Nitrogen

Total Kjeldahl nitrogen plus nitrate-nitrite make up total nitrogen. Although the discussion of total nitrogen will be very similar to the discussion of TKN, the added parameters will be used to compare the water quality sampling to the nitrogen finding in AGNPS. Table 16 below has the total nitrogen loading and loadings per acre.

The total load of nitrogen was largely determined by the amount of water passing through each site. As with most parameters, site LCT-2 had the highest concentrations and load per acre of any site. The percent of total nitrogen loads to Lake Cochrane from the AGNPS model match the loadings calculated from actual water quality samples collected almost exactly. The AGNPS model also listed site LCT-2 as the highest load per acre of the subwatersheds.

Table 16. Summary of Lake Cochrane Total Nitrogen Tributary Information

Site	Percent Watershed	Hydrologic Load (Acre-feet)	Total Nitrogen Load (kg)	Percent Load (%)	Load/Acre (kg/Acre)
LCT-1A	0.07%	.35	0.75	0.2%	0.75
LCT-1	3.62%	2.55	9.26	2.4%	0.19
LCT-2	7.25%	20.29	87.24	22.6%	**0.87**
LCT-3	33.33%	**98.43**	**145.49**	**37.6**%	0.32
LCT-4	5.07%	6.85	9.78	2.5%	0.14
LOO	**39.13%**	64.38	134.35	34.7%	0.25
TOTAL	**88.47%**	**192.85**	**386.88**	**100%**	**Mean-0.42**

The total measured nitrogen load to Lake Cochrane was only 387 kg during the sampling season. This is a very low nitrogen load. A recent study of Clear Lake, located northeast of Lake Cochrane, documented an annual nitrogen load of 139,747 kg. Since the watershed acreage for Clear Lake is 20 times larger than the watershed for Lake Cochrane, a large loading would be expected. However, the Clear Lake watershed contributed 360 times more nitrogen than the Lake Cochrane watershed.

Total Phosphorus

The total phosphorus loading to Lake Cochrane from tributary samples collected was 22.61 kg. Table 17 below shows the total load, percent, and per acre phosphorus load to Lake Cochrane from each sampled subwatershed.

Table 17. Summary of Lake Cochrane Total Phosphorus Tributary Information.

Site	Percent Watershed	Hydrologic Load (Acre/feet)	Total Load (kg)	Percent Load` (%)	Load/Acre (kg/Acre)
LCT-1A	0.07%	.35	0.029	0.1%	0.02943
LCT-1	3.62%	2.55	0.380	1.7%	0.0076
LCT-2	7.25%	20.29	4.145	18.3%	**0.04145**
LCT-3	33.33%	**98.43**	**8.806**	**38.9%**	0.01914
LCT-4	5.07%	6.85	0.503	2.2%	0.00719
LOO	**39.13%**	64.38	**8.742**	**38.8%**	0.01619
TOTAL	**88.47%**	**192.85**	**22.61**	**100%**	

Due to larger drainage areas, the total phosphorus load at sites LCT-3 and LOO was significantly greater than the other subwatersheds. In general, LCT-2 had higher concentrations of total phosphorus, while only contributing 10.5% of the total discharge. LCT-3 attributed the greatest discharge (98.43 acre-feet) to Lake Cochrane accounting for the largest total phosphorus load by a slight margin over LOO.

Due to the large acreage of grass in the subwatersheds of LCT-1A, 1 and 4, the phosphorus load was minor as grass increases infiltration of run-off and reduces erosion. Sources of phosphorus at LCT-3 were primarily from sediment run-off from increased land slope. Cattle also used the sediment basin during summer and fall for watering. The lack of riparian vegetation from season long grazing increases the likelihood of increased suspended solids. The presence of cattle surrounding the structure also increased the suspended sediment load. Suspended sediments typically carry a large phosphorus load.

The higher phosphorus load at site LOO was related to increased suspended sediment concentrations during the limited run-off period. Carp loitering at the mouth of the inlet were observed stirring up bottom sediment. Because phosphorus is attached to the sediment, the phosphorus load also increased. When carp were present at the inlet, suspended solids concentration averaged 82 mg/L and when carp were not present average suspended solids concentration was 7.5 mg/L. The total phosphorus concentrations with the presence of carp and the absence of carp were 0.134 mg/L and 0.059 mg/L, respectively. Since the AGNPS model could not compensate for the carp activity at the Lake Oliver outlet (LOO), the loadings from the model for LOO were estimated at only 6% of the total phosphorus yield. The water quality samples estimated the phosphorus load at site LOO to be 39% of the total to Lake Cochrane.

The AGNPS model identified the subwatershed above site LCT-3 as the largest contributor of phosphorus (57% of total). The model found high fertilizer availability in the small areas of cropland upstream of the pasture. The AGNPS model also agreed with the water quality sampling in that the drainage above site LCT-2 had the highest loss per acre of any other subwatershed (2.58lbs./acre). The loss per acre at site LCT-2 was twice as high as any other subwatershed according to the AGNPS model.

Total Dissolved Phosphorus

The total load and per acre loading for total dissolved phosphorus are shown in Table 18 below.

Dissolved phosphorus is the fraction of phosphorus readily available for uptake in plants. Dissolved phosphorus will sorb onto suspended particles if they are present in the water sample. Overall, the total load of dissolved phosphorus to Lake Cochrane is extremely small (7.52 kg). As can be seen from the table, sites LCT-1A and LCT-4 had very little of the total load of dissolved phosphorus to Lake Cochrane (0.2% and 4%, respectively). As with most water quality samples, inflow into Lake Cochrane, site LCT-2, had the most per acre load and site LCT-3 had the greatest load. Because of the carp and the sediment at Site LOO, the site has relatively small dissolved phosphorus concentrations. Typically in high sediment areas, total phosphorus concentrations increase and dissolved phosphorus decreases as the dissolved fraction sorbs on to the sediment particles.

Table 18. Summary of Lake Cochrane Total Dissolved. Phosphorus Tributary Information.

Site	Percent Watershed	Hydrologic Load (Acre-feet)	Total Load (kg)	Percent Load (%)	Load/Acre (kg/Acre)
LCT-1A	0.07%	0.2%	0.02	0.2%	0.018
LCT-1	3.62%	1.3%			
LCT-2	7.25%	10.5%	1.69	22.5%	0.017
LCT-3	33.33%	51.0%	3.64	48.4%	0.008
LCT-4	5.07%	3.6%	0.35	4.7%	0.005
LOO	**39.13%**	33.4%	1.82	24.2%	0.003
TOTAL	**88.47%**	**192.85**	**7.52**	**100%**	**Mean–0.0102**

Lake Oliver Water Quality

Table 19 below shows the location of the tributaries entering Lake Oliver and the duration of the flows used to calculate loadings during the 1999 sampling season.

Table 19. Latitude and Longitude of Lake Oliver Tributary Sites.

Site	Latitude	Longitude	Duration of Run-off During 1999
LOT-1	-96.4802552	44.7236646	April 3 -- July 7
LOT-2	-96.4813260	44.7227490	March 1 – June 29
LOT-3	-96.4801770	44.7201918	Flowed slightly in the spring and then only during heavy storm events.
LOT-4	-96.4802202	44.7165583	March 2 -- July 12 - After July 12, flow occurred only during storm events.

None of the tributary sites, except site LOT-4, had any flow after July 7, 1999. Site LOT-1 was downstream of a small wetland. The outlet to the wetland had been blocked, and due to the small seepage of water, no samples could be collected. Run-off from LOT-2 also settled into a small wetland/ditch before entering Lake Oliver. Site LOT-3 targeted a small watershed of CRP land so the run-off was minimal and extremely well filtered (Figure 23). Collecting samples at these intermittent samples sites was difficult.

Land area targeted by Site LOT-4 composed 83% of the watershed and made up 70% of the tributary flow to Lake Oliver. The 440 acres of land upstream of the site was a mix of wetlands, grass, CRP, hay, and a small amount agricultural row crops.

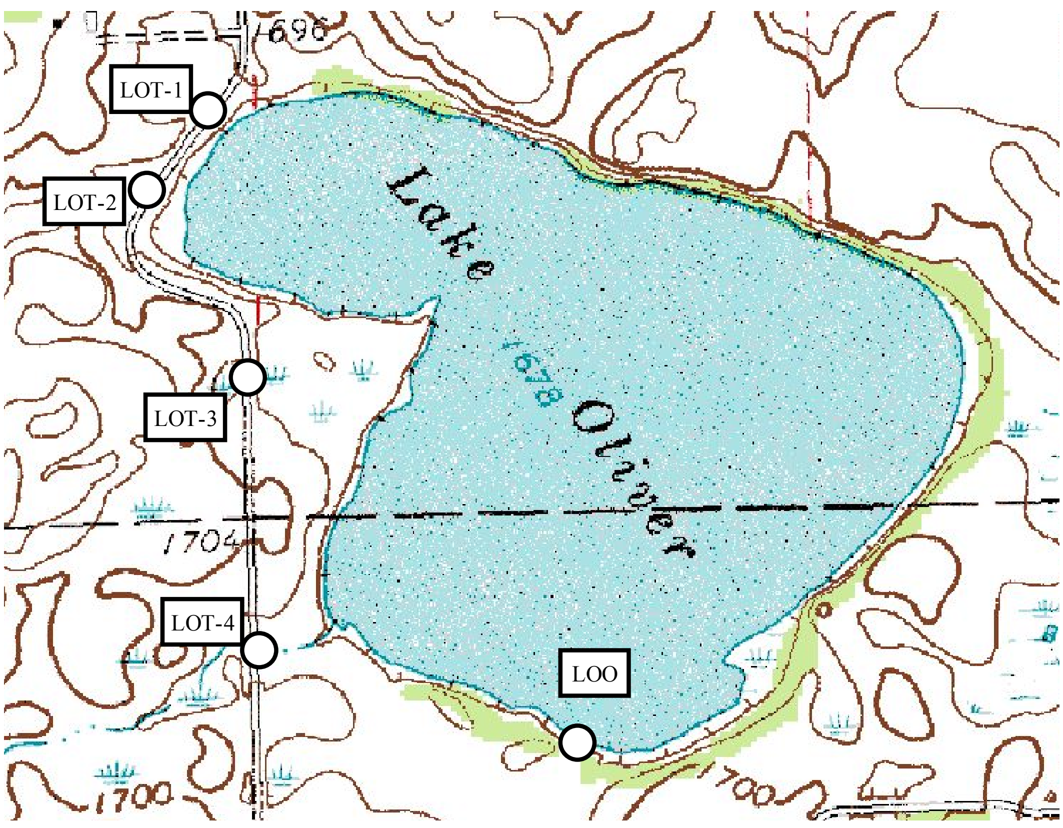


Figure 23. Location of Lake Oliver Tributary Sites.

Total Solids

Table 20 below shows a summary of total solids from the tributaries of Lake Oliver.

Table 20. Summary of Lake Oliver Total Solids Tributary Information.

Site	Average Total Solids Concentration	Average Dissolved Solids Concentration	% Dissolved Solids
LOT-1	3000 mg/L	2992 mg/L	99.7%
LOT-2	1076 mg/L	1041.8 mg/L	96.9%
LOT-3	460.5 mg/L	450 mg/L	97.7%
LOT-4	1296 mg/L	1205.8 mg/L	93.0%

Tributary samples receiving water from shallow wetlands or ground water typically have higher total dissolved solids concentrations than samples consisting of mainly surface water run-off. Site LOT-3 had lower total solids and total dissolved solids concentrations (Table 20). LOT-3 was most likely fed by surface run-off rather than ground water springs. The remaining sites were most likely spring-fed or received water from ponds concentrated by evaporation. Site LOT-1 most likely had higher total solids concentration due to evaporation of the water in the wetland upstream of the sampling site.

Suspended Solids

The total loadings collected from site LOT-1 and LOT-3 were negligible (Table 21). The high loadings at Site LOT-2 were a reflection of one sample (286 mg/L) collected on March 23, 1999. The next highest suspended solids concentration collected in the entire watershed was17 mg/L. The sample at LOT-2 may have been improperly collected due to the shallow nature of the site. The sampler may have inadvertently collected sediment from the bottom of the stream. This one sample increased the 1999 average sample concentration by 28 mg/L. By removing the high sample and replacing it with the site average without an outlier (6 mg/L), the total load at site LOT-2 is reduced to 120.74 mg/L. If the sample was collected properly, the most likely source of the high suspended solids is gravel from the road running adjacent to the site.

Table 21. Summary of Lake Oliver Suspended Solids Tributary Information.

Site	% Watershed Area	Total Load (kg)	% Susp. Solids Load	% Volatile Susp. Solids	Load/Acre (kg/Acre)
LOT-1	1.9%	-	-	-	-
LOT-2	11.3%	**1,240.67**	**81%**	**76.8%**	**20.68**
LOT-3	3.8%	11.05	1%	0.5%	0.55
LOT-4	83.0%	277.63	18%	22.7%	0.63
TOTAL	**100%**	**1,529.35**	**100%**	**100%**	**Mean–7.2867**

Site LOT-4 received additional sediment from the construction of a wetland dam just upstream. That, coupled with the higher volume of water passing through the site, made site LOT-4 the more likely contributor of suspended solids. Including the 286 mg/L outlier at site LOT-2, the total loadings to Lake Oliver were still 6 times less than the total loadings to Lake Cochrane.

The percentages of suspended solids that were volatile (mostly organic) for sites LOT-2, LOT-3 and LOT-4 were 25%, 17%, and 33%, respectively. Such a small percent of organic matter points to a source of inorganic sediment. Because the drainage for LOT-2 and LOT-3 passes adjacent to a gravel road before entering their respective sample sites, dirt from the gravel road was a very probable source of inorganic sediment. The percent volatile solids at site LOT-4 was slightly higher than at the previously mentioned sites. A small border of an alfalfa field that remained unplanted may also have contributed to the suspended solids to site LOT-4 and LOT-2.

Ammonia

Of all the ammonia samples collected at Lake Oliver, only 4 samples contained any detectable amount of ammonia (detection limit $\leq$ 0.02 mg/L). As a standard practice, one-half of the detection limit is used to calculate loading (0.01 mg/L). Site LOT-2 rated high because all four detections were found coming from its drainage (Table 22). There were no detections of ammonia at any of the other sites. The most likely source of ammonia at site LOT-2 was decaying organic matter from the wetland immediately upstream of where the samples were collected. The total load of ammonia entering Lake Oliver was 4.5 less than the ammonia load entering Lake Cochrane.

Table 22. Summary of Lake Oliver Ammonia Tributary Information.

Site	% Watershed Area	% Hydrologic Load	Ammonia Load (kg)	% Ammonia Load	Load/Acre (kg/Acre)
LOT-1	1.9%	**2.4%**	-	-	-
LOT-2	11.3%	**27.4%**	**1.70**	**70%**	**0.03**
LOT-3	3.8%	**0.9%**	0.01	1%	0.00
LOT-4	83.0%	**69.3%**	0.71	29%	0.00
TOTAL	**100%**	**100.0%**	**2.42**	**100%**	**Mean–0.01**

Nitrate-Nitrite

Site LOT-4 had the greatest load of nitrate-nitrite (Table 23). However, only 5 out of 15 samples had nitrate-nitrite levels high enough to be detected (detection limit = 0.10 mg/L) at the South Dakota State Health Laboratory. By using one-half of the detection limit (0.05 mg/L) in the loading calculation, the volume of water at site LOT-4 was enough to make the estimated load 75% of the load to Lake Cochrane. Since most of the detections of nitrate-nitrite were in the spring, decaying organic matter from the watershed is the most likely source. However, the small amount of agricultural/hay land in the far western part of this subwatershed may also be responsible for the elevated nitrate reading.

Site LOT-2 had a relatively high nitrate loading considering the size of the watershed. As with the ammonia loadings, the decay of organic matter into inorganic nitrogen was a likely source for the elevated nitrate loads. The total load of nitrate-nitrite entering Lake Oliver was 5.5 times less than the nitrate-nitrite load entering Lake Cochrane.

Table 23. Summary of Lake Oliver Nitrate-Nitrite Tributary Information.

Site	% Watershed Area	% Hydrologic Load	Nitrate Load (kg)	% Nitrate Load	Load/Acre (kg/Acre)
LOT-1	1.9%	**2.4%**	-	-	-
LOT-2	11.3%	**27.4%**	2.26	25%	**0.04**
LOT-3	3.8%	**0.9%**	0.06	1%	0.00
LOT-4	83.0%	**69.3%**	**6.59**	**74%**	0.01
TOTAL	**100%**	**100.0%**	**8.91**	**100%**	**Mean-.0167**

Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) loadings and load per acre for Lake Oliver are shown in Table 24.

Table 24. Summary of Lake Oliver TKN Tributary Information.

Site	% Watershed Area	% Hydrologic Load	TKN Load (kg)	Percent TKN` Load	Load/Acre (kg/Acre)
LOT-1	1.9%	**2.4%**	-	-	-
LOT-2	11.3%	**27.4%**	26.14	26%	**0.44**
LOT-3	3.8%	**0.9%**	0.92	1%	0.05
LOT-4	83.0%	**69.3%**	**73.59**	**73%**	0.17
TOTAL	**100%**	**100.0%**	**100.65**	**100%**	**Mean–0.22**

TKN consists of both organic nitrogen and ammonia nitrogen. Sites LOT-2 and LOT-4 had the largest loads of TKN to Lake Oliver. The percent of TKN that was organic at sites LOT-2 and LOT-4 was 84% and 86%, respectively. Only one sample was collected at site LOT-1. That sample was 98% organic. The percent of nitrogen that was organic at site LOT-3 was 91%. Bacterial breakdown of organic matter in the wetlands of LOT-2 and LOT-4 were the most likely cause of the lower organic percentages. The overall load of TKN to Lake Oliver was 3.25 times less than the load to Lake Cochrane.

Total Nitrogen

Total nitrogen is the sum of TKN and nitrate-nitrite. Nitrogen can be converted from one form to another by bacterial processes. Nitrogen can also be added from and released to the atmosphere. Because of the variety of ways nitrogen can get into a water system and the fact that nitrogen is extremely water soluble, removal of nitrogen from a lake system is very difficult. As nitrogen is essential for plant growth, all inputs of nitrogen to a lake system should be identified and assessed. Because of the relatively high amount of TKN that was organic, total nitrogen closely followed the percent and per acre load of TKN. The portion of total nitrogen that is organic does not comprise a very influential volume of total nitrogen. It should be remembered that any form of nitrogen entering a lake system will eventually be converted to inorganic nitrogen and become available for uptake by algae or macrophytes. The load of total nitrogen to Lake Oliver was 116.27 kg (Table 25). Percentages of loading per site closely follow that of TKN nitrogen. The load of total nitrogen into Lake Oliver was approximately 3.3 times less than the load to Lake Cochrane.

Table 25. Summary of Lake Oliver Total Nitrogen Tributary Information.

Site	% Watershed Area	% Hydrologic Load	Total Nitrogen Load (kg)	Percent Total Nitrogen` Load	Load/Acre (kg/Acre)
LOT-1	1.9%	**2.4%**	6.71	5.8%	0.67
LOT-2	11.3%	**27.4%**	28.40	24.4%	0.47
LOT-3	3.8%	**0.9%**	0.98	0.8%	0.05
LOT-4	83.0%	**69.3%**	80.18	69.0%	0.18
TOTAL	**100%**	**100.0%**	**116.27**	**100%**	**Mean–0.22**

Total Phosphorus

The total phosphorus load, percent by subwatershed, and load per acre for Lake Oliver are shown in Table 26 below.

Table 26. Summary of Lake Oliver Total Phosphorus Tributary Information.

Site	% Watershed Area	% Hydrologic Load	Total Phosphorus (kg)	Percent Total Phosphorus Load	Load/Acre (kg/Acre)
LOT-1	1.9%	**2.4%**	0.18	3%	0.018
LOT-2	11.3%	**27.4%**	2.28	37%	0.038
LOT-3	3.8%	**0.9%**	0.19	3%	0.010
LOT-4	83.0%	**69.3%**	3.57	**57%**	0.008
TOTAL	**100%**	**100.0%**	**6.22**	**100%**	Mean 0.012

The total phosphorus load to Lake Oliver was concentrated in sites LOT-2 and LOT4. The load at LOT-2 was relatively high considering the small size of the watershed. Site LOT-2 had 27% of the hydrologic load and 37% of the total phosphorus load. Site LOT-4 had 69% of the hydrologic load and 57% of the total phosphorus load. The per acre load at site LOT-4 was lower than any other subwatersheds entering Lake Oliver.

Since the load of total phosphorus to Lake Oliver is relatively small, the sources contributing to the load were most likely natural. Dirt from the gravel road near the sample sites may have been responsible for phosphorus hits because 50% of the suspended solids load was inorganic. With such a small percentage of agricultural land in the watershed, sedimentation from the road seems to be a more likely source. Fecal matter from native wildlife or dead animals in the culverts entering the lake were another source of phosphorus to the lake. Decaying organic matter from the watersheds of sites LOT-2 and LOT-4 was one more likely source of phosphorus.

Because the loadings are relatively small and mostly natural, there are few, if any, agricultural practices to be implemented. Watershed protection and maintenance may be the best use of resources. The loading into Lake Oliver is approximately 3.5 times less than the phosphorus load to Lake Cochrane.

Total Dissolved Phosphorus

The total dissolved phosphorus load, percent by subwatershed and load per acre for Lake Oliver are shown in Table 27.

Table 27. Summary of Lake Oliver Total Dissolved Phosphorus Tributary Information.

Site	% Watershed Area	% Dissolved Phosphorus	Total Diss. Phosphorus Load (kg)	Percent Total Diss. Phosphorus Load	Load/Acre (kg/Acre)
LOT-1	1.9%	-	-	-	-
LOT-2	11.3%	59.2%	1.35	40%	0.023
LOT-3	3.8%	68.4%	0.13	4%	0.007
LOT-4	83.0%	54.1%	**1.93**	**56%**	0.004
TOTAL	**100%**		**3.41**		Mean 0.007

The approximately 60% or less of the total phosphorus entering Lake Oliver was dissolved. This percent of dissolved phosphorus is typically found when inorganic sediment is found in a sample. As stated in the suspended solids portion of the Lake Oliver tributary discussion, the gravel road next to the sites may be responsible for the large percent of inorganic sediment. Dissolved solids are readily available for uptake by plants. If the phosphorus attached to the suspended sediment enters the lake it can be released into the water column through natural lake processes. Lake Oliver receives approximately one-half of the dissolved phosphorus of Lake Cochrane.

Fecal Coliform

Fecal coliform concentrations entering Lake Oliver had a relatively large seasonal variation. The spring samples were, for the most part, at or below the detection limit. During the summer months the fecal coliform concentrations increased to much higher levels (Figure 23). The most likely source of the higher fecal concentrations was the fecal matter of natural wildlife or domestic animals traveling through and around the culvert where the samples were collected. Fecal matter from small mammals was found in and around the sample sites in the summer.

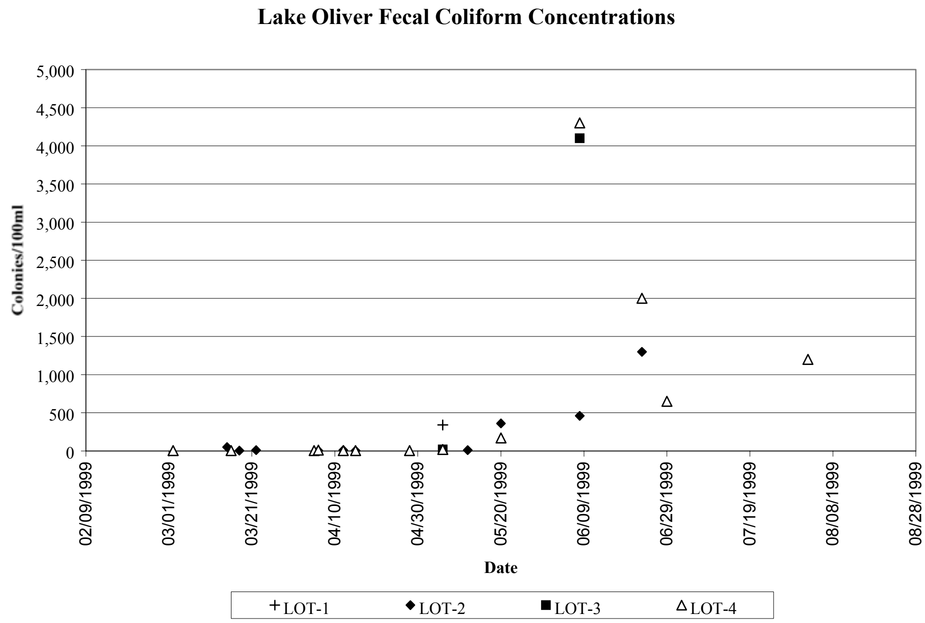


Figure 24. Lake Oliver Tributary Fecal Coliform Concentrations.

WATER, SEDIMENT, and NUTRIENT LOADINGS

Lake Cochrane

Hydrologic Budget

As stated in the Methods and Materials section of the report, all the major, and some minor tributaries, coming into Lake Cochrane were sampled. The hydrologic budget explains how much water entered the lake and how much water left the lake. The hydrologic, sediment and nutrient budgets will be based on the 1999 sampling season (April to October). Sampling and gauging began when ice left the stream and continuous discharges could be sampled.

The hydrologic inputs to Lake Cochrane included precipitation, tributary run-off gauged and ungauged, and ground water. Hydrologic outputs from Lake Cochrane included the water leaving over the spillway from the beginning of April to the end of October during 1999, evaporation, and ground water. Evaporation data was acquired from the publication Climate of South Dakota published November, 1971. Monthly precipitation data was taken from the rain gauges installed in the watershed. Tributary sites were gauged when possible, and, as stated in the previous section, ungauged discharge was estimated using the gauged data and the AGNPS model. After calculations were completed ungauged run-off was estimated to be negligible.

After all of the hydrologic outputs were subtracted from the inputs, only 117.44 acre-feet (144,876 cubic meters) were unaccounted for. The only source not yet accounted for was ground water. Ground water inputs or outputs are typically very difficult to estimate. If surficial aquifers are near streams and reservoirs they can add or take away large quantities of water. In Enemy Swim Lake, the ground water contribution appears to be negligible as input volumes were very close to the output volume.

The largest source of water input was precipitation with 66.7% (Figure 25). Site LCT-3 was the tributary with the largest water load with approximately 11 percent of the total load. Lake Oliver was responsible for approximately 7 percent of the load to Lake Cochrane. The input of ground water to Lake Oliver was approximately 117 acre-feet (13%) (Table 28). The amount of ground water would equate to approximately 6 inches (15.24 cm) of water over the entire surface of the lake.

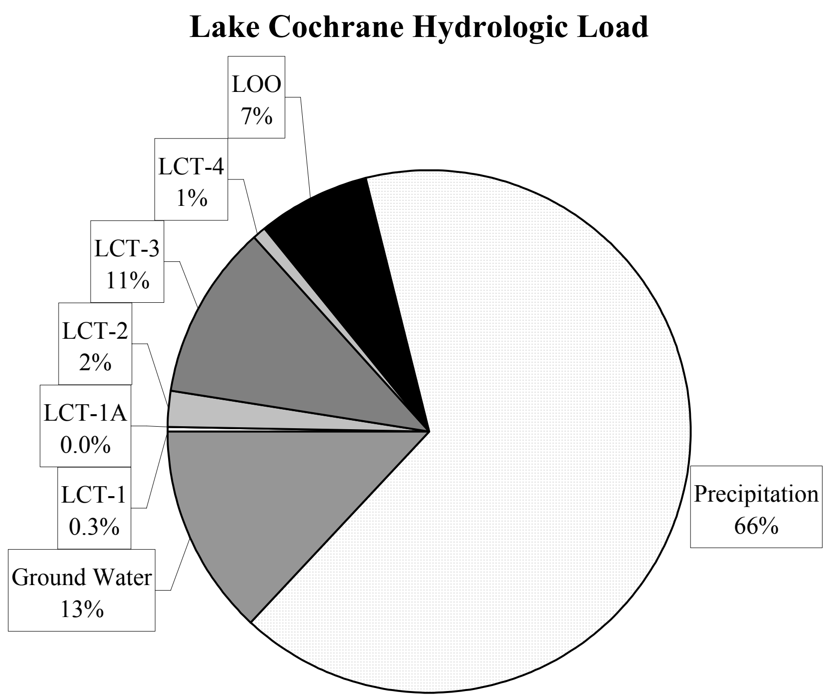


Figure 25. Lake Cochrane Hydrologic Load.

Table 28. Input and Output Sources of Lake Cochrane.

INFLOW		OUTFLOW	
Source	**Acre-Feet**	**Source**	**Acre-Feet**
Site LCT-1	2.55	Outlet (LCO)	50.77
Site LCT-1A	0.35	Evaporation (34")	1,037.00
Site LCT-2	20.29		
Site LCT-3	98.43	**Change in Storage**	**-183.00**
Site LCT-4	6.58		
Site LOO	64.38		
Precipitation (19.5")	594.75		
**Groundwater*	*117.44*		
TOTAL	**904.77**	**TOTAL**	**904.77**

* Calculated

The change of storage was measured by recording the depth of Lake Cochrane from the start of the project to the end of the project. Ground water was calculated from the loss difference of all of the known sources. Lake Cochrane has had periods when the lake has not reached the outlet level. Lake Cochrane appears to be ending a trend of high water and entering another cycle of lower water levels. Conductivity trends in the lake can indicate periods of higher evaporation. Higher evaporation rates and less inflow concentrate dissolved solids which increases inlake conductivity. Figure 26 shows the recorded lake levels.

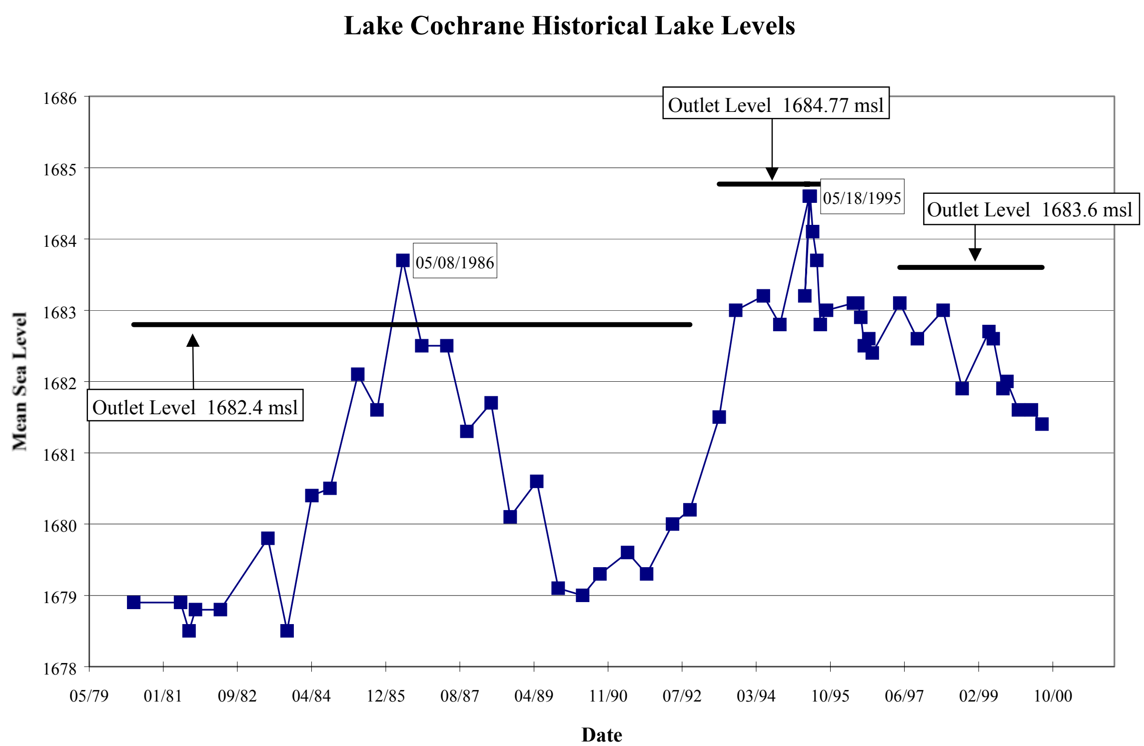


Figure 26. Lake Cochrane Historical Lake Levels.

Suspended Solids Budget

As described in the tributary section of the report, overall suspended solids from the watershed did not appear to be significant during the sampling period. According to the data collected, Lake Cochrane received an estimated load of approximately 2.9 cubic meters of sediment in 1999. The volume of sediment was calculated by dividing the annual kilograms of sediment by 2,162.5. One cubic meter of sediment weighs approximately 2,162.5 kilograms (135 lbs/ft^3) (NRCS).

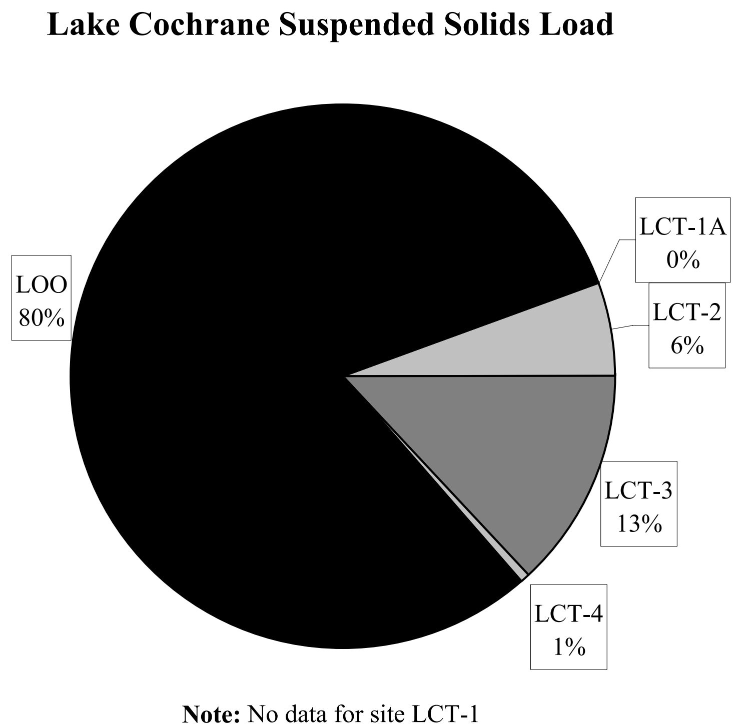


Figure 27. Lake Cochrane Suspended Solids Load.

As can be seen in Figure 27, site LOO was responsible for the majority of sediment entering Lake Cochrane. As stated in the suspended solids tributary discussion of this report, carp at the outlet of Lake Oliver were responsible for the increased suspended sediment load.

The AGNPS model predicted a much larger volume of sediment coming from the watershed at 87.38 cubic meters (114.3 cubic yards). The difference between the water quality sampling results and the AGNPS model may have been from the fact that the AGNPS model does not properly route sediment through sediment basins which retained much of the incoming sediment.

The calculated suspended solids leaving Lake Cochrane totaled 593.03 kg. The estimated volume of suspended solids leaving Lake Cochrane was 0.27 cubic meters. The resulting volume of suspended solids that remained in Lake Cochrane during this sample period was 2.6 cubic meters. This small volume is insignificant when spread over the area of the lake.

Nitrogen Budget

Sources of nitrogen entered Lake Cochrane from the tributaries, ground water and the atmosphere. Assuming ground water levels are relatively low, only tributary sample data will be used in the nitrogen budget discussion. Atmospheric nitrogen can enter a waterbody in many forms: as nitrogen, nitric acid, ammonia, nitrite, and as organic compounds either dissolved or particulate (Wetzel, 1983). It is impossible to know what ratio of inorganic to organic nitrogen entered the lake from the atmosphere. Because no water quality data from precipitation data was collected, the inputs will be estimated as minimal and not considered in this report.

The ammonia budget for Lake Cochrane showed an increase in inlake ammonia of 10.01 kg (22.08 lbs.) for the 1999 sampling season. As can be seen from Figure 28, the largest input was from site LOO. The load of ammonia at site LOO was significant partially because of the volume of water passing through the site and also the decaying organic matter that surrounded the area adjacent to the inlet. Eight-eight percent of the ammonia load to Lake Cochrane was lost to algae or converted to other forms of nitrogen. Ammonia is inorganic and used readily by algae for uptake and growth.

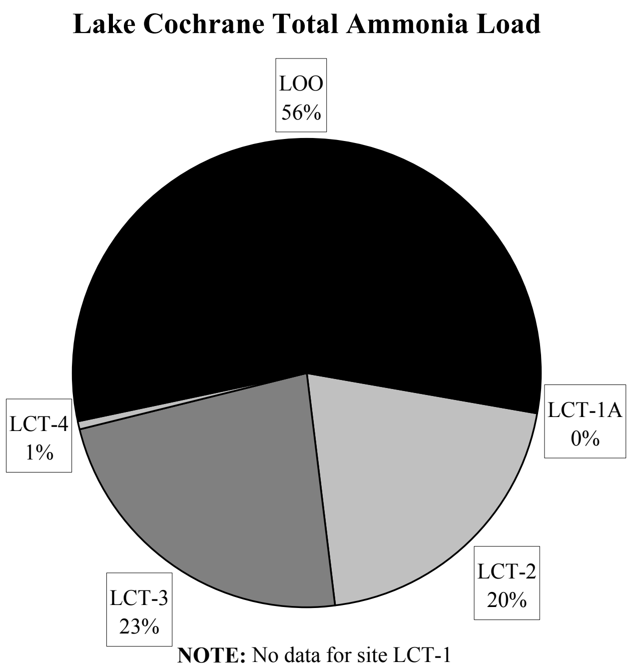


Figure 28 Lake Cochrane Ammonia Load.

Another inorganic parameter sampled was nitrate-nitrite. The nitrate-nitrite budget showed Lake Cochrane retaining approximately 92% of the nitrate to the lake. The nitrate load entering Lake Cochrane was either converted to another form of nitrogen taken up by aquatic life, or was lost to the ground water or the atmosphere. Site LCT-2 had the largest input of nitrate. This was most likely due to the breakdown of organic nitrogen in the sediments of the sediment basin. The resulting nitrate-laden water may then be seeping into the tube from a faulty closure valve. Plants can take up nitrate-nitrite nitrogen if available and then convert it to ammonia for use through a nitrate reduction process.

Total Kjeldahl Nitrogen (TKN) is a combination of organic nitrogen and ammonia. Due to the small fraction of TKN that is ammonia, TKN can be looked at as mainly organic nitrogen. Figure 29 shows both sites LCT-3 and LOO input 40% of the load to Lake Cochrane. The load from the outlet of Lake Cochrane was 3.7 times less than the loading from the inlet. The majority of TKN is organic. Typical sources include animal waste or vegetation from the watershed. If the TKN (organic nitrogen) is not dissolved, it can drop out of the water column once it reaches the lake. In the bottom sediments, TKN can be broken down to usable forms for algal and macrophyte uptake.

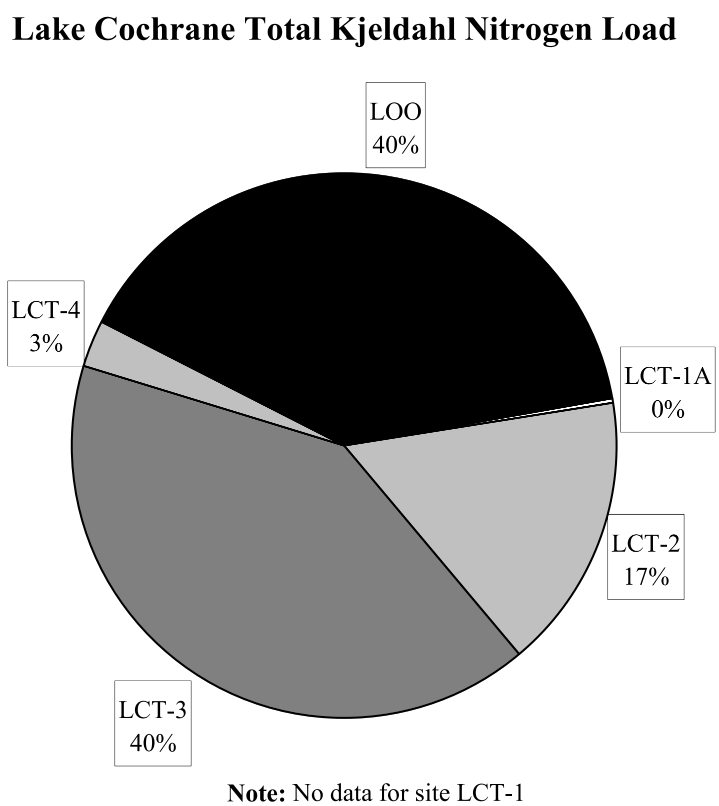


Figure 29. Lake Cochrane Total Kjeldahl Nitrogen Load.

According to the samples collected from April to October of 1999, the inlake quantity of total nitrogen in Lake Cochrane increased by 285 kg (628 pounds). The percentages of total nitrogen closely follow that of TKN nitrogen. The elevated nitrate concentrations at site LCT-2 increased the total nitrogen load at that site by approximately 6%. As all forms of nitrogen can at some time be broken down and reused for algal and aquatic plant growth, reducing the input of nitrogen to Lake Cochrane will be beneficial for reducing the lake's eutrophic state. However, since nitrogen is difficult to remove in a system and Lake Cochrane is phosphorus limited, resources should be concentrated on the removal of phosphorus. Typically, practices that remove phosphorus from a lake system also remove nitrogen. Total nitrogen loads were very similar to the TKN load due to the relatively small amount of nitrate-nitrite in the system (Figure 30).

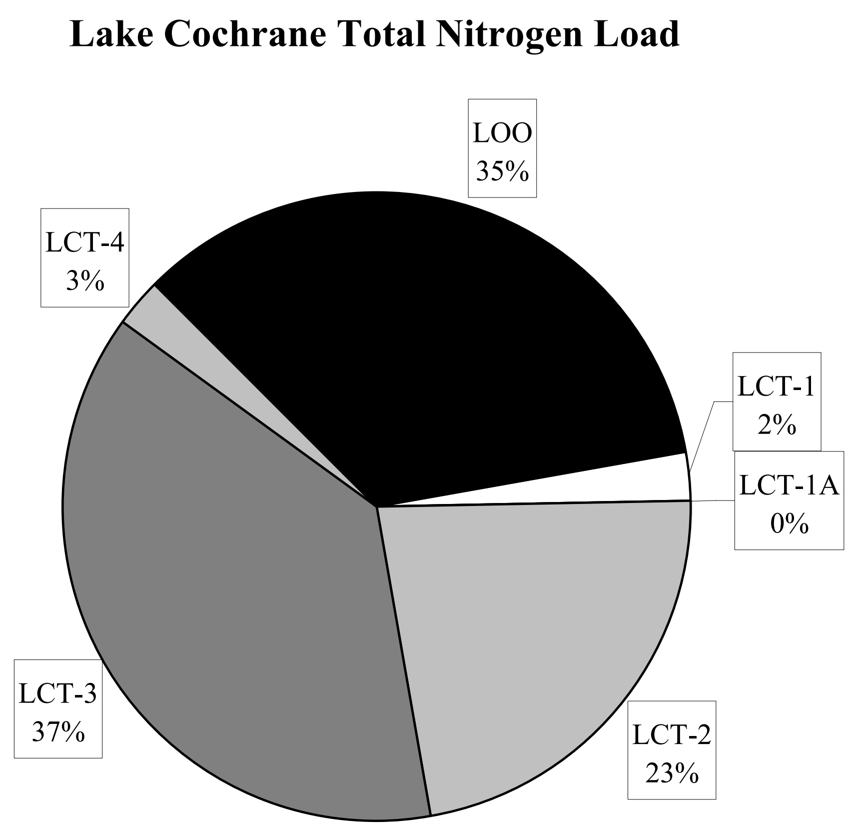


Figure 30. Lake Cochrane Total Nitrogen Load.

Phosphorus Budget

Total phosphorus input to Lake Cochrane during the 1999 sampling season totaled approximately 22.22 kg (49 lbs.). Inputs to Lake Cochrane included gauged tributaries, an estimate for ungauged tributaries, ground water, and precipitation. The precipitation and ground water load of phosphorus to most lakes is insignificant compared to tributary inputs. As with nitrogen, there is no way to know how much ground water entered the lake and how much left the lake. In addition, there is little that can be done to reduce or lessen the ground water and atmospheric phosphorus load. The tributary load at site LCT-1 was estimated by using the relative differences found between subwatersheds in the AGNPS model and applying the percent differences to actual water quality data collected. Thirty–nine percent of the phosphorus load came from site LOO. Since sediment carries a phosphorus load, the carp at the outlet of Lake Oliver were most likely contributing to much of the phosphorus load. Along with site LOO, site LCT-3 also carried 39% of the total load to Lake Cochrane (Figure 31). Sources from the LCT-3 subwatershed were most likely from livestock, decaying organic matter, and cropland. Site LCT-3 also had the largest load of dissolved phosphorus. Site LOO had a lower percentage of dissolved phosphorus most likely due to the increased sedimentation caused by carp (Figure 32).

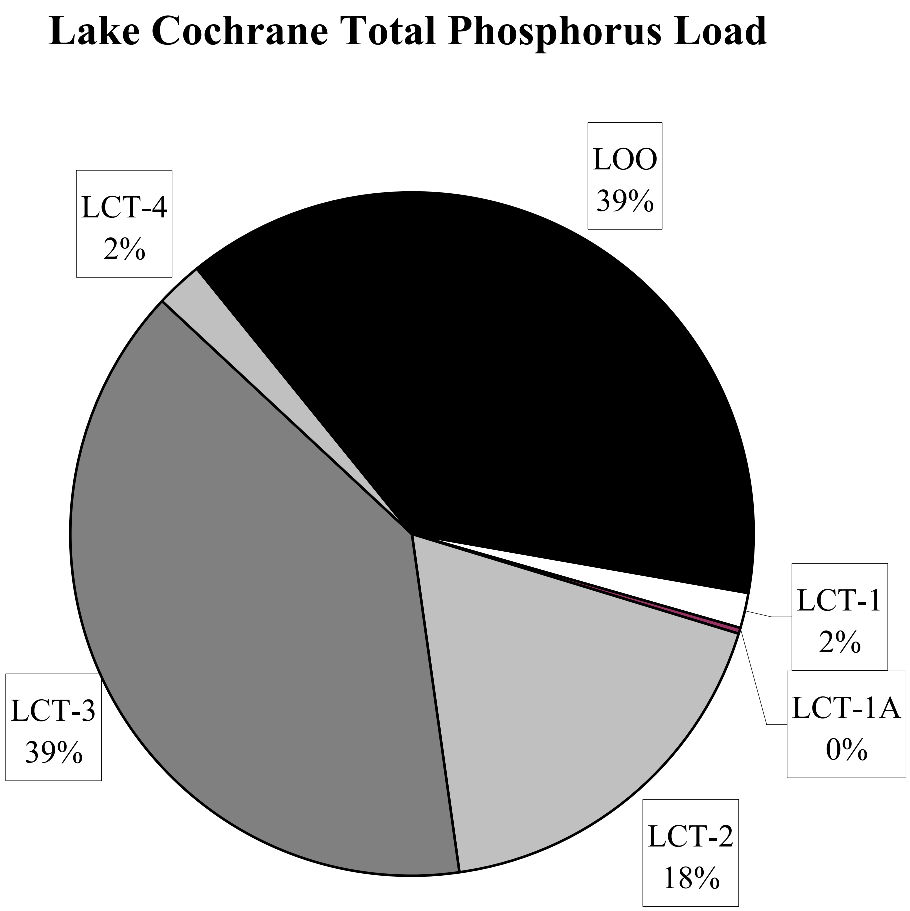
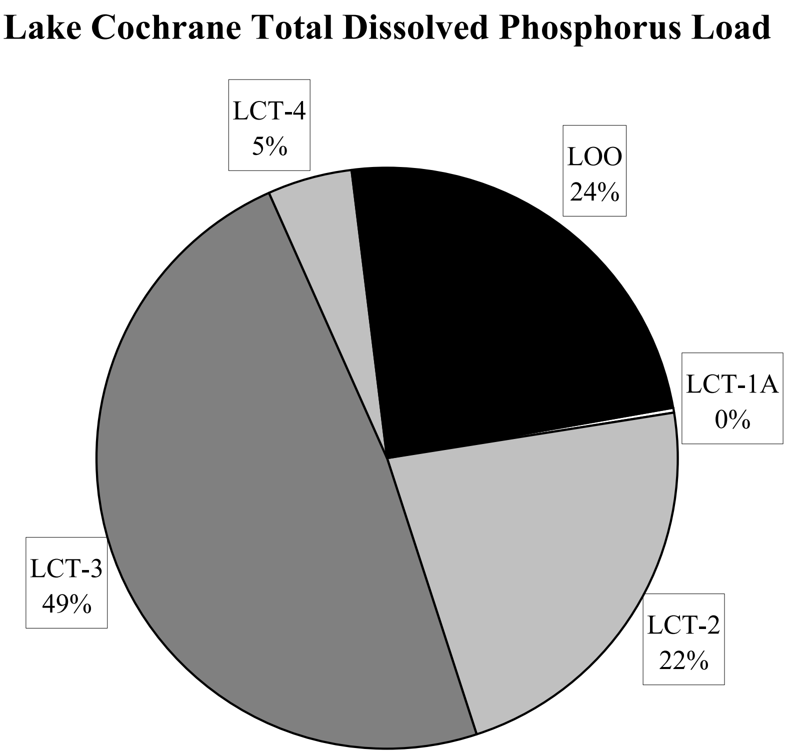


Figure 31. Lake Cochrane Total Phosphorus Load.

During the 1999 sampling season, it was estimated that 2.01 kg (4.43 lbs.) left Lake Cochrane through the outlet. The phosphorus attached to sediment typically is not released until oxygen levels are depleted. The phosphorus that entered Lake Cochrane attached to sediment was most likely not available for uptake by algae. The phosphorus may have been used by the many macrophytes that line Lake Cochrane's littoral zone. Due to low inlake concentrations and relatively little flow out Lake Cochrane's outlet, very little total phosphorus was calculated leaving Lake Cochrane. A total of 25% of the phosphorus output was of the dissolved fraction (0.50 kg).

Overall, the net amount of phosphorus remaining in Lake Cochrane was extremely low. The growing macrophytes could easily assimilate the small amount of phosphorus and use it for growth. Table 29 shows the summary of the discussed parameters and amounts left in Lake Cochrane.



Note: No data for site LCT-1

Figure 32. Lake Cochrane Total Dissolved Phosphorus Load.

Table 29. Amount of Sediment and Nutrients Left in Lake Cochrane.

Parameter	Left in Lake (kg)
Suspended Solids	5,734.49
Ammonia	10.01
Nitrate-Nitrate	45.74
TKN	239.14
Total Nitrogen	284.88
Total Phosphorus	20.21
Total Dissolved Phosphorus	7.02

Lake Oliver

Hydrologic Budget

As stated in the Methods and Materials section of the report, all of the major and some of the minor tributaries coming into Lake Oliver were sampled. The hydrologic budget explains how much water entered the lake and how much water left the lake. The hydrologic, sediment and nutrient budgets were based on the 1999 sampling season (April to October). Sampling and gauging began when ice left the stream and continuous discharges could be collected.

The hydrologic inputs to Lake Oliver included precipitation, tributary run-off (gauged and ungauged), and ground water. Hydrologic outputs from Lake Oliver included the water leaving the GF&P constructed outlet. The outlet structure is opened and closed according to the approved management plan. During 1999, water flowed out the outlet from April 9 to June 16. As with Lake Cochrane, evaporation data was gathered from the publication, Climate of South Dakota, published November, 1971. Monthly precipitation data was taken from the rain gauges installed in the watershed. Tributary sites were gauged throughout the project and discharge measurements were collected whenever possible.

After all of the hydrologic outputs were subtracted from the inputs, only 99.82 acre-feet (123,140 cubic meters) of water was unaccounted for. The remaining source not yet estimated was ground water. Ground water inputs or outputs are typically very difficult to estimate. If surficial aquifers are near streams and reservoirs, they can add or take away large quantities of water. In Lake Oliver the amount of ground water was estimated at 21% of the water load (Figure 33).

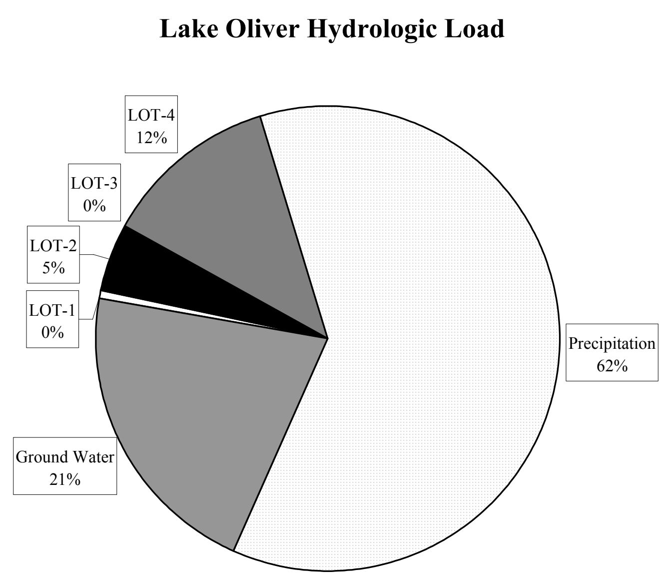


Figure 33. Lake Oliver Hydrologic Load.

The largest source of water input was precipitation with 62%. Site LOT-4 was the largest contributing tributary with approximately 12% of the water load. The input of ground water to Lake Oliver was approximately 100 acre-feet (Table 30). The amount of ground water would equate to approximately 6 inches (15.24 cm) of water over the entire surface of the lake.

Table 30. Input and Output Sources of Lake Oliver.

INFLOW		OUTFLOW	
Source	**Acre-Feet**	**Source**	**Acre-Feet**
Site LOT-1	2.00	Outlet (LOO)	64.38
Site LOT-2	22.78	Evaporation (34")	510.00
Site LOT-3	0.74		
Site LOT-4	57.54	**Change in Storage**	-99.00
Precipitation (19.5 in.)	292.50		
Ground water	99.82		
TOTAL	**475.38**	**TOTAL**	**475.38**

The change of storage was the change in depth of Lake Oliver from the start of the project to the end of the project. Ground water was calculated from the difference of all of the known sources. Lake Oliver has had extended periods when the lake did not reach the outlet level. Like Lake Cochrane, Lake Oliver appears to be ending a trend of high water and entering a cycle of lower water periods. Due to the low volume of water entering the lake, the water residence time of Lake Oliver is approximately 24 years. This figure was based on outflow information from only one year of sampling. If the water level of Lake Oliver does not reach the outlet, the residence time is much greater. Figure 34 shows the recorded historical lake levels and the changes in outlet level over recent years.

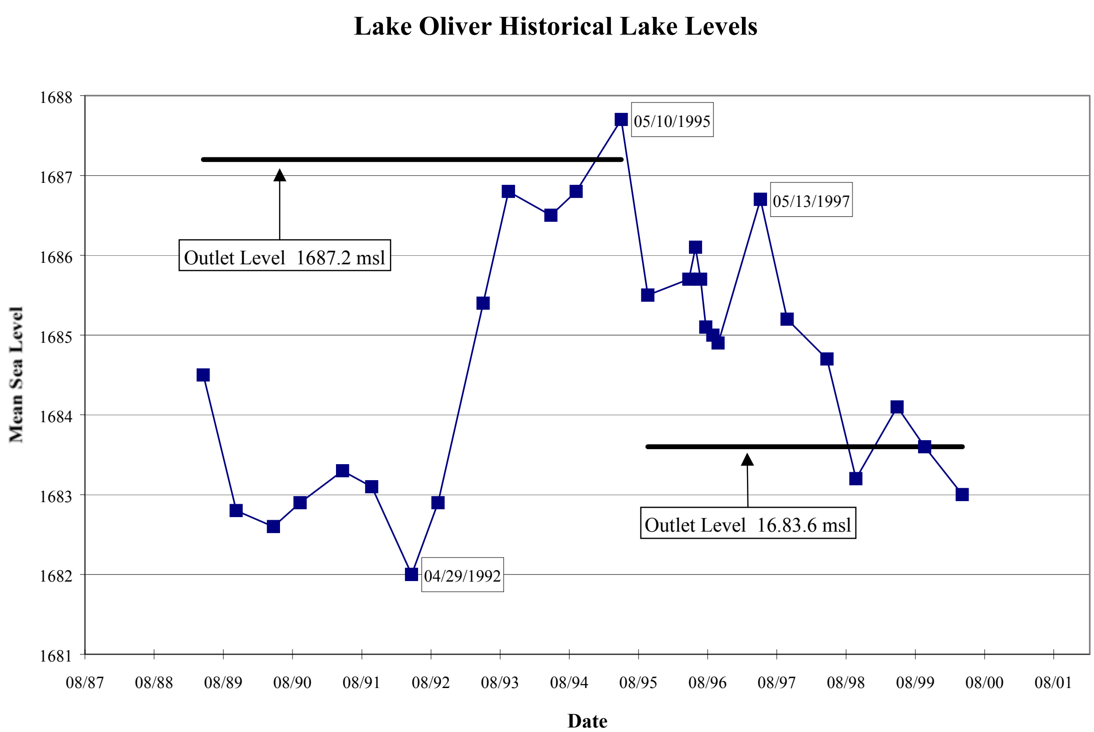


Figure 34. Lake Oliver Historical Lake Levels.

Suspended Solids Budget

The suspended solids load to Lake Oliver during the project period was much less than that delivered to Lake Cochrane. As described in the tributary section of the report, suspended solids from the watershed did not appear to be significant during the sampling period. According to the data collected and estimated from all of the tributaries, Lake Oliver received approximately 0.71 cubic meter of sediment in 1999. The volume of sediment was calculated by dividing the annual kilograms of sediment by 2,162.5. One cubic meter of sediment weighs approximately 2,162.5 kilograms (135 lbs/ft^3) (NRCS).

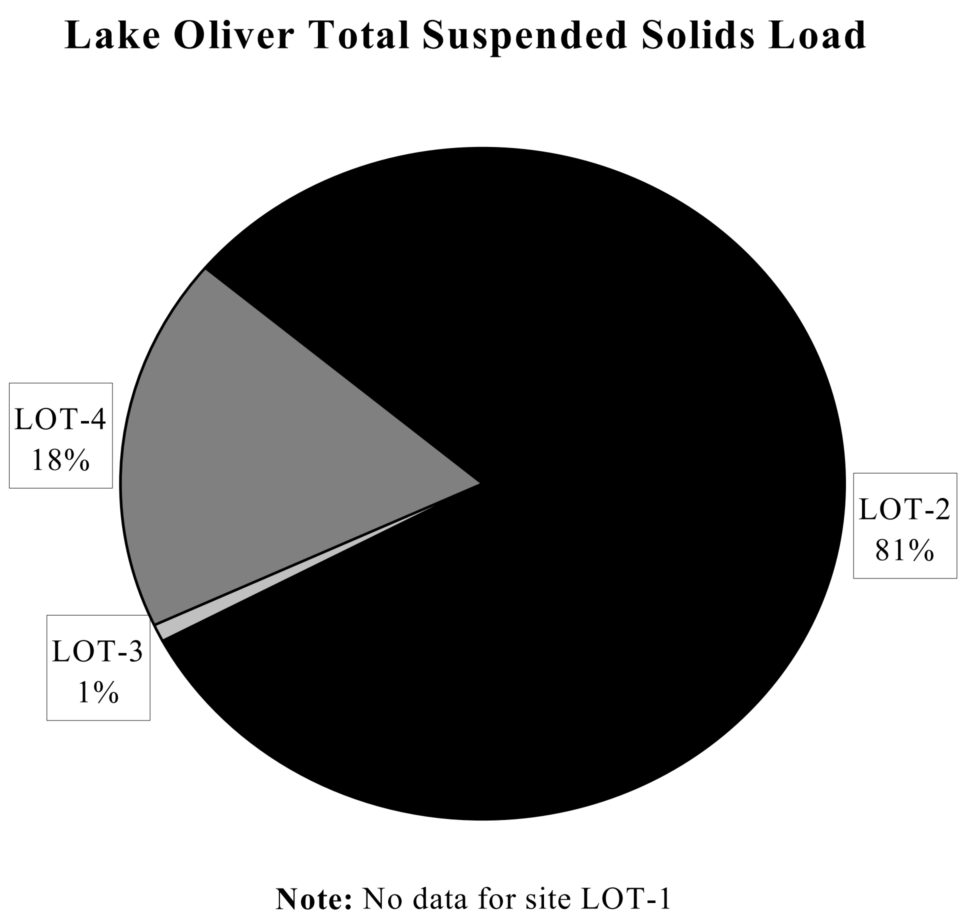


Figure 35. Lake Oliver Total Suspended Solids Load.

As can be seen in Figure 35 site LOT-2 was responsible for the majority (81%) of sediment entering Lake Oliver. As stated in the tributary discussion, this may have been an anomaly from one sample. The site received most of the sediment from the road that runs adjacent to the drainage.

The calculated suspended solids leaving Lake Oliver totaled 5,120 kg. The estimated volume of suspended solids leaving Lake Oliver was 2.37 cubic meters. The volume of sediment leaving the lake was 3 times greater than the volume entering Lake Oliver. Carp observed stirring sediment near the outlet of Lake Oliver were responsible for the increased loads leaving the lake. There does not appear to be any major loadings into Lake Oliver except the potential for larger sediment load from the watershed or road near site LOT-2.

Nitrogen Budget

Sources of nitrogen entered Lake Oliver from the tributaries, ground water and the atmosphere. Assuming ground water concentrations were relatively low, only tributary sample data will be used in the nitrogen budget discussion. Atmospheric nitrogen can enter a waterbody in many forms: as nitrogen, nitric acid, ammonia, nitrite, and organic compounds, either dissolved or particulate (Wetzel, 1983). It is impossible to know what volume of nitrogen entered the lake from the atmosphere. Because no water quality data from precipitation data was collected, the input from rainfall will be estimated as minimal and not considered in this report.

The ammonia budget for Lake Cochrane showed an decrease in inlake ammonia loads of 3.9 kg (8.6 lbs.) for the 1999 sampling season. Again, the carp at the outlet were most likely responsible for more ammonia leaving the lake than entering the lake. Ammonia concentrations tend to be higher in sediment where bacteria break down organic matter. Other factors that may have contributed to the fate may have been uptake by algae or conversion to nitrate-nitrite through bacterial oxidation. As can be seen from Figure 36, the largest input was again from site LOT-2 (71%). There is a small wetland located above the site which may be contributing to the increased ammonia load.

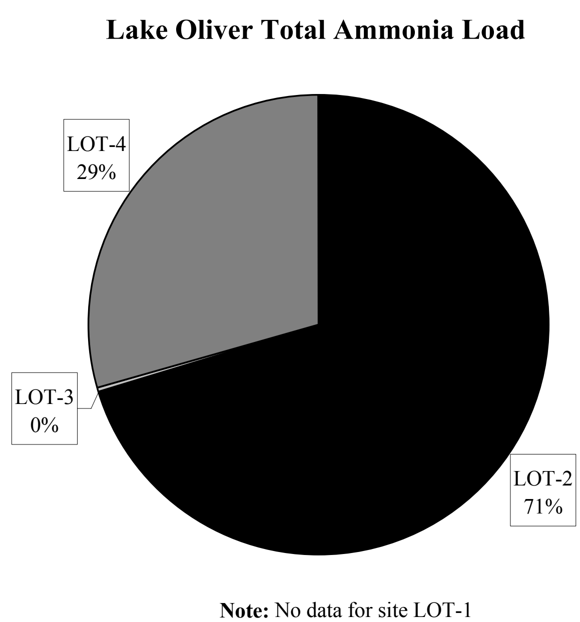
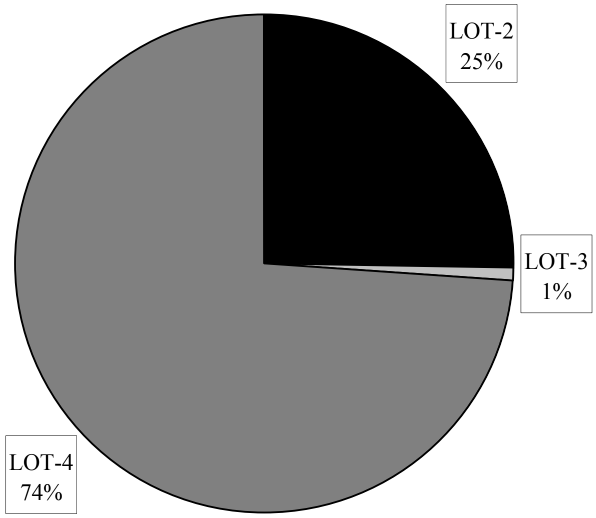


Figure 36. Lake Oliver Ammonia Load.

Lake Oliver Total Nitrate Load



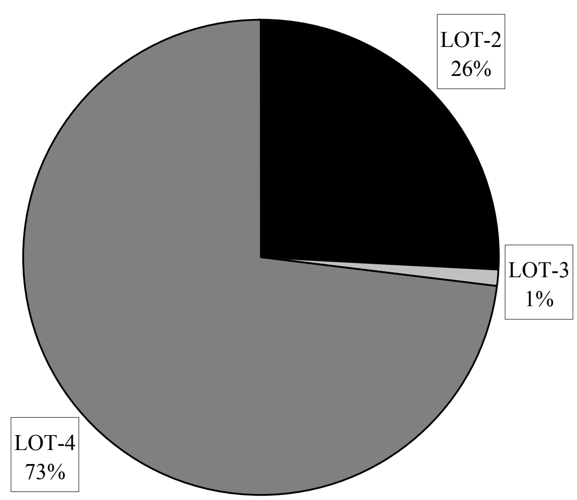
Note: No data for site LOT-1

Figure 37. Lake Oliver Total Nitrate Load

Another inorganic parameter sampled was nitrate-nitrite. The nitrate-nitrite budget showed Lake Oliver retaining approximately 54% of the nitrate load to the lake. The nitrate load entering Lake Oliver was either converted to another form of nitrate, taken up by aquatic life, or the atmosphere. Site LOT-4 had the largest input of nitrate (Figure 37). Site LOT-4 may be more oxygenated than site LOT-2. The more oxygenated water will carry more nitrate-nitrite while site LOT-2 carried more ammonia. Both inorganic forms of nitrogen are readily available for algal uptake.

