LAKE ASSESSMENT PROGRAM

1998

Upper and Lower South Long Lakes
(ID #18-0096 and 18-0136)

Crow Wing County, Minnesota

Minnesota Pollution Control Agency
Environmental Outcomes Division
and
North District

in cooperation with

Minnesota Department of Natural Resources

Crow Wing County

Upper South Long Lake Association
Lower South Long Lake Association

August 1999

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Crow Wing County, Minnesota

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SUMMARY AND RECOMMENDATIONS

Upper and Lower South Long Lakes are located in Crow Wing County, east of the city of Brainerd. Upper and Lower South Long Lakes are in the upper 10 percent of lakes in the state in terms of size - 802 and 1306 acres, respectively. They are moderately shallow lakes with mean depths of 19 and 20 feet and maximum depths of 47 and 40 feet, for Upper and Lower South Long Lakes, respectively. Upper South Long has a volume of approximately 15,006 acre-feet, while Lower South Long has a volume of about 28,063 acre-feet. The combined watershed for Upper and Lower South Long Lake is relatively large at about 68 square miles including the lake's surface.

Upper and Lower South Long Lakes was sampled during the summer of 1998 by the Minnesota Pollution Control Agency (MPCA) staff and citizens from the Upper and Lower South Long Lakes Association (Association). Water quality data collected on Upper South Long Lake during the study reveal summer-mean total phosphorus (TP) concentration of 29 µg/L, chlorophyll a of 12.4 µg/L and Secchi transparency of 7.2 feet. Water quality data collected on Lower South Long Lake during the study reveal a summer-mean TP of 35 µg/L, chlorophyll a of 25.3 µg/L and Secchi transparency of 5.7 feet. All of these measures are outside the range of values for reference lakes from this region. Total phosphorus, chlorophyll a and Secchi transparency help to characterize the trophic status of a lake. These measures indicate eutrophic conditions for Upper and Lower South Long Lakes.

Some historical data is available for assessing trends in the water quality of both lakes. Based on an analysis of 25 years of CLMP Secchi transparency data (intermittent), a long-term improvement trend is evident. Summer-mean Secchi transparency measures ranged from 4 to 9.9 feet from 1970's - 1998.

Two lake water quality models were used to estimate the water quality of Upper and Lower South Long Lakes based on morphometry and watershed characteristics. These models provide a means to compare the measured water quality of the lakes relative to the predicted water quality.

The first model, MINLEAP, was run on each lake independently and then treating the two lakes as one basin. The results of the independent run for Upper South Long Lake predicted a summer-mean phosphorus (P) concentration of 30 ug/L that compares favorably with the observed mean (29 ug/L) for 1998. This model estimated a phosphorus loading of ~1677 kg P/year and a water residence time of about one half year. A regression model predicted a background P concentration of 20 ug/L which is less than the in-lake measured P in 1998.

The independent run for Lower South Long Lake predicted a summer-mean phosphorus (P) concentration of 28 ug/L, which is significantly less than the observed in-lake P of 35 ug/L for 1998. P loading was estimated at ~2085 kg P/year and water residence time of about 1 year. A regression model predicted a background P concentration of 19 ug/L which is significantly less than the observed in-lake measured P in 1998.

When the model was run treating the two lakes as one basin, the predicted P was 25 ug/L, the P loading rate was about 2127 kg/L and the background P was 20 ug/L.

The second model, Reckhow & Simpson, estimated in-lake water quality based on estimated flow and concentration data from subwatersheds, the immediate watershed, precipitation, land use data and runoff coefficients. The Reckhow & Simpson model estimated a phosphorus balance for:

- Upper South Long Lake with the following relative contributions for 1998: Nokassippi watershed ~90%, septics ~6% and precipitation ~4%.

- Lower South Long Lake the contributions were as follows: immediate lake watershed and internal loading ~50%, Upper South Long outflow ~40%, septics 6% and precipitation 4%.

The following recommendations are based on the Lake Assessment Program (LAP) study of Upper and Lower South Long Lakes:

1. Upper and Lower South Long Lakes would be sensitive to change in trophic status with increases in the nutrient loading from watershed or in-lake sources. These sources would increase the in-lake phosphorus concentration which can degrade the lake. It is essential, therefore, that the lake protection efforts be conveyed by all local government groups with land use/zoning authorities for Crow Wing County. The Upper and Lower South Long Lakes Association should be commended for their efforts to date, which include interacting with Crow Wing County and participating in the Citizen Lake-Monitoring Program (CLMP). To complement these efforts, the Association should develop a plan for protecting the water quality of the lake. This plan, referred to as a lake management plan, should incorporate a series of activities in a prioritized fashion which will aid in the long-term protection and improvement of the lakes. The plan should be developed cooperatively by a committee consisting of representatives from state agencies (e.g., the Minnesota Department of Natural Resources (DNR), Minnesota Board of Water and Soil Resources, MPCA), local units of government, and Association members. The booklet, Developing a Lake Management Plan, may be useful in this regard and is available from the aforementioned agencies. The following activities could be included in the plan:

    a. **The Association should continue to participate in the CLMP**. Data from this program provides an excellent basis for assessing long-term and year-to-year variations in algal productivity, i.e., trophic status of the lakes. At a minimum, measurements should be taken weekly during the summer at a consistent site in each lake. The current sites (two per lake) allow for comparison of within lake differences in water quality.

b. **Further development or land use change in the lake's watershed should occur in a manner that minimizes water quality impacts on the lake**. In the shoreland areas, setback provisions should be strictly followed. DNR and county shoreland regulations will be important in this regard. Also, activities in the total watershed that change drainage patterns, such as wetland removal or major alterations in lake use, should be discouraged unless they are carefully planned and adequately controlled. The Association should continue to seek representation on boards or commissions that address land management activities so that their impact can be minimized. The booklet, <u>Protecting Minnesota's Waters: The Land-Use Connection</u>, may be a useful educational tool in this area. If possible the Association should recruit a member to be a liaison between the county zoning office and lakeshore owners. This person could also act as an advocate for the association at variance hearings involving development on the lake.

c. **A more detailed examination of land use practices in the watershed and identification of the possible nutrient sources such as urban runoff, lawn fertilizer, on-site systems and the effects of ditching and draining of wetlands, etc., may aid the Association in determining areas where best management practices may be needed**. On both lakes, further attention should be given to on-site systems. A house-to-house survey should be considered as one means of gathering information on the status and maintenance of systems around the lake. Historical records suggest that on-sites have been a concern for some time around these lakes. Some of the county offices mentioned above may be of help in this regard.

d. **Continue to work with the DNR on aquatic plant management in both lakes**. Improper aquatic plant management can contribute to phosphorus loading through the decay of un-removed vegetation. Aquatic plants should always be <u>harvested</u> rather than <u>cut</u>, the primary distinction being that when plants are harvested they are removed from the water body and when they are cut they are allowed to remain in the lake, contributing phosphorus as they decompose. Always remove cut vegetation.

2. T**he 1998 water quality of Upper and Lower South Long Lakes was poor compared to other lakes in the NLF ecoregion (near the 13-19th percentile)** Both Upper and Lower South Long Lakes could exhibit declines in transparency and increases in the amount of algae with increases in in-lake total phosphorus. Degraded water quality could shift the balance in this productive lake from desirable to less desirable species of fish. Because changes in species composition are difficult to reverse, they should be avoided whenever possible. DNR lake surveys and file correspondence for these lakes have addressed many public concerns over the past fifty years. Watershed land use practices, poor management of shorelands, urban storm water, increased development in the shoreland areas and/or draining of wetlands in the watershed provide the greatest likelihood for increases in phosphorus loading.

Conversely, a reduction of the amount of nutrients that enter the lake may result in improved transparency and a reduction in algal concentrations. One means of reducing nutrient input is by implementing best management practices (BMPs) in the watershed (land management activities used to control nonpoint source pollution). Technical assistance in BMP implementation may be available through local resources management agencies. The Association should continue to work with the Crow Wing County SWCD to examine land use practices in the watershed and develop strategies for reducing the transport of nutrients to the lake. It may be wise to first focus efforts on the immediate watershed of the lakes and then on the sub-watershed of Lower South Long Lake, that lies to the east along Highway 22.

Restoring or improving wetlands in the watershed may also be beneficial for reducing the amount of nutrients or sediments which reach Upper and Lower South Long Lakes. The U.S. Fish and Wildlife Service at Fort Snelling may be able to provide technical and financial assistance for these activities.

The MPCA's Clean Water Partnership Program (CWP) is also an option for further assessing and dealing with nonpoint sources of nutrients in the watershed. However, since there is extensive competition for CWP funding, it may be in the best interest of the Association and Upper and Lower South Long Lakes to continue to work with the Crow Wing County SWCD, local water planner and the local township to do as much as possible to protect the condition of the lake by means of local ordinances and education of shoreland residents. If these steps prove to be inadequate or lake conditions worsen (as evidenced by significant declines in Secchi transparency measurements), application to CWP may then be appropriate. *One indication of a decline in water quality for Upper and Lower South Long Lakes would be if summer-mean transparency remained consistently below the current long-term mean of 6.6 feet (2.2 m). Some specific considerations for both lakes follow:*

The phosphorus criteria value for lakes in the Northern Lakes and Forests ecoregion is less than 30 µg/L for support of swimmable use (Heiskary and Wilson, 1990). At or below 30 µg P/L, “nuisance algal blooms” (chlorophyll a > 30 µg/L) should occur less than 5 percent of the summer and transparency should remain above 1 m over 90 percent of the summer. Upper South Long with a P concentration of about 29 µg/L and Lower South Long with a P concentration of 35 µg/L are very near the criteria level. For Upper and Lower South Long Lakes, the ecoregion P criteria of 20-25 µg/L would be a reasonable in-lake P goal based on the MINLEAP, Vighi and Chiaudani, and Reckhow & Simpson model results. Significant reductions in the frequency of algal blooms and increases in transparency would be expected if in-lake P was reduced to 20-25 µg/L or lower. Because of its shallowness and susceptibility to wind mixing it may be more difficult to achieve this goal in Lower South Long Lake. *Consequently it is critical that all controllable sources of phosphorus be minimized, i.e. septics, runoff from impermeable areas, erosion and lawn fertilizer*.

A few considerations follow:

- The Association should encourage all shoreland property owners on the lakes to bring on-site systems up to code and all property owners should properly maintain existing systems. These efforts should be done in conjunction with Crow Wing County. Crow Wing County has been active in developing strategies for upgrading systems with the assistance of lake association members.
- Property owners should be encouraged to maintain buffer areas between lawns and lakeshores and if fertilizers are needed, use P-free formulations.
- The water <u>entering</u> Lower South Long Lake from Upper South Long lake is lower in phosphorus than the water <u>in</u> Lower South Long lake. However it is still important for Upper South Long Lake to continue to keep phosphorus levels as low as possible in order to provide Lower South Long Lake protection from additional phosphorus loading.
- Further investigations could be conducted in the subwatersheds to see if there are any obvious sources of excess nutrients reaching the tributaries from that subwatershed, e.g., feedlots, animal pasturing areas, wetland drainage, etc. Any further tributary sampling should be accompanied by flow monitoring so that accurate estimates of loading might be obtained. The Crow Wing Soil and Water Conservation District may be helpful in obtaining funding for best management practices in the subwatersheds.

3. Should a CWP or other natural resources grant program application be deemed necessary, this LAP study serves as a foundation upon which further studies and assessments may be based. The water and nutrient income-outgo summaries were estimated based on limited amounts of monitoring data and should be considered best approximations. The next step would be to define water and nutrient sources to the lake in a much more detailed fashion. These detailed studies would allow the estimation of reasonably accurate total phosphorus (and ortho-phosphorus), a total nitrogen (and inorganic nitrogen) and water income-outgo summaries. This should be accomplished prior to implementation of any extensive in-lake restoration techniques. However, watershed BMPs could be implemented without this step.

LAKE ASSESSMENT PROGRAM: 1998

INTRODUCTION

Upper and Lower South Long Lakes were sampled by the Minnesota Pollution Control Agency (MPCA) during the summer of 1998 as a part of the Lake Assessment Program (LAP). This program is designed to assist lake associations or municipalities in the collection and analysis of baseline water quality data in order to assess the trophic status of their lakes. The general work plan for LAP includes Association participation in the Citizen Lake-Monitoring Program (CLMP), cooperative examination of land use and drainage patterns in the watershed of the lake, and an assessment of the data collected by MPCA staff.

Upper and Lower South Long Lakes was sampled on five occasions during the spring and summer of 1998. Participants in this effort included Steve Heiskary and Pat Shelito (MPCA) and Jack Rolf and Harry Sundberg (Association). CLMP measurements were taken by Herb Nelson, Jack Rolf and Mary Kulseth (Association). Land-use and watershed information for Upper and Lower South Long Lakes was assembled by Scott Hansen with the Crow Wing County Water Plan. DNR staff, Wayne Mueller and Ron Morriem reviewed fisheries and lake level information. Terry Lahti and Sue Warner coordinated the Association's efforts on this study.

This study was conducted at the request of the Upper and Lower South Long Lakes Association, Crow Wing County local water planners, and the Minnesota Department of Natural Resources (DNR).

BACKGROUND

Watershed, Soils, and Land Use

Upper and Lower South Long Lakes are located in the Crow Wing County, southeast of the city of Brainerd. They are rather elongate lakes with a southwest-northeast orientation. The lakes are in the Elk-Nokassippi watershed and has the Nokasippi river running from north to south through the lakes. After leaving Lower South Long lake the Nokasippi river joins the Mississippi river just north of the town of Fort Ripley. Both Lakes are in the upper 10 percent of lakes in the state in terms of size (802 and 1306 acres respectively). They are relatively shallow lakes with a mean depths of about 19 feet (Upper) and 20 feet (Lower). Upper South Long Lake has a volume of approximately 15,006 acre-feet and Lower South Long Lake has a volume of about 28,063 acre-feet.

Figure 1. Upper and Lower South Long Lakes Watershed and Location Map

TABLE 1. MORPHOMETRIC, WATERSHED, FISHERY CHARACTERISTICS

STORET I.D.	# 18-0096	18-0136	
	Upper	Lower	Total
Area[1]:	**802** acres (325 ha)	**1306** acres (528 ha)	**2108** acres (854 ha)
Mean Depth:	**19** feet (6.3 m)	**20** feet (6.6 m)	
Maximum Depth	**47** feet (15.5 m)	**40** feet (13.3 m)	
Volume[1]:	**15,006** acre-feet ($18.5\ hm^3$)	**28,063** acre-feet (34.6 hm3)	**43,096** acre-feet (53.1 hm3)
Watershed Area[2]: (includes lake surface)	**34417** acres ($54\ mi^2$) (13,940 ha)	**9008** acres ($14\ mi^2$) (3648 ha)	**43425** acres ($68\ mi^2$-17,588 ha)
Watershed:Lake Surface Ratio:	**43:1**	**6:1**	**37:1**
Est Ave Water Residence Time:	**.6 yrs**		**.9 yrs**

Fisheries[4] -	Upper	Lower
Ecological type:	Centrarchid-Walleye	Centrarchid-Walleye
Management class:	Walleye-Centrarchid	Walleye-Centrarchid
Schupp's Lake class:	27	27

Public Access: 1 each
Inlets: 1 each - several ephemeral each
Outlets: 1 each

LAND USE (Percentage)	Forest	Water & Marsh	Pasture & Open	Cultivated	Urban
Upper South Long Lakeshed	39 %	24 %	23 %	6 %	8 %
Upper South Long Watershed	46 %	26 %	22 %	3 %	2 %
Lower South Long Lakeshed[2]	36 %	23 %	33 %	3 %	5 %
Total Watershed	47 %	26 %	22 %	3 %	2 %
Northern Lakes and Forests[3]	54-81 %	14-31 %	0-6 %	0-1 %	0-7 %

Shoreland Zoning: Recreational

Development	*Upper* Residences	*Lower* Residences
1941[4]	50	30-40
1969	170	120
1984	170	246
1998[5]	194	318

[1,2]Planimetered by MPCA.
[3]Derived from Heiskary and Wilson (1990) Table 6.
[4]SWIM data base, State Planning Agency, Information Center, St. Paul, Minnesota.
[5]Upper and Lower South Long Lakes Association, 1998.

Since land use affects water quality, it has proven helpful to divide the state into regions where land use and water resources are similar. Minnesota is divided into seven regions, referred to as ecoregions, as defined by soils, land surface form, natural vegetation and current land use. Data gathered from representative, minimally-impacted (reference) lakes within each ecoregion serve as a basis for comparing the water quality and characteristics of other lakes. Upper and Lower South Long Lakes are located in a region of the state referred to as the Northern Lakes and Forests (NLF) ecoregion but are very near the transition to the North Central Hardwoods Forests (NCHF) ecoregion (Figure 1). As such, watershed characteristics may be reflective of a transition from a predominately forested region (NLF) to a region of mixed land uses (NCHF).

