WATER QUALITY INVESTIGATION
FINAL REPORT

LAKES COCHRANE/OLIVER WATERSHED
DEUEL COUNTY, SOUTH DAKOTA

Prepared By

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Prepared for the

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INTRODUCTION

The natural outlet of Lake Oliver was obstructed by a network of roads and other residential development activities established around Lake Cochrane in the early 1960s. Lake Oliver eventually experienced high water levels which resulted in flooding of adjacent roads, the state recreation area and residential property. The first documented flood event occurred in 1987 with additional occurrences in 1993 and 1995.

Natural outflow from Lake Oliver to Lake Cochrane was permanently restored in 1997 following construction of a controlled outlet structure. The outlet structure is authorized by Flood Control Permit FC-23 which was approved by the state Water Management Board for the Department of Game, Fish and Parks. The permit contains several limitations, conditions and qualifications to address potential water quality concerns by restricting Lake Oliver water from entering Lake Cochrane during months when algae blooms may occur.

The permit (FC-23) contains the following operating criteria in the interest of Lake Cochrane water quality:

- The control structure will remain open October 16 through June 14 to lower the Lake Oliver water level to the established outlet elevation of 1683.6 fmsl.

- The control structure will be closed June 15 through October 15 and Lake Oliver water will be stored up to an elevation of 1685.0 fmsl.

- When an elevation of 1685.0 fmsl is reached, water will spill uncontrolled over the weir. If a precipitation event occurs during June 15 through October 15 that causes flow over the weir to reach an elevation of 1685.3 fmsl, the control structure will be opened until Lake Oliver attains an elevation of 1684.3 fmsl.

Many Lake Cochrane residents disagreed with FC-23, in particular, the decision to restore the natural outflow of Lake Oliver to Lake Cochrane. Most claimed that water from Lake Oliver would degrade the high-quality condition of Lake Cochrane. The Department of Environment and Natural Resources (DENR) was sensitive to the allegations and incorporated Lake Cochrane into annual lake sampling efforts to investigate potential changes in the water quality over time.

DENR also conducted a watershed scale water quality assessment study in 1999 (DENR, 2000). This comprehensive study documented tributary and lake water quality and recommended best management practices to protect Lakes Cochrane and Oliver. DENR later provided financial and technical assistance to the Deuel County Conservation District to support a watershed restoration project. The project started in 2002 and concluded in 2005. A final report documenting all completed activities is available at: http://denr.sd.gov/dfta/wp/TMDL/TMDLCochraneOliverImpl.pdf

DENR regularly communicates with the Lake Cochrane Improvement Association (LCIA) to provide updated information regarding water quality of Lake Cochrane. In addition, DENR has provided technical assistance for water quality monitoring, phosphorus management and guidance on permit processes. The general focus has been on phosphorus inputs from Lake Oliver, though discussions have recently involved a suite of other sources within the Lake Cochrane watershed. Information gained by the LCIA is relayed to local residents.

Several local residents claim Lake Oliver outflow has increased phosphorus levels in Lake Cochrane resulting in more algae blooms, dense aquatic plants and decreased water clarity. The objective of this investigative report is to document and explain the potential impacts, if any, concerning Lake Oliver outflow on water quality and ecology of Lake Cochrane over the past several years.

WATER QUALITY DATA

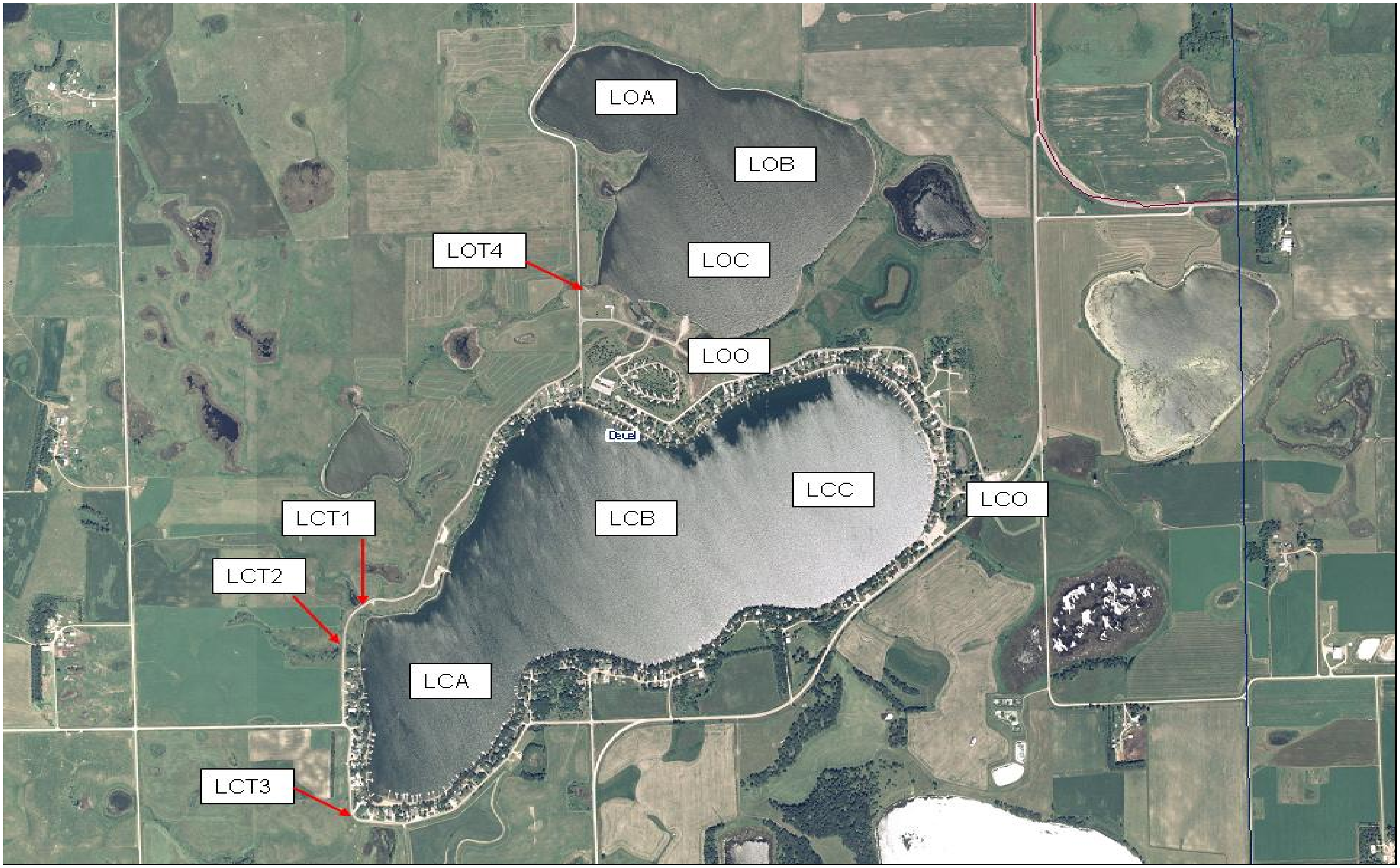
DENR considers Lake Cochrane one of the most intensively sampled lakes in South Dakota. Several sources of data were used to generate the results of this investigative report. DENR used data from sampling efforts conducted over the past 20 years including data from annual sampling visits, 1999 assessment study, 2002 restoration project and the national lakes survey.

Continuous water level recorders were installed at the Lake Oliver and Lake Cochrane outlets in 2008. The water level measurements were calibrated to the outlet elevation at feet mean sea level (fmsl) for each of the respective outlet structures. A weir equation designed for the Lake Cochrane outlet was used to convert the average daily water level measurements to an average daily flow rate. The daily flows were summed for the total recorded flow period (water above 1682.6 fmsl) to quantify a total annual flow volume.

A regression equation was used to predict the flow rate at different elevations through the Lake Oliver outlet structure. The linear regression equation was derived from paired elevation and flow rate data established during the design of the outlet structure.