Total Kjeldahl Nitrogen (TKN) is a combination of organic nitrogen and ammonia. Due to the small fraction of TKN that is ammonia, in most cases TKN can be considered as mainly organic nitrogen. Because TKN is such a large part of total nitrogen, the percentages of loading from the subwatershed sites are very similar. Figure 38 shows the percentages of TKN nitrogen. The total load of organic nitrogen to Lake Oliver during the project period was 100.65 kg. The load of total nitrogen was 116.27 kg. Site LOT-4 carries approximately 70% of the organic and total nitrogen load (Figure 39). The hydrologic load from site LOT-4 is also approximately 70%. The size of the watershed for site LOT-4 is over 80% of the total watershed to Lake Oliver. The nitrogen load appears to be a result of watershed size.

Lake Oliver Total Kjeldahl Nitrogen Load



Note: No data for site LOT-1

Figure 38. Lake Oliver Total Kjeldahl Nitrogen Load.

The load from the outlet of Lake Oliver was slightly higher than the loading of nitrogen into Lake Oliver. This again may be a result of the carp at the inlet or of internal loading. Internal loading may occur when the lake system has the ability to get nitrogen from sources within the lake itself. Due to the relatively small volume of nitrogen entering from the watershed, algae may take its nitrogen from the decay of organic matter in the lake sediments or from exchange of nitrogen with the atmosphere.

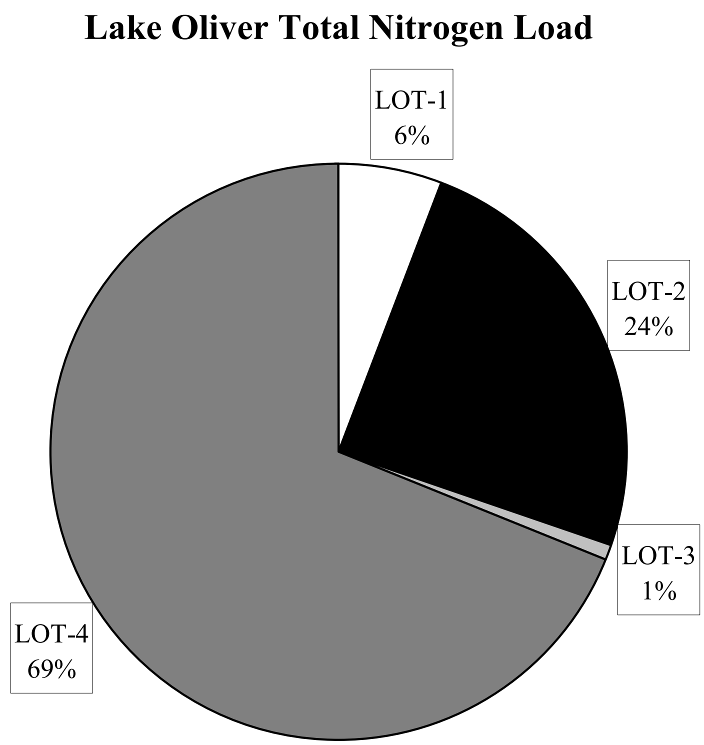


Figure 39. Lake Oliver Total Nitrogen Load.

The sources of organic nitrogen to Lake Oliver were most likely from run-off from vegetative areas or wetlands in the watershed. If the TKN (organic nitrogen) is not dissolved it can drop out of the water column once it reached the lake. In the bottom sediments, TKN can be broken down to usable forms of nitrogen. Algae or macrophytes can then use the converted nitrogen for growth. Since nitrogen is difficult to remove in a system and Lake Oliver is phosphorus limited, resources should be concentrated on the removal of phosphorus. Typically, practices that remove phosphorus from a lake system also remove nitrogen.

Phosphorus Budget

Total phosphorus inputs to Lake Oliver in the 1999 sampling season totaled approximately 6.22 kg (13.7 lbs.). Inputs to Lake Oliver included gauged tributaries, an estimate for ungauged tributaries, ground water, and precipitation. The precipitation and ground water load of phosphorus to most lakes is insignificant compared to tributary inputs. As with nitrogen, there is no way to know how much ground water entered the lake and how much left the lake. In addition, there is little that can be done to reduce the ground water and atmospheric phosphorus load. The tributary load at site LOT-1 was estimated by using the relative differences found in the AGNPS model and applying the percent differences to actual water quality data collected. Fifty-seven percent of the phosphorus load came from site LOT-4 (Figure 40). Site LOT-4 carries the majority (71%) of the water to Lake Oliver so it can be expected that the majority of the phosphorus comes from this subwatershed. Site LOT-2 however targets only a small percentage of the watershed and was responsible for 37% of the load to Lake Oliver during the project period. Since sediment carries a phosphorus load, the sediment at the site was the most likely source of the increased phosphorus load. Figure 40 shows the percent load of phosphorus from all of the tributary sites.

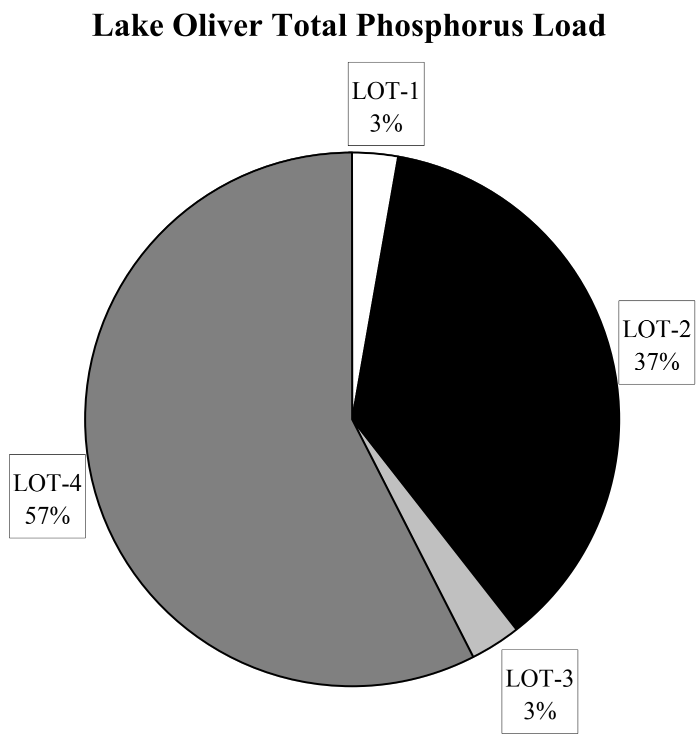


Figure 40. Lake Oliver Total Phosphorus Load.

During the 1999 sampling season it was estimated that 8.74 kg (19.27 lbs.) of phosphorus left Lake Oliver through the outlet. The extra phosphorus load at the outlet (LOO) may also have been from internal load. Internal load from Lake Oliver may have been from oxygen depletion of the microzone or from suspended bottom sediments through wind and wave action. Phosphorus-attached sediment stirred up by the carp however was the most likely source of the increased phosphorus load from the outlet. Without the carp, the phosphorus load through the outlet would have been approximately 85% less. In any case, the loading of phosphorus that left Lake Oliver was relatively low. Reducing the internal load would both improve the water quality of Lake Oliver and lessen the phosphorus load to Lake Cochrane. The percent loading from the tributaries for dissolved phosphorus closely follow that of total phosphorus.

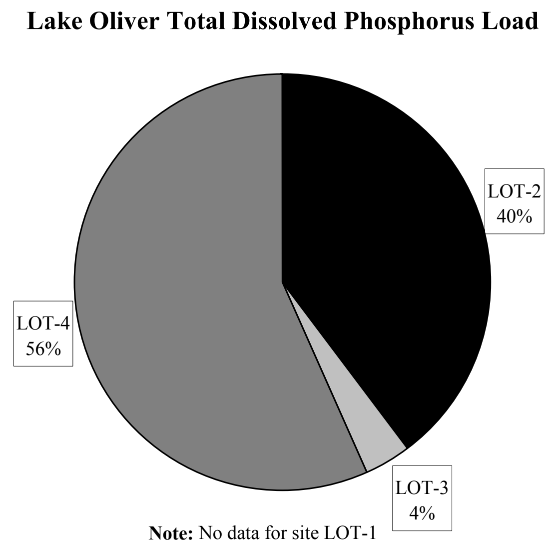


Figure 41. Lake Oliver Total Dissolved Phosphorus Load.

Lake Oliver retained a small amount of dissolved phosphorus (Table 31). Approximately 3.41 kg entered the lake as dissolved phosphorus and 1.86 kg (53%) left through the outlet. The remaining total dissolved phosphorus load, unlike total phosphorus, was retained in Lake Oliver. Due to the eutrophic condition of Lake Oliver, any available phosphorus was most likely immediately assimilated for algal growth. Used by algae or attached to sediment this fraction of phosphorus was no longer considered dissolved.

Table 31. Amount of Sediment and Nutrients Left in or Removed From Lake Oliver.

Parameter	Left in Lake* -- kg
Suspended Solids	(3,590.61)
Ammonia	(3.93)
Nitrate-Nitrite	4.8
TKN	(29.59)
Total Nitrogen	(18.08)
Total Phosphorus	(2.52)
Total Dissolved Phosphorus	1.59

* ( ) refers to more kg leaving the lake than entering the lake.

INLAKE DATA

Methods And Materials

Inlake water quality samples were collected once monthly (April-November) at three sites on Lake Cochrane and two sites on Lake Oliver (Figure 42). The South Dakota State Health Laboratory analyzed all samples. In the case when a nutrient parameter was not detectable by standard analytical procedures, a numeric value of ½ the detectable limit was used to represent the concentration for a given parameter. Undetectable concentrations do not necessarily suggest absence, however, the concentration is considered insignificant. Samples were collected at the surface and bottom at all sites for both lakes, respectively. The purpose of these samples was to assess the nutrient concentrations in the lakes and to determine their trophic condition. All samples were collected in compliance with the South Dakota Standard Operating Procedures for Field Samplers.

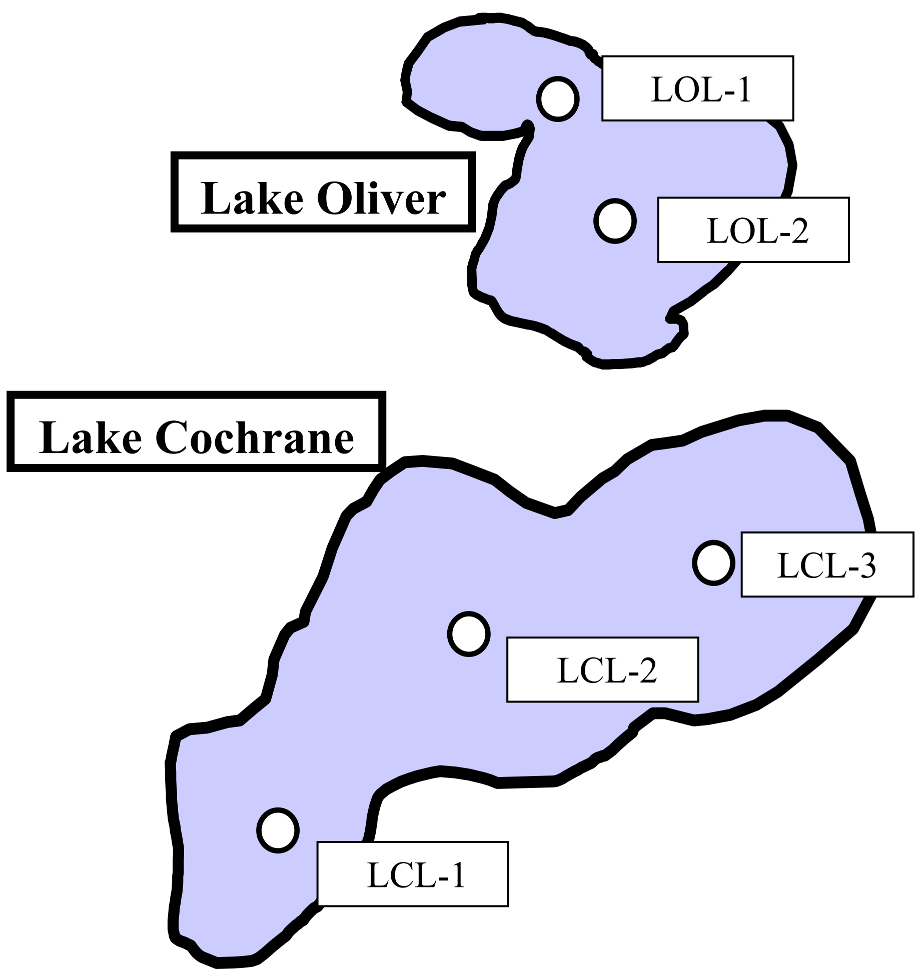


Figure 42. Location of Inlake Water Quality Sampling Sites.

Water quality parameters analyzed by the State Health Laboratory included:

Total Alkalinity	Total Solids	Total Suspended Solids
Ammonia	Nitrate-Nitrite	Total Kjeldahl Nitrogen
Fecal Coliform	Total Phosphorus	Total Dissolved Phosphorus

Water quality parameters which were calculated from the parameters above were:

Un-ionized Ammonia	Organic Nitrogen
Total Dissolved Solids	Total Nitrogen

In addition to the chemical water quality data above, physical and biological data were also collected. The following is a list of the field parameters collected:

Water Temperature	Air Temperature	Dissolved Oxygen
Field pH	Secchi Depth	

The biological parameters are listed below:

Chlorophyll *a*	Algae identification and enumeration

Chlorophyll *a* is an index used to determine quantity of algae present in the water. Algae were identified to determine the population dynamics and how they relate to water quality.

*All physical and biological parameters were collected using the standards methods described in the South Dakota Standard Operating Procedures for Field Samplers manual (Stueven, et al., 2000).

Quality Assurance/ Quality Control samples were collected in accordance to South Dakota's EPA approved Clean Lakes Quality Assurance/Quality Control Plan. This document can be obtained by contacting the South Dakota Department of Environment and Natural Resources at (605) 773-4254. A summary of QA/QC samples can be found in Appendix E.

Description of Physical and Chemical Parameters

pH is an index of how acidic or basic a solution is through the measurement of the hydrogen ion concentration. The pH of typical calcareous water is the result of the ratio of hydrogen ions (arising from the two dissociations of carbonic acid) to hydroxyl ions (provided by the hydrolysis of bicarbonate and carbonate). Photosynthesis is important to changes in pH. Plants and algae successively absorb carbon dioxide and eliminate bicarbonates, precipitate carbonates, and form hydroxyl ions. All these events can account for rises in pH. Also, extra hydrogen ions created from decomposition will tend to lower the pH in the hypolimnion. Decomposers (bacteria) will use oxygen to break down organic material into simpler inorganic forms. The lack of light in the hypolimnion prevents plant growth or photosynthesis, so no additional oxygen can be created. Typically, a high decomposition rate lowers oxygen concentrations and pH in the hypolimnion.

Dissolved oxygen (DO) is another important physical variable that is involved in two activities within an aquatic system. The first activity is respiration where oxygen is required to produce or maintain biomass for the entire aquatic community. The second activity is the biodegradation process where oxygen is used to break down organic substances (Cole, 1983). Lack of oxygen can put great stress on the aquatic system sometimes resulting in the death of organisms such as fish (winterkill and summerkill). Oxygen enters the system through the air-water interface by the process of diffusion, and through photosynthesis conducted by algae and aquatic macrophytes.

Alkalinity refers to the buffering capacity of a solution, and is usually identified as mg/L of CaCO3 (calcium carbonate). Carbonates and bicarbonates allow the water to adjust to the pH and never allow the pH to become acidic. The formal definition of alkalinity is the capacity of water to accept protons (H+). Alkalinity acts as a pH buffer and stores inorganic carbon which helps water support algal growth and other aquatic life (Manahan, 1990). The range of alkalinity values in the natural environment is usually from 20 to 200 mg/L (Lind, 1985).

Total solids are the material left after evaporation of a sample subsequent to the sample drying in the oven. Total suspended solids comprise the portion that is retained by a filter and the dissolved solids is the fraction which passes through the filter (APHA et al, 1995). Subtracting the suspended solids from the total solids yields the total dissolved solids concentration.

Ammonia is the initial product of the decay of organic wastes and is also the form which plants can easily use (Manahan, 1990). High levels of ammonia may indicate the presence of organic wastes or pollution.

Un-ionized ammonia (NH_4OH) can be highly toxic to many organisms, especially fish (Wetzel, 1983). Un-ionized ammonia is calculated from the total ammonia concentrations (mg/L), pH (su) and water temperature (C). Increases in temperature and pH usually result in an increase in the un-ionized ammonia concentrations. The concentration of total ammonia is variable, both seasonally and spatially, within each lake. The amount of total ammonia and un-ionized ammonia present also depends on how productive the lake is and how much organic material is present (Wetzel, 1983).

Nitrate and nitrite are inorganic forms of nitrogen. Both nitrate, nitrite and ammonia are the forms of nitrogen most easily assimilated by aquatic plants and algae (Wetzel, 1983). Sources of nitrate can include agricultural fertilization, loadings from septic tanks, sewage and industrial wastes, and the atmosphere. Ammonia (NH3) can be biologically converted into nitrate (NO3) through nitrification of bacteria (Nitrosomonas). Bacteria are also responsible for denitrification which takes place when nitrate and nitrite are converted to N_2, which is lost as nitrogen gas to the atmosphere (Manahan, 1990).

Total Kjeldahl Nitrogen (TKN) is used to calculate both organic nitrogen and total nitrogen. Total Kjeldahl nitrogen minus ammonia equals organic nitrogen. Total Kjeldahl nitrogen plus nitrate and nitrite is equal to the total nitrogen. Organic nitrogen can be released from decaying organic matter or it can enter the lake system from septic systems or agricultural waste. Organic nitrogen is broken down to usable ammonia and other inorganic forms of nitrogen.

Phosphorus concentrations greater than 0.02 mg/L indicate that a lake is eutrophic and may experience some algal blooms (Wetzel, 1983). The interest in phosphorus stems from its major role in biological production, which in this case means algal blooms. There are various chemical forms of phosphorus present in the lake environment. However, during the project only two forms were measured: total phosphorus and total dissolved phosphorus. The most important measure is the ***total phosphorus*** content of unfiltered water. It consists of phosphorus in the particulate form and in the dissolved form. Total phosphorus minus dissolved phosphorus equals the particulate form (Wetzel, 1983). ***Particulate phosphorus*** is sorbed to sediment or found locked within vegetation which uses phosphorus to create more biomass. Phosphorus differs from nitrogen in that it is not as water-soluble and will sorb on to sediment and other substrates. Once phosphorus sorbs to any substrate it is not readily available for uptake by algae. Phosphorus sources can occur naturally in the geography and soil, and from decaying organic matter, or be derived from septic tanks or agricultural run-off. When phosphorus enters a lake it is either consumed by the organic matter in bioproduction or it is lost to the sediments of the lake. The sediment layer of a lake will not give up phosphorus unless an anoxic (complete loss of oxygen) condition prevails, resulting in the reduction of the redox potential of the microzone. The phosphorus is then released from the sediment into the water column to be used by algae and other aquatic and semi-aquatic vegetation even though the lake does not stratify.

Total dissolved phosphorus is the fraction of total phosphorus readily available for use by algae. Dissolved phosphorus will sorb on to suspended solids or it may be immediately taken up by algae and aquatic plants.

Water Quality

<u>South Dakota Water Quality Standards</u>

The beneficial use classifications of surface waters of the state established in this section do not limit the actual use of such waters. The classifications designate the minimum quality at which the surface waters of the state are to maintained and protected (South Dakota Surface Water Quality Standards, 74:51:01:42. Beneficial uses of waters established.)

Lake Cochrane has been assigned the following water quality beneficial uses:

(4) Warmwater Permanent Fish Life Propagation
(7) Immersion Recreation
(8) Limited Contact Recreation

(9) Fish, Wildlife Propagation, Recreation and Stock Watering

Lake Oliver has been assigned the following water quality beneficial uses:

(6) Warmwater Marginal Fish Life Propagation
(7) Immersion Recreation
(8) Limited Contact Recreation
(9) Fish, Wildlife Propagation, Recreation and Stock Watering

In the case when beneficial uses have different standard limits for the same parameter, the most stringent standard is applied. Tables 32 and 33 indicate the most stringent standard limits for Lake Cochrane and Lake Oliver for the parameters analyzed in this study.

Table 32. Lake Cochrane Beneficial Use Criteria.

Parameter	Limits
Un-ionized Ammonia	< 0.04 mg/L
Dissolved Oxygen	> 5.0 mg/L
pH	> 6.5 and < 9.0 su
Total Suspended Solids	< 90 mg/L
Total Dissolved Solids	< 2500 mg/L
Temperature	< 26.67 ^{0}C
Fecal Coliform	< 400/100 mL (grab sample)
Alkalinity	< 750 mg/L
Nitrates	< 50 mg/L

Table 33. Lake Oliver Beneficial Use Criteria

Parameter	Limits
Un-ionized Ammonia	< .05 mg/L
Dissolved Oxygen	> 4.0 mg/L
pH	> 6.0 and < 9.0 su
Total Suspended Solids	< 150 mg/L
Total Dissolved Solids	< 2500 mg/L
Temperature	< 32.22 ^{0}C
Fecal Coliform	< 400/100 mL (grab sample)
Alkalinity	< 750 mg/L
Nitrates	< 50 mg/L

The only parameter that exceeded the water quality standards for Lake Cochrane was dissolved oxygen. A total of nine dissolved oxygen samples failed to meet the minimum standard of 5.0 mg/L. All nine exceedances occurred during the scheduled sampling period on July 21, 1999. Table 34 lists the dissolved oxygen exceedances for the three inlake sites.

Table 34. Dissolved Oxygen exceedances for Lake Cochrane July 21, 1999.

Site	Total Depth (ft.)	Sample Depth(ft.)	Dissolved Oxygen Concentration (mg/L)
LCL-1	13.5	12	4.6
LCL-1	13.5	13	2.4
LCL-2	20	18	4.2
LCL-2	20	19.5	4.0
LCL-3	26	20	4.4
LCL-3	26	22	2.6
LCL-3	26	24	2.6
LCL-3	26	25	2
LCL-3	26	25.5	1

Several contributing factors are possible for the decline in dissolved oxygen near the bottom reaches of the lake. It is typical of prairie lakes to stratify during the hot summer months especially in lakes with adequate depth such as Lake Cochrane. Stratification can be avoided through mixing caused by wind, though on this date (7/21/99) the wind was calm creating a stagnant situation. Foggy and cloudy conditions also prevailed during the sampling period decreasing the photosynthetic (oxygen-producing) capability of plants and algae. Dissolved oxygen depletion occurs when there is not enough oxygen being produced to sustain the loss of oxygen (biodegradation) from the decomposition and biodegradation of organic material. The average Secchi depth on this date was 3.2 ft. (0.98 meters) indicating a decrease in the ability of light to penetrate the lower reaches of the lake. The rate of biodegradation was most likely higher than the oxygen production especially in the low light reaches of the lake near the sediment. Lower pH concentrations near the bottom further indicate a potential increase in decomposition of organic material.

The pH levels were higher at the surface than near the bottom during this sampling period though they never exceeded the water quality standard of < 6 and > 9. Low dissolved oxygen and high pH combined with elevated temperature, can also be associated with an increase in the unionized fraction of ammonia. Total ammonia concentrations ranged from below the detection limit to 0.19 mg/L. No exceedance of unionized ammonia occurred .

LAKE COCHRANE INLAKE WATER QUALITY

Lake Cochrane is a small (366 acres) meandered prairie pothole lake with a maximum water depth of 26.5 feet (8.07 meters). A total of 24 surface and 24 bottom samples were collected over the course of eight months beginning April 20, 1999. A surface and bottom sample was collected once monthly for each of the three sites (Figure 43). Due to the short duration of the project, sampling was not conducted through the ice. The final lake sampling occurred on November 22, 1999. The following discussion will focus on the individual parameters and how they affect the water quality of Lake Cochrane.

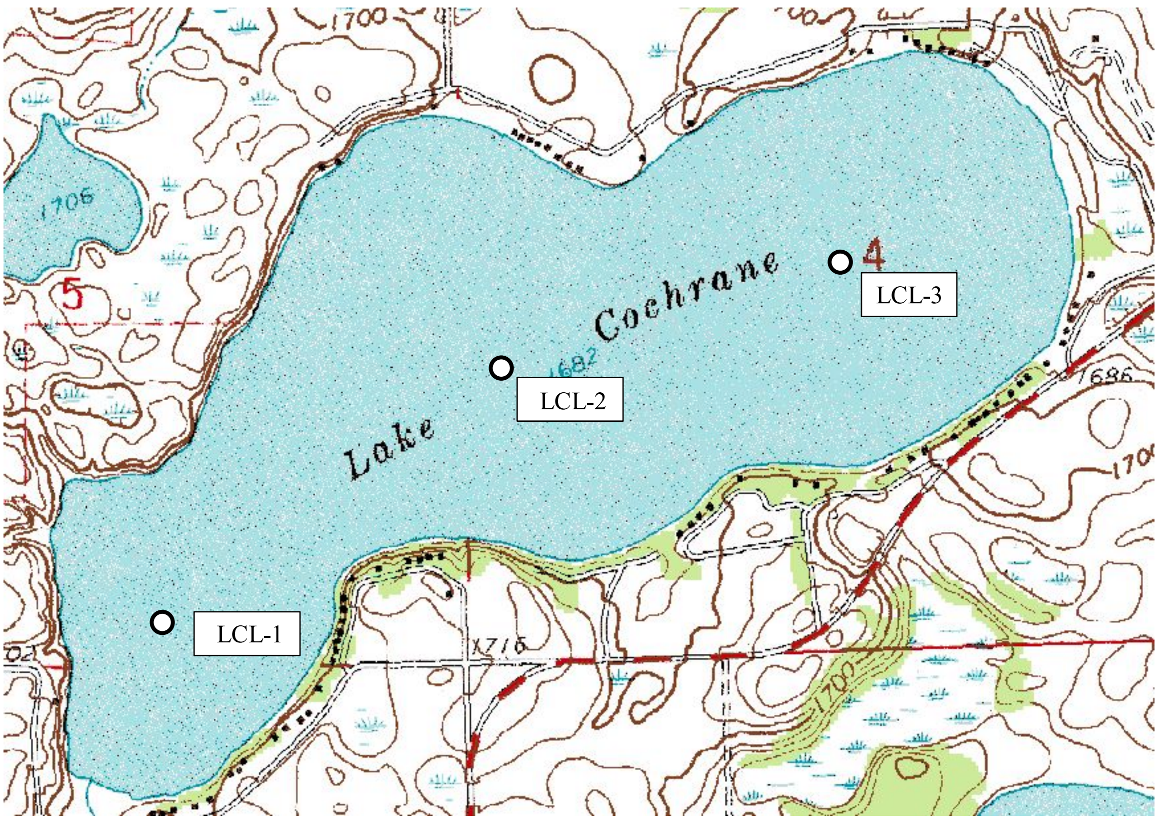


Figure 43. Lake Cochrane Inlake Monitoring Sites.

Water Temperature

Water temperature can be an important factor in many chemical and biological processes within a lake system. Higher temperature decreases the water's ability to hold gases (oxygen) in a solution (Cole, 1994). Dissolved oxygen is more likely to be held in a solution when lower temperatures are present. The un-ionized fraction of ammonia (toxic to fish) can increase proportionately with increasing water temperature. Algae population dynamics are dependent on temperature. Blue-greens are often found during higher water temperatures and green algae and diatoms are usually found during lower temperature periods (Wetzel, 1983). Fish life and propagation are also dependent on water temperature.

The overall average surface and bottom water temperature for Lake Cochrane was 15.0 ^{o}C and 14.9 ^{o}C respectively. No significant differences in temperature were observed from the surface to the bottom in any of the samples. The summer average surface water temperature was 20.8 ^{o}C compared to the summer average bottom water temperature of 20.7 ^{o}C (Figure 44). The data suggests that no thermocline was present in Lake Cochrane. Wind and wave action most likely kept Lake Cochrane's water column homogeneous throughout. The maximum surface water temperature was 24.5 ^{o}C sampled on July 21, 1999. On the same date the maximum bottom water temperature was 24 ^{o}C. During the sampling periods, no sign of thermal stratification was evident in Lake Cochrane. Complete temperature and dissolved oxygen profiles for all sample sites and dates can be found in Appendix G.

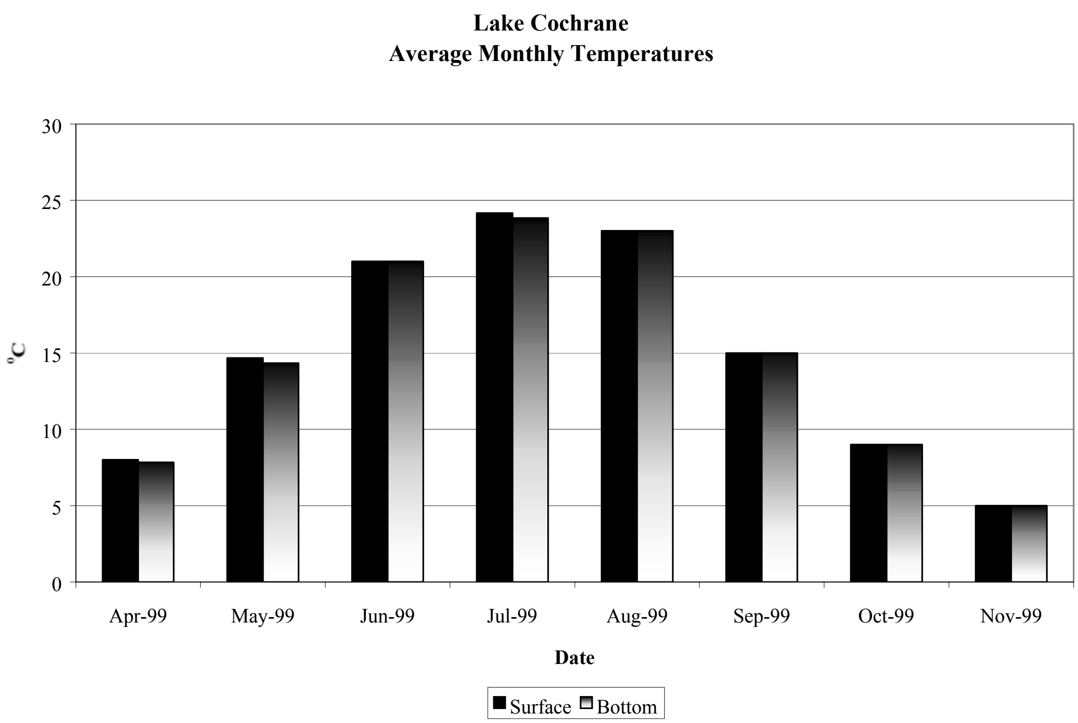


Figure 44. Lake Cochrane Average Monthly Temperatures.

Dissolved Oxygen (DO)

Dissolved oxygen is very important to the biological community, especially biota subject to the confines of an aquatic environment. In general, a concentration of ≤ 5 mg/L is stressful to aquatic vertebrates (fish) and most other aquatic life (Lind, 1985). Oxygen is produced and consumed within a lake system. Oxygen production is achieved through photosynthesis by organisms containing chlorophyll *a* (algae and macrophytes), as well as exchanges in the surface air-water interface. Decreases in oxygen can be attributed to the bacterial decomposition of organic material and respiration of algae, aquatic plants, and animals. Production and consumption can vary from the surface to the sediment especially in deeper lakes. Average DO concentration from all Lake Cochrane surface sites was 9.05 mg/L differentiating slightly from the average bottom concentration of 8.13 mg/L (Figure 45). With the exception of the July sampling period, dissolved oxygen concentrations were uniform from surface to bottom (Appendix G). Agitation from wind and waves most likely keeps the lake mixed and unable to stratify.

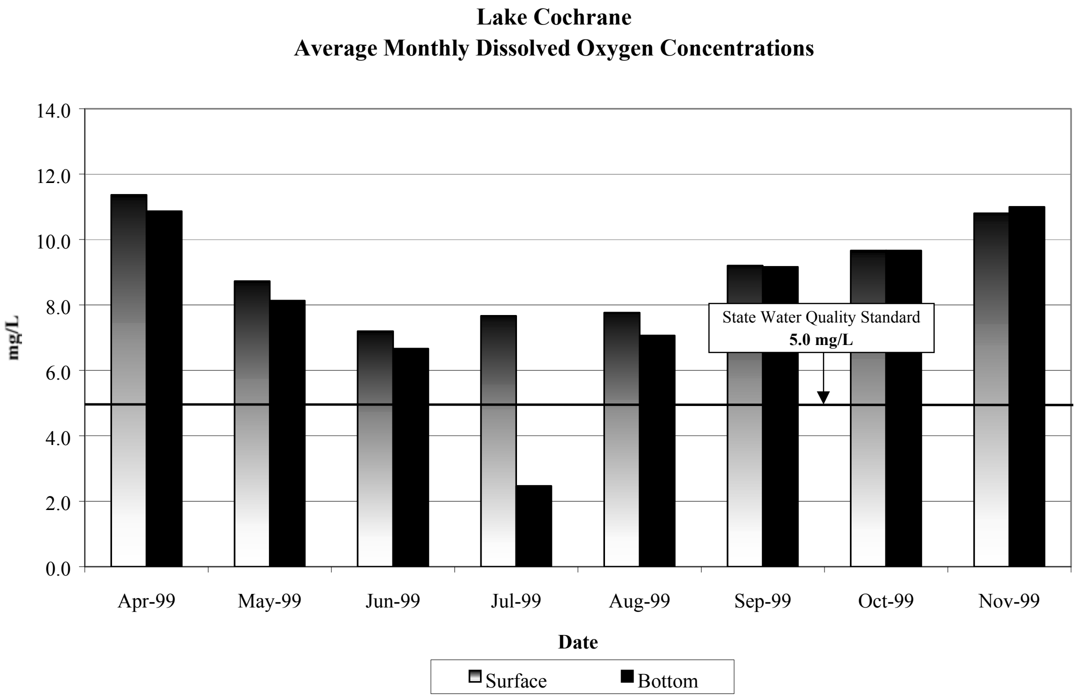


Figure 45. Lake Cochrane Average Monthly Dissolved Oxygen Concentrations.

The minimum DO concentration recorded during the study was 1 mg/L collected from the bottom (25.5 ft.) of site #3 on July 21, 1999. Low concentrations were also observed on this date near the bottom of sites LCL-1 and LCL-2 (Figure 46).

According to the coordinator's field notes, weather conditions were partly cloudy to cloudy and calm (no wind). The water appeared to have a stained appearance resembling weak tea. The average Secchi depth for all sites was only 0.98 meters (3.2 ft). Chlorophyll a concentrations were fairly high (35 mg/m^3), suggesting an algae bloom most likely shaded out sunlight and potentially caused the stained appearance. Cloud cover may have inhibited photosynthesis in the lower depths of the lake. The water color may also be contributed to humic matter and lignins from the abundant macrophytes in the lake. Lower pH concentrations at the bottom indicated that decomposition of organic material was likely occurring. Since biodegradation occurs mostly near the sediment, a reduction in oxygen is the result. Also, wind was not available to circulate the water column, allowing a band of low dissolved oxygen to form near the bottom.

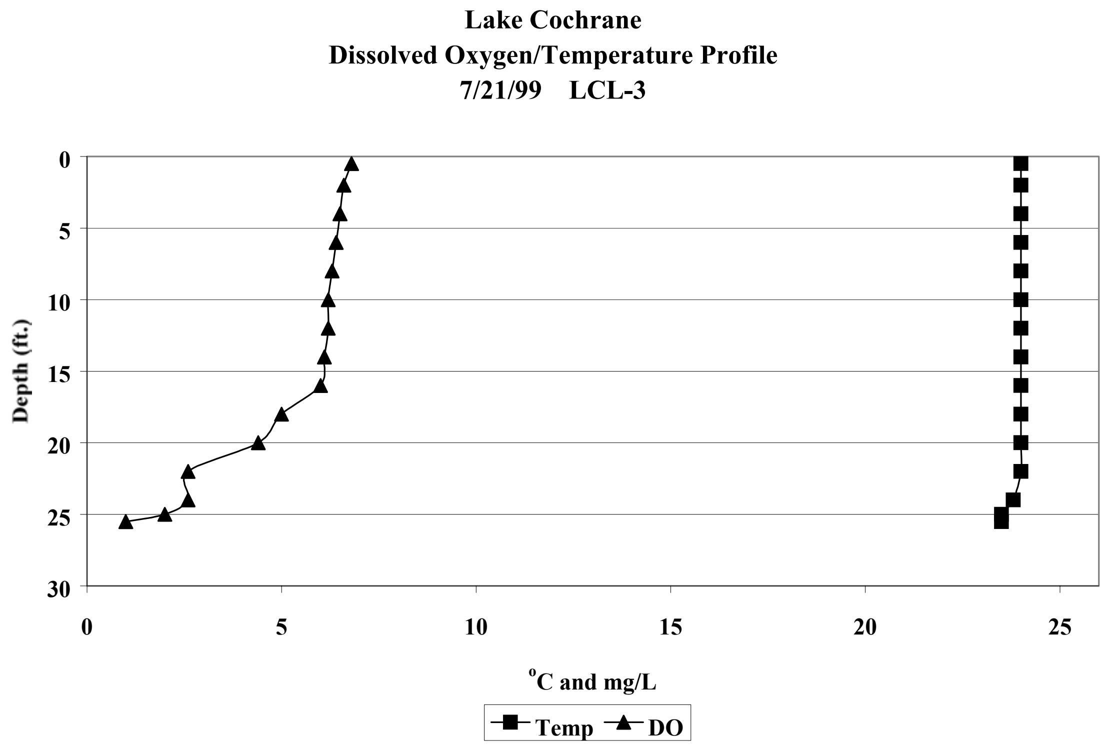


Figure 46. Lake Cochrane Diss. Oxygen/Temperature Profile 7/21/99 LCL-3.

On this date, conditions were met in which oxygen was being used more efficiently than it was produced. These conditions usually occur at night when photosynthesis ceases, and respiration and biodegradation prevail. Reid (1961) suggested that the maximum oxygen concentrations usually occur in the afternoon on clear days and the minimum immediately after dawn. No consideration was given during this study as to how DO concentrations react either at night or in the winter months when snow and ice can reduce sunlight penetration. Although a summerkill wasn't witnessed or reported during the study, several dead fish were documented after ice-off in April of 1999. Although a viral infection could have killed the fish, Lake Cochrane has in the past shown annoxia in both winter and summer (unpublished sources). Despite the low dissolved oxygen concentrations observed during this study most of the water column possessed adequate oxygen. Aquatic life (fish) could relocate to different depths to avoid being stressed.

pH

The pH is an index of how acidic or basic a solution is through the measurement of the hydrogen ion concentration. The pH rises with the production of oxygen in a system and lowers when oxygen is being used as in decomposition, for example. The pH of most natural waters falls in the range of 4.0 to 9.0 ,and much more often in the range of 6.0 to 8.0 (Lind, 1985).

The pH in Lake Cochrane demonstrated no significant differences from surface to bottom ranging from 8.6 to 8.91 in the bottom samples and 8.66 to 8.95 in the surface samples (Figure 47). Wind was likely the responsible factor for keeping the pH homogeneous from the surface to the bottom. In some instances, the pH followed the expected scenario being slightly higher at the surface than the bottom. The pH concentrations in Lake Cochrane were not extreme in any of the samples. The higher alkalinity concentrations aid in buffering any dramatic pH changes. Since increases in primary productivity increase pH, increases in pH can be an indication of increased organic productivity over time, by plants and algae.

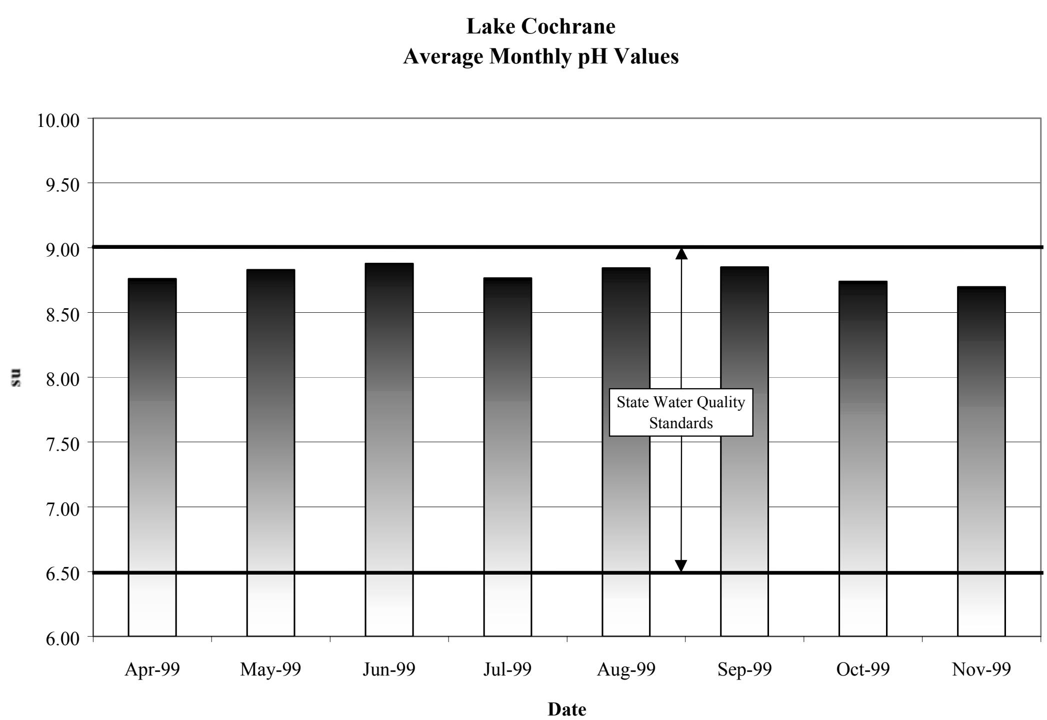


Figure 47. Lake Cochrane Average Monthly pH Values.

Secchi Depth

Secchi depth is a measure of visibility below the water surface which is beneficial in determining the extent to which light is refracted by objects within a lake system. The Secchi depth is measured in the field with a simple tool called a Secchi disk (Figure 48). The Secchi depth is useful as a means of comparing the clarity of different waters (Lind, 1985). Secchi disk readings can also be used in Carlson's Trophic State Index (TSI). Carlson's TSI is a measure of trophic status or overall health of a lake. One limitation of Secchi depth is it can't determine whether organic (algae) or inorganic (suspended sediment) concentrations are responsible for lowering the visibility levels. For instance, if Secchi disk measurements are low, it suggests abundant algae or high chlorophyll *a* concentrations (hypertrophy). This may not be the case. The presence of suspended sediment caused by wind and wave action suspending the bottom or shoreline sediments must also be considered.

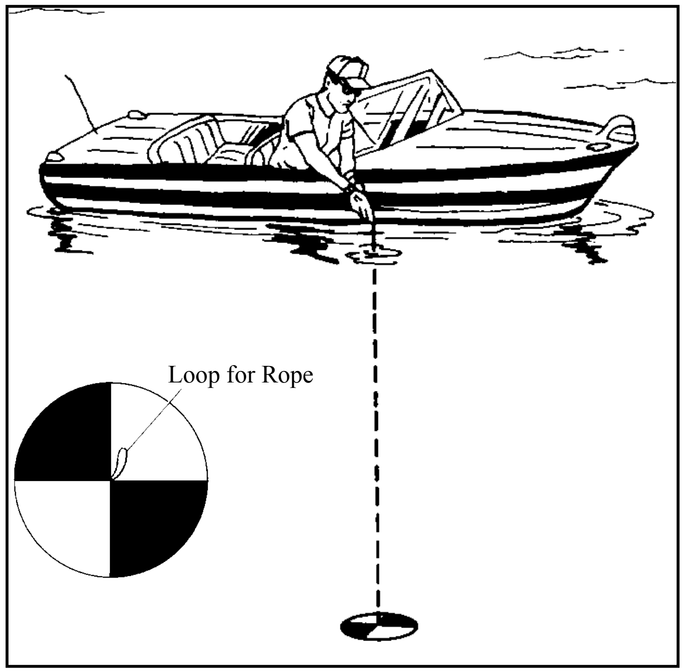


Figure 48. Secchi Disk Measurement.

Chlorophyll *a* concentrations (algae) were causing the lower Secchi depths especially in the summer when chlorophyll *a* was likely high. During the lower Secchi depths, the lake experienced a stained color resembling weak tea and algae were present at maximum annual densities (July to September - see separate discussion on algae). The best depths were seen during the early spring and late fall when chlorophyll *a* and algae concentrations were lower. Suspended solids should point towards chlorophyll *a* or organic matter during low visibility periods. Lake Cochrane is unlikely to experience suspended sediments due to adequate depths and dense aquatic macrophytes which hold the sediment in place. The shore is mostly sandy and rocky producing minimal fine particles to enter into suspension. The only exception is the west bay area where sedimentation prior to 1975 has reduced recreational use. Figure 49 shows average Secchi depths for all sampling periods.

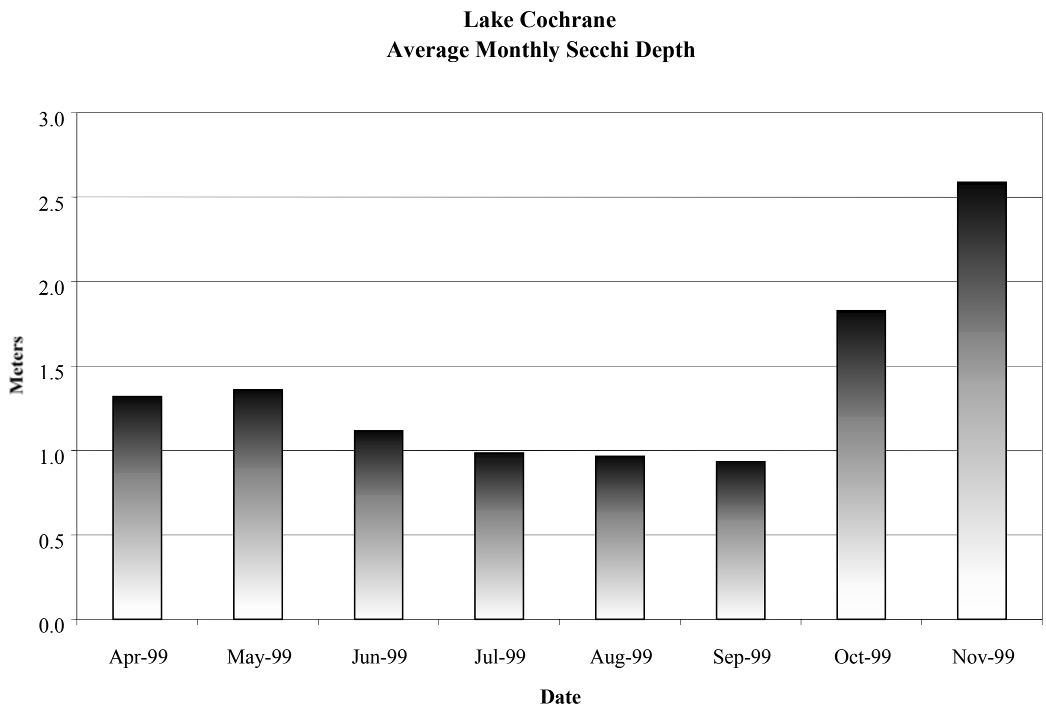


Figure 49. Lake Cochrane Average Monthly Secchi Depth.

Alkalinity

Alkalinity refers to the quantity of different compounds that shift the pH to the alkaline side of neutral (> 7.0). Alkalinity is usually dependent on geology. Alkalinity in natural environments usually ranges from 20 to 200 mg/L (Lind, 1985). The average surface alkalinity in Lake Cochrane was 217.17 mg/L (median: 217mg/L), differing insignificantly from the average bottom concentration of 217 mg/L (median: 216 mg/L). No significant concentration changes occurred between sites or depths for any of the sampling dates. Alkalinity ranged from a high of 224 mg/L (November) to a low of 212 mg/L (July). A slight increase in alkalinity was observed in the late fall (Figure 50). The relatively stable alkalinity in Lake Cochrane can most likely be attributed to natural processes. The moderate seasonal changes in alkalinity values may possibly be caused in part by the metabolic activities, seasonal growth and decay of local macrophyte and algal communities (Wetzel, 1983).

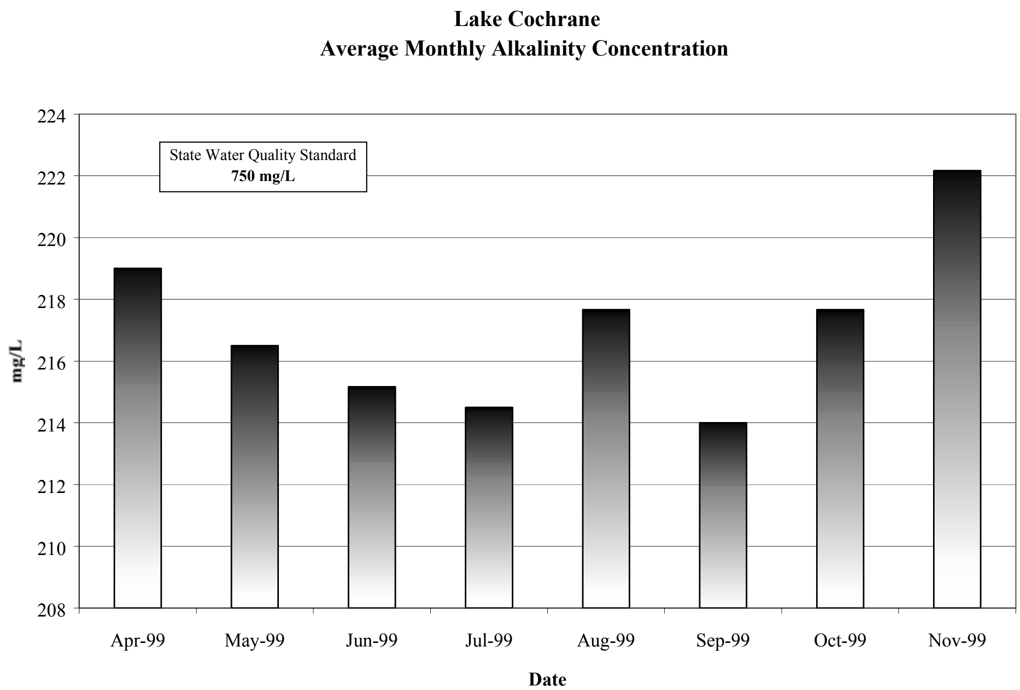


Figure 50. Lake Cochrane Average Monthly Alkalinity Concentration.

Solids

Total solids are the materials, suspended or dissolved, present in water. Dissolved solids include materials that pass through a water filter. Suspended solids are the materials that do not pass through a 0.45 *u*, (e.g. sediment and algae). Subtracting the suspended solids from the total solids yields total dissolved solid concentrations. Total dissolved solids (TDS) averaged 1,745.8 mg/L for surface samples and 1,741.6 mg/L for bottom samples. A significant difference was not observed between surface and bottom samples. The highest TDS concentration was 1,792 mg/L (7/21/99) and the lowest was 1,650 mg/L (4/20/99) (Figure 51).

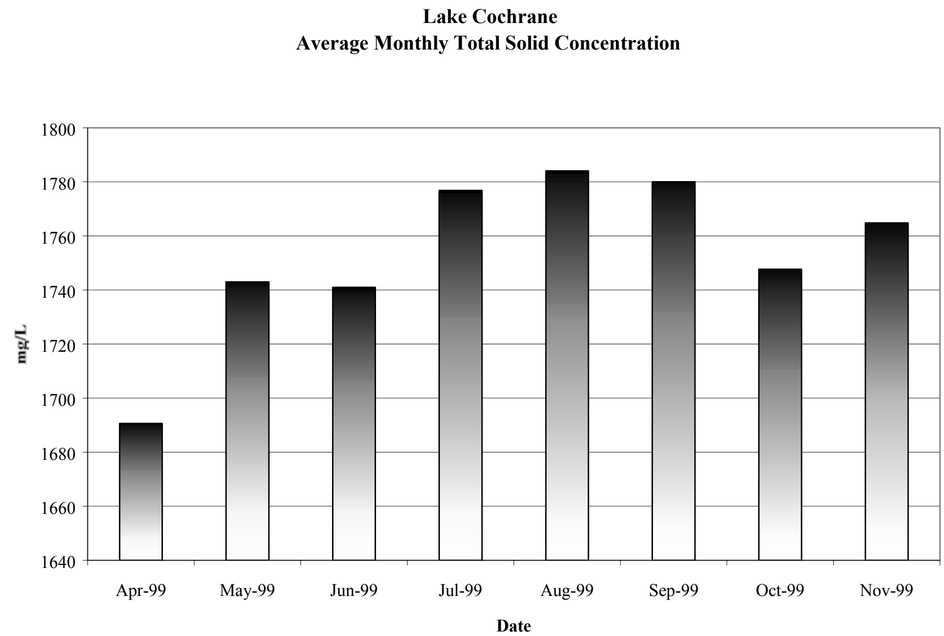


Figure 51. Lake Cochrane Average Monthly Total Solid Concentration.

The lower dissolved solids were seen during a period when snowmelt and spring run-off was most likely diluting the concentrations in the lake. Snowmelt and rain generally contain lower concentrations of dissolved solids. Following the April sampling event, dissolved solids increased slightly and remained fairly steady throughout the study. The slight increase can be attributed to evaporation. As Lake Cochrane's volume decreased via evaporation, the dissolved solids became more concentrated. Dissolved solids are typically composed of salts and other compounds that keep the alkalinity high. The higher alkalinity concentrations (> 200 mg/L) are a result of the higher (> 1600 mg/L) total dissolved solids concentrations, though neither parameter exceeded the South Dakota water quality standards.

Total suspended solids averaged 10 mg/L for surface samples and 9.58 mg/L for bottom samples. A significant difference was not observed between surface and bottom samples though, in some instances, the surface concentrations were slightly higher. The average total suspended solid concentration for each month (Apr.-Nov.) are graphed in Figure 52. The highest average concentrations appeared in July and August. Higher chlorophyll a concentrations (23 mg/m^3) and larger algae populations (see separate discussion on algae) strongly suggest algae are likely responsible for the higher suspended solid concentrations. Suspended sediment could be another possibility although, at least during the July sampling period, when the wind was calm, restricting the agitation of sediment from the bottom or shoreline. The shoreline of Lake Cochrane for the most part consisted of sand and rock, reducing the potential for suspension as opposed to finer mud-like particles. Submerged aquatic macrophytes were dense around the shoreline and mid-basin, further preventing the suspension of finer sediment. In most instances, except when suspended solid concentrations were lowest (October-November) the lake presented a stained appearance resembling weak tea suggesting the suspended solids were likely of organic origin, likely from the abundant macrophytes growing around the periphery of the lake. Suspended solids concentrations show good agreement with corresponding seasonal algae population densities.

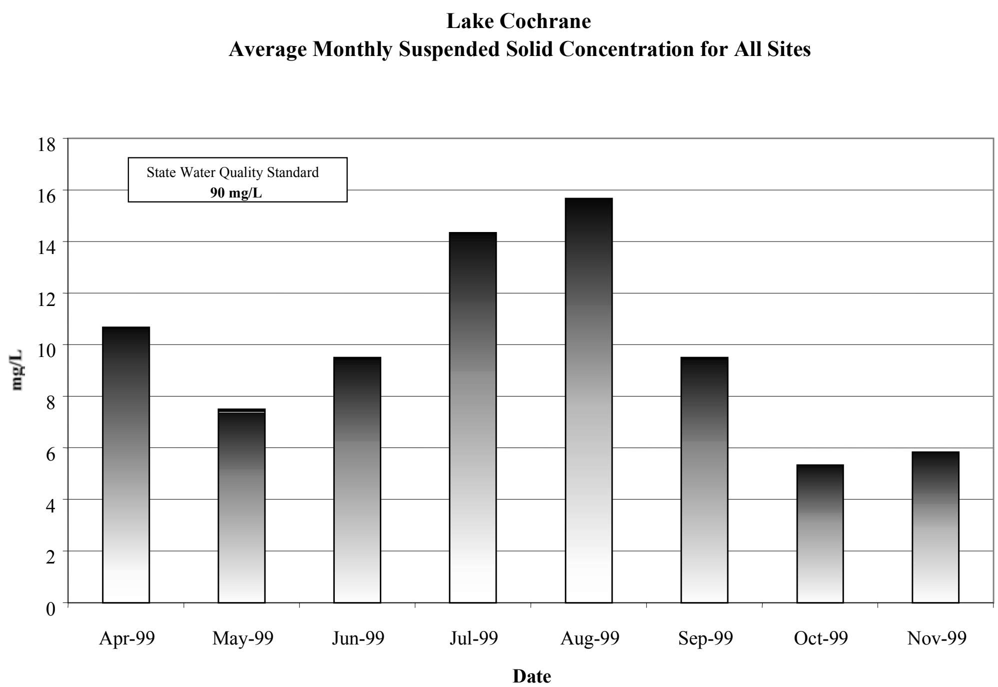


Figure 52. Lake Cochrane Average Monthly Suspended Solid Concentration for All Sites.

Ammonia

Ammonia is the nitrogen by-product of bacterial decomposition of organic matter and is the form of nitrogen most readily available to plants for uptake and growth. Ammonia can also be excreted from living organisms (Cole, 1994). Un-ionized ammonia concentrations (toxic to fish) usually increase with elevated water temperature and pH, furthered by low dissolved oxygen concentrations. There were no exceedances of the un-ionized ammonia standard during the project period (Figure 53).

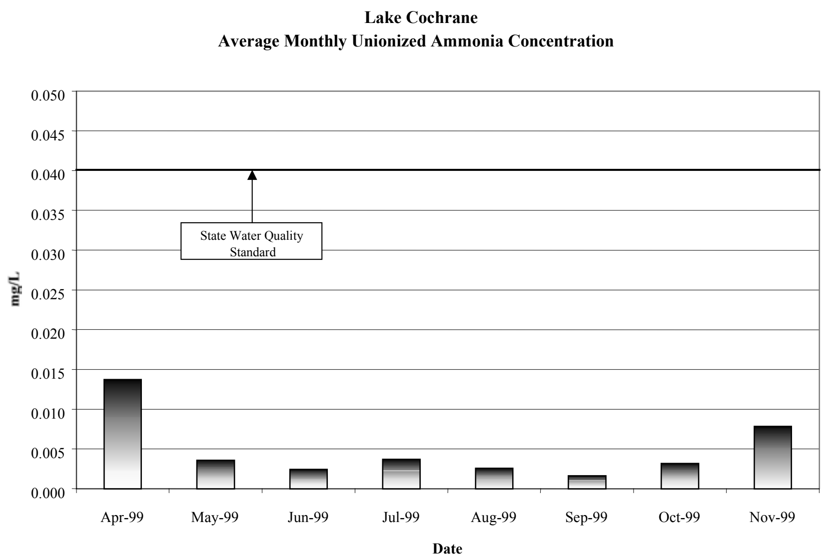


Figure 53. Lake Cochrane Average Monthly Unionized Ammonia Concentration.

Ammonia concentrations were non-detectable (< 0.02 mg/L) in most of the samples (surface or bottom) during the sampling periods of June through September. The only exception was at the bottom of site LCL-3 (0.05 mg/L) on July 21, 1999. This concentration was most likely the result of organic decomposition coupled with higher water temperature (24 ^{o}C) and low dissolved oxygen (1 mg/L). Detectable ammonia concentrations were seen during the sampling periods in April and May and again in October and November (Figure 54). Ammonia concentrations were likely detectable during the spring and fall due to the intense decomposition of the organic matter. In the summer months, the ammonia produced by biodegradation is readily usable by macrophytes and algae to promote growth. Bacterial decomposition of aquatic macrophytes was more likely to produce the higher ammonia concentrations because there is a far greater biomass of macrophytes compared to algae in Lake Cochrane.

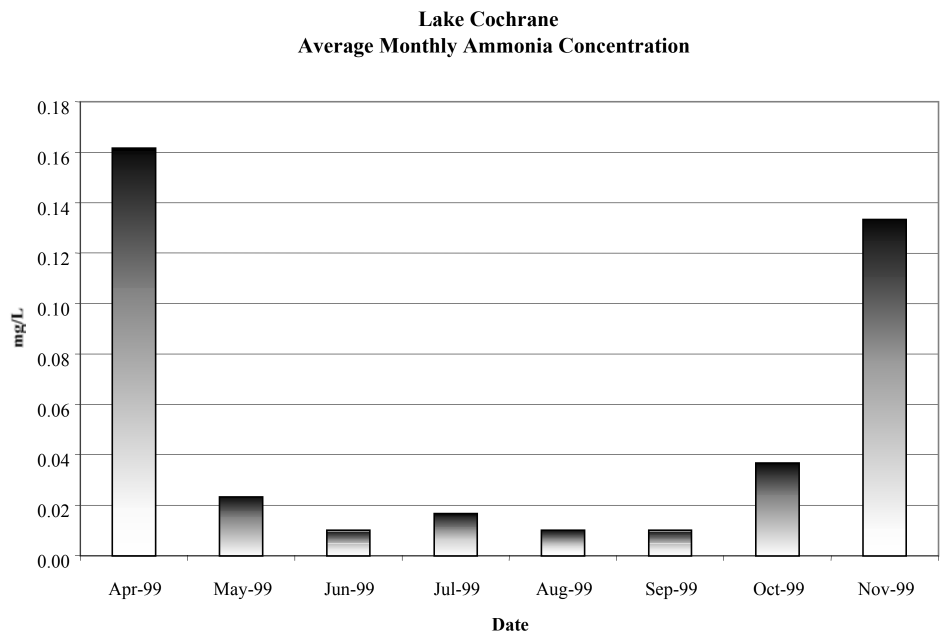


Figure 54. Lake Cochrane Average Monthly Ammonia Concentration.

The highest ammonia concentration was 0.19 mg/L collected from the surface of site LCL-3 in November. The bottom concentration was 0.12 mg/L. This was the greatest variation for any of the surface to bottom samples. In general, no significant differences were observed between sites or from the surface and bottom samples. The higher ammonia concentrations were observed during a period when dissolved oxygen, pH and temperature were optimal. The winter (ice and snow cover) could present a different scenario for ammonia concentrations in Lake Cochrane. Un-ionized ammonia may have been the cause of the fish kill (including several dead frogs) witnessed just after ice-off in April.

Nitrate-Nitrite

Nitrate and nitrite are inorganic forms of nitrogen easily assimilated by algae and macrophytes. Sources of nitrate and nitrite are associated with agricultural practices and direct input from septic tanks, and other forms of organic waste. Nitrate-nitrite can also be converted from ammonia through the denitrification of bacteria. High concentrations of nitrate nitrogen (greater than 20 mg/L) may be a health hazard to juvenile mammals (Lind, 1985). Since nitrogen is water soluble, and blue-green algae can convert many forms of nitrogen for their own use (convert atmospheric nitrogen, for example), it is more difficult to remove nitrogen than phosphorus from a lake system.

Nitrate-nitrite concentrations were non-detectable (< 0.10 mg/L) for all surface samples collected during the study period (April-November). Bottom samples were also non-detectable with the exception of two samples having a concentration of 0.1 mg/L. The detectable concentration attainable by the State Health Laboratory's analytical process for nitrate-nitrite is 0.1 mg/L. All concentrations below 0.10 mg/L were given a value of one-half the detection limit (0.05 mg/L) for the purpose of this report (Figure 55). Nitrate-nitrite is easily converted to ammonia and utilized by the high biomass of local aquatic macrophytes. Lake Cochrane receives a fairly low amount of nitrate from the watershed although fertilized row crops and a fairly active pasture exist within the watershed. Septic inputs are unlikely due to a centralized waste collection system installed in 1989. Nitrate-nitrite may also be converted into nitrogen gas (N_2) and lost to the atmosphere.

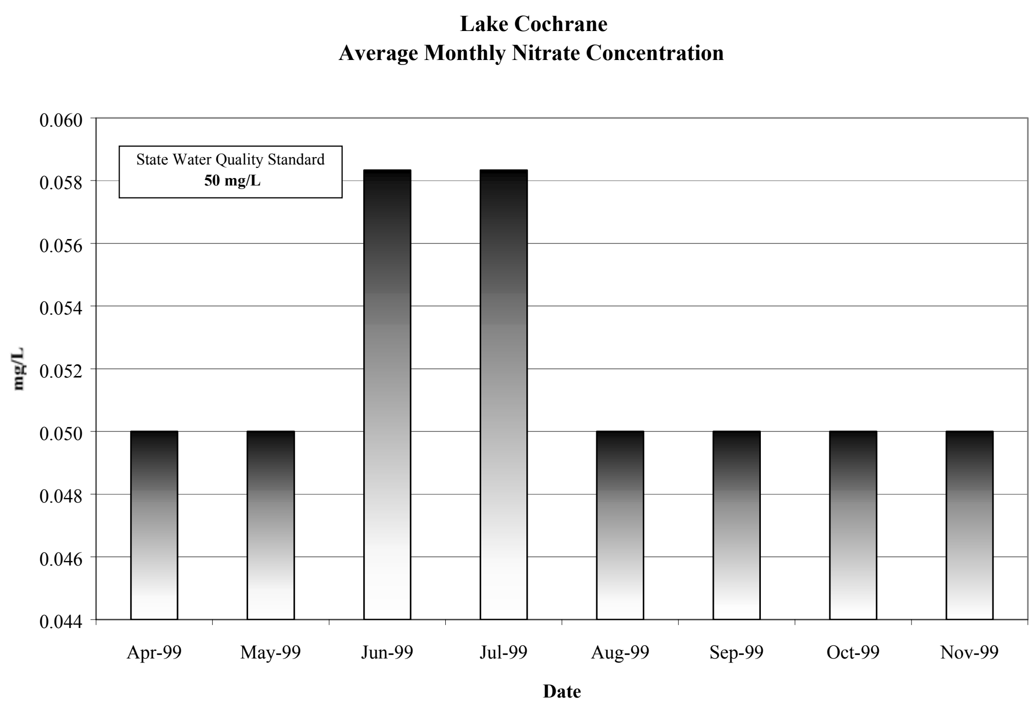


Figure 55. Lake Cochrane Average Monthly Nitrate Concentration.

Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) is used to calculate both organic and total nitrogen. TKN minus ammonia equals organic nitrogen. TKN plus nitrate-nitrite equals total nitrogen. Sources of organic nitrogen can include release from living or dead organic matter, lake shore septic systems, or agricultural waste. Organic nitrogen is broken down to more usable forms of inorganic nitrogen. The average organic nitrogen concentrations were 1.40 mg/L (median 1.39 mg/L) for surface samples and 1.37 mg/L (median 1.38 mg/L) for bottom samples. The most variance between surface and bottom concentrations was observed during the July sampling period at site LCL-1. On July 21, 1999 the surface organic nitrogen concentration was 2.15 mg/L (maximum) opposed to the bottom concentration of 1.51mg/L. Algae at the surface of site LCL-1 were most likely responsible for the elevated organic nitrogen concentration. In most other cases, concentrations differed little between the surface and bottom. The overall mean organic nitrogen concentrations differed slightly between dates, reaching the highest level in August when local algae populations reached the annual maximum density (Figure 56). Organic nitrogen dominates over inorganic nitrogen (nitrate-nitrite) with respect to total nitrogen. High organic nitrogen concentrations are most likely achieved from the dense organic matter present in Lake Cochrane mostly in the form of extensive macrophyte beds.