Upper and Lower South Long Lakes have a total watershed of approximately 68 square miles resulting in a surface area: watershed ratio of about 37:1. The total watershed is comprised of several subwatersheds, including the lakesheds for each of the individual lakes (Table 2). That portion of the total watershed which drains to Upper South Long Lake comprises the largest area at about 54 mi^2, including the lake. This is actually the watershed of the Nokasippi river upstream of Upper South Long Lake (Figure 1). The immediate lakeshed for Upper South Long Lake is much smaller-- about 5 mi^2 (including the lake). The South Long Lakes outlet to the Nokasippi River and hence to the Mississippi River. Overall, land use in the subwatersheds is characterized primarily by forested, water, and marsh land uses (Table 1) which is fairly typical for lakes in the NLF ecoregion. However, cultivated and pastured uses are somewhat higher than the typical percentages for lakes in the NLF ecoregion but not atypical for lakes near the transition of two regions. The majority of the urban/developed land use in each subwatershed is related to development around both lakes. The lakes account for a small portion of their respective subwatershed areas (Table 2).

Table 2.   Upper and Lower South Long Lakes Immediate Watershed Areas as Estimated from Crow Wing County Records.

Lakeshed	area (mi^2)	lake area (%)
Upper Lake	14 mi^2	23 %
Lower Lake	5 mi^2	4 %
Total watershed	19 mi^2	27 %

Shoreland Development and On-site Systems

Shoreland development records date back to DNR surveys of 1941, 1951, 1969 and 1984. In 1941 there were approximately 50 shoreland residences on Upper South Long Lake, 170 by 1984 and 194 in 1998.   Lower South Long had 30 residences in 1941, 120 in 1969 and 246 by 1984. 1998 there were 318.

A house-to-house septic survey questionnaire was distributed to residents on both lakes. Information was obtained from 104 of the 194 residences currently listed on Upper South Long lake. The lake association did work with county planning and zoning to get the other ninety residences in compliance earlier in the 1990's.

95 of the remaining 104 residences have a sealed septic tank and drainfield. Eighty of those were less than twenty years old (1978) indicating that they could have been designed and installed according to required standards. Thirteen were older than 1978 and eleven were unknown. Only sixteen were listed as closer than one hundred feet from the lake. Most of the homes (43) are seasonal. Fifty residents indicated that they pump their systems at least every three years, another 17 did not respond to the question.

Information was obtained from 165 of the 318 residences currently listed on Lower South Long lake. 117 residences have a sealed septic tank and drainfield. 128 of them were less than twenty years old (1978) indicating they could have been designed and installed according to required standards. 21 were older than 1978 and 22 were unknown. Only 28 were listed as closer than one hundred feet from the lake. A little more than half of the responses (72) are seasonal, the other half (61) are primary year round residence. 95 respondents indicated that they pump their systems at least every three years, another 34 either never pumped their systems or did not respond to the question. There were 32 comments submitted with the surveys; 25 of them were urging more septic system accountability. This will be an important issue for the Association and Crow Wing County to address.

History

A brief summary of some historical events in Upper and Lower South Long Lake's watershed are summarized below. This summary was developed based on Association, DNR, and MPCA records. A localized incident of elevated fecal coliform bacteria in 1988 on the shoreline of Lower South Long Lake may have been an important source of nutrients to the lake historically. Development in the 1970s and 1980s around the lakes may have had some impact on the lakes as well (Table 1).

A brief summary of some historical events in Upper South Long Lake's watershed are summarized below. This summary was developed based on Association, DNR, and MPCA records as well as interviews of long time residents in the area—

Upper South Long Lake Watershed Historical Summary

Year	**Notes**
1890-1910	Logging around the lake.
1906	A mill pond was located on the north end of the lake. A small town was located around this area. The town had a creamery, store, flour mill and other small buildings.
1918	Two cabins were located on the lake.
1918	Two farms were located on the east and west side of the lake.
1930's	The first resort was started on the lake on the north side.
1930's – 40's	Lakeshore was being developed. Paradise Shores was developed on the southeast shore.
1936	The dam was built on the outlet of the lake. The dam was built with stop logs and was manipulated at various levels.
1946	The stop logs were set in one place at 1.9 feet above the sill which is what it is maintained at this time.
1950's	The north side of the lake had additional development.
1960's – 70's	The west shore developed.

1970's	Lake owners started meeting and an association was developed. The association bought a weed cutter and continues to cut weeds on the lake.
1980's – 90's	The lakeshore continues to be developed.
1998	LAP study conducted on Upper South Long Lake

Lower South Long Lake

Year	**Notes**
~1920's	Development began on the east side from paradise Point Resort to just north of the cutoff on Paradise Beach Road.
1930's	W.P.A. project built two dams on the lake. One on the north and one on the south. There were also two small airplane crashes in the lake.
~1932	Elmer Erickson began selling lake lots to school teachers and railroad workers. Lakeshore lots sold for $375 and roadside lots for $150. The price included lumber to build a modest cabin.
1934	Rowan's store opens on Paradise Beach Road.
1937	Development of the second addition. It ran north from Rowan's store to the present dead-end.
1942	Electricity introduced.
1977	Lower South Long Lake Association formed.
1981	Aerial survey by A.W. Research.
1988	800 feet of shoreline covered with sewage. A.W. Research Lab found fecal coliform greater than 100 colonies per 100cc.
1998	Paradise Point Resort destroyed by fire. Rowan's store closes.
1998	LAP study on Lower South Long conducted

There was at one time at least four resorts on the lake. Shady Lawn on the point opposite Cedar Leaf Point. Cragan's Lone Pine Camp on the northeast end of the lake. Paradise Point Resort on the east side. All are gone now. The only remaining resort is Lakeside on the northwest send of the lake. The lake also had its own dance hall, Mogeuson's, which was located on the west side of the lake. There was an old battery dump on the north east side of the lake near the end of Paradise Beach Road and an old pig farm on the east side of the lake about a mile and a half away and south of Highway 22.

There is some animal and cultivated agriculture in the watershed. Development in the seventies no doubt had an affect on water quality (Table 1) in both lakes.

Lake Level and Climate

Based on State Climatology records, precipitation averages 28-30 inches (0.72-0.76 m) annually in this part of the state with about 18-19 inches of that amount in May to September. Water-year precipitation in the Upper and Lower South Long Lake watershed was within normal at about 30 inches based on State Climatology Office records. May to September precipitation was on the order of nineteen inches. This amount is within normal for this period. Storm events of one inch or greater during the May to September period occurred on June 4 and 18; and August 22. Evaporation typically exceeds precipitation in this part of the state and averages about 30 inches (0.76 m) per year. Runoff averages about 7.1 inches with 1-in-10 year low and high values (low and high runoff values which might occur with a frequency of once in ten years) of 3.1 inches and 9.8 inches, respectively for this area (Gunard, 1985). The 1998 water year for this area would be characterized by average flow.

The Division of Waters, with the cooperation of volunteer reader Earl Carlson, has monitored water level fluctuations in Lower South Long Lake since 1991 and Bill Kronstadt in Upper South Long Lake since 1995 (Appendix II). The period of record for both lakes extends back to 1955. The Ordinary High Water Level (OHWL) in Upper South Long has been set at 1195.5 feet. The highest recorded level was 1196.23 feet on April 20, 1965, and the lowest level was 1192.68 on September 14, 1998, for an overall range of about 3.55 feet. Since 1991 recorded levels have ranged from 1216.03 feet to 1217.33 feet and averaged 1216.4 feet. In 1998, levels were significantly below the OHWL (1195.5) and were above the runout level (1193.5) for less than two weeks in late June.

The Ordinary High Water Level (OHWL) in Lower South Long has been set at 1193.8 feet. The highest recorded level was 1194.17 feet on August 8, 1972, and the lowest level was 1191.38 on September 8 1961, for an overall range of about 2.79 feet. Since 1991 recorded levels have ranged from 1216.03 feet to 1217.33 feet and averaged 1192.52 feet. In 1998, levels were below the OHWL (1193.8) and were above the runout level (1191.8) for the entire year.

Fishery

The following information is summarized from a 1994 survey. A fishery assessment and aquatic plant assessment will be done by the DNR in the summer of 1999.

Upper South Long Lake

The aquatic plant community is fairly diverse. Emergent species like bulrush are important because they often provide preferred spawning sites for bass and panfish species. Submergent plants grow to a depth of about 10 feet in the lake. These species provide important hiding and feeding areas for a variety of fish species.

Walleyes, largemouth bass and northern pike were important gamefish species found in the 1994 netting. Compared to similar type lakes, walleyes were found in “average” numbers. Ages 2-7 were sampled and growth was good. Average size was 1.1 lbs. in ’94. About 63% of walleyes sampled were from the 1988, ’90 and ’92 year classes, when fingerlings stocking was done; the other 37% were from years when no stocking was done. Largemouth bass were also caught in “average” numbers. Ages 1-5 were sampled and growth was good. About 50% of the bass sampled were from the 1991 year class. A number of young bass were taken in shoreline seining. The northern pike catch was “low” compared to similar type lakes but appeared “typical” when compared to previous nettings of this lake. Ages 2-4 were sampled, in uniform numbers, and growth appeared good. Average size was about 2.0 lbs.

Yellow perch, tullibees and white suckers are important food sources for the lake’s gamefish. All were found in “average” numbers in ’94. Yellow perch and tullibee were found in “low” numbers in the 1989 netting, while the sucker catch was very similar to the ’94 catch.

Bluegills and black crappies are important panfish species found in the lake. Bluegills were found in “average” numbers and the catch was similar to that from the 1989 netting. Ages 2-7 were sampled and growth was slow. Nearly one-half of the bluegills were from the 1989 year class. The catch of black crappies was also “average” and similar to that found in 1989. Crappies had good growth. All crappies aged were from the 1991 year class.

Other species caught in ‘94 included black and brown bullheads, in low numbers; as well as dogfish (bowfin) and yellow bullheads, in average numbers. Golden shiners and greater redhorse were sampled in the lake for the first time in 1994.

<u>Lower South Long Lake</u>

The lake is classified as a “hardwater” lake. About 35% of the lake is shallower than 15 feet. Water clarity is slightly below average for the area. Shallow water soils are predominately sand, with areas of rubble-sized rock (3-10”) present as well. The aquatic plant community is fairly diverse. Emergent species, especially bulrush, provide preferred spawning sites for bass and panfish species. Wild rice can provide spawning habitat for northern pike. Submergent plants grow to a depth of about 15 feet in the lake. They provide important areas for shelter and feeding for a wide variety of fish species.

Walleyes were the most abundant gamefish found in the 1994 test netting. Compared to similar type lakes, their abundance was “high” but not much different from the “average” catch rate found in the 1989 netting. Walleye fingerlings have been stocked every other year since 1984. A variety of walleye stockings have been done since about 1950. Walleyes from years when stocking was done were about as abundant in the catch as were fish from years when no stocking was done. Walleyes averaged 1.5 lbs. in ’94, similar to the 1.4 lb. average in the ’89 netting.

Other game species taken in ’94 included northern pike and largemouth bass. Northern pike numbers were “low” compared to similar type lakes but were typical for the lake, based on results of past nettings. Average size was 3.3 lbs. and growth was good. About 56% of sampled northern pike were from the 1991 year class. Largemouth bass were caught in “average” numbers in ’94. Most bass sampled were from the 1990 year class and had good growth.

Panfish species present in the ’94 netting included bluegills, pumpkinseeds, rock bass, hybrid sunfish and black crappies. Bluegills were found in “average” numbers compared with similar type lakes. About 7% of bluegills were at least 7.0 inches long. Bluegill growth was slow until age 6, then improved. Black crappies were caught in “average” numbers, as well. Most were from the 1990 year class and had good growth.

Several “forage” species were present in the ’94 netting. All provide important food sources for the lake’s gamefish. Yellow perch were caught in “average” numbers. They ranged from 5.3-11.3 inches long in the sample from gillnets and averaged 7.8 inches. Tullibees were present in “average” numbers, as were white suckers.

Other specie present in ’94 included “high” numbers of bowfin (dogfish) and yellow bullheads and “low” numbers of black and brown bullheads. Catch rates for these species were similar to catches made in ’89. One common carp was sampled; the first since the ’79 netting.

RESULTS AND DISCUSSION

Water quality data was collected in May, June, July, August, and September 1998 on Upper and Lower South Long Lakes at two sites on each lake (Figure 2). Lake surface samples were collected with an integrated sampler, which is a PVC tube 6.6 feet (2 meters) in length with an inside diameter of 1.24 inches (3.2 centimeters). Phytoplankton (algae) samples were taken at site 101 with an integrated sampler. Secchi disk monitoring through the CLMP was conducted at several sites in the lake (Figure 2). Some tributary data was also collected by the MPCA. These data were used to help characterize phosphorus loading from the watershed. Data from a MPCA survey of both lakes in 1990 provides a further basis for characterizing the condition of Upper and Lower South Long Lakes.

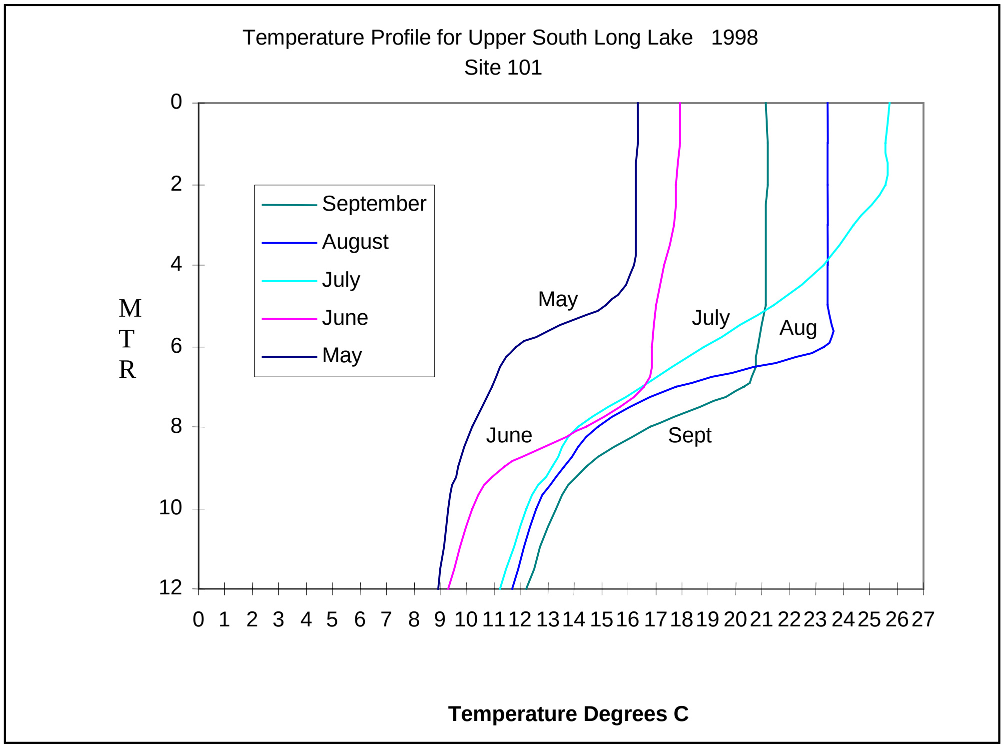
Sampling procedures were employed as described in the MPCA Quality Control Manual. Laboratory analyses were performed by the laboratory of the Minnesota Department of Health using U.S. Environmental Protection Agency (EPA)-approved methods. Samples were analyzed for nutrients, color, solids, pH, alkalinity, turbidity, conductivity, chloride and chlorophyll (Table 4).