The LCIA established a water quality committee to conduct water quality sampling. The committee members sampled locations consistent with those established by DENR (See Map on page 4). The water quality sampling was a component of a larger project to provide information and education regarding nutrients and nutrient reductions within the Lake Cochrane watershed. The majority of data used in the generation of this report, in particular, data from 2008 and 2009 was collected by the water quality committee.

John Appelen a retired civil and agricultural engineering consultant and hydrologist conducted water sampling, performed flow estimates and constructed a water-nutrient balance for 2007. Values generated by Mr. Appelen were used when appropriate.



Map depicting monitoring sites for studies conducted within the Lake Cochrane watershed overlaid on 2008 aerial imagery

RESULTS AND DISCUSSION

Lake Oliver Outlet Phosphorus

The phosphorus concentrations associated with Lake Oliver outflow to Lake Cochrane have shown improvement since 1999 (Table 1). During the 1999 assessment study, common carp were frequently observed near the upstream end of the outlet structure. The resulting carp activity contributed to increased suspended solids and associated phosphorus concentrations. The carp issue was resolved when a dense stand of cattails established in the wetland area between the main lake and the outlet structure. The cattails provide a restrictive barrier impeding carp from staging near the outlet structure. Cattails also sequester nutrients and slow sediment movement. The average phosphorus concentration from Lake Oliver outflow for samples collected after 1999 was 0.052 mg/L with a standard deviation of +/- 0.02 mg/L. In addition, suspended solids concentrations were very low with many values below the SD State Health Laboratory detection limit (<3 mg/L) indicating clear water with little to no solids.

Table 1. Phosphorus and suspended solids concentrations from Lake Oliver outflow.

Sample Date	Total Phosphorus (mg/L)	Total suspended solids (mg/L)
04/28/1999	0.058	5
05/05/1999	0.087	41
05/12/1999	0.048	8
06/03/1999	0.072	6
05/08/1999	0.055	10
05/20/1999	0.211	182
06/03/1999	0.059	8
06/08/1999	0.105	23
06/10/1999	0.06	8
04/10/2006	0.063	Na
03/28/2007	0.022	5
03/28/2007	0.038	4
04/02/2007	0.044	7
04/02/2007	0.075	<3
04/15/2007	0.044	Na
05/18/2007	0.03	Na
04/21/2008	0.09	4
05/12/2008	0.036	3
05/20/2008	0.062	Na
06/05/2008	0.072	<3
03/21/2009	0.081	<3
04/11/2009	0.062	<3
04/25/2009	0.032	<3
05/10/2009	0.029	<3

Grey bar indicates common carp were present when sample was collected

The phosphorus load from Lake Oliver to Lake Cochrane was directly measured in 1999, 2007, 2008 and 2009 (Table 2). The phosphorus loads were variable ranging from 28.5 pounds to 7 pounds. The measured phosphorus loads were used to estimate a phosphorus load for all years since the outlet was constructed.

Table 2. Years depicting actual measured phosphorus load from Lake Oliver to Lake Cochrane.

Year	1999	2007	2008	2009
LOO P-Load	19.3 lbs.	28.5 lbs	20.7 lbs	7 lbs
Source	DENR	John Appelen	DENR/LCIA	DENR/LCIA

Annual precipitation was used to determine the potential phosphorus load from Lake Oliver in years when the load was not directly measured. Average annual precipitation data was acquired from Clear Lake, South Dakota through the co-op extension with the climate center at South Dakota State University. The average annual precipitation values were paired with the measured phosphorus loads from Lake Oliver. A strong linear relationship (R^2=0.89) was observed with the four paired observations (Figure 1). This relationship indicates that nearly 90% of the variability in Lake Oliver phosphorus loading can be explained by precipitation. This makes sense given the fact that more precipitation equates to higher lake levels, more outflow and higher phosphorus loading.

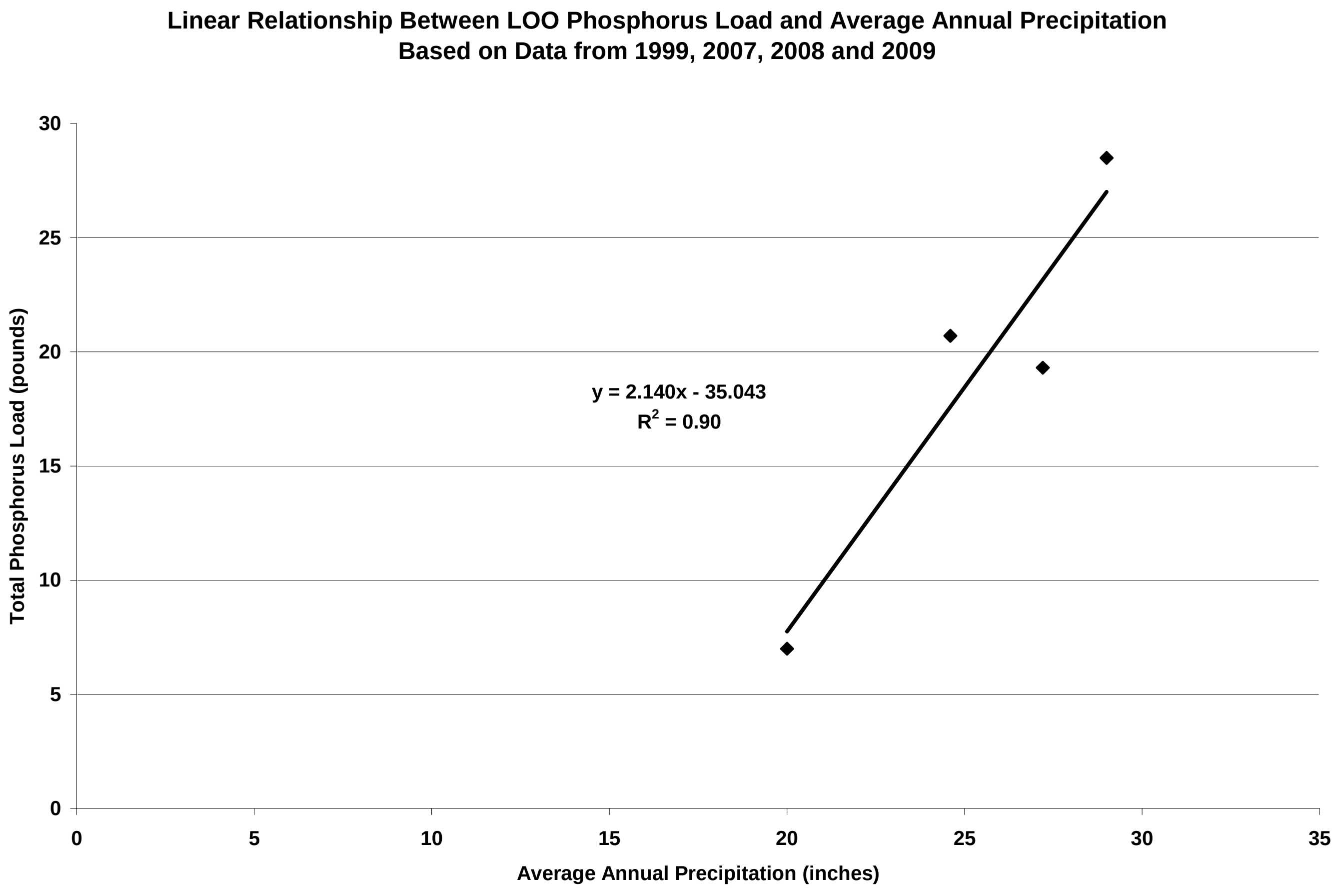


Figure 1. Linear relationship between measured Lake Oliver outlet phosphorus loads and average annual precipitation.

The regression equation (y=2.140x-35.043) derived from the line on the graph (figure 1) was used to determine Lake Oliver's annual phosphorus loading (y) based on annual precipitation (x) values for the past 13 years. The resultant phosphorus loads from 1997 through 2009 are presented in Table 3. Additional paired observations between Lake Oliver phosphorus load and annual precipitation would help strengthen this relationship.

Table 3. Estimated annual phosphorus load from the Lake Oliver outlet to Lake Cochrane over the past 13 years.