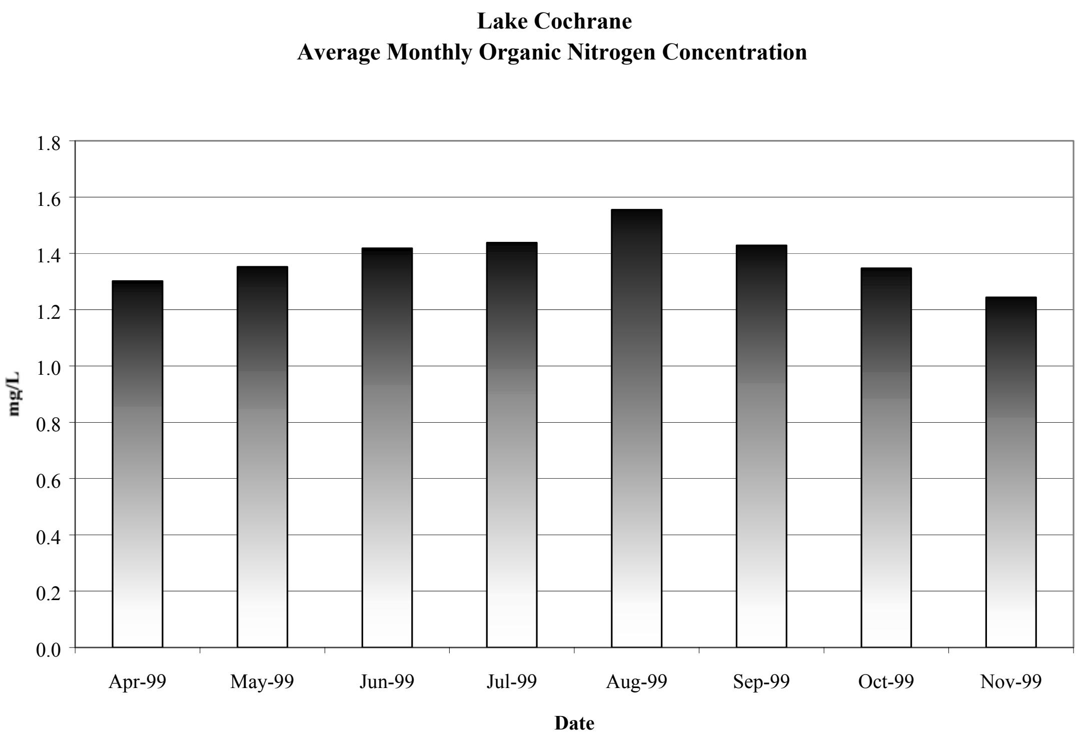


Figure 56. Lake Cochrane Average Monthly Organic Nitrogen Concentration.

Total Nitrogen

Total nitrogen is the sum of the nitrate-nitrite and the TKN concentrations. Total nitrogen is used mostly in determining the limiting nutrient discussed later in the report. The average surface and bottom total nitrogen concentrations were 1.50 mg/L and 1.47 mg/L, respectively. The maximum total nitrogen concentration for Lake Cochrane was 2.21 mg/L in a surface sample at site LCL-1 on July 21, 1999. Because the nitrate-nitrite concentrations were low (mean: 0.052 mg/L), the mean total nitrogen concentrations follow a similar trend to the mean organic nitrogen concentrations (Figure 57).

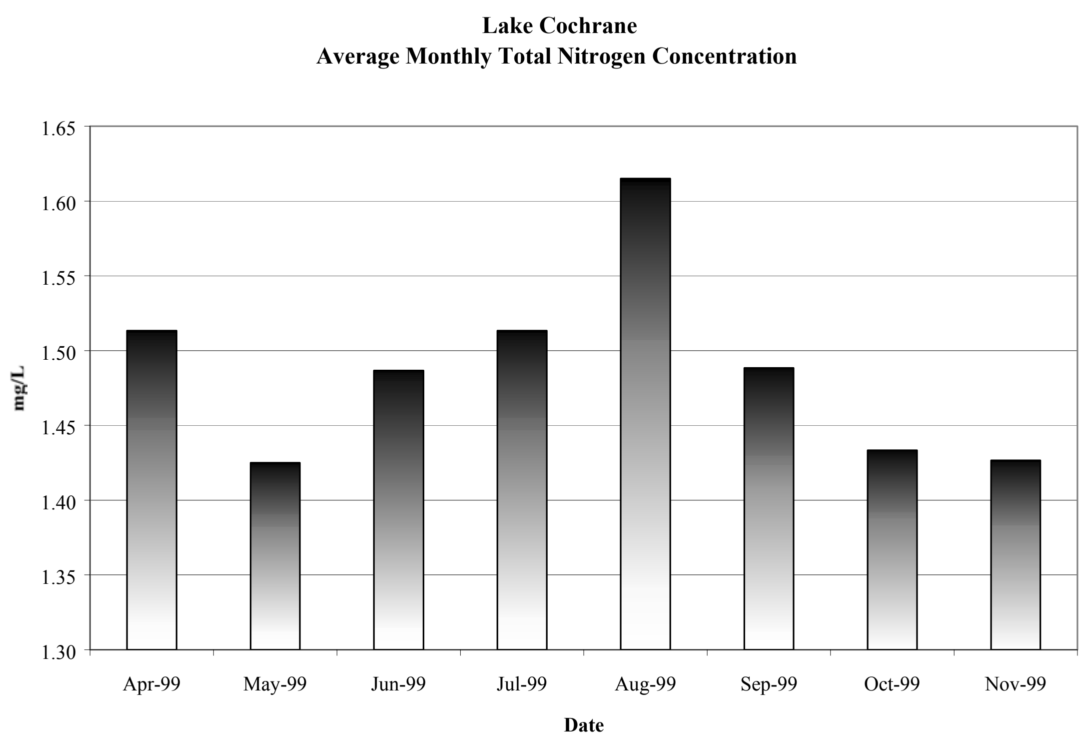


Figure 57. Lake Cochrane Average Monthly Total Nitrogen Concentration.

Total nitrogen within Lake Cochrane is primarily organic. During the summer months aquatic macrophytes grow and mature requiring nutrients. Inorganic nitrogen such as nitrates and ammonia are transformed to living tissues. As this organic matter begins to decompose, inorganic forms of nitrogen are released. This may explain the higher ammonia concentrations (discussed earlier) observed in the fall and early spring (Table 35). As the macrophytes decompose and grow they tie-up the nitrogen creating a continual cycle. Due to the abundance of aquatic macrophytes in Lake Cochrane, nitrogen becomes less available for algal growth.

Table 35. Mean Total Nitrogen, Organic Nitrogen and Nitrate-Nitrite Concentrations (mg/L) for all Lake Cochrane sampling dates.

Date	Total Nitrate-Nitrite (inorganic nitrogen)	Total Organic Nitrogen	Total Nitrogen
April-99	0.05	1.3	1.51
May-99	0.05	1.35	1.43
June-99	0.58	1.42	1.49
July-99	0.58	1.44	1.51
August-99	0.05	1.55	1.62
September-99	0.05	1.43	1.49
October-99	0.05	1.35	1.43
November-99	0.05	1.24	1.43

Total Phosphorus

Typically, phosphorus is the single best chemical indicator of the nutrient condition of a lake. Phosphorus differs from nitrogen in that it is not as water-soluble and will sorb on to sediments and other substrates. Once phosphorus sorbs on to any substrate, it is not as readily available for uptake by algae. Phosphorus sources can be naturally found in the geology and soil, from decaying organic matter, and waste from septic tanks or agricultural run-off. Once phosphorus enters a lake, it may become part of the lake sediments. Phosphorus will remain in the sediments unless released by the loss of oxygen and the reduction of the redox potential in the microzone or by wind re-suspension. The microzone is located at the sediment water interface. As the dissolved oxygen levels are reduced, the ability of the microzone to hold phosphorus in the sediments is also reduced. The re-suspension of phosphorus into a lake from the sediments is called internal loading and can be a large contributor of the phosphorus available to algae.

The average surface and bottom total phosphorus concentrations were 0.0255 mg/L (median: 0.025 mg/L) and 0.026 mg/L (median: 0.025 mg/L), respectively. A significant difference was not observed between surface and bottom samples. Concentrations ranged from the lowest concentration of 0.018 mg/L to the highest concentration of 0.051 mg/L. The highest concentration (0.051 mg/L) was observed from the surface of site LCL-1 during the July sampling period. The bottom concentration on the same date was 0.03 mg/L indicating algal production was likely at the surface. The highest mean concentrations of total phosphorus (0.031 mg/L) were present in May and again in July (Figure 58). The May and July mean concentrations only differed 0.005 mg/L from the overall average of 0.026 mg/L. The relatively low and stable concentrations of total phosphorus in Lake Cochrane were likely due to relatively low internal loading, small input from the watershed, and the large aquatic macrophyte community. Keeping the phosphorus locked up in the aquatic macrophyte population will decrease the likelihood of increased algae populations.

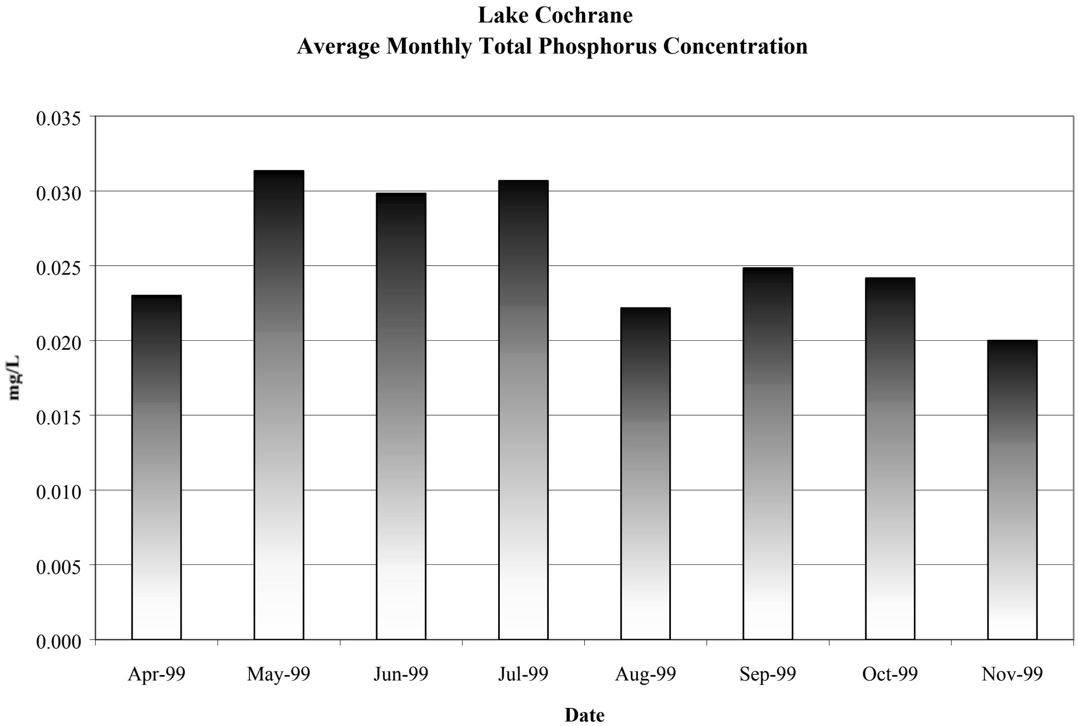


Figure 58. Lake Cochrane Average Monthly Daily Total Phosphorus Concentration.

Total Dissolved Phosphorus

Total dissolved phosphorus is the fraction of total phosphorus that is readily available for use by plants and algae. Algae need as little as 0.02 mg/L of phosphorus for blooms to occur. Dissolved phosphorus may sorb onto suspended materials (organic or inorganic) that may be present in the water column. Average surface and bottom total dissolved phosphorus concentrations were 0.0078 mg/L (median: 0.006 mg/L) and 0.0079 mg/L (median: 0.007 mg/L). No significant differences were observed between surface and bottom samples, respectively ($p < 0.05$). Concentrations ranged from a low of 0.001mg/L to a high of 0.032 mg/L. The lowest concentration was sampled in August for all sites, including surface and bottom. The high concentration was sampled at the bottom of site LCL-3 in May. The highest mean concentration of total dissolved phosphorus was sampled in May(Figure 59). The higher concentrations in May could be from the decomposition of organic matter prior to synthesis of a new crop of macrophytes. Lind (1985) suggested that phosphorus concentrations are expected to be higher during times of low synthetic activity. Chlorophyll _a_ (16.3 mg/m3) and suspended solids (7.3 mg/L) concentrations were relatively low with respect to the May sampling period. The average percentage of phosphorus that was in dissolved form was 29.5%. Since the majority of phosphorus was particulate, it was likely that organic matter and sediment reduced the potential of phosphorus to become dissolved. The average concentration of total dissolved phosphorus in Lake Cochrane was 0.00785 mg/L (median: 0.006 mg/L). Lake Cochrane averaged less than approximately two times the required minimal requirements as algae needs 0.02 mg/L of phosphorus for growth. Despite the relatively low mean dissolved phosphorus concentrations, total phosphorus concentrations indicated that enough phosphorus was available for plant growth, although it was more likely that it was attached to sediment or consumed by algae.

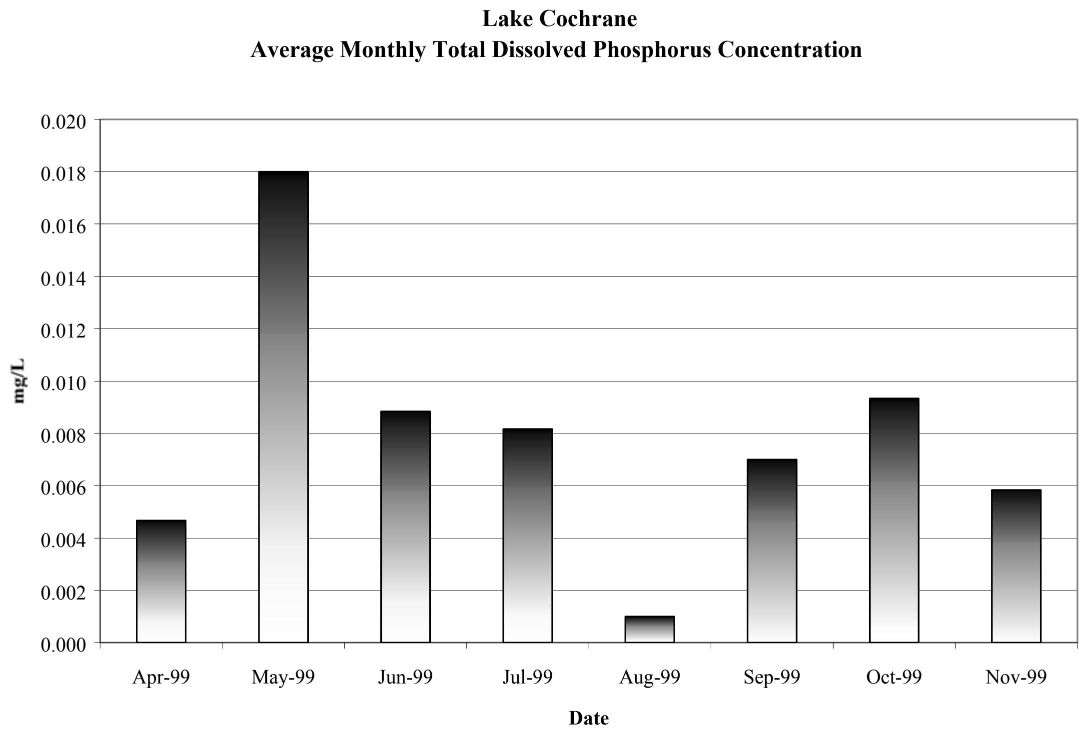


Figure 59. Lake Cochrane Average Monthly Total Dissolved Phosphorus Concentration.

Chlorophyll *a*

Chlorophyll *a* is a pigment in plants that may be used to estimate the biomass of algae (Brower, 1984). Monthly chlorophyll *a* samples were collected throughout the project period. Figure 60 shows the chlorophyll *a* concentrations per site for Lake Cochrane. As can be seen from the figure, on some of the dates there was quite a large variance between some of the samples within Lake Cochrane. Samples averaged for each date follow typical seasonal patterns. The variance in chlorophyll concentration was most likely from wind blowing a bloom from one side of the lake to another or from errors in sampling and analysis. The maximum monthly average (29.99 mg/m^3) was collected on July 1999. The minimum sample was collected in November, 1999.

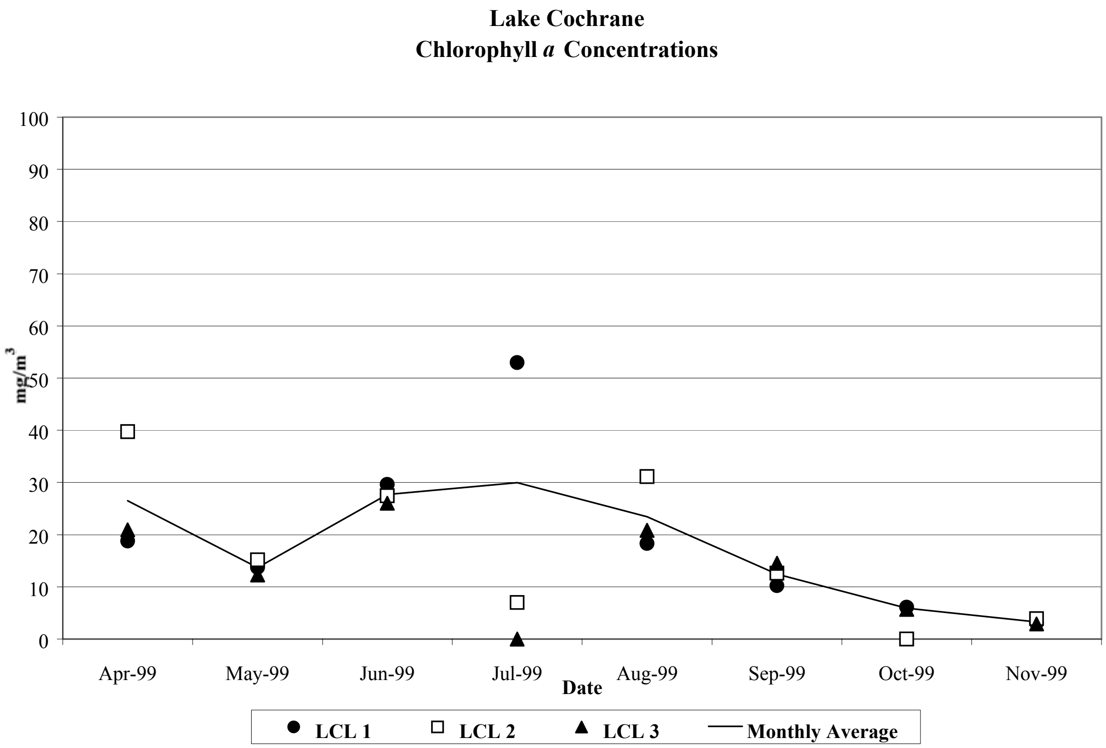


Figure 60. Lake Cochrane Chlorophyll *a* Concentrations.

Typically, chlorophyll and total phosphorus increase in concentration relationally. As total phosphorus increases, typically, chlorophyll *a* also increases. There may be factors within a waterbody that change this relationship. Poor phosphorus-to-chlorophyll *a* relationships may result from turbidity, nutrient ratios, light , temperature, or hydraulic residence time. An attempt to show a strong relationship was made by using all of the data available from the project As can be seen in Figure 61, little or no relationship between total phosphorus concentrations and chlorophyll *a* concentrations was demonstrated. In Lake Cochrane, the lack of a relationship may be due to the number of macrophytes and the relatively low nutrient concentration. Temperature, light, and dissolved solids may also be affecting the total phosphorus-to-chlorophyll *a* relationship.

When the summer samples were used in the analysis, the relationship between chlorophyll *a* and phosphorus improved to from 0.32 to 0.53 (Figure 62). Even though the relationship has improved with the summer samples, it will still be difficult to predict the effect inlake phosphorus reductions will have on chlorophyll *a* concentrations.

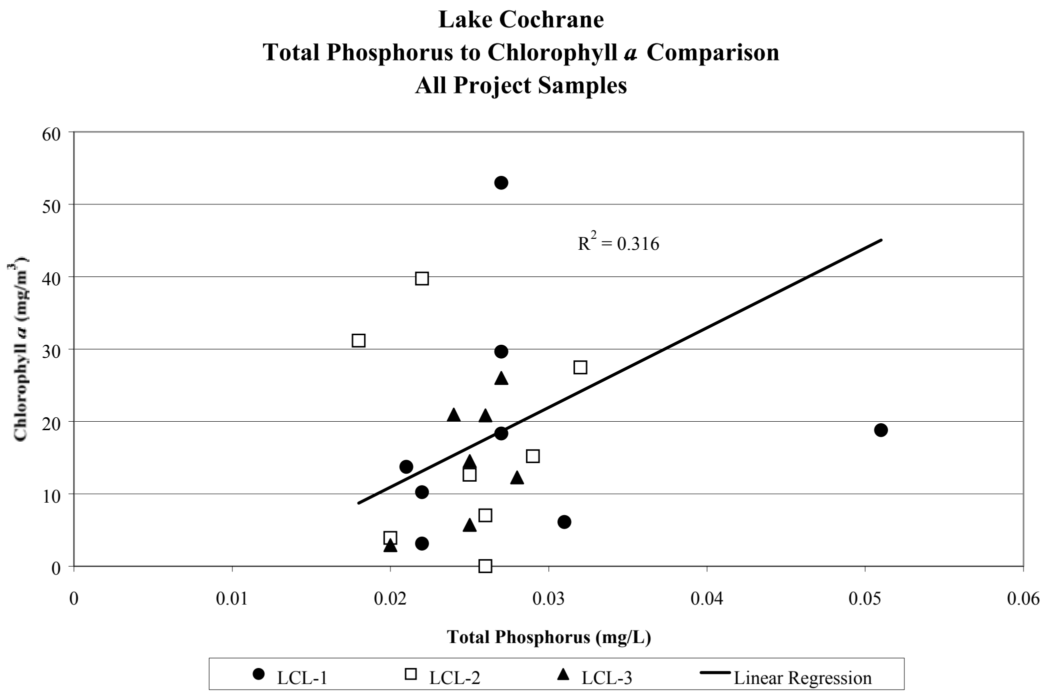


Figure 61. Lake Cochrane Total Phosphorus to Chlorophyll <u>a</u> Comparison for All Project Samples.

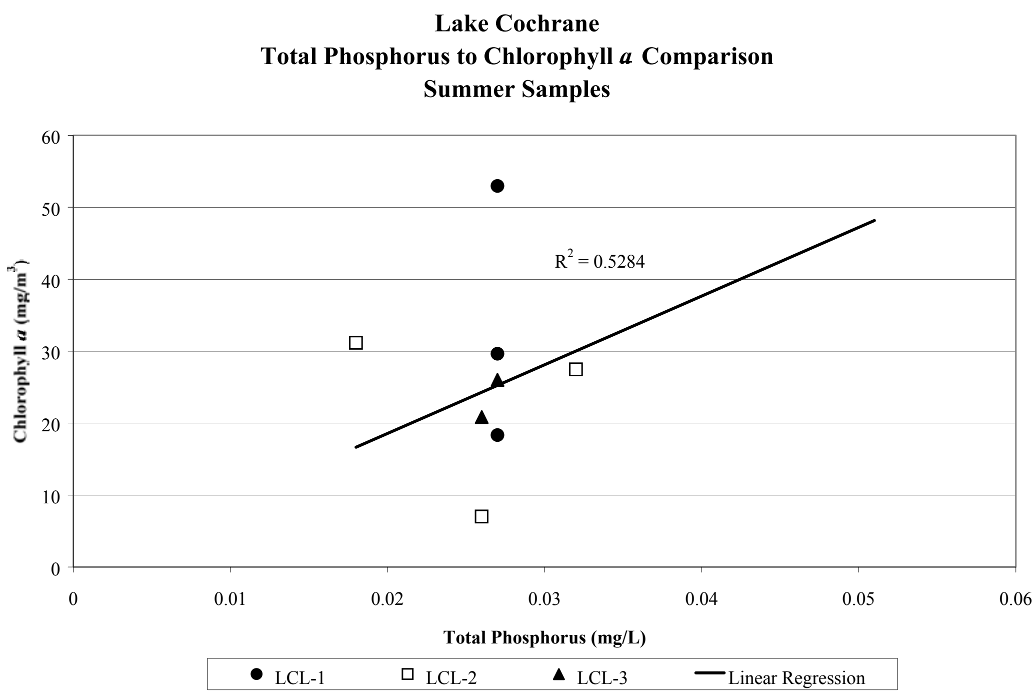


Figure 62. Lake Cochrane Total Phosphorus to Chlorophyll <u>a</u> Comparison for Summer Samples.

Fecal Coliform Bacteria

Fecal coliform bacteria are found in the intestinal tract of warm-blooded animals. Fecal coliform bacteria are used as indicators of waste in a waterbody. Many outside factors can influence the concentrations of fecal coliform. Sunlight and time seem to reduce fecal concentrations even though the nutrient concentrations remain high. Inlake concentrations are typically low because of the exposure to sunlight and the dilution of the bacteria in the large body of water (Figure 63). Of the 48 individual samples collected, only two samples contained a detectable level of fecal coliform bacteria. One sample was collected from the bottom of site LCL-3 in May and the other from the surface of site LCL-1 in September. Both samples contained the minimum detectable limit of 10 colonies/100mL. These two small concentrations may have been the result of various wildlife species, which normally inhabit Lake Cochrane. Despite the low and infrequent fecal coliform concentrations and relatively lower inlake nutrient concentrations, animal waste is likely entering the lake from the watershed. Tributary fecal coliform concentrations, discussed earlier in the report, were considerably higher than inlake. Since these concentrations entered the system in such low numbers, the effects of dilution, time and sunlight decreased the potential for detection within the lake. Most tributary fecal coliform concentrations were attributed to wildlife, domestic animals and cattle, specifically at site LCT-3.

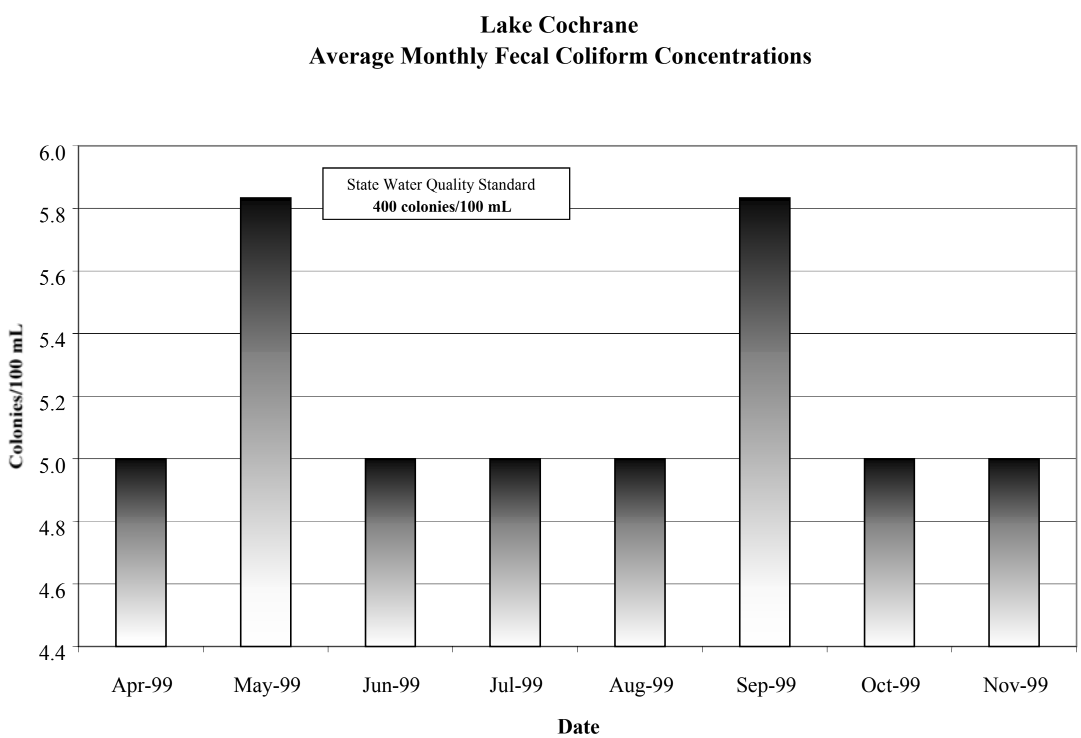


Figure 63. Lake Cochrane Average Monthly Fecal Coliform Concentrations.

Trophic State Index

Carlson's (1977) Trophic State Index (TSI) is an index that can be used to measure the relative trophic state of a waterbody. The trophic state is categorized by how much primary production occurs in the waterbody. The lower the nutrient concentrations in a waterbody, the lower the trophic level, and conversely, the larger the nutrient concentrations, the more eutrophic the waterbody. Trophic conditions range from the least productive oligotrophic lakes to nutrient-rich, highly productive, hyper-eutrophic lakes. The majority of lakes in South Dakota are in the eutrophic to hyper-eutrophic range. Table 36 below describes the different numeric limits for the various levels of the Carlson Index.

Table 36. Trophic Index Ranges

Trophic Level	Numeric Range
Oligotrophic	0 – 35
Mesotrophic	36 – 50
Eutrophic	51 – 65
Hyper-eutrophic	66 – 100

Three different parameters can be used to compare the average trophic condition of a lake: 1) total phosphorus; 2) Secchi disk; and 3) chlorophyll *a*. The calculated TSI levels for Lake Cochrane are indicated by Table 37 and Figure 64.

Table 37. Average TSI levels for Lake Cochrane.

Parameter	TSI Chlorophyll *a*	TSI Secchi Disk	TSI Total Phosphorus	Parameters Combined
Average	65.20	56.18	50.50	57.07
Median	66.06	57.14	50.59	55.44
Maximum	78.54	61.29	60.87	78.54
Minimum	50.06	46.27	45.85	45.85
Standard Deviation	7.96	5.04	3.06	8.20

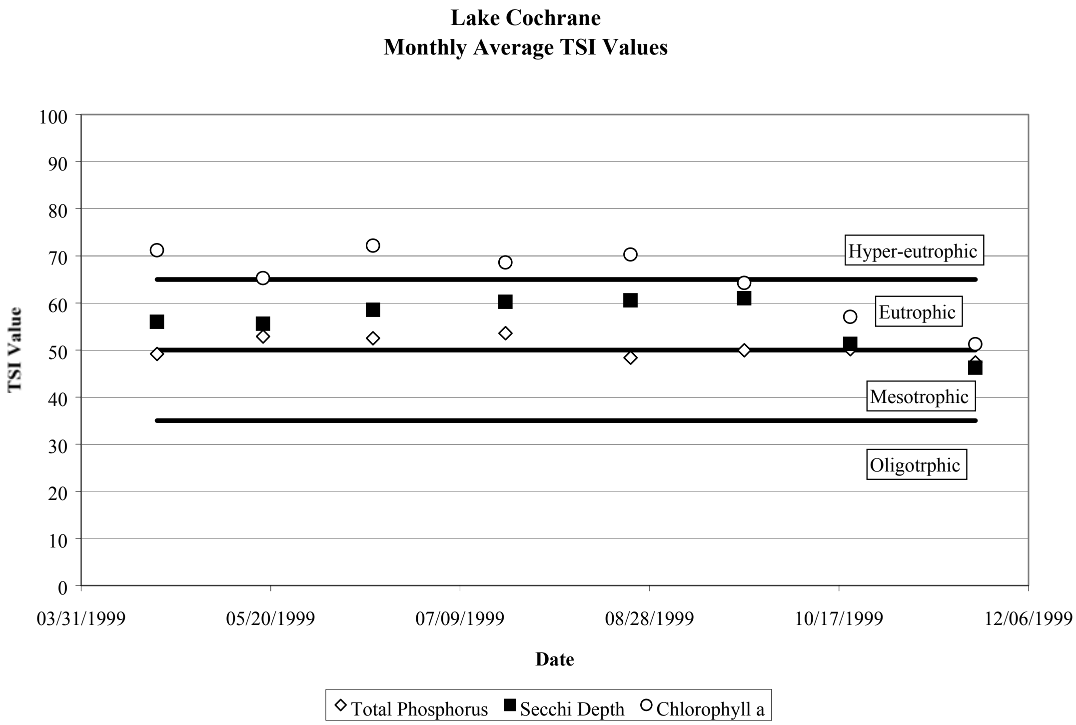


Figure 64. Lake Cochrane Monthly Average TSI Values.

As can be seen in the figure above, the phosphorus TSI was consistently lower than either the chlorophyll or the Secchi TSI values. The drop in phosphorus TSI in August and July may have been the result of macrophytes and larger algae populations taking up available phosphorus. The Secchi depth varied little and did not appear to be extremely affected by chlorophyll *a* except in the fall when algae populations were smaller and very little chlorophyll was produced. The chlorophyll *a* TSI values were in the hyper-eutrophic range for most of the project period. Eutrophic levels were only recorded in the fall and winter when cooler temperatures and shorter growing days were not conducive to algal production.

Long-Term Trend

The project period for Lake Cochrane was only a "snapshot in time" compared to the geological history of the lake. Due to the variation in weather and precipitation from year to year, it is useful to look at water quality over a longer term. Samples for Lake Cochrane have been collected since 1970 and until 1999 for different purposes. Figure 65 shows the change in TSI values for summer samples from 1970 to 1999. Summer samples were used for the comparison as most of the samples prior to this project were collected mainly in summer for the State-wide Lakes Assessment.

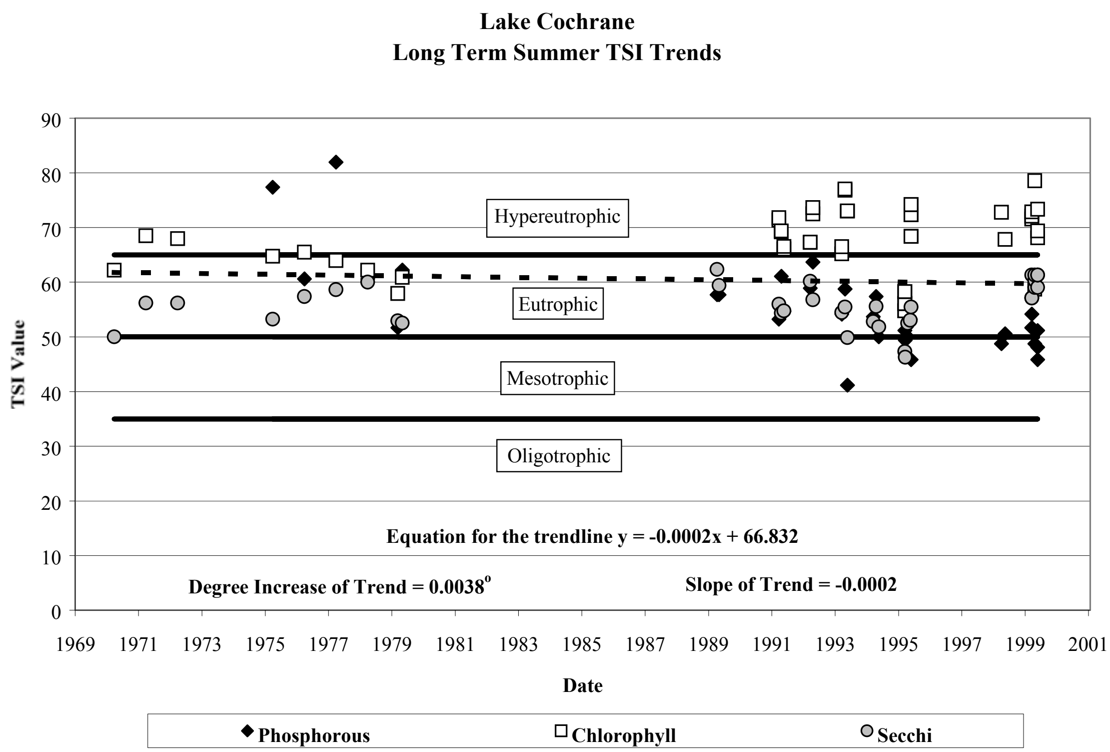


Figure 65. Lake Cochrane Long Term Summer TSI Trends.

Figure 65 shows a very small decline in eutrophication of Lake Cochrane since 1970. The angle of the trend line is actually so small (0.0038°), that the trend is negligible. In the last 7 years, even though the area has been in a wet cycle and received inflows from Lake Oliver, the TSI values for Lake Cochrane have not shown a significant change. The most recent phosphorus TSI values were slightly lower than the phosphorus TSI values from any other time period. Waters flowing from Lake Oliver into Lake Cochrane during the last six years has not affected the overall eutrophication of Lake Cochrane. The increased flow of water through Lake Cochrane may actually helped to flush out internal nutrients.

Limiting Nutrient

For an organism (algae) to survive, it must have the necessary nutrients and environment to maintain life and reproduce. If an essential component approaches a critical minimum, this component will become the limiting factor (Odum, 1959). Nutrients such as phosphorus and nitrogen are most often the limiting factor in highly eutrophic lakes. Typically, phosphorus is the most limiting nutrient for algal growth. However, if the lake has very high a phosphorus concentration, algal growth could be more limited by available nitrogen. Lakes that are phosphorus-limited respond more quickly to watershed best management practices and inlake restoration practices than lakes that are nitrogen-limited.

In order to determine which nutrient is the limiting factor, EPA (1990) has suggested a total nitrogen to total phosphorus ratio of 10:1. If the ratio of nitrogen divided by phosphorus is greater than 10:1, the waterbody is assumed to be phosphorus-limited. A ratio of less than 10:1 assumes the waterbody to be nitrogen-limited. The project average total nitrogen to total phosphorus ratio (TN:TP) is 59.86 (median: 57.05), well over the 10:1 standard, suggesting Lake Cochrane to be very phosphorus-limited (Figure 66). All individual samples had calculated TN:TP ratios greater than 10:1. The maximum ratio was 88.3 and the minimum ratio was 20.

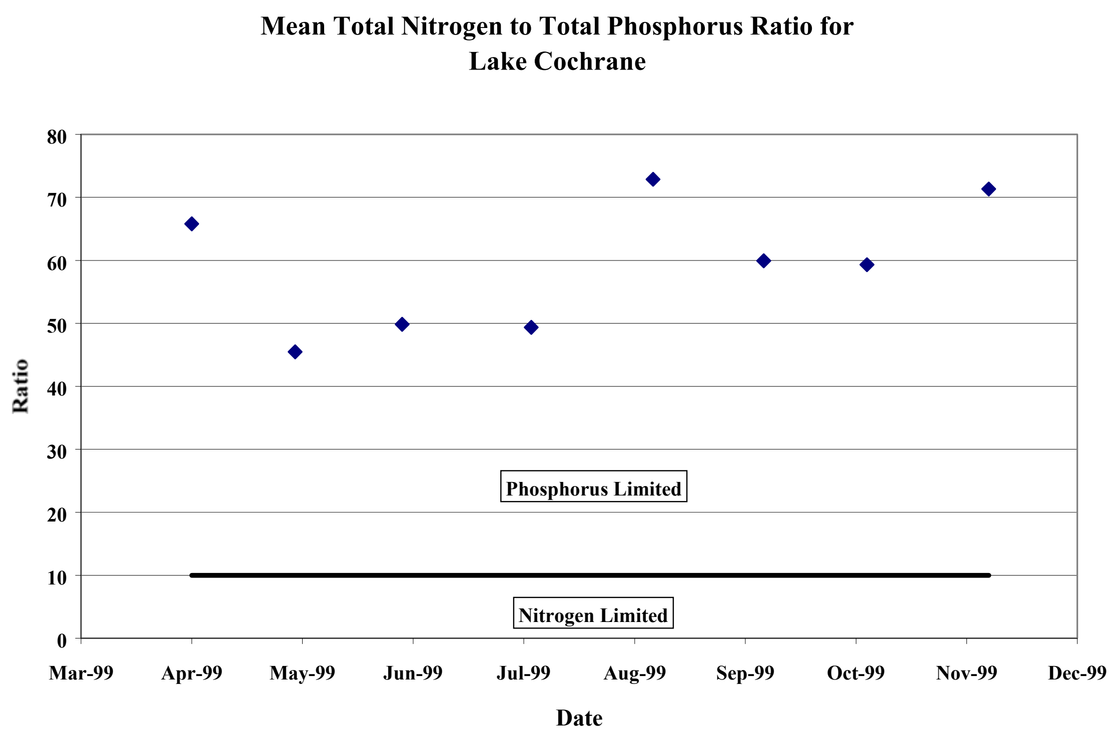


Figure 66. Mean Total Nitrogen to Total Phosphorus Ratio for Lake Cochrane.

Reduction Response Model

Inlake total phosphorus concentrations are a function of the total phosphorus load delivered to the lake by the watershed in addition to its internal load. Models have been developed to show the relationship between nutrient input and lake response. These models assume if total inlake phosphorus concentrations were reduced, the overall TSI values for total phosphorus, chlorophyll *a*, and Secchi disk would also be reduced, indicating improvement in water quality.

The BATHTUB model uses various methods to predict future lake water quality. Input data for the model consist of general lake morphology, tributary loading data, and current inlake water quality. Reductions for nutrient inputs were calculated by using the AGNPS model. The AGNPS model predicted reductions based on two different scenarios for critical cells. Critical cells were determined by selecting all cells within the watershed having an erosion rate greater than 5 tons of soil per acre. There were 16 agricultural landuse cells targeted in the immediate Lake Cochrane subwatershed. Of these 16 cells, 13 had erosion rates greater than 5 tons per acre. The first phosphorus reduction scenario was to implement the change of tillage practices on all critical erosion cells to no-till practices. The second scenario was to plant all critical cells to grass. The second scenario resulted in the best reduction one could expect from the targeted critical cells. The percent reductions of each of these two management practices were then applied to the actual water quality data collected during the project. The percent phosphorus reduction per subwatershed is identified in Table 38.

Table 38. Estimated Percent Reductions by Subwatershed.

Site	No-till Phosphorus Reduction	CRP Phosphorus Reduction	Measured Phosphorus Load (kg)	Estimated No-till Load (kg)	Estimated CRP Load (kg)
LOO	[1]30%	[1]30%	8.74	6.12	6.12
LCT-1A	0.0%	0.0%	0.03	0.03	0.03
LCT-1	4.8%	28.6%	0.38	0.36	0.27
LCT-2	26.4%	69.0%	4.14	3.05	1.29
LCT-3	31.1%	45.6%	8.81	6.07	4.79
LCT-4	0.0%	39.0%	0.50	0.50	0.31
TOTAL	28.6%	43.4%	22.61	16.14	12.80

[1]Estimated phosphorus reduction by removing carp from the outlet of Lake Oliver. (This is a conservative estimate based on the phosphorus attached to the sediment as stated in the Lake Cochrane tributary discussion.)

Estimated reductions were then entered into the BATHTUB model for an estimated effect on inlake water quality. This model predicted small reductions of inlake phosphorus, chlorophyll *a* and Secchi depth TSI values. The most likely reason for the limited reduction in TSI values is, because the amount of phosphorus entering the lake was so small, that any reduction would not have a great effect on inlake water quality. Internal load, atmospheric load and soil conditions would maintain the lake at its current level. Figure 67 depicts the estimated inlake response in Lake Cochrane to the AGNPS tributary reduction scenarios.

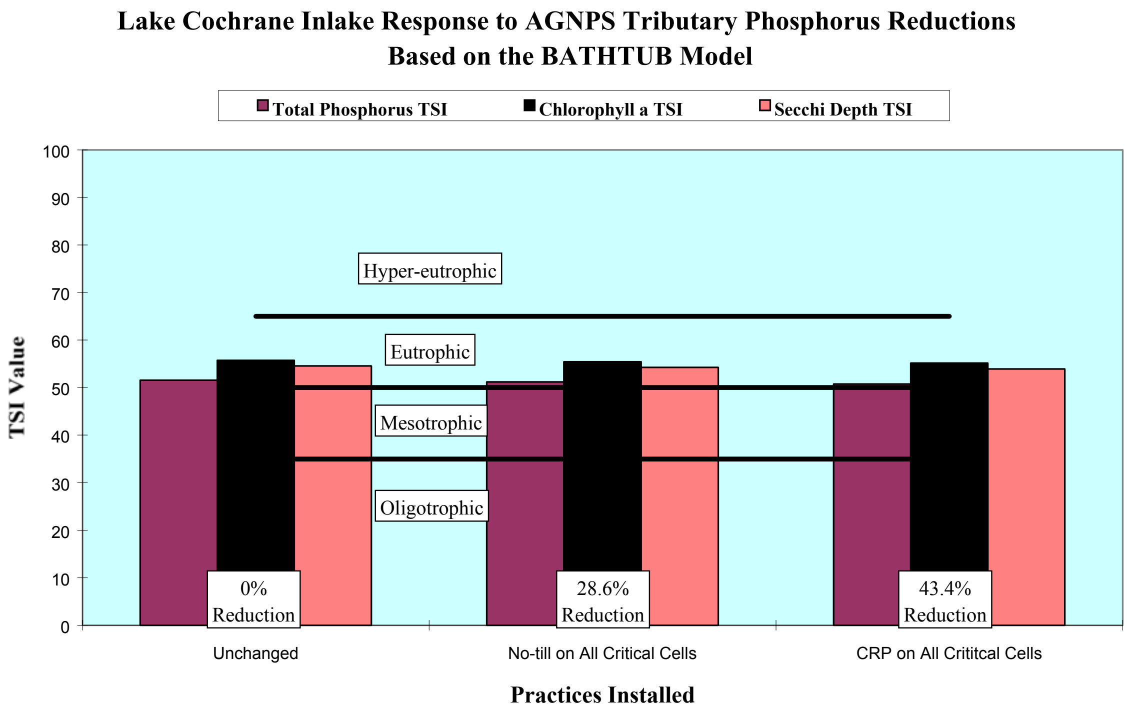


Figure 67. Lake Cochrane Inlake Response to AGNPS Tributary Phospohorus Reductions Based on the BATHTUB Model.

LAKE OLIVER INLAKE WATER QUALITY

The subsequent discussion will focus on water quality standards and beneficial uses for Lake Oliver. Of all inlake samples collected, only five samples exceeded the water quality standards. Three dissolved oxygen samples exceeded the standard during the July sampling period (July 21,1999). Two of these samples (2.2 mg/L and 1.0 mg/L) were near the bottom of site LOL-1 and the other one (2.2 mg/L) was collected near the bottom of site LOL-2. Lake Oliver most likely experienced a dissolved oxygen stratification because of lack of light penetration and biodegradation of organic material in the sediments. As bacteria decompose organic matter, more oxygen is used than can be produced at the sediment depths. Low oxygen concentrations at the microzone can be avoided if there is wind-induced water mixing, however, the wind was calm during the sampling period.

One pH sample also exceeded the water quality standard established for Lake Oliver. The water quality standard requires that a sample is $\leq$ 9.0 su. A bottom sample of 9.01 su was collected from site LOL-2 on September 22, 1999. The surface sample at site LOL-2 was 9.00 su. Lake Oliver is a eutrophic prairie lake with the water quality typical of calcareous glacial temperate regions in the Midwestern United States. These waters typically have higher pH levels (Wetzel, 1983). The soils, along with increased biological activity such as photosynthesis, probably caused the elevated pH readings.

Site LOL-1 never exceeded the pH standard of 9.00 su, although the surface reading was 8.99 su and the bottom was 8.98 su. As indicated, all four samples in September were higher than previous samples.

Lake Oliver

Lake Oliver is a 180-acre shallow lake with a maximum water depth of 12.5 feet and a mean depth of 8.7 feet. During periods of high water, Lake Oliver discharges directly into Lake Cochrane. Despite relatively low nutrient and sediment loadings from the watershed during this project, the majority of the existing concentrations must have entered the lake prior to the study when the watershed was more comprised of agricultural influences than it is today. Monthly samples were collected at the surface and bottom from two sites in Lake Oliver (Figure 68). Due to the close proximity of Lake Cochrane to Lake Oliver, sampling was conducted on Lake Oliver (April-November 1999) immediately following the sampling of Lake Cochrane. The following discussion will address the results for the sampled parameters and how they affect the water quality of Lake Oliver.

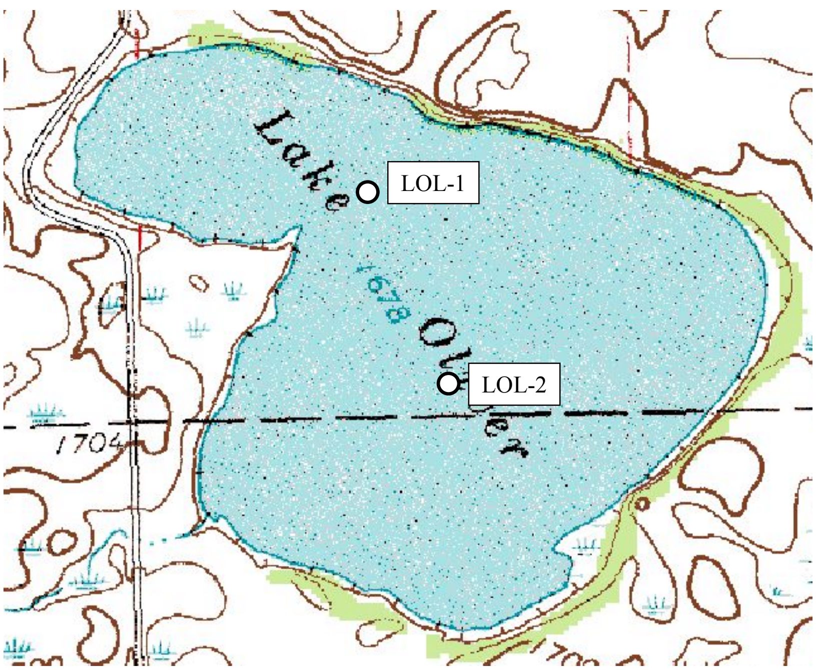


Figure 68. Lake Oliver Inlake Monitoring Sites.

Water Temperature

Water temperature is important to the biology of a lake, as it effects many chemical and biological processes in the lake. The average surface summer water temperature (June - September) for Lake Oliver was 20.7 ^{o}C, differing slightly from the average summer bottom temperature of 20.2 ^{o}C. The highest temperature of 25 ^{o}C was recorded from the surface of site #2 on July 21,1999. The bottom temperature for site #2 in July was 23.5 ^{o}C. This homogeneity in temperature indicates Lake Oliver did not undergo thermal stratification. As is typical of windswept shallow lakes, the temperature remained fairly consistent from the surface to the bottom. Temperature and dissolved oxygen profiles are shown in Appendix G.

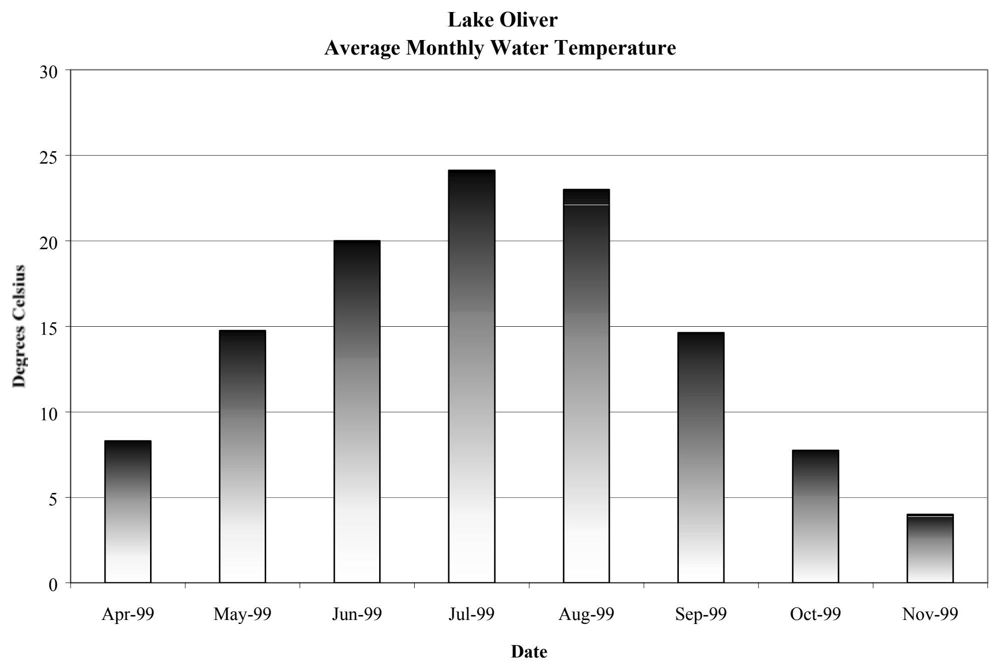


Figure 69. Lake Oliver Average Monthly Water Temperature.

Dissolved Oxygen

The average dissolved oxygen concentration for both Lake Oliver surface sites was 9.58 mg/L which varied slightly from the average bottom concentration of 8.18 mg/L. In most instances, dissolved oxygen concentrations were similar between sites, including surface and bottom, for all sampling dates. The only exception was observed on July 21, 1999, when a project minimum concentration of 1 mg/L was recorded at the bottom of site LOL-1. A low concentration of 2.2 mg/L was also collected at the bottom of site LOL-2 on the same date. Weather conditions at the time of sampling (see separate discussion on algae) were sunny and calm (no wind) and an algae bloom was reportedly in progress. The Secchi depths were relatively low at 0.85 meters (2.8 feet) and 0.91meters (3.0 feet) for sites LOL-1 and LOL-2, respectively. The chlorophyll _a_ concentration was fairly high (50 mg/m^3) suggesting that an algae bloom was most likely reducing light penetration and reducing the photosynthetic process at greater depths. As seen in Figure 70, dissolved oxygen decreased slightly from the surface to the bottom at both sites until late July. Lack of photosynthesis and biodegradation in the sediments explains why bottom samples have lower dissolved oxygen concentrations than surface samples. The pH was also lower near the bottom, adding to evidence that decomposition was likely in progress. With all the conditions in place, a band of low dissolved oxygen near the bottom of Lake Oliver was formed. Dissolved oxygen levels increased during the August sampling perhaps due to the windy conditions present during the sampling. Dissolved oxygen and temperature profiles are presented in Appendix G.

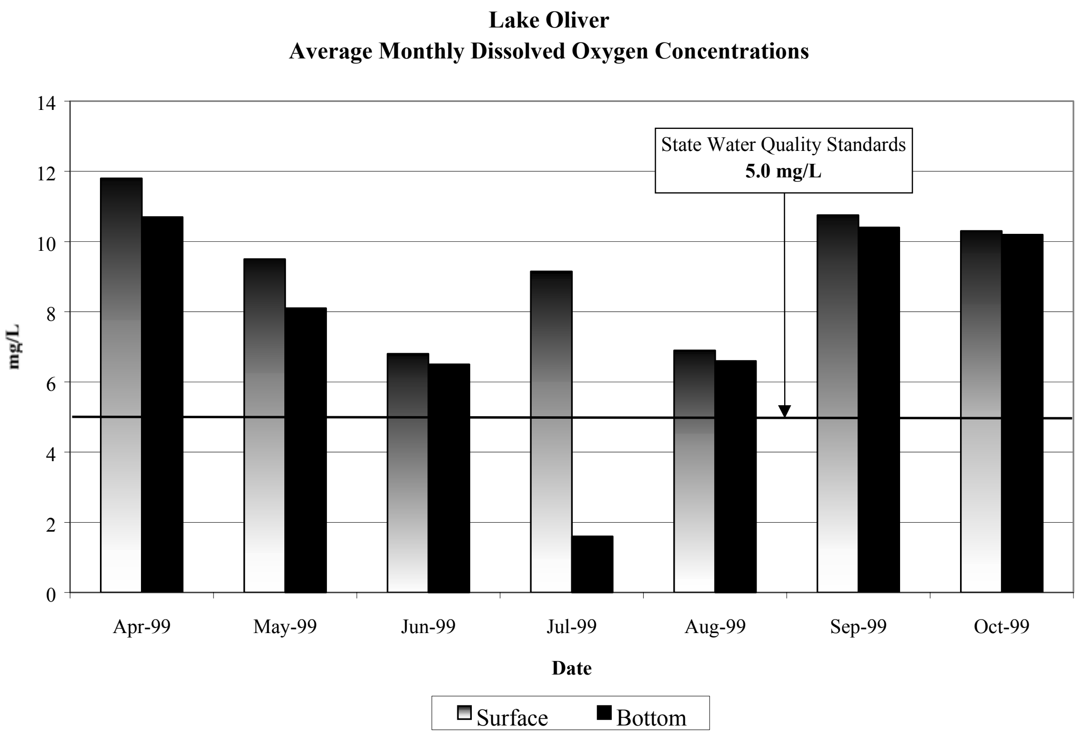


Figure 70. Lake Oliver Average Monthly Dissolved Oxygen Concentrations.

pH

The average bottom pH of 8.83 differed slightly from the average surface pH of 8.86. In most cases, the bottom pH was slightly lower than the surface pH, although this was not always the case (Figure 71). Wind and wave action is likely responsible for homogenizing the pH in this relatively shallow lake. The pH ranged from a high of 9.01 su in September to a low of 8.66 su in November. Increases in decomposition decrease pH and increases in pH can be an indication of less decomposing organic matter in a lake over time. In general, the pH concentrations in Lake Oliver are not extreme. The high alkalinity concentrations in Lake Oliver aid in buffering any dramatic pH changes.

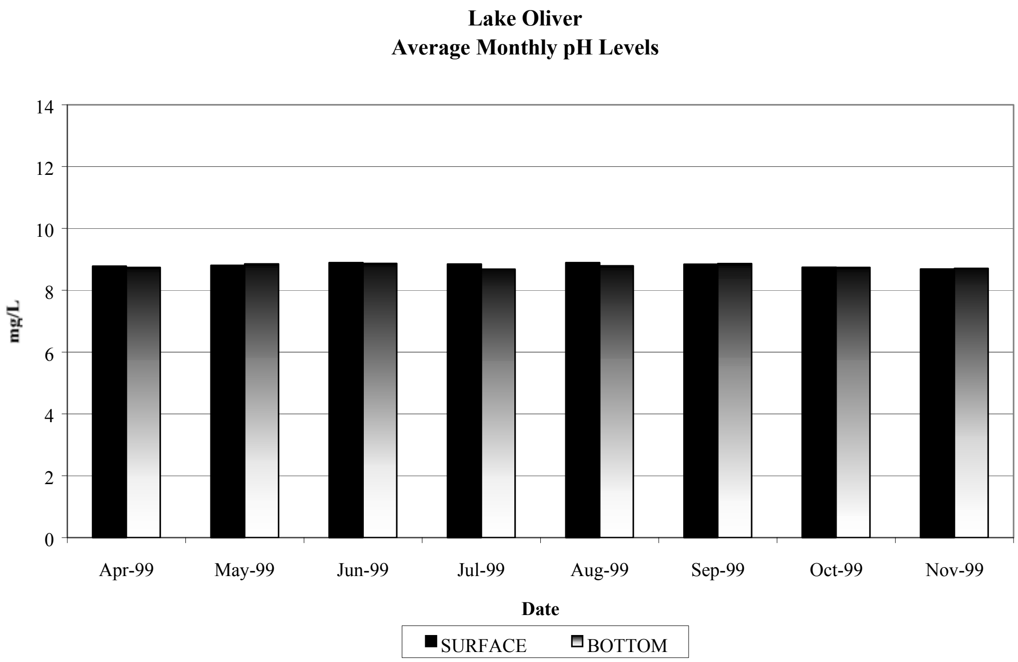


Figure 71. Lake Oliver Average Monthly pH Levels.

Secchi Depth

Over the course of the project, the average Secchi depth in Lake Oliver was 0.74 meters (2.4 ft.) with a median of 0.68 meters (2.25 ft.). Significant differences in Secchi depth were not observed between sites. The maximum Secchi depth of 1.37 meters (4.5 ft) was observed at both sites in November of 1999 which are relatively deep Secchi depths and likely follow chlorophyll a concentrations. When the chlorophyll a concentrations were high, Secchi readings were the lowest due to large algal populations. Lake Oliver is also composed of fine materials likely to suspend in the water column in the presence of wind.

According to the project field sampler, Lake Oliver water often had a green-stained or cloudy whitish color. Windy days cause the suspension of organic and inorganic (sediment) materials that most likely reduced Secchi depth visibility. The whitish color may have been a small amount of calcium precipitate that can form at high pH with high chlorophyll *a* production.

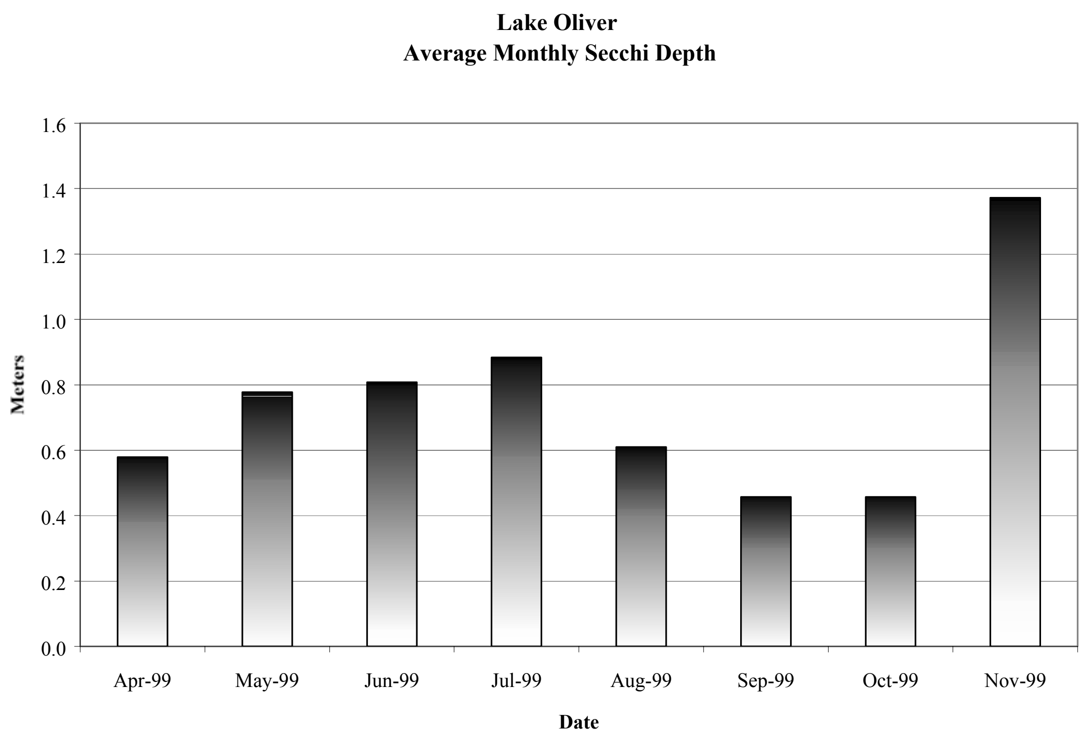


Figure 72. Lake Oliver Average Monthly Secchi Depth.

Alkalinity

The average surface alkalinity concentration was 259.1 mg/L with a median of 259 mg/L. The average bottom concentration was virtually identical at 259.2 mg/L with a median of 259.5 mg/L. Alkalinity concentrations were similar between sites LOL-1 and LOL-2. The highest concentration was 279 mg/L, sampled in November and the lowest concentration was 240 mg/L, sampled in July. Alkalinity concentrations decreased slightly from spring to summer and increased from summer to fall (Figure 73). The gradual increase in alkalinity can be attributed to evaporation. As the lake's volume decreases, dissolved solid concentrations increase. Alkalinity in Lake Oliver is relatively stable, though concentrations are fairly high. Lind (1985) suggests that alkalinity in natural environments usually ranges from 20 to 200 mg/L. Higher total alkalinity concentrations are especially effective in buffering dramatic pH changes. The alkalinity in Lake Oliver is likely a characteristic of the natural geology.

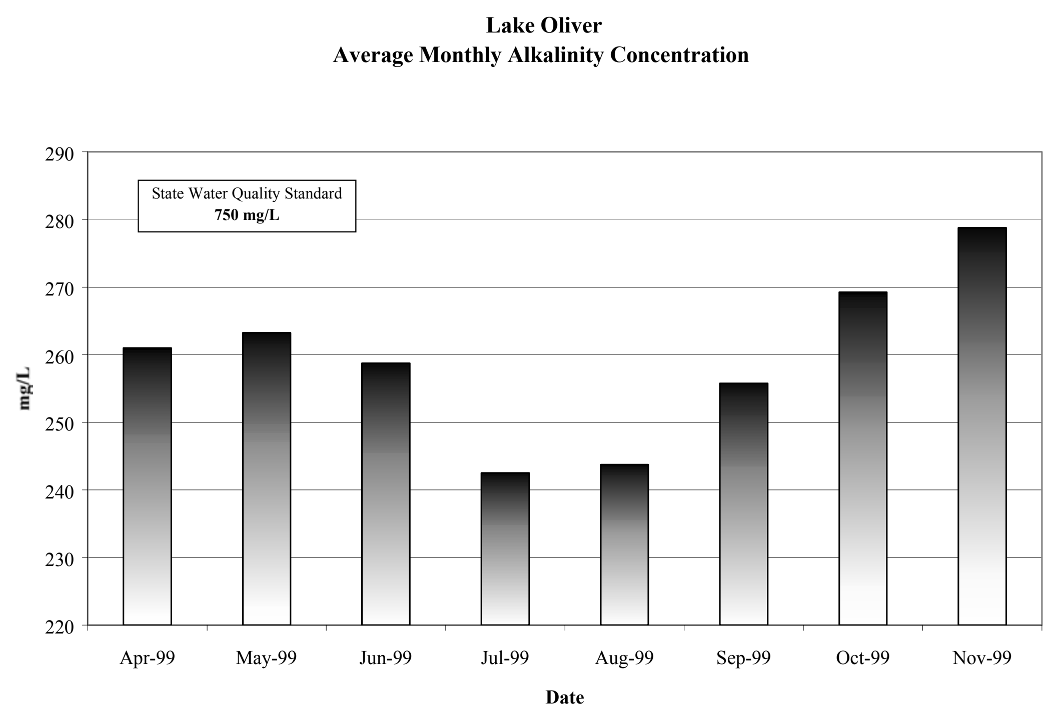


Figure 73. Lake Oliver Average Monthly Alkalinity Concentration.