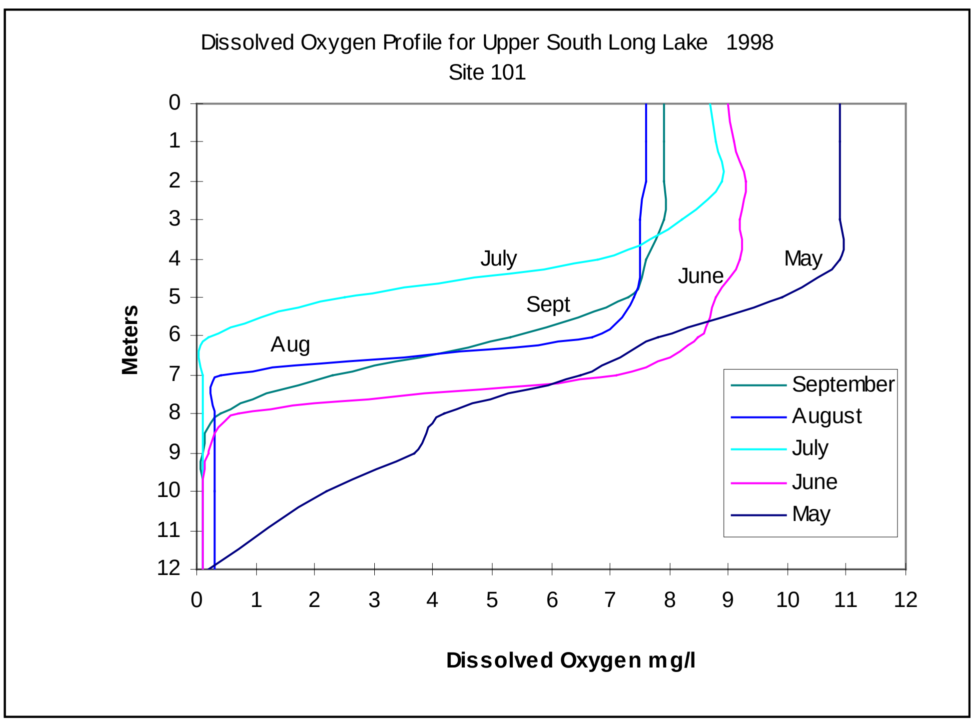
Duplicate samples for total phosphorus in 1998 revealed a mean difference of 7 µg/L and a percent difference of 16 percent. For chlorophyll a duplicate samples, the mean difference was 1.36 µg/L and the percent difference was ten percent. Temperature and dissolved oxygen profiles and Secchi disk transparency measurements were also taken. All data was stored in STORET, the EPA's national water quality data bank. The following discussion assumes that the reader is familiar with basic water quality terminology as used in the Citizens' Guide to Lake Protection.

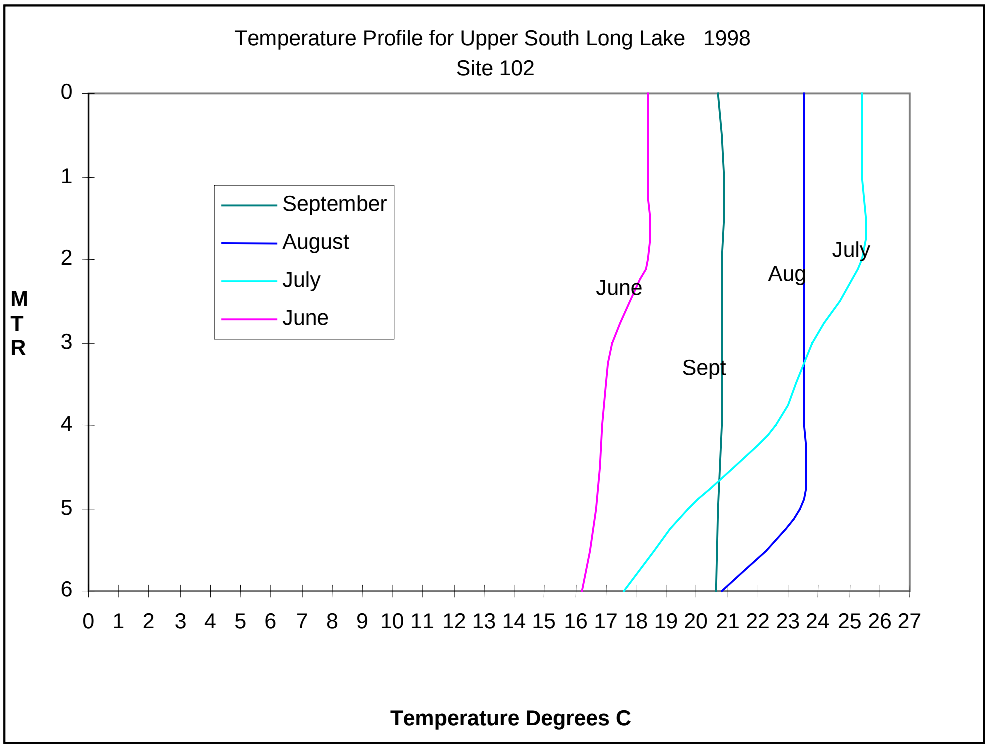
FIGURE 2. Bathymetric Map of Upper and Lower South Long Lakes. MPCA and CLMP sampling sites noted.

FIGURE 2. Bathymetric Map of Upper and Lower South Long Lakes. MPCA and CLMP sampling sites noted.

Figure 3. DO and Temperature Profiles for Upper and Lower South Long Lakes






Temperature Profile for Upper South Long Lake 1998
Site 102
September
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Temperature Degrees C
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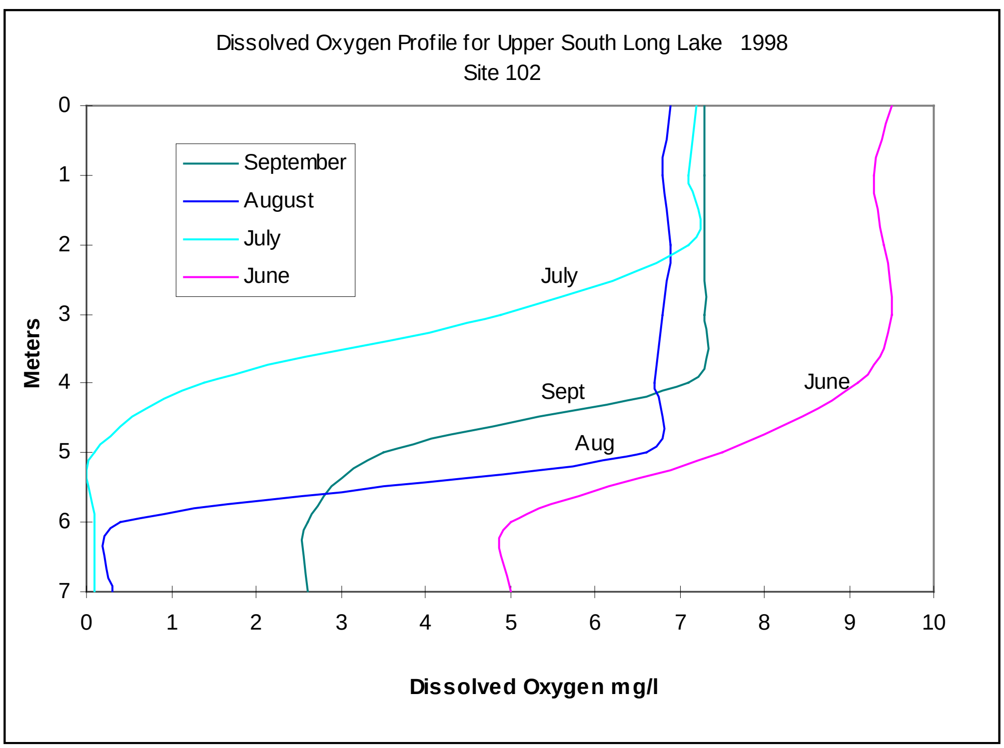
Dissolved Oxygen Profile for Upper South Long Lake 1998
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Dissolved Oxygen mg/l
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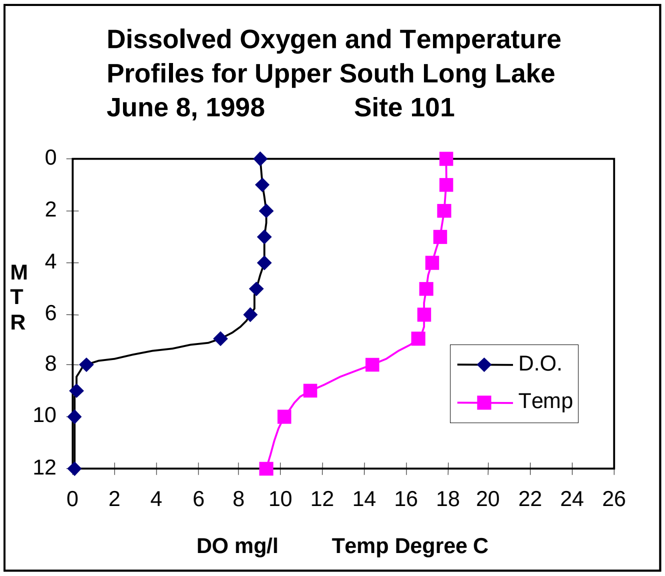
Dissolved Oxygen and Temperature
Profiles for Upper South Long Lake
June 8, 1998 Site 101
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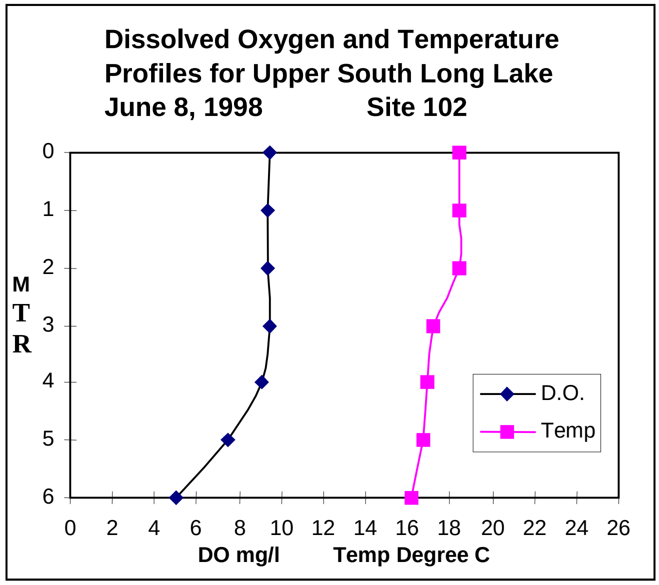
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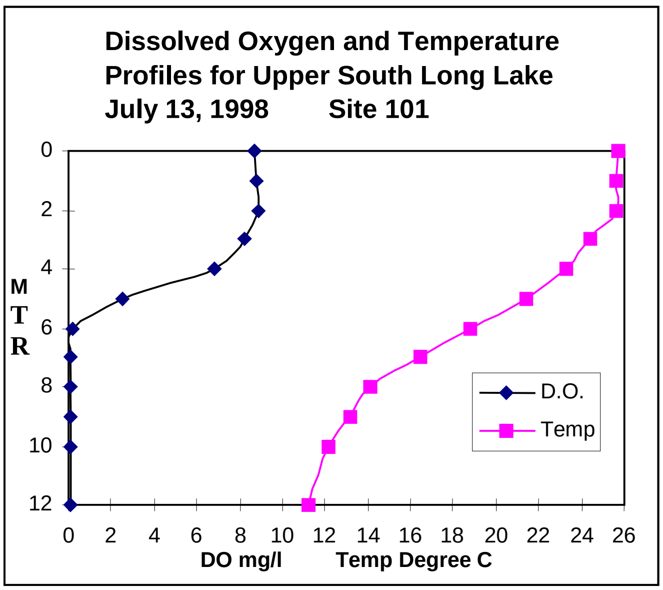
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Profiles for Upper South Long Lake
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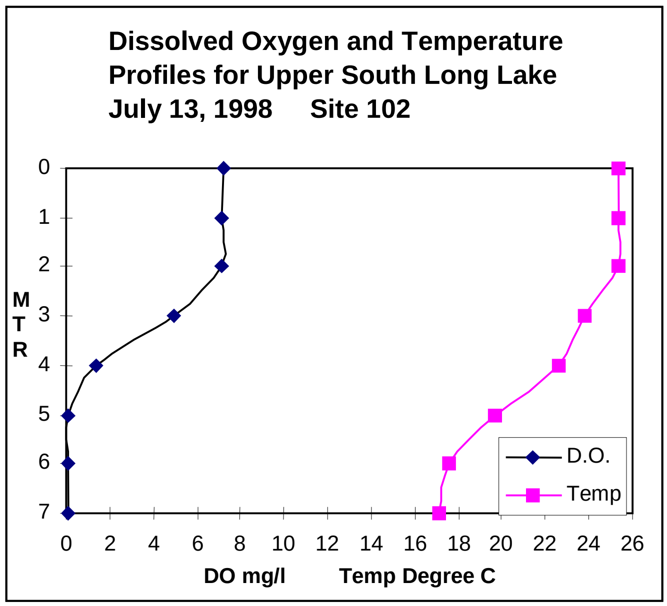
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July 13, 1998 Site 102
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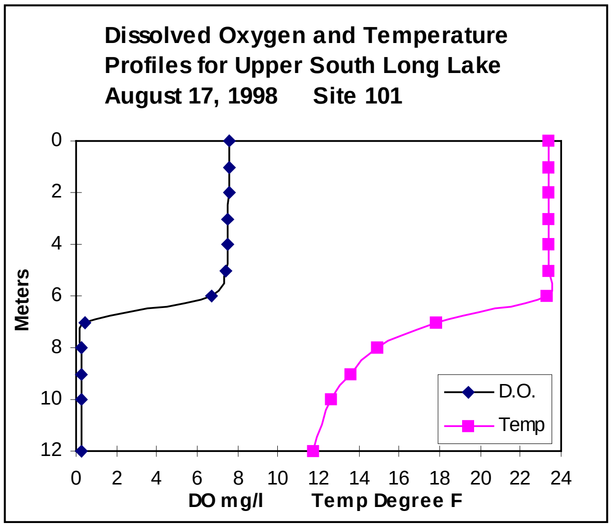
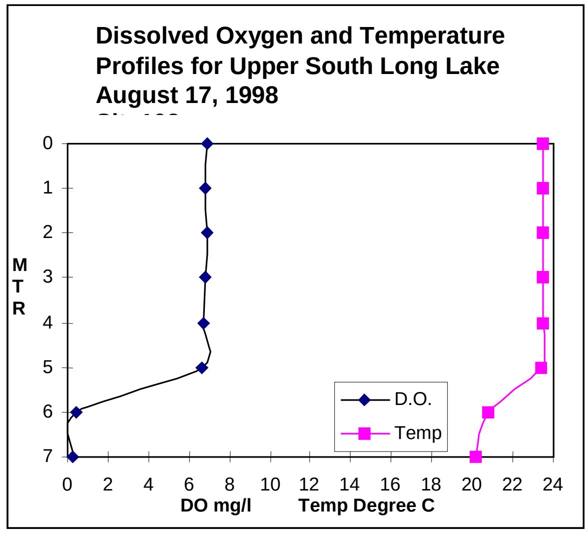
Temp
DO mg/l Temp Degree C