Year	Total Phosphorus. Load (pounds)
1997	20.9
1998	18.3
1999	**19.3**
2000	7.6
2001	29.4
2002	8.1
2003	5.2
2004	34.9
2005	28.2
2006	18
2007	**28.5**
2008	**20.7**
2009	**7**
Average Annual P	**18.9**

Actual measure values are shaded

The estimated annual phosphorus loads from Lake Oliver varied significantly, ranging from 35 pounds to 5 pounds. The average annual phosphorus load from Lake Oliver was calculated at 18.9 pounds. John Appelen estimated that Lake Oliver contributes a net gain of 15.2 pounds of phosphorus to Lake Cochrane on an average annual basis. Considering Lake Cochrane lost (LCO) approximately 4 pounds of phosphorus during 2 relatively average precipitation years (1999 and 2008) it is suspected that this estimate is reasonably accurate. Assuming an average annual net gain of 15.2 pounds equates to roughly 200 pounds of phosphorus retained by Lake Cochrane from Lake Oliver over the past 13 years.

The total water volume of Lake Oliver is approximately 1,500 acre-feet. The water volume associated with the estimated average annual phosphorus load (18.9 pounds) equates to an average annual water volume from Lake Oliver of 115 acre-feet. Multiplying 115 acre-feet by 13 years equates to roughly 1,500 acre-feet. Therefore, it is suspected that Lake Oliver has experienced a complete flush or replacement of water since outflow was restored in 1997. Lake Cochrane's flushing rate was not estimated for this investigation though Lake Oliver's inflow contribution has increased the flush rate of Lake Cochrane. Outflow is the only natural way for Lake Cochrane to expel phosphorus, sediment and other water quality constituents that promote productivity. Lake Cochrane experienced minimal outflow prior to the re-introduction of Lake Oliver which caused the lake to become saline (salty) or slightly brackish as indicated by elevated conductivity (1800 plus micro grams per centimeter) and the weak tea stained appearance.

Tributary Phosphorus

Tributaries also provide a source of phosphorus loading to Lakes Cochrane and Oliver. A small drainage to Lake Cochrane (LCT2) and the largest drainage to Lake Oliver (LOT4) have received considerable attention over the past 3 years (2007-2009). Both tributaries present unique situations that have warranted further monitoring.

Sampling efforts have focused on LCT2, despite the small drainage area. This tributary was identified as producing high phosphorus concentrations (DENR 1999). The average phosphorus concentration from 20 samples collected in 1999 was 0.184 mg/L. The average phosphorus concentration from 12 samples collected 2007 through 2009 was 0.222 mg/L.

The LCT2 drainage has a sediment retention pond with a standpipe initially constructed with the road infrastructure in the mid 1970's. This sediment basin was dredged and the standpipe was replaced during the restoration project in 2004. The sediment basin was designed to capture sediment while providing a potential nutrient reduction benefit. Initial sampling efforts on LCT2 following construction of the sediment pond revealed little benefit in nutrient reduction which is apparently still the case today (Haertel, 1978). This drainage supplies continuous low volume flow from an upstream spring. The spring fed nature of this drainage makes it difficult to drawdown the sediment pond to allow for storage as originally intended. Land-use in the drainage area is predominately agriculture which may contribute to the higher phosphorus concentrations. During the 1999 assessment study, LCT2 contributed only 2% of the hydrologic load to Lake Cochrane though 18% of the phosphorus load.

The tributary LOT4 was considered important because it contributes the largest drainage area to Lake Oliver. In addition, land-use near the downstream portion of the drainage was converted from grassland and hay ground to a golf course. The average phosphorus concentration from 12 samples collected in 2007 through 2009 prior to the official operation of the golf course was 0.06 mg/L. This is consistent with the average phosphorus concentration calculated during the 1999 assessment study (0.056 mg/L). The LOT4 drainage was estimated to contribute 2 pounds of phosphorus to Lake Oliver from 12.5 acre-feet of water volume in 2009. Future monitoring efforts should be conducted to evaluate the potential impact, if any, the golf course may have on the baseline average phosphorus concentration. Increased phosphorus concentrations will contribute to a higher loading potential to Lake Oliver.

The remaining tributaries to both lakes either contribute insignificant volume or have some best practical measure in place to minimize phosphorus loading. The LCT3 drainage is the largest direct drainage to Lake Cochrane. During the 1999 assessment study it was estimated that LCT3 and LOO contributed 78% of the annual phosphorus load to Lake Cochrane. Both these tributaries have mechanisms in place to slow nutrient and sediment inputs to Lake Cochrane.

The total phosphorus load from all the main Lake Cochrane tributaries was estimated for 2007, 2008 and 2009. The actual measured loads from the Lake Oliver outlet were used to provide a starting point to back-calculate the remaining tributary loads based on the percent phosphorus load contribution calculated during the 1999 assessment study (Table 4).

Table 4. Estimated phosphorus loads for the main Lake Cochrane tributaries for 2007, 2008 and 2009.

	1999	*2007*	*2008*	*2009*	
Site	Total P (pounds)	Total P (pounds)	Total P (pounds)	Total P Load (pounds)	Percent Contribution
LCT1A	0.06	0.07	0.051	0.02	0.1
LCT1	0.84	1.3	0.86	0.3	1.7
LCT2	9.1	13.5	9.2	3	18.3
LCT3	19.4	28.6	19.6	7	38.9
LCT4	1.1	1.6	1.1	0.4	2.2
LOO	19.3	28.5	20.7	7	38.8
Total	**49.8**	**73.5**	**50.5**	**17.7**	**100**

Grey signifies actual measured phosphorus loads

Suspended Solids

The cumulative suspended solids loading to Lake Cochrane was considered insignificant during the 1999 assessment study. However, the Lake Oliver outlet contributed 80% of the suspended solids loading to Lake Cochrane. The load was attributed to common carp activity near the upstream end of the outlet structure. As aforementioned, carp are no longer a factor and suspended solids concentrations have shown significant improvement. The average suspended solids concentration from Lake Oliver in 1999 was 32 mg/L. The average suspended solids concentration from samples collected in 2007, 2008 and 2009 was just below the health lab detection limit of 3 mg/L.

The average suspended solids concentration (2007-2009 data) from the largest direct drainage (LCT3) to Lake Cochrane was 6.3 mg/L, which is considered very low. The highest suspended solids concentrations were observed (average= 14 mg/L) from LCT2 though considered insignificant given the low annual water volume contribution. Overall, the annual suspended solids loading to Lake Cochrane is minimal. Suspended solids loading to Lake Oliver is also minimal. However, land-use in the Lake Oliver watershed has been recently undergone significant transformation, which could have an impact on suspended solids loading in the future.

Lake Cochrane Phosphorus

The growing season represents samples collected May through September. The bulk of available phosphorus data for Lake Cochrane was collected during the peak recreational season in June, July and August. Phosphorus data was available for May and September though limited to only 1999, 2008 and 2009. Therefore, the average growing season represents data collected in June, July and August. For comparison, the average May and September phosphorus concentrations were calculated at 0.024 mg/L and 0.031 mg/L, respectively.

The average growing season (June through August) phosphorus concentration of Lake Cochrane has remained steady too slightly improved since Lake Oliver outflow was restored to Lake Cochrane (Figure 2). The average phosphorus concentration of Lake Cochrane prior to the reintroduction of Lake Oliver (1989-1997) was calculated at 0.037 mg/L. The average phosphorus concentration subsequent to the reintroduction of Lake Oliver was calculated at 0.027 mg/L. This suggests that the minor phosphorus loads from Lake Oliver have had no significant impact on the phosphorus level of Lake Cochrane over the past 13 years.

