Lotus Lake Use Attainability Analysis

Prepared for
Riley-Purgatory-Bluff Creek Watershed District

May 2005

Overview

This report contains the results of a Use Attainability Analysis (UAA) of Lotus Lake. The UAA is a structured scientific assessment of the chemical, physical, and biological conditions in a water body. The analysis includes diagnosis of the causes of observed problems and prescription of alternative remedial measures (such as a diagnostic-feasibility study) that will result in the attainment of the intended beneficial uses of Lotus Lake. The analysis is based upon historical water quality data, results of an intensive lake monitoring program in 1999, and computer simulations of watershed runoff. Computer simulations were used to estimate watershed runoff (phosphorus and flow) under existing and proposed future land use and under varying climatic conditions.

Riley-Purgatory-Bluff Creek Watershed District Water Quality Goals

The approved *Riley-Purgatory-Bluff Creek Watershed District Water Management Plan*, 1996, articulated five specific goals for Lotus Lake. These goals address recreation, water quality, aquatic communities, water quantity, and wildlife. Wherever possible, Riley-Purgatory-Bluff Creek Watershed District (RPBCWD) goals for Lotus Lake have been quantified using a standardized lake rating system termed Carlson's Trophic State Index (Carlson 1977)). This rating system considers the lake's total phosphorus, chlorophyll *a*, and Secchi disc transparency measurements to assign it a water quality index number that reflects its general level of fertility. The resulting index values generally range between 0 and 100, with increasing values indicating more fertile conditions.

Total phosphorus, chlorophyll *a*, and Secchi disc transparency are key water quality parameters upon which Carlson's Trophic State Index (TSI) statistics are computed, for the following reasons:

- **Phosphorus generally controls the growth of algae in lake systems**. Of all the substances needed for biological growth, phosphorus is typically the limiting nutrient.
- **Chlorophyll *a* is the main pigment in algae**. Therefore, the amount of chlorophyll *a* in the water indicates the abundance of algae present in the lake.
- **Secchi disc transparency is a measure of water clarity** and is inversely related to the abundance of algae.

Although any one or all three parameters can be used to compute TSI, water transparency is most often used, since people's perceptions of water clarity are most directly related to recreational-use impairment. The TSI rating system is scaled to place a mesotrophic (medium fertility level) lake on the scale between 40 and 50, and high and low fertility lakes (eutrophic and oligotrophic) toward the high and low ends of the TSI range, respectively. Characteristics of lakes in different trophic status categories are listed below with their respective TSI ranges:

1. **Oligotrophic—**[20 < TSI < 38] clear, low productivity lakes, with total phosphorus concentrations less than or equal to 10 μg/L, chlorophyll *a* concentrations less than or equal to 2 μg/L, and Secchi disc transparencies greater than or equal to 4.6 meters (15 feet).

2. **Mesotrophic**—[38 < TSI < 50] intermediate productivity lakes, with 10 to 25 μg/L total phosphorus, 2 to 8 μg/L chlorophyll *a* concentrations, and Secchi disc measurements of 2 to 4.6 meters (6 to 15 feet).

3. **Eutrophic—**[50 < TSI < 62] high productivity lakes, with 25 to 57 μg/L total phosphorus, 8 to 26 μg/L chlorophyll *a* concentrations, and Secchi disc measurements of 0.85 to 2 meters (2.7 to 6 feet).

4. **Hypereutrophic—**[62 < TSI] extremely productive lakes, with total phosphorus concentrations greater than 57 μg/L, chlorophyll *a* concentrations greater than 26 μg/L, and Secchi disc measurements less than 0.85 meters (less than 2.7 feet).

The RPBCWD goals for Lotus Lake include the following:

1. **Recreation Goal—**The Recreation Goal is to provide water quality that: (1) fully supports swimming, applying the "MPCA Use Support Classification for Swimming Relative to Carlson's Trophic State Index by Ecoregion" (i.e., a Trophic State Index (TSI_{SD}) of 53 or lower); and, (2) achieves a water quality that fully supports the lake's Minnesota Department of Natural Resources (MDNR) ecological Class 24 rating (i.e., a Trophic State Index (TSI_{SD}) of 56 or lower). The goal is attainable in all climatic conditions, but only with the implementation of lake management practices as described in this UAA. The recreation goal also includes maintaining a good quality fishery and improvement of the lake's fishery habitat. The goal is attainable with implementation of the lake management practices described in this UAA.

2. **Water Quality Goal**—The Water Quality Goal is a trophic state index score that meets or exceeds the necessary level to attain and maintain full support of swimming and fishing: A Trophic State Index (TSI_{SD}) of 53 or lower to fully support swimming and a Trophic State Index (TSI_{SD}) of 56 or lower to fully support the lake's fishery. This goal is also attainable, but only with the implementation of lake management practices discussed in this UAA.

3. **Aquatic Communities Goal**—The Aquatic Communities Goal is a water quality that fully supports fishing, according to the MDNR "Ecological Use Classification," This goal is attainable, but only with the implementation of lake management practices listed herein.

4. **Water Quantity Goal**—The Water Quantity Goal for Lotus Lake is to manage surface water runoff from a regional flood, the critical 100-year frequency storm event. This goal has been achieved.

5. **Wildlife Goal—**The Wildlife Goal for Lotus Lake is to protect existing, beneficial wildlife-uses. The wildlife goal has been achieved.

Water Quality Problem Assessment

An evaluation of water quality data for Lotus Lake from 1972 to 2000 was completed to determine the current status of the lake's water quality. Results of this evaluation indicate that the lake's water quality is poor and has primarily remained in this condition over time. The poor water quality has its origins in historical and current inputs of phosphorus and the accumulation of phosphorus in lake sediments. Early measurement of water quality in Lotus Lake as far back as 1972 suggests that the water quality of Lotus Lake has been impaired for a long time. The poor water quality of Lotus Lake is perpetuated by stormwater runoff from the lake's watershed and phosphorus release from sediments.

Historical Water Quality Trends

Trend analyses of 1975 through 2000 data indicate significant improvement in the lake's water quality has occurred over time. Despite the significant improvement in water quality, the lake currently fails to meet MPCA-criteria for full support of swimmable-use. Furthermore, the slow rate of change indicates the lake is very stable. At the rate of change determined by the trend analysis, a 93-year time period would be required to achieve the District's water quality goal of a Trophic State Index (TSI_{SD}) of 53 or lower. Hence, the data indicate management practices are necessary to attain the District goal.

A comparison of baseline (i.e., 1972 to 1987) and current (1988 to 2000) trophic state index (TSI) values indicates that Lotus Lake has been unable to fully support swimmable-use during the baseline and current periods. All but one summer average exceeded MPCA-criteria (i.e., TSI <53) for full support swimmable-use. All but two summer averages failed to meet MDNR-criteria for Lotus Lake's fishery habitat.

Current Water Quality

The current water quality of Lotus Lake is poor, and recreation activities are impaired by mid-to late-summer algal blooms. In 1999 Lotus Lake's average summer concentration of total phosphorus, concentration of chlorophyll *a*, and Secchi disc transparency were 58 μg/L, 26.9 μg/L, and

1.2 meters, respectively. This current water quality condition of Lotus Lake is the result of inputs of phosphorus from stormwater runoff and the mobilization of phosphorus from lake sediments. As a result, the 1999 total phosphorus, chlorophyll *a*, and Secchi disc data indicate that Lotus Lake ranges from mesotrophic (good) to eutrophic (poor) in the spring and is hypereutrophic (very poor) during summer. The data indicate Lotus Lake observed moderate recreational-use impairment during the early-summer and severe recreational-use impairment during the late-summer (Osgood, 1989). The lake's recreational impairment appears to be due to excess algal growth.

Phosphorus Budget

There are three sources of phosphorus loading to Lotus Lake: (1) watershed runoff; (2) atmospheric deposition; and (3) internal phosphorus loading (e.g., release of phosphorus from lake sediments).

Watershed modeling and in-lake modeling under different climatic conditions and for existing watershed land uses indicate that annual total phosphorus loads to the lake range from 762 pounds for a dry year to 950 pounds for a wet year (Figure EX-1). Under future land use conditions, annual phosphorus loads to the lake are expected to range from 774 pounds for a dry year to 977 pounds for a wet year (Figure EX-1). The average rate of watershed phosphorus loading to the 240-acre lake is 3.4 pounds of phosphorus per acre of lake per year under both existing and future land use conditions. This rate of phosphorus loading is excessive and causes water quality problems ($L = 0.375$ g/m^2/yr under existing watershed land uses; $L = 0.384$ g/m2/yr under future land uses).

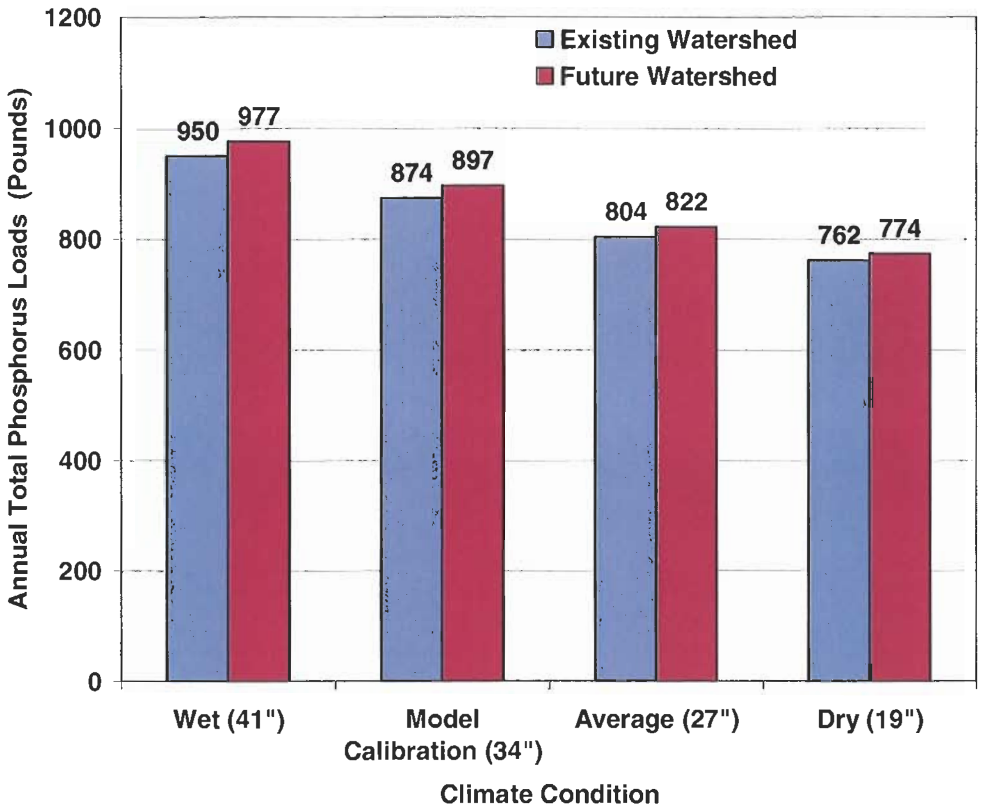

Figure EX-1 Total Phosphorus Loading to Lotus Lake with Varying Climatic Conditions and with Existing and Future Watershed Land Uses

Watershed modeling for the 1,100-acre Lotus Lake watershed (excluding Lotus Lake) shows that from 142 (dry year) to 330 (wet year) pounds of annual phosphorus loading to the lake originate from the surrounding watershed under existing land use conditions. Under existing land use conditions and average precipitation, watershed loading provides approximately 23 percent of the annual total phosphorus load to the lake, while internal loading provides approximately 62 percent of the annual total phosphorus load to the lake (Figure EX-2). The remaining phosphorus load comes from atmospheric deposition (15 percent) (Figure EX-2).

The high concentration of phosphorus that is observed in Lotus Lake is primarily the result of internal lake processes that result in the mobilization of phosphorus from lake sediments by direct release of phosphorus from the sediments. Under existing watershed land use conditions, it is estimated that the direct release of phosphorus from Lotus Lake bottom sediments is responsible for approximately half (wet) to two thirds (dry) of the total phosphorus load to Lotus Lake. Changes in future watershed land use are expected to increase the lake's total phosphorus load from stormwater runoff by 3 to 7 percent. Concurrently, the proportion of phosphorus loading from internal sources is expected to be reduced by 1 to 2 percent.

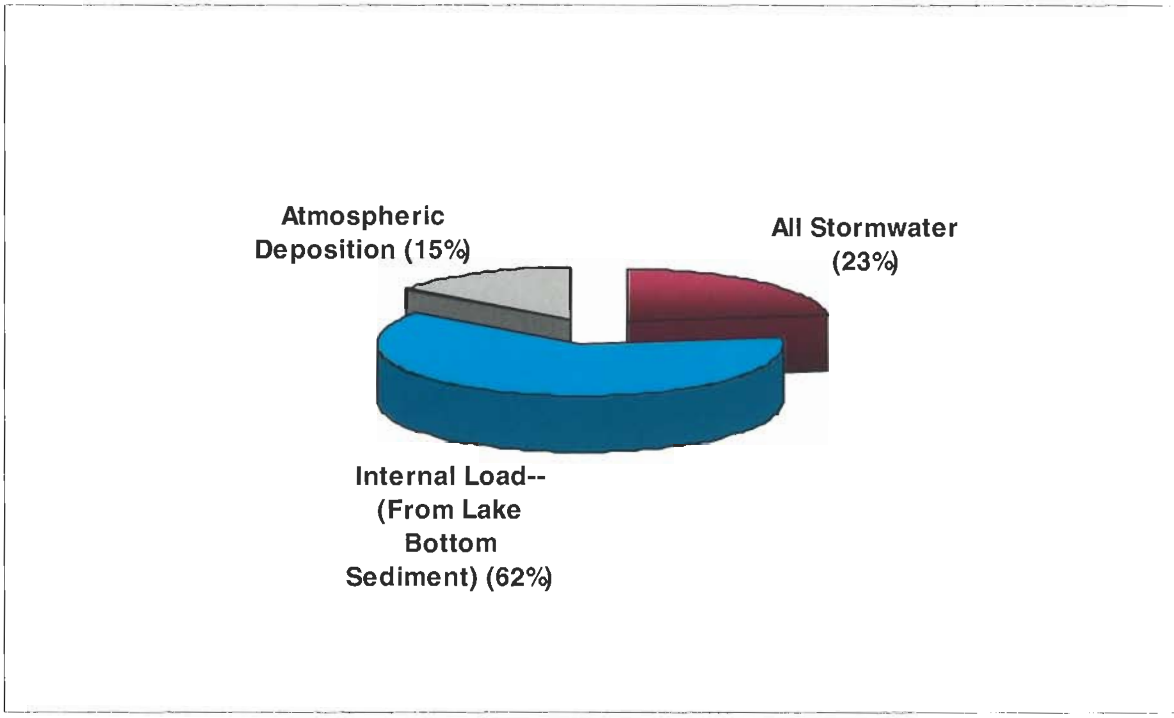

Figure EX-2 Proportion of Phosphorus Loading by Source

Aquatic Plants

District aquatic plant surveys indicate three problematic non-native species currently reside in the lake: curlyleaf pondweed, Eurasian watermilfoil, and purple loosestrife. 1999 survey results indicate: (1) curlyleaf pondweed (*Potamogeton crispus*), was found throughout the lake in light to moderate density during June; (2) Eurasian watermilfoil was found throughout the lake in light to heavy density during June and August; and (3) Purple loosestrife was found throughout the lake's shoreline during June and August. Water quality management to improve the lake's water clarity is likely to result in increased curlyleaf pondweed and Eurasian watermilfoil growth unless a program to manage these plants is completed first. Management of purple loosestrife is recommended to protect the quality of vegetation along the lake's shoreline.

Recommended Goal Achievement Alternatives

One lake improvement alternative will achieve or exceed the District goal for Lotus Lake.

1. Manage curlyleaf pondweed and Eurasian watermilfoil by herbicide (endothall for curlyleaf pondweed and 2,4-D for Eurasian watermilfoil) until no regrowth is observed and no viable turions are collected (estimate 4 years).
2. Introduce beetles (*Galerucella pusilla, Galerucella calmariensis*) in purple loosestrife infested areas to control shoreline purple loosestrife.
3. Three consecutive years of alum treatment to follow the 4th year of herbicide treatment.

Should current research efforts determine that lime is a better tool for management of curlyleaf pondweed and Eurasian watermilfoil than herbicide treatment, 3 years of alum-lime treatment followed by 1 year of lime treatment will replace items (1) and (3).

The expected cost and benefit of this alternative is presented in Table EX-1 and Figure EX-3.