Dissolved Oxygen and Temperature
Profiles for Upper South Long Lake
August 17, 1998 Site 101
Meters
D.O.
Temp
DO mg/l Temp Degree F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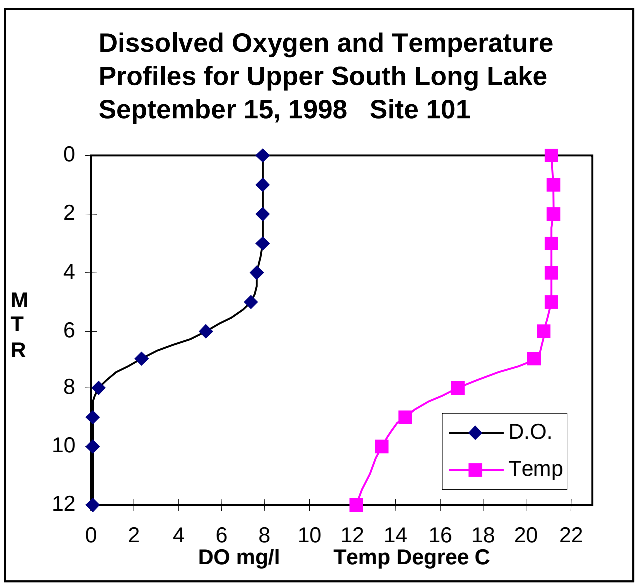
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September 15, 1998 Site 101
MTR
D.O.
Temp
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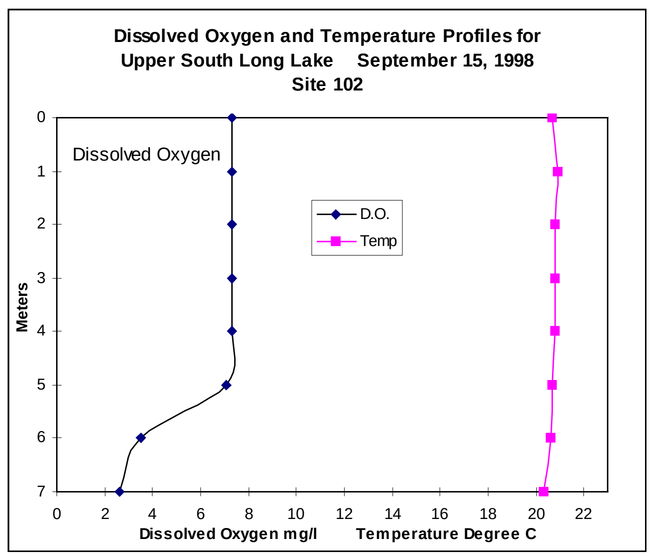
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Upper South Long Lake September 15, 1998
Site 102
Dissolved Oxygen
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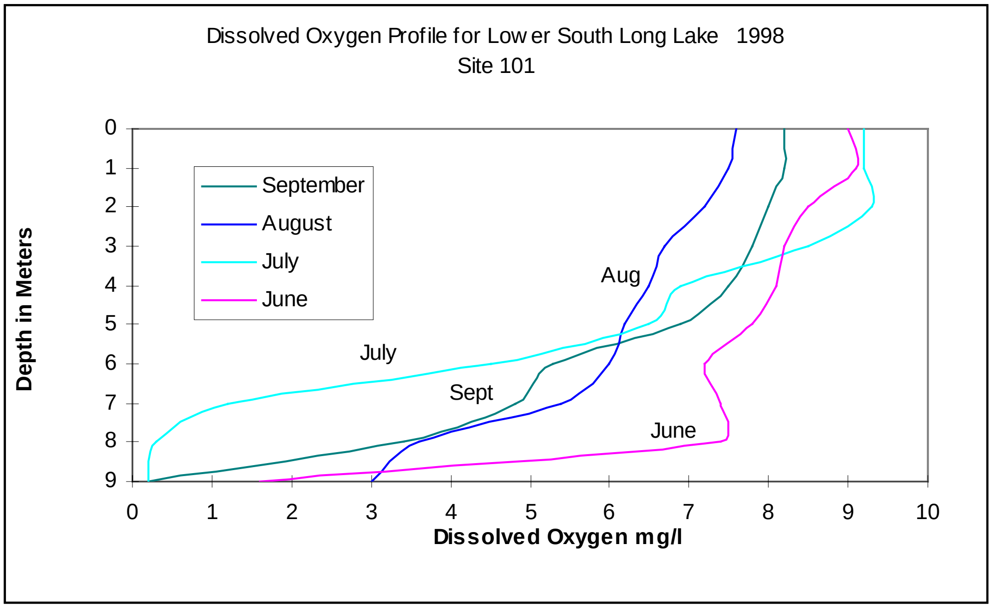
Dissolved Oxygen mg/l Temperature Degree C



Dissolved Oxygen Profile for Lower South Long Lake 1998
Site 101
Depth in Meters
Dissolved Oxygen mg/l
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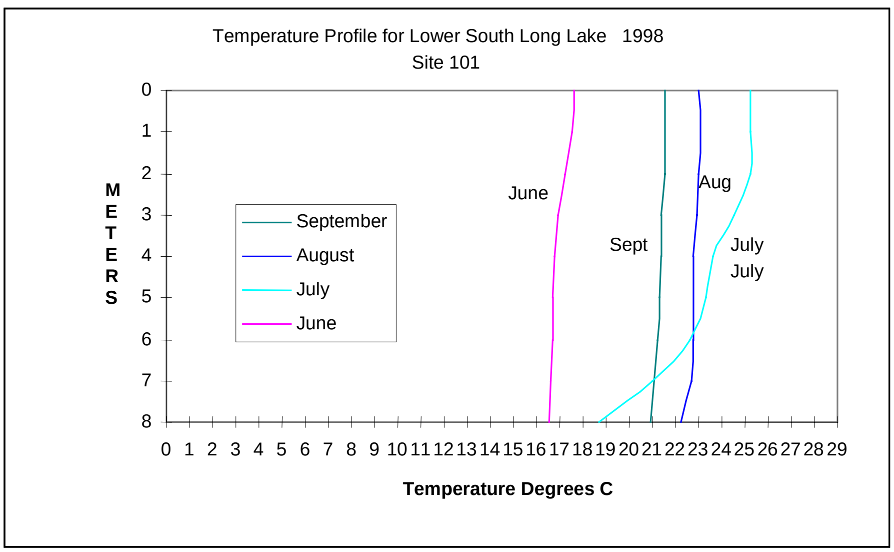

Temperature Profile for Lower South Long Lake 1998
Site 101
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Temperature Degrees C
September
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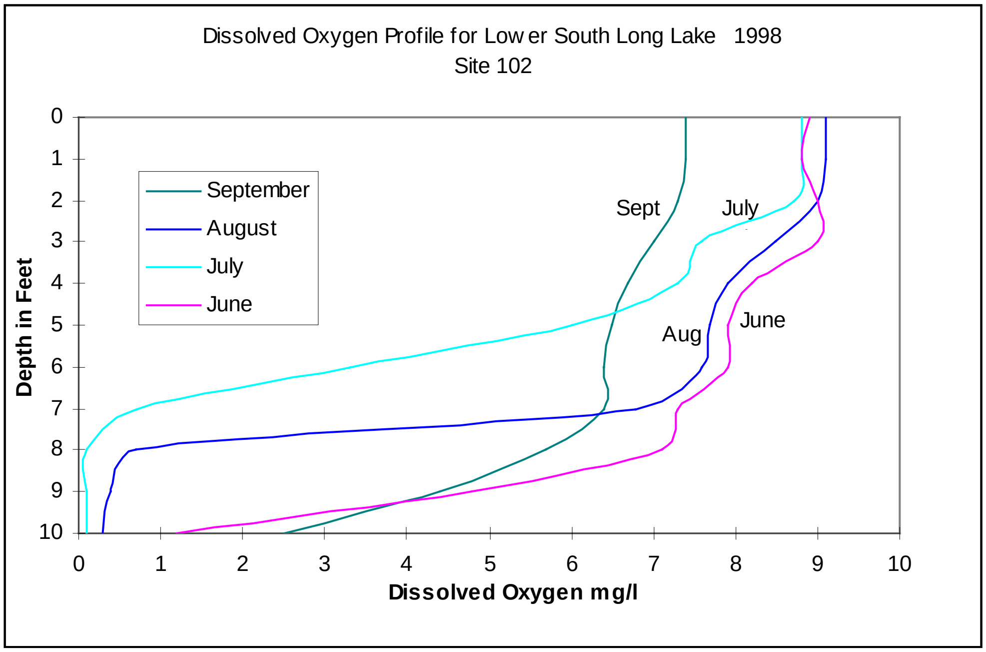
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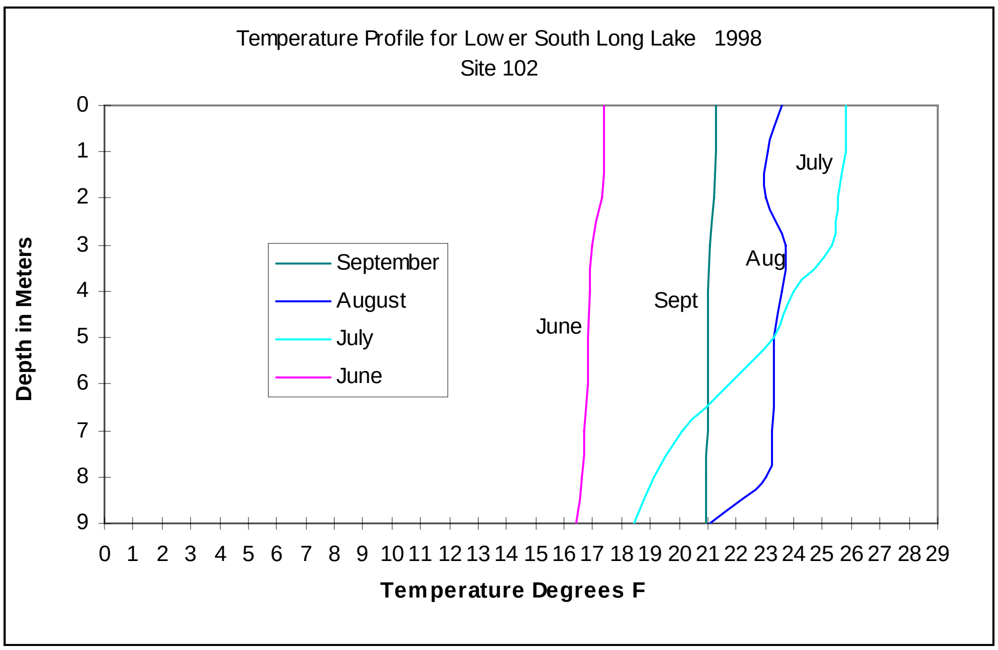
Dissolved Oxygen mg/l


Temperature Profile for Lower South Long Lake 1998
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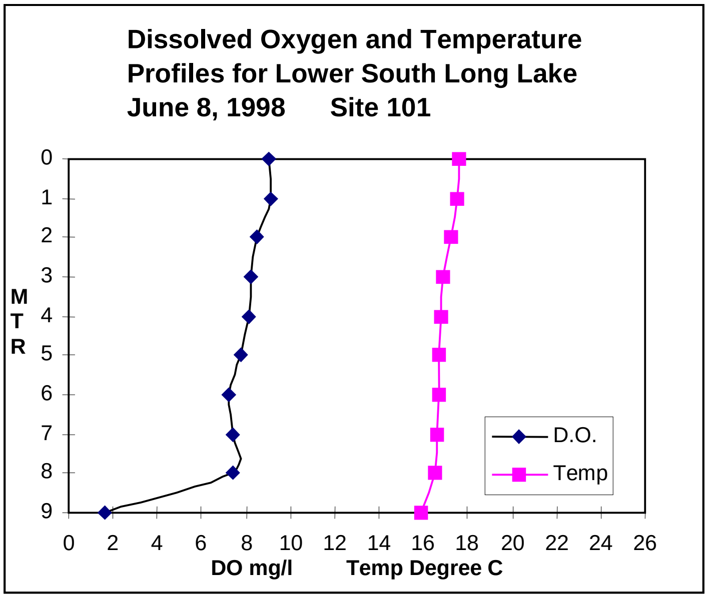
Temperature Degrees F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Profiles for Lower South Long Lake
June 8, 1998 Site 101
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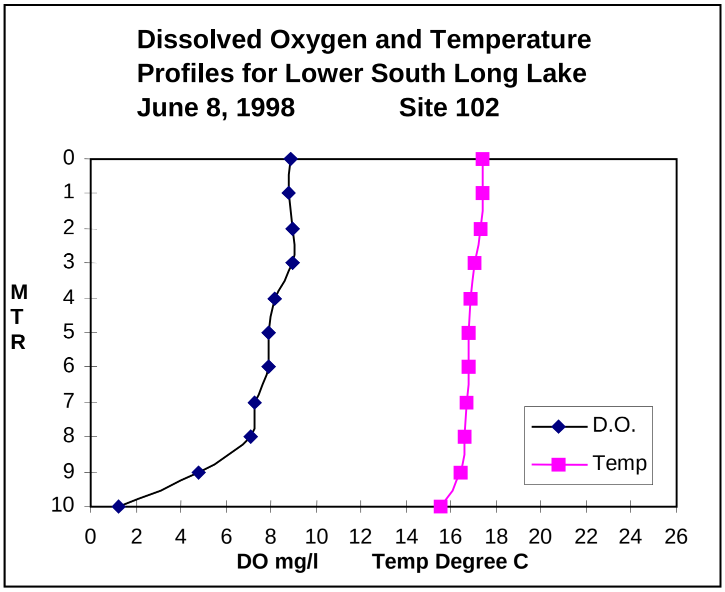
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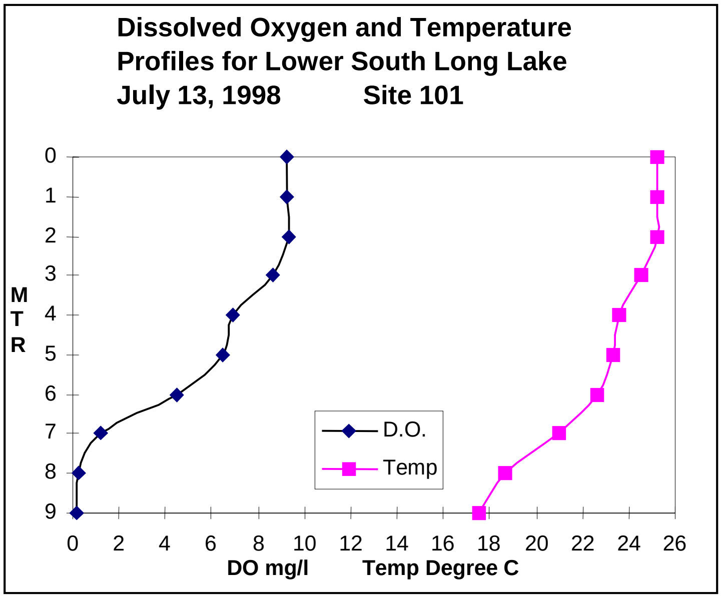
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July 13, 1998 Site 101
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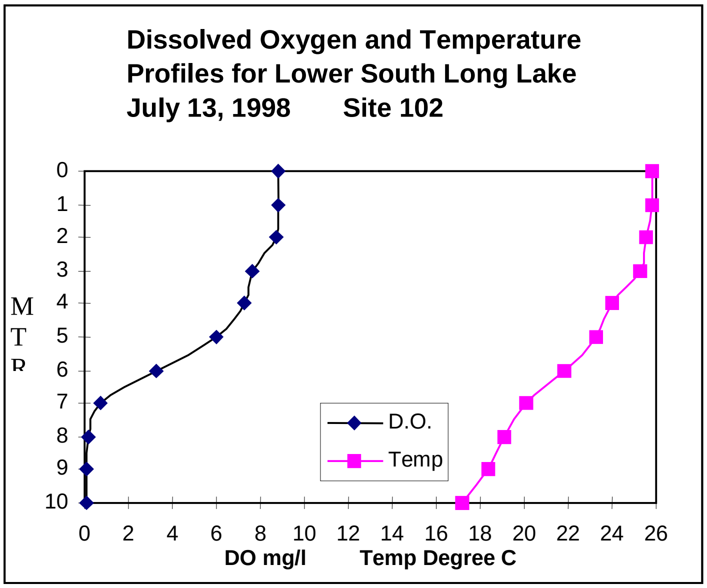
Dissolved Oxygen and Temperature
Profiles for Lower South Long Lake
July 13, 1998 Site 102
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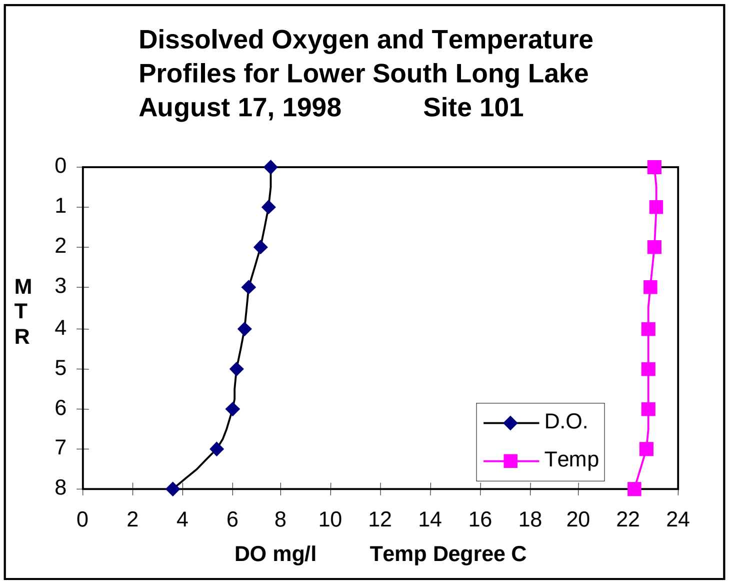
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Profiles for Lower South Long Lake
August 17, 1998 Site 101
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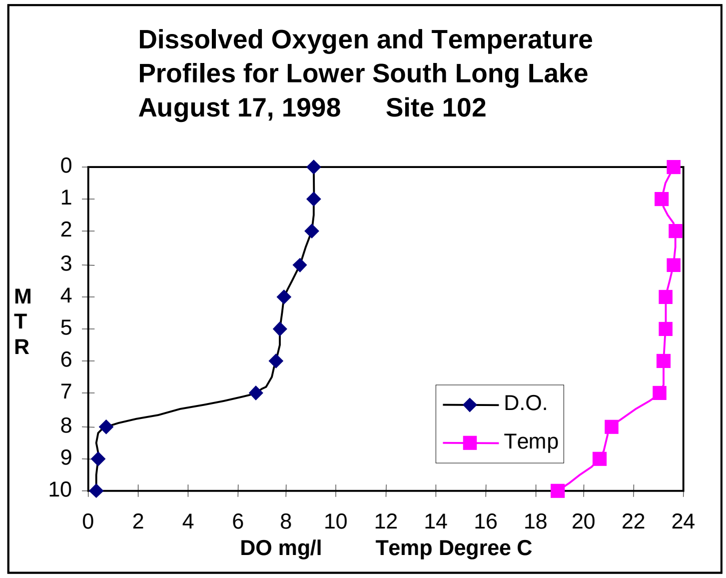
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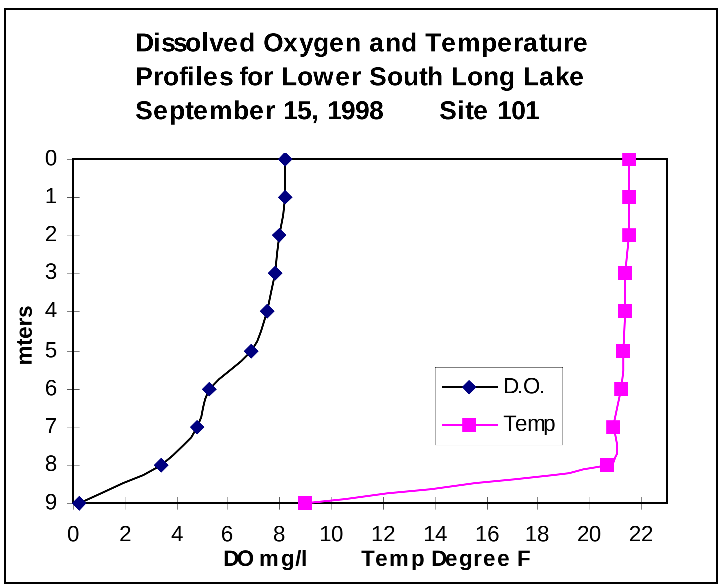
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September 15, 1998 Site 101
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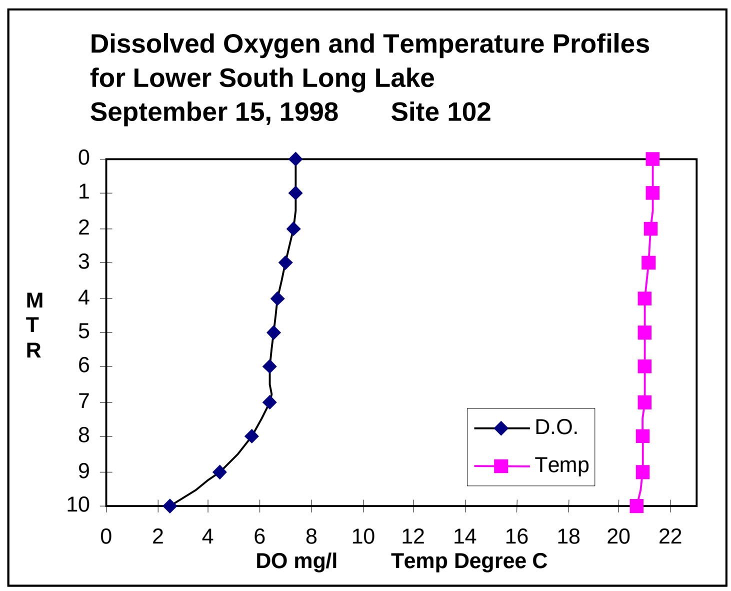
Dissolved Oxygen and Temperature Profiles
for Lower South Long Lake
September 15, 1998 Site 102
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In-lake Conditions