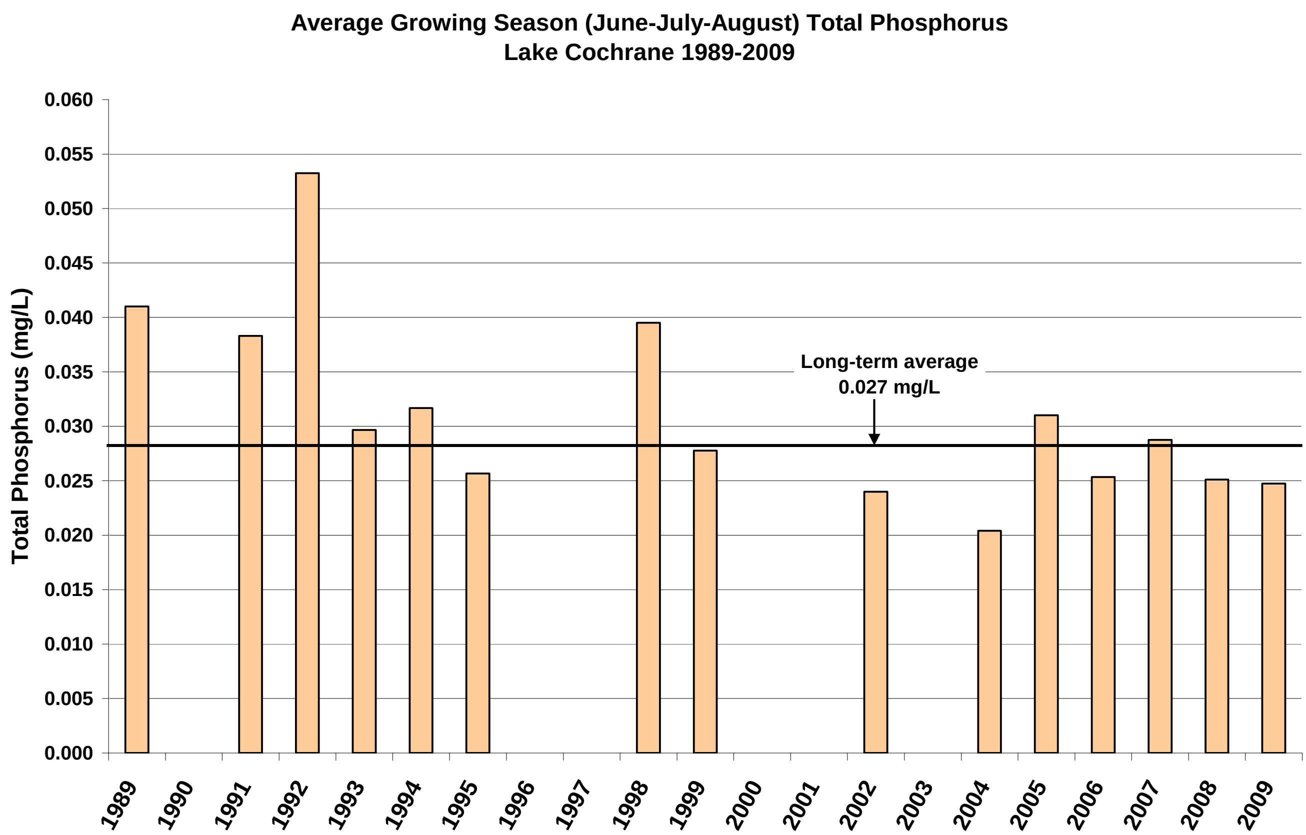


Figure 2. Average growing season phosphorus concentrations for Lake Cochrane 1989-2009.

Growing season phosphorus data collected on Lake Cochrane in 1970 and 1972 was used as a baseline for comparison. Historic phosphorus data was acquired from a peer-reviewed scientific publication produced by Dr. Lois Haertel a former limnologist and professor from South Dakota State University. Phosphorus samples were collected in locations consistent with sites LCB and LCC. The average phosphorus concentration in 1970 and 1972 was 0.026 mg/L and 0.022 mg/L, respectively (Table 5).

Table 5. Baseline phosphorus data collected by Dr. Lois Haertel 1970-1972.

Year	***1970***	***1971***	***1972***
Phosphorus (PO_4-P)	**0.026 mg/L**	0.097 mg/L	**0.022 mg/L**

Haertel (1976)

A reasonable baseline phosphorus concentration based on data from 1970 and 1972 suggests Lake Cochrane likely ranged from 0.02 mg/L to 0.03 mg/L. The average phosphorus concentration from all samples (May-September) collected in 2008 and 2009 was 0.026 mg/L, which is consistent with phosphorus concentrations observed nearly 40 years ago. This again indicates that Lake Oliver has had no impact on the phosphorus levels of Lake Cochrane since the outlet was restored.

The average growing season phosphorus concentration from 1971 was 0.097 mg/L. This value is an order of magnitude higher than any concentration observed over the past 20 years. Haertel (1976) attributed this uncharacteristic concentration to careless shoreline construction practices conducted during residential development. Dr. Haertel actually witnessed soil being bulldozed into the lake during a 1971 sampling visit. This phosphorus concentration contributed to the first documented blue-green algae bloom observed on Lake Cochrane. Lake Cochrane recovered rather quickly as the phosphorus concentration and associated blue-green algae dramatically receded by 1972.

The relatively elevated phosphorus concentrations in Lake Cochrane prior to Lake Oliver inflow was likely the result of numerous environmental factors. It is suspected that Lake Cochrane endured significant nutrient and sediment inputs from tributaries prior to the construction of sediment dams in the mid-1970s. Much of the sediment that entered from the main tributaries is still evident along the west and southwest portion of the lake. This area also harbors a very dense aquatic plant community.

In most years, Lake Cochrane receives a small amount of annual phosphorus loading. Annual changes in Lake Cochrane water quality and ecology are more likely the result of variable climate and internal nutrient dynamics associated with past nutrient inputs from agricultural run-off via the tributaries, shoreline development, early sewer systems, leaf matter, watercraft and other historic inputs that are still present within the lake basin. These factors likely mask the relatively low annual phosphorus loads received from Lake Oliver over the past 13 years.

Precipitation and Phosphorus

Annual precipitation contributes a significant portion of Lake Cochrane's hydrologic budget. In 1999, precipitation was estimated to contribute 67% of Lakes Cochrane's annual hydrologic budget (DENR 2000). The average annual precipitation for Lake Cochrane is approximately 25 inches according to long-term records acquired from the Clear Lake, SD.

Precipitation provides a source of phosphorus loading to receiving waterbodies. As rain or snow falls from the atmosphere it picks up dust particles which contain phosphorus. The actual phosphorus concentration in precipitation is variable though scientific research suggests a concentration of 0.003 mg/L is appropriate when applied to a volume or cumulative annual precipitation.

Using an average annual precipitation value of 25 inches over the surface area of Lake Cochrane (366 surface acres) equates to 732 acre-feet of volume. Applying 0.003 mg/L of phosphorus to 732 acre-feet yields an average annual phosphorus load of 6 pounds. This uncontrollable natural source of phosphorus is rather insignificant on an annual basis. Lake Oliver's estimated average annual phosphorus contribution to Lake Cochrane is only 3 times higher than the average annual phosphorus load associated with precipitation. This puts some perspective on the relatively low phosphorus contribution from Lake Oliver and the watershed in general.

Chlorophyll-*a*

Chlorophyll-*a* is a quantified measure of the green pigment found in free-floating algae. In general, increases in chlorophyll-*a* represent an increase in algae biomass. The average growing season (May-September) chlorophyll-*a* concentrations have declined consistently since 2001 in Lake Cochrane (Figure 3). The average chlorophyll-*a* concentrations were exceptionally low from 2007 through 2009. In general, the chlorophyll-*a* levels observed on Lake Cochrane are not representative of nuisance scale algae blooms. The decreasing trend in chlorophyll-*a* over the past several years implies that watershed phosphorus loads including that from Lake Oliver have not contributed to increased algae biomass in Lake Cochrane.

The chlorophyll-*a* data is not necessarily representative of all conditions that occur on Lake Cochrane during the open water season. Lake Cochrane is capable of producing nuisance level algae blooms which have been commonly reported to occur in the late summer or early fall following degradation of the resident plant community. However, the chlorophyll-*a* data suggests that algae blooms occur infrequently and are likely of short duration.