Table EX-1 Benefits and Costs of Management Alternative

Management Alternative	Trophic State Index (TSI_{SD}) Value				Cost
	District Goal	Dry Year-1988 (19 inches of precipitation)	Average Year-1995 (27 inches of precipitation)	Wet Year-1983 (41 inches of precipitation)	
Existing Watershed Land Uses					
Herbicide Treatment (4 years), Alum Treatment (3 years), and Purple Loosestrife Management by Beetles Introduction	≤ 53	34	37	39	$843,000
Future Watershed Land Uses					
Herbicide Treatment (4 years), Alum Treatment (3 years), and Purple Loosestrife Management by Beetles Introduction	≤ 53	36	37	42	$843,000

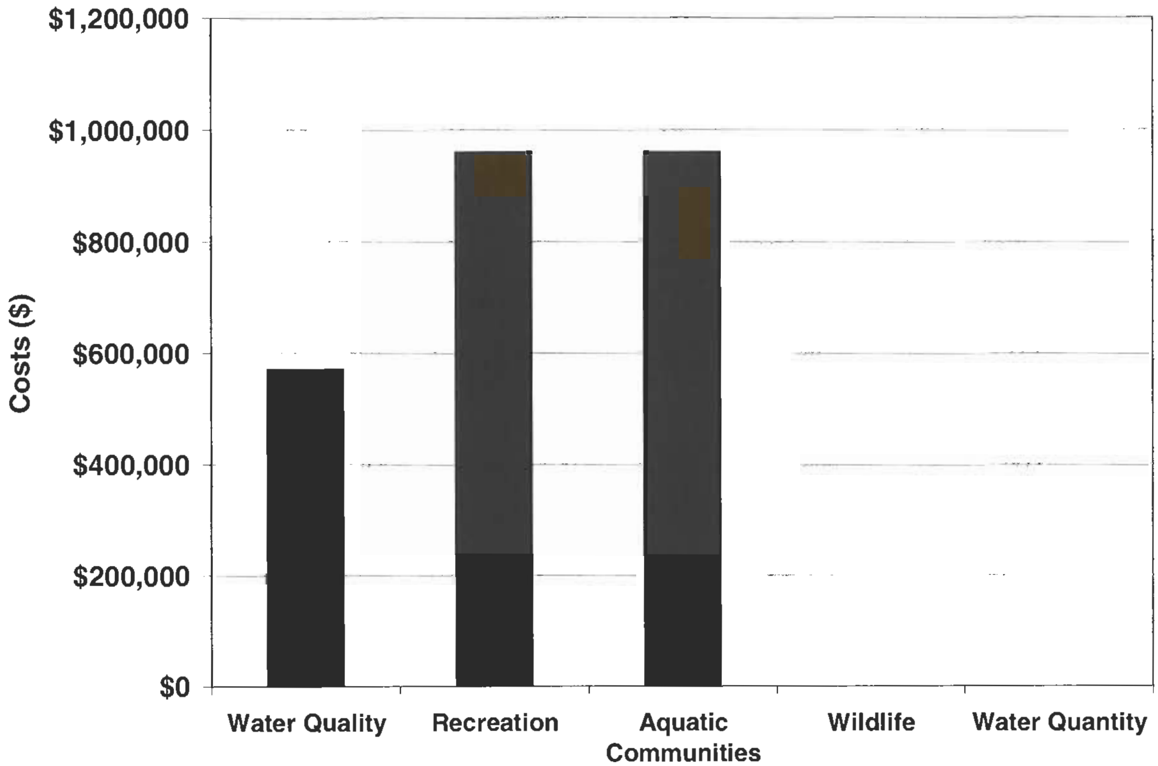

Figure EX-3 Lotus Lake Costs to Meet or Exceed Goals

Selected Implementation Plan

The selected implementation plan is herbicide treatment of curlyleaf pondweed and Eurasian watermilfoil for 4 years followed by 3 consecutive years of alum treatment. This implementation plan has been selected because lake analysis results indicate that the overall productivity of Lotus Lake needs to be significantly reduced to restore the lake to a more ecologically balanced condition. This means that phosphorus release from sediments needs to be controlled. In addition, curlyleaf pondweed and Eurasian watermilfoil management is required to avoid additional growth by these nuisance species as water quality improves. Should current research efforts determine that lime is a better tool for management of curlyleaf pondweed and Eurasian watermilfoil than herbicide treatment, the implementation plan will be changed. Three years of alum-lime treatment followed by 1 year of alum treatment will replace the four herbicide treatments followed by three alum treatments.

Beetles (*Galerucella pusilla, Galerucella calmariensis*) will be introduced in purple loosestrife infested areas to control shoreline purple loosestrife and promote native vegetation.

This plan will require monitoring throughout the restoration effort to evaluate effectiveness and determine whether the prescribed management plan remains appropriate. Aquatic plants, lake water quality, and lake sediments should be monitored. Monitoring data will be used to adjust the implementation plan as warranted.

Proposed 7050 Standards For Lakes

Because of its poor water quality, Lotus Lake is currently listed on Minnesota's 303(d) impaired waters list. Under proposed 7050 Standards for lakes, Lotus Lake would remain on the impaired waters list unless the lake's water quality improved such that the Standards were attained. Treatment of Lotus Lake with alum (i.e., implementation of the recommended water quality improvement plan) is expected to improve the lake's water quality so that the proposed 7050 standards are attained under all climatic conditions under existing and future watershed land use conditions.

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BARR

4700 West 77th Street
Minneapolis, MN 55435
Phone: (952) 832-2600
Fax: (952) 832-2601

Lotus Lake Use Attainability Analysis

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1.0 Surface Water Resources Data

The approved *Riley-Purgatory-Bluff Creek Watershed District Water Management Plan*, 1996, (Water Management Plan) inventoried and assessed Lotus Lake. The plan articulated five specific goals for Lotus Lake. These goals address (1) recreation, (2) aquatic communities, (3) water quality, (4) water quantity, and (5) wildlife. This report:

1. Evaluates the existing and potential beneficial uses intended in these goals.
2. Contains an analysis of the factors that potentially impair or limit those beneficial uses, particularly problems identified in the inventory and assessment.
3. Expands upon specific aspects of the inventory and assessment of Lotus Lake contained in the approved Water Management Plan.

A use attainability analysis of Lotus Lake was completed to provide the scientific foundation for a lake-specific best management plan that will maintain or attain the existing and potential beneficial uses of Lotus Lake. A use attainability analysis evaluates existing and potential beneficial uses of a water resource. "Use attainment" refers to the designated beneficial uses, such as swimming and fishing. Factors that potentially impair or limit existing beneficial uses, including problems identified in the inventory and assessment, are investigated in the use attainability analysis. Lake analyses rely on previously collected field data and continue with watershed evaluations using water quality modeling.

The main tools used in the technical analysis are an advanced water quality model that predicts the amount of pollutants that reach a lake via stormwater runoff and an in-lake model that is used to better understand in-lake processes. Calibrating a lake model requires an accurate measurement of land use and stormwater inputs. Impacts of upland detention and treatment of stormwater are included in the model.

1.1 Land Use

All land use practices, existing, as well as future practices within a lake's watershed, impact the lake and its water quality. Impacts result from the export of sediment and nutrients, primarily phosphorus, to a lake from its watershed. Each land use contributes a different quantity of phosphorus to the lake, thereby affecting the lake's water quality differently. Existing and proposed future land uses in the Lotus Lake watershed are discussed in the following paragraphs.

The 1,339-acre Lotus Lake watershed is comprised of:

- **Lotus Lake** (240 acres at a water elevation of 895.5 feet) and stormwater treatment ponds (32 acres).
- **Land that drains directly to Lotus Lake** (316 acres). Runoff from the lake's directly tributary watershed is not treated prior to entering the lake.
- **Land that drains directly to stormwater treatment ponds** (751 acres) and indirectly to Lotus Lake by a stormwater conveyance system. Stormwater is treated by ponds before entering the lake.

The Lotus Lake watershed is 1,339 acres, including Lotus Lake (240 acres). Approximately 64 percent of the Lotus Lake watershed is comprised of neighborhoods that are primarily single family residences (783 acres), but also contain multiple family residences (60 acres). The remainder of the lake's watershed consists of parks and open areas (219 acres), institutional (5 acres), and water (Lotus Lake 240 acres; stormwater treatment ponds 32 acres).

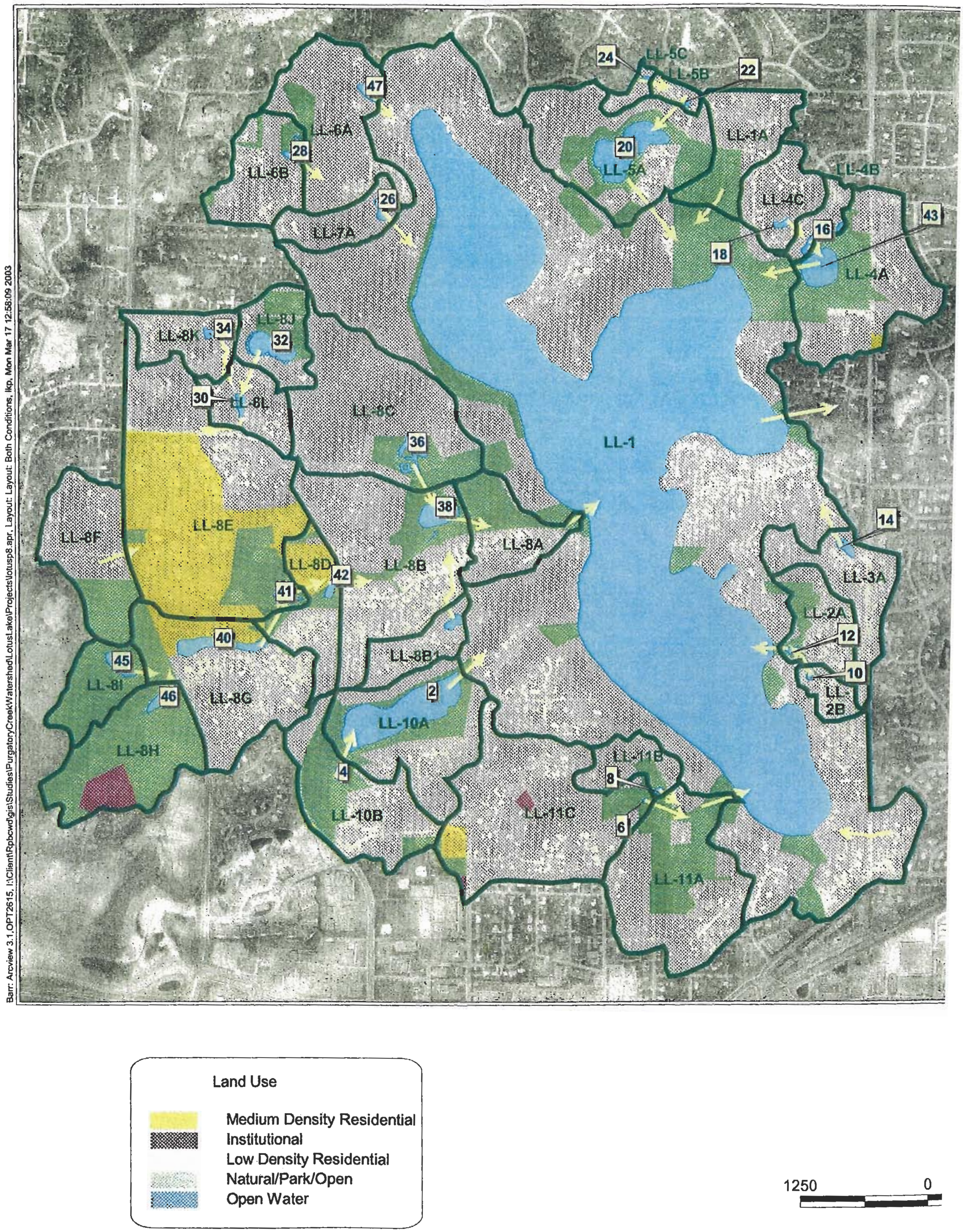
Land use data used in the Lotus Lake UAA modeling efforts were derived from the Metropolitan Council Generalized Land Use Maps for the year 1997 (existing land use) and 2020 (projected future land use). A detailed description of the existing and future land uses of the Lotus Lake watershed are presented in Tables 1 and 2, respectively. Maps of the existing and future land uses of the Lotus Lake watershed are presented in Figure 1. Lotus Lake land uses under existing and future conditions are presented in Figure 2.

Table 1 Existing Land Use in the Lotus Lake Watershed

Subwatershed Name	Institutional (acres)	Low Density Residential (acres)	Medium Density Residential (acres)	Natural/Park/ Open (acres)	Open Water (acres)	TOTAL (acres)
LL-1	0.0	270.4	0.0	45.1	239.8	555.3
LL-10A	0.0	18.8	0.0	8.7	9.6	37.1
LL-10B	0.0	17.7	0.2	10.9	0.1	29.0
LL-11A	0.0	28.5	0.0	15.3	0.0	43.7
LL-11B	0.0	8.1	0.0	1.6	0.1	9.8
LL-11C	0.9	48.6	1.9	4.3	0.1	55.7
LL-1A	0.0	12.8	0.0	6.5	0.0	19.4
LL-2A	0.0	10.8	0.0	3.3	0.2	14.2
LL-2B	0.0	4.9	0.0	0.1	0.1	5.1
LL-3A	0.0	18.6	0.0	0.0	0.5	19.1
LL-4A	0.0	23.8	0.4	11.1	2.5	37.9
LL-4B	0.0	4.6	0.0	0.4	0.6	5.5
LL-4C	0.0	13.7	0.0	0.0	0.3	14.0
LL-5A	0.0	23.3	0.0	11.9	5.2	40.4
LL-5B	0.0	2.6	0.0	0.0	0.1	2.7
LL-5C	0.0	2.5	0.0	0.0	0.1	2.6
LL-6A	0.0	29.0	0.0	3.0	0.5	32.5
LL-6B	0.0	15.9	0.0	2.8	0.4	19.1
LL-7A	0.0	10.8	0.0	0.0	0.4	11.2
LL-8A	0.0	9.8	0.0	7.9	0.0	17.7
LL-8B	0.0	41.9	0.2	7.7	2.2	51.9
LL-8B1	0.0	10.1	0.0	0.0	0.4	10.5
LL-8C	0.0	42.1	0.0	8.1	1.0	51.2
LL-8D	0.0	8.8	5.4	2.7	0.3	17.2
LL-8E	0.0	27.5	46.0	11.3	0.4	85.2
LL-8F	0.0	17.7	0.4	7.3	0.0	25.4
LL-8G	0.0	27.6	5.9	5.3	2.1	40.9
LL-8H	4.2	0.0	0.0	26.5	0.9	31.6
LL-8I	0.0	0.0	0.0	12.3	1.0	13.3
LL-8J	0.0	6.9	0.0	4.9	2.4	14.2
LL-8K	0.0	13.0	0.0	0.0	0.2	13.3
LL-8L	0.0	12.2	0.0	0.0	0.4	12.5
Grand Total	5.1	783.0	60.4	218.9	271.8	1339.3

Table 2 Future Land Use in the Lotus Lake Watershed

Subwatershed Name	Institutional (acres)	Low Density Residential (acres)	Medium Density Residential (acres)	Natural/Park/ Open (acres)	Open Water (acres)	TOTAL (acres)
LL-1	0.0	285.9	0.6	28.7	239.8	555.0
LL-10A	0.0	19.0	0.0	8.7	9.4	37.1
LL-10B	0.0	18.8	2.2	7.8	0.1	29.0
LL-11A	0.0	43.6	0.0	0.1	0.0	43.7
LL-11B	0.0	9.7	0.0	0.0	0.1	9.8
LL-11C	1.7	50.8	2.9	0.3	0.1	55.7
LL-1A	0.0	13.1	0.0	6.2	0.0	19.4
LL-2A	0.0	14.1	0.0	0.0	0.2	14.2
LL-2B	0.0	5.0	0.0	0.0	0.1	5.1
LL-3A	0.0	18.6	0.0	0.0	0.5	19.1
LL-4A	0.0	25.4	0.4	9.5	2.5	37.9
LL-4B	0.0	4.9	0.0	0.0	0.6	5.5
LL-4C	0.0	13.7	0.0	0.1	0.3	14.0
LL-5A	0.0	32.4	0.0	2.8	5.2	40.4
LL-5B	0.0	2.6	0.0	0.0	0.1	2.7
LL-5C	0.0	2.5	0.0	0.0	0.1	2.6
LL-6A	0.0	32.0	0.0	0.0	0.5	32.5
LL-6B	0.0	18.8	0.0	0.0	0.3	19.1
LL-7A	0.0	10.8	0.0	0.0	0.4	11.2
LL-8A	0.0	17.1	0.0	0.5	0.0	17.7
LL-8B	0.0	42.7	0.2	7.0	2.1	51.9
LL-8B1	0.0	10.0	0.0	0.0	0.4	10.5
LL-8C	0.0	49.4	0.0	0.8	1.0	51.2
LL-8D	0.0	8.6	5.4	2.8	0.3	17.2
LL-8E	0.0	28.3	46.0	10.5	0.4	85.2
LL-8F	0.0	25.0	0.4	0.0	0.0	25.4
LL-8G	0.1	32.4	5.9	0.4	2.1	40.9
LL-8H	14.5	15.0	0.0	1.2	0.9	31.6
LL-8I	0.0	12.3	0.0	0.0	1.0	13.3
LL-8J	0.0	9.9	0.0	2.3	2.0	14.2
LL-8K	0.0	13.0	0.0	0.0	0.2	13.3
LL-8L	0.0	12.2	0.0	0.0	0.4	12.5
Grand Total	16.25	897.77	64.08	89.94	270.99	1339.03



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LL-1A
LL-2A
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LL-3A
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Land Use
Medium Density Residential
Institutional
Low Density Residential
Natural/Park/Open
Open Water
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0