Dissolved oxygen and temperature profiles were taken at one-meter intervals at each sample site on each date. The lakes were well mixed on the May sampling date (Figure 3). Weak thermal (temperature) stratification (layer formation) was noted in June at site 101 in Upper South Long Lake; and became more pronounced in July and August. Site 102 on Upper South Long and both sites on Lower South Long Lake remained well mixed thoughout the summer. Overall surface temperatures ranged from 16 degrees C in May to a maximum of 25 degrees C in July. Near-bottom temperatures were on the order of 15-20 degrees C during most of the summer, except for site 101 on Upper South Long Lake where temperatures were cooler, ranging from 9-12 degrees C. Weather conditions in September 1998 remained unusually warm resulting in surface temperatures which only cooled to 21 degrees C. Based on the July and August profiles the thermocline (zone of maximum change in temperature over the smallest change in depth) at site 101 on Upper South Long Lake was located between 22-25 feet (Figure 3).

Dissolved oxygen concentrations ranged from 7-11 mg/L near the surface of Upper and Lower South Long Lakes on all dates throughout the summer. Concentrations at site 101on Upper South Long Lake remained consistent throughout the *epilimnion* (upper, well-mixed layer) but declined rapidly in the *hypolimnion* (lower, cooler layer) in June and remained low into September. At site 102 on Upper South Long and at both sites on Lower South Long, concentrations were consistent in the epilimnion but declined in the hypoliminion in July and August. However by September, concentrations had increased to 2-5 mg/L.

In Upper South Long Lake DO concentrations remained above 5 mg/L throughout the water column on only the June sample date and only at Site 102. Concentrations declined rapidly in the thermocline in July and August and there was little or no oxygen below about 27 feet at both sites during these months.

In Lower South Long Lake DO measurements remained above 5 mg/L throughout most of the water column in May and September but fell below 1 mg/L in the hypolimnion in July at both sites and remained that low in August at Site 102.

The distribution of oxygen in the water column is significant since game fish typically require a dissolved oxygen concentration of 5 mg/L or greater for long-term survival. Also, as oxygen concentrations fall below 2 mg/L at the sediment-water interface, internal recycling of phosphorus from the sediments to the water may occur. Thus based on DO concentrations near the sediment - water interface it seems likely that internal recycling of phosphorus from the sediments (as related to low DO concentrations) may have occurred over much of the summer in both lakes. However because of the lack of a stable thermocline in Lower South Long Lake, the phosphorus was distributed throughout the water column, triggering higher algae concentrations near the surface. In contrast, the thermocline in Upper South Long lake acted as a barrier preventing phosphorus from reaching the upper waters resulting in lower algae concentrations near the surface.

Total phosphorus (TP) concentrations (an important nutrient for plant growth) averaged approximately 29 and 35 µg/L (micrograms per liter or parts per billion) respectively in the surface waters of Upper and Lower South Long Lakes during the summer of 1998. This value is higher than the range of concentrations typically found in reference lakes in the NLF ecoregion (Table 3). TP concentrations in surface waters ranged from 17-29 µg/L in the spring and then declined to about 22 ug/L in July and rose to 31-40 in August and peaked at 29-58 in September (Figure 4). Generally, both lakes had similar surface TP concentrations except in September when Lower South Long had considerably higher levels than Upper.

There was very little difference in surface TP concentrations between the two sites on both lakes.

Concentrations tend to increase in September coincident with fall turnover. A decline in surface TP from spring through summer is common in lakes and generally results from a decline in TP loading from the watershed, algal uptake of TP, and sedimentation of TP (organically bound - algae and inorganically bound - soil) in the lake. However in 1998 TP concentrations increased in August and September which may be due to climatic factors such as two storm events on August 17 and 22 and an extended warm spell into mid-September.

Based on a comparison of means plus or minus the standard error of the mean, there is no statistically significant difference in the phosphorus concentrations of the two lakes (Table 4). Data for Upper South Long Lake, from 1990 show higher concentrations in June and July, but lower in August and September. However the 1990 range of concentrations for Lower South Long Lake show an increase in TP in all the summer samples, especially in August and September.

TABLE 3: AVERAGE SUMMER WATER QUALITY AND TROPHIC STATUS INDICATORS

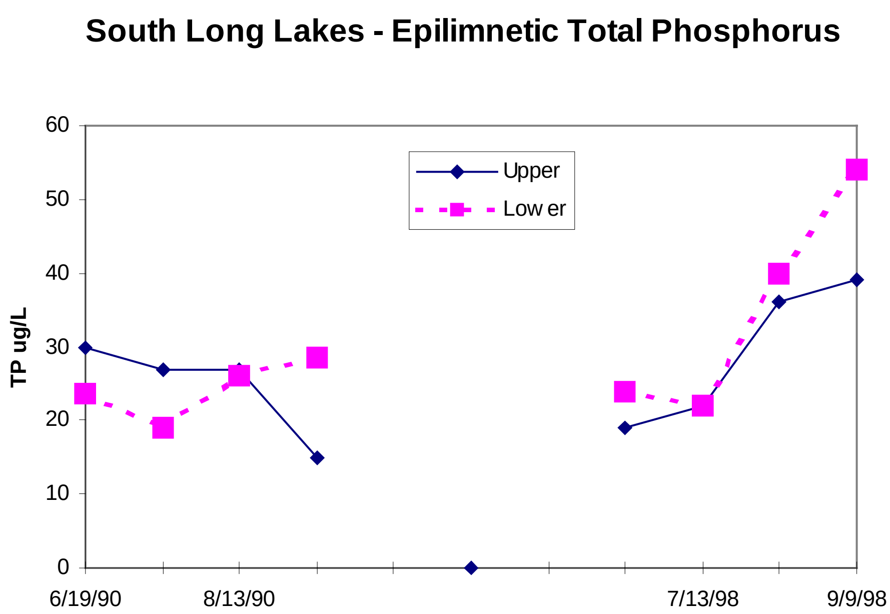
	Upper		Lower		
Parameters	**1998 Mean**	**1990 Mean**	**1998 Mean**	**1990 Mean**	**Typical Range for NLF Ecoregion[1]**
Total Phosphorus (µg/L)	29	24.5	35	24	14-27
Chlorophyll a (µg/L)[3]					
Mean	12.4	16.6	25.3	24	< 10
Maximum	22.5	24.4	55.8	58.3	< 15
Secchi disk (feet)	7.2 (2.3 m)	4.6 (1.5 m)	5.7 (2 m)	4.9 (1.6 m)	8-15
Total Kjeldahl Nitrogen (mg/l)	.66	.84	.73	.83	< 0.75
Nitrite + Nitrate-N (mg/l)		.01		.01	< 0.01
Alkalinity (mg/l)	110	114	110	110	40-140
Color (Pt-Co Units)	20	14	18	15	10-35
pH (SU)		9		9	7.2-8.3
Chloride (mg/l)	3	3.4	3.2	3.5	< 2
Total Suspended Solids (mg/l)	3.8	4.2	5.2	5.5	< 1-2
Total Suspended Inorganic Solids	.6	1.5	.8	2	<1-2
Turbidity (NTU)		3.3		4.6	< 2
Conductivity (µmhos/cm)	110	203		241	50-250
TN:TP Ratio	20:1	34:1	23:1	33:1	25:1-35:1

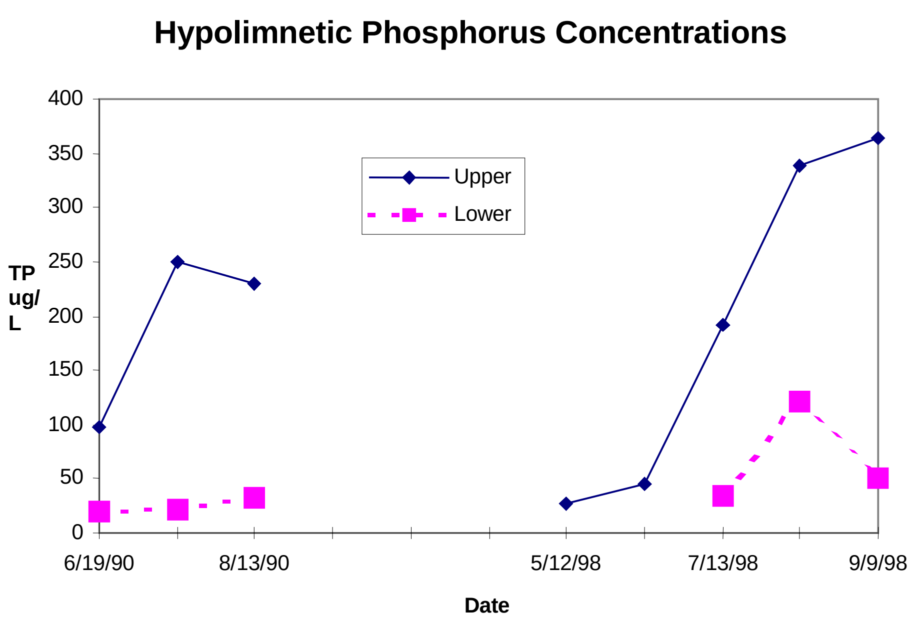
Trophic Status Indicators: Upper and Lower South Long Lakes

		Carlson Trophic State Index Values		Percentile[2] NLF	
		Upper	***Lower***	***Upper***	***Lower***
TP	TSIP =	52	55	46	46
Chl a	TSIC =	55	62	15	8
Secchi	TSIS =	48	53	23	20
Mean (All)	TSI =	52	57	19	13

[1] Derived from Heiskary and Wilson (1990).
[2] Relative to approximately 700 assessed lakes in the Northern Lakes and Forests Ecoregion, whereby the lower the trophic state (TSI), the higher the percentile ranking (100 percent level implies lowest TP or deepest Secchi disk for that ecoregion).
[3] Chlorophyll a measurements have been corrected for pheophytin.

Figure 4. Upper and Lower South Long Lakes Phosphorus Concentrations: 1990 and 1998





Near-bottom (hypolimnetic) TP samples were taken on July, August and September. Concentrations were markedly higher than epilimnetic concentrations (ranged from 27 to 689 ug/L) on most dates. TP concentrations in Upper South Long Lake rose dramatically under stratified conditions in 1990 and 1998. In both 1990 and 1998 hypolimnetic TP concentrations were higher in Upper South Long Lake as compared to Lower South Long Lake. This was likely the result of firmer stratification and low oxygen concentrations above the sediments in Upper South Long Lake.

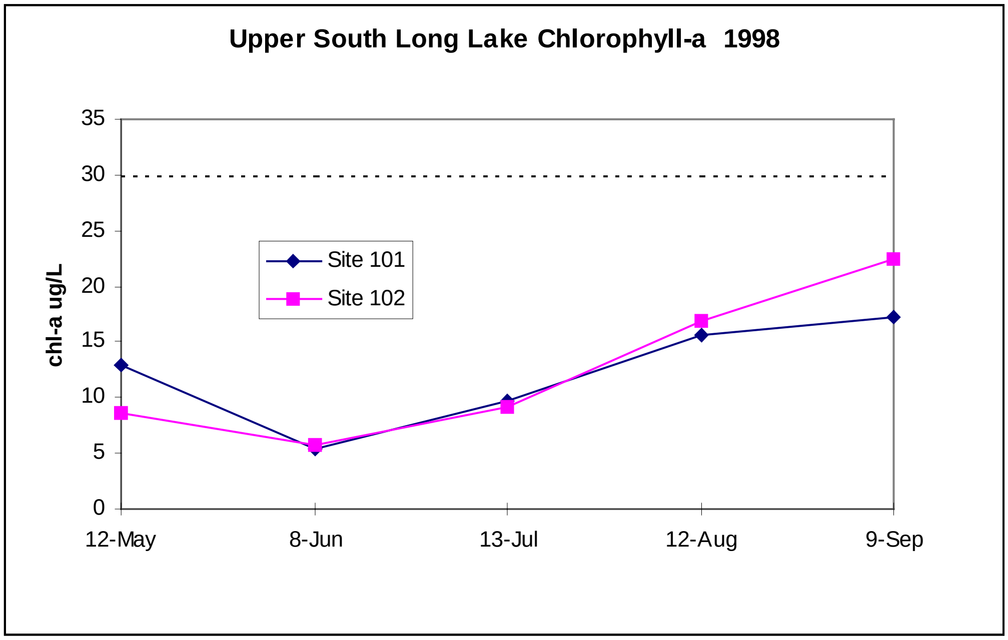
Total nitrogen (TN) concentrations, which consists of total Kjeldahl nitrogen plus nitrite and nitrate-N, averaged 0.66 and 0.73 mg/L respectively on Upper and Lower South Long Lakes over the 1998 summer. These concentrations are within the TN concentrations for reference lakes in NLF ecoregion. The TN concentrations for both lakes were lower in 1998 than in 1990.