Solids

Dissolved solids averaged 1,356.4 mg/L for surface samples and 1,353.7 mg/L for bottom samples. No significant differences were observed between the two sites including surface and bottom samples ($p < 0.05$). The lower dissolved solids were found in April (Figure 74). The lower dissolved solids concentrations were probably due to snowmelt and spring run-off diluting the concentrations in the lake. Snowmelt and rain generally have lower concentrations of dissolved solids. Dissolved solids are typically made up of salts and compounds that keep the alkalinity high. As the total dissolved solids increased, so did the alkalinity.

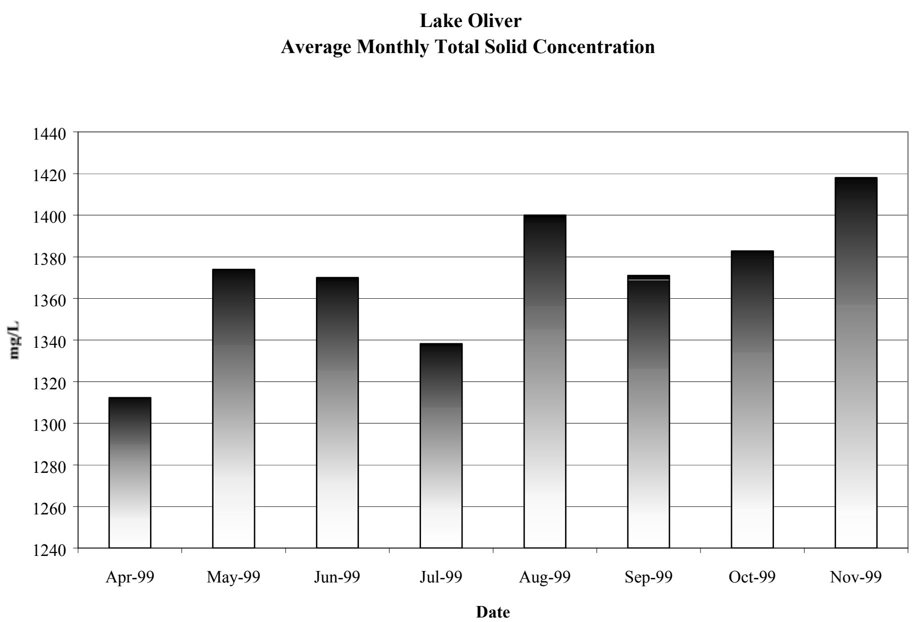


Figure 74. Lake Oliver Average Monthly Total Solid Concentrations.

Total suspended solids surface samples averaged 14.25 mg/L (median: 12.5 mg/L) and bottom samples averaged 17.25 mg/L (median: 17.5 mg/L). Suspended solids concentrations were slightly higher in the bottom samples, most likely from suspended bottom sediments. A significant difference was not observed between sites. Suspended solids were highest (29 mg/L and 27 mg/L) in August, approximately two times the average (Figure 75). According to the sampler's field notes, conditions were cloudy and windy during the sampling period. Due to the higher average of bottom total suspended solids, it is likely that the wind stirred up the finer sediment particles from the bottom and suspended them throughout the water column. Lake Oliver has a "mucky" bottom composed of fine organic and inorganic material substrate which together with the shallow depths, made it likely for wind to agitate and suspend the bottom substrates of the lake. Chlorophyll *a* concentrations were moderately high (35-40 mg/m^3) suggesting algae may have also been contributing to suspended solids concentrations (see separate discussion on algae). Algae are more likely to contribute to suspended solids on calm days and suspended sediment on windy days is likely to shade sunlight from algae reducing photosynthesis and preventing severe blooms from occurring.

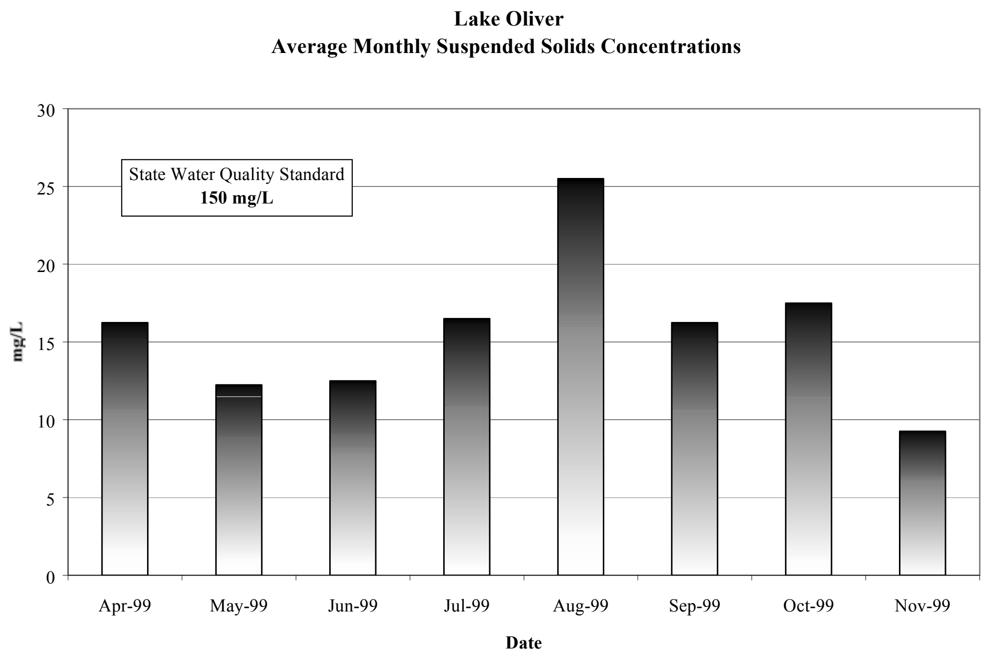


Figure 75. Lake Oliver Average Monthly Total Suspended Concentration.

Ammonia

The average surface ammonia concentration was 0.059 mg/L with a median of 0.01 mg/L. The average ammonia concentration for bottom samples was 0.072 mg/L with a median of 0.08 mg/L. Occasionally, ammonia concentrations varied between surface and bottom samples. The highest surface ammonia concentration of 0.23 mg/L occurred from site LOL-2 in May. The bottom concentration was only 0.01 mg/L and was collected on the same date. Because of the one-time occurrence, and no real difference in observed water quality, the 0.23 mg/L may be a sample anomaly, although the spring diatom bloom had collapsed by May 18 (see separate discussion on algae). The highest bottom ammonia concentration of 0.17 mg/L occurred in July when the surface concentration was only 0.01 mg/L. Decomposition of organic material was likely responsible for detectable ammonia concentration in the bottom sample. The lowest ammonia concentrations were seen during the sampling during August, September and October (Figure 76). Utilization by algae is probable here because the 3-month period was the height of the blue-green bloom in Lake Oliver (see separate discussion on algae).

The un-ionized fraction of ammonia is toxic to fish and increases with increasing pH and temperature. There were no exceedances of the water quality standards during the project period (Figure 77).

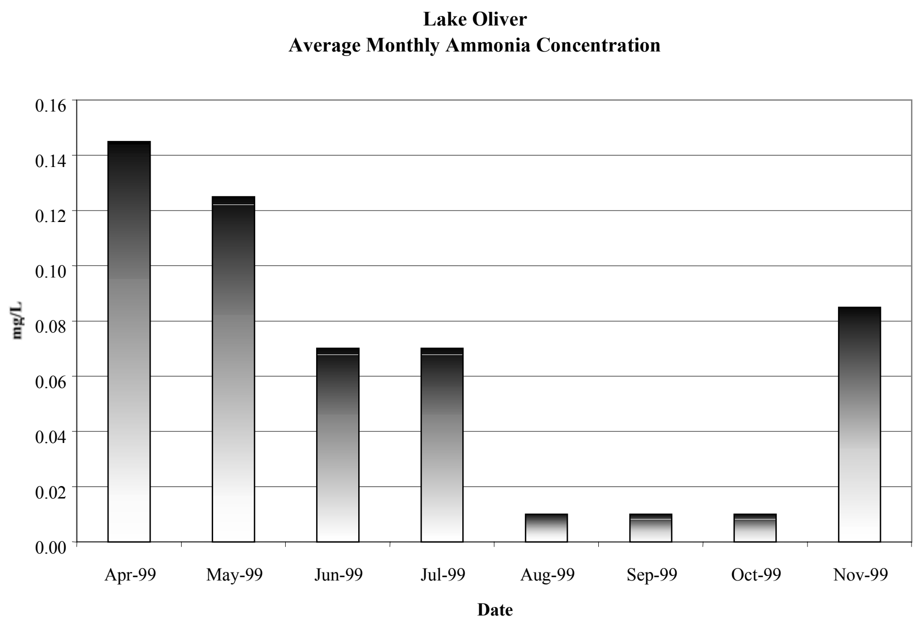


Figure 76. Lake Oliver Average Monthly Unionized Ammonia Concentration.

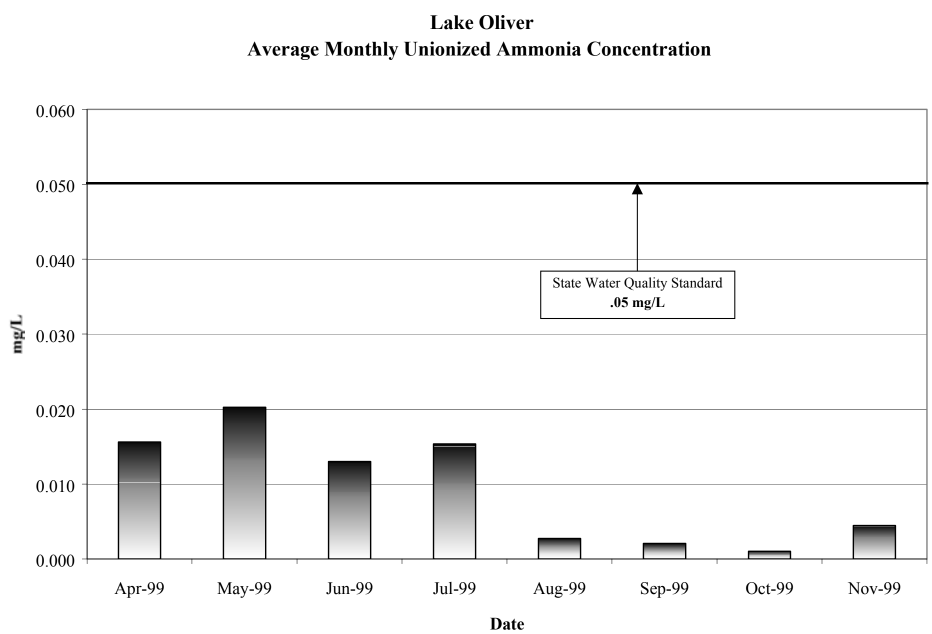


Figure 77. Lake Oliver Average Monthly Unionized Ammonia Concentration.

Nitrate-Nitrite

Nitrogen, in the form of nitrate and nitrite, is most readily available for assimilation. Nitrate-nitrite concentrations were given a value of 0.05 mg/L when undetected by standard laboratory procedures. The overall average nitrate-nitrite concentration (surface and bottom) was 0.058 mg/L for the entire project. There were no significant differences between surface and bottom samples. The highest concentration of 0.1 mg/L was observed at the surface of LOL-1 in July and in all samples in November (Figure 78). Nitrate-nitrite concentrations were relatively low in all samples. The low nitrate-nitrite concentrations are likely the result of these forms being taken up by the algae.

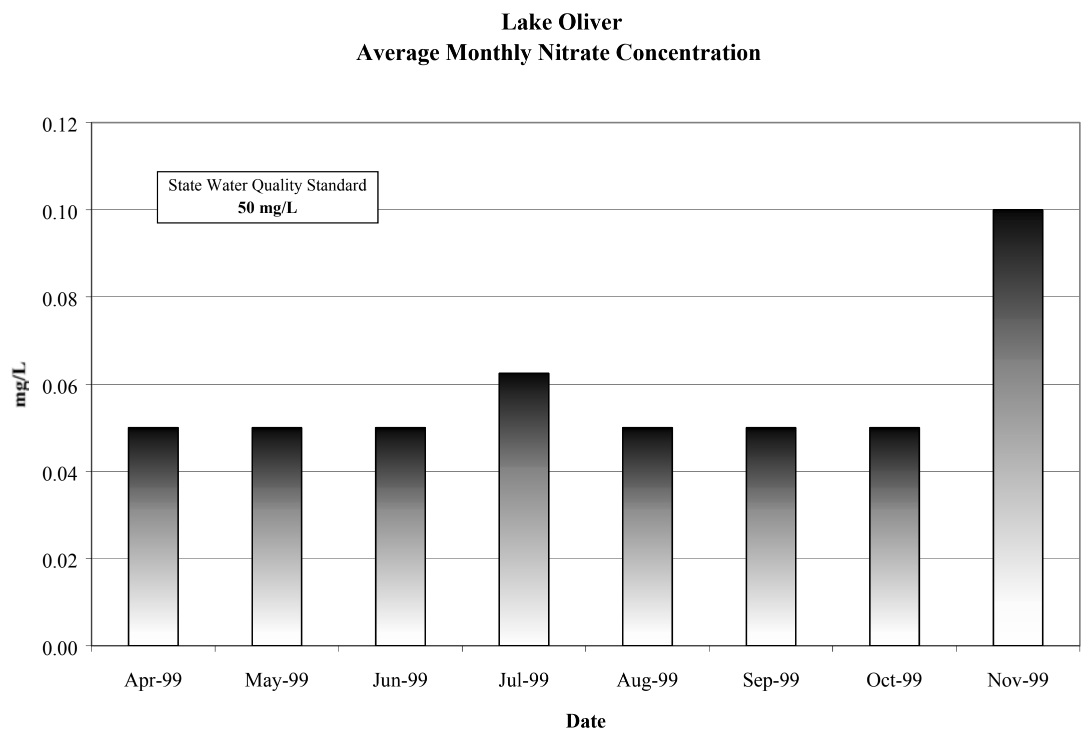


Figure 78. Lake Oliver Average Monthly Nitrate Concentrations.

Total Kjeldahl Nitrogen / Organic Nitrogen

Total Kjeldahl nitrogen (TKN) minus the ammonia fraction is organic nitrogen. The average surface organic nitrogen concentration was 1.87 mg/L (median: 1.94 mg/L) and the average bottom concentration was 1.88 mg/L (median: 2.0 mg/L). A significant difference was not observed between surface and bottom samples or between sites. Wind most likely kept the concentrations uniform throughout the water column. Organic nitrogen ranged from the highest concentration of 2.84 mg/L sampled in October (maximum annual algae population) to the lowest concentration of 1.15 mg/L sampled in May (minimum annual algae population). The overall mean concentration of organic nitrogen increased from spring to summer and into fall similar to the algae population in Lake Oliver (Figure 79). The lower concentrations of organic nitrogen in the spring are due to decomposition of organic matter being converted from organic nitrogen to ammonia. Higher organic nitrogen is the result of increased organic matter (algae) throughout the lake. Concentrations may have also increased due to evaporation of the lake.

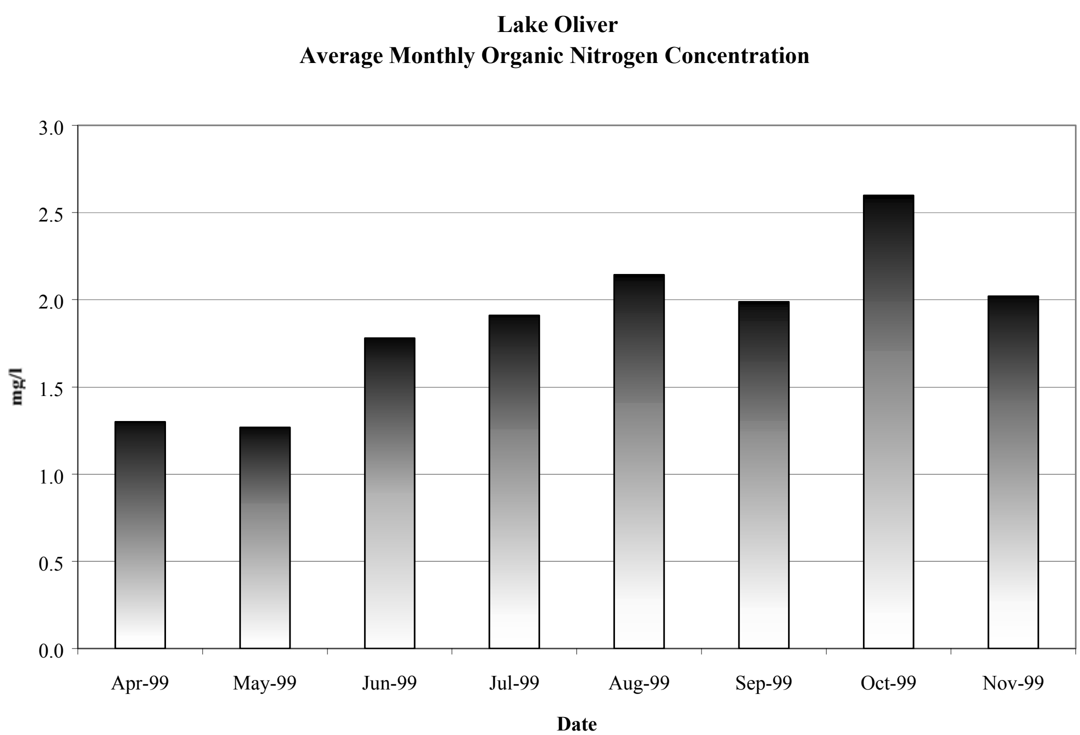


Figure 79. Lake Oliver Average Monthly Organic Nitrogen Concentration.

Total Nitrogen

Total nitrogen is the sum of the nitrate-nitrite and the TKN concentrations. Total nitrogen concentrations were similar to those discussed in organic nitrogen section of the report. Due to low mean concentrations of nitrate-nitrite, total nitrogen mean concentrations nearly mirror the mean organic nitrogen concentrations (Figure 80). The overall average total nitrogen concentration of 2.00 mg/L (median: 2.12) was slightly higher than the overall organic nitrogen concentration of 1.875 mg/L (median: 1.97). This was due to the occasional ammonia concentrations, which decreased the organic nitrogen concentrations. Ammonia is a product of organic decomposition and is readily available for uptake by plants and algae for growth. During the sampling periods (April-November), the nitrogen in Lake Oliver was almost entirely organic. Sources of organic nitrogen can include the release from living or decaying organic matter, lake septic systems, or agricultural waste. Detritus (dead plant material) and algae are the likely source of organic nitrogen in Lake Oliver. Due to the water-soluble nature of nitrogen, it is difficult to remove from an aquatic ecosystem, especially since blue green algae are capable of fixing or converting different forms of nitrogen for growth.

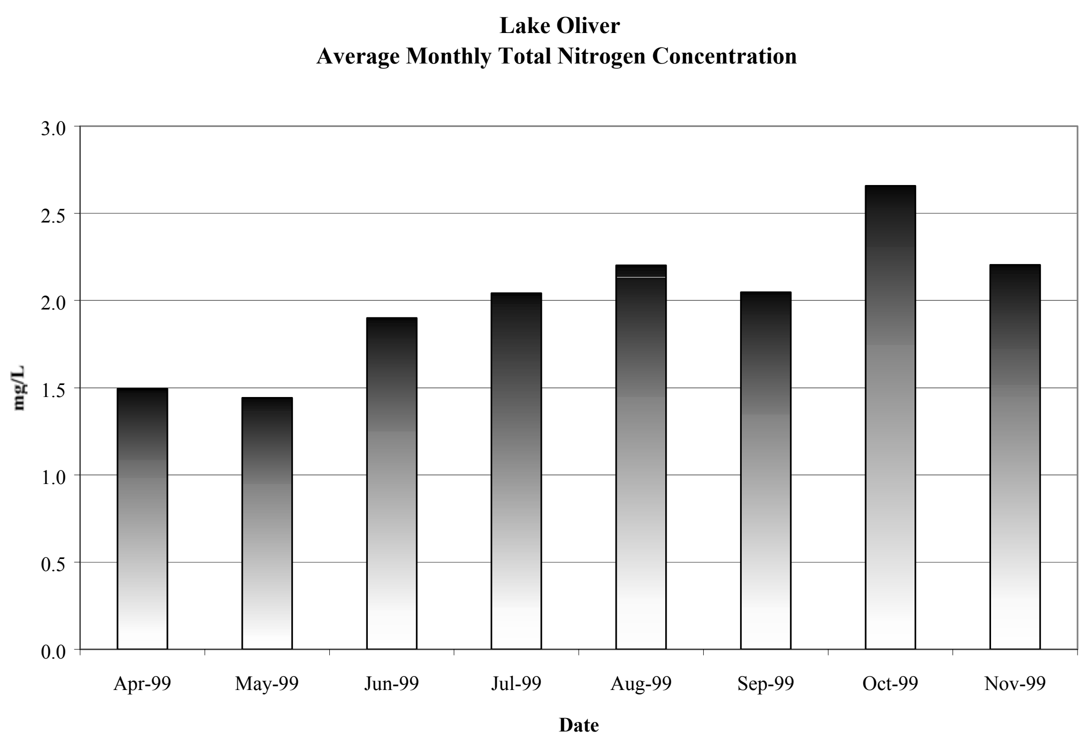


Figure 80. Lake Oliver Average Monthly Total Nitrogen Concentration.

Total Phosphorus

Total phosphorus concentrations in Lake Oliver averaged 0.069 mg/L (median: 0.0685) for bottom samples and 0.0649 mg/L (median: 0.0615 mg/L) for surface samples. Little variation was observed between surface and bottom samples. The greatest variance in surface to bottom samples occurred in July when calm wind conditions prevented mixing. Bottom total phosphorus concentrations were slightly higher than surface concentrations, perhaps the result of internal loading from a release of phosphorus from the sediments. Low dissolved oxygen concentrations were also observed near the bottom in July. Total phosphorus ranged from the lowest concentration of 0.042 mg/L in April to the highest concentration of 0.09 mg/L in October. As seen in Figure 81, phosphorus increased from April to October before declining in November. Total phosphorus was likely higher during periods of increased algal production or from suspended sediments caused by wind. Whatever the case, preventing phosphorus from being suspended in the water column will reduce availability to algae. Due to fairly sparse aquatic vegetation within the main basin of Lake Oliver, algae have less competition for available nutrients.

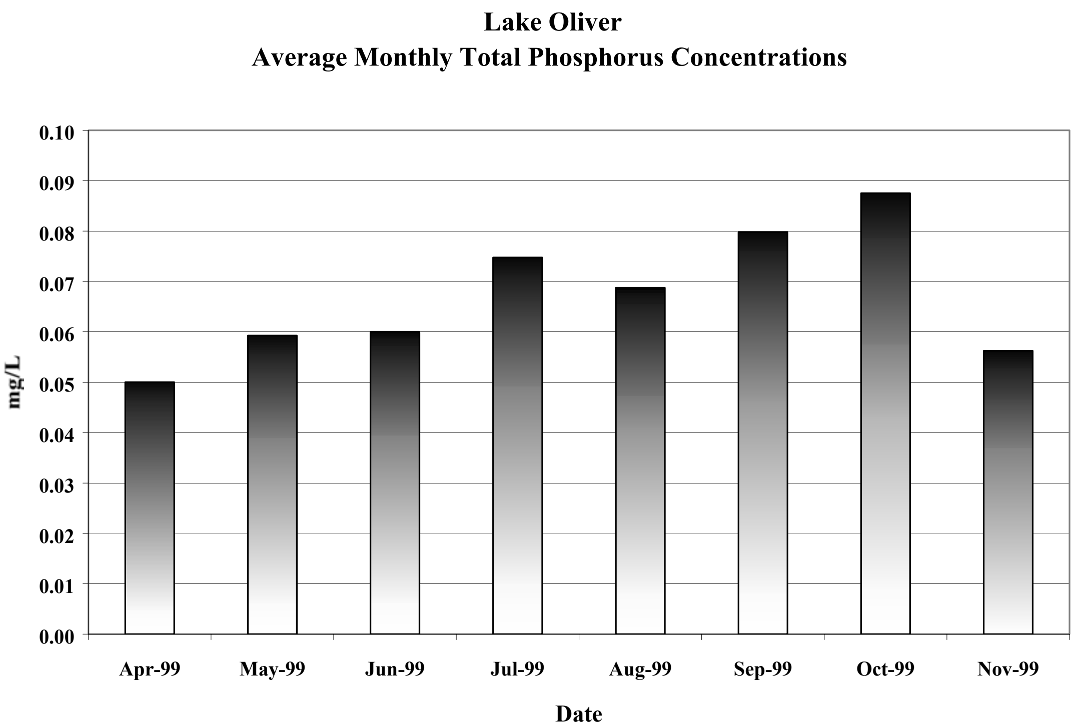


Figure 81. Lake Oliver Monthly Average Total Phosphorus Concentrations.

Total Dissolved Phosphorus

Total dissolved phosphorus is the fraction of total phosphorus that is readily available for use by algae. The average total dissolved phosphorus concentration was 0.0193 mg/L for both surface (median: 0.021 mg/L) and bottom (median: 0.0195 mg/L) samples. Dissolved phosphorus exhibited a uniform distribution between surface and bottom samples. Concentrations ranged from a high of 0.025 mg/L to a low of 0.011 mg/L. Dissolved phosphorus fluctuated from month to month, with the lowest readings in April and the highest in September (Figure 82). The average percentage of total phosphorus that was dissolved was 29.2%, which signifies that most of the phosphorus is of particulate formation. The average dissolved phosphorus concentration in Lake Oliver was 0.0193 mg/L (median: 0.02 mg/L). Wetzel (1983) suggested that a total phosphorus concentration of 0.02 mg/L indicates that a lake is eutrophic and may experience an algal bloom. Phosphorus concentrations in Lake Oliver meet or exceed the minimal requirements necessary to experience re-occurring algae blooms.

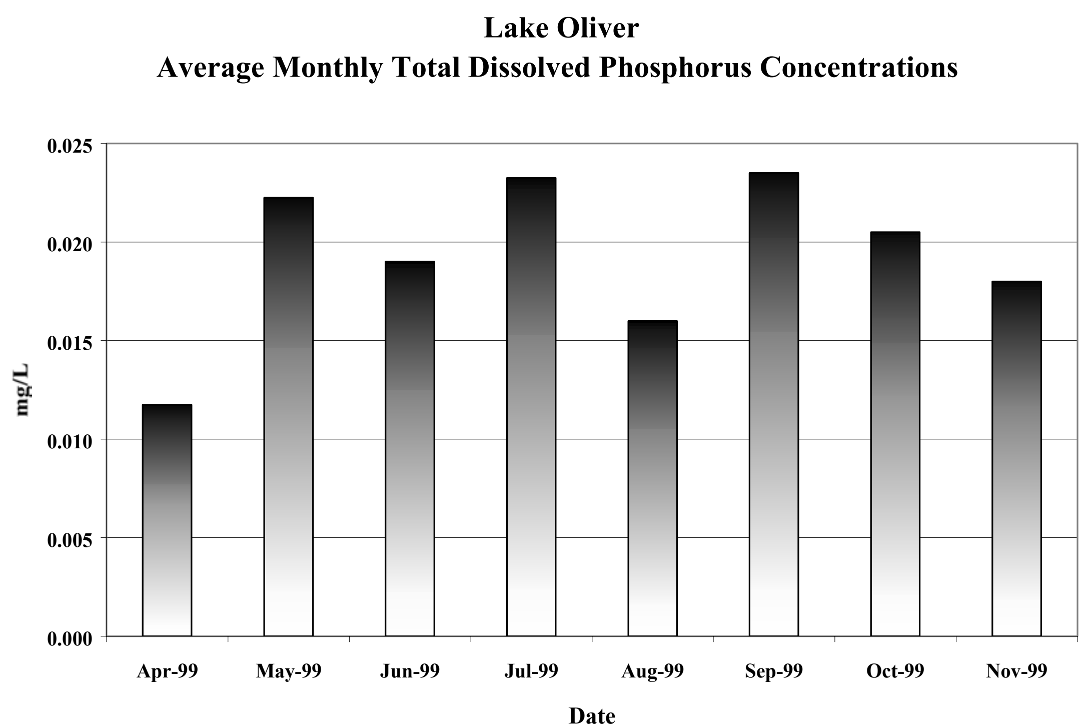


Figure 82. Lake Oliver Average Daily Total Dissolved Phosphorus Concentrations.

Chlorophyll *a*

Chlorophyll *a* is a pigment in plants that may be used to estimate the biomass of algae (Brower, 1984). Monthly chlorophyll *a* samples were collected throughout the project period. Figure 83 shows the chlorophyll *a* concentrations per site for Lake Oliver. The variance between the samples was not as great as the variance for the Lake Cochrane chlorophyll samples. Algal densities and biovolume increased steadily from mid-June through late summer and fall to reach an annual maximum on October 20, 1999, before collapsing in November (see separate discussion on algae). The chlorophyll *a* values show a similar, though not exact pattern for the June through November period.

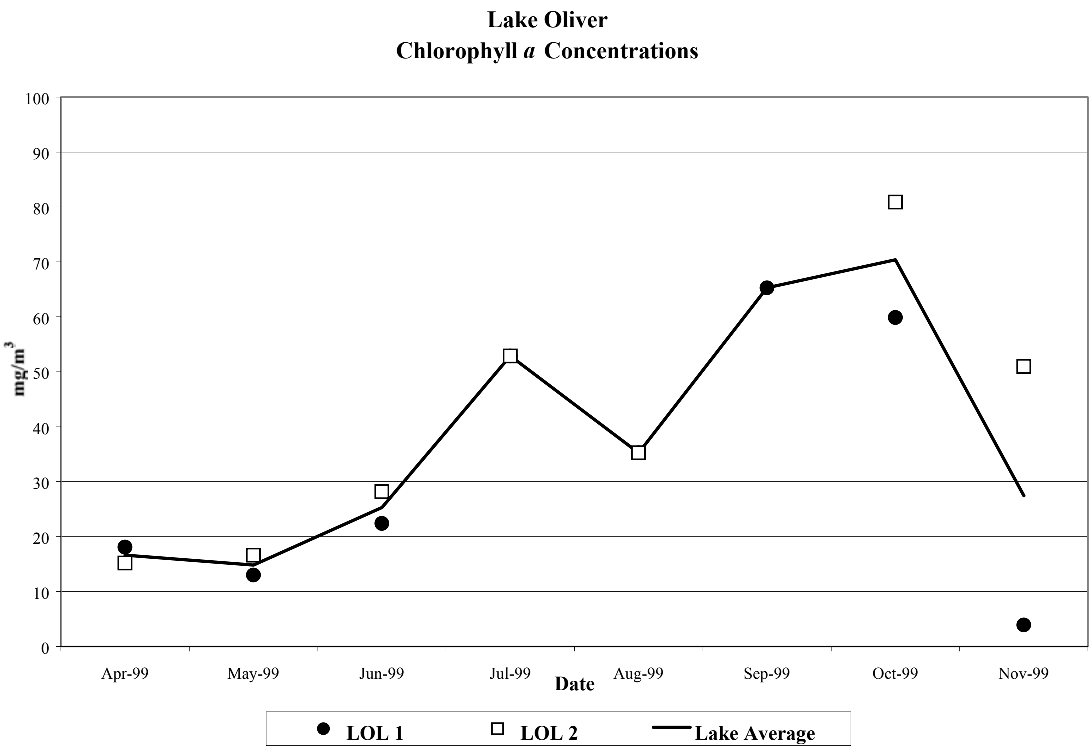


Figure 83. Lake Oliver Chlorophyll *a* Concentrations.

The monthly average should have been the highest in August or July, however as stated earlier, a collapsed bloom or an error in analysis was most likely responsible for the lower chlorophyll concentrations. As can be seen by the chart, the month of October had the highest recorded monthly average (70.39 mg/m^3). Correspondingly, algal densities were at their annual maximum in October. The minimum monthly average chlorophyll *a* concentration was collected in the spring samples for April and May. The diatom blooms of early spring may have produced larger algal counts, however chlorophyll *a* concentrations in diatoms are generally lower.

Typically, chlorophyll and total phosphorus have a relationship in regards to increasing concentrations. As total phosphorus increases, chlorophyll *a* typically follows. There may be factors within a waterbody that change this relationship. It may be turbidity from bottom sediments, nutrient ratios, light, temperature, or hydraulic residence time. The correlation between Lake Oliver's phosphorus and chlorophyll *a* concentrations can be seen below (Figure 84).

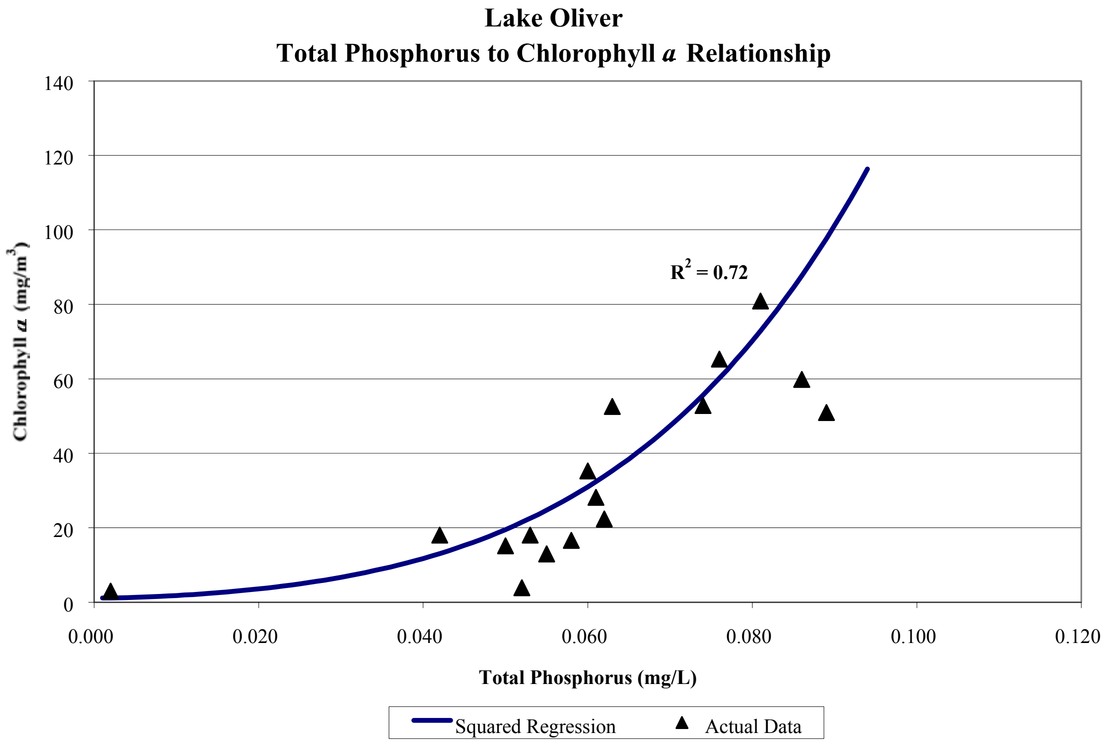


Figure 84. Lake Oliver Total Phosphorus to Chlorophyll a Relationship.

In Lake Oliver there is a very good total phosphorus to chlorophyll a relationship (R^2 = 0.72). As the R^2 value increases, the relationship increases. An R^2 value of 1.00 would be a perfect relationship where all of the points fall on the line. The data presented in the above figure is good evidence that a reduction of the inlake total phosphorus concentration should show a reduction in chlorophyll *a*.

Fecal Coliform

Fecal coliform bacteria originate from the digestive tract of warm-blooded mammals and birds. Concentrations of fecal coliform are often an indication of animal waste. Several factors can influence the presence of fecal coliform in a waterbody. Exposure to sunlight and time seem to sharply reduce the size of fecal coliform concentrations even though high nutrient concentrations often suggest potential waste.

Of the 32 total fecal coliform samples collected during the study, only 2 detectable concentrations were observed (Figure 85). A minimum concentration of 10 colonies/100mL was detected from a surface sample in July and again in August. The Lake Oliver watershed is composed mostly of grass and hay ground with a majority planted into the Conservation Reserve Program (CRP). CRP is a contract to plant the selected area to native grass for 10 years. A few small pastures are present in the watershed though cattle were not witnessed during the study period. A small feedlot is positioned at the western edge of the watershed though drainage passes through several wetlands heavily covered with riparian vegetation before reaching LOT-4. At the time when both inlake samples were collected, all the tributaries were dry. Because animal waste was unlikely to enter from the watershed, detectable fecal coliform concentrations can most likely be attributed to wildlife species (waterfowl) that frequently inhabit Lake Oliver.

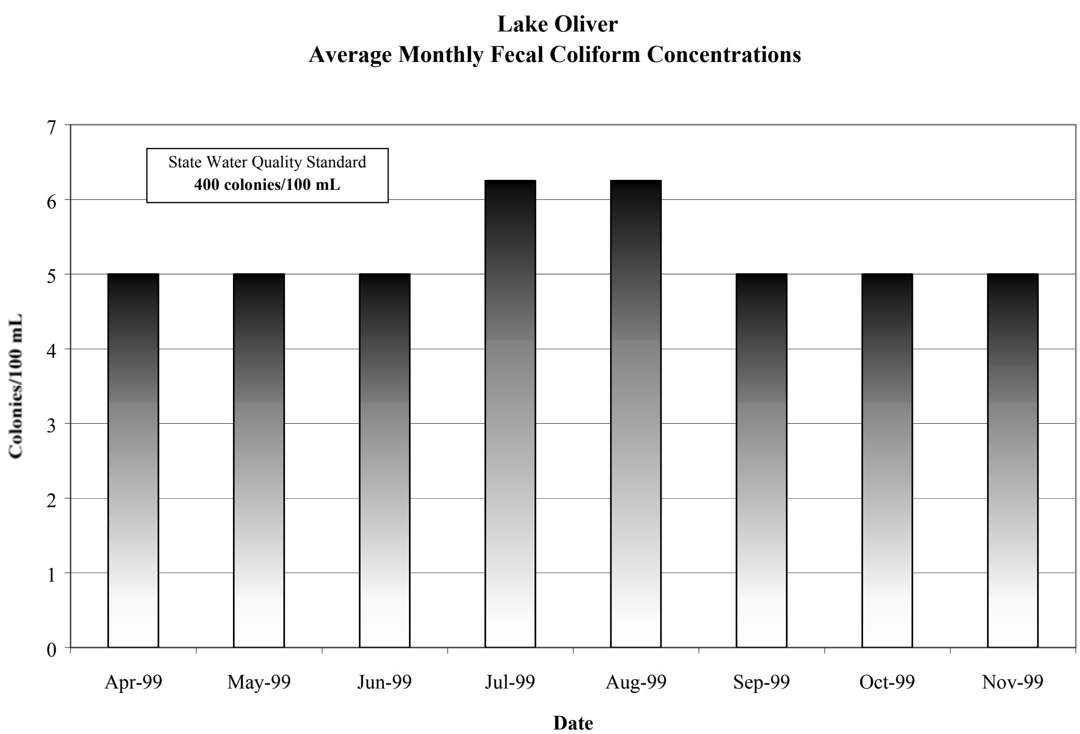


Figure 85. Lake Oliver Average Monthly Fecal Coliform Concentrations.

Trophic State Index

Carlson's (1977) Trophic State Index (TSI) is an index that can be used to measure the relative trophic state of a waterbody. The trophic state is categorized by how much production occurs in the waterbody. The smaller nutrient concentrations in a waterbody are typical of a lower trophic level, and larger nutrient concentrations are typical of more eutrophic waterbodies. Trophic conditions range from the least productive, oligotrophic lakes to nutrient-rich highly productive hyper-eutrophic lakes. The majority of lakes in South Dakota are in the eutrophic to hyper-eutrophic range. Table 39 describes the different numeric limits for the various levels of the Carlson index. During the project, the mean TSI parameter for all samples placed Lake Oliver within the hypereutrophic class.

Table 39. Trophic Index Ranges

Trophic Level	Numeric Range
Oligotrophic	0 – 35
Mesotrophic	36 – 50
Eutrophic	51 – 65
Hyper-eutrophic	66 – 100

Three different parameters can be used to compare the average trophic condition of a lake: 1) total phosphorus; 2) Secchi disk; and 3) chlorophyll *a*. The calculated TSI levels for Lake Oliver are indicated by Table 40 and Figure 86.

Table 40. Average TSI levels for Lake Oliver

Parameter	TSI Chlorophyll a	TSI Secchi Disk	TSI Total Phosphorus	Parameters Combined
Average	72.16	65.20	64.04	67.03
Median	72.35	65.53	63.58	66.63
Maximum	82.70	71.29	68.91	82.70
Minimum	52.96	55.44	58.07	52.96
Standard Dev.	7.94	5.17	3.06	6.62

As can be seen in this graph, the phosphorus and Secchi TSI values were consistently lower than the chlorophyll *a* TSI. The continual increase in phosphorus TSI from August to October may have been the result of increased concentration from evaporation or internal phosphorus load. Due to the landuse and the relatively small size of the watershed, Lake Oliver has little nutrient input from the watershed. The Secchi depth appears to be closely related to chlorophyll *a* concentrations, however at times during the project, suspended sediment was observed from increased wind and wave action. The relatively low November TSI values were most likely the result of algae being removed from the water column (see separate discussion on algae).

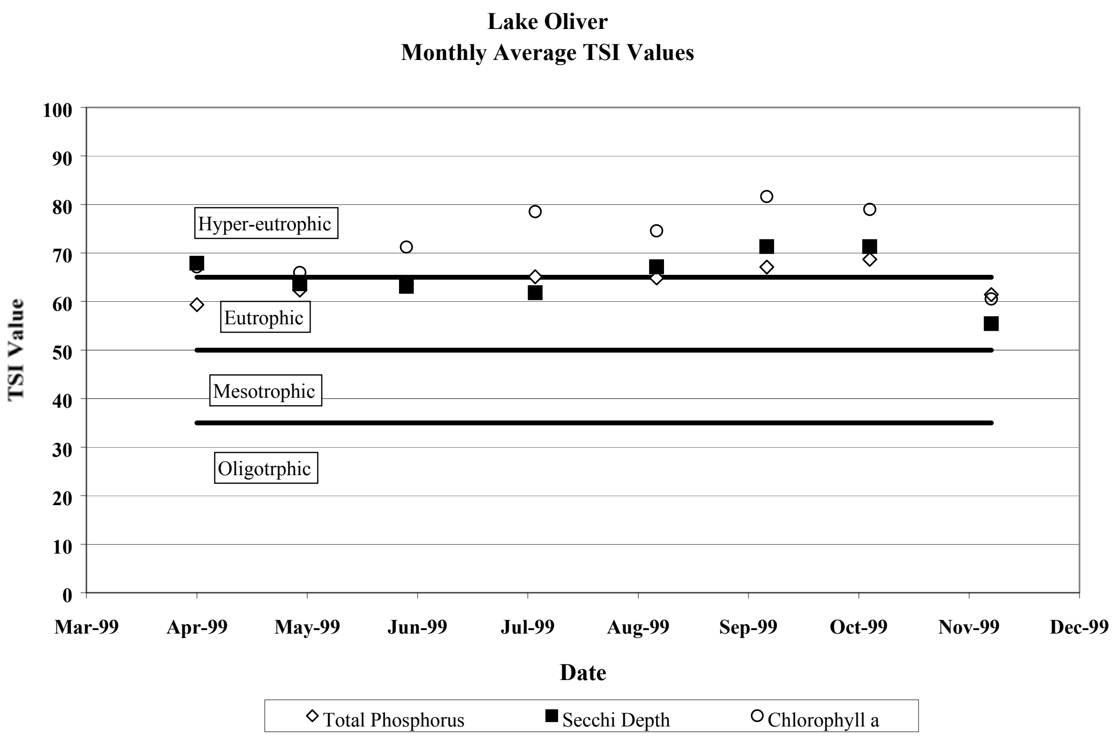


Figure 86. Lake Oliver Monthly Average TSI Values.

Long Term Trend

The project period for Lake Oliver was only a "snapshot in time" compared to the geological history of the lake. Due to the variation in weather and precipitation from year to year, it is useful to look at water quality on a long term basis. Samples for Lake Oliver have been collected from 1995 until 1999 for different projects. Figure 86 shows the change in TSI values for summer samples for data from 1995 to 1999. Summer samples were used for the comparison since most of the samples prior to the 1999 were collected during the summer months.

Figure 87 shows that there has been a very slow rate of change (slope = 0.00633) in Lake Oliver since 1995. Although the angle of the trend line was slightly increasing (1.84^{o}), changes in inlake water quality over the 4-year period were minimal. Oliver has very little water entering from the watershed and in many years has no outflow. When there is no outflow, internal loading in the lake increases, increasing eutrophication. Lake Oliver experienced extremely high run-off in 1994 and again in the spring of 1997. These wet years have allowed Lake Oliver to "flush out" internal nutrients. If the lake does not receive water from external sources, the lake will continue to increase in eutrophy in dry years. Lake Oliver should see improved water quality if the internal nutrient loadings in the lake could be lessened. Since very few nutrients are entering from the watershed, direct inlake restoration activities would be the most beneficial way to realize better water quality.

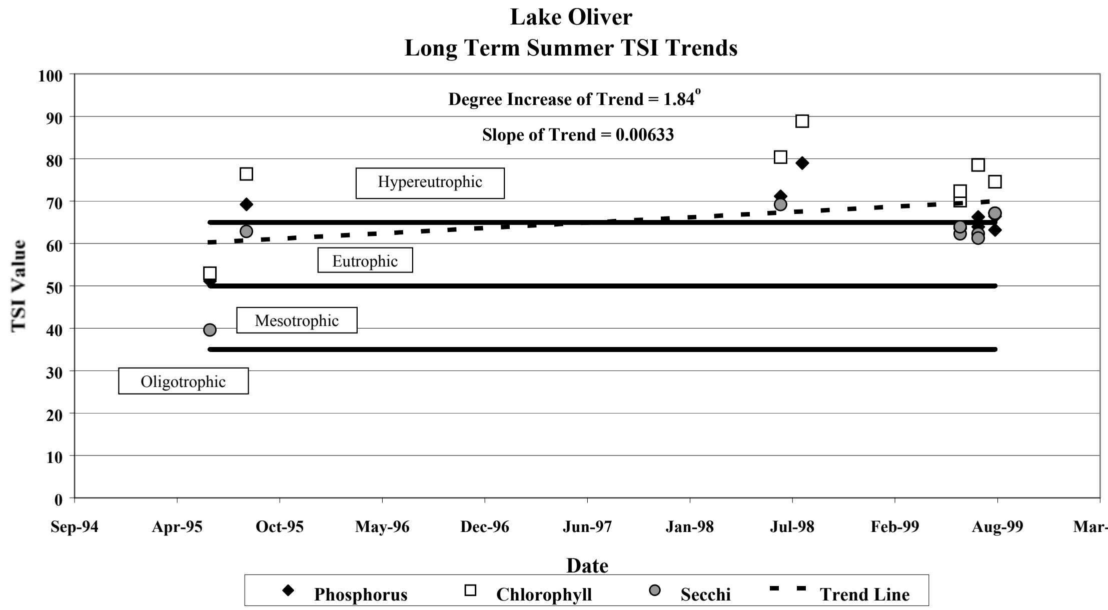


Figure 87. Lake Oliver Long Term Summer TSI Trends.

Limiting Nutrient for Lake Oliver

In order for algae to reproduce (bloom) and sustain life, a certain amount of nutrients must be available. Nitrogen and phosphorus are most often the essential nutrients in highly eutrophic lakes. When one of these nutrients reduce the potential for algal growth and reproduction, it is considered the limiting nutrient (Odum, 1959). Typically, phosphorus is the limiting nutrient for algal growth. However, in many highly eutrophic lakes with an over abundance of phosphorus, nitrogen can become the limiting nutrient. In general, phosphorus can be managed more practically than nitrogen.

To determine the limiting nutrient for algae production in Lake Oliver, a ratio of total nitrogen to total phosphorus (TN:TP) was calculated. If the ratio is greater than 10:1 for TN:TP, algae are considered to be phosphorus-limited. The inverse (<10:1) suggests nitrogen limitation. The average total nitrogen to total phosphorus ratio was 30.2 mg/m^3 (median: 28.9 mg/m^3) suggesting Lake Oliver to be phosphorus-limited. The TN:TP ratios ranged from a high of 44:1 to a low of 20:1, which further suggests phosphorus limitation in all samples during the project period (Figure 88).

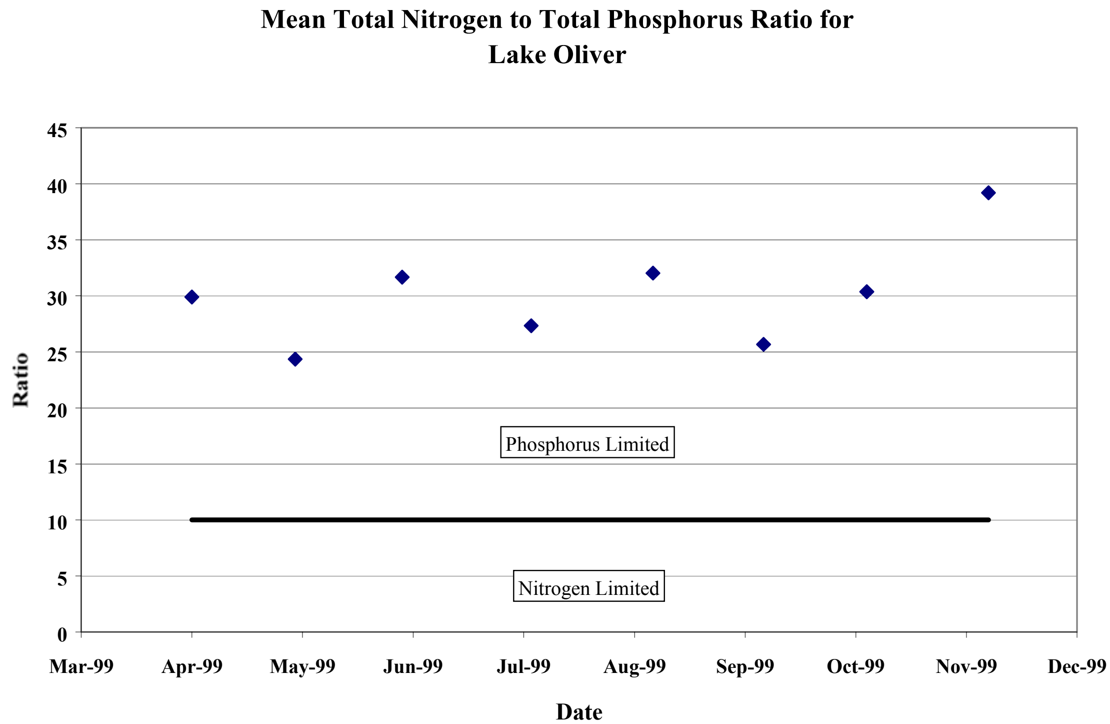


Figure 88. Mean Total Nitrogen to Total Phosphorus Ratio for Lake Oliver.

Several physical factors such as temperature, sunlight and turbidity can also limit algae growth. Since these factors are difficult to manage, management efforts and resources should focus on reducing inlake phosphorus concentrations.

Reduction Response

A reduction of inlake nutrient concentrations typically reduces the amount of biological production in a waterbody. The phosphorus to chlorophyll *a* R^2 value in Lake Oliver was 0.72 (1.0 would be a perfect relationship). The inlake phosphorus reduction should reduce the chlorophyll *a* concentration by a determined amount according to Equation 1. Table 41 shows what various reductions in total phosphorus would do to the chlorophyll TSI.

Chlorophyll a Concentration in mg/m^3 =

Equation 1. Chlorophyll a Reduction Equation.

$$=10\text{^}(((LOG(TP))*6.41583)+((LOG(TP)^2)*1.48186)+6.99989)$$

where TP = Total Phosphorus Concentration in mg/L

Table 41. Lake Oliver Chlorophyll Reduction.

Current Average Inlake Phosphorus Concentration	Percent Reduction of Phosphorus	Estimated Reduction of Chlorophyll *a*	Estimated Phosphorus TSI Reduction	Estimated Chlorophyll *a* TSI Reduction
mg/L	%	mg/m^3		
0.069	0%	35.32	65.24	74.57
0.062	10%	26.01	63.72	71.57
0.055	20%	18.78	62.02	68.37
0.048	30%	13.27	60.09	64.96
0.041	40%	9.14	57.87	61.31
0.035	50%	6.12	55.24	57.38
0.028	60%	3.97	52.02	53.13
0.021	70%	2.50	47.87	48.59
0.014	80%	1.56	42.02	43.96
0.007	90%	1.14	32.02	40.85

RECOMMENDED WATER QUALITY TARGET

Lake Cochrane

The water quality target for Lake Cochrane is to maintain the current water quality with average phosphorus TSI levels at or below 50. Water quality monitoring showed relatively low nutrient and sediment inputs from the watershed, that includes discharge from Lake Oliver. Both the AGNPS and BATHTUB models showed that a 26% reduction of tributary phosphorus load from the watershed would not greatly affect inlake water quality. However, improvements in watershed management techniques that remove nutrients or sediment will help protect Lake Cochrane so it can maintain its relatively good water quality for future generations to enjoy.

The watershed model did not consider how inlake improvements to Lake Oliver would affect the inlake water quality of Lake Cochrane. Suspended sediment loads caused by carp stirring up sediment at the outlet of Lake Oliver should be controlled to reduce the sediment and associated nutrient load to Lake Cochrane. Other inlake work on Lake Oliver that is intended to reduce algal blooms and internal load will also benefit Lake Cochrane. An estimated water quality target for these unspecified improvements is not possible. However, long term monitoring in Lake Cochrane will determine if inlake water quality is improving, or at least maintaining, lower eutrophic or mesotrophic levels.

Cleanout of the sediment ponds and repair of the drawdown tube should control the input of sediment from ponds at site LCT-1 and LCT-2. Nutrient controls established above the lake in the watershed would also help reduce nutrient loads. Increasing the height of the drawdown tube at the pond that runs to Site LCT-3 should allow the ponds to hold more water and reduce the sediment inputs from the subwatershed. Any significant phosphorus load from the ponds in the future could be controlled by a small alum trickle system. The installed alum trickle system could virtually eliminate any phosphorus input at the inlets. If the trickle system was designed specifically for the small ponds, the system would only need to be operated during periods of flow from the watershed. After installation, operational costs are minimal. The sediment survey indicated that selective dredging in the west bay of Lake Cochrane should remove material that was most likely deposited prior to the installation of the sediment control structures. Dredging would increase beneficial uses and water quality in that portion of the lake.

Lake Oliver

The amount of phosphorus that entered Lake Oliver (6.22 kg) during the study period was a relatively small amount. The AGNPS model found no critical cells within the watershed. Most of Lake Oliver's relatively small watershed is planted in CRP and releases very little nutrients or run-off compared to that possible from cropland. Because the AGNPS model could not identify critical cells within the watershed, emphasis on improving water quality in Lake Oliver should concentrate on improving inlake water quality. The water quality target for Lake Oliver is to remove approximately 50% of the total phosphorus concentration inlake and reduce the chlorophyll *a* concentration from a hyper-eutrophic TSI level to a eutrophic level. Figure 89 below shows what the predicted chlorophyll a reduction would be with a 50% reduction in total phosphorus (approximate TSI of 58).

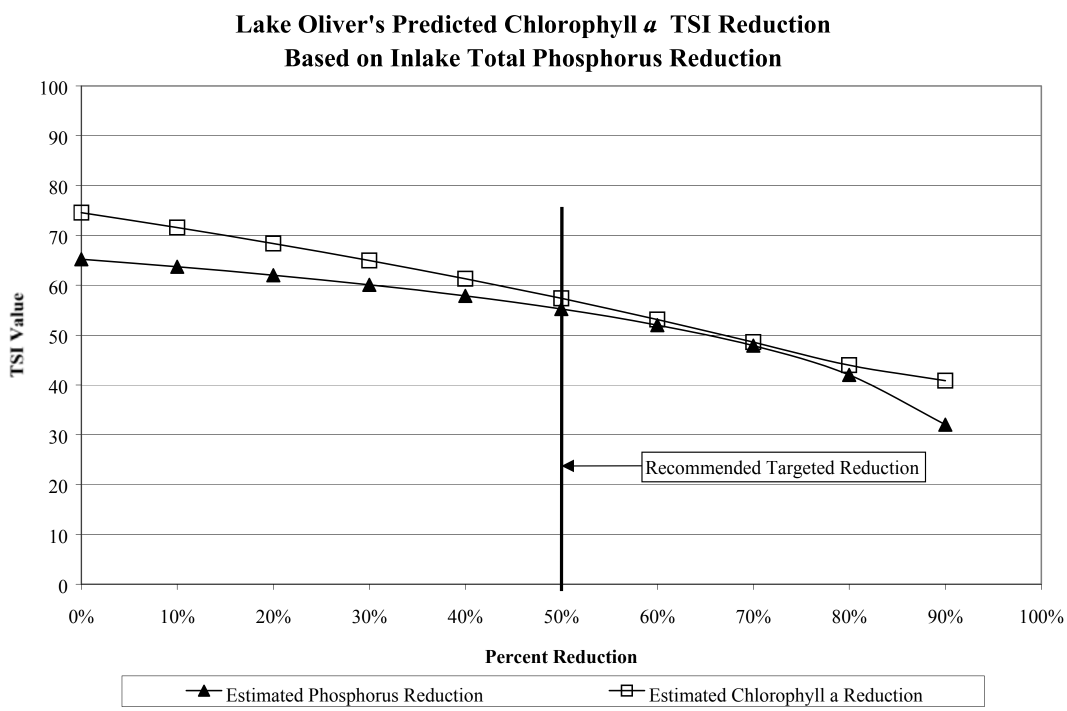


Figure 89. Lake Oliver's Predicted Chlorophyll *a* TSI Reduction Based on Inlake Total Phosphorus Reduction.

Recommended Methods to Reach Water Quality Target for Lake Oliver

The target may be reached by a number of inlake restoration activities. The end result of all of the recommended methods will be to remove phosphorus from the water column. Biomanipulation of the current lake's ecosystem will switch the lake from an algal dominated lake to that of a macrophyte-dominated lake. A result of the phosphorus removal, plus other activities, should result in reduced algal production and chlorophyll *a* concentrations.

Removal and Control of Rough Fish

Rough fish, like carp and bullheads, disturb bottom sediments and uproot macrophytes. Fish removal can be accomplished by a total rotenone application to the lake, or by selective harvest through seining. Rotenone is a chemical that will, if properly applied, selectively kill fish. A short time after application, the chemical becomes inert and fish may be restocked. If rotenone is used, all of the dead floating fish should be collected and disposed of properly. Rotenone can be expensive; however, it is highly effective. The estimated cost to rotenone Lake Oliver is $25,000 to $50,000.

Although less effective, seining is less expensive and will not harm as many game fish. Two or more seining times may be needed to ensure the majority of rough fish are removed from the lake. An incentive payment may need to be paid to the commercial seine company to cover the cost of seining. Cost will be dependent on how many fish are in the lake and how many seining efforts are needed to ensure sufficient removal. Moss (1997) suggests that removal of two thirds of the rough fish population may not be enough to gain positive results. Prolific fish populations can rebound in a season or two. Insufficient rough fish removal in many cases is the cause of any failed biomanipulation attempt.

After the rough fish are removed, measures must be taken to maintain low rough fish populations. Measures may include, but are not limited to, periodic seining, stocking of large piscivore fish species, the installation of an electric weir, or any combination. Periodic seining of Lake Oliver would be dependant on the rough fish population and the observed damage to the aquatic macrophyte population. Large piscivore fish species can keep rough fish populations in check. Large piscivorous fish would also help keep other planktivorous fish numbers low. Planktivorous fish eat zooplankton. As zooplankton feed on algae, an increased population of zooplankton should equate to less algae production.

Installing an electronic weir in the culverts between Lake Oliver and Lake Cochrane would be a very effective means in keeping fish from migrating between the two lakes. No matter what other controls are chosen to keep rough fish numbers controlled in Lake Oliver, a fish weir or some other device will be needed to keep the rough fish in Lake Cochrane from entering Lake Oliver. The end result of the rough fish removal should be that bottom sediments and aquatic macrophytes are left undisturbed and not transported into Lake Cochrane.

Selective Dredging

Alum treatment works best when sediments are not disturbed by wind, wave, or boating action. A sediment survey conducted during the project period, indicated that Lake Oliver had lost approximately 1/3 of the total lake volume to sediment. However, the survey also showed that the depths of Lake Oliver were sufficient to benefit from alum treatment. Alum is typically applied at depths greater than four feet (Sweetwater, 2000). It is estimated that approximately 100 surface acres are deep enough for this treatment method. A selective dredging project that deepens some of the marginal areas may increase the length of time the alum treatment is effective. Alum should not be applied to Lake Oliver at depths less than 5 feet.

The result of clearer water from restoration activities may be to encourage vigorous macrophyte growth. According to formulas based on Secchi depth measurements (Cooke, 1986), macrophytes could grow from 2.0 to 2.5 meters. Dredging could then keep macrophyte beds from encroaching into the majority of the lake's surface area.

Although dredging may increase the effectiveness of the alum treatment and may improve fish habitat, it is a very expensive restoration alternative. Table 42 below shows the estimated cost of dredging based on the cost of $3.50 per cubic yard.

Table 42. Estimated Cost for Dredging Lake Oliver.

Cubic Yards of Sediment Removed	Percent of Sediment Removed	Estimated Dredging Cost
142,857	15.8%	$500,000
214,286	23.7%	$750,000
285,714	31.6%	$1,000,000
902,856	100.0%	$3,159,997

Alum Treatment

Alum, which is a non-toxic aluminum sulfate slurry, forms an aluminum hydroxide floc when properly applied to water. Upon application, the floc removes phosphorus and suspended solids (including algae) from the water column and settles to the lake bottom. The floc also reacts with phosphorus to form an aluminum phosphate compound that, if left undisturbed, will not release the phosphorus for algal use (Sweetwater, 2000).

Studies show that the effectiveness of an alum treatment is directly related to the incoming phosphorus loads, depth and proper application. In many cases, the alum treatments effect on phosphorus reduction may last more than 10 years (Welch, Cooke, 1995). Currently, the phosphorus load entering Lake Oliver is as low as can be expected. Approximately 100 acres of the lake has sufficient depth to be treated with alum. As stated earlier, adding depth to the marginally shallow areas (5–7 ft.) may extend the effective life of an alum treatment. Welch (et al., 1995), in a study of shallow lakes, found that phosphorus concentrations were reduced 30% to 90% immediately after application. If inlake and tributary conditions remained favorable, phosphorus concentrations should be reduced and remain at 50% or less than the concentration prior to the treatment.

A side benefit of the alum treatment would be that the clearer water. Clearer water would allow for increased aquatic macrophyte growth. Aquatic macrophytes assimilate the nutrients usually used by algae and thus would reduce the algal population, and as a result, the chlorophyll *a* concentration.

Aquatic Macrophyte Farming

It is possible to convert an algal-dominated lake to an aquatic macrophyte-dominated lake (Moss, 1997). Lake Oliver has the proper physical and chemical make-up to allow a significant macrophyte population. After an alum treatment, macrophyte growth would be encouraged, if an increase in biomass across the lake had not already started. Carp, and the dominance of algae, are presently keeping macrophyte numbers low. An alum treatment should lock the phosphorus in the sediment for eight years or more. The macrophytes will add extra insurance if the alum-treated bottom is ever disturbed to the degree where phosphorus is again released from the sediments into the water column. Once the lake has transformed from an algal-dominated lake to that of a macrophyte-dominated lake, the macrophytes will use the nutrients that was being used by the algae. In a macrophyte dominated lake, the chlorophyll *a* concentrations should remain below the eutrophic level. If macrophytes do not naturally switch the lake from an algal-dominated lake to a macrophyte-dominated lake, macrophyte farming would encourage growth of favorable macrophyte species.

Concerns of Biomanipulation

Biomanipulation of an aquatic system is a complicated restoration activity. Restoration activities need to be scheduled in proper succession in order to help reduce the cost of restoration and ensure its success. Measures must be taken to keep rough fish from migrating between Lake Oliver and Lake Cochrane. Macrophytes are needed to maintain a healthy piscivore population. Establishment of a health macrophyte community would help ensure successful stocking of piscivores. There are other concerns in maintaining a stable fish community. Piscivores can decimate their food supply and starve or turn to cannibalism. When the food supply is in short supply, many piscivores may not survive. As the planktivorous population again rebounds, there may not be enough piscivores to control the zooplankton-eating fish population (Moss, 1997).

There may be an increase in the number of parasite-hosting snails and other parasites typically kept in check by bottom-dwelling or planktivorous fish. Although only a few cases were documented (Moss, 1997), low planktivorous fish populations may result in an increased number of large predator zooplankton. These predator zooplankton could lower the algal-eating zooplankton population enough to revert the lake back to a algal-dominate lake. Periodic monitoring of the ecosystem is needed to ensure that the lake community is following the desired end result of lower chlorophyll *a* concentrations.

The first recommended activity is the installation of a fish barrier between the two lakes to that no more fish will enter Lake Oliver from Lake Cochrane after the rough fish are removed. The next step should be rough fish elimination followed by dredging, if dredging is chosen. Rough fish removal is less expensive and easy to do at shallow depths. Alum treatment should follow rough fish removal.. After the alum treatment, aquatic macrophyte growth should be encouraged and promoted. Next, stocking of fish in proper numbers to ensure that a change in lake plant community from a macrophyte community to an algal community does not occur. Finally, periodic surveys and checks must be made to make sure the lake is maintaining the desired community.

CONCLUSIONS

Lake Cochrane and Lake Oliver are two glacial lakes found in the Coteau de Prairie region of eastern South Dakota. Both lakes have small watersheds for the size of their surface areas. Lake Oliver is estimated at 180 acres with approximately 540 acres of direct run-off. Lake Cochrane is estimated at 366 acres with 800 acres of direct run-off. The Lake Oliver watershed becomes a contributing factor to Lake Cochrane when the outlet structure is opened in the spring and Lake Oliver is at a high enough water elevation to run into Lake Cochrane (1,683.6 msl). At the elevation of 1685.0 msl, water will overtop the control structure of Lake Oliver and flow into Lake Cochrane. The purpose of the control structure is to keep the more nutrient-rich waters of Lake Oliver out of Lake Cochrane.