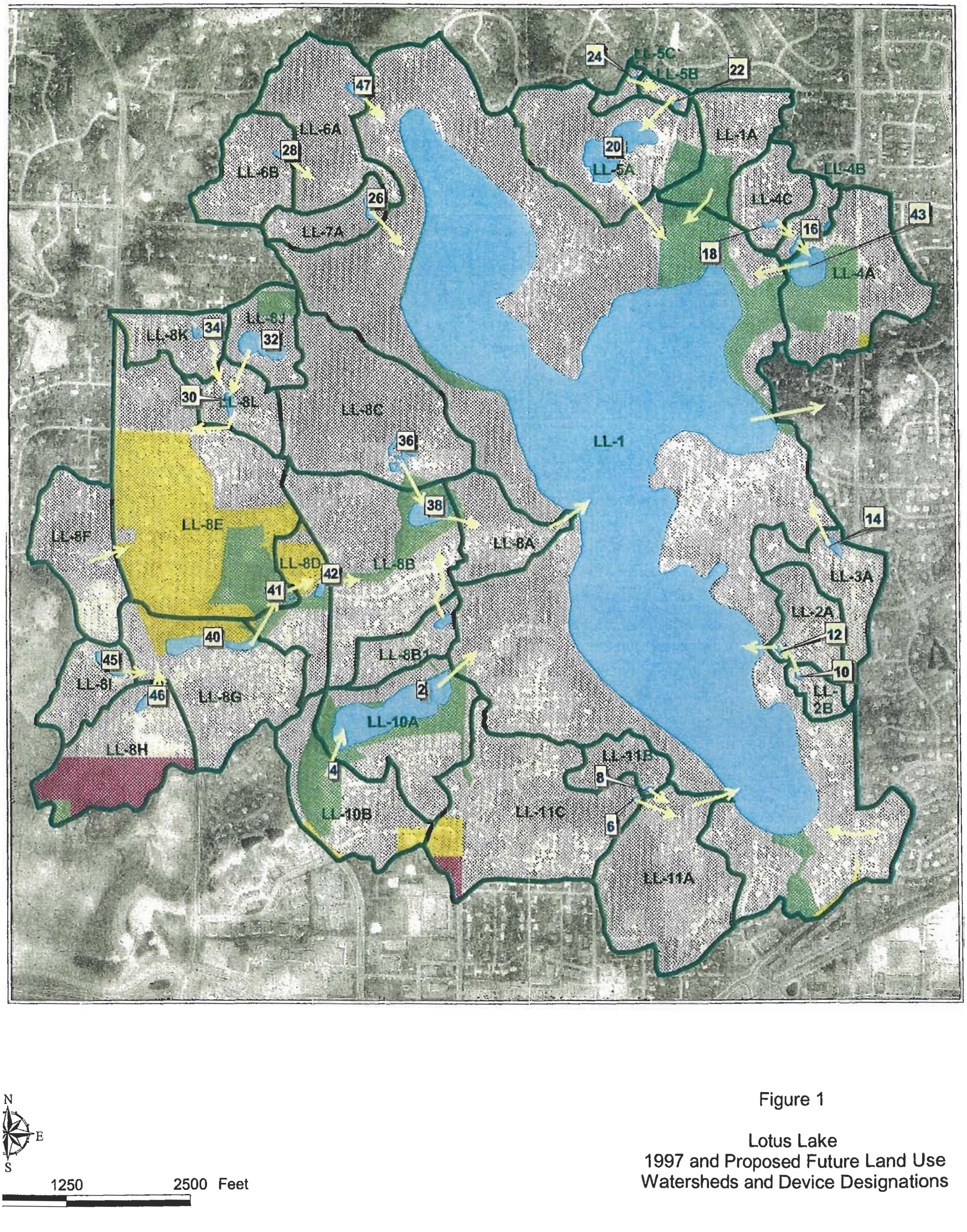
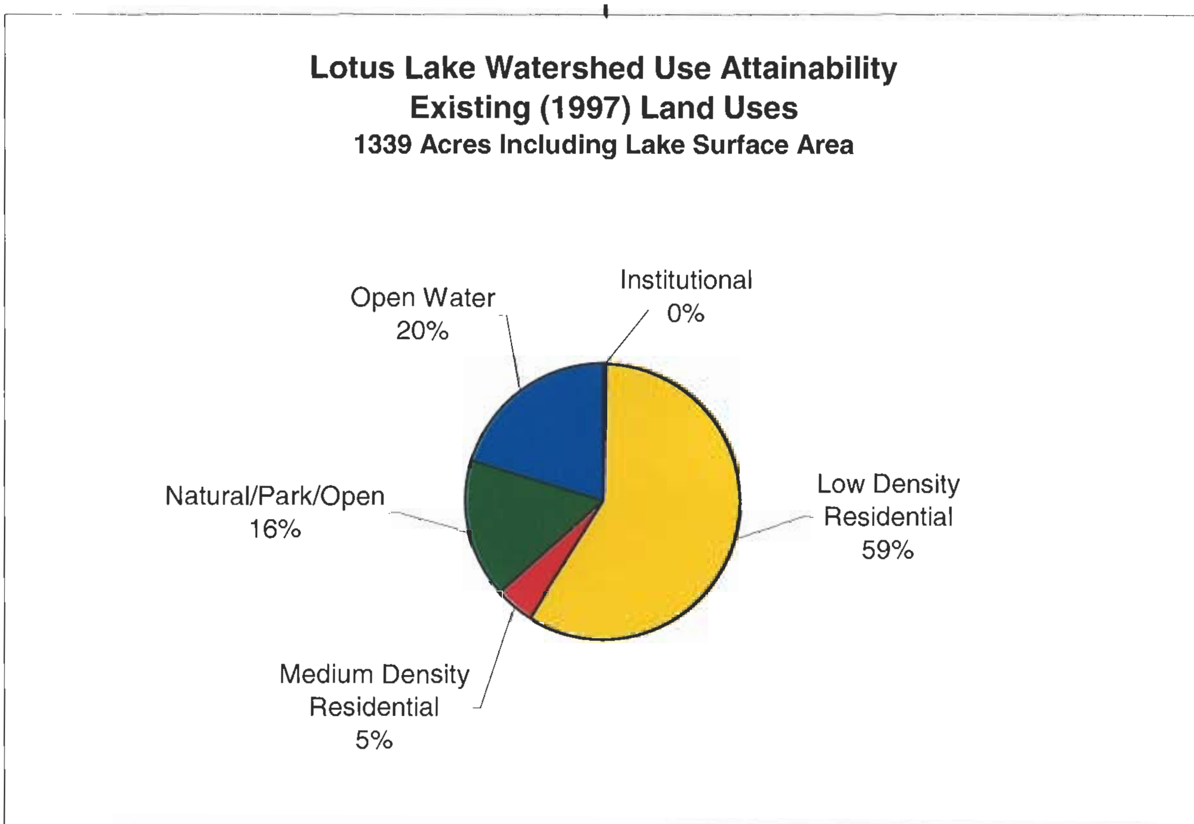


Figure 1

Lotus Lake
1997 and Proposed Future Land Use
Watersheds and Device Designations



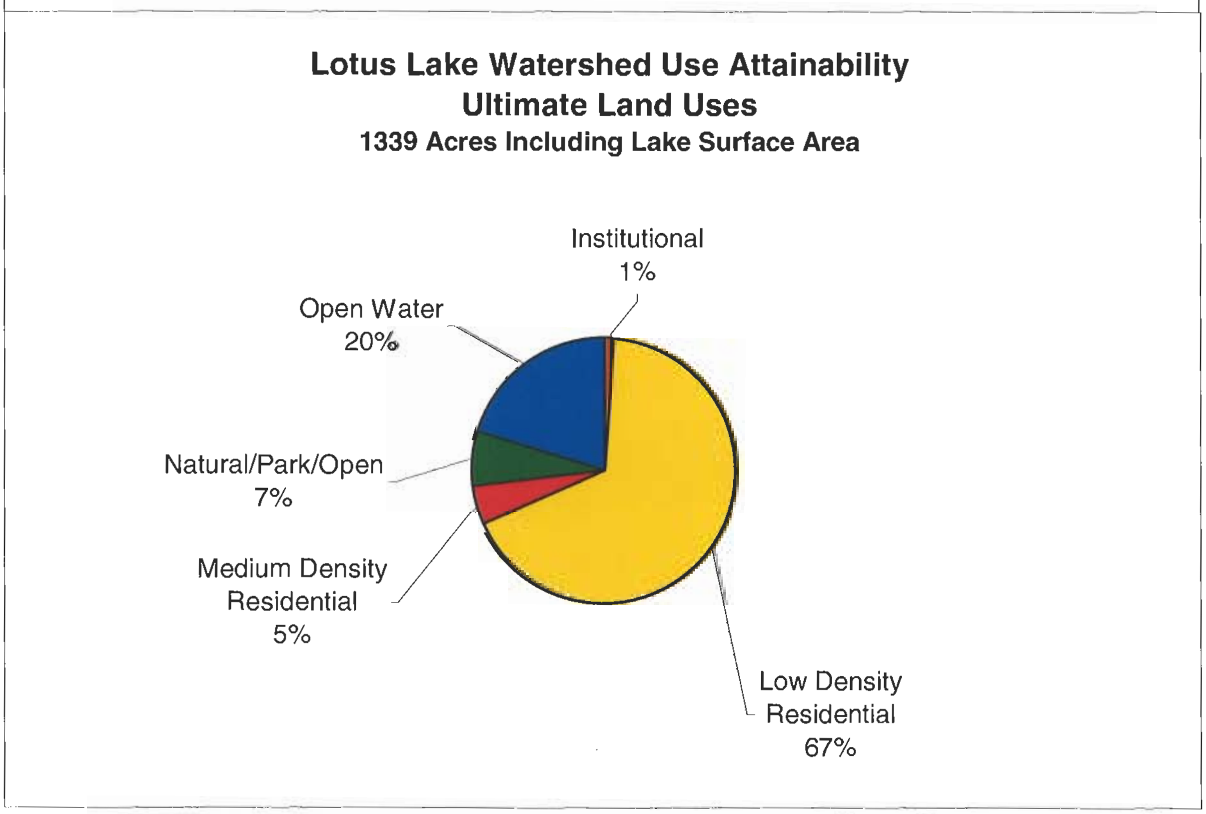


Figure 2
Lotus Lake Watershed
Land Uses

1.2 Major Hydrologic Characteristics

At a water elevation of 895.5 feet, Lotus Lake has a surface area of 240 acres, a maximum depth of approximately 31 feet, and an average depth of 16 feet. Water enters the lake by either direct precipitation, runoff from surrounding land, or storm water conveyances. Water exits the lake by ground water infiltration or through an outlet which discharges to Purgatory Creek. The outlet is at elevation 895.4 feet and hence water discharges from Lotus Lake through this outlet when the surface elevation of the lake exceeds this elevation. Its outflow volume and hydrologic residence time vary with climatic conditions (Table 3).

Table 3 Estimated Average Lake Volume, Estimated Lake Outflow Volume, and Estimated Hydraulic Residence Time of Lotus Lake During a Range of Climatic Conditions (Existing Watershed Land Use).

Water Year (Inches of Precipitation)	Average Lake Volume m^3 (ac-ft)	Estimated Annual Lake Ouflow Through Outlet* m^3 (ac-ft)	Estimated Annual Lake Outflow by Seepage* m^3 (ac-ft)	Hydraulic Residence Time Years
1995 (27 Inches)	4,225,234 (3,425)	11,102 (9)	756,224 (613)	5.5
1996 (20 Inches)	4,231,402 (3,430)	23,439 (19)	758,682 (615)	5.4
1997 (39 Inches)	4,225,234 (3,425)	62,916 (51)	735,252 (596)	5.3
1998 (30 Inches)	4,395,477 (3,563)	275,103 (223)	655,065 (531)	4.7
1999 (34 Inches)	4,364,636 (3,538)	215,888 (175)	701,944 (569)	4.8
2000 (24 Inches)	4,280,748 (3,470)	64,150 (52)	751,290 (609)	5.2
2001 (36 Inches)	4,320,224 (3,502)	135,701 (110)	720,449 (584)	5.0
2002 (39 Inches)	4,328,860 (3,509)	151,738 (123)	706,879 (573)	5.0

* The estimated annual lake outflow through the outlet and by seepage is based upon WATBUD modeling results.

1.3 Water Quality

The water quality of a lake provides an indication of how a lake functions. A standardized lake rating system is often used to classify the ecological condition of a lake. The rating system uses phosphorus, chlorophyll *a*, and Secchi disc transparency values to classify a lake into four categories:

Oligotrophic (clear, low productivity lakes with excellent water quality), Mesotrophic (intermediate productivity lakes with good water quality), Eutrophic (high productivity lakes with poor water quality) and Hypereutrophic (extremely productive lakes with very poor water quality).

1.3.1 Data Collection

Water quality data were collected by the District for Lotus Lake from 1972 to 1999 (for years 1972, 1975, 1978, 1981, 1984, 1988, 1991, 1994, and 1999). Lake monitoring data also used in this study have been provided by the Metropolitan Council for 1985, 1990, 1999, and 2000.

From April through October, 1999, an intensive water quality monitoring program was completed for Lotus Lake to calibrate a water quality model for the lake. This data collection effort involved more frequent lake sampling and the collection of samples at additional depths in the lake. 1999 water quality data are found in Appendix A-1.

1.3.2 Baseline/Current Water Quality

A comparison of baseline and current water quality (total phosphorus, chlorophyll *a*, and Secchi disc transparency) was completed to determine whether changes in the lake's water quality occurred during the 1972 to 2000 monitoring period. Baseline water quality is defined as the average summer water quality for the years 1972 through 1987, while current water quality is defined as the average summer water quality for years 1988 through 2000.

For the baseline and current period, Lotus Lake can be classified as eutrophic (poor water quality) to hypereutrophic (very poor water quality). The lake's overall water quality has remained relatively stable during the baseline and current periods, despite year-to-year fluctuations in individual parameters. Based on the lake's water transparency, it appears that the lake's water quality has not changed during the period of record. The lake's average Secchi disc water transparency was the same for the baseline and current periods. The lake's current mean total phosphorus value was lower and the current mean chlorophyll value was higher than baseline values. The average total phosphorus value was within the hypereutrophic (very poor) category during the baseline period and the eutrophic (poor) category during the current period. The average chlorophyll value was within the hypereutrophic (very poor) category during baseline and current periods. The average Secchi disc value was within the eutrophic (poor) water quality category during baseline and current periods (See Figure 3). The data indicate the lake's water quality has been poor or very poor throughout the period of record.

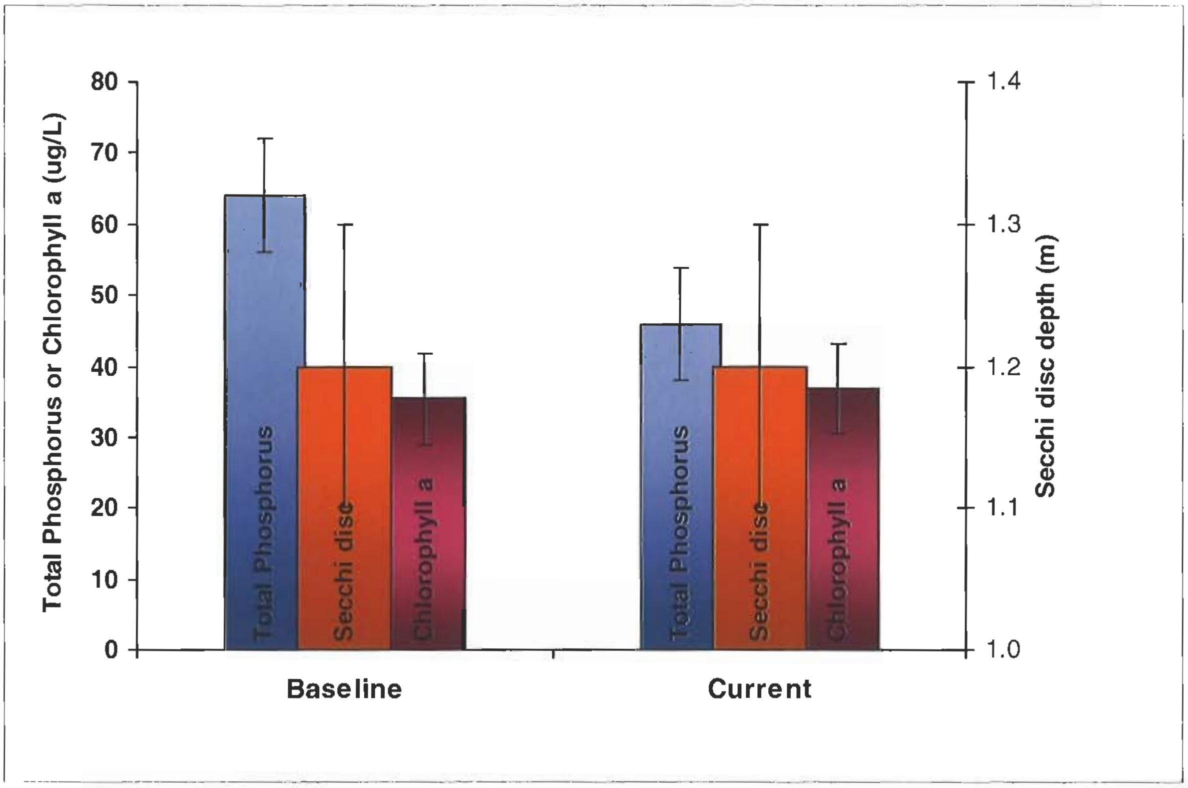


Figure 3 **A Comparison of Baseline Water Quality of Lotus Lake with Current Conditions Based on Summer (June through August) Averages**

As shown in Figure 4, the water transparency of lakes with poor water quality tends to be very stable. Hence, large changes in phosphorus concentrations result in little change in water transparency. Lotus Lake's high phosphorus concentrations throughout the period of record have resulted in a stable water transparency. Fluctuations in average baseline and current summer phosphorus concentrations have not been large enough to cause a change in the lake's average baseline and current summer Secchi disc measurements.

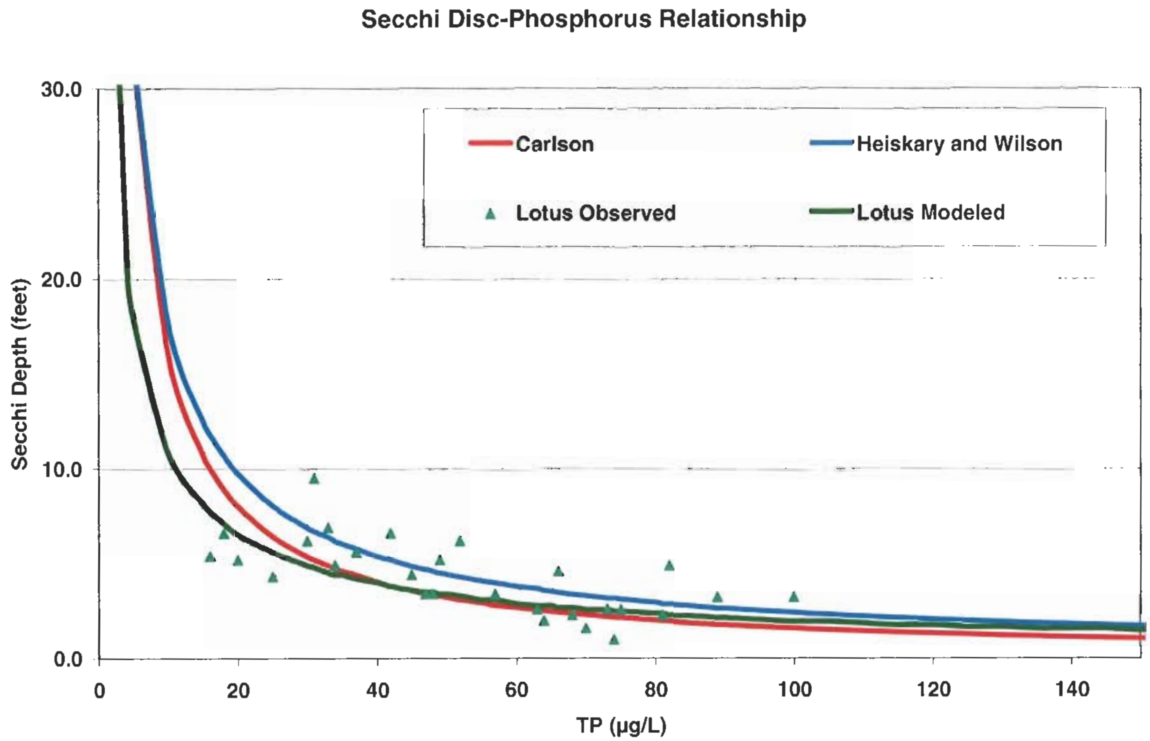


Figure 4 Total Phosphorus-Secchi Disc Relationship From Lotus Lake Data and According to Carlson (1977) and Heiskary and Wilson (1990)

1.3.2.1 Present Water Quality

An evaluation of water quality data for Lotus Lake in 1999 was completed to examine the lake's present water quality. The evaluation was based upon a standardized lake rating system. The rating system uses the lake's total phosphorus, chlorophyll *a*, and Secchi disc transparency as the key water quality indicators to determine the lake's present water quality for the following reasons.