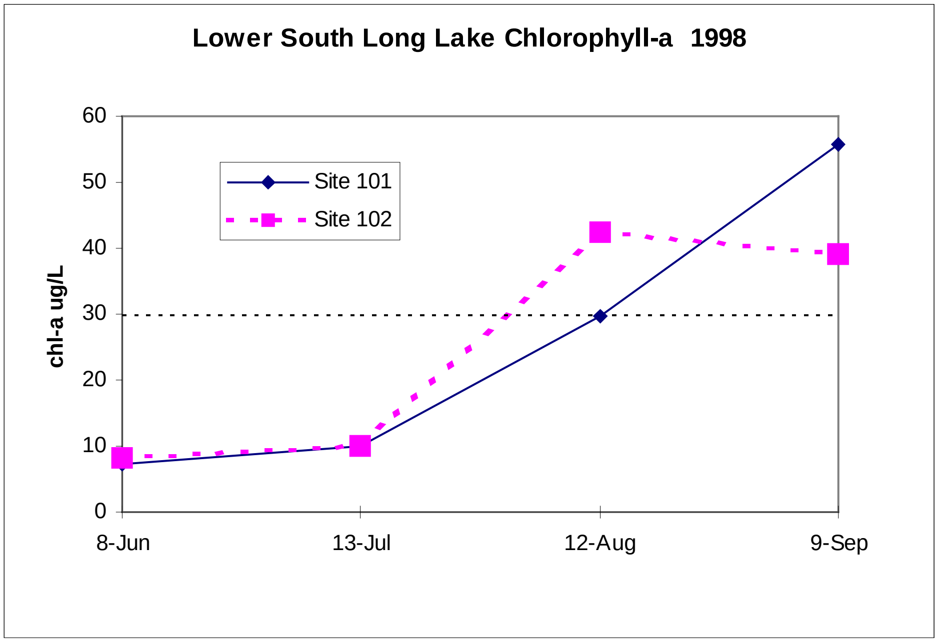
The ratio of TN:TP can provide an indication as to which nutrient is limiting the production of algae in the lake. For Upper and Lower South Long Lakes, the TN:TP ratio is about 20:1 and 23:1 respectively. These ratios suggest that phosphorus is the limiting nutrient. Generally, phosphorus is the least abundant nutrient and, therefore, is the limiting nutrient for biological productivity in a lake.

Chlorophyll a concentrations provide an estimate of the amount of algal production in a lake. During the summer of 1998, chlorophyll a concentrations on Upper and Lower South Long Lakes ranged from less than 5 µg/l to over 50 µg/L with averages of 12 and 25 µg/L respectively (Figure 5). Concentrations from 10-20 µg/L are frequently perceived as a mild algal bloom, while concentrations greater than 30 µg/L may be perceived as a severe nuisance (Heiskary and Walker, 1988). Severe nuisance conditions were evident in August and September on Lower South Long Lake.

The average and maximum chlorophyll-a concentrations for Upper and Lower South Long Lakes were greater than the typical range based on NLF reference lakes (Table 3). Concentrations on Upper and Lower South Long Lakes increased throughout the summer period and concentrations on Lower South Long Lake were consistently higher than on Upper South Long Lake (Figure 5). The increases in chlorophyll-a from May through August were also evident in 1990 and some very high concentrations were noted for Lower South Long Lake. An increase in chlorophyll-a concentrations from late spring to late summer is typical for Minnesota lakes.

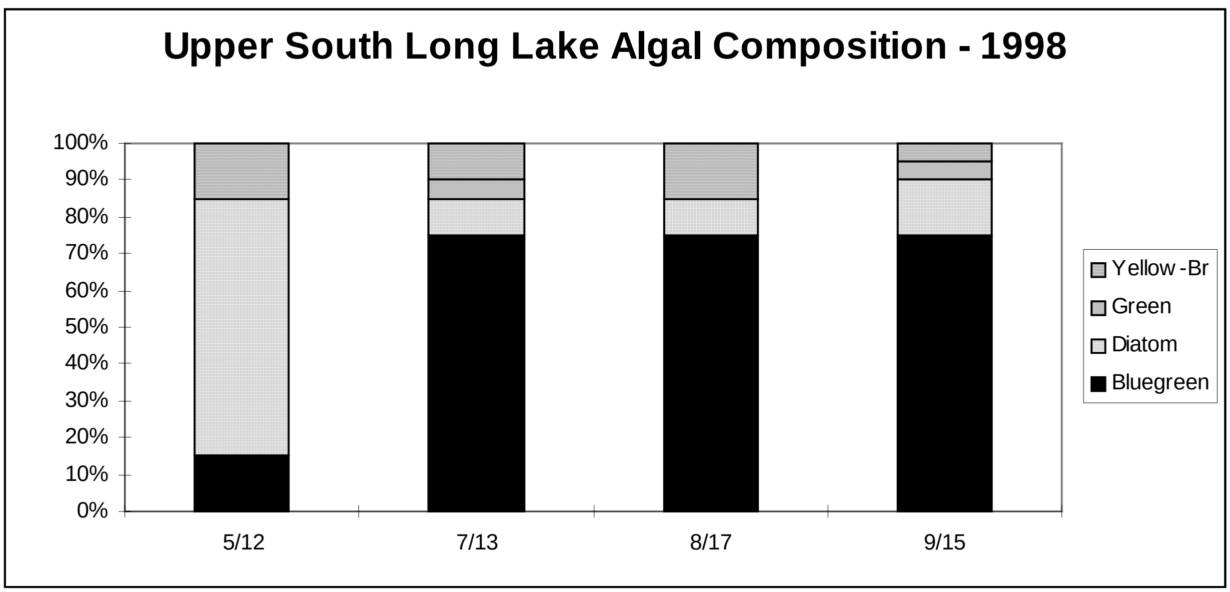
Figure 5. Upper and Lower South Long Lakes Chlorophyll-a Concentrations 1998

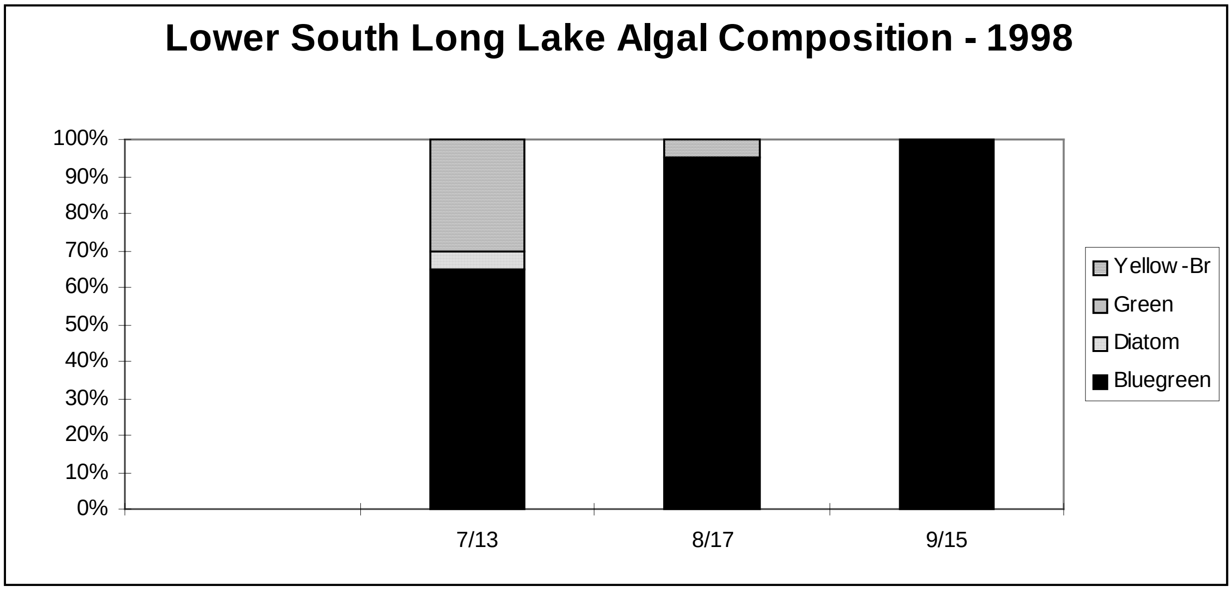




The composition of the *phytoplankton* (algae) population of Upper and Lower South Long Lakes is presented in Figure 6. Data is presented in terms of algal type. Samples were collected at site 101 in each lake. In May, diatoms, with the forms Tabellaria, Asterionella, and Melosira, were most common. By July, blue-green algae dominated the algae population in Upper and Lower South Long Lakes. There were many different forms of blue-greens present - Anabaena, Anacystis, Chroococcus, Nostoc and Oscillatorial/Lyngbya. In August and September, blue-greens remained dominant with the genera Anabena, Anacystis, Nostoc and Aphanizomenon being most common. Bloom conditions >20 µg/L chlorophyll a) were noted in Lower South Long Lakes in July through September, with nuisance bloom levels in August and September (Figure 5). Algal blooms during this period were most commonly associated with blue-green algae which are often considered a nuisance and may form scums near the surface or in the case of Aphanizomenon they may appear as clumps of "grass clippings". A seasonal transition in algal types from diatoms to greens to blue-green is rather typical for mesotrophic and eutrophic lakes in Minnesota. In contrast, for Upper and Lower South Long Lakes, the blue-greens were the dominant form over most of the summer.

Figure 6. Upper and Lower South Long Lakes Algal Composition.





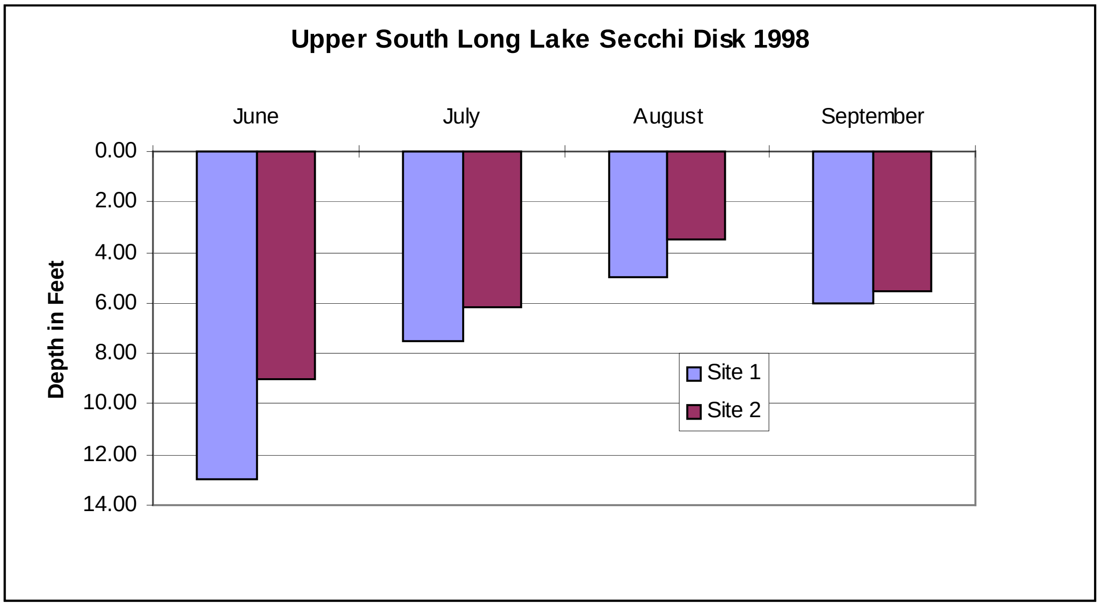
Total suspended solids (TSS) averaged 3.8 and 5.2 mg/L and total suspended inorganic solids (TSIS) averaged .6 mg/L for Upper and .8 mg/L for Lower South Long Lakes over the summer. Organic matter (primarily algae) is the primary contributor to the TSS. The total suspended solids values are moderately high compared to reference lakes in this region. The inorganic solids values though are within the range for the ecoregion (Table 4). These levels of color and inorganic suspended solids should not appreciably limit water transparency in Upper and Lower South Long Lakes. The other water quality parameters measured were quite similar to the NLF reference lakes. Alkalinity and conductivity for both lakes are within the typical range for the reference lakes and are indicative of moderately hard water. Chloride concentrations, at 3.2 µg/L, are slightly higher than the reference lake concentrations.

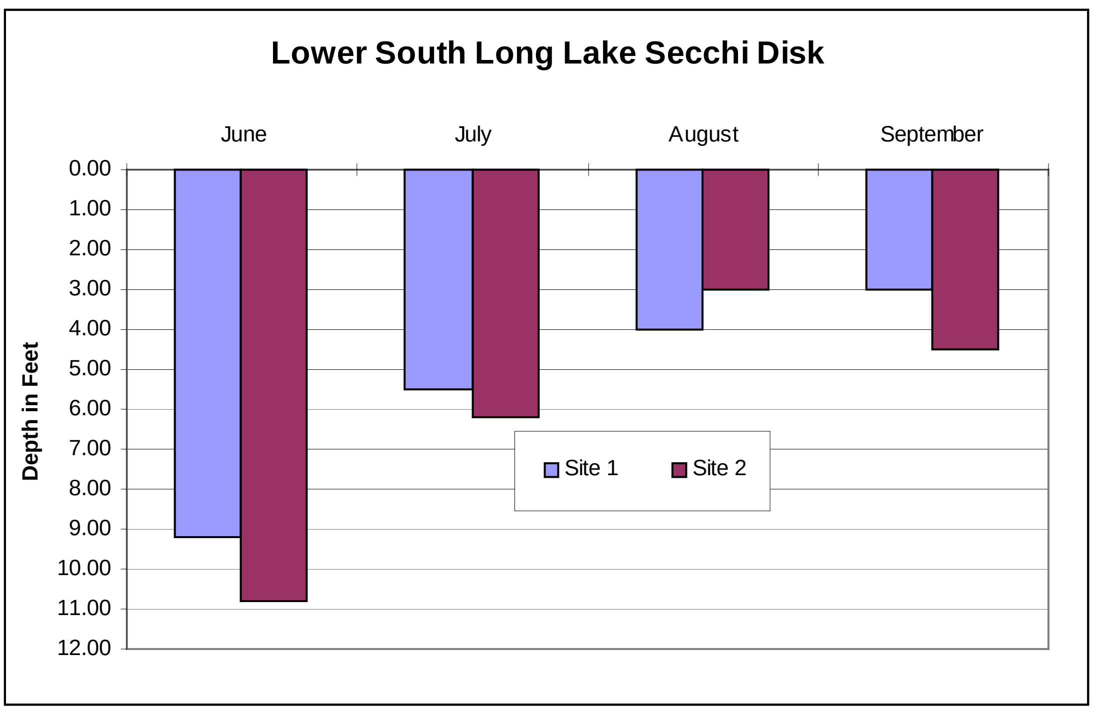
Secchi disk transparency is generally a function of the amount of algae in the water. Suspended sediments or color due to dissolved organic material may also reduce water transparency. Color for Upper and Lower South Long Lakes averaged 18-20 Pt-Co Units, indicating slight coloration due to incompletely dissolved organic matter. This is a relatively low value as compared to a lake like Big Sandy which exhibits color values in excess of 150 Pt-Co Units and is very dark in appearance. This "coffee coloring" or bog stain as it is referred to arises from the wetlands which drain to the lake.

Secchi disk transparency on Upper and Lower South Long Lakes, ranged from about 13 feet (4.3 m) in June to a minimum of 3 feet (1 m) in August and September (Figure 7) and averaged 7.2 feet (2.3 m) and 5.7 feet (1.9 m) respectively during the summer of 1998 (Table 3) based on data collected at two sites on each lake. These transparency measures are lower than the typical range for reference lakes in the NLF ecoregion (Table 3). Figure 7 displays Secchi transparency from the two sites on each lake. In general there was minimal difference between the two sites on each lake.

Along with CLMP transparency measurements, subjective measures of Upper and Lower South Long Lake's "physical appearance" and "recreational suitability" were made by the CLMP observer. Physical appearance ratings range from "some algae present" (Class 2) ... to "definite algae present" (Class 3) and recreational suitability ratings range from "minor aesthetic problem" (Class 2) ... to "swimming…slightly impaired" (Class 3) in this rating system (Heiskary and Wilson, 1988). Based on the 1998 data, lake conditions were typically characterized as "slight to definite algal coloration" (Class 2 and 3) and "minor aesthetic problems to swimming impaired" (Class 2 and 3) throughout much of the summer at both sites Lower South Long Lake. Perceptions of "algal green" (Class 3) and "swimming impaired" (class 3) corresponded to transparencies of 4 feet or less and chlorophyll-a concentrations in excess of 30 μg/L. The reduced Secchi transparency in August through September (Figure 7) corresponded to increases in the amount of algae in the lakes. Chlorophyll-a ranged from 36-47 ug/L in Lower South Long Lake during that period of time (Figure 5), and the algae population was dominated by blue-green algae (Figure 6). Blue-green algae often form visible blooms near the surface. These scums are most likely to accumulate near the surface during extended hot and calm periods.