Lake Cochrane was listed on the 1998 South Dakota Waterbody List for fecal coliform impairment based on public beach monitoring information. Only two detectable fecal samples were collected during the assessment (concentrations were at 10 colonies/100mL.). No fecal coliform concerns could be substantiated by this study. Also, there have not been any beach closures due to unacceptable bacteria levels since monitoring began in 1994. The state had no authority to close public beaches due to unsafe bacterial levels until 1996. Lake Oliver was listed for nutrients and high TSI values. The nutrient and TSI levels were substantiated and a water quality goal of a 50% reduction of inlake total phosphorus concentration and a TSI value of 58 targeted to restore the lake from a hyper-eutrophic to eutrophic condition.

Since 1975, sediment basins around Lake Cochrane have reduced the sediment load from the watershed. The sediment basins do not appear to reduce nutrient loads. Sedimentation in the western end of Lake Cochrane was either from loadings prior to the construction of the sediment dams or, to a lesser extent, the removal of shoreline protective vegetation. The two deeper sediment basins that correspond to sites LCT-1 and LCT-2, have lost 35% and 31% of their capacity, respectively, due to sediment. The basin at site LCT-3 was not surveyed due to its shallow depth. The volume of water held at site LCT-3 was smaller than the original design due to the reduction of the height of the stand pipe.

The Lake Oliver sediment survey discovered that Lake Oliver has lost approximately 27% of its original depth. The majority of the sedimentation occurred in the northern bay; however, the original deep depths have leveled with the current bottom. The maximum measured depths of sediment was eight feet. The low sedimentation rate for the tributaries during the project conclude that the majority of the sediment entered Lake Oliver previous to 1975.

Algal samples indicated that the two lakes are quite different in composition and biomass. Blue-green algae contributed 66 percent of the biovolume in Lake Oliver and only 31% of the biovolume in Lake Cochrane. Lake Oliver also had less diversity than Lake Cochrane (49 taxa compared to 79 taxa, respectively). An aquatic macrophyte survey showed Lake Cochrane to have a large population of macrophytes which most likely has kept algal populations low by using the available nutrients. Lake Oliver is an algae-dominated lake.

The AGNPS model identified 16 critical cells within the Lake Cochrane watershed and only 1 critical cell within the Lake Oliver watershed. The majority of the critical cells in the Lake Cochrane watershed were due to cropland run-off into site LCT-3 and LCT-2. The AGNPS model agreed with the water quality sampling that the majority of the load came from site LCT-3 while the largest loading per acre came from site LCT-2. The accuracy of the model on site LOO was not dependable as AGNPS does not properly process cells that pass through a waterbody as large as Lake Oliver.

The watershed of Lake Oliver is mostly grassed. A few cells in the Lake Oliver watershed are cropped, however, these cells are routed through two wetlands before they reached the lake and no significant loading occurs from these sites.

The results of the water samples collected found the overall inputs to Lake Cochrane and Lake Oliver from the tributaries to be relatively low. Most nutrient and sediment loading from upland tributaries into Lake Cochrane were largest from site LCT-3. However, the largest per acre load came from site LCT-2. The outlet of Lake Oliver input a large percentage of sediment and nutrients into Lake Cochrane. The majority of nutrient and sediment loadings were attributed to carp stirring up sediment near the inlet. Without the carp present, the loading of suspended solids was estimated to be reduced by 85%. The phosphorus concentrations were twice as high (0.134 mg/L) when carp were present as when carp were not present (0.059 mg/L).

The tributary loadings into Lake Oliver were lower than those into Lake Cochrane as little water quality impairment could be found in the watershed due to the grassed watershed and wetlands. Due to the size of the watershed, Site LOT-4 typically had the largest nutrient load. However, site LOT-2 had the largest sediment and ammonia load. The sediment most likely came from the road running parallel to the tributary, and the source of the ammonia is most likely the road ditch or the wetland just upstream of the site. For the size of the watershed, there was also a relatively high loading per acre of other nutrients from site LOT-2.

The hydrologic budget of both lakes indicated that precipitation is the largest input and evaporation is the biggest output. The low sedimentation rates of both lakes show the relatively good condition of the watersheds and functioning sediment dams on Lake Cochrane. Because of the carp at its outlet, Lake Oliver actually showed more sediment and nutrients leaving the lake than entering the lake. Since the overall inputs to both lakes are low, the future nutrient and sedimentation concentrations for both lakes will be more dependant on internal loads than external influence.

Lake Cochrane was found to be eutrophic in regard to chlorophyll *a* and Secchi depth TSI values. Phosphorus TSI levels in Lake Cochrane were almost mesotrophic. The overall water quality in Lake Cochrane is better than most natural lakes in the state. The only exceedance of the water quality standards was for dissolved oxygen (1.0 mg/L) of one bottom sample. It was the only time the lake stratified during the monthly lake sampling effort. The average inlake dissolved oxygen concentration for that same sample day was approximately 7.0 mg/L. Lake Oliver experienced its only lake stratification in July also. The one dissolved oxygen exceedance in Lake Oliver also occurred in a bottom sample. The average dissolved oxygen concentration for Lake Oliver was greater than the state water quality standard (5.0 mg/L).

Lake Cochrane had a total nitrogen to phosphorus ratio (N:P) of 60 while Lake Oliver had a N:P of 30. Many of the concentrations of the parameters of concern for Lake Oliver were significantly different than those of Lake Cochrane. Table 43 below shows the average concentrations for each lake during the project period. Highlighted parameters are those with a significant difference ($p < 0.05$).

The long-term trends in Lake Cochrane (1970 – 1999) show a slight trend toward less eutrophication. Lake Oliver shows a slightly higher trend towards eutrophication, although the trend analysis only included three years of summer samples between 1995 and 1999. Although Lake Oliver has been a source of nutrients to Lake Cochrane in recent years, no noticeable adverse water quality can be attributed to the water received from Lake Oliver.

Recommended water quality targets for Lake Cochrane were to maintain pr improve the current water quality with a phosphorus TSI level at or around 50. To reach this target, best management practices should be implemented on the critical cells, targeted by AGNPS. The two deeper sediment ponds should be cleaned out and if needed, the drawdown tubes repaired. The sediment basins along the south road should be repaired to function as designed. Installing an alum trickle system at or near the drawdown tubes of the three sediment basins should reduce the nutrient content of the water entering the lake. Dredging the west bay, if sufficient sediment is found, would improve water quality and beneficial uses in that part of the lake.

Table 43. Comparison of Lake Cochrane and Lake Oliver Mean Water Quality Parameters.

Parameter	Cochrane	Oliver
Secchi (m)	1.39	0.74
pH (su)	8.80	8.83
Water Temp °C	14.93	14.57
Fecal Coliform (Colonies/100ml)	5.21	5.31
Alkalinity (mg/L)	217.08	259.13
Total Solids (mg/L)	1753.50	1370.78
Total Susp. Solids (mg/L)	9.79	15.75
Total Volatile Susp. Solids (mg/L)	6.500	7.875
Ammonia (mg/L)	0.050	0.066
Nitrate (mg/L)	0.052	0.058
Total Kjeldahl Nitrogen (mg/L)	1.436	1.941
Organic Nitrogen (mg/L)	1.385	1.876
Total Nitrogen (mg/L)	1.488	1.999
Unionized Ammonia (mg/L)	0.005	0.009
Total Phosphorus (mg/L)	0.026	0.067
Total Dissolved Phosphorus (mg/L)	0.008	0.019
Chlorophyll *a*	17.09	35.56

The recommended water quality goal for Lake Oliver is to reduce the inlake phosphorus concentrations by 50%. A 50% reduction in inlake phosphorus should reduce chlorophyll TSI levels to a target level below 60. Chlorophyll levels would move from hyper-eutrophic to eutrophic. The first activity needed to reach the water quality goal in Lake Oliver, is the installation of a fish barrier between the two lakes to ensure that no more fish will enter Lake Oliver from Lake Cochrane after rough fish are removed from Lake Oliver. The next step should be rough fish removal in Lake Oliver followed by dredging, if chosen. Rough fish removal would be less expensive and easier to perform at shallow depths. Alum treatment should follow rough fish or sediment removal. After the alum treatment, aquatic macrophyte growth should be encouraged and promoted. Proper stocking of fish in correct numbers should ensure a stable community that should not change the lake plant community from a macrophyte community back to an algal community. Finally, periodic surveys and checks must be made to make sure the lake is maintaining the desired community.

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APPENDIX A

Lake Cochrane Perimeter Road Sediment Traps Project Final Report

United States
Environmental Protection
Agency

Region 8
1860 Lincoln Street
Denver, Colorado 80295

EPA 908/3-79-001

EPA

Lake Cochrane Perimeter Road-Sediment Traps Project

Final Report

April 1979

EPA 908/3-79-001

LAKE COCHRANE PERIMETER ROAD-SEDIMENT TRAPS PROJECT

FINAL REPORT

by

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EPA CLEAN LAKES GRANT NO. S804248-01-2

Project Officer

Ronald M. Eddy

Environmental Protection Agency, Region VIII
Water Division
Denver, Colorado 80295

April, 1979

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ABSTRACT

Lake Cochrane is one of the few deep high quality prairie lakes in northeastern South Dakota. Local interests tried unsuccessfully for several years to develop measures to reduce sediment inflow. The proposal to develop sediment traps as a part of the lake's perimeter road system was selected for a grant award under EPA's "Clean Lakes" program initiated in 1975.

This small lake preservation project utilized the technical and/or financial resources of every level of government. For an allocated cost of about $20,000, three sediment traps were developed to control the sediment inflow from 66% of the lake's watershed area. By incorporating the sediment traps into the perimeter road system, 2700 feet of new gravel road, the sediment traps, and a new boat access area were constructed at a cost of $34,700. In addition, two of the sediment traps have been utilized as fish rearing ponds.

Due to limited data and numerous sediment-nutrient producing activities occurring concurrently, it has been difficult to evaluate the impact of the project on the lake. Preliminary evidence indicates good suspended solids removal in the sediment traps. There is evidence, however, that temporary storage of runoff water may not provide any nutrient removal. A comprehensive evaluation program needs to be developed.

The completed project has demonstrated a low cost, effective technique for reducing sediment inflow into a lake which may have application in other areas.

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SECTION 1

INTRODUCTION

THE LAKE COCHRANE RESOURCE

Lake Cochrane is a very pretty 366-acre lake located close to the South Dakota-Minnesota border in Deuel County, South Dakota. The lake has intermittent surface water inflow, very infrequent surface outflow, and moderate groundwater recharge. Although the Prairie Coteau region in northeastern South Dakota has about 250 natural lakes, Lake Cochrane is one of a very few having a maximum depth greater than 20 feet.

The lake was ranked into the first priority grouping by the South Dakota State Lakes Preservation Committee (1977), meaning that it was ranked as one of the top ten lake resources of eastern South Dakota.

The lake is unique in this area in that it did not experience a noticeable algal bloom until the summer of 1971. Prior to this 1971 algal bloom, most local people felt that the lake would remain "crystal clear" forever.

Figure 1 is a map showing Lake Cochrane, its drainage area, and the surrounding area.

The total direct drainage area of the lake is very small at about 765 acres.

PROBLEMS AFFECTING THE LAKE

The major watershed problem affecting the lake before this project was developed was the sediment-nutrient inflow from three small drainage areas located on the southwest side of the lake. Heavy shoreline and lake bottom sediments found in that area provided strong evidence that these three watershed inflows were adversely affecting the lake.

The other main input of lake sediments and nutrients prior to 1976 was erosion and runoff resulting from sometimes careless construction of lakeshore residences. Although there are a number of lakeshore residences, seepage from domestic wastes has

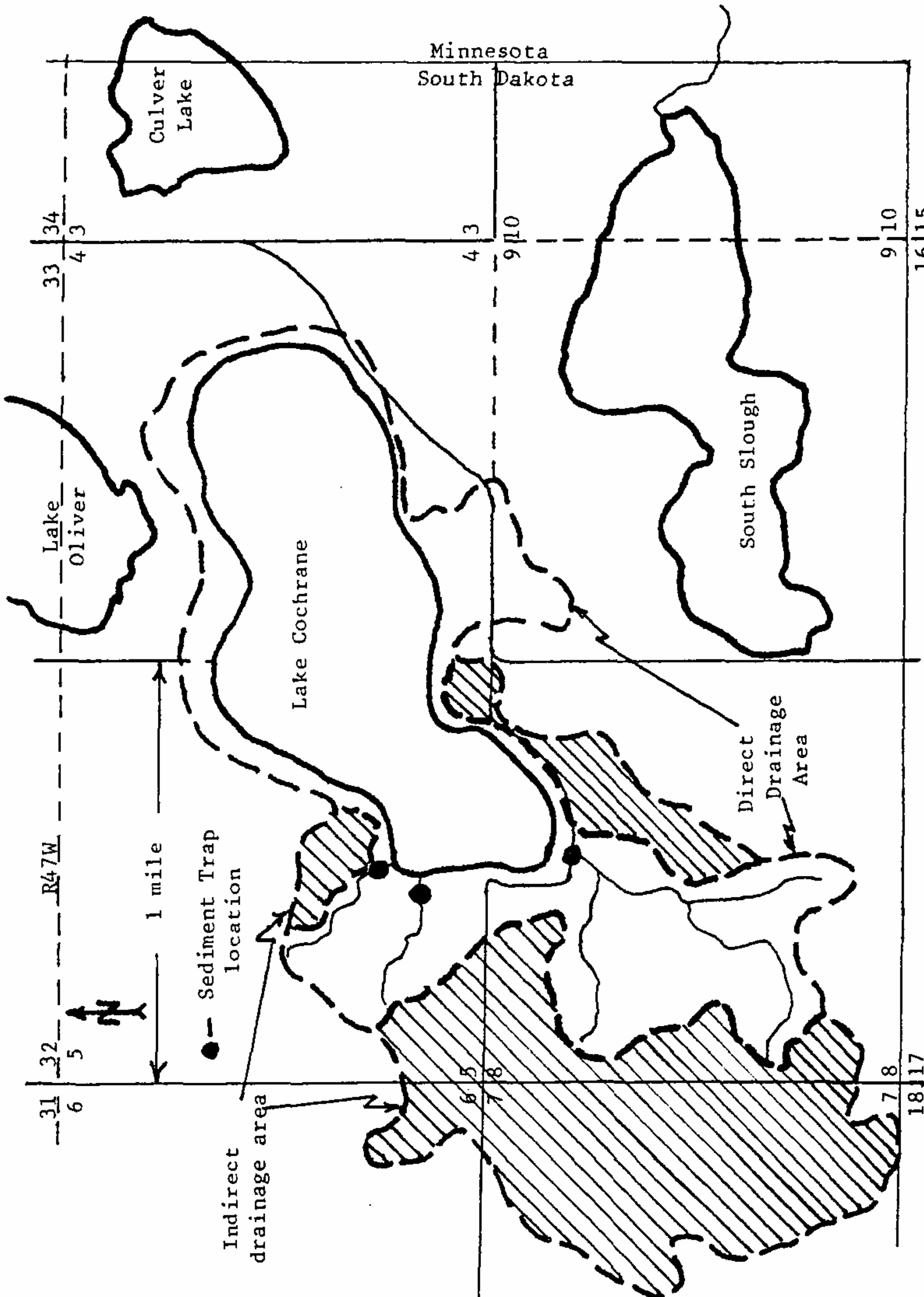

Figure 1. Map showing Lake Cochrane, the lake watershed, and surrounding area.

been minor due to a strong push to install sealed tanks as opposed to septic tanks and drainfields.

PUSH FOR ACTION TO PRESERVE THE LAKE

The urgency for reducing sediment and nutrient inflows received a strong boost from the 1971 algal bloom which was the first major evidence that this lake was becoming euthrophic. This interest received another boost in study reports prepared by Dr. Lois Haertel (1972), a biologist at South Dakota State University, and by Douglas Hansen (1973), a Watershed Biologist for the South Dakota Department of Game, Fish and Parks. Both reports strongly recommended development of sediment control measures for the lake.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

This project accomplished the stated project objective of demonstrating a low cost, effective technique for reducing sediment inflow into a lake by incorporating sediment traps into either existing or new roads located along the perimeter of the lake.

Nearly every high quality, heavily used lake has some type of access road developed around all or a portion of the perimeter of the lake. The landowners along this road system are generally willing to participate in efforts to preserve the lake because the quality of the lake directly affects their land values and their enjoyment of the lake.

Limited water quality data collected as a part of this project and research conducted by Dr. Haertel (1978) has provided evidence that temporary storage of runoff water will provide a significant reduction of suspended solids but may not provide any nutrient removal. This is a significant conclusion since a large portion of lake sediments in many prairie lakes is organic material produced within the lake itself. Thus, trapping inorganic sediments in watershed control structures while allowing nutrients which stimulate lake productivity to pass through will reduce but will not stop the filling of a lake with sediment and will not likely improve lake water quality.

The development of sediment control was cost effective under this multi-purpose technique because the road function financed a portion of the cost of the (a) earth fill, (b) structures to carry water through the roadway and (c) land rights.

This technique in many instances would have the following advantages:

(a) Because land requirements for developing sediment control measures are reduced, land rights are also generally easier to secure.

(b) The sediment control structures by being located on the perimeter road are located relatively close to the lake; thus sediments are restricted from adjacent

~~lands~~ The lake s which often contribute a high percentage of the lake's sediment load.

(c) By being located on a road, access for operation and maintenance purposes is much easier.

It is recommended that a comprehensive, well-planned monitoring program be developed which is geared to evaluating the efficiency of these sediment traps and their specific impact on the quality of Lake Cochrane.

The project facilities offer an opportunity to research the effectiveness of two different sediment trap designs. More importantly, the sediment traps with controlled drawdown tubes offer an important research facility for making a thorough evaluation of the impact of temporary versus more permanent water storage on nutrient removal efficiency. As noted above, the initial evaluation of this project has indicated that temporary water storage may not have a positive impact on lake water quality beyond restriction of inorganic sediments. There are many important questions in this regard that need to be answered before large amounts of public funds are used to develop sediment and/or nutrient control measures for shallow glacial lakes in the United States.

SECTION 3

DEVELOPMENT OF LAKE PRESERVATION PROJECT

DEVELOPMENT OF PROJECT CONCEPT AND GRANT PROPOSAL

In the early 1970's various local and state interests in eastern South Dakota began searching in earnest for methods and programs to accomplish the goal of developing sediment control measures for Lake Cochrane. They explored the possibility of reconstructing an existing township road crossing the lake's largest drainage course to make it function as a sediment trap. At the same time there was a strong interest in completing the perimeter road system around the lake's western side where the next two largest drainage inlets are located. Unsuccessful attempts were made to secure funds through the U.S. Department of Agriculture, South Dakota's Water Resources Institute and other programs.

The project did not fit any ongoing program in the early 1970's.

The U.S. Environmental Protection Agency, in releasing the first $4 million of funds appropriated under Sections 104(h) and 314 of PL92-500 in 1976, stressed that high priority would be given to lake preservation and/or restoration proposals that

(a) would demonstrate innovative new techniques,

(b) would attack sources of lake problems such as sediment-nutrient inflows, and

(c) could have wide application.

The East Dakota Conservancy Sub-District, working with other local interests, developed a project proposal to construct three low-cost sediment traps; the first by redesigning and reconstructing an existing township road and the other two by altering the design of a proposed new perimeter road where it would cross the two other main drainage inlets. The proposal was one of eleven projects in six states initially funded under the new federal "Clean Lakes" program.

TECHNICAL ASPECTS OF MULTI-PURPOSE PROJECT FEATURES

The multi-purpose project features were as follows:

(a) Construction of 2700 feet of gravel road, this completing the lake's perimeter road system.

(b) Development of three sediment traps, thus reducing the sediment inflow from 66% of the lake's total direct drainage area.

(c) Development of a major new boat access area. This access area was developed as a multi-purpose use of a needed project borrow pit.

(d) Multi-purpose use of two of the sediment traps as fish rearing ponds by the South Dakota Department of Game, Fish and Parks.

The two sediment traps incorporated into the construction of the new road (known as Sites 1 and 2), shown in Figure 2, were designed with manually controlled drawdown openings to allow permanent storage of water if desired up to the top of the riser pipes.

A schematic diagram of the sediment trap developed by reconstruction of the existing road (known as the Cochrane Site) is shown in Figure 3. Water cannot be permanently impounded because it has an uncontrolled drawdown tube.

Table 1 contains summary design information for all three sediment traps.

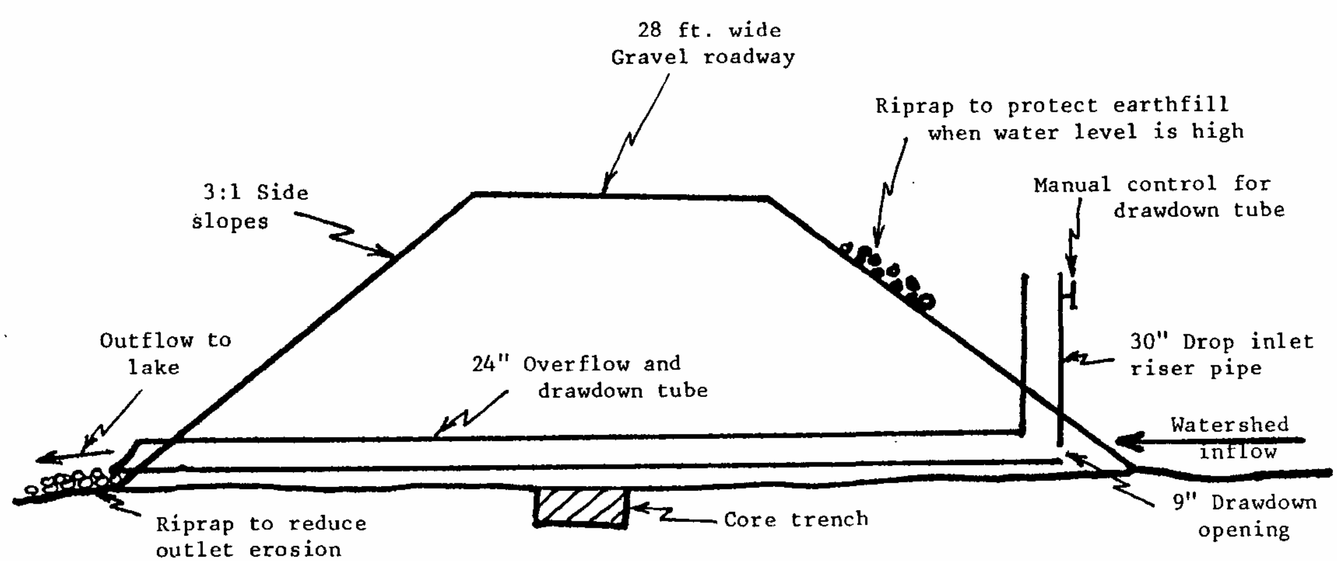

Figure 2. Schematic design of two sediment traps incorporated into construction of the new road.

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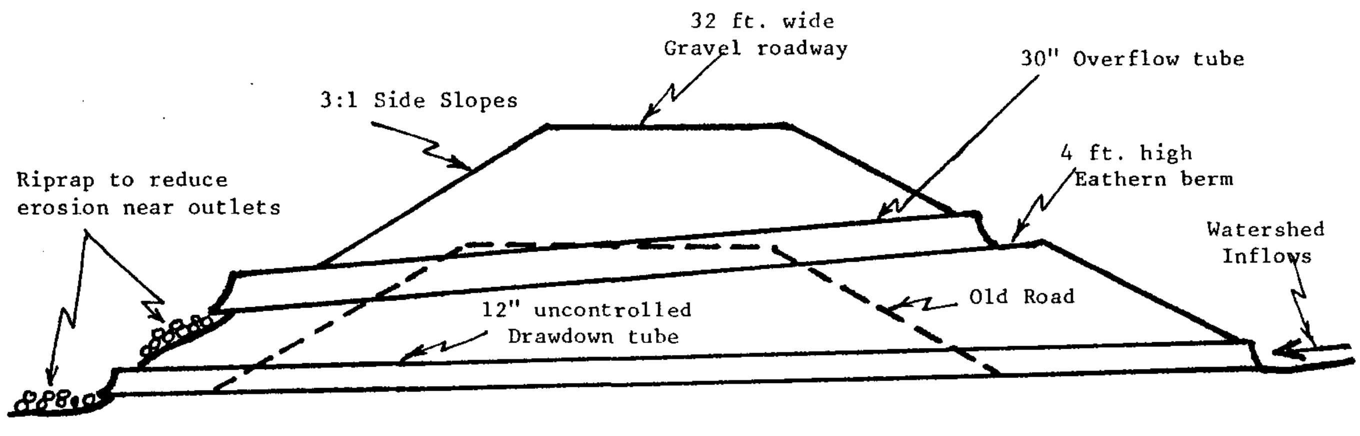

Figure 3. Schematic design of the existing road as redesigned to function as a sediment trap.

TABLE 1. DESIGN SUMMARY FOR ALL THREE SEDIMENT TRAPS

Design Feature		New Road North Site	New Road South Site	Existing Road Cochrane Site
Drainage Area	(Acres)	41	57	411
Height of Fill	(Feet)	15	19	7
Pool height at main overflow tube	(Feet)	10	11	4
Storage at main overflow tube	(Ac-ft)	5.0	3.4	11.6
Length - Main overflow tube	(Feet)	108	128	84
Diameter - Main overflow tube	(Inches)	24	24	30
Diameter - Riser pipe	(Inches)	30	30	
Diameter - Drawdown tube or opening	(Inches)	9	9	12
Controlled drawdown tube		Yes	Yes	No

MULTI-AGENCY PARTICIPATION IN PROJECT DEVELOPMENT

It is pertinent to review the participation of the six main governmental entities involved in the development of the overall project.

At the local level, Deuel County and Norden Township played a strong role by financing the construction of the new road and securing easements for the entire project. The county also handled the construction contracts for the project.

At a multi-county level, the East Dakota Conservancy Sub-District provided a $10,000 grant toward the additional cost of incorporating the three sediment traps into the road system. The Sub-District also applied for and administered the EPA "Clean Lakes" grant and served as overall project coordinator

At the state level, the Department of Game, Fish and Parks contributed $3,000 in cash and designed and supervised the construction of the new road portion of the project.

At the federal level, the Soil Conservation Service, assisting the local Deuel County Conservation District, designed and supervised the reconstruction of the Cochrane Site and EPA provided a $9,906 grant toward the allocated cost of incorporating the three sediment traps into the road system.

Whenever a large number of entities are involved in the financing, design, construction and/or operation of a project, there is the strong likelihood that problems will develop. The five non-federal entities sought to avoid such problems by discussing in detail and arriving at clear-cut agreements on all aspects of project development. These agreements were incorporated into a five-party Memorandum of Agreement which all parties signed.

OBJECTIVES OF THE DEMONSTRATION PROJECT

According to the grant application, the objective of the project was to demonstrate a simple low-cost method of reducing lake sediment and nutrient inflow which should have wide applicability in the United States and to demonstrate the technique for both existing and planned new perimeter road systems.

PROJECT ACTIVITIES DURING GRANT PERIOD

It was noted in the original grant proposal that the Soil Conservation Service would design all project works. When all the non-federal entities met on August 21, 1976 and developed a Memorandum of Agreement for the project, it was decided to have the Department of Game, Fish and Parks design Sites 1 and 2 since the Department had offered to design and supervise construction of the road itself.

After the EPA grant was officially awarded on January 8, 1976 local entities took immediate steps to secure needed project easements and to ready the project for construction.

In early March the Project Manager notified Barbara Schroeder, who was placed in charge of the project by EPA officials in Denver, that Deuel County was ready to open bids for the project and asked for instructions. Construction bids were opened for the new road portion of the project on March 29, 1976 with six firms bidding. Halstead and Lewis Construction of Brookings, South Dakota submitted the low bid of $21,089.47 which was accepted by the county commissioners.

Bids were opened by the commissioners for the Cochrane Site on April 20. The commissioners awarded the contract to Annet Construction, Inc. of Milbank, South Dakota who submitted a low bid of $6,912.

On June 8, Bruce Perry, EPA-Denver, informed the Project Manager that John Brink was replacing Barbara Schroeder as Project Officer. On June 22, Mr. Brink toured the project and noted he was impressed with the construction work in progress.

The Game, Fish and Parks Department Engineer noted after a June 23 inspection of the new road portion of the project that it was complete except for dressing the ditches, placing riprap and cleanup. He indicated that his department would seed the project area later in the fall.

On July 14, the Soil Conservation Service Area Engineer and Deuel County States Attorney notified the Project Manager that three problems had developed concerning the Cochrane Site: (1) a pipe specification change had resulted in an increased cost of about $350; (2) access driveways to two lake lots had been omitted in the plans, and (3) the landowner on the south side "understood" that the county was going to do some private work for him if he gave a "free" easement for the project work. Meetings with the county, township and contractor were set by the Project Manager. Although the access driveways cost $600 and the landowner was offered and paid a fair price for his easement, these problems were resolved without any additional EPA grant.

On July 29, John Brink, EPA Project Officer, called and asked the Project Manager to submit monthly reports. After reviewing the Project Grant Agreement, however, it was determined that the only monthly activity required was water quality monitoring. After a discussion of local laboratory limitations, Mr. Perry and Mr. Brink agreed during August to accept the bimonthly monitoring program in progress.

By September, the construction work under both contracts was complete except for grass seeding. Mr. Brink toured the project area on September 20 and noted that with establishment of this grass cover the project would be satisfactorily completed.

On October 21, a dedication ceremony was held at the Shady Beach Resort on Lake Cochrane. The ceremony was well attended by local residents and received excellent area news coverage. Stuart McDonald and Barbara Schroeder represented EPA.

Sites I and II were seeded and mulched prior to the dedication. The Cochrane Site was not seeded at that time due to a standoff between Deuel County and the contractor regarding the seeding work.

During the spring runoff of 1977 all three sediment traps filled with water. Personnel were not able to get to the project area in time to collect water quality samples of the inflow and outflow of the sediment traps because the lake was located in a remote location, the runoff was unseasonably early, and the perimeter road was blocked with snow because it was not maintained during the winter season.

The Department of Game, Fish and Parks successfully reared walleyes that spring in Sites 1 and 2. They opened the drain tubes in late May to collect the fingerlings for distribution to Lake Cochrane and other lakes.

Bruce Perry, current EPA Project Director from Denver, toured the project on May 26. He was very favorably impressed with the project but urged the Project Manager to resolve the grass seeding stalemate at the Cochrane Site.

In October the Project Manager located a free source of native grass seed and asked the Game, Fish and Parks if they would seed and mulch the area for the $200 contained in the construction contract for the seeding work. At a meeting between the county commissioners, Game, Fish and Parks and the Project Manager, on October 11, the seeding issue was resolved.

On October 18, the Project Manager set up a meeting between Jack Opitz, Department of Game, Fish and Parks (who was responsible for operating structure Sites 1 and 2) and Dr. Lois Haertel, SDSU Botony-Biology Department, to discuss her concern that the lake received a heavy nitrogen load when the sediment traps were emptied into the lake in early summer for fish removal. Mr. Opitz agreed to leave the drain tubes closed and remove the fish in another manner the following year to allow better nutrient removal.

On October 19, Mr. Opitz provided notification that he had inspected the project area ana found that the 1976 seeding program was pretty well established.

On November 23, the Department of Game, Fish and Parks completed the seeding and mulching work on the Cochrane Site.

On November 30, final grant payment was requested from EPA for the completed work and Bruce Perry, EPA-Denver, was notified that the work was successfully completed.

In the spring of 1978 two sets of water samples of the sediment traps inflow-outflow were collected with considerable difficulty. The Project Manager determined that unauthorized personnel desiring a higher lake level had opened the drain tubes prior to the spring runoff. The tubes were closed in time to catch most of the runoff and were padlocked to prevent this from happening again. The inflow was heavy enough so that water flowed through the overflow tubes of all three sediment traps.

New EPA Project Officer, Debbie Patterson of Denver, inspected the project with the Project Manager on April 26. Sites 1 and 2 were still filled to the top of the risers (overflow tubes) whereas the uncontrolled Cochrane Site was completely drained down. .Grass was well established on the project area.

The project was selected by EPA for presentation at the August 22-24 National Lakes Restoration Conference in Minneapolis. The Project Manager made the presentation.

Fish were not reared in Sites 1 and 2 during 1978. The north site (Site 1) held water all year whereas Site 2 eventually drained dry due to a leak in the drain tube. This leak was corrected in late 1978.

SECTION 4

RESULTS AND DISCUSSION

ECONOMIC FEASIBILITY OF THE TECHNIQUE

The cost of developing the sediment traps was reduced below the costs of normal development under this lake preservation technique because the raod function financed a portion of the cost of

(a) the earth fill,

(b) structures to carry water through the roadway, and

(c) needed land rights for the structures.

The full cost of reconstructing the existing road was allocated to the lake project since the road was already suitable for transportation purposes. The existing road fill and road easements reduced the costs of this construction, however.

Due to these multi-function cost savings, the cost allocated to the sediment traps was slightly less than $20,000.

The $20,000 allocated to the lake preservation project covered the following items not required in normal road construction:

(a) Flood easements for the sediment pool areas;

(b) Rip-rap of the face of these areas;

(c) Increased fill height and width to provide desired water storage;

(d) Excavation and refilling of a core trench, and

(e) Increased costs resulting from design changes in the drainage structures; the added cost resulting from the need for caulked, close-riveted seams, water seepage collars and secondary overflow tubes is somewhat counterbalanced because when water can be stored behind the road fill, the diameter and thus the cost of the main drain tubes can be reduced.

TECHNICAL EFFECTIVENESS

Concurrent Impact of Other Activities

It is somewhat difficult at this point to draw definite conclusions on the impact of the completed sediment traps on lake water quality because very limited project data have been collected on the actual inflow-outflow of the sediment traps. It is very difficult to evaluate the sediment traps using in-lake data because of the concurrent impact on the lake of a number of sediment-nutrient producing construction activities. This construction has included a number of lakeshore homes, a new state park area on the north side of the lake, and the project works including the associated new road.

In addition, the lake area exprienced a severe drought during 1974-77 which reduced normal surface and groundwater inflows and resulted in a lower than normal lake level.

Summary of Project Water Quality Data

There were no funds in the EPA grant to cover water quality monitoring. During the period of the grant, water quality samples were generally collected bi-monthly by the Project Manager under a cooperative East Dakota Conservancy Sub-District/Department of Environmental Protection lake monitoring program. Samples were analyzed by the State Health Laboratory in Pierre. It was difficult to meet grant requirements for chlorophyll a data since none of the main water quality laboratories in the state were equipped to analyze chlorophyll a.

The grantee did contract with Randall Brich, a Department of Biology graduate student at South Dakota State University, in July, 1977 for collect of chlorophyll a data which is shown in Table 2.

TABLE 2. LAKE CHOCHRANE CHLOROPHYLL a DATA

Station	Chlorophyll a mg/l - Average of 3 grab samples		
	8/16/77	9/4/77	9/22/77
1-S (southwest bay - surface)	12.1	11.2	11.4
3-S (northeast quadrant - surface)	13.1	10.4	13.2
3-B (northeast quadrant - bottom)	11.3	11.6	12.9

All water quality data collected under this grant agreement has been transmitted to the EPA regional office in Denver.

Table 3 contains average annual values for selected water quality parameters for the period 1975-1978.

TABLE 3. AVERAGE VALUES OF SELECTED WATER QUALITY PARAMETERS

	Unit	1975	1976	1977	1978
No. of Samples		3	5	4	4
Conductivity	micromho	3053/22	2782/23	3535/24	2700/23
Suspended Solids	mg/l	99	28	103	87
NH_3-N	mg/l	.125	.11	.34	.28
Ortho PO_4-P	mg/l	.022	.018	.011	.014
Total PO_4-P	mg/l	.034	.037	.036	.087

Table 4 contains values for selected constituents from samples collected and analyzed from the three sediment traps during the spring runoff of 1978.

TABLE 4. ANALYSIS OF SEDIMENT TRAP INFLOW/OUTFLOW

Parameter		Cochrane Site (uncontrolled drawdown) Inflow/Outflow		Inflow/Outflow		Inflow/Outflow	
			March 29, 1978				
Suspended Solids	mg/l	121	17	25	-	31	-
NH_3-N	mg/l	.23	.48	.037	-	.07	-
TKN-N	mg/l	1.65	1.21	1.67	-	.086	-
Ortho PO_4-P	mg/l	.089	.150	.033	-	.082	-
Total PO_4-P	mg/l	.168	.192	.111	-	.131	-
			April 4, 1978				
Suspended Solids	mg/l	54	25	40	23	33	8
NH_3-N	mg/l	.15	.19	.34	.19	.04	.07
TKN-N	mg/l	.72	.80	1.71	.073	.82	.70
Ortho PO_4-P	mg/l	.060	.108	.027	.018	.044	.053
Total PO_4-P	mg/l	.075	.135	.075	.038	.062	.067

These limited samples indicate good removal of suspended solids in the sediment traps.

Project Evaluation through other Research

Dr. Lois Haertel (1978) has evaluated lake water quality and algal abundance before, during and after construction of the sediment dams through a grant funded by the Office of Water Resources Research and Technology. Her data is much more complete than the project data noted above. The most recent project evaluation report is contained in the Appendix.

OPERATION OF THE SEDIMENT TRAPS

Effects of Design and Use for Fish Rearing

Multi-purpose use of two of the sediment traps as fish rearing ponds imposed two requirements in this case (a) the sediment traps had to be designed with manually controlled devices to close the drain tubes during spring and early summer and (b) efficient removal of the fingerlings required emptying the water in the sediment trap which allowed nutrient-laden runoff water to pass into the lake as noted below.

Use of the sediment traps for fish rearing might have either a desirable or undesirable impact on nutrient concentrations in the ponds. This aspect should be evaluated further.

Nutrient Removal Efficiency

For sediment control purposes only a structure is designed to reduce the velocity of water to the point that suspended solids will drop to the bottom of the pool area. This requires very little storage time except for the very fine sediment particles.

Theoretically a significant portion of the phosphorus load will be trapped along with these sediments because phosphorus is presumed to be attached to the soil particles. The limited sampling from the spring runoff of 1978, however, did not indicate good phosphorus removal. The phosphorus may be attached to the very fine particles which do not readily settle and stay at the bottom of the pond.

Nitrogen is dissolved in the runoff water and according to Dr. Haertel is probably equal in importance to phosphorus as a limiting factor in algal production in Lake Cochrane. A long detention period will be required for nitrogen removal in the sediment pools because the nitrogen will need to be taken up by plant growth.

REFERENCES

1. Haertel, L. 1972. Ecological factors influencing production of algae in northern prairie lakes. South Dakota Water Resources Institute, Brookings, South Dakota.

2. Haertel, Lois. 1978. Effect of sediment control dams on the water quality of Prairie Lake. Annual Report #A-061-SDAR submitted to OWRT.

3. Hansen, D. R. 1973. Watershed inventory of Lake Cochrane, Deuel County, South Dakota, 1971-1972. South Dakota Department of Game, Fish and Parks.

4. State Lakes Preservation Committee. 1977. A plan for the classification-preservation-restoration of lakes in northeastern South Dakota. State of South Dakota and the Old West Regional Commission.

APPENDIX. INDEPENDENT PROJECT EVALUATION REPORT

Agreement No. 14-34-001-7088
Effect of Sediment-Control Dams
on the Water Quality of a Prairie Lake
OWRT Project No. A-061-SDAK
FCCSET (COWRR) Research Category: 6B

Proj. Began--Month: March Year: 1977
To be completed--Month: June Year: 1979

Principal Investigator: Lois Haertel

Student Assistant: Randall Brich

A. Research Project Accomplishments:

(1) Purpose of the Research Project

Three sediment control dams were constructed on Lake Cochrane South Dakota during the summer of 1976 with the purpose of decreasing the sediment and nutrient influx into the lake. Fortunately, 4 years of prior data had been collected from Lake Cochrane through other OWRT projects and a background data base was already present. The purpose of this project has been to evaluate the impact of the sediment control dams on water quality and algal growth both during and after construction of the dams.

(2) Lake Water Quality Response to the Sediment Control Structure

Sampling has been conducted approximately biweekly over 3 open water seasons both during the construction of the sediment control dam and the 2 seasons after its construction. Table 1 compares the results from 7 years of lake water quality data.

Table 1. Comparison of selected mean values from Lake Cochrane over 6 years of sampling

	1970	1971	1972	1975	1976[a]	1977	1978[b]
Water transparencey (Secchi, m.)	2.0	1.3	1.3	1.6	1.2	1.1	1.2
Algae (chlorphylla, ppb)	10	19	18	13	14	12	10
Zooplankton (calculated filtering rate, % water vol/day)	75	21	23	87	41	58	115
Chemical parameters (ppm)							
NO_3-N	.05	.03	.02	.02	.01	.03	.07
NH_3-N	.06	.02	.00	.04	.15	.44	.46
Organic N	1.12	1.55	1.35	1.27	1.38	1.48	1.18
Ortho PO_4-P	.01	.02	.01	.04	.02	.04	.01
Total PO_4-P				.16	.05	.22	.05
Acid-hydrolyzable PO_4-P	.03	.10	.02				

a) The sediment control structures were built in 1976.
b) Data computed through 7/26 (zooplankton), 8/16 (chemical data) and 8/31 (chlorophyll and Secchi disc readings).

Mean chlorophyll a and organic nitrogen values are definitely lower in 1978 than in any years after 1970. Whether this is a response to the lower phosphate levels in 1978, or the higher zooplankton estimated grazing rate is difficult to tell. Inorganic nitrogen levels remain high in 1978. Water transparency (secchi disc) levels are still poor in 1978; the low chlorphyll values suggest that this is partially due to non-algal turbidity. Although erosion from construction operations and from the steep slopes of the sediment control structures and boat landing areas is suspected as a cause of the low 1976 and 1977 transparency readings, better growth of vegetation on those slopes should have lessened that source of input in 1978. One cottage owner has completely laid bare a steep slope draining directly into the lake for private construction, and erosion off that slope may be contributing to the poor water transparency in 1978.

(3) Water Quality Measurements Above and Below the Sediment Control Dams

Due to an administrative oversight, the sediment dams were left open for much of the 1977 season. Thus, few measurements above and below the dams could be taken during that year. Two of the dams were kept closed during the 1978 season. Measurements were taken above and below the one dam that experienced seepage. The other dam was water tight and never had water going over the riser tube on any sampling date. Nutrients trapped behind that dam were assumed to be effectively sealed off from the lake. Measurements taken above and below the second dam showed a surprising phenomenon. On 5/3/77, 4/20/78 and 5/16/78, water was going over the riser tube (Fig. 1) and flowing into the lake by the designed overflow method. On those dates, the measurements were higher above the dam than below (Table 2), as would be expected if settling or biological uptake behind the dam were reducing the quantities of nutrient going over the riser tube and through the culvert. However, on most subsequent dates, water was not going over the riser tube and seepage, possibly through a bad connecting joint at the base of the riser tube, had to be assumed to be the source of the water coming out. On almost all of those dates, nutrient concentrations were substantially increased rather than diminished below the sediment control dams. A possible source of the enrichment of the water with nutrients could have been percolation through the sediments behind the dam. The substantial increase in nutrient concentrations may not represent a threat to the water quality of Lake Cochrane, because the quantity of water draining out is small, and on most dates does not flow directly into the lake but on to a large flat vegetated beach area. The vegetation may be removing most of the nutrients before they get to the lake. However, the possibility of stopping the leakage should be investigated.

Table 2. Difference between Measurements of Variables above and below Sediment Control Dams (ppm)

Year	1977		1978									1977	1978
Date	5/3	9/20	4/20	5/16	5/31	6/14	6/28	7/12	7/26	8/17	8/31	Mean	Mean
# reps			1	2	2	2	2	2	2	2	2		
Dam #			#2	#2	#2	#2	#2	#2	#2	#2	#2		
Above-below:*													
NO_3-N	.47	-.01	.20	.06	-.95	-.04	-.08	-.02	-.11	-.26	-.24	.23	-.16
NH_3-N	.05	-.10	.10	-.05	-.32	-.15	-.60	-.70	.45	-.33	-.23	-.03	-.20
Org.-N	0	-.05	-.18	-.12	.02	.28	-.31	.23	-.22	-.05	.77	-.03	.05
Ortho-PO_4	.02	.02	-.02	-.01	-.05	-.73	-1.22	-.12	.08	.18	.34	.02	-.17
Total-PO_4	.06	.09	-.02	.01	.04	-.97	-1.57	-.59	-.48	.10	.32	.08	-.36
HCO_3	0	-	120	-65	76	-109	-89	-85	-111	-144	-114	0	-58
CO_3	0	-	0	5	0	0	0	0	0	-5	-39	0	-4
Si	-0.4	-	-	-2.1	7.5	-9.8	-8.8	6.7	-8.4	-22.0	-21.3	-.02	-15.3

*A negative value means the concentration was higher below the sediment control dam than above it.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA 908/3-79-001	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Lake Cochrane Perimeter Road - Sediment Traps Project Final Report		5. REPORT DATE April 1979
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Jerry L. Siegel		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS East Dakota Conservancy Sub-District Brookings, South Dakota 57006		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. S8 04248-01-2
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Protection Agency 1860 Lincoln Street Denver, Colorado 80295		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

Lake Cochrane is one of the few deep high quality prairie lakes in northeastern South Dakota. Local interests tried unsuccessfully for several years to develop measures to reduce sediment inflow. The proposal to develop sediment traps as a part of the lake's perimeter road system was selected for a grant award under EPA's "Clean Lakes" program initiated in 1975.

This small lake preservation project utilized the technical and/or financial resources of every level of government. For an allocated cost of about $20,000, three sediment traps were developed to control the sediment inflow from 66% of the lake's watershed area. By incorporating the sediment traps into the perimeter road system, 2700 feet of new gravel road, the sediment traps, and a new boat access area were constructed at a cost of $34,700. In addition, two of the sediment traps have been utilized as fish rearing ponds.

Due to limited data and numerous sediment-nutrient producing activities occurring concurrently, it has been difficult to evaluate the impact of the project on the lake. Preliminary evidence indicates good suspended solids removal in the sediment traps. There is evidence, however, that temporary storage of runoff water may not provide any nutrient removal. A comprehensive evaluation program needs to be developed.

The completed project has demonstrated a low cost, effective technique for reducing sediment inflow into a lake which may have application in other areas.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Lakes Sediments Nutrients	Clean Lakes Sediment traps Non-point sources Lake Cochrane	

18. DISTRIBUTION STATEMENT Distribution Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 31
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APPENDIX B
1998 Fisheries Study of Lake Cochrane

STATEWIDE FISHERIES SURVEYS, 1998
SURVEY OF PUBLIC WATERS
Part 1
Lakes-Region IV

South Dakota
Department of
Game, Fish and Parks
Wildlife Division
Joe Foss Building
Pierre, South Dakota 57501-3182

Annual Report
No. 99-19

SOUTH DAKOTA STATEWIDE FISHERIES SURVEY

2102-F21-R-31

Name: Lake Cochrane County(ies): Deuel
Legal description: T114N, R47W, Sect. 4,5,8
Location from nearest town: 5 1/2 miles south, 2 west of Gary
Dates of present survey: June 23-25, 1998
Date last surveyed: June 25-26, 1996
Management classification: Warm-water permanent
Contour mapped: 1958
Report prepared by: Matthew Hubers
Scales aged and digitized by: Corey Flor

PHYSICAL CHARACTERISTICS

Surface Area: 366 acres; Watershed: 833 acres
Maximum depth: 26.5 feet; Mean depth: 11 feet
Lake elevation at survey (from known benchmark): Full feet

1. Describe ownership of lake and adjacent lakeshore property:

Lake Cochrane is owned by the State of South Dakota and managed by the Game, Fish and Parks. Game, Fish and Parks owns and maintains a park and access area on the lake. The remainder of the lakeshore is under private ownership.

2. Describe watershed condition and percentages of land use:

The watershed is composed of 55% cropland, 23% pasture, 16% municipal, 5% woodland, and 1 % other.

3. Describe aquatic vegetative condition:

Submergent vegetation is extensive and is found throughout the lake. Species identified include *Chara sp.* and *Ruppia maritima*. Emergent vegetation covers less than 5% of the shoreline.

4. Describe pollution problems:

Agricultural and residential run-off is probably resulting in nutrient enrichment. Lake Cochrane is classified as eutrophic.

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BIOLOGICAL DATA

Species detected during past and present surveys:

1. Walleye (WAE)
2. Largemouth Bass (LMB)
3. Bluegill (BLG)
4. Black Crappie (BLG)
5. Yellow Perch (YEP)
6. Whiter Sucker (WHS)
7. Hybrid Sunfish (BGH)
8. Black Bullhead (BLB)
9. Common Carp (COC).
10. Green Sunfish (GSF)

Methods:

Six monofilament gill net sets were used to sample fish populations. Two nets were fished for approximately 24-hour periods and reset at different locations. Gill nets measured 47.5 m x 1.8 m and had six 7.6 m sections composed of 1.3 cm, 1.9 cm, 2.5 cm, 3.2 cm, 3.8 cm and 5.1 cm mesh. Scales were taken at the tip of the left pectoral fin below the lateral line from all walleye sampled. One hundred lengths and one hundred weights were taken for each species when possible. Fish, which were counted but not measured, were assigned to length groups based upon distribution of measured sub-sample. Age and growth data was computed using DISBCAL (Frie 1982) and further processed by PC MINNOW (NGPC 1997). Fish not aged were assigned by PC MINNOW (NGPC 1997) to age groups based on length. PC MINNOW (NGPC 1997) was utilized to calculate common fisheries indices. Appendix A provides a description of indices utilized. Figure 9 depicts contour map. Electrofishing and trap netting was conducted by South Dakota State University (SDSU) as Lake Cochrane is currently part of a study which is investigating effects of mechanical removal in conjunction with high predator populations on size structure of overly abundant panfish populations. This survey report will primarily report findings of gill netting activities but available results of fish removal and electrofishing activities associated with this project will be mentioned. Guidelines for the removal included the return of yellow perch greater than 203 mm and return of sunfish greater than 152 mm. All black crappie were placed back into the lake regardless of length. A detailed report will be issued upon completion by SDSU.

Results and Discussion:

Walleye

Gillnetting in 1998 suggested a decline in abundance when compared to values seen in previous years (Figure 1). Catch per unit effort (CPUE) of 14.2 still indicates moderate to moderate-high abundance but is the lowest value seen in recent surveys (Table 1). Larger fish dominated size structure resulting in PSD of 70 and RSD-P of 12 (Table 1). These are the highest values seen in recent surveys (Figure 2). Increased size structure was precipitated by strong 1993 and 1994 year classes that had mean average length at capture of 481 mm and 425 mm, respectively. Age-4 and age-5 fish constituted almost

74% of the gill net sample. Past surveys have suggested that age-1 walleye are not effectively sampled and that age-2 walleye are readily sampled with gear used. With only three walleye from the 1996 year class being sampled, indications are that this year class is weak. Based on the aged sample, 1994 and 1995 year classes are classified as strong while the 1995 year class is classified as moderate (Table 3). Walleye average 310 mm at age-3 compared to 355 mm for other northeastern South Dakota populations. Back-calculated lengths of age-3 walleye have ranged from 298 mm to 352 mm and varied by a maximum of 54 mm over the years with available data (Figure 4). Length at age-3 is most likely still strongly impacted by size at stocking as well as direct competition with abundant panfish. As fish reach age-5 and older, length at age is comparable to other northeast populations. Growth is considered acceptable and walleye surpass the 356-mm minimum length limit during their fourth growing season (Table 3). Walleye condition ranged from low of 85 for stock-quality (250-380 mm) length to 97 for preferred to memorable length (510-630 mm) (Table 2). It is possible that differences of condition among length categories are related to ability of larger walleye to more effectively utilize available forage. Wr of all stock length fish was 92 indicating good condition.

Length frequency (Figure 3) shows fish larger than the 356-minimum length limit dominated the sample. From size structure as well as relative abundance, it can be deduced that excessive harvest is not occurring. The possibility exists that high populations of small panfish serve to protect small walleye from exploitation by taking angler bait/lure before walleye discover it. Abundant submergent vegetation limits methods available to anglers and most likely limits distance bait or lures are visible to walleye. High abundance of small panfish may provide easily available forage, further decreasing catchability.

Indications are that annual stocks of large fall fingerlings (25/lb.) have established several consecutive strong year classes. Because of stocking strategy utilized, natural reproduction cannot be evaluated. It is, however, thought to be poor because of probable predation by panfish. In 1998 poor return from natural rearing ponds prevented Lake Cochrane from being stocked for the first time since 1991 (Table 4). Figure 4 shows relatively few fish less than 31 cm. To fill this void and to maintain high abundance indicated by past surveys, stocking should be conducted in 1999.

The walleye population in Lake Cochrane can be characterized as having moderate to moderate-high density and being comprised mainly of individuals longer than 356 mm. Condition of walleye is considered good and growth is average. Size distribution as well as abundance suggests that anglers experience low catch rates.

Management Recommendations

1. Continue surveys on biennial schedule to monitor population parameters.

2. Proceed with annual stocks of large fall walleye fingerlings (25/lb.) at 1.0 lb./ac.

3. Utilize conclusions of SDSU panfish removal study to modify stocking strategy if data warrants change.

4. Maintain 356-mm length limit unless available data suggests otherwise.

Yellow Perch

Improvements in size structure of yellow perch as a result of removal efforts have not been apparent in gill net samples (Figure 7). Although all perch of quality length (200 mm) and larger are returned, PSD values for gill nets were 3 and RSD-P was 0. Length frequency was dominated by yellow perch ranging in length from 13-15 cm (Figure 5). Wr values indicated good condition for sub-stock (>130 mm) and stock (130 mm) through quality (200 mm) length fish (Table 2). The lowest Wr value was observed for quality to preferred (200-250 mm) length fish sampled at 85. This perhaps indicates lack of appropriate forage for this length group, which may further explain absence of larger yellow perch. Since 1994 removal of yellow perch by SDSU has totaled 3537.1 kg (Table 5). Gill net CPUE of 131.3 suggests moderate to moderate-high density and abundance appears to be slightly lower than in 1994-1996 (Figure 6).

Currently yellow perch are not in a position to provide a satisfactory fishery. Perhaps information gained from SDSU removal project will provide information that will aid in restructuring the yellow perch population.

Management Recommendations

1. Continue biennial surveys to monitor changes in population size structure and abundance.

2. Collect scale samples during next survey to gather age and growth information.

3. Utilize information gained from SDSU removal study to formulate panfish management plan.

Black Bullhead

Gill net CPUE of 8.2 is the highest value seen since 1992 but still denotes low abundance. All cm groups from 19-26 cm were sampled resulting in PSD of 46 (Figure 8). Lack of preferred (200 mm) length bullhead resulted in RSD-P of 0. Interspecific competition with overly abundant panfish population is most likely effecting black bullhead and has limited bullhead abundance in Lake Cochrane. It could also be speculated that although removal of panfish has only totaled 8208.1 kg since 1994 (Table 5), enough biomass has been removed to allow for a slight increase in black bullhead as indicated by gill net CPUE of 8.2.

Management Recommendations

1. Continue biennial surveys to monitor changes in population size structure and abundance.

2. Utilize SDSU data from removal project to monitor population trends in trap nets since 1994.

Northern Pike

Gill nets sample ranged in length from 45 to 87 cm. Wr values ranged from 106 to 78 depending on length group and generally indicated good condition (Table 2). Gill net CPUE of 1.5 was the highest value seen since inception of annual surveys in 1992 but still denotes low abundance (Table 1). Recruitment may be negatively effected by high abundance of panfish.

Given high density of forage available as well as submergent vegetation, catchability of northern pike for anglers maybe low. Trophy individuals may attract anglers.

Management Recommendations

1. Continue biennial surveys to monitor changes in population size structure and abundance.

2. Utilize SDSU data from removal project to monitor population trends in trap nets since 1994.

Black Crappie, Bluegill, Green Sunfish and Bluegill X Green sunfish

Inferences in regards to panfish populations are best based upon trap net data as sunfish as well as back crappie recruit more readily to frame nets gear. Hybrid sunfish and black crappie comprised 3.2% of all fish sampled in gill nets. Gill nets did sample some larger black crappie (Table 1). The 23-fish sample had stock to quality (130-200 mm) length individuals that ranged in length from 17 to 23 cm. Wr values indicated good conditions for all length groups sampled (Table 2). During the 1998 SDSU removal project bluegill averaged 18/kg, bluegill x green sunfish were 22/kg and all panfish (including yellow perch) were 24/kg. As soon as SDSU removal project is complete, data as well as the final report will be available and provide a comprehensive picture of the panfish population in Lake Cochrane. History of removal project from 1994 to 1998 can be seen in table 5.

Management Recommendations

1. After SDSU removal project is completed (year 2000), incorporate frame nets into biennial surveys to monitor changes in population size structure, species composition and abundance.

2. Utilize SDSU data from removal project to establish panfish management plan.

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Table 1. Catch of six 150 ft. experimental gill net sets in Lake Cochrane, June 23-25, 1998.

Species	N	%COMP.	CPUE (80% C.I)	CPUE RANGE (1992-1998)	PSD (90% C.I)	RSD-P (90% C.I)
BLB	49	5.1	8.2+-5.7	0.0-8.2	46(34,58)	0(0,0)
NOP	9	0.9	1.5+-0.9	0.0-1.5	-	-
HSF	9	0.9	1.5+-0.8	1.8-6.6	-	-
BLC	23	2.3	3.8+-2.3	0.3-2.3	52(34,70)	0(0,0)
YEP	788	81.8	131.3+-22.9	72.8-297.3	3(2,4)	0(0,0)
WAE	85	8.8	14.2+-3.3	14.2-36.3	70(62,79)	12(6,18)

Table 2. Weighted mean Wr by length category from gill net samples for selected species collected in Lake Cochrane, June 1998.

Species	NOP	BLC	YEP	WAE
<S	-	-	110	93
S	93	103	99	92
S-Q	106	106	99	85
Q-P	95	101	85	94
P-M	90	-	-	97
M-T	78	-	-	-

S=Stock; Q=Quality; P=Preferred; M=Memorable; T=Trophy Length Categories.

Table 3. Average back-calculated lengths (mm) for walleye from Lake Cochrane, June 1998.

			Back-calculation Age					
Year Class	AGE	N	1	2	3	4	5	6
1997	1	4	157					
1996	2	3	194	262				
1995	3	11	168	244	298			
1994	4	34	153	244	324	391		
1993	5	28	136	227	320	400	453	
1992	6	4	129	212	296	401	469	511
Mean			156	238	310	397	461	511
N		84	84	80	77	66	32	4

000122

Table 4. Stocking record for Lake Cochrane, Deuel County, 1986-1998.

SPECIES	SIZE	NUMBER	YEAR
NOP	JUN	24	1986
WAE	FGL	900	1986
LMB	FGL	37,000	1987
WAE	FGL	5,842	1987
LMB	FGL	18,500	1988
WAE	LFG	10,466	1989
LMB	ADT	450	1990
WAE	LFG	12,000	1990
WAE	LFG	3,746	1991
WAE	LFG	13,500	1992
WAE	LFG	4,170	1993
WAE	LFG	4,800	1993
WAE	LFG	8,250	1994
LMB	FGL	9,600	1995
WAE	LFG	3,600	1995
WAE	LFG	7,000	1996
WAE	LFG	9,250	1997

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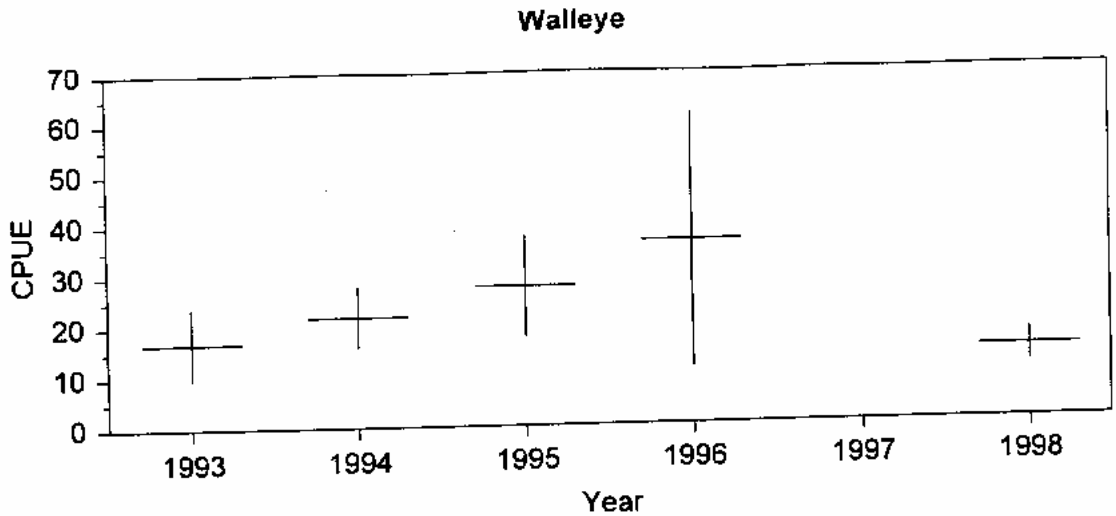


Figure 1.
Gill net CPUE (80% C.I) from Lake Cochrane, 1993–1998.

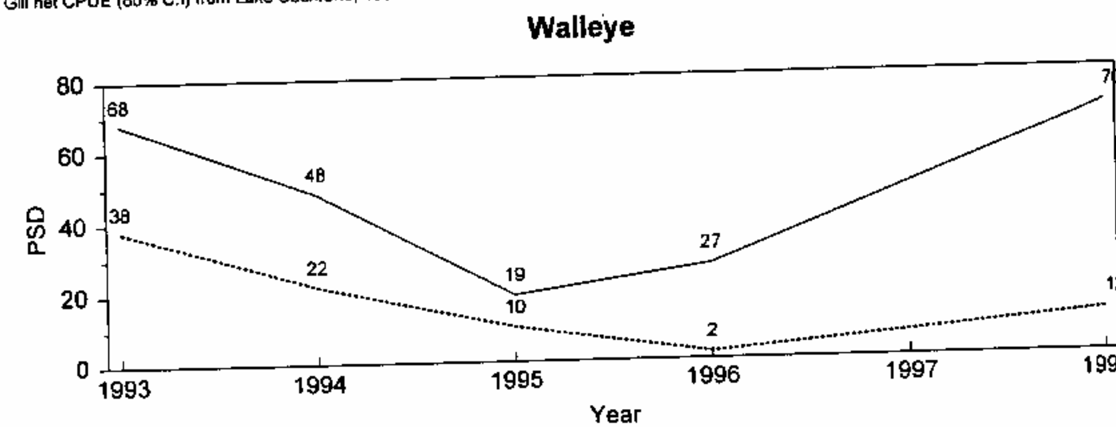


Figure 2.
Walleye PSD (—) and RSDP (- -) values from gill net samples, 1993-96, 1998.

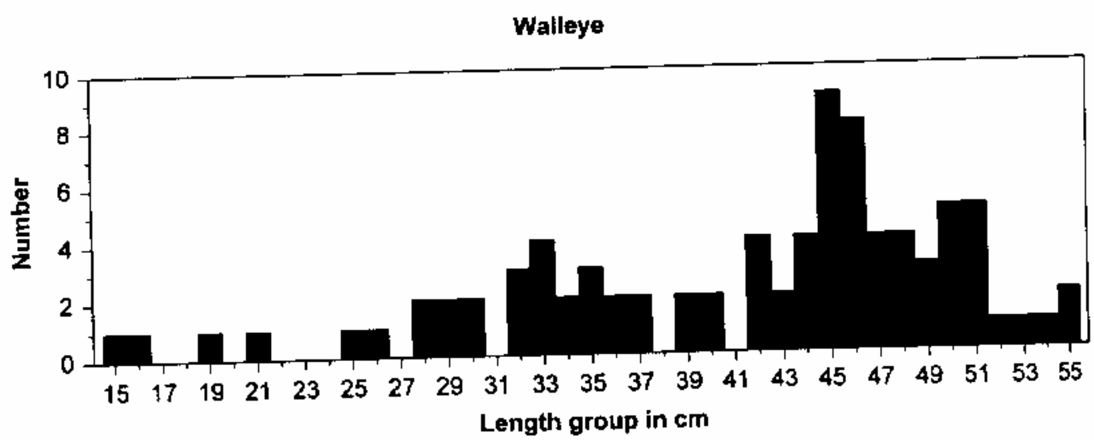


Figure 3.
Length frequency of walleye from gill nets in Lake Cochrane, 1998.

000124

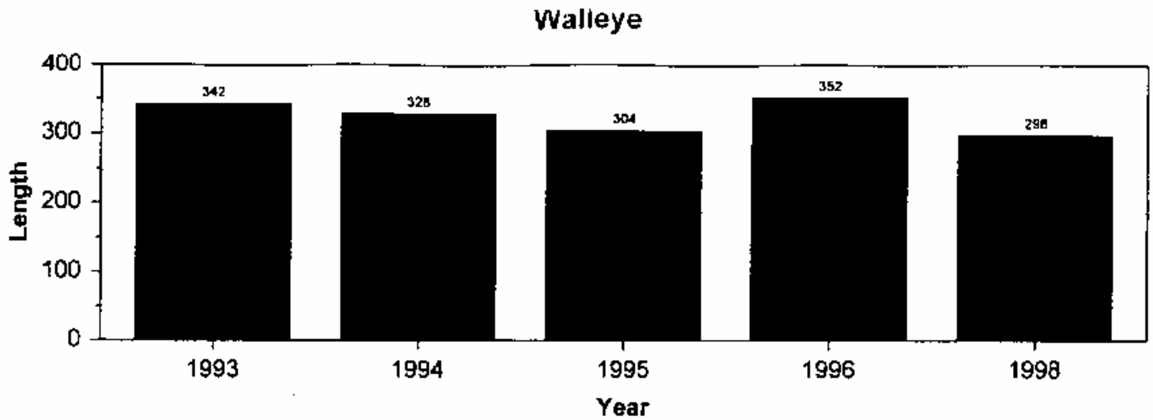


Figure 4.
Back-calculated lengths of age three walleye, Lake Cochrane, 1993-96, 1998.