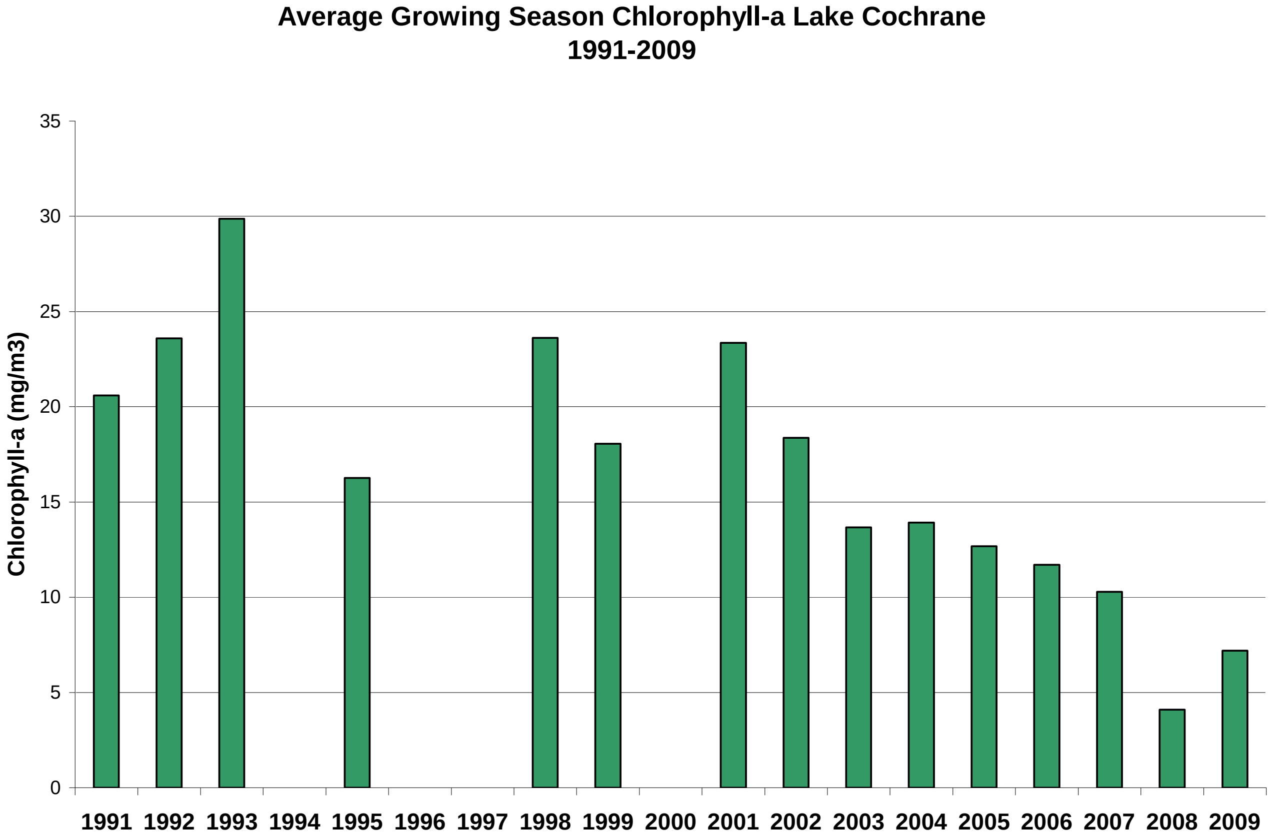


Figure 3. Average growing season chlorophyll-*a* concentrations for Lake Cochrane 1991-2009

Secchi Depth-Water Clarity

Secchi depth transparency is a measure of water clarity. Water clarity can be impeded by biological material such as particles associated with plants, algae or other aquatic organisms or by inorganic turbidity such as soil or clay particles in suspension. In general, the higher the Secchi depth value the greater the water clarity.

The average annual Secchi depth measurements on Lake Cochrane have been variable over the past nearly 40 years (Figure 4). Average growing season (May-September) Secchi depth ranged from a low of 3 feet to a high of just over 14 feet. Despite considerable variability, the Secchi depth has improved in Lake Cochrane in recent years. Water clarity is conducive to the aquatic plant community as plants require adequate sunlight to conduct photosynthetic processes. The Secchi depth has remained consistent if not slightly improved from the 1970's (Haertel, 1978), which further implies Lake Oliver has not had a major impact on the water clarity of Lake Cochrane.

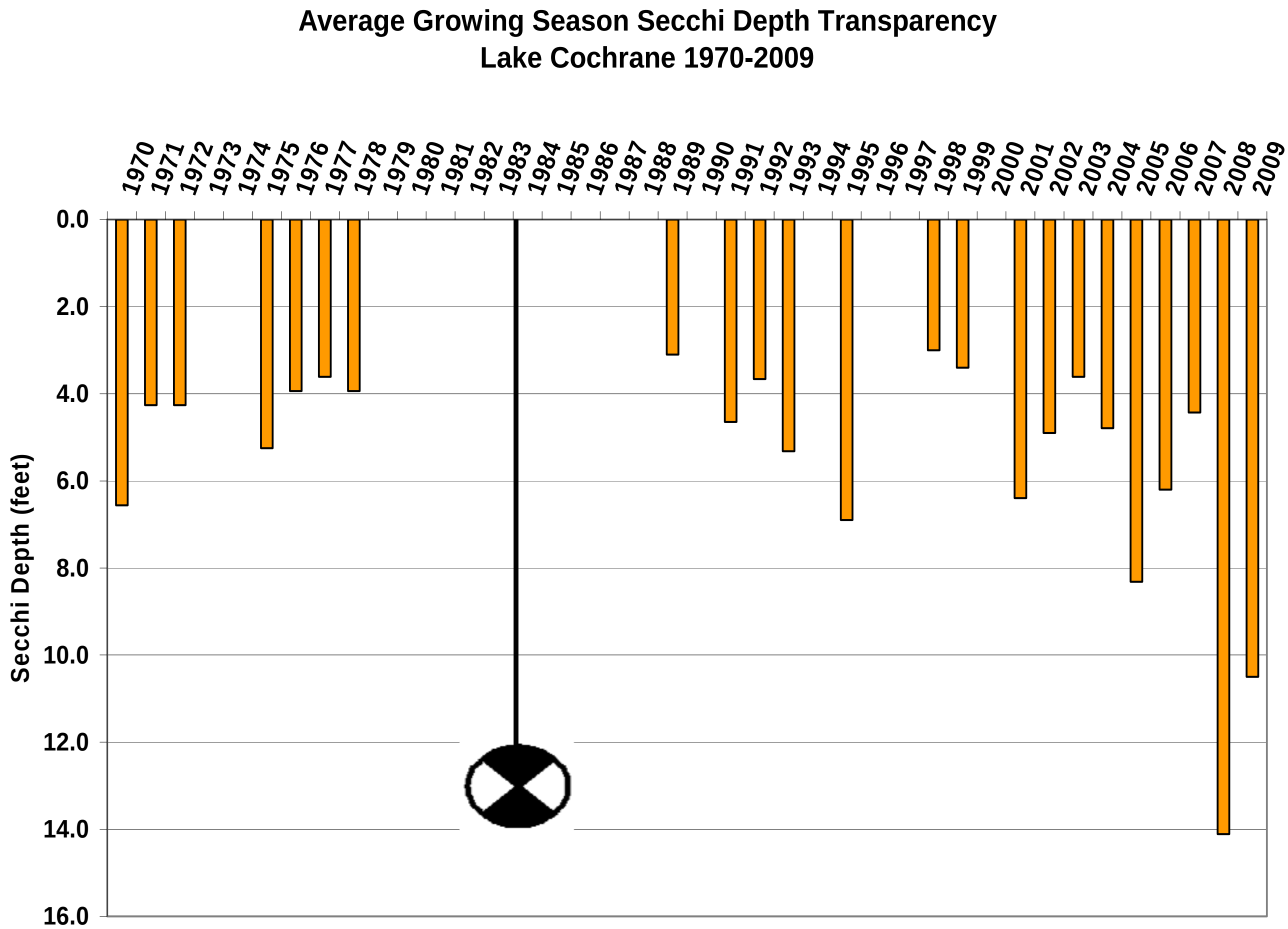


Figure 4. Average growing season Secchi depth for Lake Cochrane 1970-2009. Data from 1970-1978 acquired from Haertel, 1978.