Phosphorus generally controls the growth of algae in lake systems. Of all the substances needed for biological growth, phosphorus is generally the one present in limited quantity. Consequently, when phosphorus is added to a system, it enhances algal growth. Chlorophyll *a* is the main pigment in algae; therefore, the concentration of chlorophyll *a* in the water indicates the amount of algae present in the lake. Secchi disc transparency is a measure of water clarity, and is inversely related to algal abundance. Water clarity determines recreational use-impairment. Figure 5 summarizes the seasonal changes in concentrations of total phosphorus and chlorophyll *a*, and Secchi disc transparencies for Lotus Lake in 1999. The data are compared with a standardized lake rating system.

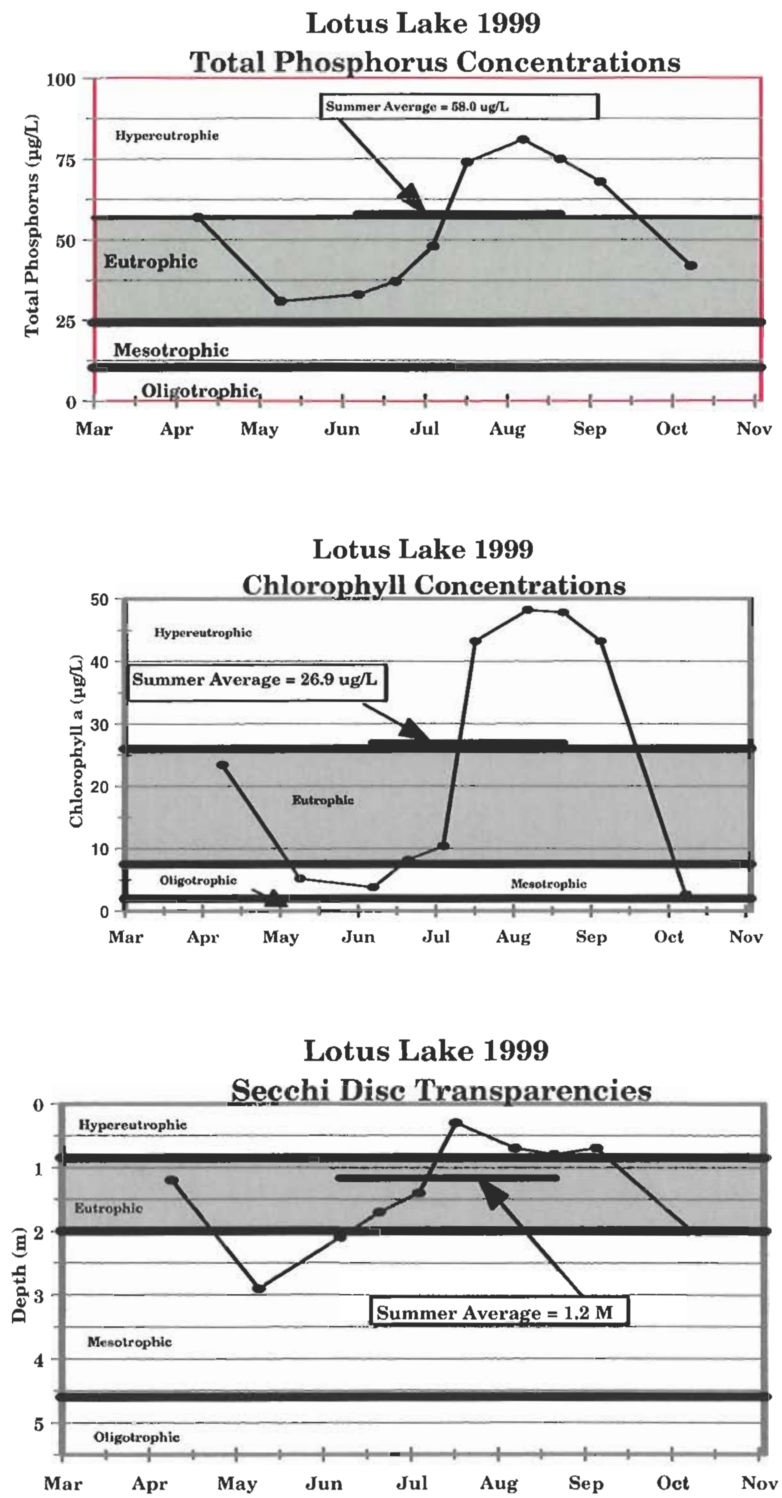


Figure 5 **Seasonal Changes in Concentrations of Total Phosphorus and Chlorophyll *a* and Secchi disc Transparencies in Lotus Lake**

Water quality in Lotus Lake was poor throughout the monitoring period. Nonetheless, changes in total phosphorus and chlorophyll concentrations and water transparency followed a seasonal pattern. The three parameters concurrently indicated the lake's water quality worsened between the early-and late-summer period. Total phosphorus concentrations were in the eutrophic (nutrient-rich) category during the spring and early-summer, but worsened to the hypereutrophic (extremely nutrient-rich) category by late-summer. Chlorophyll measurements were in the mesotrophic (moderately productive) to eutrophic (very productive) category during the spring and early-summer periods and worsened to the hypereutrophic (extremely productive) category by late-summer and fall periods. Secchi disc transparency was in the mesotrophic (good) category during May and early-June, worsened to eutrophic (poor) during late-June and early-July, and further worsened to hypereutrophic (very poor) during July through September (See Figure 5).

Modeling results and sediment sampling suggest that the release of phosphorus from the lake's bottom sediments is primarily responsible for the observed late-summer increase in the lake's phosphorus concentrations, which cause increases in chlorophyll *a* concentrations and declining water transparency (See Figure 5).

1.4 Ecosystem Data

1.4.1 Aquatic Ecosystem

The interactions of the physical, chemical, and biological components of the Lotus Lake aquatic ecosystem have a large effect on the capacity of Lotus Lake to achieve the recreation, aquatic communities, and water quality goals that have been established for the lake. Hence, this use attainability analysis includes an evaluation of Lotus Lake's aquatic ecosystem.

The aquatic ecosystem of Lotus Lake is a good example of how the biological community of a lake, (i.e., the fish, zooplankton, algae, and aquatic plants) can affect the chemical environment of a lake (i.e., pH, phosphorus levels, and dissolved oxygen) which can then also affect the biological community. Data collected for each component of the aquatic ecosystem is reviewed below and then in Section 1.9 a discussion is provided to interpret how these different components function in Lotus Lake.

1.4.2 Phytoplankton

The diverse population of phytoplankton in Lotus Lake goes through a seasonal transformation where green algae are dominant in the spring but decline in the summer, while blue-green algae populations are low in spring and dominate in the summer and fall (Figures 6 and 7). Other taxa, including diatoms, cryptomonads, and dinoflagellates, fluctuate in number and volume during the growing season. Algal blooms are observed in Lotus Lake from July through September (Figures 6 and 7). The blooms primarily consist of blue-green algae which are large and visible and are often noted to be floating on the surface during periods of severe blooms.

There are several reasons why dominance of blue-green algae during summer is unfavorable for Lotus Lake:

- Blue-green algae are not a preferred food source for zooplankton,
- Blue-green algae can float at the lake surface causing highly visible algal blooms,
- Certain blue-green algae can be toxic to animals, and
- Blue-green algae disrupt lake recreation during the summer.

Large populations of blue-green algae are most often associated with high levels of phosphorus. Blue-green algae have a competitive advantage (i.e. grow more quickly) over other algal species when phosphorus levels are high. Hence, phosphorus levels will need to be reduced to reduce blue-green algae populations in Lotus Lake.

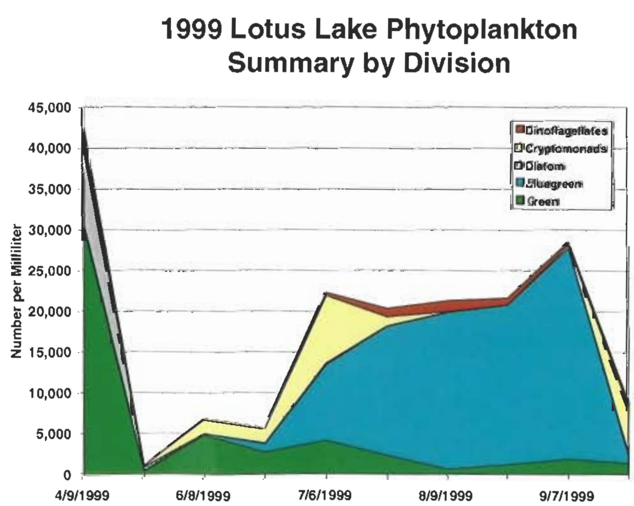


Figure 6 Phytoplankton Abundance and Diversity in Lotus Lake

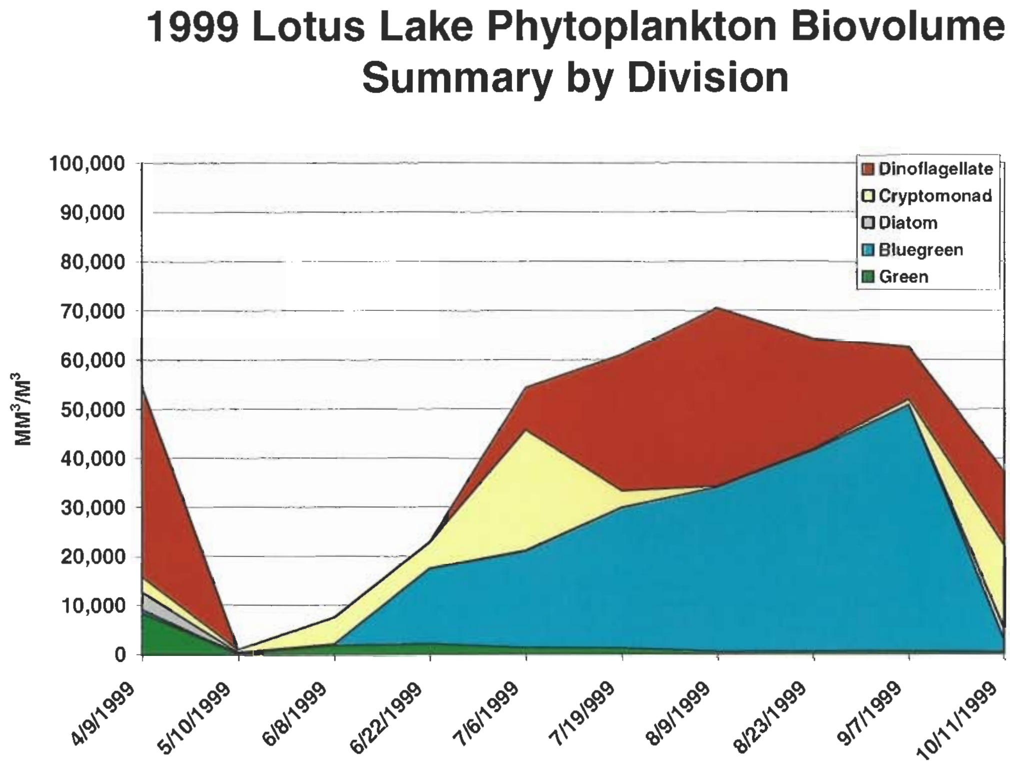


Figure 7 Phytoplankton Biovolume and Diversity in Lotus Lake

1.4.3 Zooplankton

Zooplankton are an important component of the aquatic ecosystem of Lotus Lake. They are particularly important for the lake's fishery and for the biological control of algae. Healthy zooplankton communities are characterized by balanced densities (number per meter squared) of the three major groups of zooplankton: Cladocera, Copepods, and Rotifers. Fish predation, however, may alter community structure and reduce the numbers of larger-bodied zooplankters (i.e., larger bodied Cladocera).

All three groups of zooplankton are well represented in Lotus Lake (Figure 8). A large population of large-bodied cladocerans was observed during April through June, which is good because they have the capacity to biologically control algal growth. Daily zooplankton grazing rates of the lake's surface waters (0- to 6-feet) during April through June was estimated to range from 7 to 20 percent (See Figure 9). During this period, the phytoplankton (algae) community was comprised of small-bodied algae that are easily eaten by zooplankters. Biological control of the lake's algae resulted in a reduction of the lake's chlorophyll *a* concentration and improved water transparency during May and early-June, despite an increase in the lake's phosphorus concentration.

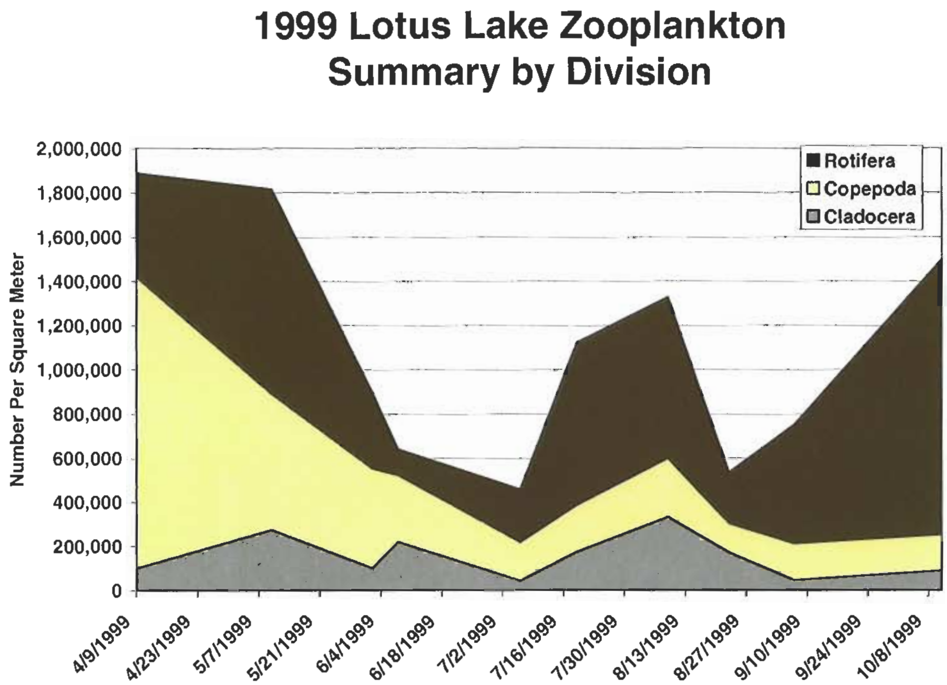


Figure 8 Zooplankton Abundance and Diversity in Lotus Lake

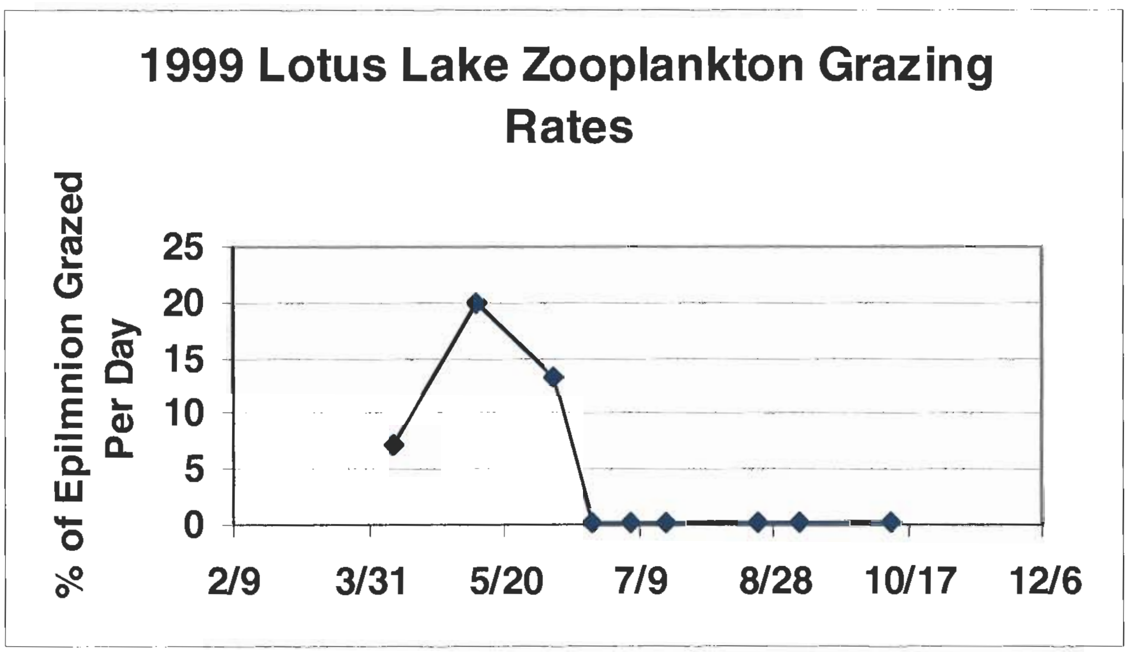


Figure 9 Percent of Lotus Lake Surface Waters (0- to 6-feet) Grazed by Zooplankton Each Day

Reductions in the numbers of large-bodied cladocera and in the fraction of the algal community comprised of small-bodied, edible algae are the apparent causes of the lack of biological control on the lake's algal growth during late-summer. Declining grazing rates observed during June (See Figure 9) corresponded with declining numbers of large-bodied cladocera (See Appendix A) and increasing volumes of blue-green algae (See Figure 7). The algal community was primarily comprised of inedible dinoflagellates and blue-green algae during late-June through September. Hence, zooplankters were unable to exert biological control during this period.