Figure 7. Upper and Lower South Long Lakes CLMP Secchi Transparency 1998





Although the Secchi disk values are lower than typical lakes in the Northern Lakes and Forest ecoregion; the change in the transparency of Upper and Lower South Long Lakes over the course of the summer is fairly typical for lakes in Minnesota. Typically, transparency is high in the spring when the water is cool and algae populations are low. Frequently, zooplankton (small crustaceans which feed on algae) populations are high at this time of year also, but will decline later in the summer because of predation by young fish. As the summer goes on, the waters warm and the algae make use of available nutrients. As the algae become more abundant, the transparency declines. The decrease in the abundance of zooplankton may allow for further increases in the amount of algae. Later in the summer, surface blooms of algae may appear. In the case of Upper and Lower South Long Lakes, zooplankton were apparent on the June and July sample dates. This may have contributed to the slightly higher transparency in June and early July as compared to later in the summer.

One means to evaluate the **trophic status** of a lake and to interpret the relationship between total phosphorus, chlorophyll a and Secchi disk readings is Carlson's Trophic State Index (TSI) (Carlson 1977). This index was developed from the interrelationships of summer Secchi disk transparency and the concentrations of surface water chlorophyll a and total phosphorus. TSI values are calculated as follows:

Total phosphorus TSI (TSIP) = 14.42 1n (TP) + 4.15
Chlorophyll a TSI (TSIC) = 9.81 1n (Chl-a) + 30.6
Secchi disk TSI (TSIS) = 60 - 14.41 1n (SD)

Figure 8.

Carlson's Trophic State Index Values for Upper and Lower South Long Lakes: 1998

TP and chlorophyll a are in µg/L and Secchi disk transparency is in meters. TSI values range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). In this index, each increase of 10 units represents a doubling of algal biomass.

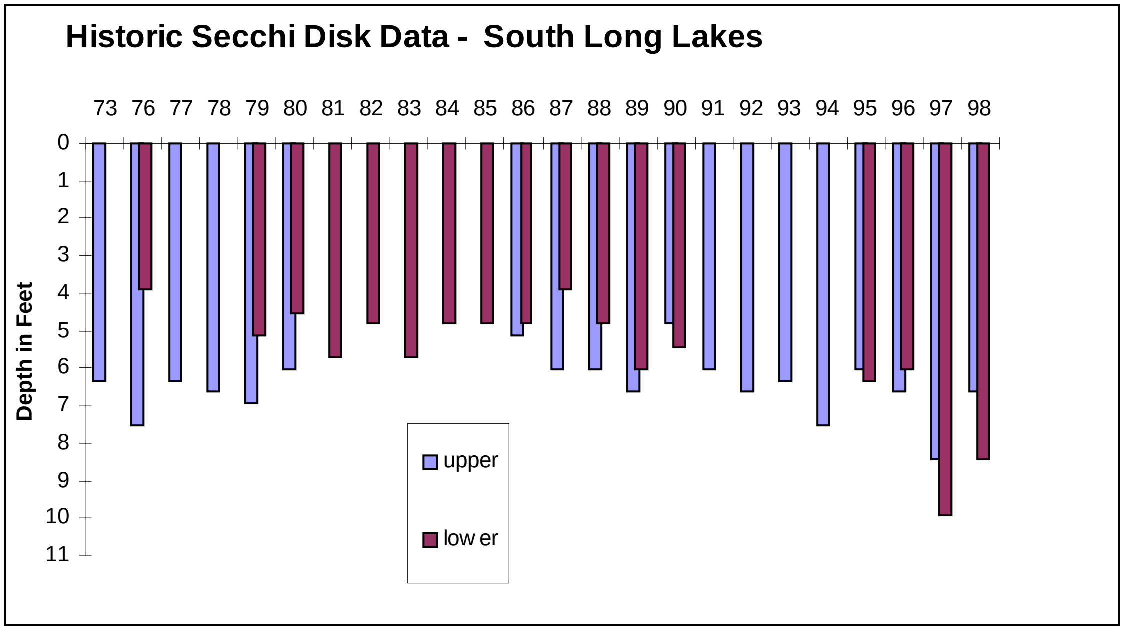
Average values for the trophic variables in Upper and Lower South Long Lakes and respective TSIs are presented in Figure 8. Based on these values, Upper and Lower South Long Lakes are eutrophic in condition. The TSI values for Upper and Lower South Long Lakes rank between the 15th to the 20th percentile relative to 700 other lakes in the NLF ecoregion. This implies that relative to lakes in the NLF, about 80-85 percent had lower TSI values. The individual TSI values for TP and chlorophyll-a agree very well with one another on Upper South Long, while the Secchi disk TSI values are slightly higher in each lake. This may be a result of the predominance of blue-green algae; the blue-greens tend to float on top of the water rather being distributed throughout the water column. This can result in deeper Secchi disk readings, as they tend to disperse or clump together with wind or wave action. In general, Secchi transparency provides a good estimation of trophic status for Upper and Lower South Long Lakes.

Water Quality Trends

Some historical data are available for describing year-to-year variations in water of Upper and Lower South Long Lakes. The majority of the data was collected by citizen volunteers through the CLMP and monitoring conducted by the MPCA. Both have data from the 1990 MPCA monitoring on the lakes and data dating to the 1970's through the CLMP.

Based on 25 (intermittent) years of record, the long-term mean Secchi in Upper South Long Lake is 2.1 m (6.3 feet) and for Lower South Long Lake 1.6 to a maximum of 3.3 m (9.9 feet) in 1997. There is a long-term trend of increased transparency for both lakes (Figure 9), however only Lower South Long Lake shows a statistically significant improvement. The between-year differences in transparency may, in part, be a reflection of "wet" years (high precipitation and high runoff) as compared to "dry" years (low precipitation and runoff) such as 1988.

Figure 9.

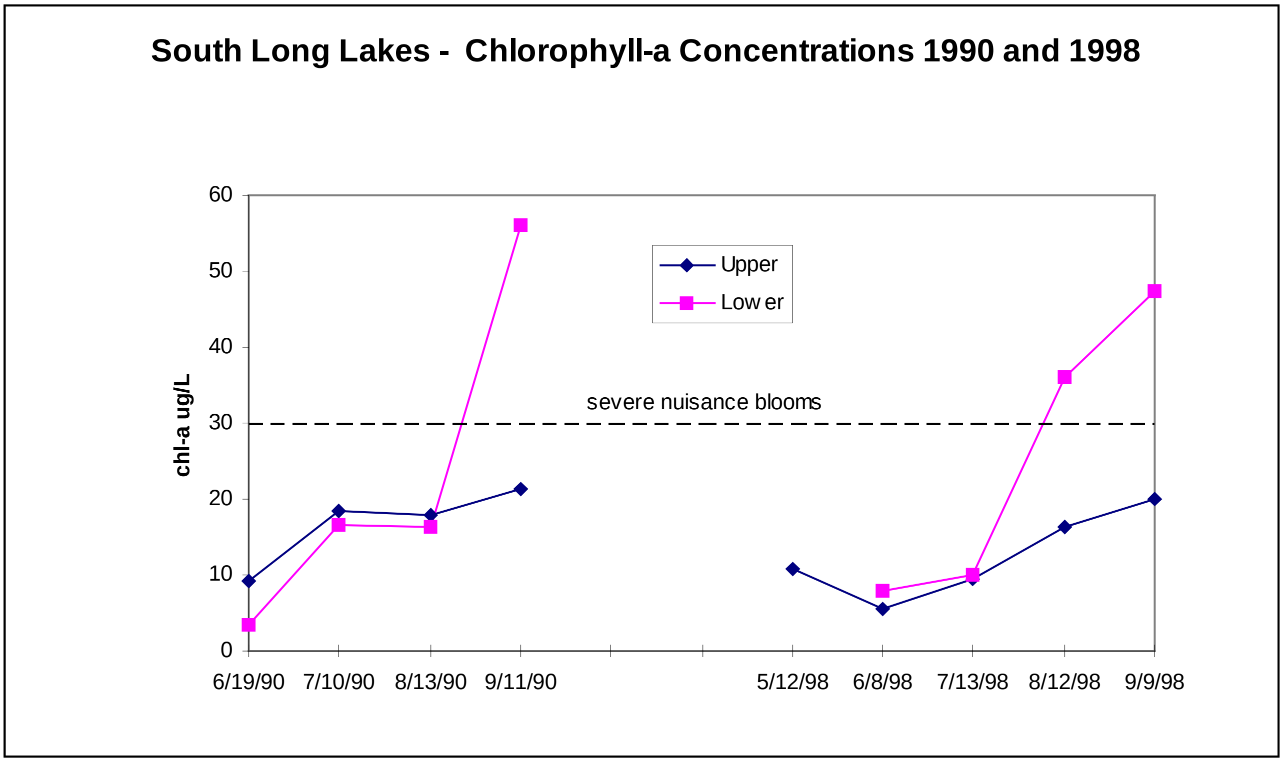


Data from a 1990 MPCA survey on the Lakes is available for comparison as well (Table 4). Based on Table 5, there was not a statistically significant difference in TP and chlorophyll-a concentrations, between 1990 and 1998. However in both years Lower South Long Lake TP and chlorophyll-a concentrations were higher and more variable (based on the high standard error of the means) than corresponding values for Upper South Long Lake.

Table 4. Summer-mean TP and Chlorophyll-a Data: 1990 and 1998

	1990	1998
Upper	n = 8	n = 8
TP (std err)	24 (3) µg/L	29 (4) µg/L
Chl-a (std err)	16 (2) µg/L	12 (2) µg/L
Lower		
TP (std err)	24 (2) µg/L	35 (7) µg/L
chl-a (std err)	24 (8) µg/L	25 (8) µg/L

Upper and Lower South Long Lakes Chlorophyll-a Concentrations: 1990 and 1998



Inflow Monitoring

A few inflow samples for TP were collected during 1998 at the primary inflow point to Upper South Long Lake—the culvert under Highway 24, on the Nokasippi River which drains the north portion of the watershed (Figure 2). Three other intermittent tributaries were also sampled in July after a heavy rain. #1 is on the east side of Upper South Long Lake about 1.5 miles south of Highway 24; #2 is on the east side of Lower South Long just north of Highway 22; and #3 is on the east side of Lower South Long just south of Highway 22. Estimates of flow were made when possible (Table 5).

Table 5. Upper and Lower South Long Lakes Inflow TP and Flow Measurements

	Upper South Long inflow	Lower South Long outflow	Eastern U S L Inflow #1	Eastern L S L Inflow #2	Eastern L S L Inflow #3
Date	**TP ug/L @ Flow cfs**	**TP ug/L @ Flow cfs**	**TP ug/L @ Flow cfs**	**TP ug/L @ Flow cfs**	**TP ug/L @ Flow cfs**
5/5/99	39ug/l				
6/18/99	46ug/L @ 34.9 cfs				
7/9/99	33 ug/L@ 45.7 cfs	22 ug/L@ 76.1 cfs	86 ug/L	28 ug/L	153 ug/L

Relative to minimally-impacted stream TP concentrations in the NLF ecoregion, a concentration of 153 µg/L would rank above the 90th percentile. In contrast a concentration of 33 ug/L would rank near the 50th percentile. This suggests that TP concentrations from the Nokassippi river portion of the watershed are average relative to minimally impacted streams in the NLF ecoregion. However, this data set is rather weak and is biased, to some degree, by the three measurements were all taken when flows were rather high in the stream (and thus loading to the lake would be high). Any future stream assessments should include flow or stage measures on each sample date so that more accurate assessments of loading rate might be obtained.

Modeling Summary

Numerous complex mathematical models are available for estimating nutrient and water budgets for lakes. These models can be used to relate the flow of water and nutrients from a lake's watershed to observed conditions in the lake. Alternatively, they may be used for estimating changes in the quality of the lake as a result of altering nutrient inputs to the lake (e.g., changing land uses in the watershed) or altering the flow of amount of water that enters the lake. To analyze the in-lake water quality of Upper and Lower South Long Lakes, the models MINLEAP (Wilson 1988) and Reckhow and Simpson, 1980 were used. The "Minnesota Lake Eutrophication Analysis Procedures" (MINLEAP), was developed by MPCA staff based on an analysis of data collected from the ecoregion reference lakes. It is used as a screening tool for estimating lake conditions with minimal input data and is described in greater detail in Wilson and Walker (1989). Reckhow and Simpson is a spreadsheet model that estimates phosphorus loading to the lake based on phosphorus and runoff coefficients.

The **MINLEAP model** was run individually for each lake and for both combined -- treating them as one lake. This provides a way to predict a range in background TP concentrations for Upper and Lower South Long Lakes. The respective lake and watershed areas were derived from Table 1.

The model run for Upper South Long Lake used the Nokassippi River watershed above the lake as the principal drainage to the lake. MINLEAP predicts a summer-mean P concentration of 30 µg/L for Upper South Long Lake that compares favorably with the observed mean (29 µg/L) for 1998 (Table 6). The predicted chlorophyll a concentration (based upon predicted TP) is 9.5 µg/L, which is not significantly different than the measured value for 1998. As a result the predicted transparency is comparable to observed . The model also estimates the frequency of occurrence of *nuisance* (>20 µg/L) and *severe nuisance* (>30 µg/L) algal blooms. Based on an observed summer-mean chlorophyll-a of 13 µg/L nuisance blooms likely occurred 13 percent of the summer. In contrast at a predicted concentration of 9.5 µg/L nuisance blooms would occur from 4-12 percent of the summer.

Since the majority of the watershed drains through Upper South Long, via the Nokassippi River, a rather high water and phosphorus loading is anticipated. The predicted P loading rate for Upper South Long was on the order of 1,677 kg P/yr. Of this amount, Upper South Long Lake retains about 43 percent of the P that enters the lake -- hence about 57 percent of the upstream load is transported to Lower South Long Lake. These estimates are based on the size of the watershed and an average inflow P concentrations of 53 µg/L P for the NLF ecoregion. MINLEAP also provides an approximation of the water budget for the lake. Upper South Long Lake’s water residence time (time it would take to fill the lake if it were empty) is on the order of 0.6 years. The areal water load (water load from runoff and precipitation divided by lake surface area) is between 9.7 m/yr and outflow from the lake is estimated at 32 HM^3/yr (~ 36 cfs).

Lower South Long was modeled in a similar fashion using its surface area, mean depth, and the total watershed -- inclusive of Upper South Long Lake. The predicted in-lake (28 µg/L) was lower than the observed in-lake P (35 µg/L) for 1998. Likewise predicted summer-mean chlorophyll-a and the frequency of nuisance blooms were lower as well (Table 6). P loading was estimated at 2,085 and of that about 48 percent was retained in the lake. Since the predicted P concentration is less than observed it is likely that the actual P loading is greater than this estimate. Water residence time is on the order of 0.9 years for Lower South Long Lake.

A third model run was made as well -- treating both basins as a single lake. The predicted P was 25 µg/L that was lower than the volume-weighted mean of 33 µg/L for the two lakes. Likewise predicted summer-mean chlorophyll-a and the frequency of nuisance blooms were lower as well. The estimated P loading rate was about 2,127 kg P/yr with a retention coefficient of 0.53.

A regression model developed by Vighi and Chiaudani (1985), which is based on the morphoedaphic index commonly used in fishery science, was used to estimate background TP for Upper and Lower South Long Lakes. Based on their regression equation, which predicts TP based on lake morphometry and alkalinity, a TP concentration of 19 - 20, µg/L was predicted for the two lakes. Based on the combined results of MINLEAP (NLF inputs) and the Vighi and Chiaudani regression, the background TP concentration for these lakes may be on the order of 19-30 µg/L.

TABLE 6. MINLEAP Model Results for Upper and Lower South Long Lakes comparison of observed and predicted.

	Upper		**Lower**		**Area-weighted combined**	
Parameter	**Obs 1998**	**Pred**	**Obs 1998**	**Pred**	**Obs 1998**	**Pred**
TP (µg/L)	29	30	35	28	33	25
chl-a (µg/L)	13	9.5	25	8.4	20	7.3
% chl-a >20 µg/L	13%	4%	59%	2%	40%	1%
% chl-a >30 µg/L			27%		14%	
Secchi (meters)	2.3	2.0	2.1	2.2	2.2	2.4
P loading rate kg P/yr		1,677		2,085		2,127
P retention (%)		.43		0.48		0.53
P inflow conc. ug/L		53		53		54
water load m/yr		9.7		7.4		4.8
outflow volume hm^3/yr		31.7		39.3		39.6
"background P" µg/L		20		19		20
residence time years		0.6		0.9		1.3

We anticipated that the observed P concentration for Lower South Long would have been lower than the predicted P concentration since the MINLEAP model does not account for P retention in Upper South Long Lake, however that was not the case. Thus the P loading from Lower South

Long's immediate watershed, nearshore sources (such as septic systems), or internal loading may be greater than anticipated.