Aquatic Plant Community

The plant community in Lake Cochrane has been established for many years. It is unknown exactly when the aquatic plants established in Lake Cochrane. Some local residents claim aquatic plants have inhabited Lake Cochrane for at least 40 years. Therefore, it is highly likely the aquatic plant community established sometime in the 1970s. Shoreline altering development and associated pollution sources such as sediment erosion, lawn fertilization and potential sewage issues likely laid the foundation for the current dense aquatic plant community.

The main tributaries (LCT1, LCT2, &LCT3) also contributed excessive sediment to Lake Cochrane prior to the construction of sediment basins in the mid 1970s. Legacy sediment is still evident in the west and southwest portions of the lake. This area of Lake Cochrane has a very dense community of aquatic plants. Aquatic plant surveys were conducted on

Lake Cochrane in 1999 and 2003. Both surveys concluded Lake Cochrane contained a dense and fairly diverse community of aquatic plants.

Aquatic plants were present at all depths over nearly the entire surface area of Lake Cochrane. Four species of aquatic plants were documented in Lake Cochrane. *Chara* sp. commonly referred to as Muskgrass or Stonewart was the most abundant aquatic plant. This "aquatic plant" is actually an algae species with physical plant-like features. *Chara* sp. in Lake Cochrane has a gritty texture from lime deposits indicative of hardwater or brackish lakes. *Chara* sp. typically reaches a maximum height of 1 meter, making it relatively inconspicuous in deeper water in the main basin.

Three other species of aquatic plant were identified in Lake Cochrane. Sago pondweed (*Potamogeton pectinatus*) and coontail (*Ceratophyllum desmersum*) common to many South Dakota lakes was found in relatively moderate density. A rare species of widgeon grass (*Ruppia* sp.) was found at low density. The water quality and physical structure of Lake Cochrane provides a favorable condition for both Chara sp. and Ruppia sp. which are relatively rare in South Dakota lakes. These species likely favor the hardwater or slightly brackish condition of Lake Cochrane resulting from minimal outflow over several decades.

Aquatic plants likely out-compete algae for nutrients and thus keep the incidence of prolific blooms in check. Water clarity is an important component for the health of aquatic plants as they need adequate sunlight to carry out photosynthetic processes. The plant community provides many ecological benefits to the biological community in Lake Cochrane. Because the plant community was well established and dense prior to the restoration of Lake Oliver outflow it is difficult to determine the actual impact, if any, the annual nutrient loads have had on plant productivity. The relative high density of the plant community indicates the lake is very productive.

Dissolved Oxygen

Dissolved oxygen is an important water quality element. Aquatic organisms such as invertebrates and fish rely on dissolved oxygen for survival. Dissolved oxygen is an important factor in phosphorus migration from bottom sediments. Bacteria use dissolved oxygen in the decay process of plants and algae. Lake Cochrane is susceptible to periodic low dissolved oxygen concentrations, due in large, to annual decomposition processes associated with the dense aquatic plant community.

Members of the water quality committee at Lake Cochrane collected dissolved oxygen measurements throughout the water column at three locations (LCA, LCB & LCC) monthly May through September in 2008 and 2009. Results indicated that Lake Cochrane maintained well oxygenated conditions in both years, respectively. On one occasion (July 2009), oxygen levels fell just below 5 mg/L throughout the water column. The lower values did not indicate severe oxygen depletion or anoxic conditions. The highest risk for low dissolved oxygen likely occurs in the fall and winter when bacterial decomposition of the plant community is most prominent.

Low dissolved oxygen near the sediment water interface can promote the release of phosphorus from sediments. Phosphorus released from the sediments can migrate throughout the water column, especially in well-mixed (wind and wave action) shallow lakes. In deep lakes, oxygen migration can be impeded by thermal stratification or the zone where water temperatures become colder near the bottom of the lake. Denser colder water acts as a barrier impeding the migration of phosphorus. Thermal stratification was not evident in Lake Cochrane (2008 and 2009) even at the deepest location. The incidence of thermal stratification on Lake Cochrane is rare and limited to days when the winds are relaxed.

The plant community in Lake Cochrane reduces the risk of phosphorus migration from the sediments during the growing season. Plants release oxygen into the water column minimizing the risk of low oxygen (<2 mg/L) conditions near the sediment water interface. Plants also provide a protective barrier between the bottom sediments and upper water column minimizing the potential for wind driven agitation to migrate phosphorus into the upper water column. In addition, the dense plant community requires a significant amount of phosphorus annually from the sediments for growth and maintenance, which limits availability to algae.

The bottom sediments in Lake Cochrane are likely rich in nutrients, in particular phosphorus due to historical inputs from natural and human induced sources. A combination of the current low annual phosphorus loading and internal controls (i.e., plant community and depth) that limit phosphorus recycling from the sediments are all mechanisms that shape the current ecology of Lake Cochrane. While the plant community provides many positives and negatives, disturbing the current ecological balance of Lake Cochrane could promote the increased risk of blue-green algae domination common of many prairie lakes in eastern South Dakota. Lake Cochrane's complex limnology and ecology makes it is difficult to predict the long-term effect, if any, that Lake Oliver will have on Lake Cochrane. However, the data provides no significant evidence that outflow from Lake Oliver has negatively impacted the water quality or ecology of Lake Cochrane over the past 13 years.

Nitrogen

The primary nutrient of concern for Lake Cochrane and Oliver has historically focused on phosphorus rather than nitrogen. Nitrogen is often overlooked due to its ubiquitous nature. Haertel (1976) reported that inorganic nitrogen was correlated to algae biomass in Lake Cochrane in the early 1970s. Most of the nitrogen in Lake Cochrane is in the organic form tied up in plant biomass. Therefore, algae growth in the summer months may be limited by available nitrogen. As plants die in late summer and early fall, Lake Cochrane commonly experiences an algae bloom. These blooms are likely the result of available inorganic nitrogen (nitrates and ammonia) as well as phosphorus released from decaying plant matter. To the contrary, the rather dense plant community out-competes algae for nutrients during the peak recreation season keeping prolific algae blooms from forming.

Lake Oliver

Lake Oliver receives very little phosphorus loading from its small watershed. In 2009, it was estimated that LOT4 contributed 2 pounds of phosphorus to Lake Oliver at an average concentration of 0.06 mg/L. During the 1999 assessment study LOT4 was estimated to contribute 57% of the total phosphorus load to Lake Oliver. Therefore, it was estimated that Lake Oliver received approximately 4 pounds of phosphorus from the main tributaries in 2009.

The average growing season (June through August) phosphorus concentrations of Lake Oliver has been stable with slight improvement over the past 4 years (Figure 5). Most of the Lake Oliver watershed was taken out of agricultural production and planted to native grasses as part of the Conservation Reserve Program (CRP). The improved phosphorus concentrations displayed by Lake Oliver in recent years, is likely a response of low annual phosphorus loading associated with CRP, coupled with restored outflow. A change in land-use practices is currently ongoing in the Lake Oliver watershed as most CRP contracts expired in 2007.