1.4.4 Macrophytes

Aquatic plants are a natural part of most lake communities and provide many benefits to fish, wildlife, and people. Typical functions of a lake's macrophyte community include:

- Provide habitat for fish, insects, and small invertebrates (Savino and Stein 1989)
- Provide food for waterfowl, fish, and wildlife (Savino and Stein 1989)
- Produce oxygen
- Provide spawning areas for fish in early-spring
- Help stabilize bottom sediments, marshy borders, and protect shorelines from wave erosion (Maceina et al. 1992)
- Provide nesting sites for waterfowl and marsh birds

Macrophytes (aquatic plants) are an important component of the lake ecosystem (Ozimek, Gulati, and Van Donk 1990). However, the introduction of exotic (nonnative) aquatic plants into a lake may cause undesirable changes to the plant community and to the lake ecosystem. Dense stands of some mat-forming plant species reduce oxygen exchange, deplete available dissolved oxygen, increase water temperatures, and increase internal loading rates of nutrients (Frodge, Thomas, and Pauley 1991; Frodge et al. 1995; Seki, Takahashi, and Ichimura 1979). Dense canopies formed by some nonnative species (e.g., curlyleaf pondweed) reduce native plant diversity and abundance (Madsen et al. 1991), thereby reducing habitat complexity. This reduction in habitat complexity results in reduced macroinvertebrate diversity and abundance (Krull 1970, Keast 1984) and also reduces growth of fishes (Lillie and Budd 1992). The introduction of a nonnative plant species to a lake is not only deleterious to human use of aquatic systems, but is also detrimental to the native ecosystem.

Submersed aquatic macrophytes can play an important role in the phosphorus budget of a lake. In particular, macrophytes can directly recycle phosphorus from the sediment via root uptake, incorporation into tissue, and subsequent senescence (Barko and Smart 1980; Carpenter 1980;

Landers 1982; Smith and Adams 1986; Barko and James 1998). They can also indirectly recycle phosphorus from the sediment via increasing pH in the water column through photosynthetic activities. Phosphorus release from the sediments can be enhanced at high pH as a result of ligand exchange on iron oxides contained in the sediment (Drake and Heaney 1987).

Lotus Lake's macrophytes were surveyed on June 25 (Figures 10 and 11) and August 27, 1999 (Figures 10 and 12) to identify the conditions of plant growth throughout the lake. Thirteen species were observed in both surveys. These species are common to Minnesota lakes and provide good habitat for the fish and aquatic animals living within the lake.

Macrophytes were identified to a maximum depth of 8 to 10 feet during the June and August surveys. Macrophyte densities ranged from light to heavy.

The growth of the exotic (nonnative) species, curlyleaf pondweed (*Potamogeton crispus*) and Eurasian watermilfoil (*Myriophyllum spicatum*), in Lotus Lake are of concern. Curlyleaf pondweed was found throughout the lake during June. Densities of this plant were generally light, but moderate growths were observed on the lake's east side (Figure 13).

Figure 10 1999 Lotus Lake Aquatic Plants

1999 Lotus Lake Aquatic Plants			
Common Name	**Scientific Name**	**1999 Density**	**Picture**
Submerged Aquatics			
Muskgrass	*Chara sp.*	1	
Curlyleaf pondweed	*Potamogeton crispus*	1-2	
Sago pondweed	*Potamogeton pectinatus*	1	

Figure 10 1999 Lotus Lake Aquatic Plants (continued)

Common Name	Scientific Name	1999 Density	Picture
Submerged Aquatics			
Eurasian watermilfoil	*Myriophyllum spicatum*	1-3	
Water stargrass	*Zosterella dubia*	1	
Coontail	*Ceratophyllum demersum*	1-3	
Bushy pondweed and naiad	*Najas flexilis*	1	

Figure 10 1999 Lotus Lake Aquatic Plants (continued)

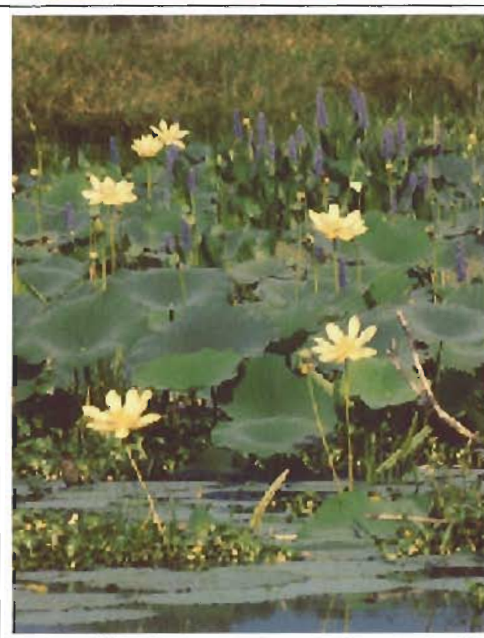
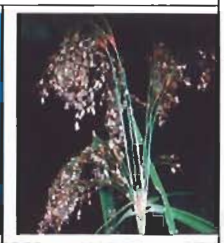
Common Name	Scientific Name	1999 Density	Picture
Floating Leave Plants			
White waterlily	*Nymphaea odorata* (Shown: *subsp.Tuberose*)	--	
Yellow waterlily	*Nuphar variegate*	--	
American lotus	*Nelumbo lutea*	--	

Figure 10 1999 Lotus Lake Aquatic Plants (continued)

Common Name	Scientific Name	1999 Density	Picture
Emergent Plants			
Bulrush	*Scirpus spp.*	--	  
Cattil	*Typha spp.* *Left: T. latifolia, broadleaf(native).* *Right: T. angustifolia, narrow-leaf (non-native)*	--	 
Purple Loosestrife	*Lythrum salicaria*		

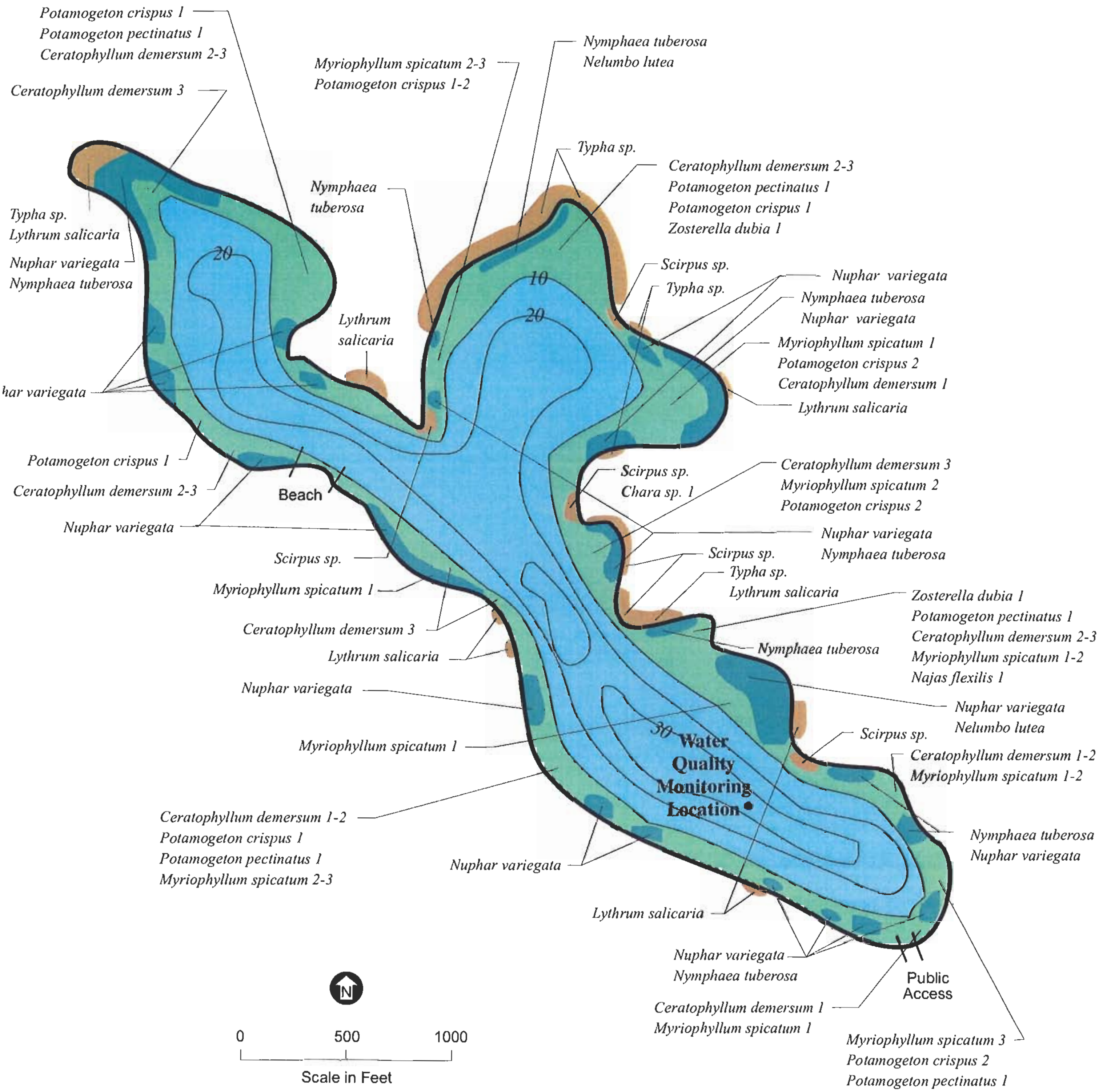


Figure 11

LOTUS LAKE
MACROPHYTE SURVEY
JUNE 25, 1999

- No Macrophytes Found in Water >8' - 10'
- Areas of the Lake Shore have been Treated.
- Submerged Macrophytes with Algal Growth.
- Macrophyte Densities Estimated As Follows:1 = light; 2 = moderate; 3 = heavy

	Common Name	Scientific Name
Submerged Aquatic Plants:	Sago pondweed	*Potamogeton pectinatus*
	Curlyleaf pondweed	*Potamogeton crispus*
	Eurasian watermilfoil	*Myriophyllum spicatum*
	Coontail	*Ceratophyllum demersum*
	Muskgrass	*Chara sp.*
	Bushy pondweed and Naiad	*Najas flexilis*
	Water stargrass	*Zosterella dubia*
Floating Leaf:	Yellow waterlily	*Nuphar variegata*
	White waterlily	*Nymphaea tuberosa*
	American lotus	*Nelumbo lutea*
Emergent:	Bulrush	*Scirpus sp.*
	Cattail	*Typha sp.*
	Purple loosestrife	*Lythrum salicaria*
No Aquatic Vegetation Found:		

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- No Macrophytes Found in Water >8' - 10'
- Areas of the Lake Shore have been Treated.
- Submerged Macrophytes with Algal Growth.
- Macrophyte Densities Estimated As Follows:1 = light; 2 = moderate; 3 = heavy

	Common Name	Scientific Name
Submerged Aquatic Plants:	Sago pondweed	*Potamogeton pectinatus*
	Curlyleaf pondweed	*Potamogeton crispus*
	Eurasian watermilfoil	*Myriophyllum spicatum*
	Coontail	*Ceratophyllum demersum*
	Muskgrass	*Chara sp.*
	Bushy pondweed and Naiad	*Najas flexilis*
	Water stargrass	*Zosterella dubia*
Floating Leaf:	Yellow waterlily	*Nuphar variegata*
	White waterlily	*Nymphaea tuberosa*
	American lotus	*Nelumbo lutea*
Emergent:	Bulrush	*Scirpus sp.*
	Cattail	*Typha sp.*
	Purple loosestrife	*Lythrum salicaria*
No Aquatic Vegetation Found:		

P:23\27\053\LakeMacrophyteMaps\Lotus\1994\AUGUST1994.CDR RLG 05-27-04

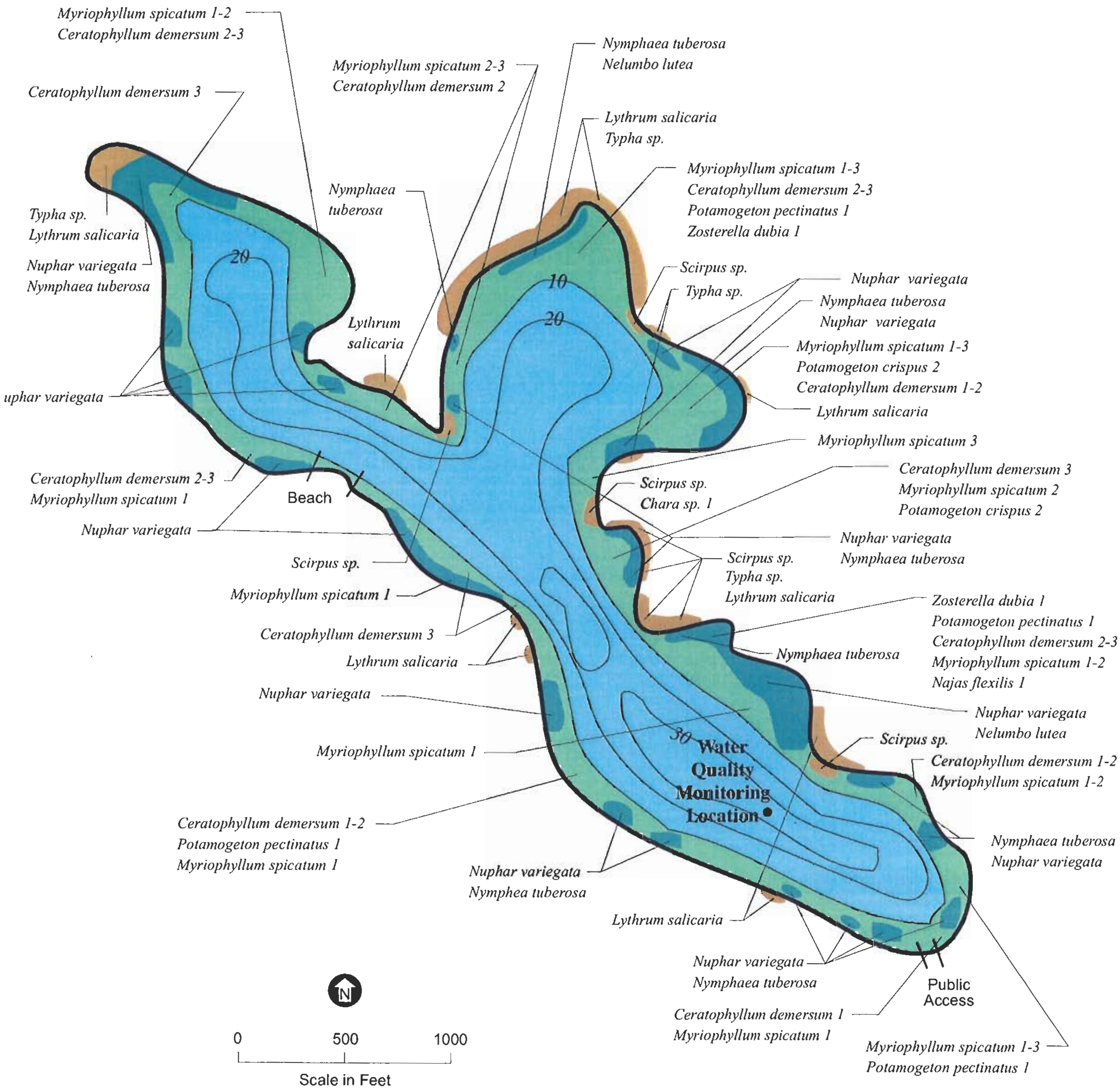


Figure 12

LOTUS LAKE
MACROPHYTE SURVEY
AUGUST 27, 1999

- No Macrophytes Found In Water > 8.0'.
- Macrophyte Densities Estimated As Follows: 1 = light; 2 = moderate; 3 = heavy
- *Spirogyra* (Green algae) Present on East Side of Lake.

	Common Name	Scientific Name
Submerged Aquatic Plants:	Eurasian watermilfoil	*Myriophyllum spicatum*
	Curlyleaf pondweed	*Potamogeton crispus*
	Water stargrass	*Zosterella dubia*
	Sago pondweed	*Potamogeton pectinatus*
	Coontail	*Ceratophyllum demersum*
	Muskgrass	*Chara sp.*
	Bushy pondweed and naiad	*Najas flexilis*
	Flatstem pondweed	*Potamogeton zosteriformis*
	Elodea	*Elodea canadensis*
Floating Leaf Plants:	Yellow waterlily	*Nuphar variegata*
	White waterlily	*Nymphaea tuberosa*
	Lotus	*Nelumbo lutea*
Emergent Plants:	Bulrush	*Scirpus sp.*
	Cattail	*Typha sp.*
	Purple loosestrife	*Lythrum salicaria*
No Aquatic Vegetation Found:		

Figure 13 ***Potamogeton crispus*** **(Curlyleaf pondweed)**

Once a lake becomes infested with curlyleaf pondweed, this plant typically replaces native vegetation, thereby increasing its coverage and density. Curlyleaf pondweed begins growing in late-August, grows throughout the winter at a slow rate, grows rapidly in the spring, and dies in early-summer (Madsen et al. 2002). Native plants that grow from seed in the spring are unable to grow in areas already occupied by curlyleaf pondweed, and are displaced by this plant. Curlyleaf pondweed die-off in early-summer releases phosphorus to the lake, causing increased algal growth for the remainder of the summer.

The light- to moderate- densities of curlyleaf pondweed in Lotus Lake during 1999 indicates a successful competition by native species has controlled curlyleaf pondweed growth in Lotus Lake. However, water quality management to improve the lake's water transparency is likely to result in heavier curlyleaf pondweed growth unless a curlyleaf pondweed management program is concurrently implemented.

Eurasian watermilfoil growth occurred throughout Lotus Lake during 1999 and densities ranged from light to heavy. Eurasian watermilfoil is a nuisance non-native species that typically replaces native vegetation (See Figure 14). It has a canopy style growth pattern that causes heavy growth near the surface, making it more visible and a greater nuisance for boaters and fishermen. Eurasian watermilfoil has been observed in the lake since 1990. A 1994 survey by the City of Chanhassen indicated the plant covered about 65 acres (Mc Comas et al. 1995). Eurasian watermilfoil is currently found throughout the lake's littoral area (approximately 100 acres) and growth is problematic. Water quality management to improve the lake's water clarity is likely to result in increased Eurasian watermilfoil growth unless a program to manage this plant is completed first.