The Reckhow and Simpson model provides a further basis for estimating water and nutrient budgets for the South Long Lakes using a combination of runoff and P export coefficients based on land use in the watershed. Estimates for P and water loading were made as follows:

1. *Septic loading* was based on 194 residences for Upper South (estimated as 100 seasonal and 94 permanent) and 318 for Lower South (estimated at 168 seasonal and 150 permanent), standard P loading per capita, and P retention by septic systems and soils ranging from "high retention" of 90 % to a "low retention" of 60 %. High retention is anticipated for well maintained systems in good soils and poor retention is anticipated for poorly maintained systems in poor (e.g. water-logged soils).
2. *P export coefficients* - standard coefficients based on the literature and past experience were used. These were applied to lands in the "immediate" watershed of Lower South Long Lake.
3. *Precipitation* and runoff were estimated from statewide isopleth maps.
4. *Atmospheric deposition rates* of 15 (low) and 20 (high) kg/km^2 / yr.
5. *P loading from Upper South Long Lake's portion* of the watershed to Lower South was estimated based on MINLEAP model run for Upper South Long.

Based on the aforementioned approach and values the following estimates of relative contributions of P loading to the lakes was made as follows:

1. **Upper South Long Lake –** estimated P loading is 1,676 kg P/yr

	Loading range	Percent
• Precipitation on the lake:	48 – 65 kg P	3 – 4 %
• Septics	33 – 132 kg P	3 – 8 %
• Watershed (i.e., Nokassippi)		88 – 94 %

1. **Lower South Long Lake –** estimated P loading is 2,276 kg P/yr

	Loading range	Percent
• Precipitation	79 – 106 kg P	3 – 5 %
• Septics	53 – 213 kg P	2 – 9 %
• Upper South outflow	940 kg P	41 %
• Immediate watershed (and internal loading)		45 – 55 %

Based on this assessment the primary contributor of P to Upper South would be from its watershed that is essentially the Nokassippi River. This is consistent with our expectations for the lake given the size of this watershed. Based on the MINLEAP model run and the limited data from the

Nokassippi in-stream P concentrations and loads from this watershed are consistent with our expectations for a river in the NLF ecoregion.

In the case of Lower South Long the primary sources of P are the inflow from Upper South (remembering that about 43 percent of the upstream load is retained in Upper South) and from the immediate watershed of Lower South. Included in the estimate for the "immediate" watershed is any internal recycling from sediments or other sources in the lake. Based on these estimates it appears that the most significant sources of P to Lower South may arise from its immediate watershed or recycling in the lake. In the case of both lakes septic (on-site) system inputs are estimated as a small portion of the overall loading to each basin, however it may be among the most "controllable" portion of the P loading to the lakes considering that atmospheric and natural background loads cannot be reduced. Also any P which leaches to the sub-surface waters from improperly maintained systems will most likely reach the lake and contribute to the overall growth of algae in the lake and /or near-shore growths of attached algae or excessive rooted plant growth.

Goal Setting

The phosphorus criteria value for lakes in the Northern Lakes and Forests ecoregion is less than 30 µg/L for support of swimmable use (Heiskary and Wilson, 1990). At or below 30 µg P/L, "nuisance algal blooms" (chlorophyll-a >20 µg/L) should occur less than 5 percent of the summer and transparency should remain above 2 meter over 70 percent of the summer. Based on 1998 data Upper and Lower South Long Lakes had an area-weighted summer-mean P of 33 µg/L and summer-mean chlorophyll-a of 20 µg/L and were estimated to have experienced nuisance blooms (chlorophyll-a >20 µg/L) over 40 percent of the summer (MINLEAP Model, Table 7).

Table 7. Upper and Lower South Long Lakes Summer-Mean P Concentrations and Model Estimates

Lake	1998 Mean	Range in Summer-Mean P	MINLEAP NLF	Vighi-P
Upper	**29 ±3 µg/L**	**24 - 29 µg/L**	**30 + 8**	**19**
Lower	**35 ± 7 µg/L**	**24 - 35 µg/L**	**28 + 8**	**19**
Area-weighted	**33 ± 4 µg/L**	**24 - 35 µg/L**	**25 ± 7**	**19**

For Upper and Lower South Long Lakes, it would be desirable to reduce in-lake P concentrations. An in-lake goal on the order of 25 - 30 µg/L or less as a long-term mean would seem to be a reasonable goal based on data from 1990 and 1998 and model predictions (Table 7). Achieving a phosphorus concentration of 30 µg/L or less should keep nuisance algal blooms to less than *10* *percent* of the summer and Secchi transparency of *2 meters or greater for more than 70 percent of the summer*. Based on South Long Lake's user perception responses in 1998, Secchi transparency of 1.3 m (4.0 feet) or less and chlorophyll-a of 30 µg/L or more were characterized as "swimming impaired to no swimming" and "algal green to dense algal blooms." In Upper South Long Lake nuisance blooms occurred about 13 percent of the summer based on a summer average of 13 ug/L – which is consistent with model projections. In Lower South, however, nuisance blooms occurred about 40 percent of the summer and "severe nuisance blooms" (chlorophyll-a greater than 30 ug/L) were noted on two occasions and may have been more frequent than the projected frequency of 10 – 15 percent of the summer as per MINLEAP model. *Based on existing data it may be more difficult to maintain a TP concentration of 25 - 30 µg/L or less in Lower South Long Lake, which is slightly shallower and more susceptible to wind mixing than Upper South Long Lake. This shallowness contributes to internal recycling of P during the summer and allows for more extensive macrophyte growth as well. A more detailed investigation of nutrient sources in the watershed may be needed to identify potential sites for implementation of BMPs and other measures intended to reduce nutrient loading to the lake. In the case of Lower South Long Lake the primary focus should be on its immediate watershed.*

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Appendix

Appendix II. Climatic Data and Lake Levels

Water Quality Data Abbreviations and Units
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DATE= yr-mo-da
SITE= sampling site ID, 100 series=MPCA, 200=CLMP, etc.
DM= sample depth in meters(0=0-2 m integrated)
TP= total phosphorus in mg/l(decimal) or ug/L as whole number
OP= total ortho-phosphorus in mg/l
DP= dissolved phosphorus in mg/l
TKN= total Kjeldahl nitrogen in mg/l
N2N3= nitrite+nitrate N in mg/l
NH4= ammonia-N in mg/l
TNTP=TN:TP ratio
PH= pH in SU (F=field, L or _=lab)
ALK= alkalinity in mg/l (lab)
TSS= total suspended solids in mg/l
TSV= total suspended volatile solids in mg/l
TSIN= total suspended inorganic solids in mg/l
TURB= turbidity in NTU (F=field)
CON= conductivity in umhos/cm (F=field, L=lab)
CL= chloride in mg/l
SI= total silica in mg/L
DO= dissolved oxygen in mg/l
TEMP= temperature in degrees centigrade
SD= Secchi disk in meters (SDF=feet)
CHLA= chlorophyll-a in ug/l
TSI= Carlson's TSI (P=TP, S=Secchi, C=Chla)
PHEO= pheophytin in ug/l
PHYS= physical appearance rating (classes=1 to 5)
REC= recreational suitability rating (classes=1 to 5)
RTP, RN2N3...= remark code; k=less than, Q=exceeded holding time

Commonly used statistical abbreviations in data printouts

NTP, NSD,....= number of observations
MTP, MSD,....= mean TP, Secchi, etc.(typically June-Sept. mean)
STP, SSD, ...= standard error of the mean for TP, Secchi, etc.
[std err= std deviation/square root of number of observations]
TPCV, SDCV, .= coefficient of variation of mean for TP, Secchi, etc.
[CV=(100*std deviation)/mean]; and is expressed as a % of the mean

Appendix II. Climatic Data and Lake Levels

Appendix III. Model Outputs

Upper South Long Lake Water Quality Data

DATE	D	SITE	TP	TKN	N2N3	TSS	TSIN	ALK	PHF	CL	CONF	TURB	COL	CHLA	PHEO	SDF	DO	TEMP
			mg/L	mg/L							umhos	NTU	Pt-C0	ug/L		feet	mg/L	C
7/9/79	0	204	.016	.56									40			8.5		
7/23/79	0	203	.036	.80									30					
7/31/79	0	204	.016	.27									25					
8/7/79	0	203	.024	.53									25					
8/15/79	0	204	.025	.65									30					
9/2/79	0	203	.038	.73									25					
9/17/79	0	203	.042	.79									20					
9/17/79	0	204	.024	.60									20					
7/7/80	0	203	.046	.69									10			6.5		
7/7/80	0	204	.032	.60									5			7.5		
7/28/80	0	203	.044	.80									20					
7/28/80	0	204	.050	.67									20					
8/19/80	0	204	.030	1.00									10			6		
9/21/80	0	203	.060	1.10									20			5		
9/21/80	0	204	.041	.89									20			5		

Upper South Long Lake Water Quality Data (continued)

DATE	D	SITE	TP	P	TKN	N2N3	R	TSS	TSIN	ALK	PHF	CL	CONF	TURB	COL	CHLA	PHEO	SDF	DO	TEMP
			mg/L		mg/L								umhos	NTU	Pt-C0	ug/L		feet	mg/L	C
6/19/90	0	101	.027		.70	.01	K	5	2	130		3	215	2	20	8.97	2.88	5.9	9.2	20
6/19/90	39	101	.098		1.17	.01	K												.3	10.6
6/19/90	0	102	.032		.80	.01	K						220			9.13	1.60	4.6		
7/10/90	0	101	.022		.77	.02		4.6	2.4	110	9.1	3.8	200	3.5	20	13.10	1.60	4.9	10.1	25.9
7/10/90	39	101	.250		1.42	.01													.4	10.9
7/10/90	0	102	.031		1.00	.01	K				9.2		200			23.70	1.60	4.3		
8/13/90	0	101	.017		.85	.01	K	3.8	1.2	110	8.8	3.8	200	4.1	10	20.20	2.93	3.6	8.2	22.4
8/13/90	32	101	.230		1.50														.3	11.6
8/13/90	0	102	.037		.92						8.7		200			15.40	.64	3		
9/12/90	0	101	.010		.83	.01	K	3.8	1	110	8.9	3.3	190	3.6	10	17.90	.32	5.6	9	22.1
9/12/90	0	102	.020		.84	.02		3.6	.8	110	8.8	3.1	195	3.5	10	24.40	1.60	4.9		

Upper South Long Lake Water Quality Data (continued)

DATE	D	SITE	TP	TKN	N2N3	TSS	TSIN	ALK	PHF	CL	CONF	TURB	COL	CHLA	PHEO	SDF	DO	TEMP
			mg/L	mg/L							umhos	NTU	Pt-C0	ug/L		feet	mg/L	C
5/12/98	0	101	.030	.59		4.8	2.4	120					20	12.9	2.27	5.6	10.9	16.4
5/12/98	39	101	.027														.2	8.9
5/12/98	0	102	.029								110			8.59	1.67	5.6		
6/8/98	0	101	.017	.45		2.8	.8	120					20	5.35	.88	13.8	9	17.9
6/8/98	32	101	.046														.1	10.2
6/8//98	0	102	.021											5.83	.77	9.8	9.5	18.4
7/13/98	0	101	.019	.72		3.2	.4	110					20	9.61	1.29	7.5	8.7	25.7
7/13/98	42	101	.227															
7/13/98	0	102	.024											9.12	1.36	6.2	7.2	25.4
7/13/98	26	102	.155															
8/17/98	0	101	.031	.76		4.8	.4	90		3.1			20	15.60	1.18	5	7.6	23.4
8/17/98	42	101	.573															
8/17/98	0	102	.041											16.90	2.84	3.5		
8/17/98	22	102	.102															
9/15/98	0	101	.049	.71		4.4	.8	120		3			20	17.30	1.56	6	7.9	21.1
9/15/98	39	101	.689														0	12.2
9/15/98	0	102	.029											22.50	1.50	5.6	7.3	20.7
9/15/98	19	102	.038														2.6	20.6

Lower South Long Lake Water Quality Data

DATE	D	SITE	TP		TKN	N2N3	RN	TSS	TSIN	ALK	PHF	CL	CONF	TURB	COL	CHLA	PHEO	SDF	DO	TEMP
			mg/L		mg/L								umhos	NTU	Pt-C0	ug/L		feet	mg/L	C
7/9/79	0	201	.023		.52										20			8		
7/11/79	0	202	.018		.44										20			7		
7/25/79	0	201	.027		.24										10			5		
8/8/79	0	202	.032		.84										25			5.5		
8/15/79	0	201	.037		.77										20			4		
8/29/79	0	202	.051		.74										15			3		
9/8/79	0	202	.058		.85										20			4		
9/17/79	0	201	.057		.65										15			6		
6/26/80	0	201	.052		.74										10			5		
6/26/80	0	202	.028		.68										10			6		
7/18/80	0	201	.038		.87										10					
7/19/80	0	202	.007		.80										10			4		
8/5/80	0	202	.057		.80										10					
8/18/80	0	201	.014		.59										10					
9/8/80	0	202	.126		1.29										20			3		
9/23/80	0	201	.095		1.17										30			4		

Lower South Long Lake Water Quality Data (continued)

DATE	**D**	**SITE**	**TP**	**TKN**	**N2N3**	**TSS**	**TSIN**	**ALK**	**PHF**	**CL**	**CONF**	**TURB**	**COL**	**CHLA**	**PHEO**	**SDF**	**DO**	**TEMP**
			mg/L	**mg/L**							**umhos**	**NTU**	**Pt-C0**	**ug/L**		**feet**	**mg/L**	**C**
6/30/81	0	202	.039	.57									10			9.5		
7/4/81	0	203	.022	.68									15			9		
7/20/81	0	202	.042	.70									10			4		
7/25/81	0	203	.053	.73									15			5		
8/23/81	0	202	.009	.49									5					
8/25/81	0	203	.054	.90									10					
6/19/90	0	101	.020	.50	.01	2.6	1.2	130		3	225	2.3	10	4.70	1.60	7.9	8.4	19.2
6/19/90	29	101	.020	.40	.01												4.9	16.9
6/19/90	0	102	.027	.34	.01						220			1.92	5.29	7.2		
7/10/90	0	101	.018	.72	.01	6.6	3.2	110	9.1	3.8	195	5.2	20	18.30	1.60	4.6	10.7	25.5
7/10/90	29	101	.021	.60	.03												.3	17.5
7/10/90	0	102	.020	.78	.01				9.1		195			15.10	3.20	4.6		
8/13/90	0	101	.027	.98	.01	4.2	2.2	110	8.8	3.8	500	3.7	20	16.30	2.24	4.3	8.4	22.4
8/13/90	32	101	.033	.84														
8/13/90	0	102	.025	.82												4.3		
9/11/90	0	101	.030	1.29	.01	8.4	1.6	90	8.8	3.3	180	7.3	10	58.30	3.20	3	9.4	22
9/11/90	0	102	.027	1.18	.01				9		175			53.80	.32	3.3		

Lower South Long Lake Water Quality Data (continued)

DATE	**D**	**SITE**	**TP**	**TKN**	**N2N3**	**TSS**	**TSIN**	**ALK**	**PHF**	**CL**	**CONF**	**TURB**	**COL**	**CHLA**	**PHEO**	**SDF**	**DO**	**TEMP**
			mg/L	**mg/L**							**umhos**	**NTU**	**Pt-C0**	**ug/L**		**feet**	**mg/L**	**C**
6/8/98	0	101	.028	.57		2.4	.8	120					10	7.35	1.22	9.2	9	17.6
6/8/98	0	102	.021											8.20	1.14	10.8	8.9	17.4
7/13/98	0	101	.022	.57		3.2	.8	100					20	10.00	1.26	5	9.2	25.2
7/13/98	29	101	.049														.2	17.5
7/13/98	0	102	.022											9.85	1.75	6	8.8	25.8
7/13/98	32	102	.020														.1	17.2
8/17/98	0	101	.040	.77		6.4	.8	110		3.2			20	29.70	1.42	4	7.6	23
8/17/98	26	101	.063														3.6	22.2
8/17/98	0	102	.040											42.50	1.62	3	9.1	23.6
8/17/98	32	102	.178														.3	18.9
9/15/98	0	101	.058	1.04		8.8	.8	110		3.1			20	55.80	1.94	3	8.2	21.5
9/15/98	32	101	.060															
9/15/98	0	102	.050											39.00	.73	4.5	7.4	21.3
9/15/98	32	102	.039														2.5	20.7