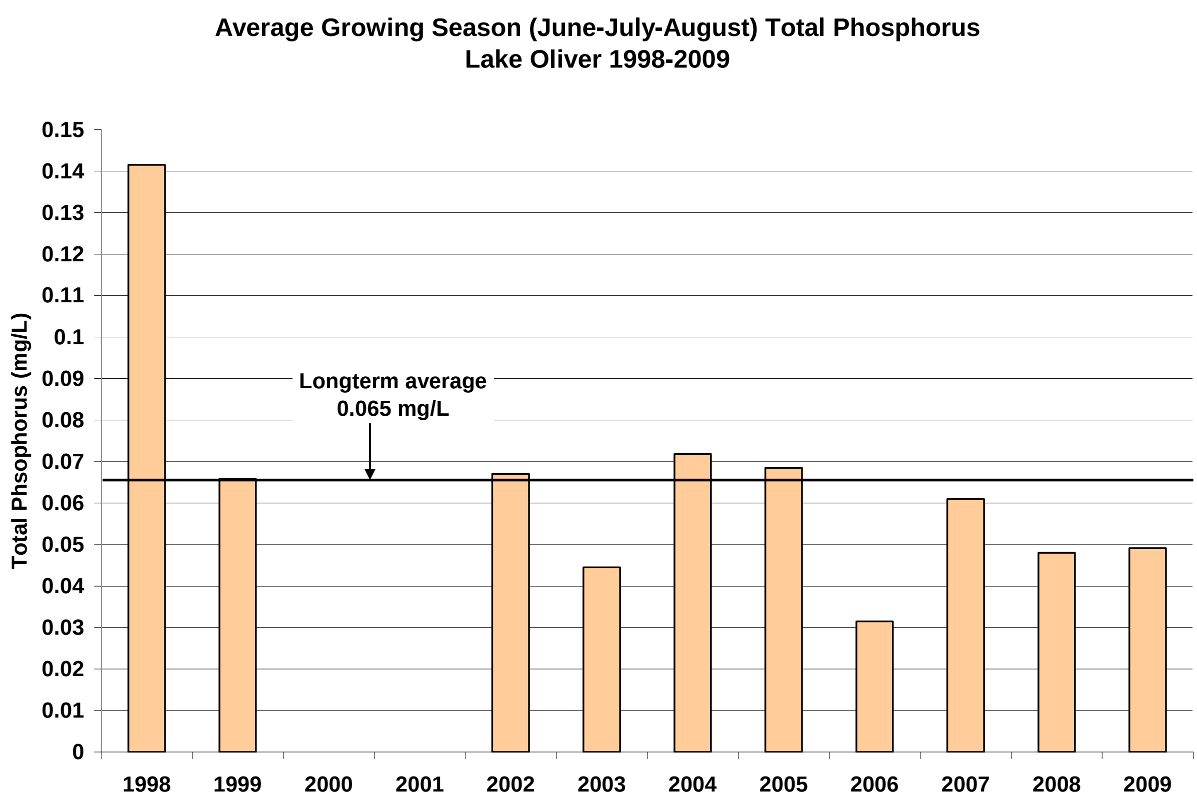


Figure 5. Average growing season phosphorus concentration from Lake Oliver 1998-2009.

The average growing season chlorophyll-*a* concentrations (May through September) in Lake Oliver have slightly declined since 1999 with the exception of 2007 (Figure 6). Summer algal biomass has been moderate to low over the past 10 years. Summer chlorophyll-*a* concentrations are not representative of concentration expected in April, May and early June when outflow from Lake Oliver occurs to Lake Cochrane. The average chlorophyll-*a* concentration for Lake Oliver in April-May of 2008 and 2009 was calculated at 6.2 mg/m^3.

Limiting outflow from Lake Oliver to spring and early summer has reduced the potential of releasing moderate algae blooms to Lake Cochrane. Flow exchange from Lake Oliver has typically been clear with minimal solids including algae. Allowing outflow to occur in spring reduces the chance of outflow in the summer months when algae biomass may be at moderate levels.

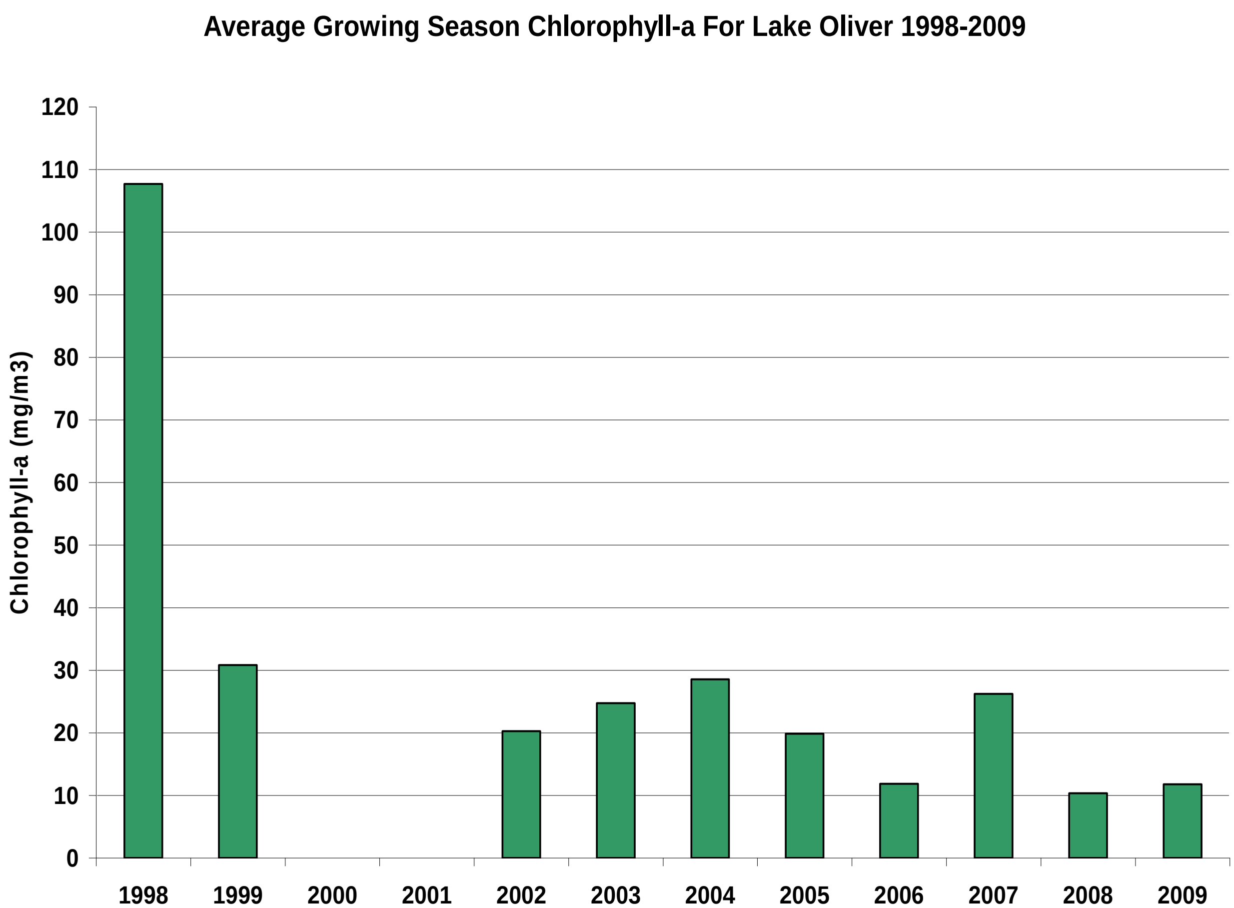


Figure 6. Average growing season chlorophyll-a concentrations for Lake Oliver 1998-2009.

The average growing season (May through September) Secchi depth measurements for Lake Oliver have been relatively steady over the past several years, with considerable improvement displayed in 2008 and 2009 (Figure 7). The water clarity of Lake Oliver is expected to be exceptionally better in the spring when algal abundance in Lake Oliver is relatively low. The main source of spring turbidity in Lake Oliver is likely inorganic sediment caused by wind and wave action. Water that exits Lake Oliver travels through a small wetland area between the main lake basin and the outlet structure which is congested with cattails. Dense cattails provide a mechanism for reducing sediment transport from Lake Oliver. As a result, spring outflow from Lake Oliver is generally of exceptional clarity supported by the low suspended solids concentrations observed from samples collected in 2007, 2008 and 2009.