Figure 14 ***Myriophyllum spicatum*** **(Eurasian watermilfoil)**

Management of curlyleaf pondweed and Eurasian watermilfoil is recommended to protect the lake's native plant community and to prevent dense plant growths.

In 1999, purple loosestrife was observed throughout the lake's shoreline area. Purple loosestrife, an emergent plant, is native to Europe and the temperate regions of Asia (See Figure 15). Once introduced into an area, the plant typically replaces native vegetation and rapidly becomes the sole emergent species. Management of purple loosestrife is recommended to protect the quality of vegetation along the lake's shoreline.

Figure 15 ***Lythrum salicaria*** **(Purple loosestrife**

1.5 Water Based Recreation

Lotus Lake is used by local residents for all kinds of recreational activities, including swimming. A public access, provided by the City of Chanhassen, is located on the south end of the lake. A swimming beach is also located on the lake.

1.6 Fish and Wildlife Habitat

The MDNR has developed a classification system for Minnesota lakes relative to the chemical and physical properties of each lake class and the fishery that is supported by each lake (Schupp 1992). According to its ecological classification, Lotus Lake is a Class 24 lake. Class 24 lakes typically have a good permanent fishery (Schupp, 1992). The MDNR has indicated that the average water quality for a Class 24 lake is a TSI_{SD} (Trophic State Index in terms of Secchi disc transparency) of approximately 56 or lower (i.e., a summer average Secchi disc transparency of about 4.3 feet or greater). The recommendation is based upon the water quality needs of the fishery found in a Class 24 lake. Lotus Lake's water quality does not meet this recommendation based upon the 1999 data. The lake's current water quality (monitoring year 1999) corresponds to a TSI_{SD} of 57 (a summer average Secchi disc of approximately 3.9 feet). Lotus Lake has met the MDNR recommended water quality goal during approximately 17 percent of the monitoring years during the 1972 through 2000 period (1972 and 1991).

According to its classification, Lotus Lake's primary fish species are northern pike, bluegill, and carp. Northern pike is a predator fish (eats bluegills). Bluegills are planktivores (eat zooplankton). Carp is considered a benthic or bottom feeding fish.

The lake's fishery currently (1999) consists of panfish, gamefish, rough fish, and other fish species. The 1999 MDNR fish survey showed that the following species are present in Lotus Lake:

- **Panfish**—black crappie, bluegill, hybrid sunfish, green sunfish, and pumpkinseed sunfish

photo by Konrad Schmidt

Black Crappie

photo by Konrad Schmidt

Bluegill

photo by Konrad Schmidt

Green Sunfish

photo by Konrad Schmidt

Pumpkinseed

- **Gamefish**—largemouth bass, northern pike, yellow perch, and walleye

photo by Konrad Schmidt

Largemouth Bass

photo by Konrad Schmidt

Northern Pike

photo by Konrad Schmidt

Yellow Perch

photo by Konrad Schmidt

Walleye

- **Rough fish**—black bullhead, yellow bullhead, and common carp

photo by Konrad Schmidt

Black Bullhead

photo by Konrad Schmidt

Yellow Bullhead

photo by Konrad Schmidt

Common Carp

- **Other fish—**golden shiner, spottail shiner, fathead minnow, Johnny darter, and whiter sucker

photo by Konrad Schmidt

Golden Shiner

photo by Konrad Schmidt

Spottail Shiner

photo by Konrad Schmidt

Fathead Minnow

photo by Konrad Schmidt

Johnny Darter

photo by Konrad Schmidt

White Sucker

Results of the 1999 fisheries survey indicate an excellent fishery was observed in Lotus Lake. In general, increased numbers of gamefish were observed in the 1999 survey as compared with the 1994 survey. Fish numbers, sizes, and growth rates were good when compared with the other lakes of its lake class (i.e., Class 24). Survey details follow.

The walleye population in Lotus Lake has increased since the 1994 survey and is currently at the second highest level recorded. The population is within the normal range of lakes of this type. The mean length sampled in 1999 was 19.5 inches and the mean weight was 3.0 pounds. Walleye growth appears good to age 6 and then slows.

The northern pike population has increased since the 1994 survey and is at the highest observed level since 1954. The population is within the normal range of lakes of this type. The mean length sampled in 1999 was 27.6 inches and the mean weight was 5.6 pounds. Growth is above average.

Largemouth bass, which are normally not caught in trapnets, were rather abundant in 1999. The average length sampled was 10.4 inches. The largest bass sampled was 18.8 inches. They are exhibiting good growth rates and good natural reproduction.

The 1999 gillnet catch of yellow perch was the highest recorded and was over 3 times higher than the 75 percent quartile for Class 24 lakes. The trapnet catch is the second highest recorded and was just above the 50 percent quartile for Class 24 lakes. Mean lengths sampled were 6.4 inches in the gillnets and 6.8 inches in the trapnets. Growth is good to age 2 and then slows. The high yellow perch population could make walleye fishing tough due to abundant forage.

Bluegills are extremely abundant. More than 66 percent are 6 inches or more in length, but there are a few fish that are larger than 7 inches. Growth is good to age 3 and then slows.

Pumpkinseed sunfish were sampled at their highest level in the trapnets. The trapnet catch exceeds the 75 percent quartile for Class 24 lakes by nearly 2 times. This is the first survey to capture pumpkinseed sunfish in the gillnets. The mean length sampled was 5.0 inches in the trapnets and 5.1 inches in the gillnets.

The black crappie population is currently at the lowest level recorded in a MDNR survey. The gillnet and trapnet catches were below the 25 percentile for Class 24 lakes. The mean length from the gillnets and trapnets were 6.5 inches and 6.1 inches, respectively. They have good growth rates.

Both black and yellow bullheads are present in Lotus Lake. The black bullheads are less abundant and smaller than the yellow bullheads that were sampled.

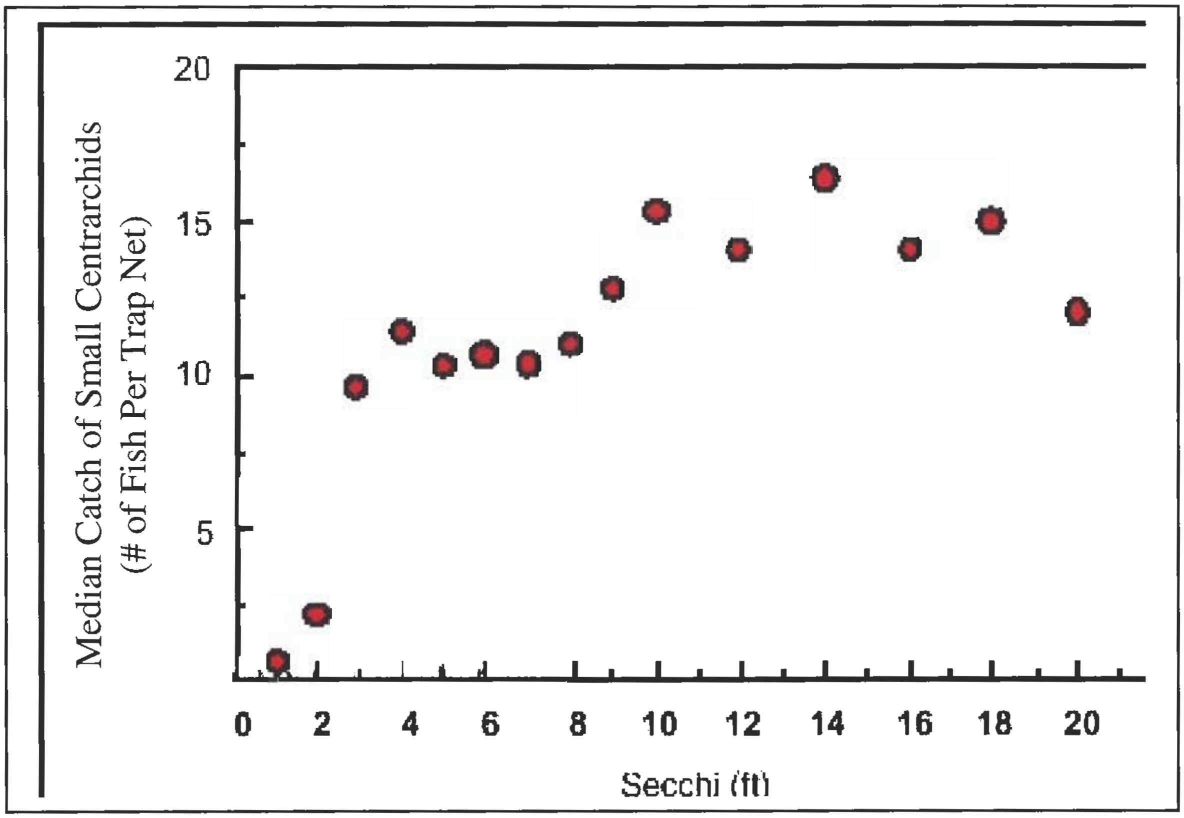
White suckers, golden shiners, and carp were sampled in similar abundance to previous years. Green sunfish and hybrid sunfish were each sampled for the first time during the 1999 survey.

The 1999 MDNR fisheries survey report indicates walleye are the primary management species in Lotus Lake. The 2001 MDNR Lotus Lake Management Plan reiterates the emphasis of walleye management. Walleye stocking has occurred periodically during 1965 through 1989 and biennially since 1989. Walleye stocking was increased to 2 pounds per littoral acre (364 pounds) in 2001. The higher stocking rate was continued in 2003. A lake survey will be completed in 2005 to determine whether the walleye stocking rate needs to be adjusted.

The MDNR 2001 Lotus Lake Management Plan indicates the MDNR will work with the Riley Purgatory Bluff Creek Watershed District and the City of Chanhassen to lower phosphorus loading, thereby improving the lake's water quality. The MDNR water quality concerns are based upon fisheries habitat considerations and a desire to improve and protect the lake's fisheries habitat.

Improvement of the lake's water transparency is expected to result in an improved fishery. MDNR evaluated data from its data warehouse to determine whether a relationship between water transparency and fishery quality occurred. The evaluation included the trap net data collected in Minnesota lakes since 1980 in 6,109 fisheries surveys. The evaluation indicated that improved Secchi disc water transparency resulted in improved fishery. Fewer rough fish and increased numbers of small Centrarchids (i.e., bluegills, green sunfish, hybrid sunfish, and pumpkinseeds) occurred with increased Secchi disc transparency (shown in Figure 16). The evaluation also indicated that below a Secchi disc transparency of 3 feet, the lakes' fishery "crashed" resulting in extremely low numbers of small Centrarchids and a value of 0 for the proportion of small Centrarchids (i.e., virtually all fish were rough fish) (also shown in Figure 16).

Fisheries Quality vs. Water Transparency



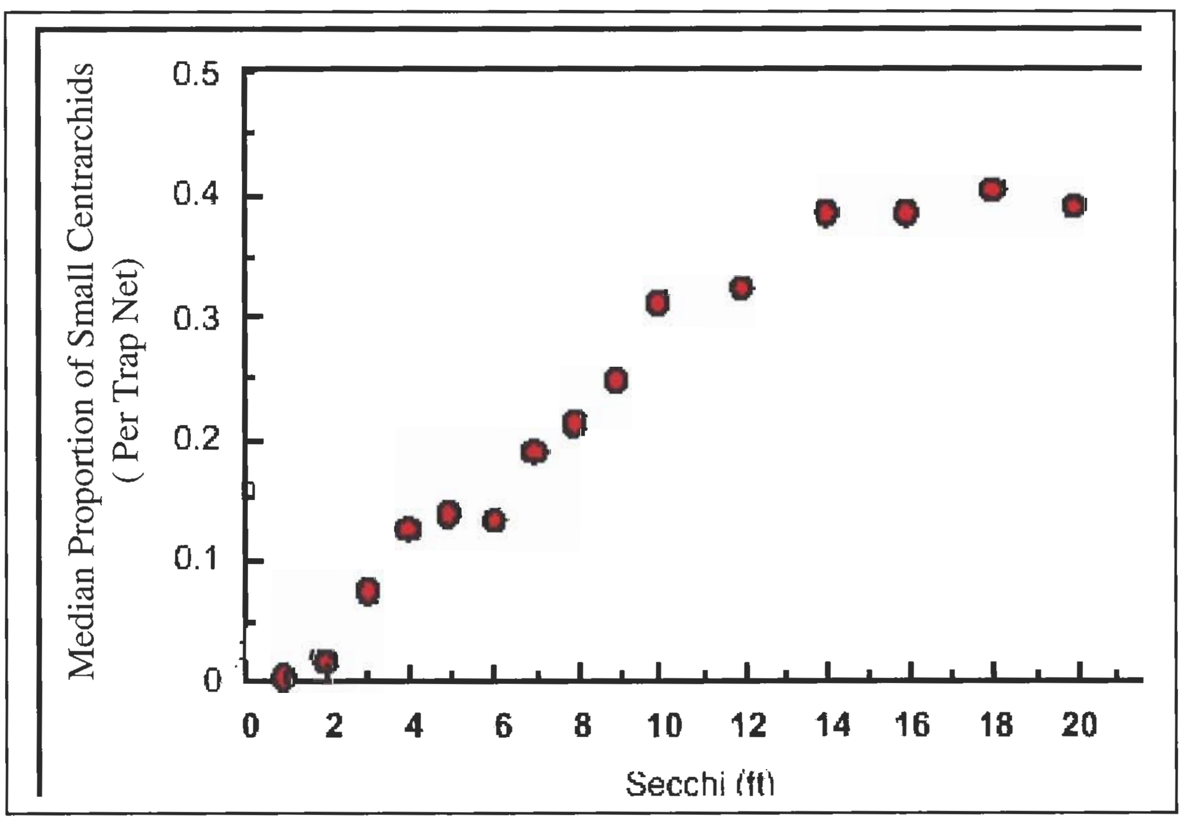


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Figure 16

During 1999, Lotus lake's average summer Secchi disc water transparency was 3.9 feet. The data indicate the lake's current water transparency is sufficient to preserve the lake's fisheries. However, improved water transparency is expected to result in an improved fishery. A reduction in the lake's total phosphorus concentration is required to improve the lake's Secchi disc water transparency.

Lotus Lake provides habitat for seasonal waterfowl, such as ducks and geese.

1.7 Discharges

1.7.1 Natural Conveyance Systems

The natural inflow to Lotus Lake is comprised of stormwater runoff from its direct watershed (i.e., LL-1A and LL-1 on Figure 1) and groundwater discharge. Runoff from the lake's direct watershed drains directly to the lake without treatment.

1.7.2 Stormwater Conveyance Systems

The Lotus Lake stormwater conveyance system is comprised of a network of storm sewers and wet detention ponds within the indirect watershed tributary to the lake. Runoff from the lake's indirect watershed is treated by at least one wet detention pond before entering the lake. Storm sewers convey stormwater runoff to and from many of the wet detention ponds, and eventually convey the runoff to Lotus Lake. Some wet detention ponds convey runoff to Lotus Lake via overland flow.

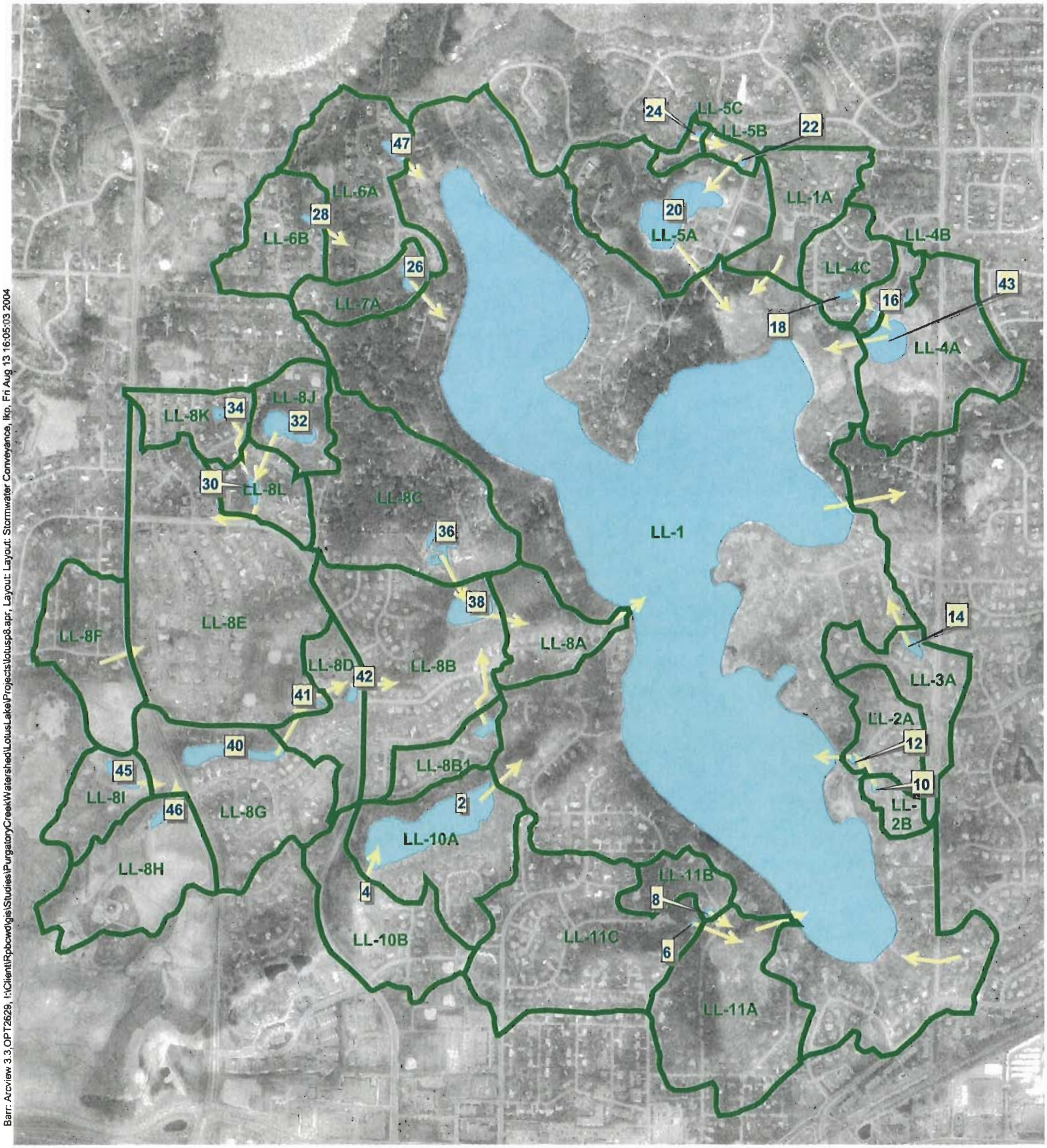
Stormwater, treated by 25 wet detention ponds, is conveyed to the lake through 10 stormwater conveyance systems. Details of each wet detention pond are provided in Appendix D. Figure 17 shows the wet detention ponds and stormwater conveyance systems of the Lotus Lake watershed.