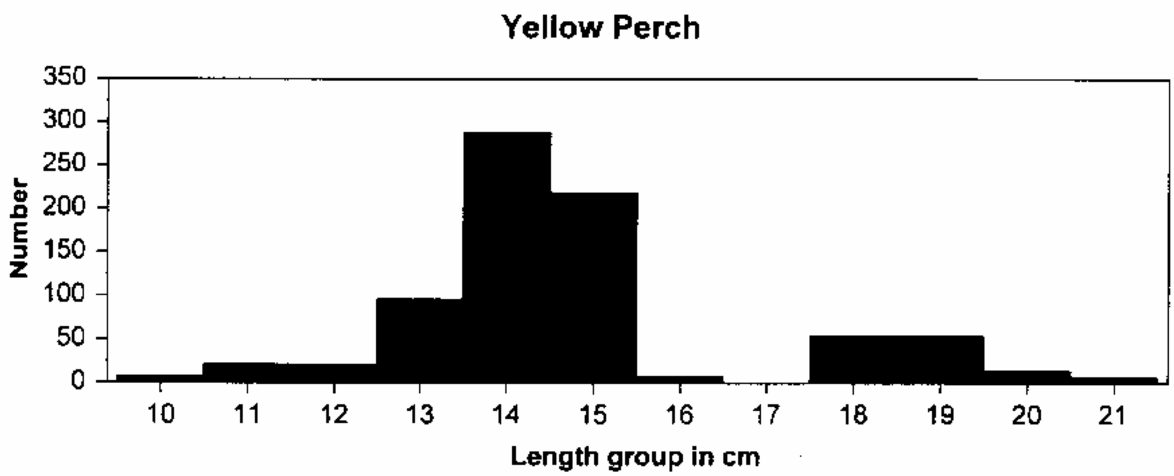


Figure 5.
Length frequency of yellow perch from gill nets in Lake Cochrane, 1998.

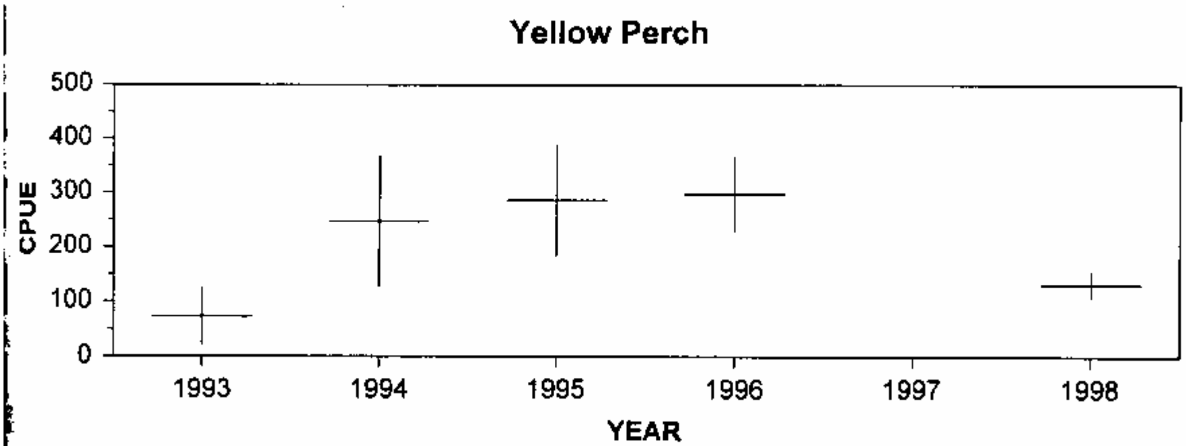


Figure 6.
CPUE of yellow perch from gill nets in Lake Cochrane, 1992-96, 1998.
80% confidence intervals

000125

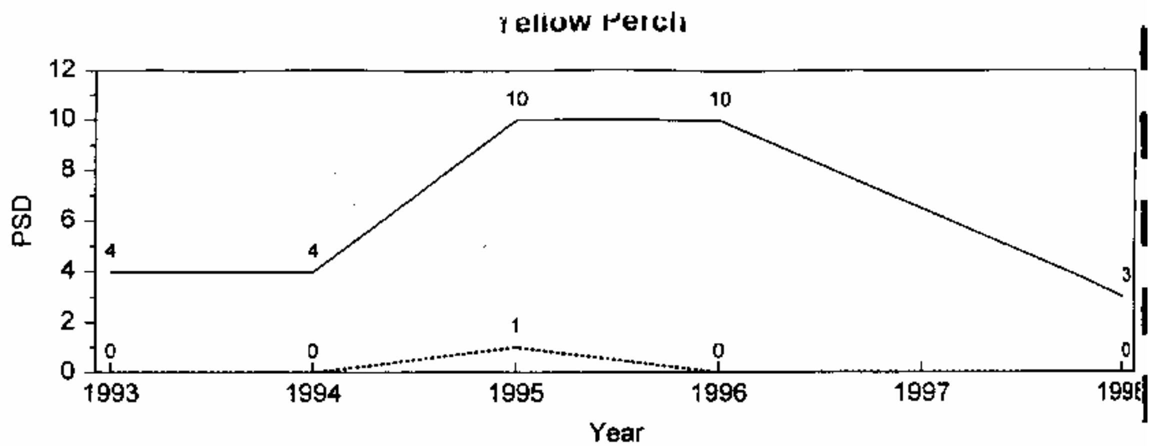


Figure 7.
Walleye PSD (-) and RSDP (- -) values from gill net samples, 1993-96, 1998.

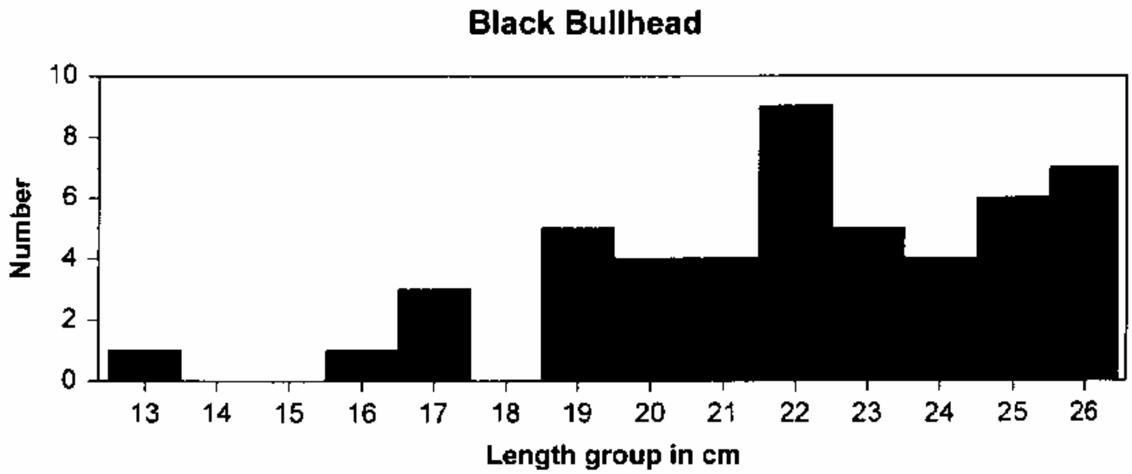


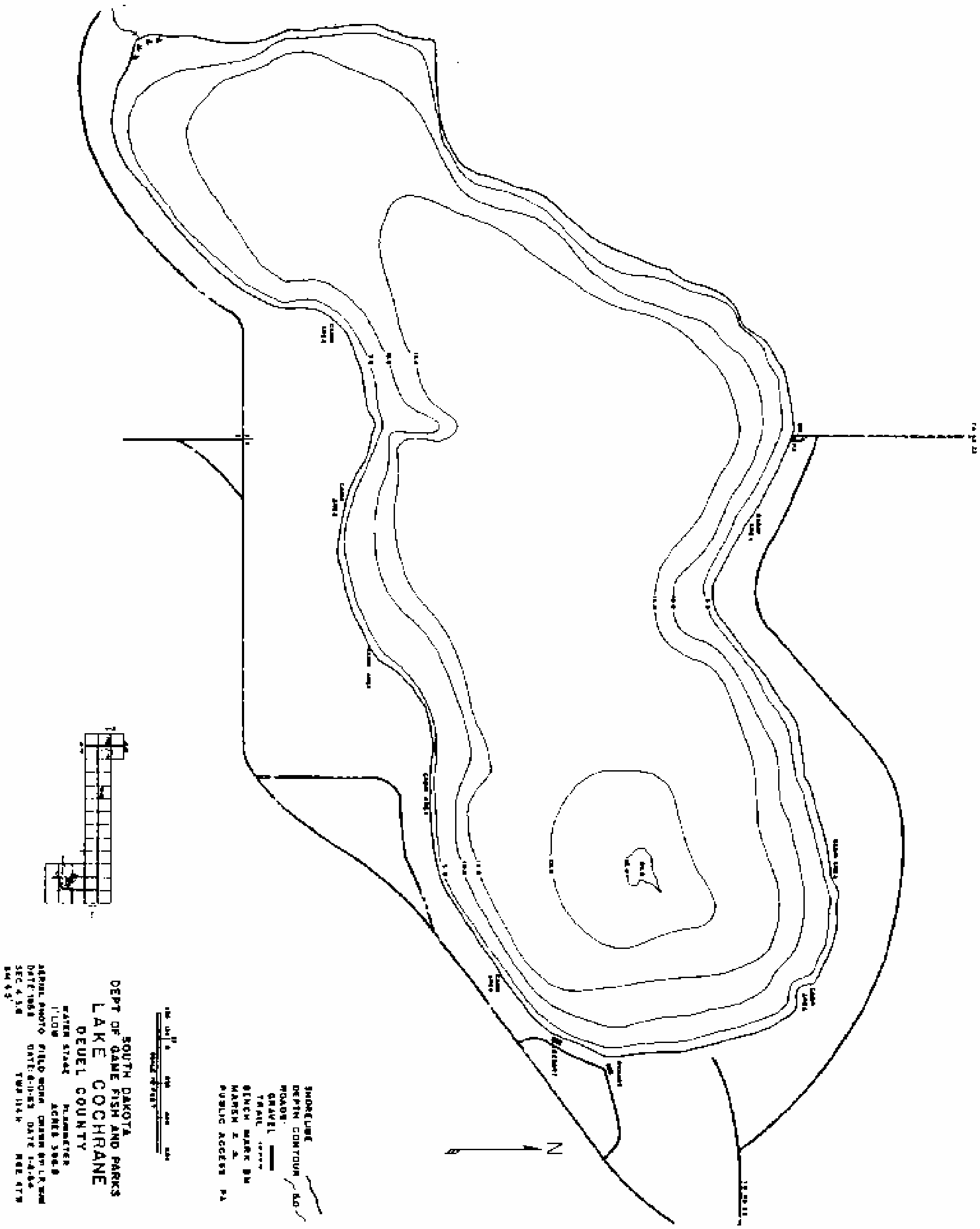
Figure 8.
Length frequency of black bullhead from gill nets in Lake Cochrane, 1998.

Table 5. Panfish (in kg) removal from Lake Cochrane by SDSU,1994-1998.

	Year					
Species	1994	1995	1996	1997	1998	Total
YEP	504.6	1969.2	702.3	118.3	242.7	3537.1
BLG	357.2	225.9	135.8	446.3	389.9	1555.1
BXG	667.2	855.1	403.4	424.7	765.5	3115.9
Total	1529	3050.2	1241.5	989.3	1398.1	8208.1

000126

Figure 9. Lake map of Lake Cochrane.



000127

APPENDIX C

Additional Algae Information

Table C-1a

Lake Cochrane Algal Taxa List	
Achnanthes minutissima	Gomphonema angustatum
Anabaena flos-aquae	Gomphosphaeria aponina
Anacystis marina	Gomphosphaeria lacustris
Ankistrodesmus falcatus	Gymnodinium sp.
Anomoeoneis vitrea	Mallomonas sp.
Aphanizomenon flos-aquae	Merismopedia tenuissima
Aphanothece sp.	Microcystis aeruginosa
Botryococcus braunii	Navicula pupula
Ceratium hirundinella	Navicula sp.
Chaetoceros sp.	Navicula tripunctata
Chlamydomonas sp.	Nitzschia acicularis
Chlorella sp.	Nitzschia amphibia
Chromulina sp.	Nitzschia capitellata
Chroococcus minimus	Nitzschia frustulum
Chroomonas sp.	Nitzschia palea
Chrysochromulina sp.	Nitzschia paleacea
Cosmarium sp.	Nitzschia sp.
Crucigenia quadrata	Oocystis lacustris
Cryptomonas erosa	Oocystis parva
Cyclotella atomus	Oocystis pusilla
Cyclotella comta	Oscillatoria sp.
Cyclotella kuetzingiana	Peridinium cinctum
Cyclotella meneghiniana	Pinnularia sp.
Cyclotella ocellata	Rhodomonas minuta
Cyclotella stelligera	Rhoicosphenia curvata
Cymbella affinis	Scenedesmus bijuga
Cymbella cesatii	Scenedesmus quadricauda
Cymbella microcephala	Sphaerocystis schroeteri
Cymbella minuta	Synedra acus
Denticula elegans	Synedra delicatissima
Diatoma tenue v. elongatum	Synedra radians
Diatomella balfouriana	Synedra rumpens
Dinobryon sertularia	Synedra ulna
Entomoneis ornata (Amphiprora)	Synedra ulna v. contracta
Epithemia sorex	Ulothrix sp.
Glenodinium sp.	Unidentified flagellates
Gloeocystis sp.	

Table C-1b

Lake Oliver Algal Taxa List	
Amphora ovalis	Melosira granulata
Anabaena flos-aquae	Microcystis aeruginosa
Anabaena planctonica	Mougeotia sp.
Anacystis marina	Navicula capitata
Ankistrodesmus falcatus	Navicula cryptocephala v. veneta
Aphanizomenon flos-aquae	Navicula rhynchocephala
Asterionella formosa	Nitzschia acicularis
Chlamydomonas sp.	Nitzschia amphibia
Chromulina sp.	Nitzschia dissipata
Chroococcus minimus	Nitzschia paleacea
Chrysochromulina sp.	Oocystis lacustris
Chrysococcus rufescens	Oocystis pusilla
Closteriopsis longissima	Oscillatoria sp.
Cocconeis placentula	Peridinium cinctum
Cryptomonas erosa	Rhodomonas minuta
Cyclotella meneghiniana	Scenedesmus quadricauda
Cyclotella stelligera	Sphaerocystis schroeteri
Cymbella muelleri	Staurastrum sp.
Dinobryon sertularia	Stephanodiscus astraea minutula
Fragilaria crotonensis	Surirella ovata
Glenodinium sp.	Synedra acus
Gomphosphaeria aponina	Synedra delicatissima
Gomphosphaeria lacustris	Synedra ulna
Gymnodinium sp.	Unidentified flagellates
Mallomonas sp.	

Table C-2

Summary of Cells/ml by Date and Algae Type					
Date	**Type**	**Site Number**			
		LCL-1	**LCL-2**	**LCL-3**	**Grand Total**
20-Apr-99	Blue Green	6,460	104	11,931	18,495
	Diatom	1,464	2,183	2,147	5,794
	Dinoflagellate	113			113
	Flagellated Algae	10,824	11,847	16,727	39,398
	Green Algae		624		624
20-Apr-99 Total		**18,861**	**14,758**	**30,805**	**64,424**
18-May-99	Blue Green	1,260	12,255		13,515
	Diatom	8,569	11,766	8,413	28,748
	Flagellated Algae	2,074	2,206	1,630	5,910
	Green Algae	2,071	858	1,310	4,239
18-May-99 Total		**13,974**	**27,085**	**11,353**	**52,412**
16-Jun-99	Blue Green	6,139	14,438	23,490	44,067
	Diatom	244	138	117	499
	Dinoflagellate	61			61
	Flagellated Algae	9,178	7,632	11,509	28,319
	Green Algae	1,331	344	705	2,380
16-Jun-99 Total		**16,953**	**22,552**	**35,821**	**75,326**
21-Jul-99	Blue Green	21,699	39,780	29,164	90,643
	Diatom	150	176	196	522
	Dinoflagellate	657	31	38	726
	Flagellated Algae	449	145	75	669
	Green Algae	75	311	418	804
21-Jul-99 Total		**23,030**	**40,443**	**29,891**	**93,364**
23-Aug-99	Blue Green	40,111	19,930	38,495	98,536
	Diatom	84	143	75	302
	Dinoflagellate	141	116	169	426
	Flagellated Algae	606	204	303	1,113
	Green Algae	661	614	741	2,016
23-Aug-99 Total		**41,603**	**21,007**	**39,783**	**102,393**
22-Sep-99	Blue Green	38,524	27,239	20,597	86,360
	Diatom	189	149	167	505
	Dinoflagellate	94	74	14	182
	Flagellated Algae	1,150	938	713	2,801
	Green Algae	801	639	1,749	3,189
22-Sep-99 Total		**40,758**	**29,039**	**23,240**	**93,037**
20-Oct-99	Blue Green	4,509	12,158	11,282	27,949
	Diatom	683	702	970	2,355
	Dinoflagellate		15	15	30
	Flagellated Algae	974	703	591	2,268
	Green Algae	1,170	464	754	2,388
20-Oct-99 Total		**7,336**	**14,042**	**13,612**	**34,990**
22-Nov-99	Blue Green	15,587	8,480	4,904	28,971
	Diatom	721	795	725	2,241
	Flagellated Algae	443	541	167	1,151
	Green Algae	774	474	1,097	2,345
22-Nov-99 Total		**17,525**	**10,290**	**6,893**	**34,708**
Grand Total		**180,040**	**179,216**	**191,398**	**550,654**

Figure C-1

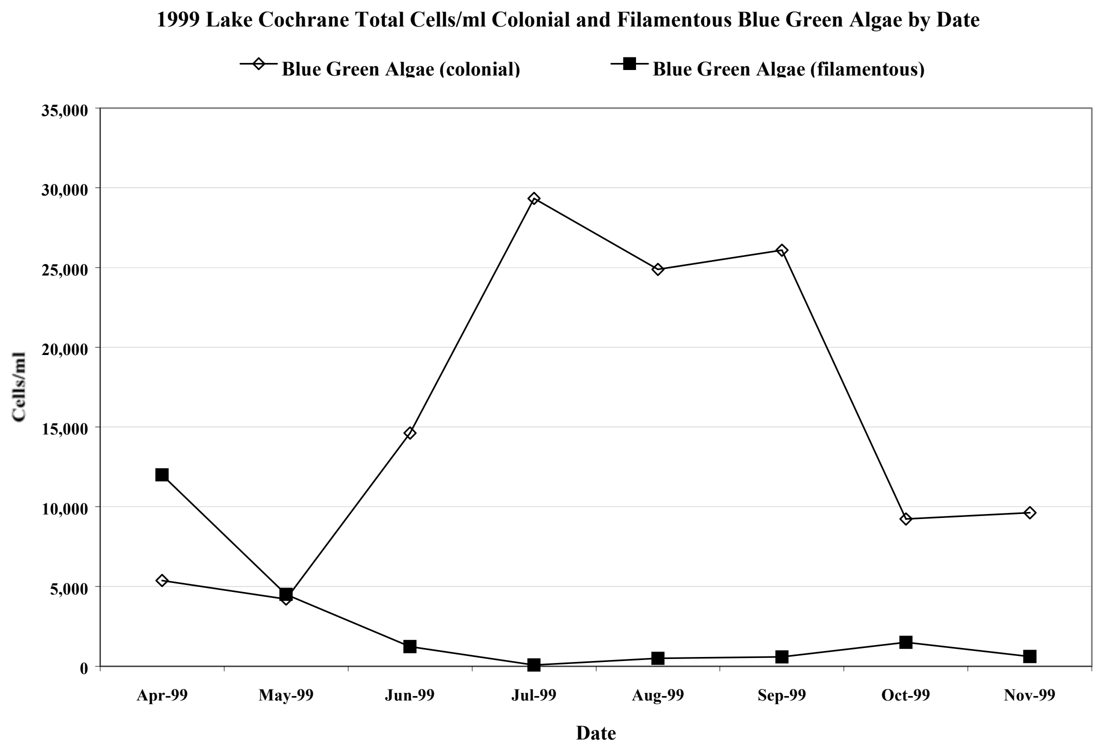


Figure C-2

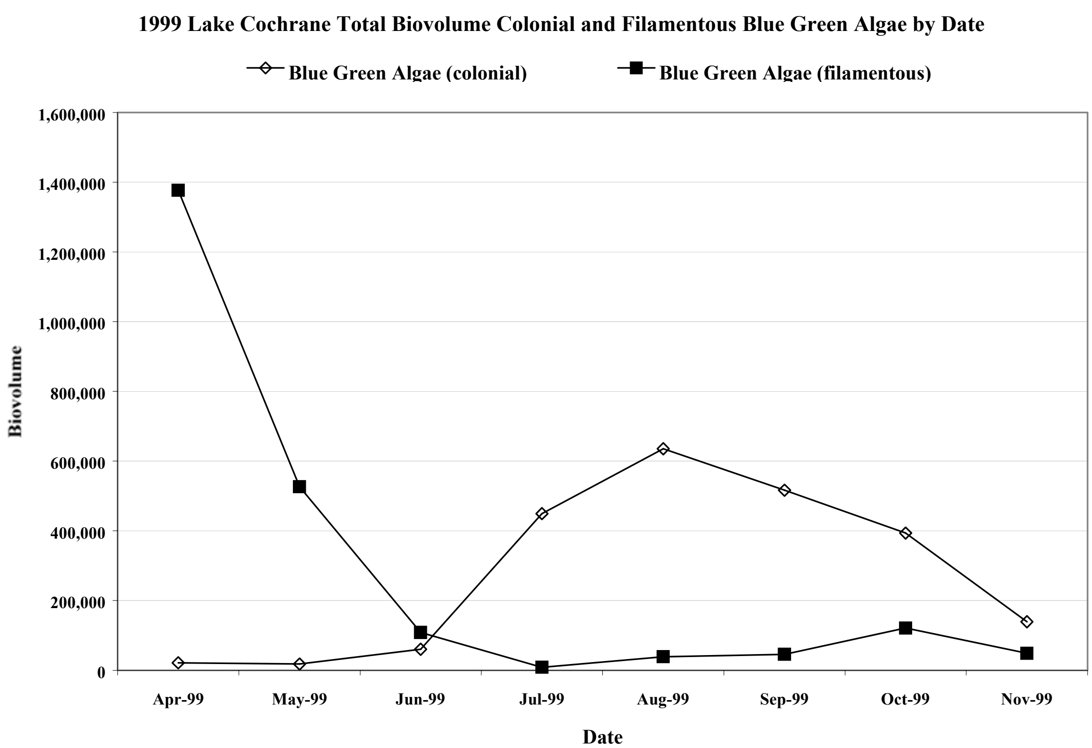


Table C-3

Lake Oliver Sum of Cells/ml				
Date	**Algal Group**	**SiteNumber**		
		LOL-1	**LOL-2**	**Grand Total**
20-Apr-99	Blue-Green Algae	20,505	16,100	36,605
	Diatom	85,826	60,885	146,711
	Flagellated Algae	1,367	1,288	2,655
20-Apr-99 Total		**107,698**	**78,273**	**185,971**
18-May-99	Blue-Green Algae	2,355	12,575	14,930
	Diatom	4,548	6,158	10,706
	Flagellated Algae	1,047	5,031	6,078
18-May-99 Total		**7,950**	**23,764**	**31,714**
16-Jun-99	Blue-Green Algae	32,295	21,546	53,841
	Diatom	1,820	1,807	3,627
	Flagellated Algae	1,089	874	1,963
	Green Algae	1,704	1,434	3,138
16-Jun-99 Total		**36,908**	**25,661**	**62,569**
21-Jul-99	Blue-Green Algae	108,535	86,222	194,757
	Diatom	624	93	717
	Dinoflagellate	35	31	66
	Flagellated Algae	277	248	525
	Green Algae	1,527	372	1,899
21-Jul-99 Total		**110,998**	**86,966**	**197,964**
23-Aug-99	Blue-Green Algae	187,783	183,337	371,120
	Diatom	621	431	1,052
	Flagellated Algae	155	144	299
	Green Algae		573	573
23-Aug-99 Total		**188,559**	**184,485**	**373,044**
22-Sep-99	Blue-Green Algae	394,093	240,075	634,168
	Diatom	881	87	968
	Dinoflagellate	176		176
	Flagellated Algae	1,057	433	1,490
	Green Algae	4,228	867	5,095
22-Sep-99 Total		**400,435**	**241,462**	**641,897**
20-Oct-99	Blue-Green Algae	369,825	352,845	722,670
	Diatom		111	111
	Flagellated Algae	1,128	1,217	2,345
	Green Algae	376		376
20-Oct-99 Total		**371,329**	**354,173**	**725,502**
22-Nov-99	Blue-Green Algae	1,125		1,125
	Diatom	225	440	665
	Flagellated Algae	7,742	9,337	17,079
	Green Algae		440	440
22-Nov-99 Total		**9,092**	**10,217**	**19,309**
Grand Total		**1,232,969**	**1,005,001**	**2,237,970**

Table C-4

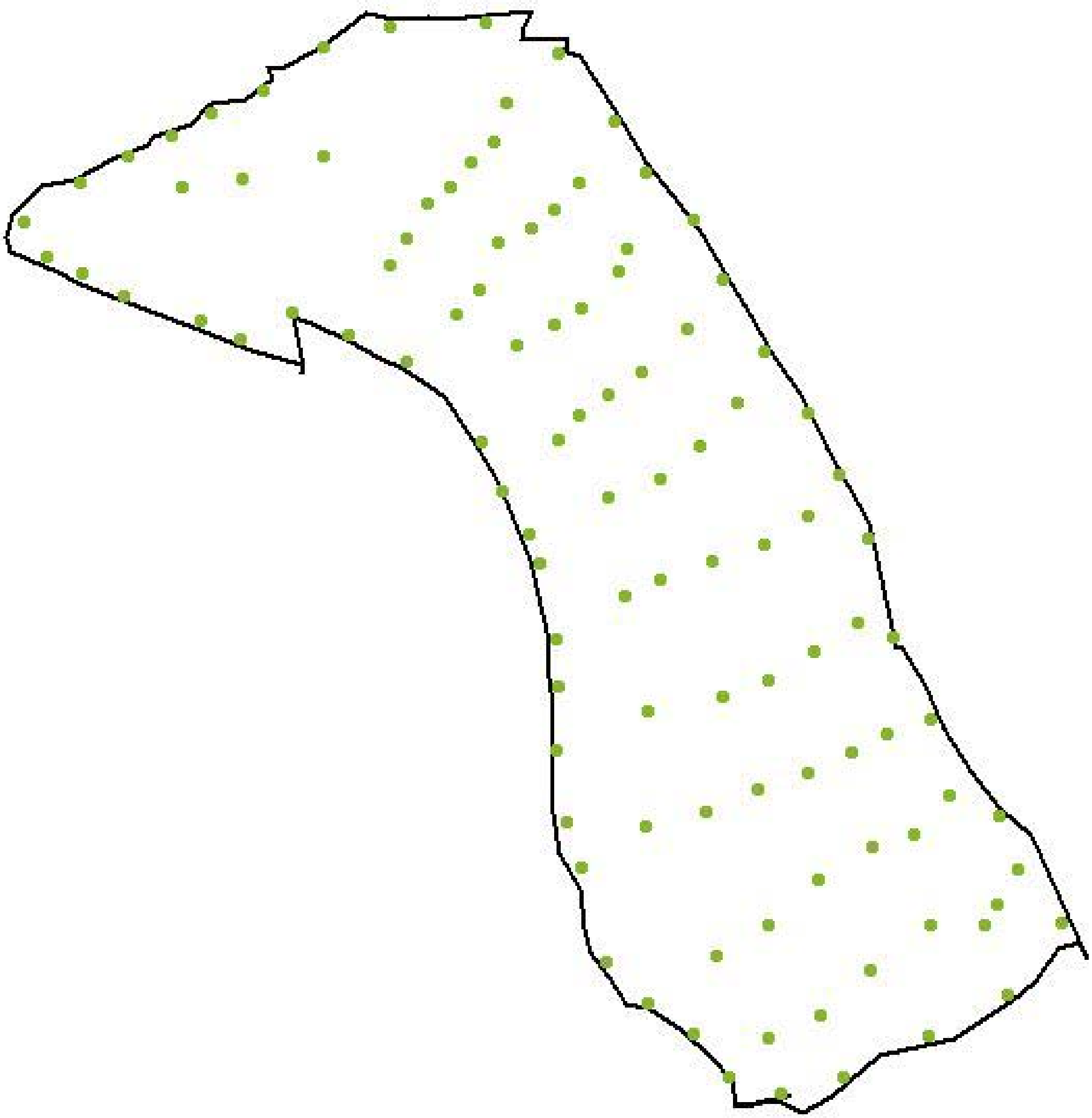
Lake Oliver Sum of Bio Volume

Date	Algal Group	SiteNumber LOL-1	LOL-2	Grand Total
20-Apr-99	Blue-Green Algae	2,399,085	1,886,400	4,285,485
	Diatom	8,391,184	6,397,688	14,788,872
	Flagellated Algae	394,166	336,168	730,334
20-Apr-99 Total		**11,184,435**	**8,620,256**	**19,804,691**
18-May-99	Blue-Green Algae	275,535	872,700	1,148,235
	Diatom	692,906	1,031,231	1,724,137
	Flagellated Algae	156,864	371,514	528,378
18-May-99 Total		**1,125,305**	**2,275,445**	**3,400,750**
16-Jun-99	Blue-Green Algae	3,778,515	2,658,474	6,436,989
	Diatom	745,730	431,566	1,177,296
	Flagellated Algae	71,220	29,048	100,268
	Green Algae	255,622	237,322	492,944
16-Jun-99 Total		**4,851,087**	**3,356,410**	**8,207,497**
21-Jul-99	Blue-Green Algae	9,246,698	8,734,619	17,981,317
	Diatom	343,200	51,150	394,350
	Dinoflagellate	24,500	21,700	46,200
	Flagellated Algae	194,068	298,034	492,102
	Green Algae	113,733	204,476	318,209
21-Jul-99 Total		**9,922,199**	**9,309,979**	**19,232,178**
23-Aug-99	Blue-Green Algae	11,107,713	11,001,578	22,109,291
	Diatom	260,188	207,482	467,670
	Flagellated Algae	52,746	55,392	108,138
	Green Algae		35,723	35,723
23-Aug-99 Total		**11,420,647**	**11,300,175**	**22,720,822**
22-Sep-99	Blue-Green Algae	45,736,773	27,905,625	73,642,398
	Diatom	484,550	8,526	493,076
	Dinoflagellate	475,200		475,200
	Flagellated Algae	128,500	92,046	220,546
	Green Algae	228,312	46,818	275,130
22-Sep-99 Total		**47,053,335**	**28,053,015**	**75,106,350**
20-Oct-99	Blue-Green Algae	43,269,525	41,282,865	84,552,390
	Diatom		10,878	10,878
	Flagellated Algae	158,484	77,842	236,326
	Green Algae	36,942		36,942
20-Oct-99 Total		**43,464,951**	**41,371,585**	**84,836,536**
22-Nov-99	Blue-Green Algae	131,625		131,625
	Diatom	93,000	418,000	511,000
	Flagellated Algae	1,106,118	1,332,760	2,438,878
	Green Algae		40,128	40,128
22-Nov-99 Total		**1,330,743**	**1,790,888**	**3,121,631**
Grand Total		130,352,702	106,077,753	236,430,455

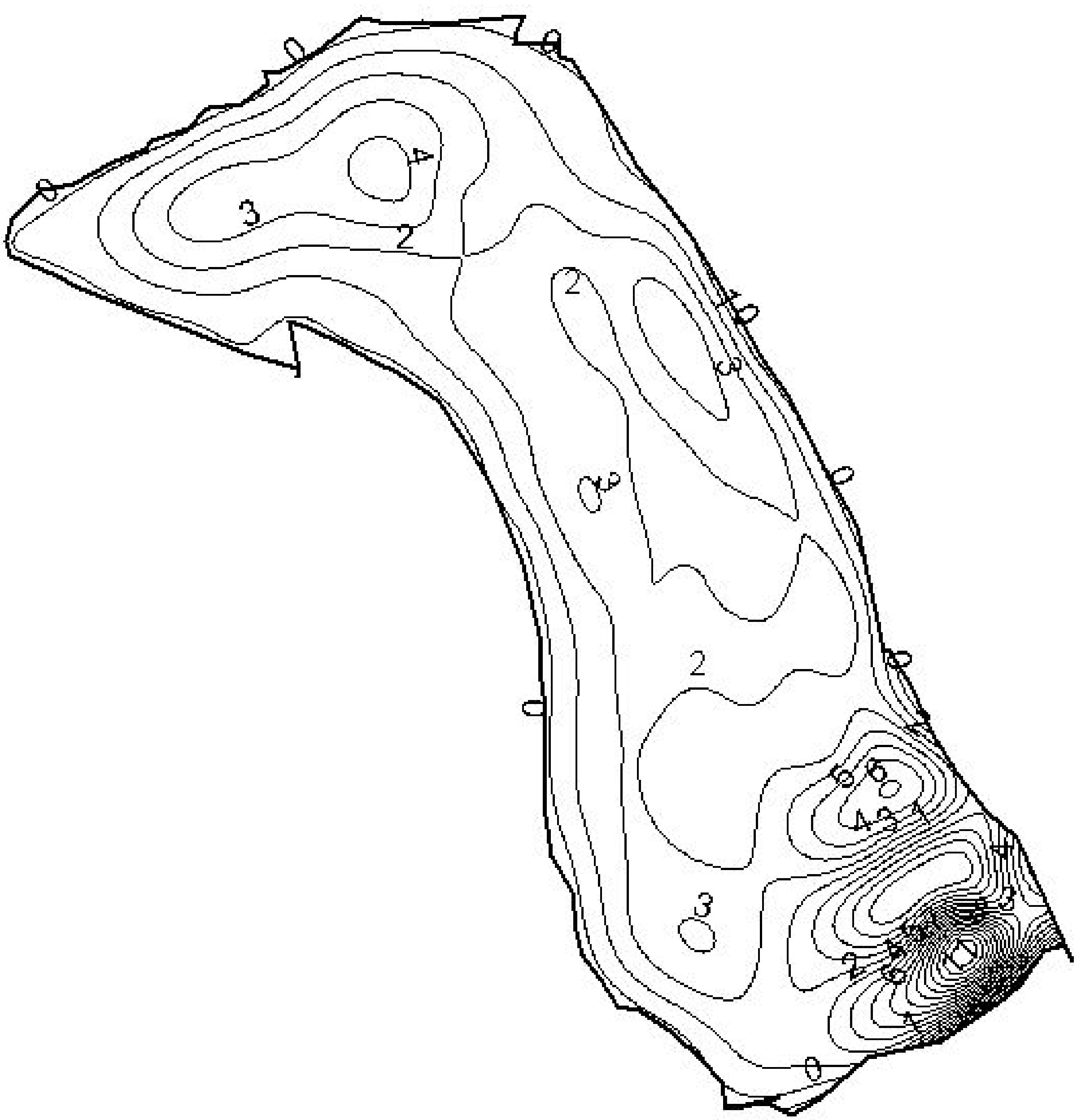
Appendix D

Sediment Trap and Lake Oliver Survey Points and Sediment Depths

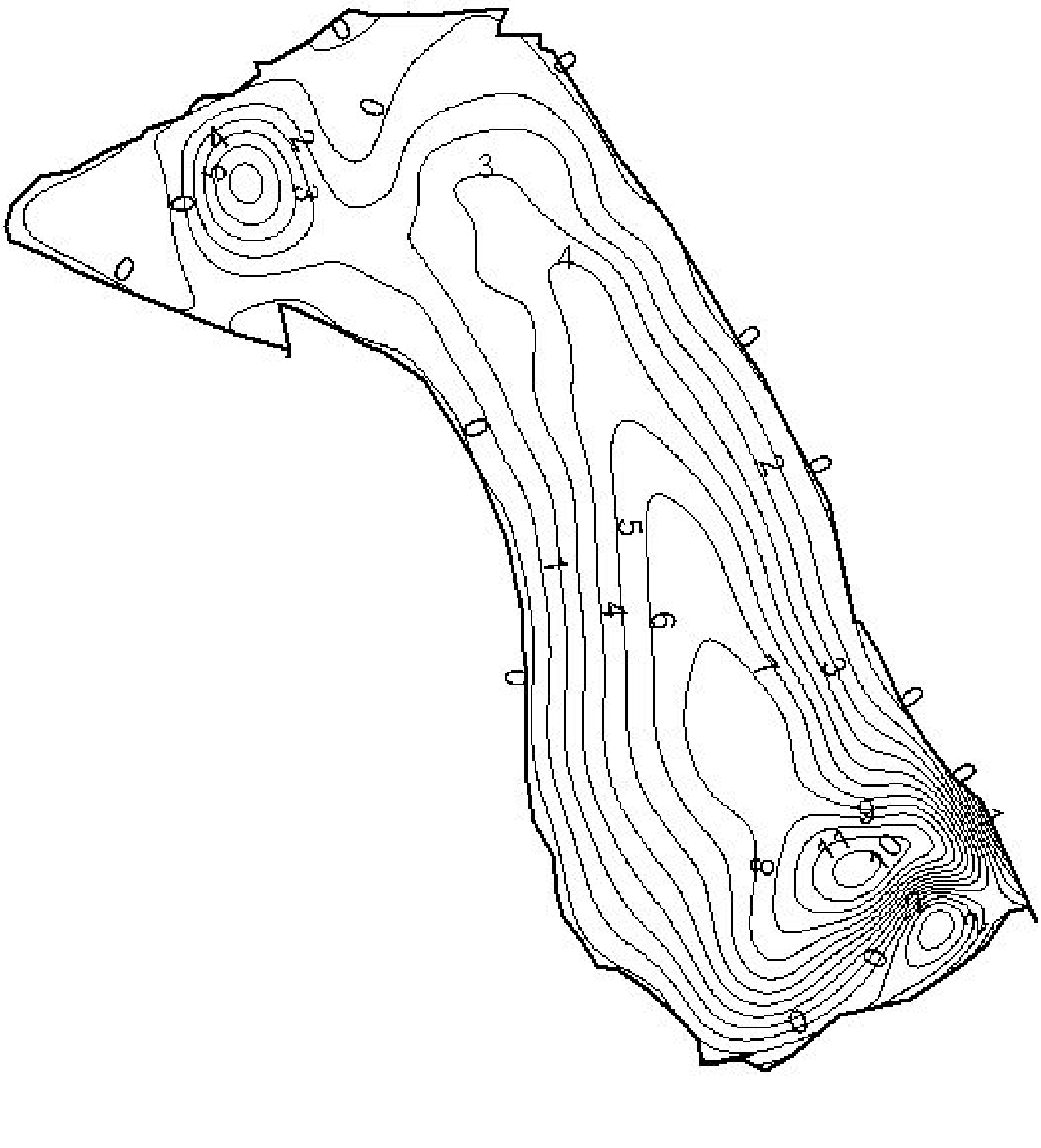
Lake Cochrane Sediment Basin LCT-1
Survey Holes



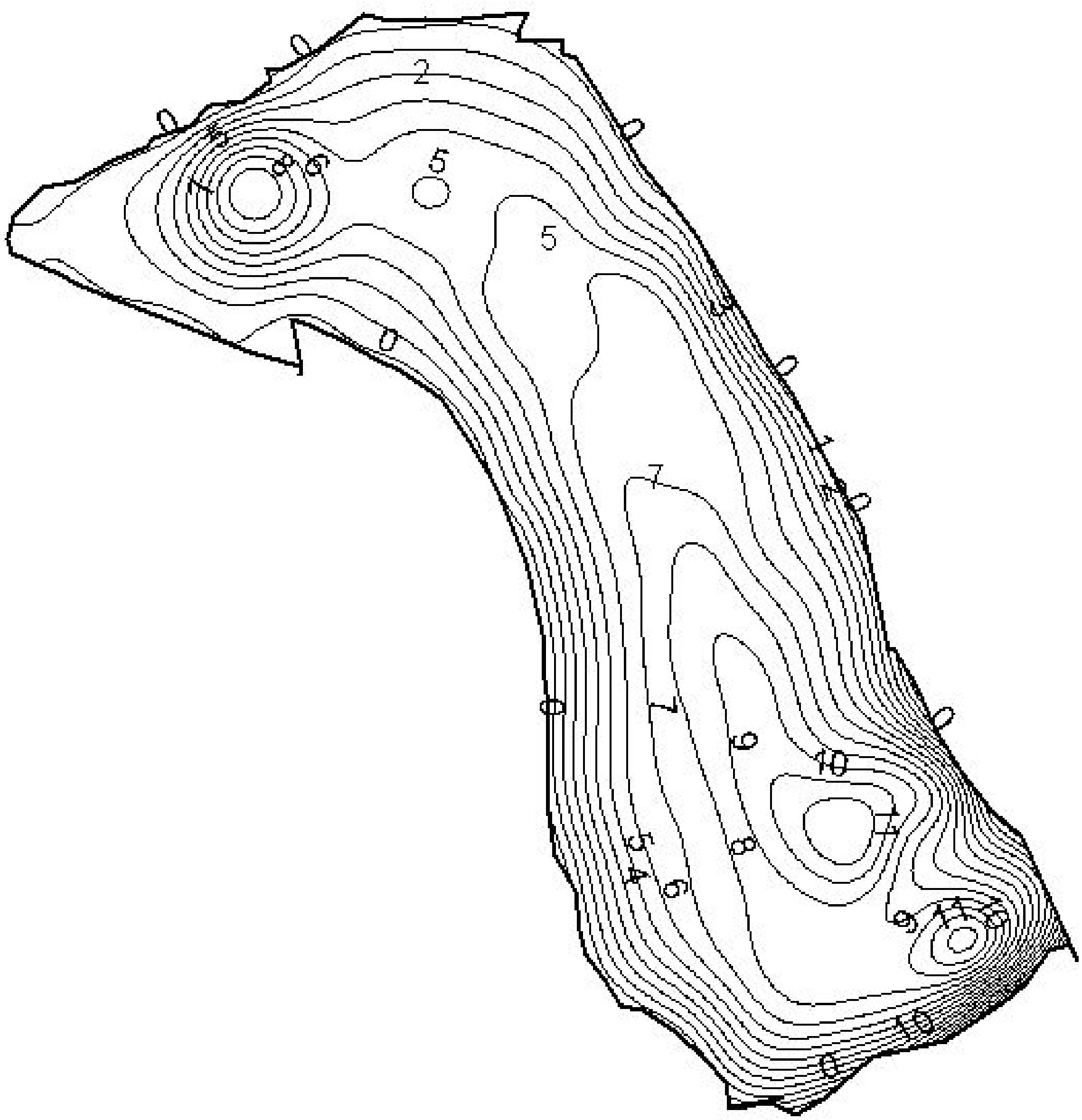
Lake Cochrane Sediment Basin LCT-1
Sediment Depths



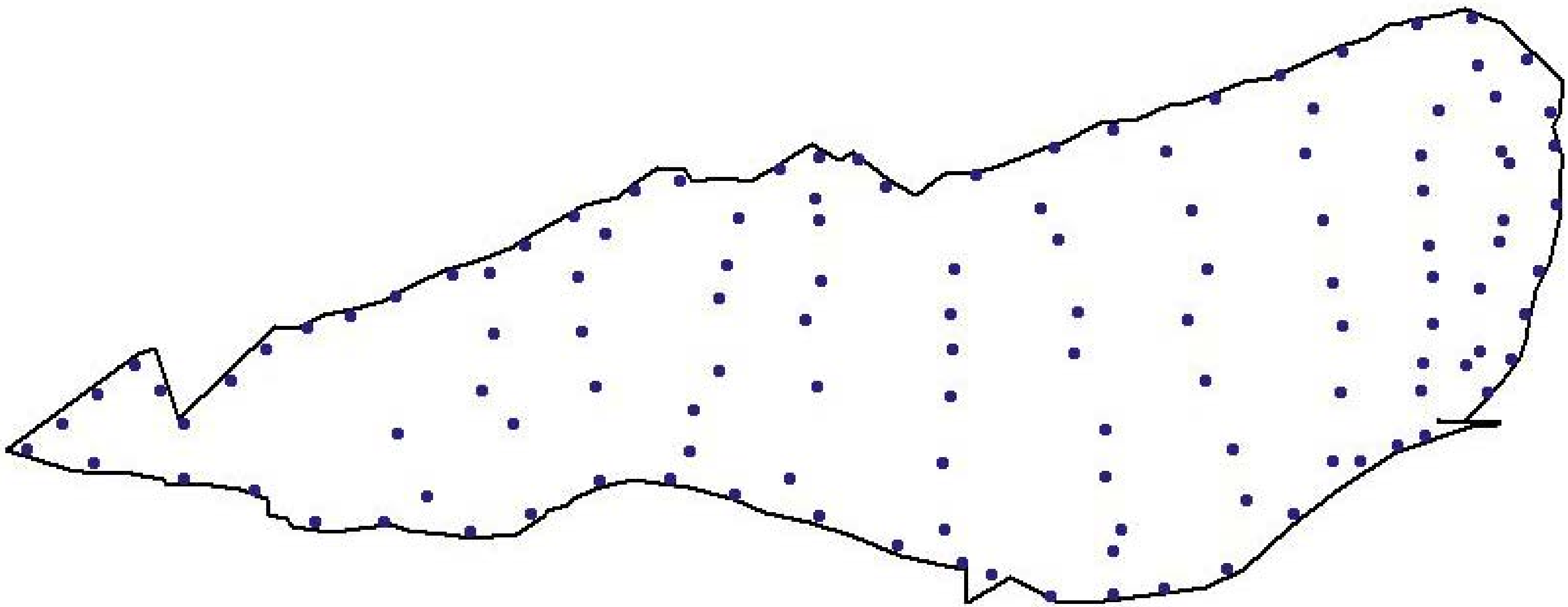
Lake Cochrane Sediment Basin LCT-1
Current Water Depths



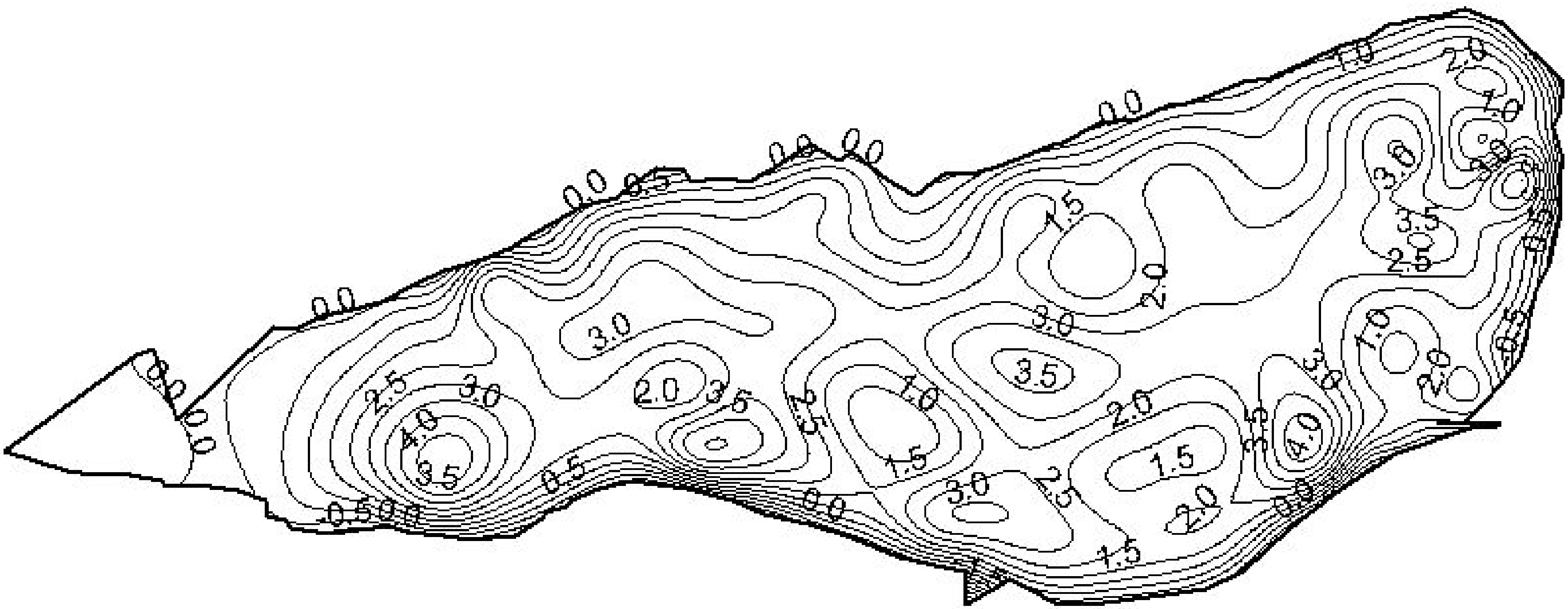
Lake Cochrane Sediment Basin LCT-1
Total Depths (Water + Sediment)



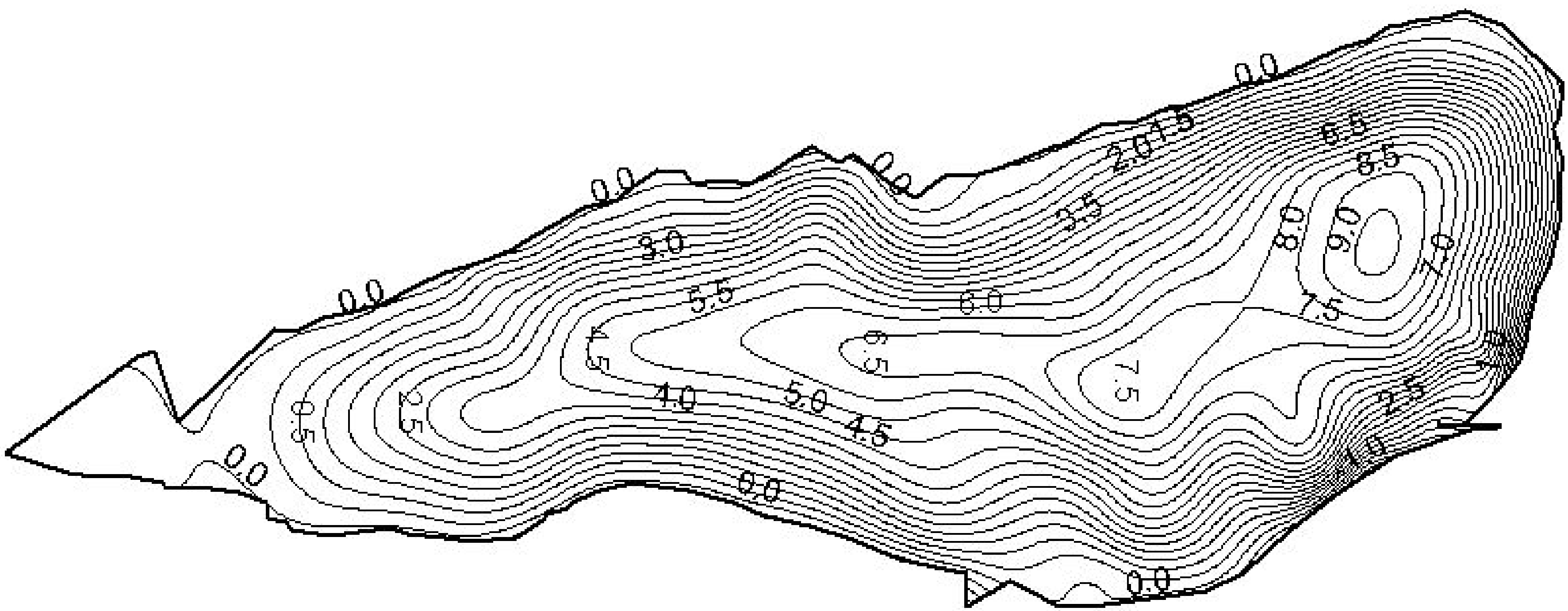
Lake Cochrane Sediment Basin LCT-2
Survey Holes



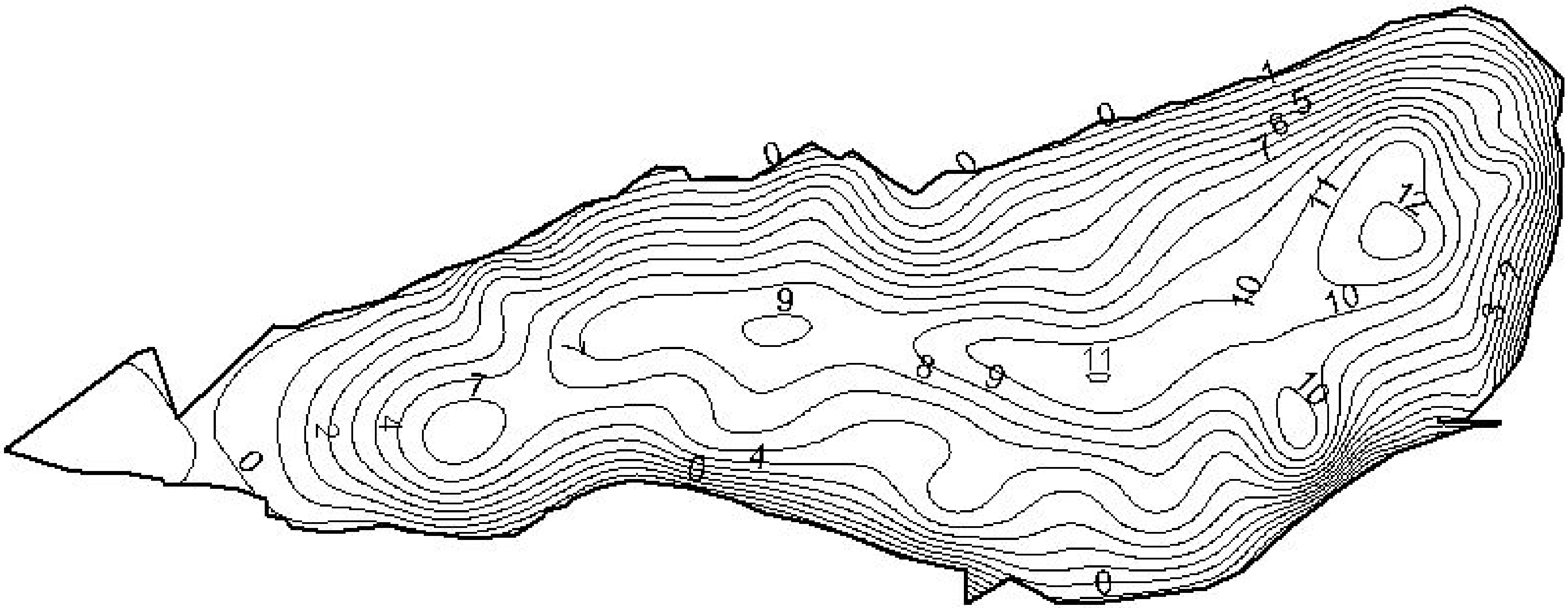
Lake Cochrane Sediment Basin LCT-2
Sediment Depths



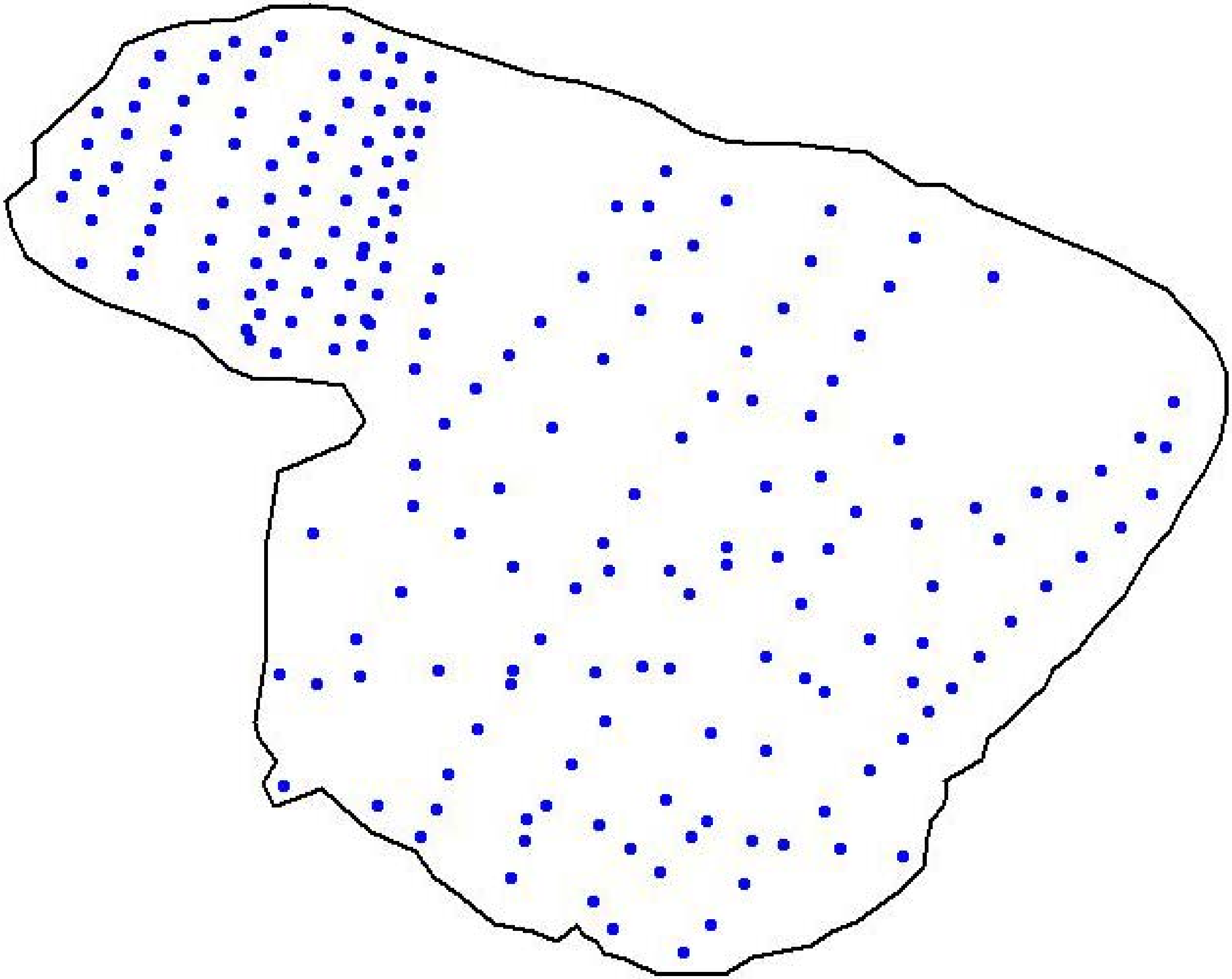
Lake Cochrane Sediment Basin LCT-2
Current Water Depths



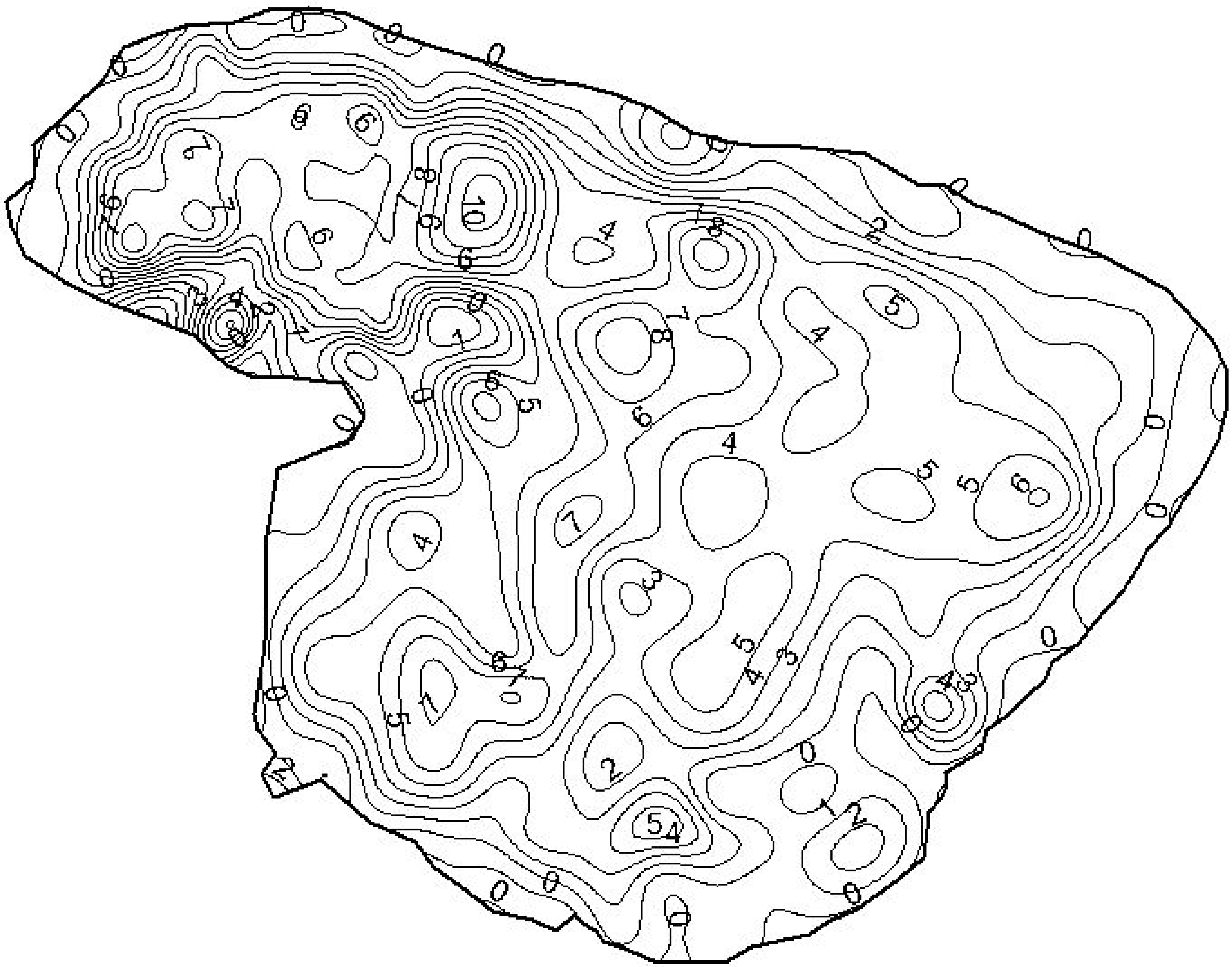
Lake Cochrane Sediment Basin LCT-2
Total Volume (Water + Sediment)



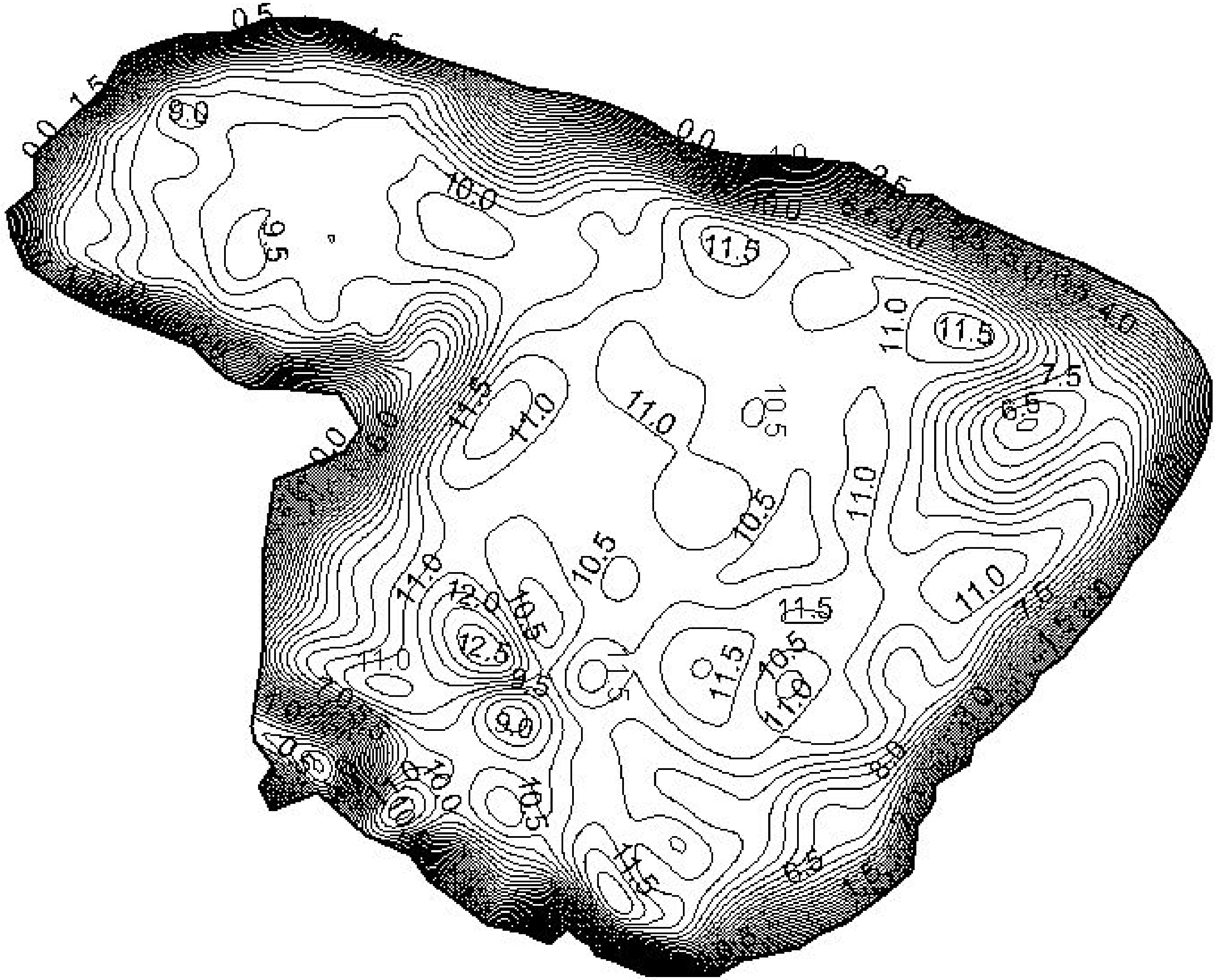
Lake Oliver
Survey Holes



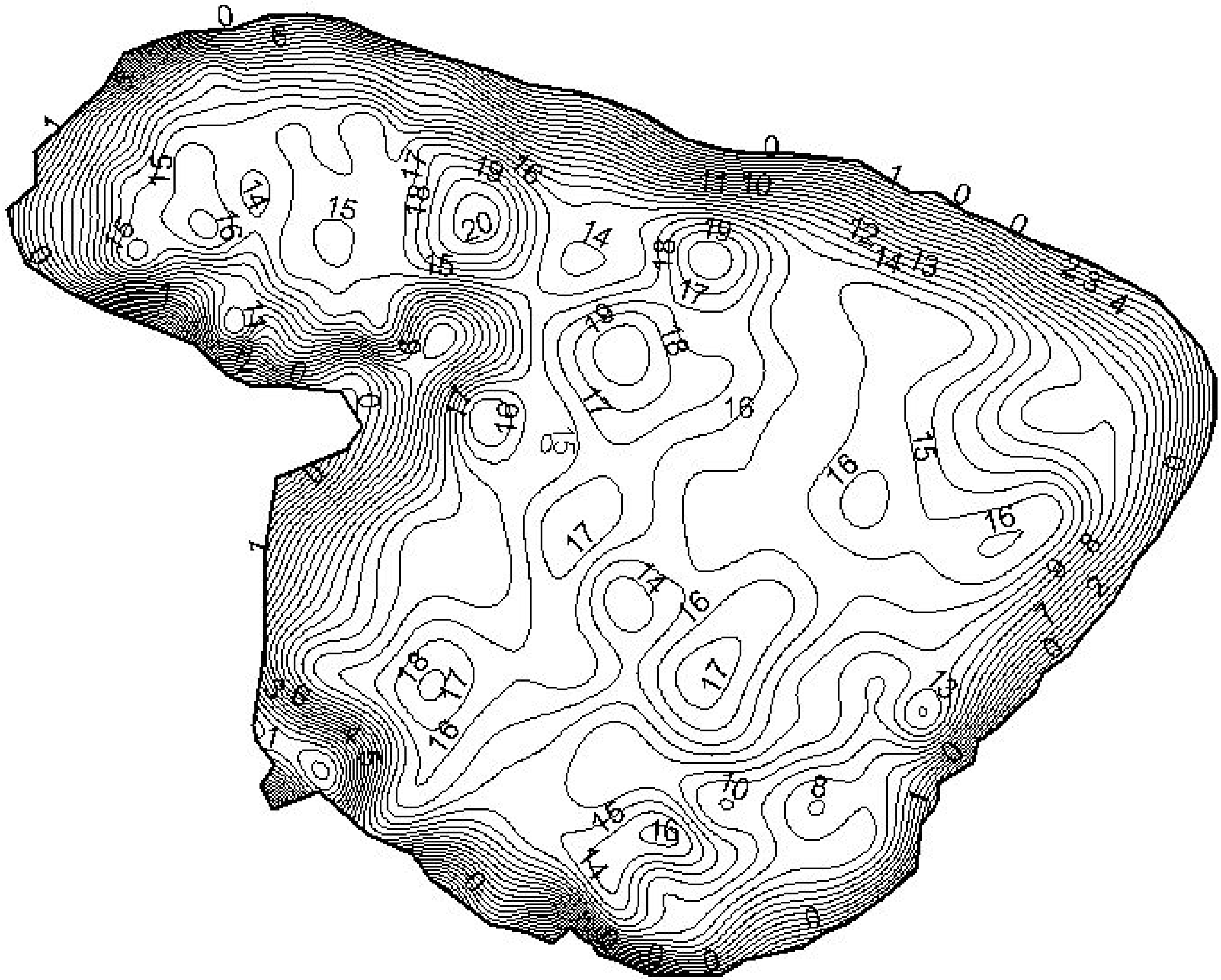
Lake Oliver
Sediment Depths



Lake Oliver
Current Water Depths



Lake Oliver
Total Depth (Water + Sediment)



Appendix E

Quality Assurance Quality Control

Tributary QA/QC Results

Site	Time	Date	Sample Depth	Fecal Coliform	Total Alkalinity	Total Solids	Total Susp. Solids	Total Volatile Susp. Solids	Ammonia	Nitrate-Nitrite	TKN	Total Phosphorus	Total Diss. Phosphorus
LCT-2	1400	03/18/1999	Surface	10	234	654	14	6	1.2	1.3	5.7	0.457	0.304
LCT-5	1400	03/18/1999	Surface	20	231	658	10	4	1.54	1.4	5.83	0.459	0.318
			Industrial Statistic	[1] ***33%***	1%	0%	[2] ***17%***	[3] ***20%***	12%	4%	1%	0%	2%
			Standard Deviation	***7.07***	2.12	2.83	***2.83***	***1.41***	0.24	0.07	0.09	0.00	0.01

[1] Difference is natural variability of fecal coliform.
[2] Sampler may have picked up something in the second bottle. Not unusual in field duplicates.
[3] Result of difference in suspeded solids sample.