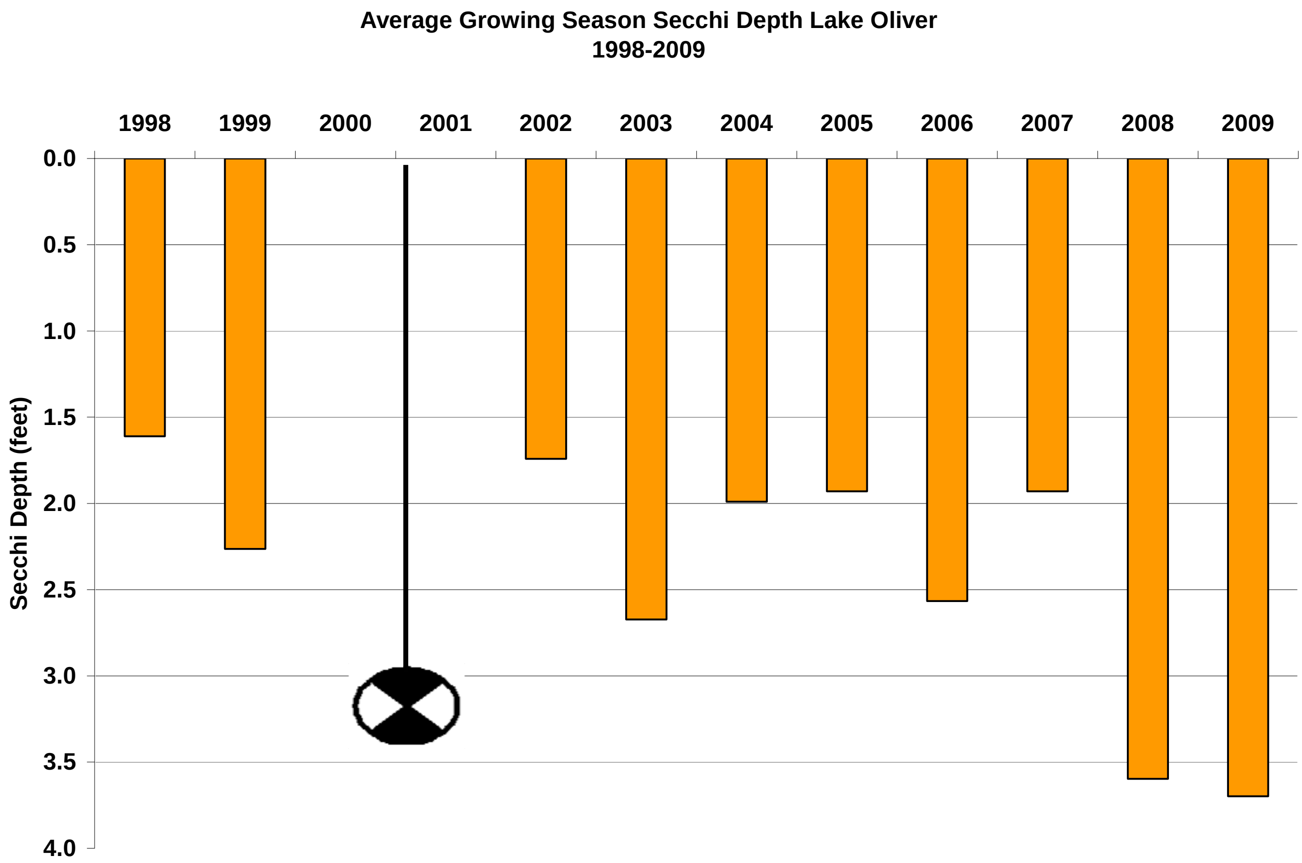


Figure 7. Average growing season Secchi depth measurements for Lake Oliver 1998-2009

CONCLUSION

The perception that Lake Oliver would degrade the high-quality condition of Lake Cochrane probably stemmed from flood conditions that occurred in the mid 1990's. During initial flood conditions the county installed temporary culverts to provide outflow from Lake Oliver to Lake Cochrane. The initial outflow from Lake Oliver was essentially unregulated. Several mechanisms are currently in place to minimize nutrient and sediment loading from Lake Oliver. Flood control permit FC-23 provides qualifications to limit inflow from Lake Oliver to spring and early summer when algae and associated nutrients are at a minimum. Dense cattails established in the small wetland between the main Lake Oliver basin and the outlet structure trap and sequester nutrients and sediment reducing transport from Lake Oliver to Lake Cochrane. In addition, dense cattails eliminate rough fish activity near the upstream end of the outlet structure providing further reduction benefits. The result has been relatively low annual phosphorus loads from Lake Oliver to Lake Cochrane from 1997 to 2009.

Lake Cochrane apparently has the capacity to assimilate the relatively low annual phosphorus loads from the watershed. Annual phosphorus received by Lake Cochrane, including that from Lake Oliver is likely exported in outflow, stored in the sediments or used by organisms such as fish, invertebrates, aquatic plants and algae. The general, trophic condition (phosphorus, chlorophyll-*a* and Secchi depth) of Lake Cochrane has not been significantly impacted by annual phosphorus loads from Lake Oliver since outflow was permanently restored in 1997.

The water quality and ecology of Lake Cochrane is likely dictated by historic nutrient and sediment inputs. The main tributaries to Lake Cochrane provided significant sedimentation and associated nutrients prior to the construction of sediment dams in the mid 1970s. Intense residential development and shoreline alterations including a host of other natural and human induced sources have contributed significant nutrients and sediment to Lake Cochrane. Considering outflow from Lake Cochrane has been relatively minimal, especially prior to the re-introduction of Lake Oliver, most of the pollutants received by Lake Cochrane are still contained in the lake. The rather dense aquatic plant community is a likely result of these historic nutrient and sediment inputs.

The dense aquatic plant community in Lake Cochrane provides many ecological benefits. The aquatic plant community likely out competes algae for nutrients reducing the incidence of frequent and intense blue-green algae blooms common to many prairie lakes in eastern South Dakota. The relatively good water clarity displayed by Lake Cochrane is a function of the plant community. The plant community can also have some negative effects though it is an important component of the ecology of Lake Cochrane.

The results of this investigative study conclude that Lake Oliver has not had a significant impact on Lake Cochrane water quality or ecology over the past 13 years. A host of management options are recommended to encourage future protection and enhance the beneficial uses of Lake Cochrane.

RECOMMENDATIONS

Aquatic Plant Control: Work in conjunction with the Department of Game, Fish and Parks and the Department of Environment and Natural Resources to implement an appropriate aquatic plant removal program. Selective harvest of aquatic plants will increase shoreline usability and remove nutrients stored in plant biomass.

Rough Fish Removal: Develop a plan to encourage long-term eradication of rough fish, primarily bullheads and carp, from Lakes Oliver and Cochrane. The removal of rough fish would remove nutrients and reduce the potential risk for nutrient migration caused by bottom sediment agitation.

Leaf and Debris Removal: Promote the annual removal of fallen leaves and other organic materials including aquatic plants from residential shorelines to decrease nutrient inputs to Lake Cochrane.

Continued Public Outreach: The LCIA should continue to promote nutrient and sediment reduction practices to local residents, landowners in the watershed and the general public through continued information and education outreach. Strongly encourage local residents to use non-phosphorus based lawn fertilizer as a common lawn care practice.

Prairie View Golf Course: The LCIA should form a relationship with the golf course manager or developer to encourage the use of non-phosphorus based fertilizer for turf management. In addition, encourage sediment erosion control measures for the irrigation ponds to minimize the potential for sediment transport, especially during spring run-off. Incorporating best management practices tailored to reduce nutrient and sediment transport from the golf course is strongly recommended to minimize loading to Lake Oliver.

Water Quality Monitoring:

Continue to monitor annual water quality of Lakes Cochrane/Oliver and associated tributaries. Results of future water quality monitoring efforts can be used to document potential changes or trends over-time.

Lake Outlet Debris Removal: Develop a plan and locate volunteers to keep the Lake Oliver outlet and the Lake Cochrane outlet free of debris in the spring during potential outflow. Ensuring proper function of the outlets is important to nutrient management and reduces the potential for flooding during high water.

Additional management options include selective sediment dredging along the west and southwest near the main tributary inlets of Lake Cochrane and the establishment of aquatic plants in Lake Oliver. These options would require outsourcing and may not be feasible due to expense.

LITERATURE CITIED

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