1.7.3 Public Ditch Systems

There are no public ditch systems that affect Lotus Lake.

1.8 Appropriations

There are no known water appropriations from Lotus Lake.



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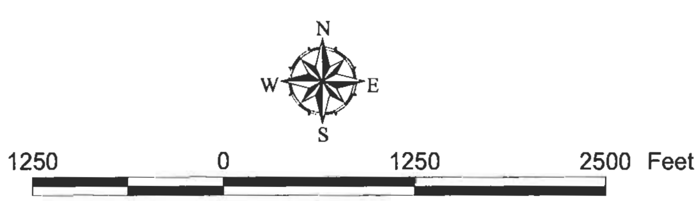


Figure 17

Lotus Lake
Stormwater Conveyance System

1.9 Summary of Surface Water Resource Data

The current water quality and ecological status of Lotus Lake is largely the result of phosphorus loading from internal lake processes that result in the mobilization of phosphorus from lake sediments by direct release of phosphorus from the sediments.

The concentration of phosphorus in the lake sediments that can release into the water column (i.e. mobile phosphorus) of Lotus Lake is very high (Figure 18) and corresponds to a potential phosphorus release rate of approximately 4.7 mg per square meter of lake surface per day. Only a portion of the phosphorus released from the sediments is entrained in the lake's surface waters. An estimated 10 percent of the phosphorus released from the sediments during the summer and 1 percent of the phosphorus released from the sediments in the winter is entrained in the lake's surface waters.

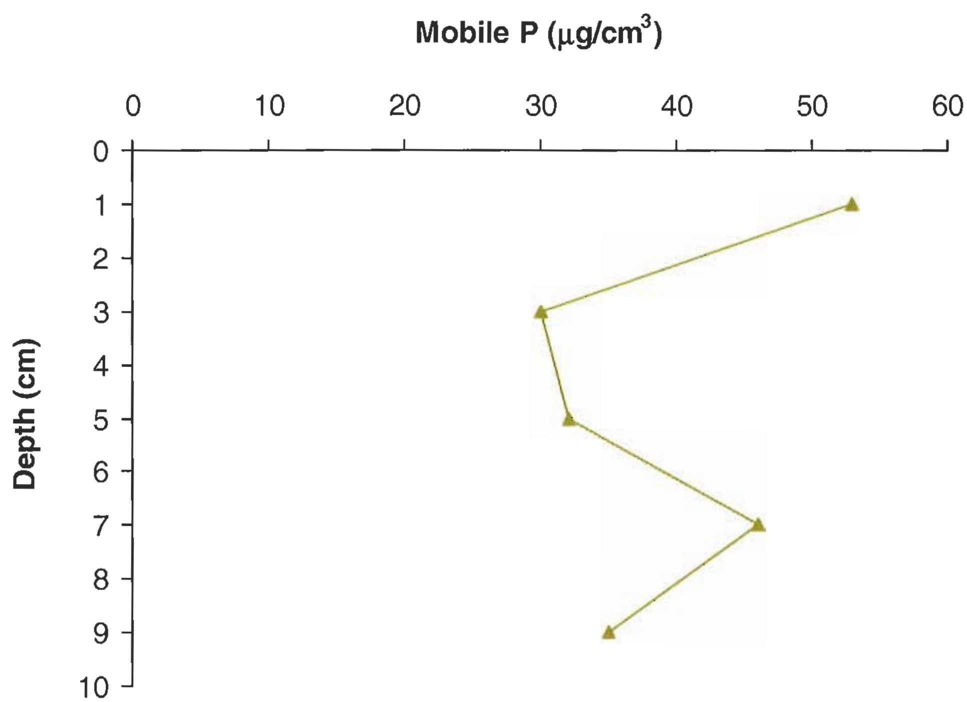


Figure 18 Distribution of Potentially Releasable Phosphorus in Lotus Lake Sediment

Internal phosphorus loading comprises a significant fraction of the lake's total phosphorus load. An estimated 500 pounds of phosphorus is released from the lake's sediments and entrained in Lotus Lake's surface waters annually. Under existing watershed land use and wet, model calibration, average, and dry climatic conditions, the internal phosphorus load comprises 53, 57, 62, and

66 percent of the lake's total phosphorus load, respectively. Under future watershed land use conditions, increased volumes of stormwater runoff will slightly reduce the proportion of the internal phosphorus load to 51 (wet), 56 (model calibration), 61 (average), and 65 percent (dry).

Currently, the ecology of Lotus Lake is being driven by internal phosphorus loading. In mid-to late-summer there is a significant increase in phosphorus in the lake that can be partially attributed to the release of phosphorus from lake sediments. This increase in phosphorus is associated with mid-to late-summer algal blooms (Figure 19).

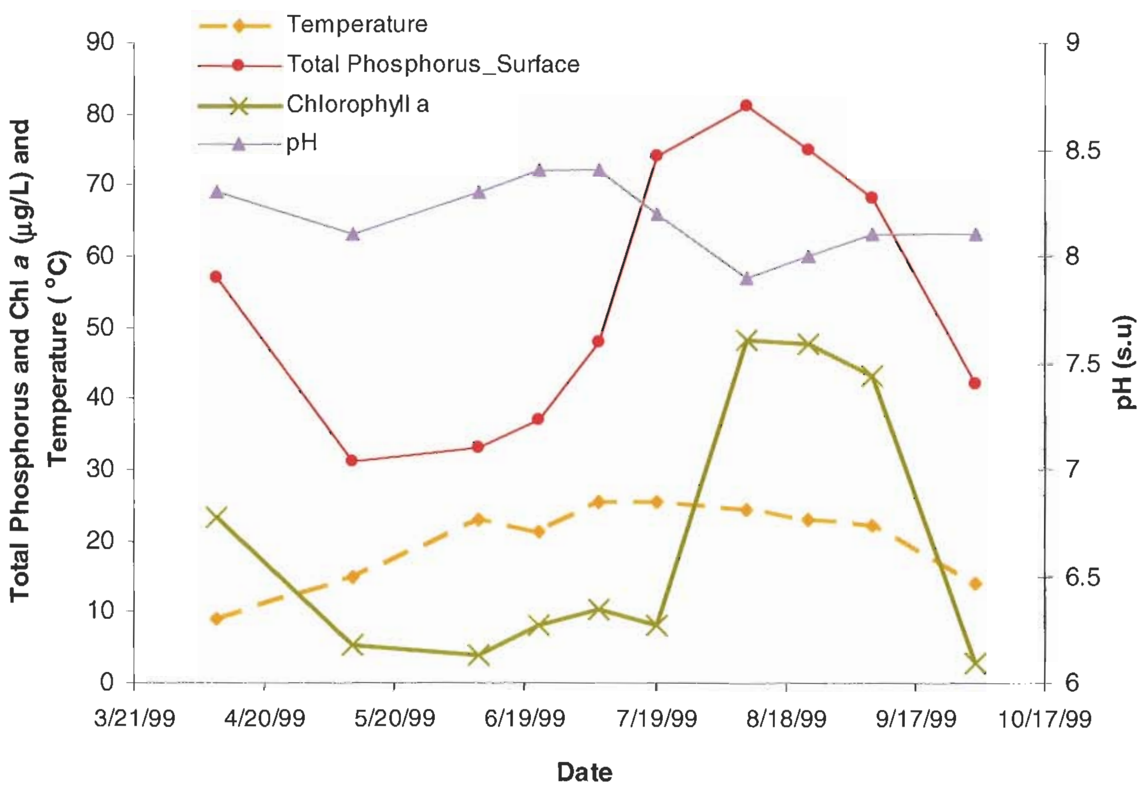


Figure 19 Seasonal Pattern of pH, Total Phosphorus, Temperature, and Chlorophyll *a* in Lotus Lake

According to the 1999 MDNR fish survey, an excellent fishery was observed in Lotus Lake. In general, increased numbers of gamefish were observed in the 1999 survey as compared with the 1994 survey. Fish numbers, sizes, and growth rates were good when compared with the other lakes of its lake class (i.e., Class 24).

The MDNR is managing Lotus Lake for a walleye fishery. Walleye stocking has occurred periodically during 1965 through 1989 and biennially since 1989. Walleye stocking was increased to

2 pounds per littoral acre (364 pounds) in 2001. The higher rate was continued in 2003. A lake survey will be completed in 2005 to determine whether the walleye stocking rate needs to be adjusted.

The MDNR is concerned that the lake's current water quality provides suboptimal habitat for the lake's fishery. The MDNR 2001 Lotus Lake Management Plan indicates the MDNR will work with the District and the City of Chanhassen to lower phosphorus loading to improve and protect the lake's fisheries habitat.

2.0 Assessment of Lotus Lake Problems

2.1 Appropriations

There are no known water appropriations from Lotus Lake.

2.2 Discharges

The model P8 (IEP Inc. 1990) was used to determine the water and phosphorus loading to Lotus Lake from the surrounding park and residential areas and from conveyed stormwater discharges to the lake. The discharge of stormwater from the Lotus Lake watershed conveys phosphorus to the lake. These discharges, together with internal phosphorus loading, are the cause of high phosphorus levels that are observed in Lotus Lake. Details of the phosphorus discharges to the lake are provided below.

2.2.1 Natural Conveyance Systems

Natural conveyance systems contribute stormwater to Lotus Lake from parkland and residences that surround the lake. There are no other natural conveyances to Lotus Lake such as streams.

2.2.1.1 Direct Watershed

The Lotus Lake direct watershed is the land that surrounds the lake. There is no treatment of this runoff. Phosphorus loading from this watershed area was modeled using four climatic conditions:

- **Wet Year:** Annual precipitation of 41 inches, the amount of precipitation that occurred during the 1983 water year.
- **Model Calibration Year:** Annual precipitation of 34 inches, the amount of precipitation that occurred during the 1999 water year. (The model calibration year is the year in which data were collected from the lake. The data were used to calibrate the in-lake model).
- **Average Year:** Annual precipitation of 27 inches, the amount of precipitation that occurred during the 1995 water year.
- **Dry Year:** Annual precipitation of 19 inches, the amount of precipitation that occurred during the 1988 water year.

Loading from the direct watershed to Lotus Lake is estimated to range from 78 to 170 pounds per year under existing land uses and from 84 to 182 pounds per year for future land uses (Table 4). Currently loading from the direct watershed represents approximately 10 to 18 percent of the total phosphorus load to Lotus Lake. Little change is expected to occur under future land use conditions when loading from the direct watershed will represent approximately 11 to 19 percent of the lake's total phosphorus load.

Table 4 Estimated Annual Total Phosphorus Loads from the Lotus Lake Direct Watershed for Existing and Future Land Use

Climate Condition (inches of precipitation)	Annual Total Phosphorus Load From Direct Watershed (Pounds)	% of Total Annual Lotus Lake Total Phosphorus Load
Existing Land Use		
Wet (41")	170	18
Model Calibration (34")	138	16
Average (27")	104	13
Dry (19")	78	10
Future Land Use		
Wet (41")	182	19
Model Calibration (34")	148	17
Average (27")	112	14
Dry (19")	84	11

Increased infiltration of stormwater runoff was considered as a treatment alternative to reduce phosphorus loading from the lake's direct watershed. Model simulations were completed to estimate the reduction in phosphorus loading to Lotus Lake from ¼-, ½-, and ¾-inch infiltration of stormwater runoff in the lake's direct watershed. Model simulation results indicate an annual phosphorus load reduction of from 23 to 72 pounds (from 3 to 9 percent of the lake's annual phosphorus load) would occur under existing and future land uses (See Table 5).

Table 5 Estimated Total Phosphorus Loading Reduction From Infiltration of One-Fourth, One-Half, and Three-Fourths Inches of Runoff Within the Lake's Direct Watershed

Climatic Condition	Annual Total Phosphorus Load Reduction in Pounds (% of Annual Total Phosphorus Load)		
	One-Fourth Inch	One-Half Inch	Three Fourths Inch
Existing Land Use			
Wet (41")	29 (3)	53 (6)	69 (7)
Model Calibration (34")	30 (4)	57 (7)	67 (8)
Average (27")	24 (4)	41 (5)	54 (7)
Dry (19")	23 (3)	36 (5)	46 (6)
Future Land Use			
Wet (41")	30 (3)	55 (6)	72 (8)
Model Calibration (34")	31 (4)	59 (7)	74 (9)
Average (27")	25 (3)	43 (5)	56 (7)
Dry (19")	24 (3)	38 (5)	48 (6)

Infiltration of ¼ to ¾ inch of stormwater in the lake's direct watershed is expected to have a negligible effect on the lake's water quality and would not attain the District's recreation, water quality, and aquatic communities goals (See Table 6).

Table 6 Expected Lotus Lake Water Quality From Infiltration of One-Fourth, One-Half, and Three-Fourths Inches of Runoff Within the Lake's Direct Watershed

Management Approach	Trophic State Index (TSI_{SD}) Value				
	District Goal	Wet Year (41")	Model Calibration Year (34")	Average Year (27")	Dry Year (19")
Existing Land Use					
No Action	≤ 53	57	57	57	56
One-Fourth Inch Infiltration of LL-1 Runoff	≤ 53	57	57	57	56
One-Half Inch Infiltration of LL-1 Runoff	≤ 53	57	57	57	56
Three-Fourths Inch Infiltration of LL-1 Runoff	≤ 53	57	57	57	56

Management Approach	Trophic State Index (TSI_{SD}) Value				
	District Goal	Wet Year (41")	Model Calibration Year (34")	Average Year (27")	Dry Year (19")
Future Land Use					
No Action	≤ 53	58	57	57	57
One-Fourth Inch Infiltration of LL-1 Runoff	≤ 53	58	57	57	57
One-Half Inch Infiltration of LL-1 Runoff	≤ 53	58	57	57	57
Three-Fourths Inch Infiltration of LL-1 Runoff	≤ 53	58	57	57	57

2.2.2 Stormwater Conveyance Systems

The annual phosphorus load from all stormwater conveyance systems to Lotus Lake (Table 7) is estimated to range from 64 to 161 pounds under existing land uses and from 71 to 176 pounds for future land uses. Currently loading from all stormwater conveyance systems represents approximately 8 to 17 percent of the total phosphorus load to Lotus Lake. Under future land use conditions, loading from all stormwater conveyance systems will change little and represent approximately 9 to 18 percent of the lake's total phosphorus load (the lake's total phosphorus load includes both external and internal phosphorus loads).

Table 7 Estimated Total Phosphorus Loads from All Lotus Lake Stormwater Conveyance Systems Under Varying Climatic Conditions-Existing and Future Land Use

Climate Condition (inches of precipitation)	Annual Total Phosphorus Load From All Stormwater Conveyance Systems (Pounds)	% of Annual Lotus Lake Total Phosphorus Loads
Existing Land Use		
Wet (41")	161	17
Model Calibration (34")	116	13
Average (27")	79	10
Dry (19")	64	8
Future Land Use		
Wet (41")	176	18
Model Calibration (34")	129	14
Average (27")	91	11
Dry (19")	71	9

Each of the 10 stormwater conveyance systems discharging into Lotus Lake (locations shown on Figure 17) adds a different amount of phosphorus to the lake, based on the size of the watershed, the land uses within the watershed, and the stormwater treatment that occurs prior to discharge to the lake. Phosphorus loading from the lake's individual conveyance systems is relatively small and few opportunities for additional phosphorus loading reductions are available.

As shown in Table 8, inflow locations LL-3A, LL-4A, LL-5A, LL-6A, LL-7A, LL-10A, and LL-11B each contribute from 1 to 3 percent of the lake's annual watershed phosphorus load under existing and proposed future land use conditions. Inflow locations LL-2A and LL-11C each contribute from 5 to 6 percent of the lake's annual watershed phosphorus load under existing and proposed future land use conditions. Collectively, these 9 subwatersheds: (1) comprise 35 percent of the lake's watershed, (2) add from 5 to 9 percent of the lake's annual total phosphorus load under existing watershed land use conditions, and (3) add from 5 to 10 percent of the lakes' annual total phosphorus load under proposed future land use conditions.

Storm sewer outlet LL-8B contributes a phosphorus load to the lake that is only slightly less than the collective total of the other 9 stormwater conveyance systems (See Table 8). Yet, this phosphorus load is relatively small when compared with the lake's total load. Under existing watershed land use conditions, the storm sewer outlet LL-8B is estimated to add from 29 to 73 pounds of phosphorus per year to Lotus Lake, comprising from 4 to 8 percent of the lake's annual phosphorus load. Under proposed future watershed land use conditions, the storm sewer outlet LL-8B is estimated to add from 33 to 82 pounds of phosphorus per year to Lotus Lake, comprising from 4 to 8 percent of the lake's annual phosphorus load.