Site	Time	Date	Sample Depth	Fecal Coliform	Total Alkalinity	Total Solids	Total Susp. Solids	Total Volatile Susp. Solids	Ammonia	Nitrate-Nitrite	TKN	Total Phosphorus	Total Diss. Phosphorus
LCT-4	1000	04/06/1999	Surface	10	252	1407	1	1	0.01	0.1	0.9	0.034	0.029
LCT-5	1000	04/06/1999	Surface	5	256	1397	0.5	0.5	0.01	0.1	0.96	0.035	0.03
			Industrial Statistic	33%	1%	0%	33%	33%	0%	0%	3%	1%	2%
			Standard Deviation	3.54	2.83	7.07	0.35	0.35	0.00	0.00	0.04	0.00	0.00
LCT-4	1330	04/12/1999	Surface	5	285	1549	3	2	0.01	0.05	0.71	0.042	0.027
LCT-5	1330	04/12/1999	Surface	5	285	1551	3	3	0.01	0.05	0.64	0.042	0.026
			Industrial Statistic	0%	0%	0%	0%	20%	0%	0%	5%	0%	2%
			Standard Deviation	0.00	0.00	1.41	0.00	0.71	0.00	0.00	0.05	0.00	0.00
LCT-3	1030	04/15/1999	Surface	20	257	664	3	1	0.01	0.05	0.75	0.025	0.014
LCT-5	1030	04/15/1999	Surface	5	257	665	2	2	0.01	0.05	0.72	0.029	0.016
			Industrial Statistic	[4] ***60%***	0%	0%	20%	33%	0%	0%	2%	7%	7%
			Standard Deviation	***10.61***	0.00	0.71	0.71	0.71	0.00	0.00	0.02	0.00	0.00

[4] Difference most likely from the natural variability of fecal coliform bacteria.

Site	Time	Date	Sample Depth	Fecal Coliform	Total Alkalinity	Total Solids	Total Susp. Solids	Total Volatile Susp. Solids	Ammonia	Nitrate-Nitrite	TKN	Total Phosphorus	Total Diss. Phosphorus
LCT-3	1215	05/05/1999	Surface	30	242	719	5	1	0.01	0.05	1	0.047	0.022
LCT-5	1215	05/05/1999	Surface	120	241	716	7	4	0.01	0.05	1.06	0.048	0.018
			Industrial Statistic	[5] ***60%***	0%	0%	17%	[6] 60%	0%	0%	3%	1%	10%
			Standard Deviation	***63.64***	0.71	2.12	1.41	2.12	0.00	0.00	0.04	0.00	0.00

[5] Difference most likely from the natural variability of fecal coliform bacteria.
[6] Sampler may have picked up something in the second bottle. Not unusual in field duplicates.

Site	Time	Date	Sample Depth	Fecal Coliform	Total Alkalinity	Total Solids	Total Susp. Solids	Total Volatile Susp. Solids	Ammonia	Nitrate-Nitrite	TKN	Total Phosphorus	Total Diss. Phosphorus
LOO	1100	06/03/1999	Surface	20	267	1426	8	5	0.01	0.05	1.59	0.059	0.028
LOT-5	1100	06/03/1999	Surface	110	261	1401	9	6	0.01	0.05	1.97	0.071	0.025
			Industrial Statistic	[7] ***69%***	1%	1%	6%	9%	0%	0%	11%	9%	6%
			Standard Deviation	***63.64***	4.24	17.68	0.71	0.71	0.00	0.00	0.27	0.01	0.00

[7] Difference most likely from the natural variability of fecal coliform bacteria.

Site	Time	Date	Sample Depth	Fecal Coliform	Total Alkalinity	Total Solids	Total Susp. Solids	Total Volatile Susp. Solids	Ammonia	Nitrate-Nitrite	TKN	Total Phosphorus	Total Diss. Phosphorus
LCI	1200	06/08/1999	Surface	400	238	1289	23	7	0.01	0.05	2.63	0.105	0.029
LCT-5	1200	06/08/1999	Surface	490	240	1297	24	4	0.01	0.05	2.66	0.102	0.029
			Industrial Statistic	10%	0%	0%	2% [8]	***27%***	0%	0%	1%	1%	0%
			Standard Deviation	63.64	1.41	5.66	0.71	***2.12***	0.00	0.00	0.02	0.00	0.00

[8] Sampler may have picked up something in the second bottle. Not unusual in field duplicates.

Site	Time	Date	Sample Depth	Fecal Coliform	Total Alkalinity	Total Solids	Total Susp. Solids	Total Volatile Susp. Solids	Ammonia	Nitrate-Nitrite	TKN	Total Phosphorus	Total Diss. Phosphorus
LOT4	900	06/29/1999	Composite	650	270	1288	2	2	0.01	0.05	0.9	0.028	0.010
LOT-5	900	06/29/1999	Composite	570	270	1274	3	2	0.01	0.05	1.04	0.027	0.021
			Industrial Statistic	7%	0%	1%	20%	0%	0%	0%	7%	2%	[9] ***35%***
			Standard Deviation	56.57	0.00	9.90	0.71	0.00	0.00	0.00	0.10	0.00	***0.01***

[9] Improperly rinsed bottles or filters.

Site	Time	Date	Sample Depth	Fecal Coliform	Total Alkalinity	Total Solids	Total Susp. Solids	Total Volatile Susp. Solids	Ammonia	Nitrate-Nitrite	TKN	Total Phosphorus	Total Diss. Phosphorus
LOT-4	1830	09/19/1999	Composite		216	2253	2	2	0.01	0.1	1.41	0.098	0.034
LOT-5	1830	09/19/1999	Composite		217	2255	9	3	0.01	0.1	1.11	0.111	0.036
			Industrial Statistic		0%	0%	[10] ***64%***	20%	0%	0%	12%	6%	3%
			Standard Deviation		0.71	1.41	***4.95***	0.71	0.00	0.00	0.21	0.01	0.00

[10] Sampler may have picked up something in the second bottle. Not unusual in field duplicates.

Site	Time	Date	Sample Depth	Fecal Coliform	Total Alkalinity	Total Solids	Total Susp. Solids	Total Volatile Susp. Solids	Ammonia	Nitrate-Nitrite	TKN	Total Phosphorus	Total Diss. Phosphorus
LCT-6	1400	03/18/1999	Surface	5	3	6	1	0.5	0.01	0.05	0.16	0.001	0.010
LCT-6	1000	04/06/1999	Surface	5	3.5	6	0.5	0.5	0.01	0.05	0.05	0.001	0.007
LCT-6	1330	04/12/1999	Surface	5	3	2.5	1	[14] 1	0.01	0.05	[15] 0.05	0.003	0.001
LCT-6	1030	04/15/1999	Surface	5	3	[12] 2.5	0.5	0.5	0.01	0.05	0.07	0.008	[17]
LCT-6	1215	05/05/1999	Surface	5	3.5	2.5	[13] 1	0.5	0.01	0.05	0.16	[16] 0.001	0.001
LOT-6	1100	06/03/1999	Surface	5	3.5	4	0.5	0.5	0.01	0.05	0.16	0.001	0.001
LCT-6	1200	06/08/1999	Surface	[11] 20	3.5	3	0.5	0.5	0.01	0.05	0.07	0.001	0.001
LOT-6	900	06/29/1999	Composite	5	3.5	2.5	1	0.5	0.01	0.05	0.07	0.002	0.001
LOT-6	1830	09/19/1999	Composite		3.5	2.5	0.5	0.5	0.01	0.05	0.07	0.001	0.001
			Average	**6.88**	**3.33**	**3.50**	**0.72**	**0.56**	**0.01**	**0.05**	**0.10**	**0.002**	**0.003**
			Median	**5.00**	**3.50**	**2.50**	**0.50**	**0.50**	**0.01**	**0.05**	**0.07**	**0.001**	**0.001**
			Standard Deviation	**5.303**	**0.250**	**1.500**	**0.264**	**0.167**	**0.000**	**0.000**	**0.049**	**0.002**	**0.004**

[11] Cross contamination.
[12] Improperly rinsed bottles.
[13] Improperly rinsed bottles.
[14] Improperly rinsed bottles.
[15] Improperly rinsed bottles.
[16] Improperly rinsed bottles.
[17] Improperly rinsed bottles or filters.

Inlake QA/QC Results

Date	Time	Site	Sample Depth	Fecal Coliform	Total Alkalinity	Total Solids	Total Susp. Solids	Total Volatile Susp. Solids	Ammonia	Nitrate-Nitrite	TKN	Total Phosphorus	Total Diss. Phosphorus
04/20/1999	13:00	LOL#1	BOTTOM	5	263	1298	18	3	0.13	0.05	1.46	0.054	0.012
04/20/1999	13:00	LOL#3	BOTTOM	5	261	1329	18	5	0.39	0.05	1.23	0.062	0.018
			Industrial Stat.	0%	0%	1%	0%	25%	[1] ***50%***	0%	9%	7%	[2] ***20%***
			St. Deviation	0.00	1.41	21.92	0.00	1.41	***0.18***	0.00	0.16	0.006	***0.004***

[1] May have been higher due to the increased suspended solids in this sample.
[2] Although the IS is higher than 15% the standard deviation is quite small.

Date	Time	Site	Sample Depth	Fecal Coliform	Total Alkalinity	Total Solids	Total Susp. Solids	Total Volatile Susp. Solids	Ammonia	Nitrate-Nitrite	TKN	Total Phosphorus	Total Diss. Phosphorus
05/18/1999	12:00	LOL#1	BOTTOM	5	265	1370	16	1	0.13	0.05	1.35	0.07	0.021
05/18/1999	12:00	LOL#3	BOTTOM	5	264	1380	11	7	0.09	0.05	1.4	0.065	0.021
			Industrial Stat.	0%	0%	0%	19%	[3] ***75%***	[4] ***18%***	0%	2%	4%	0%
			St. Deviation	0.00	0.71	7.07	3.54	***4.24***	***0.03***	0.00	0.04	0.004	0.000

[3] Variance in sample may have been from collecting a clump of organic matter in the second sample.
[4] Variance in sample may have been from collecting a clump of organic matter in the second sample.

Date	Time	Site	Sample Depth	Fecal Coliform	Total Alkalinity	Total Solids	Total Susp. Solids	Total Volatile Susp. Solids	Ammonia	Nitrate-Nitrite	TKN	Total Phosphorus	Total Diss. Phosphorus
06/16/1999	10:30	LOL#1	BOTTOM	5	258	1360	15	3	0.16	0.05	2.26	0.057	0.020
06/16/1999	10:30	LOL#3	BOTTOM	5	258	1366	21	6	0.01	0.1	1.61	0.061	0.020
			Industrial Stat.	0%	0%	0%	[5] ***17%***	[6] ***33%***	[7] ***88%***	[8] ***33%***	[9] ***17%***	3%	0%
			St. Deviation	0.00	0.00	4.24	***4.24***	***2.12***	***0.11***	***0.04***	***0.46***	0.003	0.000

[5] Duplicate sample appears to have a larger amount of suspended solids that increase many nitrogen parameters.
[6] Duplicate sample appears to have a larger amount of suspended solids that increase many nitrogen parameters.
[7] Higher nitrogen concentration due to increased suspended solids.
[8] Higher nitrogen concentration due to increased suspended solids.
[9] Higher nitrogen concentration due to increased suspended solids.

Date	Time	Site	Sample Depth	Fecal Coliform	Total Alkalinity	Total Solids	Total Susp. Solids	Total Volatile Susp. Solids	Ammonia	Nitrate-Nitrite	TKN	Total Phosphorus	Total Diss. Phosphorus
07/21/1999	11:30	LOL#1	BOTTOM	5	246	1315	20	9	0.17	0.05	2.36	0.088	0.023
07/21/1999	11:30	LOL#3	BOTTOM	5	242	1406	21	9	0.13	0.05	2.1	0.085	0.022
			Industrial Stat.	0%	1%	3%	2%	0%	13%	0%	6%	2%	2%
			St. Deviation	0.00	2.83	64.35	0.71	0.00	0.03	0.00	0.18	0.002	0.001
08/23/1999	13:00	LOL#1	BOTTOM	5	242	1384	24	16	0.01	0.05	2.1	0.067	0.014
08/23/1999	13:00	LOL#3	BOTTOM	5	243	1396	22	14	0.01	0.05	2.24	0.07	0.015
			Industrial Stat.	0%	0%	0%	4%	7%	0%	0%	3%	2%	3%
			St. Deviation	0.00	0.71	8.49	1.41	1.41	0.00	0.00	0.10	0.002	0.001

Date	Time	Site	Sample Depth	Fecal Coliform	Total Alkalinity	Total Solids	Total Susp. Solids	Total Volatile Susp. Solids	Ammonia	Nitrate-Nitrite	TKN	Total Phosphorus	Total Diss. Phosphorus
09/22/1999	12:00	LOL#1	BOTTOM	5	256	1374	17	10	0.01	0.05	1.84	0.08	0.025
09/22/1999	12:00	LOL#3	BOTTOM	5	258	1379	24	13	0.01	0.05	2.26	0.078	0.023
			Industrial Stat.	0%	0%	0%	[10] ***17%***	13%	0%	0%	10%	1%	4%
			St. Deviation	0.00	1.41	3.54	***4.95***	2.12	0.00	0.00	0.30	0.001	0.001

One sample appears to have picked up a larger suspended solids concentration, most likely a natural variation.

[11] [12]

Date	Time	Site	Sample Depth	Fecal Coliform	Total Alkalinity	Total Solids	Total Susp. Solids	Total Volatile Susp. Solids	Ammonia	Nitrate-Nitrite	TKN	Total Phosphorus	Total Diss. Phosphorus
10/20/1999	11:30	LOL#1	BOTTOM	5	269	1379	18	15	0.01	0.05	2.59	0.09	0.017
10/20/1999	11:30	LOL#3	BOTTOM	5	270	1384	14	13	0.01	0.05	2.67	0.09	0.02
			Industrial Stat.	0%	0%	0%	13%	7%	0%	0%	2%	0%	8%
			St. Deviation	0.00	0.71	3.54	2.83	1.41	0.00	0.00	0.06	0.000	0.002
11/22/1999	11:30	LOL#1	BOTTOM	5	279	1413	9	4	0.08	0.1	2.09	0.061	0.017
11/22/1999	11:30	LOL#3	BOTTOM	5	280	1414	10	7	0.09	0.05	2.08	0.063	0.019
			Industrial Stat.	0%	0%	0%	5%	[11] ***27%***	6%	[12] ***33%***	0%	2%	6%
			St. Deviation	0.00	0.71	0.71	0.71	***2.12***	0.01	***0.04***	0.01	0.001	0.001

The difference in volatile suspended solids was most likely a natural variation.

The duplicate sample was under detection limit and recorded as 0.05 mg/L. The original was just at the detection limit.

FIELD BLANKS

Date	Time	Site	Sample Depth	Fecal Coliform	Total Alkalinity	Total Solids	Total Susp. Solids	Total Volatile Susp. Solids	Ammonia	Nitrate-Nitrite	TKN	Total Phosphorus	Total Diss. Phosphorus
04/20/1999	13:00	LOL#4	BOTTOM	5	3	[13] **9**	[14] **1**	0.5	0.01	0.05	0.05	0.001	0.001
05/18/1999	12:00	LOL#4	BOTTOM	5	3.5	[13] **9**	0.5	0.5	0.01	0.05	0.05	0.001	[18] **0.006**
06/16/1999	10:30	LOL#4	BOTTOM	5	3.5	[13] **5**	[14] **1**	0.5	0.01	0.05	0.07	[17] **0.003**	0.001
07/21/1999	11:30	LOL#4	BOTTOM	5	3.5	[13] **27**	0.5	0.5	0.01	0.05	0.05	[17] **0.013**	[18] **0.007**
08/23/1999	13:00	LOL#4	BOTTOM	5	3.5	2	[14] **2**	0.5	0.01	0.05	[16] **0.19**	0.001	0.001
09/22/1999	12:00	LOL#4	BOTTOM	5	3.5	2.5	0.5	0.5	0.01	0.05	0.07	0.001	0.001
10/20/1999	11:30	LOL#4	BOTTOM	5	3.5	2.5	0.5	0.5	0.01	[15] **0.1**	0.07	0.001	0.001
11/22/1999	11:30	LOL#4	BOTTOM	5	3.5	[13] **6**	0.5	0.5	0.01	[15] **0.1**	0.07	0.001	0.001
			Mean	**5.00**	**3.44**	**7.88**	**0.81**	**0.50**	**0.01**	**0.06**	**0.08**	**0.003**	**0.002**
			Standard Deviation	**0.00**	**0.18**	**8.21**	**0.53**	**0.00**	**0.00**	**0.02**	**0.05**	**0.004**	**0.003**

Slightly contaminated distilled water or, from not properly rinsing the bottle.

[13] Slightly contaminated distilled water or, from not properly rinsing the bottle.

[14] Samples just at the detection limit. Most likely from improper rinsing.

[15] Sample 0.05 mg/L greater than the detection limit.

[16] Improperly rinsed bottles.

[17] Improperly rinsed filter.

[18]

Appendix F
AGNPS Report

REPORT ON THE
AGRICULTURAL NONPOINT SOURCE (AGNPS) ANALYSIS OF THE LAKE COCHRANE/OLIVER WATERSHED DEUEL COUNTY, SOUTH DAKOTA

SOUTH DAKOTA WATER RESOURCES ASSISTANCE PROGRAM
DIVISION OF FINANCIAL & TECHNICAL ASSISTANCE
SOUTH DAKOTA DEPARTMENT OF
ENVIRONMENT AND NATURAL RESOURCES

FEBRUARY 2000

OVERVIEW OF AGNPS DATA INPUTS

OVERVIEW

Agricultural Nonpoint Source Pollution Model (AGNPS) is a computer simulation model developed to analyze the water quality of run-off from watersheds. The model predicts run-off volume and peak rate, eroded and delivered sediment, nitrogen, phosphorus, and chemical oxygen demand concentrations in the run-off and the sediment for a single storm event for all points in the watershed. Proceeding from the headwaters to the outlet, the pollutants are routed in a step-wise fashion so the flow at any point may be examined. AGNPS is to be used to objectively evaluate the water quality of the run-off from agricultural watersheds and to present a means of objectively comparing different watersheds throughout the state. The model is intended for watersheds up to about 320,000 acres (8000 cells @ 40 acres/cell).

The model works on a cell basis. These cells are uniform square areas that divide the watershed. This division makes it possible to analyze any area, down to 1.0 acres, in the watershed. The basic components of the model are hydrology, erosion, sediment transport, nitrogen (N), phosphorus (P), and chemical oxygen demand (COD) transport. In the hydrology portion of the model, calculations were made for run-off volume and peak concentration flow. Total upland erosion, total channel erosion, and a breakdown of these two sources into five particle size classes (clay, silt, small aggregates, large aggregates, and sand) for each of the cells are calculated in the erosion portion. Sediment transport is also calculated for each of the cells in the five particle classes as well as the total. The pollutant transport portion is subdivided into one part handling soluble pollutants and another part handling sediment attached pollutants.

PRELIMINARY EXAMINATION

A preliminary investigation of the watershed is necessary before the input file can be established. The steps to this preliminary examination are:

1) Detailed topographic map of the watershed (USGS map 1:24,000)
2) Establish the drainage boundaries.
3) Divide watershed up into cells (10 acre). Only those cells with greater than 50% of their area within the watershed boundary should be included.
4) Number the cells consecutively from one to the number of cells (begin at NW corner of watershed and precede west to east then north to south.
5) Establish the watershed drainage pattern from the cells.

DATA FILE

Once the preliminary examination is completed, the input data file can be established. The data file is composed of the following 21 inputs per cell :

<u>Data input for watershed</u>

1) a) Area of each cell (acres)
b) Total number of cells in watershed
c) Precipitation for a ___ year, 24 hour rainfall
d) Energy intensity value for storm event previously selected

Data input for each cell

1) **Cell number**
2) **Receiving cell number**
3) **SCS number**: run-off curve number (use antecedent moisture condition II)
4) **Land slope** (topographic maps) average slope if irregular, water or marsh = 0
5) **Slope shape factor** water or marsh = 1 (uniform)
6) **Field slope length** water or marsh = 0, for S.D. assume slope length area 1
7) **Channel slope** (average), topo maps, if no definable channel, channel slope = 1/2 land slope, water or marsh = 0
8) **Channel sideslope**, the average sideslope (%), assume 10% if unknown, water or marsh=0
9) **Manning roughness coefficient for the channel** If no channel exists within the cell, select a roughness coefficient appropriate for the predominant surface condition within the cell
10) **Soil erodibility factor** water or marsh = 0
11) **Cropping factor** assume conditions at storm or worst case condition (fallow or seedbed periods), water or marsh = .00, urban or residential = .01
12) **Practice factor** worst case = 1.0, water or marsh = 0 ,urban or residential = 1.0
13) **Surface condition constant** a value based on land use at the time of the storm to make adjustments for the time it takes overland run-off to channelize.
14) **Aspect** a single digit indicating the principal direction of drainage from the cell (if no drainage = 0)
15) **Soil texture**, major soil texture and number to indicate each are:

Texture	Input Parameter
Water	0
Sand	1
Silt	2
Clay	3
Peat	4

16) **Fertilization level**, indication of the level of fertilization on the field.

	Assume Fertilization (lb./acre)		
Level	N	P	Input

No fertilization	0	0	0
Low Fertilization	50	20	1
Average Fertilization	100	40	2
High Fertilization	200	80	3

avg. manure - low fertilization
high manure - avg. fertilization
water or marsh = 0
urban or residential = 0 (for average practices)

17) **Availability factor**, the percent of fertilizer left in the top half inch of soil at the time of the
storm. Worst case 100%, water or marsh = 0, urban or residential = 100%.
18) **Point source indicator**: indicator of feedlot within the cell (0 = no feedlot, 1 = feedlot).
19) **Gully source level**: tons of gully erosion occurring in the cell or input from a sub-watershed.
20) **Chemical oxygen demand (COD) demand**, a value of COD for the land use in the cell.
21) **Impoundment factor**: number of impoundments in the cell (max. 13)
a) Area of drainage into the impoundment
b) Outlet pipe (inches)
22) **Channel indicator**: number which designates the type of channel found in the cell

DATA OUTPUT AT THE OUTLET OF EACH CELL

Hydrology
Run-off volume
Peak run-off rate
Fraction of run-off generated within the cell

Sediment Output
Sediment yield
Sediment concentration
Sediment particle size distribution
Upland erosion
Amount of deposition
Sediment generated within the cell
Enrichment ratios by particle size
Delivery ratios by particle size

Chemical Output
Nitrogen
Sediment associated mass
Concentration of soluble material
Mass of soluble material

Phosphorus
Sediment associated mass
Concentration of soluble material
Mass of soluble material

Chemical Oxygen Demand
Concentration
Mass

PARAMETER SENSITIVITY ANALYSIS
The most sensitive parameters affecting sediment and chemical yields are:
Land slope (LS)
Soil erodibility (K)
Cover-management factor (C)
Curve number (CN)
Practice factor (P)

LAKE COCHRANE/OLIVER WATERSHED AGNPS ANALYSIS

In order to further understand the Nonpoint Source (NPS) loadings in the Lake Cochrane/Lake Oliver watershed as well as aid in predicting the impacts of Best Management Practices (BMPs) in the watershed, the AGNPS version 3.65 computer model was selected in order to asses the NPS loadings throughout the drainage. This model was developed by the USDA – Agricultural Research Service to analyze the water quality of run-off events in the watershed. The model predicts run-off volume and peak rate, eroded and delivered sediment, nitrogen, phosphorus, and chemical oxygen demand (COD) concentrations in the run-off and sediment, The model was designed to run utilizing a single storm event of equal magnitude for all acreage in the watershed. The model then analyzes the run-off data from the headwaters of the watershed to the outlet. The pollutants are routed in a step-wise fashion so the flow at any point may be examined. The AGNPS model was to be used to objectively compare different subwatersheds and individual cells within a watershed to other watersheds within a drainage basin.

The Lake Cochrane/Oliver watershed is located in eastern Deuel County close to the South Dakota- Minnesota border. The watershed exists in an area that has been glaciated, resulting in rolling hill topography with many small pocketed marshes and wetlands. AGNPS defines the watershed as having approximately 2,000 acres. Of this total acreage, 520 acres was lake surface area and 1,480 acres was balanced with grasslands, pasture and crop ground. The drainage area for Lake Oliver was approximately 640 acres and the drainage area for Lake Cochrane was approximately 840 acres. All of the crop ground (240 acres) in the combined watershed were located in the Lake Cochrane drainage.

Initially, the watershed was divided into cells each of which had an area of 10 acres with the dimensions of 660 feet by 660 feet. The dominant fluid flow direction within each cell was then determined. Based on the fluid flow directions and drainage patterns, five subwatersheds were delineated. Along with the dominant fluid flow direction, 21 watershed parameters were collected and entered into the model for each cell. The model then calculated the nonpoint source pollution loadings for each cell, subwatershed, and animal feeding area and estimated hydrology run-off volume for each of the storm events modeled.

The storm events chosen for the model are indicative of the regions average annual rainfall. By using storm event intensities comparable to those commonly experienced in the studied watershed, the AGNPS model can more accurately represent nutrient and sediment loadings resulting from a single storm event of variable intensity or a composite of an average years' rainfall events. Both the subwatershed and the critical single cell analysis were performed using an annualized (average year) sum of individual events. The feeding area analysis was performed using a single rainfall event of 25-year intensity. This storm event results in higher run-off volumes than the annualized event and will produce a wider range in the AGNPS animal feeding area ranking which makes it more conducive to selecting critical feedlots. The rainfall and energy intensity values associated with the annualized as well as the 25-year events can be found in **Table 1**.

Table 1. Rainfall Information Used for the AGNPS model.

Rainfall Specs For The Lake Cochrane/Oliver Watershed Assessment		
Event Intensity	Rainfall	Energy
Monthly	0.9 inches	3.8
Six Month	1.6 inches	13.4
One Year	2.1 inches	24.3
Twenty Five Year	4.5 inches	127.9
NRCS R-factor for the Enemy Swim Lake watershed = 105		
Annual Loading Calculation		
monthly events	1 events x 3.8 = 41.8	
six month events	3 events x 13.4 = 40.2	
one year event	1 event x 24.3 = 24.3	
	TOTAL = 106.3	

The primary objectives of running the AGNPS model on the Lake Cochrane/Oliver watershed were to:

1. Evaluate and quantify NPS loadings from each subwatershed.
2. Define critical NPS cells within each subwatershed (elevated sediment, nitrogen, phosphorus).
3. Priority ranking of each animal feeding area and quantify the nutrient loadings from each area.

OBJECTIVE 1 – EVALUATE SUBWATERSHED LOADINGS

The first step in the analysis of a watershed using the AGNPS model is to delineate the watershed drainage of the water body in focus. Using a 7.5-minute quad map of the region, the watershed is delineated and then broken into 10 acre cells. Each of these 10 acre cells is assigned a run-off flow direction where it drains into an adjacent cell. The flow was routed step-wise until it ultimately drained into a primary waterbody. By examining these flow paths, small pockets of cells display run-off patterns that will sometimes converge at a central point. These pockets of cells within a watershed are called “subwatersheds”.

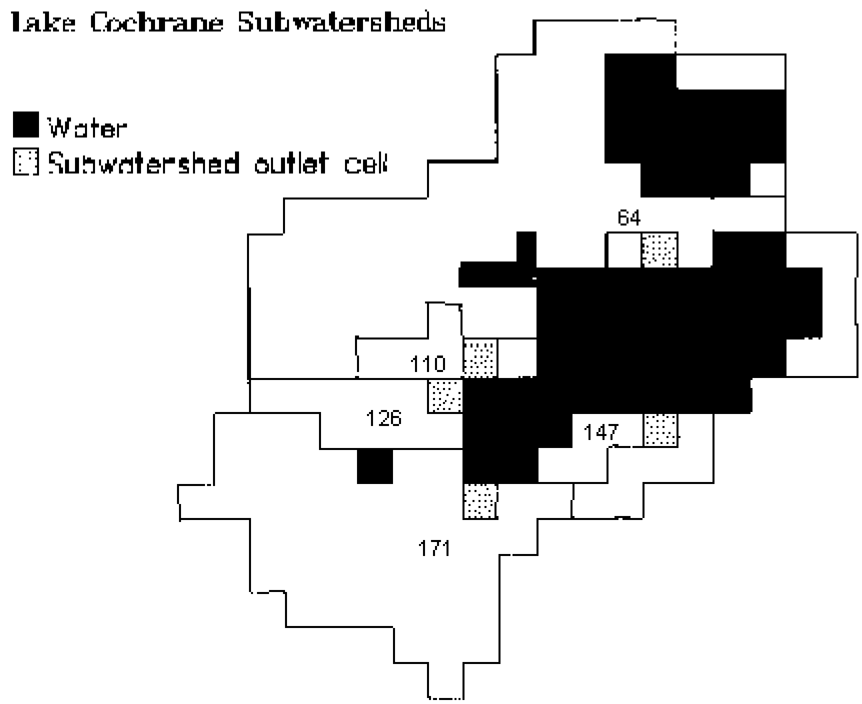


Figure 1. Subwatershed Locations

The Lake Cochrane watershed contains just five subwatersheds as delineated by the AGNPS model. These subwatersheds vary in drainage areas from 800 acres to just 50 acres (Table 2).

Table 2. Subwatershed Size and Outlet cell.

SUBWATERSHED NUMERATION

OUTLET CELL #	DRAINAGE AREA (ACRES)
64	800
110	50
126	100
147	70
171	460

Once the subwatersheds have been established, one may then examine both the sediment and nutrient loadings from the subwatersheds on a broader scale than if done on a cell by cell basis. Some factors pertaining to a subwatershed's relevance to waterbody loadings are: the proximity to the waterbody, volume of run-off draining from the subwatershed, and velocity of run-off from the subwatershed. Both the subwatershed and the critical individual cell analysis concentrated on loadings of sediment, nitrogen and phosphorus.

Subwatershed Sediment Analysis

The AGNPS model calculated that Lake Cochrane receives approximately 208 tons of sediment annually. This estimate is very low when compared to other regional lakes. Clear Lake, for example, receives over 3,000 tons of sediment from run-off during an average year. Three factors contributing to the very low sediment delivery rate to Lake Cochrane are: the relatively small size of the watershed (2,000 acres), the presence of two sediment trap basins located on the west shore of the lake, and the high ratio of grassland to crop ground in the watershed. One important note on the annual sediment load as modeled by AGNPS was that even though the rate was low, it would be much lower if the model had the capability to calculate the full effectiveness of designed sediment traps that were present on the west shore (Cell #s 110, 126, and 171). The model also had limitations when interpreting the engineered structure placed at the outlet of Lake Oliver (Cell #64).

Table 3. Subwatershed Sediment Loads

Lake Cochrane Inlet Cell #	Water Quality Monitoring Site	Drainage Area (acres)	Annual Sed. Yield (lbs/acre)	Annual Sed. Yield (tons)	% of Total Sed. Yield	% of Watershed Area
64	LOO	800	12.43	4.97	2	40
110	LCT-1	50	162.4	4.06	2	3
126	LCT-2	100	1612.8	80.64	39	5
147	LCT-4	70	69.1	2.42	1	4
171	LCT-3	460	505.2	116.19	56	23
TOTAL			**2361.9**	**208.28**	**100**	**74**
Outlet	LCO	2,000	32.89	32.89		

The AGNPS sediment data above indicated that subwatersheds #126 and #171 were delivering the highest amounts of sediment to Lake Cochrane. Subwatershed #126 delivered 81 tons annually, which was 39% of the total delivered sediment load. Subwatershed #171 was roughly four times larger than #126; therefore it delivered more sediment. Subwatershed #171 delivered over 116 tons of sediment to Lake Cochrane on an annual basis. The AGNPS data indicated that even though subwatershed #171 was four times larger than subwatershed #126, it delivered only 30% more sediment. This was probably due to the disparity in crop ground acreage contained in each subwatershed. Subwatershed #126 had approximately 80 acres of crop ground while subwatershed #171 contained 40 to 50 acres of tilled crop ground.

Subwatersheds #64 (Oliver outlet). #110, and #147 showed very little sediment delivery. Subwatershed #64 has the largest drainage area of all of the Lake Cochrane subwatersheds, but has the benefit of Lake Oliver as a sediment trap. The model suggests that Lake Oliver receives approximately 11 tons of sediment annually.

The impact of sediment erosion derived from gully erosion, riparian areas, shoreline erosion, wind and their deliverability to the watershed was not modeled.

Subwatershed Nitrogen Analysis

The AGNPS model estimated that the Lake Cochrane watershed has a total nitrogen deliverability rate of 15 lbs/acre/year. The annual load delivered to Lake Cochrane was calculated to be 1.7 tons of total nitrogen (soluble and sediment bound). For comparison, the Clear Lake watershed consists of 27,360 acres and according to the AGNPS model, receives almost 76 tons of total nitrogen annually (Table 4).

Table 4. Subwatershed Nitrogen Loads

Lake Cochrane Inlet Cell #	Water Quality Monitoring Site	Drainage Area (acres)	Annual Total Nitrogen (lbs/acre)	Annual Total Nitrogen (tons)	% of Total Nitrogen	% of Watershed Area
64	LOO	800	1.47	1,176.0	35	40
110	LCT-1	50	1.57	78.5	2	3
126	LCT-2	100	7.43	743.0	22	5
147	LCT-4	70	1.76	123.2	4	4
171	LCT-3	460	2.7	1,242.0	37	23
TOTAL			**14.93**	**3,362.7**	**100**	**74**
Outlet	LCO	2,000	1.87	3,740.0		

When comparing the % total nitrogen yield in the above table to the % of watershed area, the subwatershed #126 delivers 22% of the total nitrogen load and occupies only 5% of the watershed. This can be explained by the presence of an animal feeding area in the subwatershed as well as 80 acres of crop ground. The crop ground contained in this subwatershed has a low to medium fertilizer application rate but has a fertilizer availability rate of 50%. Meaning 50% of the applied fertilizer was left in the top ½ inch of soil and was available to run-off. The animal feeding are may not have a direct impact but care should be taken on the application of the manure on the cropland in the subwatershed. Ordinarily, a 50% fertilizer availability rate is not inordinate but given the close proximity to the lake, there was little chance for nitrogen reduction before delivery to the lake.

Subwatershed Phosphorus Analysis

The AGNPS model estimated that the Lake Cochrane watershed received a total phosphorus (soluble and sediment bound) loading rate of 4.5 lbs/acre/year cumulatively from the subwatersheds (Table 5). This rate translates to approximately 0.4 tons/year. Clear Lake, by comparison, receives 1.18 lbs/acre/year or 16 tons of total phosphorus from its subwatersheds.

Using an analysis method similar to the nitrogen study, the impact of each subwatershed phosphorus load Lake Cochrane can be compared by relating the percent of watershed area to percent of total phosphorus load. Subwatersheds # 126 and #171 had markedly higher levels of total phosphorus for their relative drainage areas. Subwatershed #126, as stated previously, consisted of mostly fertilized crop ground. This lead to a higher level of total phosphorus in the run-off emitted from the subwatershed. Subwatershed #171 had only a small number of acres of crop ground (30-40 acres) but these acres had a high percentage of available fertilizer. Roughly thirty acres in this subwatershed had fertilizer availability of 70%. There was also an abundance of grass and hay ground included in this subwatershed.

Table 5. Subwatershed Phosphorus Loads

Lake Cochrane Inlet Cell #	Water Quality Monitoring Site	Drainage Area (acres)	Annual Total Nitrogen (lbs/acre)	Annual Total Nitrogen (tons)	% of Total Nitrogen	% of Watershed Area
64	LOO	800	0.06	48.0	6	40
110	LCT-1	50	0.42	21.0	3	3
126	LCT-2	100	2.58	258.0	31	5
147	LCT-4	70	0.41	28.7	3	4
171	LCT-3	460	1.03	473.8	57	23
TOTAL			**4.5**	**829.5**	**100**	**74**
Outlet	LCO	2,000	0.24	480.0		

OBJECTIVE 2 – EVALUATE CRITICAL CELL LOADINGS

Once the initial study and selection of critical subwatersheds were complete, the next step was to examine individual cells within these subwatersheds in an effort to narrow down critical areas. One important consideration for evaluating critical ten acre cells is its proximity to the waterbody draining the entire watershed. A cell may have a particularly high loading but it may also lie at the head of the watershed. The amount of the sediment or nutrient may decrease dramatically as it is routed through the watershed. Therefore, many of the critical cells listed below are noted not necessarily for their loading, but for the loading delivered to the lake.

As with the subwatershed analysis, the study of critical cells will be broken into three aspects: sediment analysis, nitrogen analysis, and phosphorus analysis. The loadings from the critical cells are the result of running the model using an annualized (average year) string of storm events.

Critical Cell Sediment Analysis

An analysis of the Lake Cochrane watershed indicated that there were 15 out of 200 cells having erosion rates greater than the critical level of 9 ton/acre. All 15 cells designated as delivering critical levels of sediment were currently in use as crop ground. In general, the high sediment levels were not the result of farming alone, but can be attributed to the average land slopes of the critical cells. The average slope of the critical sediment cells was 10%. This figure is fairly high for tilled ground. The fifteen cells, along with their annual sediment loadings are listed below.

Table 6. Critical Sediment Cells.

Cell #	Annual Sediment (tons)
125	232.09
190	191.85
196	189.37
71	167.59
155	139.3
141	134.6
123	107.11
124	107.11
107	106.55
154	79.46
140	71.62
138	70.72
172	68.24
89	61.8
160	53.14

Referring back to the subwatershed analysis, eleven of the critical sediment cells were within subwatershed #s 126 and #171. One must keep in mind that subwatershed #126 had a sediment trap constructed to stop large amounts of sediment from entering the lake. Subwatershed #171 also had a one acre wetland with a drop pipe outlet structure that acted as a simple sediment trap. Because the AGNPS model did not precisely represent reductions in sediment due to constructed sediment traps, the actual water quality data also must be analyzed to determine the effectiveness of these structures. The sediment loadings from critical areas may not impact the lake as much as the AGNPS model predicted.

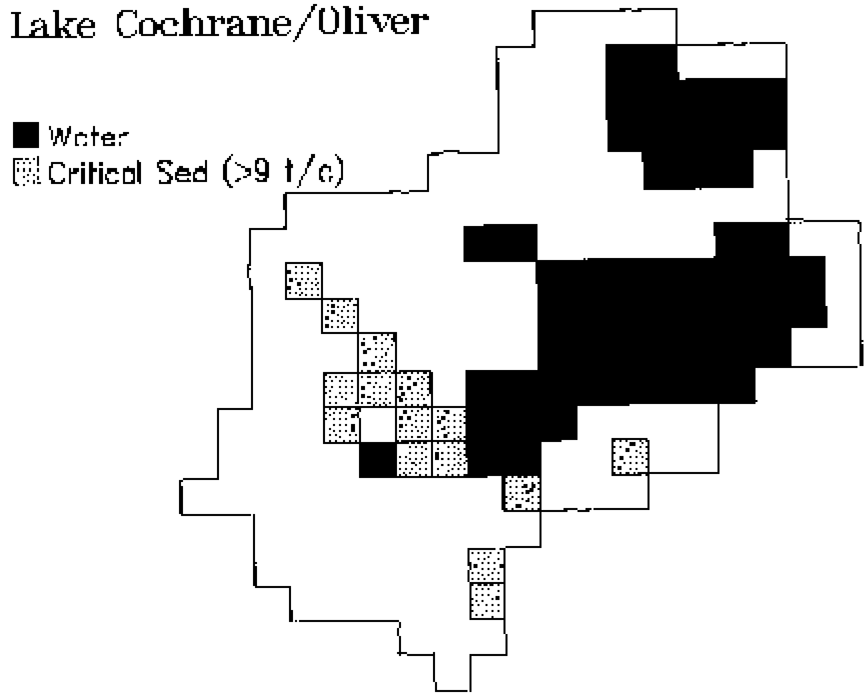


Figure 2. Critical Sediment Cells

Critical Cell Nitrogen Analysis

The AGNPS model indicated that the Lake Cochrane watershed contained eleven cells having an annual total nitrogen load greater than the critical level 10 lbs/acre. The critical nitrogen cells are listed below along with the corresponding annual load (Table 7). With the exception of cell #122, the cells are all cropped land.

Table 7. Critical Nitrogen Cells.

Cell #	Priority Nitrogen (lbs/acre)
190	30.97
196	30.7
107	21.8
155	18.88
141	15.83
138	14.1
160	13.22
122	12.34
140	11.71
125	10.95
12	10.87

Upon examination of the nitrogen data, a commonality among the cells having the largest annual total nitrogen loads was the percentage of fertilizer availability accompanied by steep land slopes. The average fertilizer availability percent was 70% and the average landslope among the critical cells was 10%. The locations of critical nitrogen cells within the Lake Cochrane watershed are shown in Figure 3.

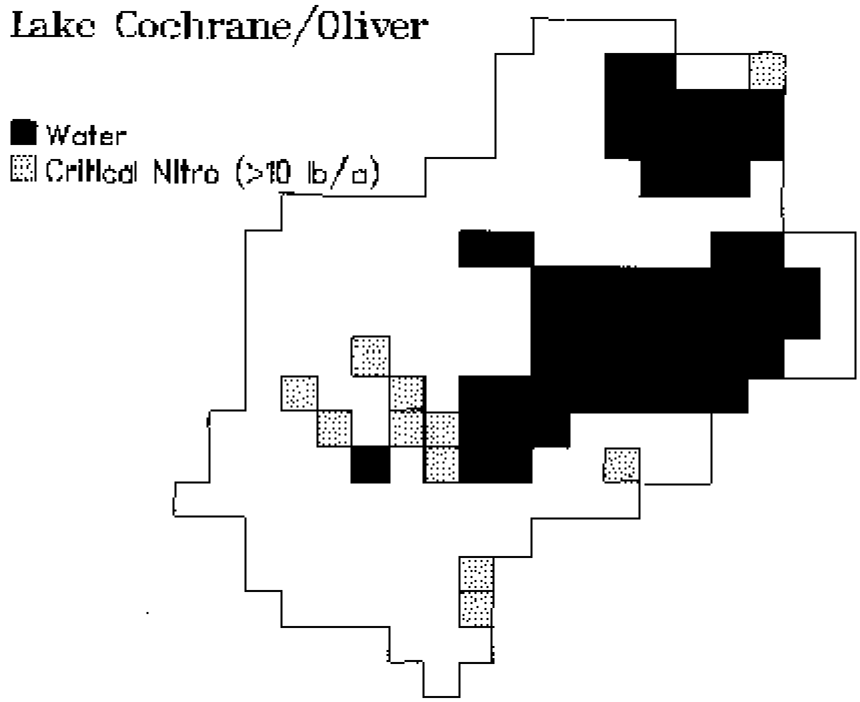


Figure 3. Location of Critical Nitrogen Cells.

Critical Cell Phosphorus Analysis

According to the model, Lake Cochrane received a low total phosphorus delivery rate from the watershed. The data indicated there were only eight cells exceeding the minimum critical loading of 5 lbs./acre. These eight cells are included in the critical nitrogen listing as well as the critical sediment designation (Table 8).

Table 8. Critical Phosphorus Cells

Cell #	Priority Phosphorus (lbs/acre)
190	14.21
196	14.01
107	9.85
155	8.89
141	7.43
138	6.73
140	5.49
160	5.32

As with the critical nitrogen analysis, the primary usage of the land contained in these eight critical cells is crop land. This cropland is situated in an area of 10% land slope and has an average fertilizer availability of 65%.

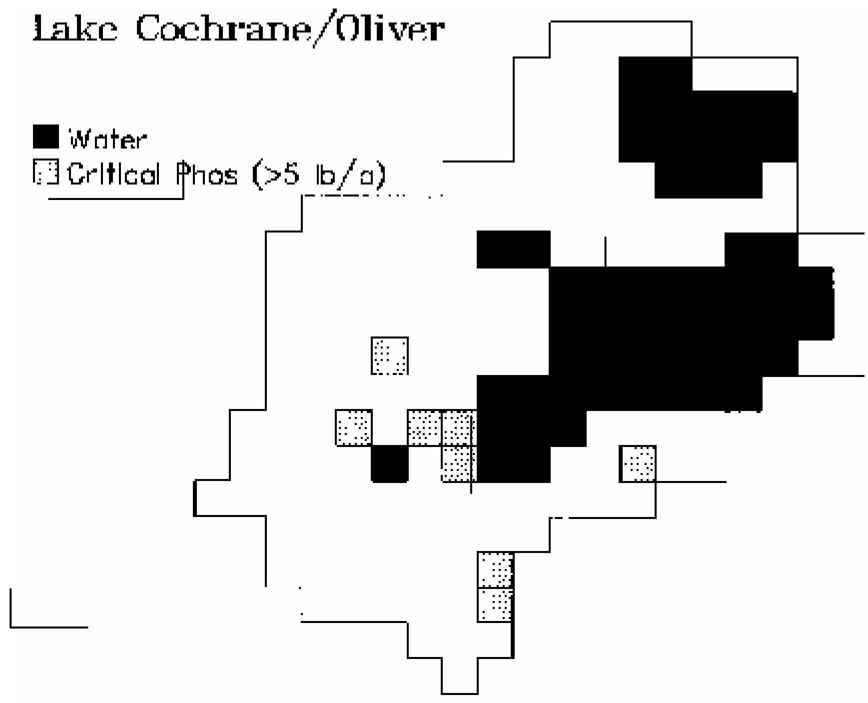


Figure 4. Location of Critical Phosphorus cells.

There were 17 critical cells in the Lake Cochrane subwatershed. Most of which were targeted because they exceeded the limit for critical sediment loads. Having stated that the above cells are the result of farming practices on high landslope areas, the AGNPS model was run with the data input changed to reflect a more environmentally friendly condition. Cell input data was changed to reflect two different scenarios.

The first scenario was that all of the critical cells would be changed to a minimum till farming practice. The model was rerun to reflect the change in the loadings at the inlets to the lake. Table 9 shows the reduction of sediment nitrogen and phosphorus based on the changed residue management practice.

Table 9. Predicted Sediment Reductions with Various Management Techniques.

Lake Cochrane Inlet Cell #	Water Quality Monitoring Site	Current Annual Sed. Yield (tons)	Percent Reduction of Sediment with No-till %	Percent Reduction of Sediment with CRP %
64	LOO	4.97		
110	LCT-1	4.06	6.2%	6.9%

126	LCT-2	80.64	39.6%	87.9%
147	LCT-4	2.42	10.3%	11.6%
171	LCT-3	116.19	39.7%	60.5%
TOTAL		208.28	40.1%	70.5%

Using a combination of the no till conservation practices and CRP plantings, approximately 60% of the sediment load could be removed from the lake. Land managers should work on the critical area cells to get the best sediment reductions per unit effort. The annual sediment load could potentially decreased from 208 tons/year to 83 tons/year.

In order to understand the impact nitrogen critical cells may have on the lake, the model was run using the same set of data modifications used in the sediment reduction analysis. The two scenarios were run on the same number of acres in no-till and CRP (Table 10). The AGNPS model predicted from 55% - 65% reduction in total nitrogen loads using the suggested best management practices.

Table 10. Predicted Nitrogen Reductions with Various Management Techniques.

Lake Cochrane Inlet Cell #	Water Quality Monitoring Site	Current Annual Nitrogen. Yield (lbs.)	Percent Reduction of Nitrogen with No-till %	Percent Reduction of Sediment with CRP %
64	LOO	1,176.00		
110	LCT-1	78.5	1.9%	32.5%
126	LCT-2	743	18.3%	54.0%
147	LCT-4	123.2	0.0%	27.8%
171	LCT-3	1,242.00	43.0%	43.0%
TOTAL		**3,362.70**	**54.9%**	**64.5%**

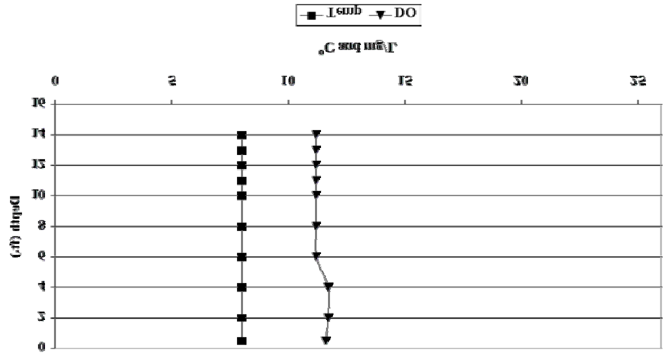
In a manner similar to the critical nitrogen cell analysis, the critical phosphorus cells (Table 11) were modified to represent the same changes as the other two previous parameters. The result of this BMP on the phosphorus load into Lake Cochrane was a 43% reduction in total phosphorus. The total phosphorus load to Lake Cochrane dropped from 830 pounds of phosphorus entering the lake annually to 565 – 370 lbs. pounds annually.

Table 11. Predicted Nitrogen Reductions with Various Management Techniques.

Lake Cochrane Inlet Cell #	Water Quality Monitoring Site	Current Annual Phosphorus (lbs.)	Percent Reduction of Phosphorus with No-till %	Percent Reduction of Phosphorus with CRP %
64	LOO	48.0		
110	LCT-1	21.0	4.8%	28.6%
126	LCT-2	258.0	26.4%	69.0%
147	LCT-4	28.7	0.0%	39.0%
171	LCT-3	473.80	31.1%	45.6%
TOTAL		**829.50**	**31.9%**	**55.4%**

Appendix G

Temperature and Dissolved Oxygen Profiles



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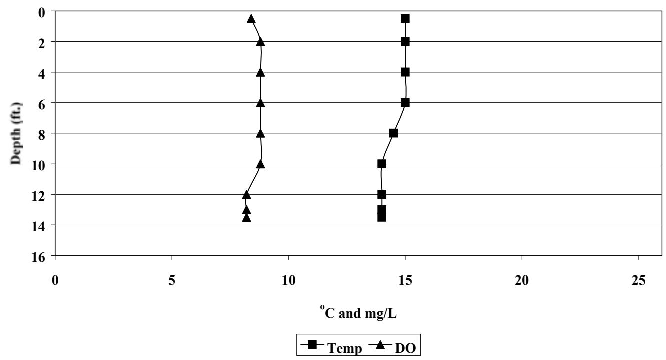
4/20/99 LCL-1

Lake Cochrane
Dissolved Oxygen/Temperature Profile
5/18/99 LCL-1



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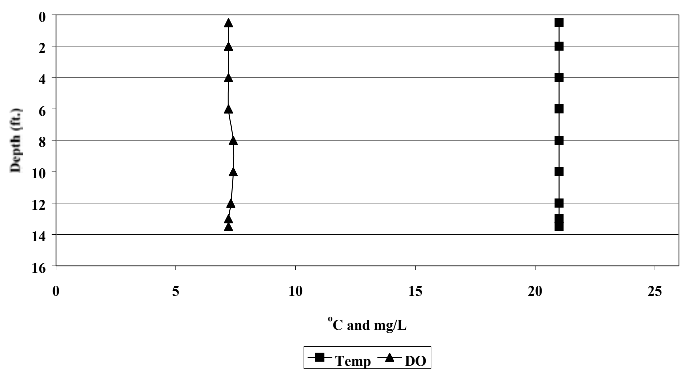

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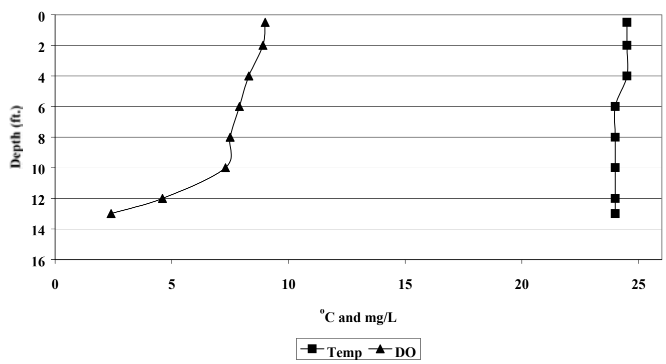

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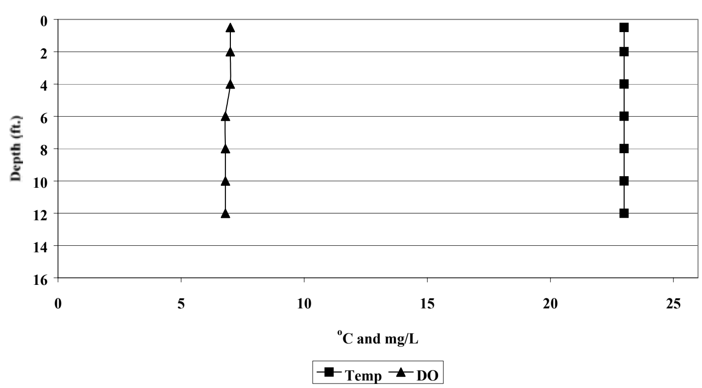

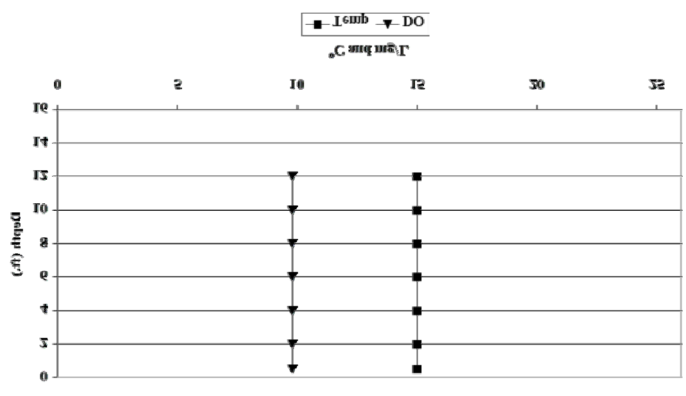

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9/22/99 LCL-1

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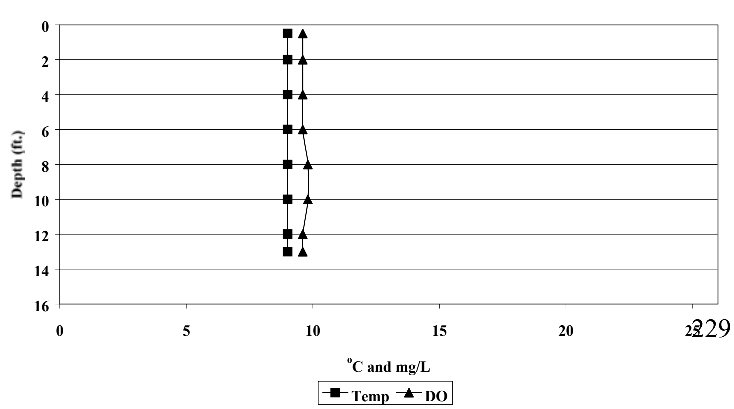

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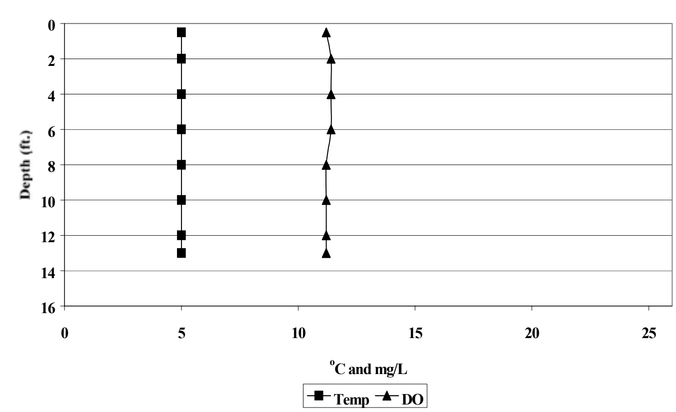

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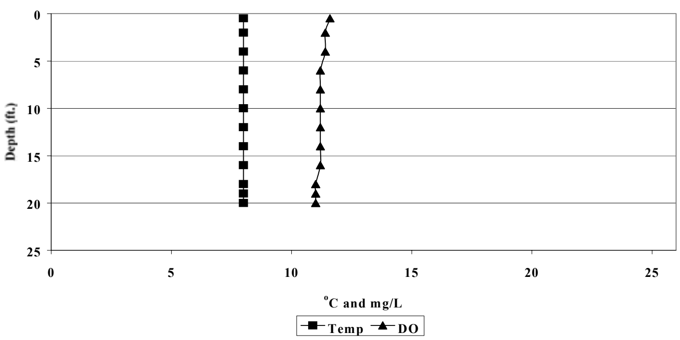

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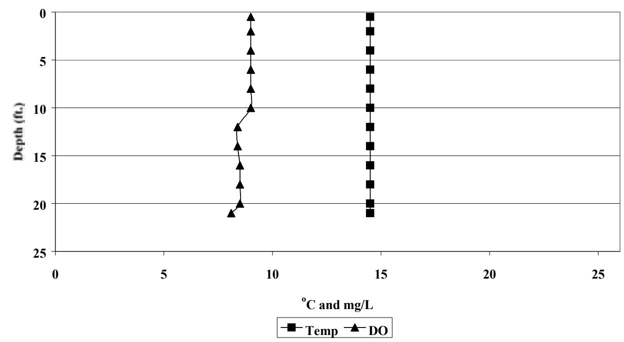

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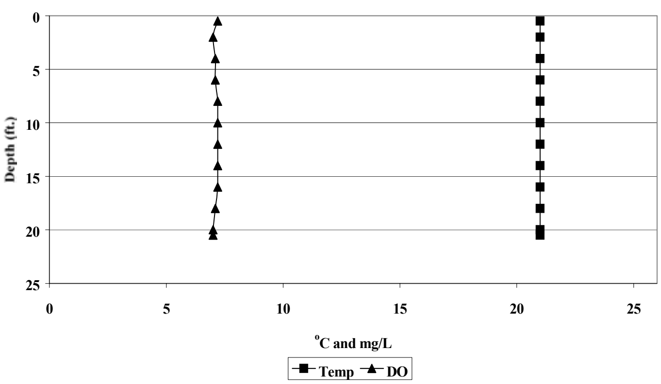

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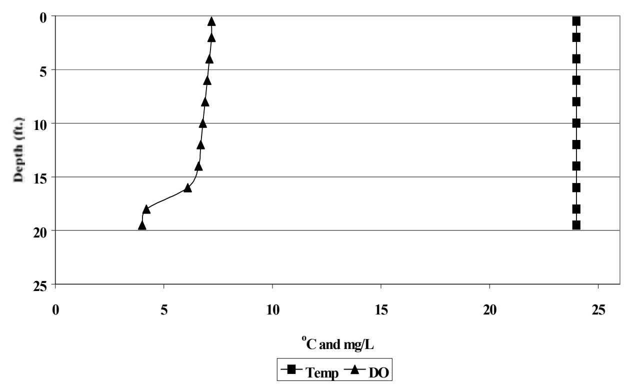

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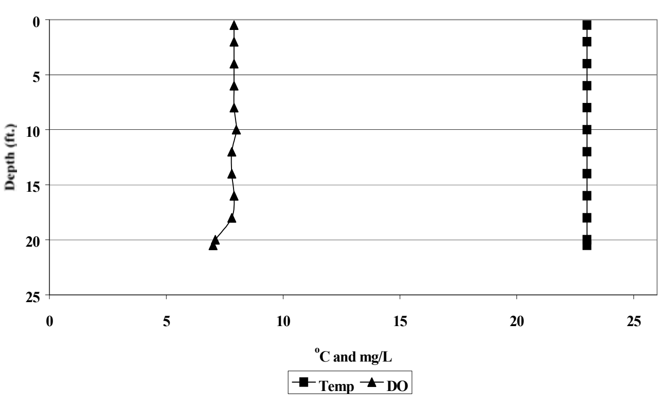

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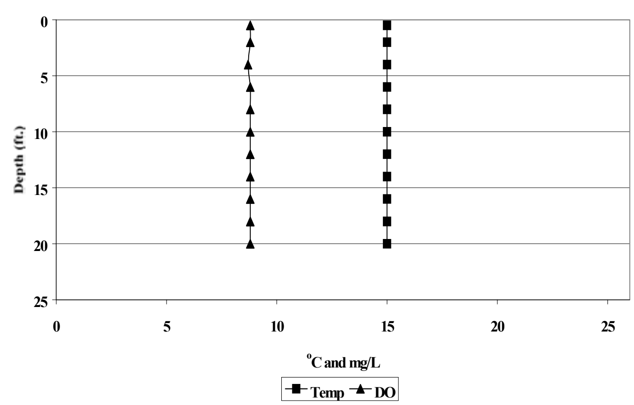

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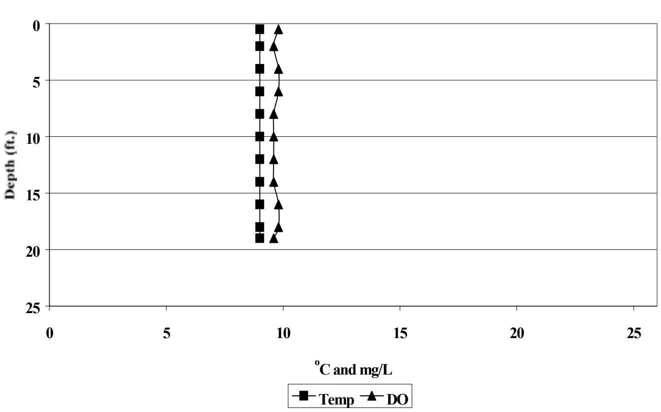

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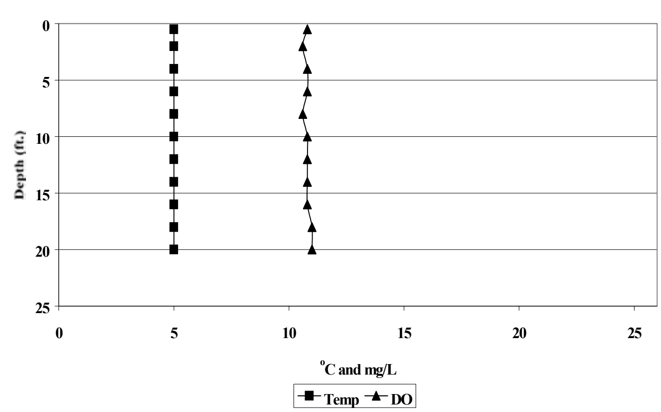

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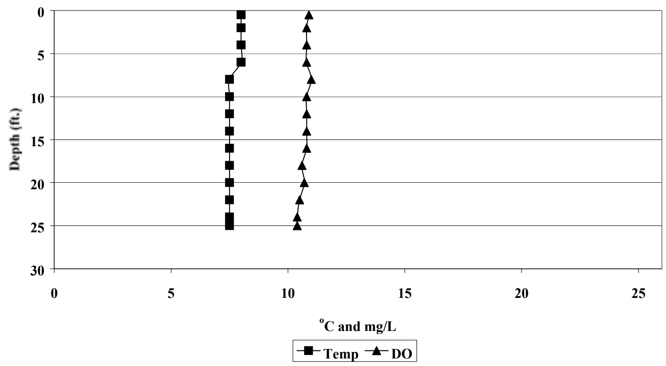

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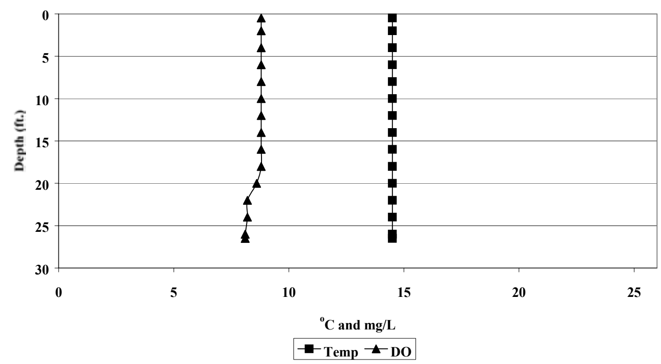

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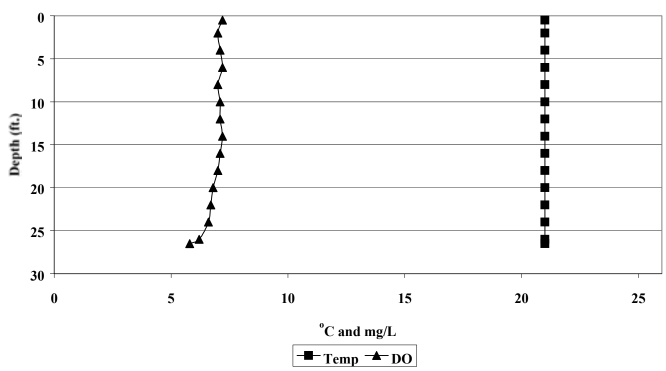
6/16/99 LCL-3



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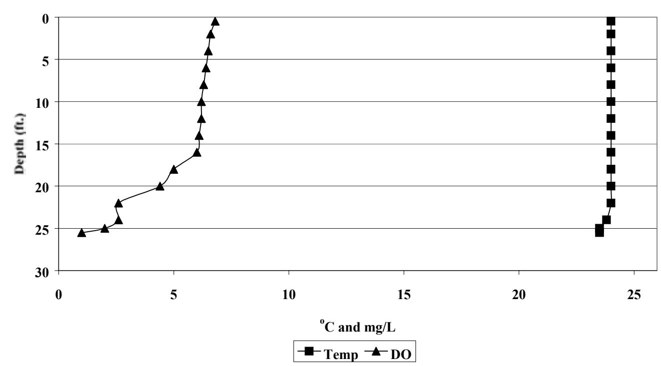

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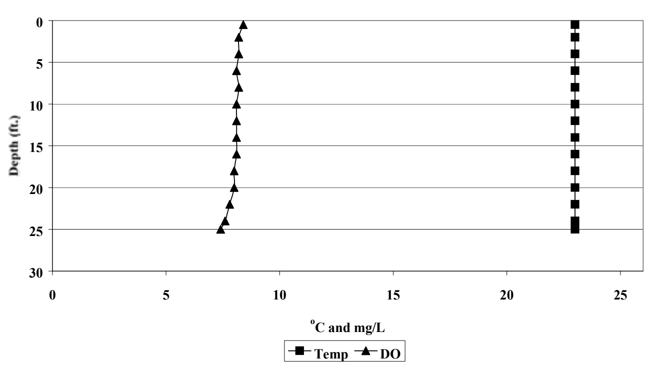
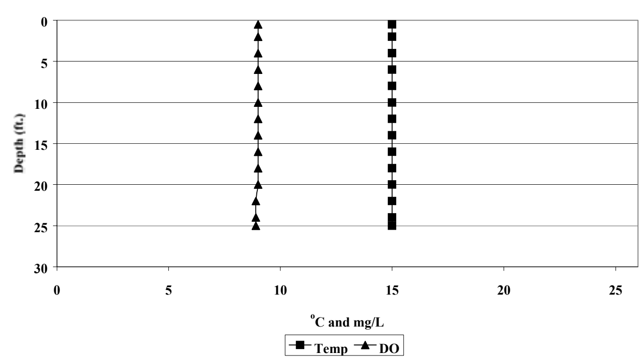
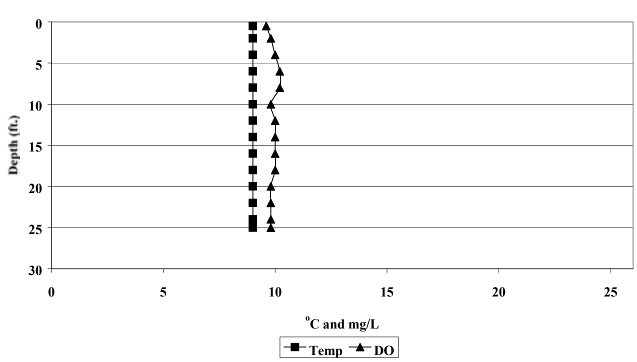
Dissolved Oxygen/Temperature Profile
8/23/99 LCL-3



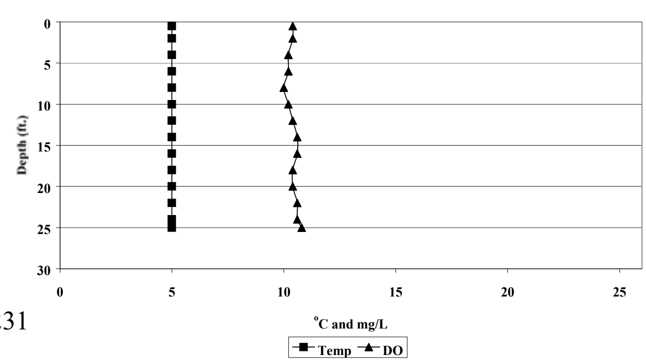
Lake Cochrane
Dissolved Oxygen/Temperature Profile
9/22/99 LCL-3



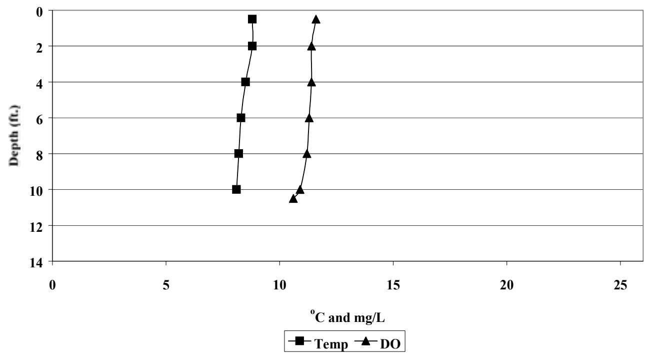
Lake Cochrane
Dissolved Oxygen/Temperature Profile
10/20/99 LCL-3



Lake Cochrane
Dissolved Oxygen/Temperature Profile
11/22/99 LCL-3



Lake Oliver
Dissolved Oxygen/Temperature Profile
4/20/99 LOL-1



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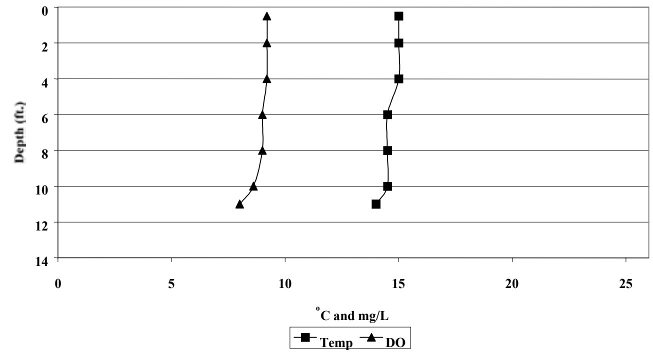
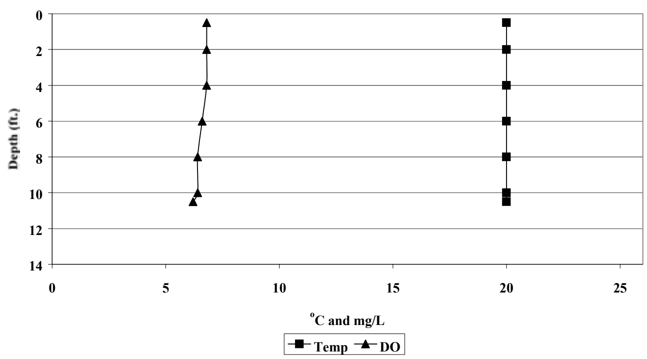
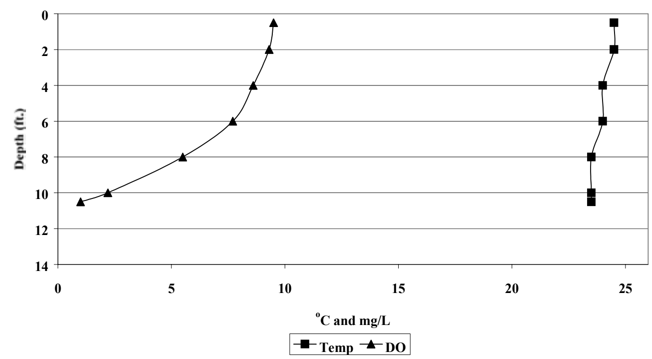
Dissolved Oxygen/Temperature Profile
5/18/99 LOL-1

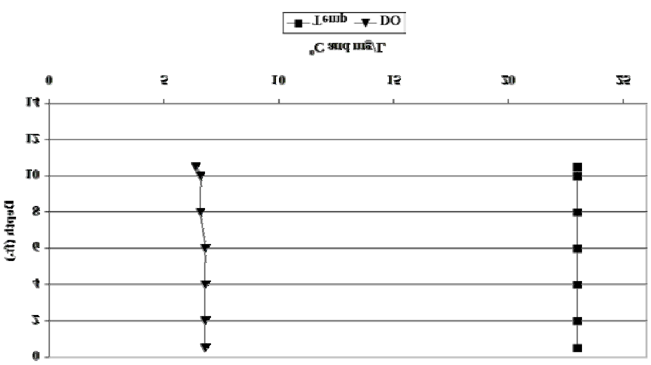


Lake Oliver
Dissolved Oxygen/Temperature Profile
6/16/99 LOL-1



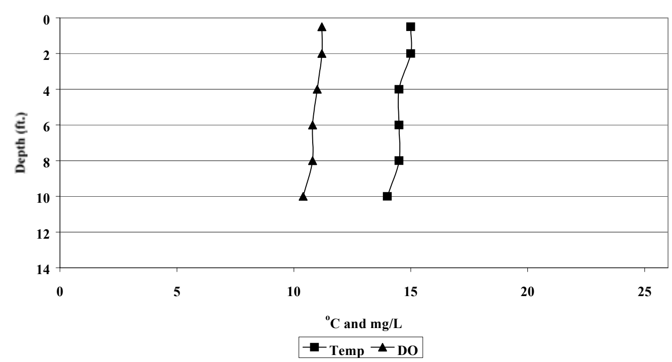
Lake Oliver
Dissolved Oxygen/Temperature Profile
7/21/99 LOL-1

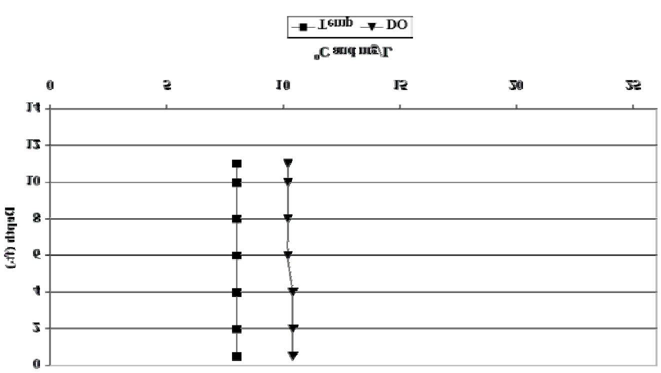




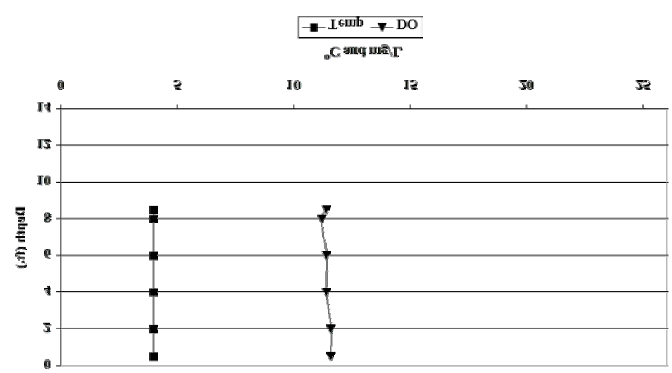
Lake Oliver
Dissolved Oxygen/Temperature Profile
8/23/99 LOL-1

Lake Oliver
Dissolved Oxygen/Temperature Profile
9/22/99 LOL-1



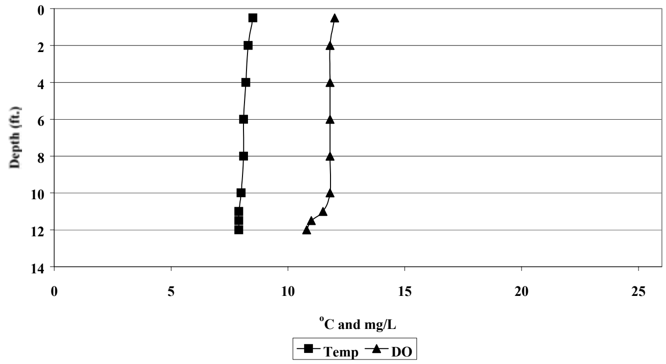


Lake Oliver
Dissolved Oxygen/Temperature Profile
10/20/99 LOL-1

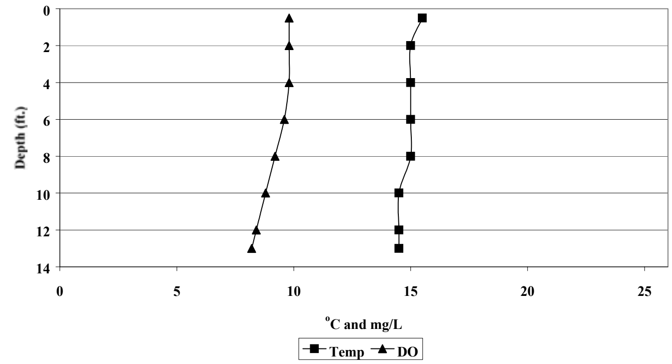


Lake Oliver
Dissolved Oxygen/Temperature Profile
11/22/99 LOL-1

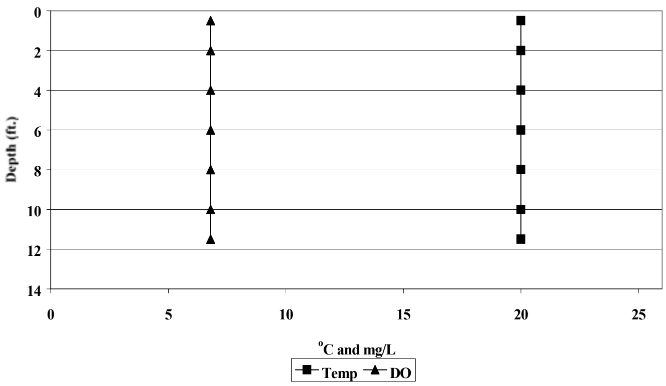
Lake Oliver
Dissolved Oxygen/Temperature Profile
4/20/99 LOL-2



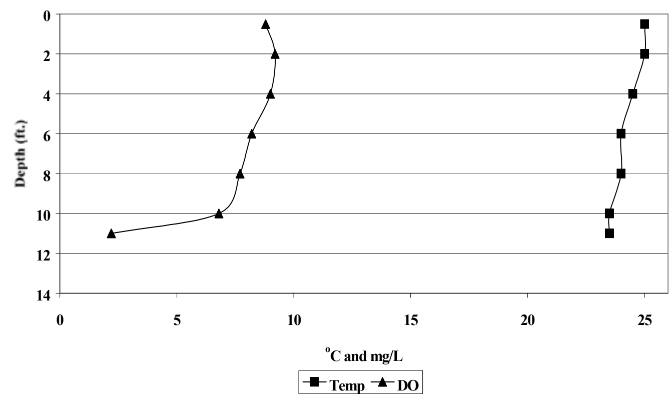
Lake Oliver
Dissolved Oxygen/Temperature Profile
5/18/99 LOL-2

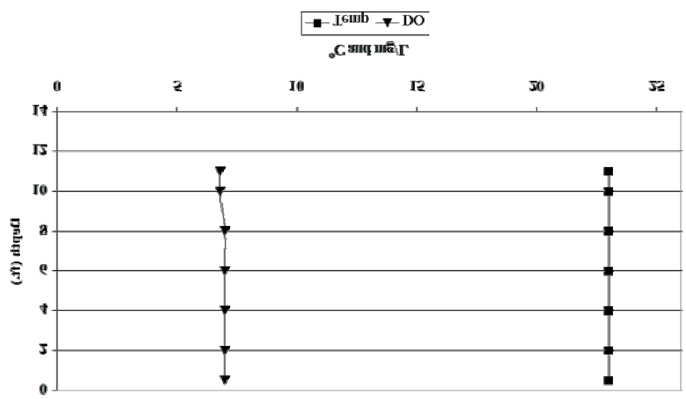


Lake Oliver
Dissolved Oxygen/Temperature Profile
6/16/99 LOL-2

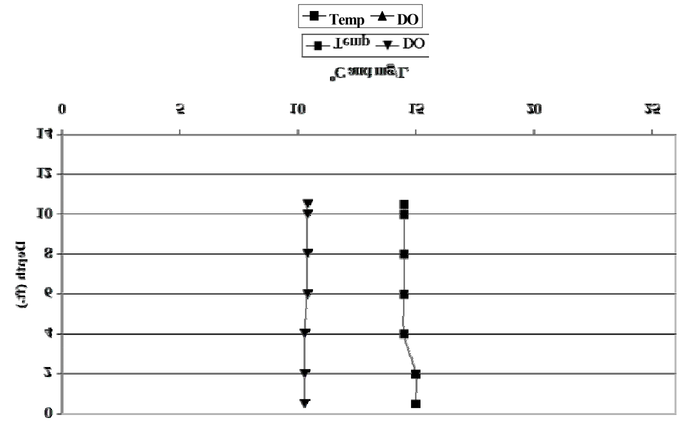


Lake Oliver
Dissolved Oxygen/Temperature Profile
7/21/99 LOL-2



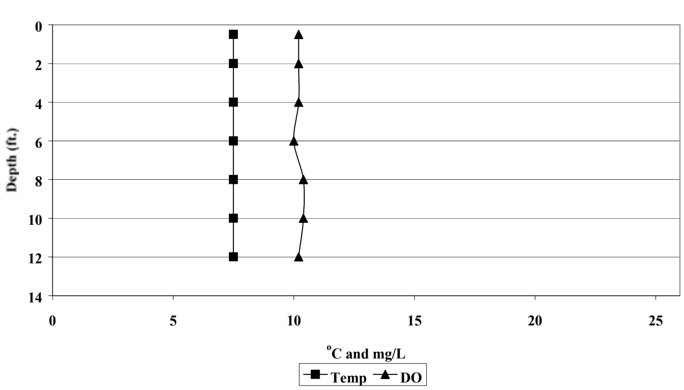


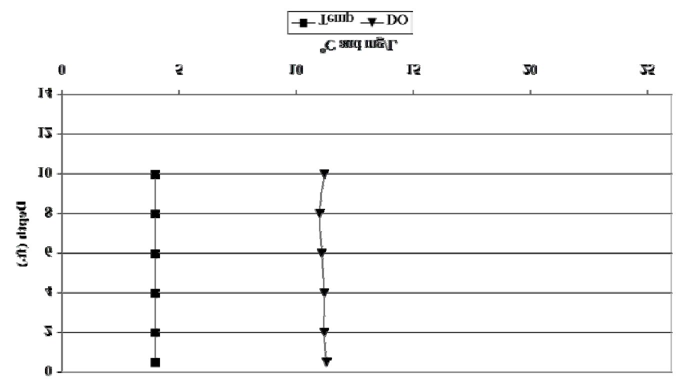
Lake Oliver
Dissolved Oxygen/Temperature Profile
8/23/99 LOL-2



Lake Oliver
Dissolved Oxygen/Temperature Profile
9/22/99 LOL-2

Lake Oliver
Dissolved Oxygen/Temperature Profile
10/20/99 LOL-2





Lake Oliver
Dissolved Oxygen/Temperature Profile
11/22/99 LOL-2

Appendix H
Lake Cochrane Public Swimming Beach Fecal Coliform Data

Swimming Beach Fecal Coliform Samples for Lake Cochrane

Date	Result		Date	Result		Date	Result
06/29/1992			08/07/1995	<10		08/03/1998	<10
07/06/1992	16		08/14/1995	310		08/03/1998	10
07/13/1992	8		08/21/1995	<10		08/17/1998	<10
07/20/1992	<2		08/28/1995	<10		08/24/1998	20
07/27/1992	26		06/17/1996	10		09/01/1998	<10
08/03/1992	2		06/24/1996	50		06/01/1999	20
08/10/1992	<2		07/01/1996	60		06/08/1999	<10
08/17/1992	38		07/08/1996	10		06/14/1999	50
08/24/1992	100		07/15/1996	<10		06/21/1999	130
08/31/1992	2		07/22/1996	<10		06/28/1999	90
07/19/1993	<10		07/29/1996	<10		07/06/1999	190
07/26/1993	10		08/05/1996	50		07/12/1999	<10
08/02/1993	10		08/12/1996	<10		07/19/1999	<10
08/02/1993	10		08/19/1996	<10		07/26/1999	680
08/09/1993	20		08/26/1996	<10		08/02/1999	10
08/16/1993	20		06/09/1997	40		08/09/1999	<10
08/23/1993	10		06/16/1997	<10		08/16/1999	<10
08/30/1993	10		06/23/1997			08/23/1999	<10
06/06/1994	<10		06/23/1997	530		08/30/1999	30
06/13/1994	50		06/30/1997	10		05/30/2000	40
06/20/1994	1300		07/07/1997	<10		06/05/2000	100
06/27/1994	100		07/14/1997	10		06/12/2000	10
07/05/1994	<10		07/21/1997	<10		06/19/2000	400
07/11/1994	<10		07/28/1997	<10		06/26/2000	10
07/18/1994	10		08/04/1997			07/03/2000	
07/25/1994	<10		08/11/1997	<10		07/10/2000	<10
08/01/1994	<10		08/18/1997	<10		07/17/2000	<10
08/08/1994	<10		08/25/1997	20		07/24/2000	10
08/15/1994	20		06/01/1998	40		07/31/2000	<10
08/22/1994	<10		06/08/1998	10		08/07/2000	<10
08/29/1994	50		06/15/1998	60		08/14/2000	<10
06/26/1995	30		06/22/1998	<10		08/21/2000	<10
07/03/1995			06/29/1998	70		08/28/2000	<10
07/10/1995	20		07/06/1998	10			
07/17/1995	20		07/13/1998	<10			
07/24/1995	<10		07/20/1998	250			
07/31/1995	50		07/27/1998	<10			

Appendix I
Raw Water Quality Data

SITE	SAMPLE DEPTH	DATE	WATER TEMP	pH	ALKA-M	SECCHI (m)	FECAL COLIFORM	DISSOLVED OXYGEN (mg/L)	CHLOROPHYLL A
LOL#1	SURFACE	04/20/1999	8.8	8.81	262	0.549	5	11.6	18.0625
LOL#1	BOTTOM	04/20/1999	8	8.81	263		5	10.6	
LOL#1	SURFACE	05/18/1999	15	8.83	262	0.792	5	9.2	13.005
LOL#1	BOTTOM	05/18/1999	14	8.83	265		5	8	
LOL#1	SURFACE	06/16/1999	20	8.79	259	0.853	5	6.8	22.3975
LOL#1	BOTTOM	06/16/1999	20	8.79	258		5	6.2	
LOL#1	SURFACE	07/21/1999	24.5	8.7	240	0.853	5	9.5	52.866
LOL#1	BOTTOM	07/21/1999	23.5	8.7	246		5	1	
LOL#1	SURFACE	08/23/1999	23	8.89	243	0.610	10	6.8	35.244
LOL#1	BOTTOM	08/23/1999	23	8.89	242		5	6.4	
LOL#1	SURFACE	09/22/1999	15	8.98	255	0.457	5	11.2	65.2815
LOL#1	BOTTOM	09/22/1999	14	8.98	256		5	10.4	
LOL#1	SURFACE	10/20/1999	8	8.84	269	0.457	5	10.4	59.87475
LOL#1	BOTTOM	10/20/1999	8	8.84	269		5	10.2	
LOL#1	SURFACE	11/22/1999	4	8.68	279	1.372	5	11.6	3.904875
LOL#1	BOTTOM	11/22/1999	4	8.68	279		5	11.4	
LOL#2	SURFACE	04/20/1999	8.5	8.91	259	0.610	5	12	15.1725
LOL#2	BOTTOM	04/20/1999	7.9	8.91	260		5	10.8	
LOL#2	SURFACE	05/18/1999	15.5	8.87	263	0.762	5	9.8	16.6175
LOL#2	BOTTOM	05/18/1999	14.5	8.87	263		5	8.2	
LOL#2	SURFACE	06/16/1999	20	8.71	259	0.762	5	6.8	28.1775
LOL#2	BOTTOM	06/16/1999	20	8.71	259		5	6.8	
LOL#2	SURFACE	07/21/1999	25	8.8	243	0.914	10	8.8	52.66575
LOL#2	BOTTOM	07/21/1999	23.5	8.8	241		5	2.2	

SITE	SAMPLE DEPTH	DATE	TOTAL SOLIDS	TOTAL SUSP. SOLIDS	VTSS	AMMONIA	NITRATE	TKN	TOTAL PHOS.	T.DISS. PHOS.
LOL#1	SURFACE	04/20/1999	1303	21	5	0.12	0.05	1.54	0.042	0.012
LOL#1	BOTTOM	04/20/1999	1298	18	3	0.13	0.05	1.46	0.054	0.012
LOL#1	SURFACE	05/18/1999	1385	10	4	0.13	0.05	1.42	0.055	0.021
LOL#1	BOTTOM	05/18/1999	1370	16	1	0.13	0.05	1.35	0.07	0.021
LOL#1	SURFACE	06/16/1999	1382	11	0.5	0.01	0.05	1.68	0.062	0.018
LOL#1	BOTTOM	06/16/1999	1360	15	3	0.16	0.05	2.26	0.057	0.02
LOL#1	SURFACE	07/21/1999	1299	15	9	0.01	0.1	2.1	0.074	0.023
LOL#1	BOTTOM	07/21/1999	1315	20	9	0.17	0.05	2.36	0.088	0.023
LOL#1	SURFACE	08/23/1999	1399	22	13	0.01	0.05	2.17	0.06	0.017
LOL#1	BOTTOM	08/23/1999	1384	24	16	0.01	0.05	2.1	0.067	0.014
LOL#1	SURFACE	09/22/1999	1378	15	10	0.01	0.05	1.95	0.076	0.022
LOL#1	BOTTOM	09/22/1999	1374	17	10	0.01	0.05	1.84	0.08	0.025
LOL#1	SURFACE	10/20/1999	1389	17	16	0.01	0.05	2.39	0.086	0.023
LOL#1	BOTTOM	10/20/1999	1379	18	15	0.01	0.05	2.59	0.09	0.017
LOL#1	SURFACE	11/22/1999	1416	8	1	0.09	0.1	2.02	0.053	0.021
LOL#1	BOTTOM	11/22/1999	1413	9	4	0.08	0.1	2.09	0.061	0.017
LOL#2	SURFACE	04/20/1999	1322	10	0.5	0.19	0.05	1.44	0.05	0.012
LOL#2	BOTTOM	04/20/1999	1326	16	6	0.14	0.05	1.34	0.054	0.011
LOL#2	SURFACE	05/18/1999	1371	8	5	0.23	0.05	1.38	0.058	0.022
LOL#2	BOTTOM	05/18/1999	1370	15	6	0.01	0.05	1.42	0.054	0.025
LOL#2	SURFACE	06/16/1999	1388	11	4	0.01	0.05	1.82	0.061	0.019
LOL#2	BOTTOM	06/16/1999	1350	13	4	0.1	0.05	1.64	0.06	0.019
LOL#2	SURFACE	07/21/1999	1360	13	8	0.01	0.05	1.69	0.063	0.022
LOL#2	BOTTOM	07/21/1999	1379	18	11	0.09	0.05	1.77	0.074	0.025

SITE	SAMPLE DEPTH	DATE	WATER TEMP	pH	ALKA-M	SECCHI (m)	FECAL COLIFORM	DISSOLVED OXYGEN (mg/L)	CHLOROPHYLL A	
LOL#2	SURFACE	08/23/1999	23	8.88	245	0.610	5	7		
LOL#2	BOTTOM	08/23/1999	23	8.88	245		5	6.8		
LOL#2	SURFACE	09/22/1999	15	9.01	258	0.457	5	10.3	80.901	
LOL#2	BOTTOM	09/22/1999	14.5	9	254		5	10.4		
LOL#2	SURFACE	10/20/1999	7.5	8.88	271	0.457	5	10.2	50.966125	
LOL#2	BOTTOM	10/20/1999	7.5	8.88	268		5	10.2		
LOL#2	SURFACE	11/22/1999	4	8.68	278	1.372	5	11.3	18.22275	
LOL#2	BOTTOM	11/22/1999	4	8.68	279		5	11.2		

SITE	SAMPLE DEPTH	DATE	TOTAL SOLIDS	TOTAL SUSP. SOLIDS	VTSS	AMMONIA	NITRATE	TKN	TOTAL PHOS.	T.DISS. PHOS.
LOL#2	SURFACE	08/23/1999	1400	29	16	0.01	0.05	2.16	0.075	0.016
LOL#2	BOTTOM	08/23/1999	1417	27	14	0.01	0.05	2.18	0.073	0.017
LOL#2	SURFACE	09/22/1999	1329	12	10	0.01	0.05	2.07	0.081	0.022
LOL#2	BOTTOM	09/22/1999	1403	21	7	0.01	0.05	2.13	0.082	0.025
LOL#2	SURFACE	10/20/1999	1382	17	15	0.01	0.05	2.85	0.089	0.022
LOL#2	BOTTOM	10/20/1999	1381	18	15	0.01	0.05	2.6	0.085	0.02
LOL#2	SURFACE	11/22/1999	1427	9	5	0.09	0.1	2.23	0.053	0.017
LOL#2	BOTTOM	11/22/1999	1416	11	6	0.08	0.1	2.08	0.058	0.017

SITE	SAMPLE DEPTH	DATE	WATER TEMP °C	pH su	ALKA-M mg/L	SECCHI (m) m	FECAL COLIFORM Counts/100ml	DISSOLVED OXYGEN mg/L	CHLOROPHYLL a mg/m^3
LCL#1	SURFACE	04/20/1999	8	8.76	218	1.372	5	10	18.785
LCL#1	BOTTOM	04/20/1999	8	8.87	222		5	12	
LCL#2	SURFACE	04/20/1999	8	8.89	219	1.219	5	9	39.7375
LCL#2	BOTTOM	04/20/1999	8	8.6	219		5	9	
LCL#3	SURFACE	04/20/1999	8	8.7	218	1.372	5	9	20.9525
LCL#3	BOTTOM	04/20/1999	7.5	8.74	218		5	7	
LCL#1	SURFACE	05/18/1999	15	8.78	217	1.402	5	10	13.7275
LCL#1	BOTTOM	05/18/1999	14	8.89	216		5	10	
LCL#2	SURFACE	05/18/1999	14.5	8.8	217	1.463	5	11	15.1725
LCL#2	BOTTOM	05/18/1999	14.5	8.82	216		5	11	
LCL#3	SURFACE	05/18/1999	14.5	8.83	217	1.219	5	11	12.2825
LCL#3	BOTTOM	05/18/1999	14.5	8.86	216		10	12	
LCL#1	SURFACE	06/16/1999	21	8.85	216	0.914	5	13	29.6225
LCL#1	BOTTOM	06/16/1999	21	8.83	215		5	14	
LCL#2	SURFACE	06/16/1999	21	8.95	215	1.219	5	14	27.455
LCL#2	BOTTOM	06/16/1999	21	8.91	213		5	15	
LCL#3	SURFACE	06/16/1999	21	8.87	216	1.219	5	15	26.01
LCL#3	BOTTOM	06/16/1999	21	8.86	216		5	15	
LCL#1	SURFACE	07/21/1999	24.5	8.87	216	0.914	5	9	52.966125
LCL#1	BOTTOM	07/21/1999	24	8.65	214		5	13	
LCL#2	SURFACE	07/21/1999	24	8.86	216	0.975	5	12	7.00875
LCL#2	BOTTOM	07/21/1999	24	8.71	214		5	11	
LCL#3	SURFACE	07/21/1999	24	8.82	214	1.067	5	13	
LCL#3	BOTTOM	07/21/1999	23.5	8.68	213		5	7	

SITE	SAMPLE DEPTH	DATE	TOTAL SOLIDS mg/L	TOTAL SUSP. SOLIDS mg/L	VTSS mg/L	AMMONIA mg/L	UNIONIZED AMMONIA mg/L	NITRATE mg/L	TKN mg/L	TOTAL PHOS. mg/L	T.DISS. PHOS. mg/L
LCL#1	SURFACE	04/20/1999	1662	12	5	0.15	0.01258	0.05	1.58	0.022	0.006
LCL#1	BOTTOM	04/20/1999	1665	12	3	0.15	0.01583	0.05	1.5	0.021	0.006
LCL#2	SURFACE	04/20/1999	1703	13	4	0.17	0.01869	0.05	1.57	0.022	0.004
LCL#2	BOTTOM	04/20/1999	1705	9	2	0.16	0.00953	0.05	1.51	0.024	0.006
LCL#3	SURFACE	04/20/1999	1706	10	3	0.17	0.01256	0.05	1.28	0.024	0.003
LCL#3	BOTTOM	04/20/1999	1703	8	3	0.17	0.01318	0.05	1.34	0.025	0.003
LCL#1	SURFACE	05/18/1999	1730	7	4	0.01	0.00142	0.05	1.39	0.031	0.014
LCL#1	BOTTOM	05/18/1999	1757	7	4	0.03	0.00494	0.05	1.38	0.029	0.013
LCL#2	SURFACE	05/18/1999	1766	9	6	0.02	0.00285	0.05	1.33	0.029	0.022
LCL#2	BOTTOM	05/18/1999	1739	8	6	0.03	0.00445	0.05	1.39	0.036	0.012
LCL#3	SURFACE	05/18/1999	1744	7	5	0.02	0.00303	0.05	1.34	0.028	0.015
LCL#3	BOTTOM	05/18/1999	1722	7	5	0.03	0.00481	0.05	1.42	0.035	0.032
LCL#1	SURFACE	06/16/1999	1742	9	6	0.01	0.00232	0.05	1.4	0.027	0.016
LCL#1	BOTTOM	06/16/1999	1719	9	7	0.01	0.00224	0.05	1.4	0.027	0.014
LCL#2	SURFACE	06/16/1999	1797	10	5	0.01	0.00276	0.05	1.54	0.032	0.005
LCL#2	BOTTOM	06/16/1999	1729	11	5	0.01	0.00258	0.1	1.55	0.034	0.005
LCL#3	SURFACE	06/16/1999	1738	9	5	0.01	0.00241	0.05	1.31	0.027	0.005
LCL#3	BOTTOM	06/16/1999	1721	9	6	0.01	0.00236	0.05	1.37	0.032	0.008
LCL#1	SURFACE	07/21/1999	1811	19	14	0.01	0.00289	0.05	2.16	0.051	0.015
LCL#1	BOTTOM	07/21/1999	1762	13	10	0.01	0.00191	0.1	1.52	0.03	0.006
LCL#2	SURFACE	07/21/1999	1776	15	11	0.01	0.00277	0.05	1.11	0.026	0.006
LCL#2	BOTTOM	07/21/1999	1740	14	9	0.01	0.00214	0.05	1.18	0.026	0.008
LCL#3	SURFACE	07/21/1999	1773	11	8	0.01	0.00259	0.05	1.41	0.022	0.007
LCL#3	BOTTOM	07/21/1999	1799	14	10	0.05	0.00983	0.05	1.35	0.029	0.007

SITE	SAMPLE DEPTH	DATE	WATER TEMP °C	pH su	ALKA-M mg/L	SECCHI (m) m	FECAL COLIFORM Counts/100ml	DISSOLVED OXYGEN mg/L	CHLOROPHYLL a mg/m^3
LCL#1	SURFACE	08/23/1999	23	8.82	218	1.067	5	15	18.322875
LCL#1	BOTTOM	08/23/1999	23	8.78	217		5	12	
LCL#2	SURFACE	08/23/1999	23	8.94	218	0.914	5	17	31.138875
LCL#2	BOTTOM	08/23/1999	23	8.77	216		5	16	
LCL#3	SURFACE	08/23/1999	23	8.92	218	0.914	5	18	20.826
LCL#3	BOTTOM	08/23/1999	23	8.83	219		5	15	
LCL#1	SURFACE	09/22/1999	15	8.84	212	0.914	10	16	10.21275
LCL#1	BOTTOM	09/22/1999	15	8.85	214		5	16	
LCL#2	SURFACE	09/22/1999	15	8.85	216	0.975	5	16	12.61575
LCL#2	BOTTOM	09/22/1999	15	8.87	213		5	16	
LCL#3	SURFACE	09/22/1999	15	8.83	214	0.914	5	16	14.518125
LCL#3	BOTTOM	09/22/1999	15	8.86	215		5	15	
LCL#1	SURFACE	10/20/1999	9	8.73	217	1.829	5	11	6.107625
LCL#1	BOTTOM	10/20/1999	9	8.73	218		5	13	
LCL#2	SURFACE	10/20/1999	9	8.74	217	1.829	5	11	0
LCL#2	BOTTOM	10/20/1999	9	8.74	219		5	11	
LCL#3	SURFACE	10/20/1999	9	8.76	218	1.829	5	11	5.707125
LCL#3	BOTTOM	10/20/1999	9	8.74	217		5	11	
LCL#1	SURFACE	11/22/1999	5	8.72	222	2.591	5	4	3.103875
LCL#1	BOTTOM	11/22/1999	5	8.73	224		5	4	
LCL#2	SURFACE	11/22/1999	5	8.66	222	2.591	5	3	3.904875
LCL#2	BOTTOM	11/22/1999	5	8.68	222		5	3	
LCL#3	SURFACE	11/22/1999	5	8.69	221	2.591	5	4	2.903625
LCL#3	BOTTOM	11/22/1999	5	8.71	222		5	4	

SITE	SAMPLE DEPTH	DATE	TOTAL SOLIDS mg/L	TOTAL SUSP. SOLIDS mg/L	VTSS mg/L	AMMONIA mg/L	UNIONIZED AMMONIA mg/L	NITRATE mg/L	TKN mg/L	TOTAL PHOS. mg/L	T.DISS. PHOS. mg/L
LCL#1	SURFACE	08/23/1999	1774	15	13	0.01	0.00246	0.05	1.59	0.021	0.001
LCL#1	BOTTOM	08/23/1999	1796	14	13	0.01	0.00229	0.05	1.64	0.022	0.001
LCL#2	SURFACE	08/23/1999	1770	16	15	0.01	0.00301	0.05	1.54	0.018	0.001
LCL#2	BOTTOM	08/23/1999	1777	17	14	0.01	0.00225	0.05	1.57	0.02	0.001
LCL#3	SURFACE	08/23/1999	1791	17	13	0.01	0.00291	0.05	1.61	0.026	0.001
LCL#3	BOTTOM	08/23/1999	1796	15	12	0.01	0.00250	0.05	1.44	0.026	0.001
LCL#1	SURFACE	09/22/1999	1777	7	7	0.01	0.00159	0.05	1.55	0.022	0.006
LCL#1	BOTTOM	09/22/1999	1780	8	8	0.01	0.00162	0.05	1.42	0.022	0.007
LCL#2	SURFACE	09/22/1999	1779	10	7	0.01	0.00162	0.05	1.33	0.025	0.007
LCL#2	BOTTOM	09/22/1999	1791	10	7	0.01	0.00169	0.05	1.45	0.024	0.007
LCL#3	SURFACE	09/22/1999	1769	12	9	0.01	0.00156	0.05	1.42	0.025	0.006
LCL#3	BOTTOM	09/22/1999	1784	10	9	0.01	0.00166	0.05	1.46	0.031	0.009
LCL#1	SURFACE	10/20/1999	1744	4	4	0.03	0.00254	0.05	1.46	0.022	0.005
LCL#1	BOTTOM	10/20/1999	1754	5	5	0.03	0.00254	0.05	1.47	0.023	0.005
LCL#2	SURFACE	10/20/1999	1749	4	3	0.04	0.00346	0.05	1.26	0.026	0.016
LCL#2	BOTTOM	10/20/1999	1746	5	5	0.04	0.00346	0.05	1.3	0.025	0.01
LCL#3	SURFACE	10/20/1999	1744	7	6	0.05	0.00451	0.05	1.37	0.025	0.014
LCL#3	BOTTOM	10/20/1999	1749	7	5	0.03	0.00259	0.05	1.44	0.024	0.006
LCL#1	SURFACE	11/22/1999	1758	5	0.5	0.12	0.00739	0.05	1.38	0.02	0.004
LCL#1	BOTTOM	11/22/1999	1762	4	0.5	0.12	0.00755	0.05	1.34	0.019	0.008
LCL#2	SURFACE	11/22/1999	1772	6	1	0.13	0.00703	0.05	1.5	0.02	0.004
LCL#2	BOTTOM	11/22/1999	1774	8	3	0.12	0.00678	0.05	1.48	0.023	0.005
LCL#3	SURFACE	11/22/1999	1765	6	2	0.19	0.01096	0.05	1.41	0.02	0.005
LCL#3	BOTTOM	11/22/1999	1758	6	4	0.12	0.00723	0.05	1.15	0.018	0.009

Lake Name	Site	Spec #	Date	Time	Air Temp °C	DO mg/L	pH su	Water Temp °C	Fecal Col. counts / 100ml	Alkalinity Total mg/L	Solids, Total mg/L	Solids, Suspended mg/L	Solids, Volatile mg/L
Cochrane	LCO	E99EC002858	05/08/1999	1315	18.33	10.0	8.82	13		220	1675	5.0	3.0
Cochrane	LCO	E99EC003211	05/20/1999	930	18.33	9.4	8.77	16	5	217	1677	9.0	1.0
Cochrane	LCO	E99EC003760	06/03/1999	1200	26.67	9.6	8.7	18	5	264	1753	14.0	8.0
Cochrane	LCO	E99EC004083	06/10/1999	1400	26.67	8.6	8.67	21	20	216	1682	9.0	0.5
Cochrane	LCT1A	E99EC003868	06/08/1999	1100	29.44	7.4	7.82	24	1100	205	507	4.0	0.5
Cochrane	LCT1A	E99EC004600	06/23/1999	930	31.11	8.1	7.89	25	1400	204	448	1.0	0.5
Cochrane	LCT2	E99EC001190	03/15/1999	30	1.67	11.4	7.91	1.8	5	310	974	0.5	0.5
Cochrane	LCT2	E99EC001363	03/18/1999	1430	7.22	13.0	7.911	4	5	234	654	14.0	6.0
Cochrane	LCT2	E99EC001956	03/29/1999	1230	12.78	15.5	8.55	9	5	324	1105	17.0	12.0
Cochrane	LCT2	E99EC001807	04/05/1999	1145	4.44	11.4	8.41	8	5	280	1029	16.0	5.0
Cochrane	LCT2	E99EC001957	04/06/1999	1600	15.56	12.2	8.21	10		296	1050	17.0	13.0
Cochrane	LCT2	E99EC001995	04/09/1999	1700	10.00	12.0	8.25	10		309	1016	6.0	5.0
Cochrane	LCT2	E99EC001996	04/12/1999	1230	15.56	14.0	8.05	9	420	308	985	2.0	2.0
Cochrane	LCT2	E99EC002175	04/15/1999	1015	4.44	11.0	7.97	6	20	315	988	7.0	3.0
Cochrane	LCT2	E99EC002568	04/28/1999	1000	18.33	10.2	8.47	16	5	254	1099	10.0	8.0
Cochrane	LCT2	E99EC002809	05/06/1999	1200	21.11	10.0	8.52	17	5	204	919	19.0	8.0
Cochrane	LCT2	E99EC003360	05/20/1999	800	18.33	9.4	8.38	17	140	310	1060	11.0	5.0
Cochrane	LCT2	E99EC003870	06/08/1999	1115	29.44	9.6	8.17	23	120	230	1034	14.0	6.0
Cochrane	LCT2	E99EC004601	06/23/1999	945	31.11	9.2	8.46	24	170	225	876	14.0	7.0
Cochrane	LCT2	E99EC004766	06/29/1999	1000	23.89	6.2	7.79	24	40	237	908	9.0	6.0
Cochrane	LCT2	E99EC005839	08/02/1999	1100	18.33	4.8	7.37	17.5	110	148	940	12.0	5.0
Cochrane	LCT2	E99EC007084	08/30/1999	1600	33.33	8.0	7.97	20	5	117	1021	22.0	6.0
Cochrane	LCT2	E99EC007914	09/19/1999	1815	18.33	6.8	7.87	9.5		121	930	10.0	6.0
Cochrane	LCT2	E99EC009127	10/19/1999	1300	5.56	10.8	8.23	10	30	174	1090	106.0	22.0
Cochrane	LCT2	E99EC009661	11/02/1999	1000	3.89	9.2	8.18	3.2	5	238	1013	7.0	0.5
Cochrane	LCT2	E99EC009662	11/02/1999	1000	3.89	9.2	8.18	3.2	10	162	1055	14.0	4.0

Lake Name	Site	Spec #	Date	Time	Ammonia mg/L	Unionized Ammonia mg/L	Nitrate mg/L	TKN mg/L	Phosphorus Total mg/L	Phosphorus, Tot. Dissolved mg/L
Cochrane	LCO	E99EC002858	05/08/1999	1315	0.05	0.00672	0.10	1.45	0.027	0.009
Cochrane	LCO	E99EC003211	05/20/1999	930	0.04	0.00593	0.10	1.43	0.026	0.007
Cochrane	LCO	E99EC003760	06/03/1999	1200	0.01	0.00147	0.05	1.21	0.035	0.006
Cochrane	LCO	E99EC004083	06/10/1999	1400	0.01	0.00167	0.05	1.48	0.035	0.009
Cochrane	LCT1A	E99EC003868	06/08/1999	1100	0.01	0.00034	0.05	1.73	0.067	0.039
Cochrane	LCT1A	E99EC004600	06/23/1999	930	0.01	0.00042	0.05	1.45	0.069	0.046
Cochrane	LCT2	E99EC001190	03/15/1999	30	0.20	0.00155	2.10	1.52	0.104	0.064
Cochrane	LCT2	E99EC001363	03/18/1999	1430	1.20	0.01116	1.30	5.70	0.457	0.304
Cochrane	LCT2	E99EC001956	03/29/1999	1230	0.01	0.00058	0.50	1.88	0.150	0.049
Cochrane	LCT2	E99EC001807	04/05/1999	1145	0.01	0.00039	0.90	1.67	0.114	0.013
Cochrane	LCT2	E99EC001957	04/06/1999	1600	0.06	0.00176	2.10	2.68	0.236	0.080
Cochrane	LCT2	E99EC001995	04/09/1999	1700	0.20	0.00641	2.80	3.23	0.335	0.215
Cochrane	LCT2	E99EC001996	04/12/1999	1230	0.10	0.00190	2.80	2.44	0.311	0.206
Cochrane	LCT2	E99EC002175	04/15/1999	1015	0.01	0.00012	2.70	2.33	0.195	0.140
Cochrane	LCT2	E99EC002568	04/28/1999	1000	0.01	0.00080	1.50	1.62	0.078	0.017
Cochrane	LCT2	E99EC002809	05/06/1999	1200	0.01	0.00095	0.10	2.33	0.112	0.021
Cochrane	LCT2	E99EC003360	05/20/1999	800	0.01	0.00071	1.90	2.08	0.124	0.024
Cochrane	LCT2	E99EC003870	06/08/1999	1115	0.01	0.00068	0.05	2.04	0.130	0.028
Cochrane	LCT2	E99EC004601	06/23/1999	945	0.01	0.00133	0.05	1.53	0.118	0.024
Cochrane	LCT2	E99EC004766	06/29/1999	1000	0.01	0.00032	0.05	1.27	0.088	0.038
Cochrane	LCT2	E99EC005839	08/02/1999	1100	0.08	0.00061	0.10	1.83	0.178	0.048
Cochrane	LCT2	E99EC007084	08/30/1999	1600	0.01	0.00036	0.05	1.98	0.184	0.036
Cochrane	LCT2	E99EC007914	09/19/1999	1815	0.28	0.00367	0.10	1.46	0.098	0.025
Cochrane	LCT2	E99EC009127	10/19/1999	1300	0.27	0.00828	0.10	1.28	0.307	0.022
Cochrane	LCT2	E99EC009661	11/02/1999	1000	0.91	0.01463	0.50	1.90	0.124	0.029
Cochrane	LCT2	E99EC009662	11/02/1999	1000	0.01	0.00016	0.10	1.10	0.243	0.023

Lake Name	Site	Spec #	Date	Time	Air Temp °C	DO mg/L	pH su	Water Temp °C	Fecal Col. counts / 100ml	Alkalinity Total mg/L	Solids, Total mg/L	Solids, Suspended mg/L	Solids, Volatile mg/L
Cochrane	LCT3	E99EC000999	03/03/1999	1345	-13.11	15.0	7.69	1.8	5				
Cochrane	LCT3	E99EC001191	03/15/1999	1400	4.44	13.2	7.72	2	5	353	837	10.0	5.0
Cochrane	LCT3	E99EC001263	03/16/1999	1300	8.89	13.0	7.48	2	10	149	337	0.5	0.5
Cochrane	LCT3	E99EC001416	03/22/1999	1100	10.00	15.5	7.9	6	5	198	448	5.0	3.0
Cochrane	LCT3	E99EC001657	03/29/1999	1330	12.78	13.0	8.23	10	5	238	612	5.0	3.0
Cochrane	LCT3	E99EC001809	04/05/1999	1035	4.44	10.4	8.08	7	5	274	748	1.0	1.0
Cochrane	LCT3	E99EC001868	04/06/1999	1130	15.56	15.0	8.24	11	10	255	677	3.0	3.0
Cochrane	LCT3	E99EC00 1998	04/09/1999	1715	10.00	13.0	8.13	12		263	666	0.5	0.5
Cochrane	LCT3	E99EC001999	04/12/1999	1300	19.72	10.0	8.3	10	5	247	624	0.5	0.5
Cochrane	LCT3	E99EC002176	04/15/1999	1030	4.44	13.0	8.14	6	20	257	664	3.0	1.0
Cochrane	LCT3	E99EC002569	04/28/1999	1030	18.33	11.8	8.12	16	10	251	773	0.5	0.5
Cochrane	LCT3	E99EC002810	05/06/1999	1215	21.11	11.4	8.22	16	30	242	719	5.0	1.0
Cochrane	LCT3	E99EC003361	05/20/1999	1530	18.33	9.6	8.17	17	150	215	614	5.0	0.5
Cochrane	LCT3	E99EC003873	06/08/1999	1130	29.44	10.0	7.98	23	960	110	553	13.0	4.0
Cochrane	LCT3	E99EC004603	06/23/1999	1000	31.11	8.9	8.37	25	2200	122	462	19.0	3.0
Cochrane	LCT3	E99EC004767	06/29/1999	1030	23.89	6.8	7.77	23	180	220	596	5.0	3.0
Cochrane	LCT3	E99EC005840	08/02/1999	1130	18.33	4.8	7.57	20	280	223	621	15.0	8.0
Cochrane	LCT3	E99EC007085	08/30/1999	1615	33.33	8.0	7.53	20	1900	165	1140	15.0	5.0
Cochrane	LCT3	E99EC007915	09/19/1999	1800	18.33	6.4	8.01	10		120	476	10.0	5.0
Cochrane	LCT4	E99EC001810	04/05/1999	900	4.44	7.0	7.76	6	10	332	1972	7.0	3.0
Cochrane	LCT4	E99EC001869	04/06/1999	1015	15.56	14.0	7.78	9	10	252	1407	1.0	1.0
Cochrane	LCT4	E99EC002001	04/12/1999	1330	19.72	11.0	8.03	12	5	285	1549	3.0	2.0
Cochrane	LCT4	E99EC003875	06/08/1999	1145	29.44	9.6	8.15	23	2900	239	1314	4.0	0.5
Cochrane	LCT4	E99EC004605	06/23/1999	1015	31.11	8.1	8.17	23	1700	262	1308	4.0	0.5
Cochrane	LCT4	E99EC004768	06/29/1999	1045	23.89	6.0	7.43	22	430	334	1627	6.0	4.0

Lake Name	Site	Spec #	Date	Time	Ammonia mg/L	Unionized Ammonia mg/L	Nitrate mg/L	TKN mg/L	Phosphorus Total mg/L	Phosphorus, Tot. Dissolved mg/L
Cochrane	LCT3	E99EC000999	03/03/1999	1345	0.08	0.00037	0.20	1.06	0.098	0.023
Cochrane	LCT3	E99EC001191	03/15/1999	1400	0.01	0.00005	0.10	1.29	0.100	0.051
Cochrane	LCT3	E99EC001263	03/16/1999	1300	0.01	0.00003	1.00	1.82	0.168	0.095
Cochrane	LCT3	E99EC001416	03/22/1999	1100	0.01	0.00011	0.05	0.94	0.066	0.025
Cochrane	LCT3	E99EC001657	03/29/1999	1330	0.01	0.00031	0.10	0.94	0.076	0.063
Cochrane	LCT3	E99EC001809	04/05/1999	1035	0.01	0.00017	0.20	0.82	0.021	0.011
Cochrane	LCT3	E99EC001868	04/06/1999	1130	0.01	0.00034	0.10	0.74	0.037	0.019
Cochrane	LCT3	E99EC00 1998	04/09/1999	1715	0.01	0.00029	0.10	0.65	0.040	0.016
Cochrane	LCT3	E99EC001999	04/12/1999	1300	0.01	0.00036	0.10	0.70	0.029	0.013
Cochrane	LCT3	E99EC002176	04/15/1999	1030	0.01	0.00018	0.05	0.75	0.025	0.014
Cochrane	LCT3	E99EC002569	04/28/1999	1030	0.01	0.00037	0.05	0.75	0.028	0.013
Cochrane	LCT3	E99EC002810	05/06/1999	1215	0.01	0.00047	0.05	1.00	0.047	0.022
Cochrane	LCT3	E99EC003361	05/20/1999	1530	0.05	0.00225	0.05	0.99	0.039	0.016
Cochrane	LCT3	E99EC003873	06/08/1999	1130	0.01	0.00045	0.05	1.37	0.078	0.028
Cochrane	LCT3	E99EC004603	06/23/1999	1000	0.01	0.00118	0.05	1.21	0.097	0.041
Cochrane	LCT3	E99EC004767	06/29/1999	1030	0.01	0.00028	0.05	1.16	0.057	0.037
Cochrane	LCT3	E99EC005840	08/02/1999	1130	0.01	0.00015	0.05	2.32	0.241	0.071
Cochrane	LCT3	E99EC007085	08/30/1999	1615	0.06	0.00080	0.10	1.55	0.372	
Cochrane	LCT3	E99EC007915	09/19/1999	1800	0.13	0.00243	0.05	1.60	0.155	0.034
Cochrane	LCT4	E99EC001810	04/05/1999	900	0.01	0.00008	0.20	1.27	0.062	0.035
Cochrane	LCT4	E99EC001869	04/06/1999	1015	0.01	0.00010	0.10	0.90	0.034	0.029
Cochrane	LCT4	E99EC002001	04/12/1999	1330	0.01	0.00023	0.05	0.71	0.042	0.027
Cochrane	LCT4	E99EC003875	06/08/1999	1145	0.01	0.00065	0.05	1.58	0.096	0.065
Cochrane	LCT4	E99EC004605	06/23/1999	1015	0.01	0.00068	0.05	1.15	0.065	0.045
Cochrane	LCT4	E99EC004768	06/29/1999	1045	0.01	0.00012	0.05	1.17	0.055	0.044

Lake Name	Site	Spec #	Date	Time	Air Temp °C	DO mg/L	pH su	Water Temp °C	Fecal Col. counts / 100ml	Alkalinity Total mg/L	Solids, Total mg/L	Solids, Suspended mg/L	Solids, Volatile mg/L
Cochrane	LCI	E99EC002859	05/08/1999	1530	18.33	9.4	8.87	14		267	1366	10.0	5.0
Cochrane	LCI	E99EC003358	05/20/1999	1000	18.33	8.2	8.11	17	10	274	1506	182.0	16.0
Cochrane	LCI	E99EC003758	06/03/1999	1100	26.67	9.2	8.65	19	20	267	1426	8.0	5.0
Cochrane	LCI	E99EC003869	06/08/1999	1200	29.44	7.8	8.43	23	400	238	1289	23.0	7.0
Cochrane	LCI	E99EC004084	06/10/1999	1330	29.44	8.2	8.8	23	30	252	1316	8.0	1.0
Oliver	LOO	E99EC002567	04/28/1999	1000	18.33	10.0	8.56	17	5	276	1401	5.0	4.0
Oliver	LOO	E99EC002812	05/05/1999	1130	15.56	9.8	8.86	16	270	285	1370	41.0	10.0
Oliver	LOO	E99EC002962	05/12/1999	1030	18.33	9.8	8.71	14	30	276	1359	8.0	1.0
Oliver	LOO	E99EC003759	06/03/1999	1030	26.67	10.2	8.81	20	10	217	1410	6.0	4.0
Oliver	LOT1	E99EC002807	05/06/1999	1115	21.11	8.0	8.32	17	340	239	3000	8.0	2.0
Oliver	LOT2	E99EC001199	03/15/1999	1530	4.44	12.0	7.98	2	50	71	240	20.0	8.0
Oliver	LOT2	E99EC001364	03/18/1999	1300	4.44	14.0	8	2	5	155	801	15.0	6.0
Oliver	LOT2	E99EC001415	03/22/1999	1330	10.00	11.0	7.81	8	10	249	1320	286.0	68.0
Oliver	LOT2	E99EC001866	04/06/1999	1230	15.56	14.0	8.14	11	5	219	1297	3.0	1.0
Oliver	LOT2	E99EC001997	04/12/1999	1145	15.56	13.0	7.97	12	10	249	1277	3.0	2.0
Oliver	LOT2	E99EC002173	04/15/1999	945	4.44	12.0	8.31	7	5	256	1265	6.0	1.0
Oliver	LOT2	E99EC002963	05/12/1999	930	18.33	10.8	8.04	12	10	274	1393	0.5	0.5
Oliver	LOT2	E99EC003356	05/20/1999	1000	18.33	8.2	7.98	18	360	270	1228	2.0	0.5
Oliver	LOT2	E99EC003871	06/08/1999	1030	29.44	8.1	8.11	24	460	221	893	1.0	1.0
Oliver	LOT2	E99EC004602	06/23/1999	900	31.11	7.8	8.78	24	1300	263	1042	2.0	0.5
Oliver	LOT3	E99EC002808	05/06/1999	1100	21.11	8.8	8.72	17	20	208	581	4.0	0.5
Oliver	LOT3	E99EC003872	06/08/1999	1015	29.44	9.8	7.91	21	4100	135	340	17.0	3.0

Lake Name	Site	Spec #	Date	Time	Ammonia mg/L	Unionized Ammonia mg/L	Nitrate mg/L	TKN mg/L	Phosphorus Total mg/L	Phosphorus, Tot. Dissolved mg/L
Cochrane	LCI	E99EC002859	05/08/1999	1530	0.01	0.00158	0.05	1.43	0.055	0.030
Cochrane	LCI	E99EC003358	05/20/1999	1000	0.01	0.00039	0.05	1.68	0.211	0.021
Cochrane	LCI	E99EC003758	06/03/1999	1100	0.01	0.00142	0.05	1.59	0.059	0.028
Cochrane	LCI	E99EC003869	06/08/1999	1200	0.01	0.00117	0.05	2.63	0.105	0.029
Cochrane	LCI	E99EC004084	06/10/1999	1330	0.01	0.00237	0.05	1.70	0.060	0.025
Oliver	LOO	E99EC002567	04/28/1999	1000	0.18	0.01865	0.05	1.56	0.058	0.016
Oliver	LOO	E99EC002812	05/05/1999	1130	0.19	0.03348	0.10	1.83	0.087	0.019
Oliver	LOO	E99EC002962	05/12/1999	1030	0.30	0.03455	0.05	1.38	0.048	0.020
Oliver	LOO	E99EC003759	06/03/1999	1030	0.01	0.00204	0.05	1.62	0.072	0.027
Oliver	LOT1	E99EC002807	05/06/1999	1115	0.01	0.00062	0.05	2.67	0.075	0.037
Oliver	LOT2	E99EC001199	03/15/1999	1530	0.92	0.00851	2.40	4.89	0.419	0.116
Oliver	LOT2	E99EC001364	03/18/1999	1300	0.22	0.00213	0.05	1.44	0.191	0.093
Oliver	LOT2	E99EC001415	03/22/1999	1330	0.11	0.00112	0.20	1.36	0.161	0.093
Oliver	LOT2	E99EC001866	04/06/1999	1230	0.01	0.00027	0.10	0.75	0.048	0.030
Oliver	LOT2	E99EC001997	04/12/1999	1145	0.01	0.00020	0.05	0.58	0.072	0.044
Oliver	LOT2	E99EC002173	04/15/1999	945	0.15	0.00437	0.05	0.74	0.057	0.020
Oliver	LOT2	E99EC002963	05/12/1999	930	0.01	0.00023	0.05	0.72	0.023	0.018
Oliver	LOT2	E99EC003356	05/20/1999	1000	0.01	0.00032	0.05	0.70	0.022	0.017
Oliver	LOT2	E99EC003871	06/08/1999	1030	0.01	0.00064	0.05	1.07	0.109	0.086
Oliver	LOT2	E99EC004602	06/23/1999	900	0.01	0.00242	0.05	1.00	0.051	0.038
Oliver	LOT3	E99EC002808	05/06/1999	1100	0.01	0.00143	0.10	0.75	0.137	0.110
Oliver	LOT3	E99EC003872	06/08/1999	1015	0.01	0.00034	0.05	1.16	0.245	0.170

Lake Name	Site	Spec #	Date	Time	Air Temp °C	DO mg/L	pH su	Water Temp °C	Fecal Col. counts / 100ml	Alkalinity Total mg/L	Solids, Total mg/L	Solids, Suspended mg/L	Solids, Volatile mg/L
Oliver	LOT4	E99EC000991	03/02/1999	1510	1.67	15.0	7.84	0.7	5	232	981	6.0	2.0
Oliver	LOT4	E99EC001264	03/16/1999	1400	7.22	15.5	7.91	2	5	174	717	8.0	2.0
Oliver	LOT4	E99EC001808	04/05/1999	1300	4.44	10.0	7.78	7	5	287	1517	2.0	1.0
Oliver	LOT4	E99EC001867	04/06/1999	1200	18.33	11.2	7.94	9	10	241	1165	4.0	3.0
Oliver	LOT4	E99EC002000	04/09/1999	1645	10.00	11.0	7.89	11		260	1248	1.0	1.0
Oliver	LOT4	E99EC002002	04/12/1999	1030	15.56	11.0	8.03	6	5	236	1121	3.0	3.0
Oliver	LOT4	E99EC002174	04/15/1999	1000	4.44	12.8	8.24	6	5	244	1161	2.0	0.5
Oliver	LOT4	E99EC002570	04/28/1999	945	18.33	11.0	7.87	16	5				
Oliver	LOT4	E99EC002811	05/06/1999	1000	15.56	11.4	7.99	16	20	278	1307	3.0	0.5
Oliver	LOT4	E99EC003357	05/20/1999	1500	18.33	9.8	7.56	15.5	170	251	1189	2.0	1.0
Oliver	LOT4	E99EC003874	06/08/1999	1045	29.44	9.6	7.89	22	4300	233	1198	13.0	3.0
Oliver	LOT4	E99EC004604	06/23/1999	915	31.11	8.8	8.24	23	2000	201	972	5.0	1.0
Oliver	LOT4	E99EC004769	06/29/1999	900	23.89	6.4	7.68	24	650	270	1288	2.0	2.0
Oliver	LOT4	E99EC005841	08/02/1999	1030	18.33	5.0	7.45	18	1200	268	2027	4.0	0.5
Oliver	LOT4	E99EC007916	09/19/1999	1830	18.33	7.4	7.69	10		216	2253	2.0	2.0

Lake Name	Site	Spec #	Date	Time	Ammonia mg/L	Unionized Ammonia mg/L	Nitrate mg/L	TKN mg/L	Phosphorus Total mg/L	Phosphorus, Tot. Dissolved mg/L
Oliver	LOT4	E99EC000991	03/02/1999	1510	0.01	0.00006	0.05	1.07	0.106	0.026
Oliver	LOT4	E99EC001264	03/16/1999	1400	0.01	0.00008	0.20	1.37	0.135	0.058
Oliver	LOT4	E99EC001808	04/05/1999	1300	0.01	0.00009	0.30	0.90	0.020	0.018
Oliver	LOT4	E99EC001867	04/06/1999	1200	0.01	0.00015	0.50	0.03	0.063	0.790
Oliver	LOT4	E99EC002000	04/09/1999	1645	0.01	0.00015	0.05	0.80	0.042	0.031
Oliver	LOT4	E99EC002002	04/12/1999	1030	0.01	0.00014	0.05	0.78	0.057	0.029
Oliver	LOT4	E99EC002174	04/15/1999	1000	0.01	0.00023	0.05	0.87	0.032	0.025
Oliver	LOT4	E99EC002570	04/28/1999	945	0.01	0.00021	0.05	0.93	0.024	0.016
Oliver	LOT4	E99EC002811	05/06/1999	1000	0.01	0.00028	0.05	0.99	0.021	0.018
Oliver	LOT4	E99EC003357	05/20/1999	1500	0.01	0.00010	0.05	1.06	0.023	0.019
Oliver	LOT4	E99EC003874	06/08/1999	1045	0.01	0.00034	0.10	1.45	0.084	0.040
Oliver	LOT4	E99EC004604	06/23/1999	915	0.01	0.00079	0.10	1.17	0.078	0.042
Oliver	LOT4	E99EC004769	06/29/1999	900	0.01	0.00025	0.05	0.90	0.028	0.010
Oliver	LOT4	E99EC005841	08/02/1999	1030	0.01	0.00010	0.05	1.42	0.034	0.023
Oliver	LOT4	E99EC007916	09/19/1999	1830	0.01	0.00009	0.10	1.41	0.098	0.034

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