Table 8 A Comparison of Estimated Total Phosphorus Loads from Ten Lotus Lake Stormwater Conveyance Systems Under Varying Climatic Conditions

Stormwater Conveyance System	Annual Total Phosphorus Load in Pounds (% of Total Watershed Load)			
	Wet (41")	Model Calibration (34")	Average (27")	Dry (19")
Existing Land Use				
LL-2A	19 (6%)	11 (5%)	9 (5%)	8 (6%)
LL-3A	6 (2%)	4 (2%)	3 (2%)	2 (1%)
LL-4A	10 (3%)	6 (3%)	5 (3%)	4 (3%)
LL-5A	7 (2%)	4 (2%)	3 (2%)	3 (2%)
LL-6A	10 (3%)	6 (3%)	5 (3%)	4 (3%)
LL-7A	6 (2%)	4 (2%)	3 (2%)	2 (1%)
LL-8B	73 (22%)	44 (20%)	37 (20%)	29 (20%)
LL-10A	9 (3%)	5 (2%)	4 (2%)	4 (3%)
LL-11B	3 (1%)	2 (1%)	1 (1%)	1 (1%)
LL-11C	18 (5%)	11 (5%)	9 (5%)	7 (5%)
Total Annual Load from Stormwater Conveyance Systems	**161**	**116**	**79**	**64**
Total Annual Load from Watershed	**331**	**254**	**183**	**142**
Total Annual Load to Lotus Lake (Includes Atmospheric Deposition, Watershed, and Internal Loads)	**950**	**831**	**804**	**762**
Future Land Use				
LL-2A	21 (6%)	15 (5%)	11 (5%)	8 (5%)
LL-3A	6 (2%)	4 (1%)	3 (1%)	2 (1%)
LL-4A	11 (3%)	7 (3%)	5 (2%)	4 (3%)
LL-5A	8 (2%)	6 (2%)	4 (2%)	3 (2%)
LL-6A	10 (3%)	8 (3%)	6 (3%)	4 (3%)
LL-7A	6 (2%)	5 (2%)	3 (1%)	3 (2%)
LL-8B	82 (23%)	61 (22%)	43 (21%)	33 (21%)
LL-10A	10 (3%)	7 (3%)	4 (2%)	4 (3%)
LL-11B	3 (1%)	2 (1%)	2 (1%)	1 (1%)
LL-11C	19 (5%)	14 (5%)	10 (5%)	8 (5%)
Total Annual Load from Stormwater Conveyance Systems	**176**	**129**	**91**	**70**
Total Annual Load from Watershed	**358**	**277**	**203**	**154**
Total Annual Load to Lotus Lake (Includes Atmospheric Deposition, Watershed, and Internal Loads)	**977**	**860**	**822**	**774**

The treatment effectiveness of the detention ponds and wetlands that lie within the Lotus Lake watershed was determined for wet, model calibration, average, and dry conditions. It can be seen that approximately half of the ponds and wetlands in the Lotus Lake watershed have annual treatment efficiencies near or above 50 percent total phosphorus removal (Table 9). Overall, removal in downstream ponds was reduced because the ponds upstream (See Figure 17) had removed most of the phosphorus that could readily settle. For example, phosphorus removal in Pond LL-8G, an upstream pond, ranged from 57 to 66 percent under varying climatic conditions and existing watershed land use. Pond LL-8B, the most downstream pond in a nine pond conveyance system, removed 30 to 38 percent of its phosphorus load under the same conditions. Most of the phosphorus that entered these downstream ponds was associated with very small particles or was considered to be dissolved. An increase in the dead storage volume of these ponds would not lead to measurable improvements in phosphorus removal.

Table 9 Estimated Total Phosphorus Removal Efficiency of Lotus Lake Watershed Detention Ponds Under Existing Watershed Land Use Conditions

Stormwater Conveyance System	Pond Name	Total Phosphorus Removal Efficiency (% Removed)			
		Wet ('83) 41" pptn.	Model Calibration ('99) 34" pptn.	Avg. ('95) 27" pptn.	Dry ('88) 19" pptn.
LL2A	LL-2B	51	56	59	57
	LL-2A	8	10	11	10
LL-3A	LL-3A	38	43	46	43
LL-4A	LL-4C	52	57	61	58
	LL-4B	35	39	41	38
	LL-4A	43	49	52	49
LL-5A	LL-5C	54	59	62	60
	LL-5B	38	43	46	44
	LL-5A	55	60	64	60
LL-6A	LL-6B	48	54	57	55
	LL-6A	34	39	42	40
LL-7A	LL-7A	36	41	43	41
LL-8B	LL-8J	58	64	67	63
	LL-8K	53	59	63	59
	LL-8L	27	32	35	33
	LL-8G	57	63	66	62
	LL-8E	10	10	12	11
	LL-8D	6	7	8	7
	LL-8C	53	59	62	59
	LL-8B1	46	52	54	52
	LL-8B	30	36	38	36
LL-10A	LL-10B	40	48	52	48
	LL-10A	50	54	58	53
LL-11B	LL-11B	33	39	43	42
LL-11C	LL-11C	35	41	45	44

Dissolved phosphorus is estimated to comprise the majority of the lake's current watershed phosphorus load because treatment ponds in the lake's watershed effectively remove particulate phosphorus from stormwater runoff waters. Therefore, over a range of climatic conditions, dissolved phosphorus is estimated to comprise an average of 83 to 90 percent of the watershed total phosphorus load entering Lotus Lake (see Table 10).

Table 10 Estimated Average Percent Dissolved Phosphorus Load from Lotus Lake Inflow Waters Under Varying Climatic Conditions for Existing and Proposed Future Watershed Land Use

Climate Condition (inches of precipitation)	Average Percent Dissolved Phosphorus Load From Lotus Lake Inflow Waters Under Existing and Proposed Future Land Use Conditions
Wet (41")	83
Model Calibration (34")	85
Average (27")	87
Dry (19")	90

Some of the wet detention basins (ponds) in the lake's watershed were constructed prior to the establishment of current MPCA- and NURP-criteria. Fourteen of the 25 ponds (56 percent) in the lake's watershed currently meet MPCA- and NURP-criteria. Additional phosphorus removal from stormwater runoff will occur if eleven ponds are upgraded to meet MPCA-and NURP-criteria. Stormwater in two of the lake's subwatersheds is treated by "dry" ponds (temporarily hold stormwater and then drain dry). Upgrading dry detention basins to wet detention basins in two subwatersheds would enhance the phosphorus removal capability of the ponds. Five of the lake's subwatersheds currently do not have a treatment pond to treat stormwater runoff. Adding a wet detention basin in each of these five subwatersheds would further reduce phosphorus loading to the lake. Removal of a total of approximately 47,000 cubic yards of material would be required to upgrade 11 wet detention basins, convert two dry detention basins to wet detention basins, and add five wet detention basins to the lake's watershed. However, this additional treatment of stormwater runoff to the lake would only slightly reduce the lake's annual phosphorus load. The upgrade is expected to result in the removal of an additional 7 to 15 pounds of phosphorus (1 to 2 percent of the lake's annual total phosphorus load) under existing land use conditions and 6 to 12 pounds of phosphorus (1 percent of the lake's annual total phosphorus load) under future land use conditions (See Table 11).

Table 11 Estimated Total Phosphorus Loading Reduction From Upgrade of Wet Detention Ponds LL-2A, LL-3A, LL-4A, LL-6A, LL-6B, LL-8B1, LL-8D, LL-8E, LL-10B, LL-11B, and LL-11C, Upgrade of Dry Detention Ponds LL-8H and LL-8I to Wet Detention Ponds, and Adding Wet Detention Ponds LL-1, LL-1A, LL-8A, LL-8F, and LL-11A (All Ponds Would Meet MPCA-and NURP-Criteria)

Climatic Condition	Additional Pounds of Phosphorus Removed
Existing Land Use	
Wet (41")	15
Model Calibration (34")	13
Average (29")	12
Dry (25")	7
Future Land Use	
Wet (41")	12
Model Calibration (34")	10
Average (29")	10
Dry (25")	6

The upgrade of the 11 wet detention ponds, two dry detention ponds, and addition of five wet detention ponds is expected to have a negligible effect on the lake's water quality. The relatively small loading decrease from upgrading or adding watershed ponds to meet MPCA- and NURP-criteria is believed due to the low quantity of particulate phosphorus that remains in the lake's inflow waters following current treatment. The lake's inflow waters are primarily composed of dissolved phosphorus (See Table 10). Hence, the District's recreation, water quality, and aquatic communities goals would not be attained by upgrading existing ponds or adding additional ponds (See Table 12).

Table 12 Expected Lotus Lake Water Quality From Upgrade of Wet Detention Ponds LL-2A, LL-3A, LL-4A, LL-6A, LL-6B, LL-8B1, LL-8D, LL-8E, LL-10B, LL-11B, and LL-11C, Upgrade of Dry Detention Ponds LL-8H and LL-8I to Wet Detention Ponds, and Adding Wet Detention Ponds LL-1, LL-1A, LL-8A, LL-8F, and LL-11A (All Ponds Would Meet MPCA- and Nurp-Criteria)

	Trophic State Index (TSI_{SD}) Value				
Management Approach	District Goal	Wet Year (41")	Model Calibration Year (34")	Average Year (27")	Dry Year (19")
Existing Land Use					
No Action	≤ 53	57	57	57	56
Upgrade Ponds to MPCA-and NURP-Criteria	≤ 53	57	57	57	56
Future Land Use					
No Action	≤ 53	58	57	57	57
Upgrade Ponds to MPCA-and NURP-Criteria	≤ 53	58	58	57	57

2.2.3 Public Ditch Systems

There are no known ditch systems affecting Lotus Lake.

2.3 Fish and Wildlife Habitat

The MDNR has established criteria for the support of Lotus Lake's fishery, based upon Lotus Lake's classification as a Class 24 lake. The current habitat for Lotus Lake fails to meet the criteria of a TDI_{SD} of 56 or lower (a summer average Secchi disc transparency of at least 4.3 feet). The lake's poor water transparency is caused by algal blooms which result from excessive phosphorus.

In addition to the impairment of the Lotus Lake fishery caused by high phosphorus levels and severe summer algal blooms, dissolved oxygen levels can become severely depressed in the summer as a result of algal senescence. Oxygen is depleted or consumed when dead algae decay. In May of 1999, the lake's upper 6 meters contained sufficient oxygen (>5 mg/L) to support the lake's gamefish. Oxygen depletion caused by algal senescence reduced the area habitable by gamefish to the upper 4 meters by June. It can be seen in Figure 20 that severe oxygen depletion during the summer caused stressful conditions for the lake's gamefish. The oxygen content of the lake's upper 5 meters in August was below 5 mg/L and the lake was void of oxygen below the 5-meter depth. Clearly the severe dissolved oxygen depletion that is observed in Lotus Lake is harmful to the lake's fishery.

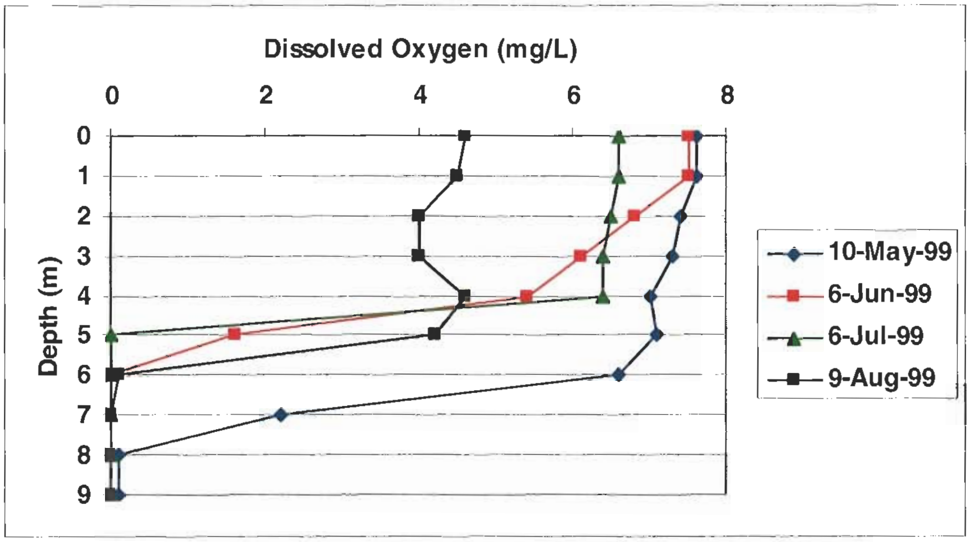


Figure 20 Dissolved Oxygen in Lotus Lake from the Surface (0 meters) to the Bottom (~9 m)

2.4 Water Based Recreation

The recreational uses of Lotus Lake include swimming, fishing, boating, waterskiing, jet skiing, canoeing, sailing, and aesthetic viewing. All recreational uses are currently impaired by severe algal blooms. Swimming requires a higher water quality than other recreational activities and is the most severely impaired use.

2.5 Ecosystem Data

Development of a more balanced ecosystem at Lotus Lake is needed for the lake to achieve the recreation, aquatic communities, and water quality goals that have been set for the lake. There are two primary imbalances in Lotus Lake: (1) high phosphorus levels and severe summer algal blooms; and (2) growths of non-native species including curlyleaf pondweed, Eurasian watermilfoil, and purple loosestrife.

It appears that Lotus Lake's zooplankton population is generally well balanced by the existing fishery. However, a short-term imbalance occurs each summer when disappearance of the lake's zooplankton refuge results in reduced numbers of large-bodied zooplankton. A refuge is the deepest spot in a lake with sufficient oxygen for zooplankton (1 to 3 mg/L) but insufficient oxygen for predatory fish (at least 3 mg/L). Zooplankton hide in a refuge when one is available to them, thus avoiding predation by fish. When a lake's refuge thins to a meter or less, its protection to large-bodied zooplankton is inadequate. Senescence from summer algal blooms depleted Lotus Lake's oxygen and destroyed the lake's zooplankton refuge. With no place to hide, large-bodied zooplankton were easily eaten by fish and their numbers were reduced. Reduction of phosphorus is necessary to minimize oxygen depletion and preserve the lake's zooplankton refuge during the summer period. Attaining a balanced zooplankton community during the summer period will help attain the lake's water quality, recreation, and aquatic communities goals.

According to a 1999 MDNR fish survey, an excellent fishery was observed in Lotus Lake. However, the MDNR is concerned that the lake's poor water quality will have a detrimental effect on the lake's fishery. MDNR concerns are based upon fishery habitat considerations and a desire to improve and protect the lake's fisheries habitat. The MDNR 2001 *Lake Management Plan for Lotus Lake* indicates the MDNR will work with the Riley Purgatory Bluff Creek Watershed District and the City of Chanhassen to lower phosphorus loading, thereby improving the lake's water quality.

2.6 Water Quality

2.6.1 Baseline/Current Analysis

Evaluation of the baseline and current trophic state index (TSI) of Lotus Lake shows that the lake consistently has been unable to fully support swimmable use (MPCA-criteria of $TSI_{SD} \leq 53$) and has not met MDNR-criteria ($TSI_{SD} \leq 56$) for the lake's fishery during the baseline and current periods (Figure 21).

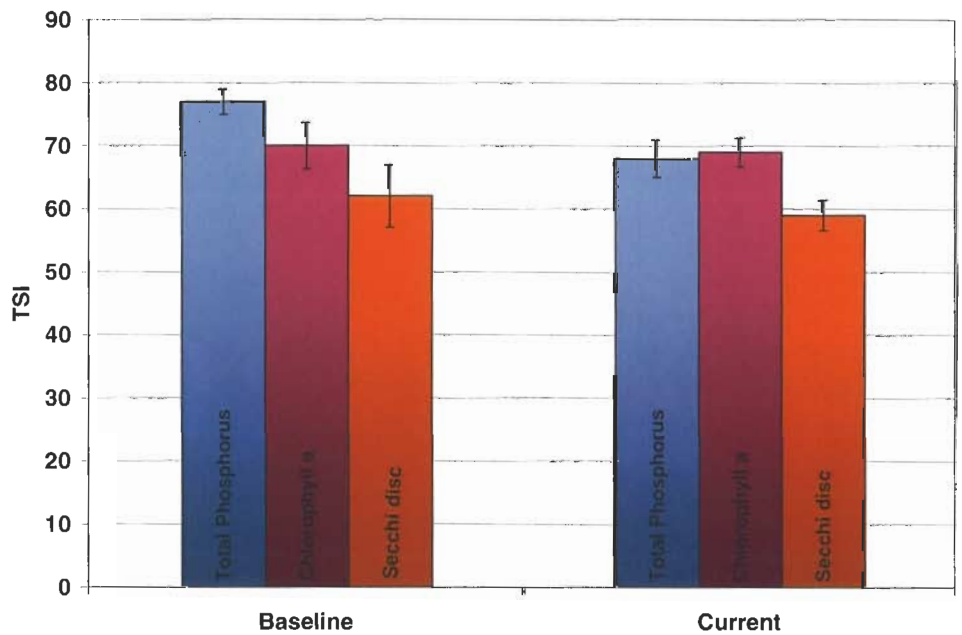


Figure 21 Baseline and Current Trophic State Index (TSI) for Lotus Lake

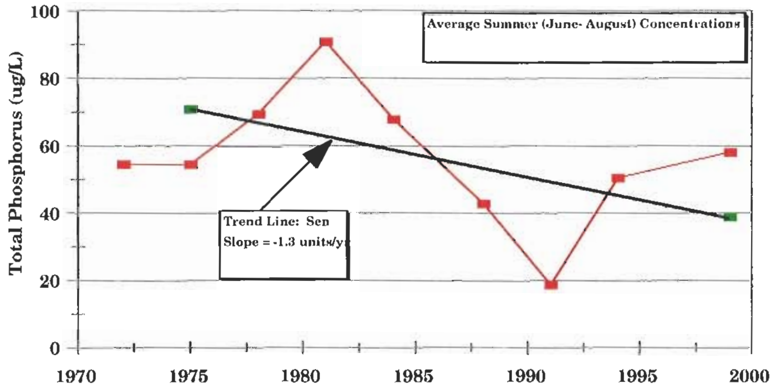
2.6.2 Historical Water Quality-Trend Analysis

A trend analysis of Lotus Lake was completed to determine if the lake had experienced significant degradation or improvement during the years for which water quality data are available. The results of the trend analysis show significant improvement in the lake's water quality during the 1975 through 1999 period. The analysis was based upon Secchi disc transparency, total phosphorus, and chlorophyll *a* observations collected since 1975 (24 years of data). The nonparametric Seasonal Kendall trend analysis was used. The three response variables for Lotus Lake were plotted versus the independent variable, time (in years) since 1975, along with the predicted trend line. The response variable was only considered to have either a positive or negative trend if the slope of the line was significantly different from zero. The standard 95 percent confidence level was used, although the 90 percent and 85 percent confidence levels were also calculated. Plots of the three water quality variables and the fitted regression lines resulting from the analysis are shown in Figure 22.

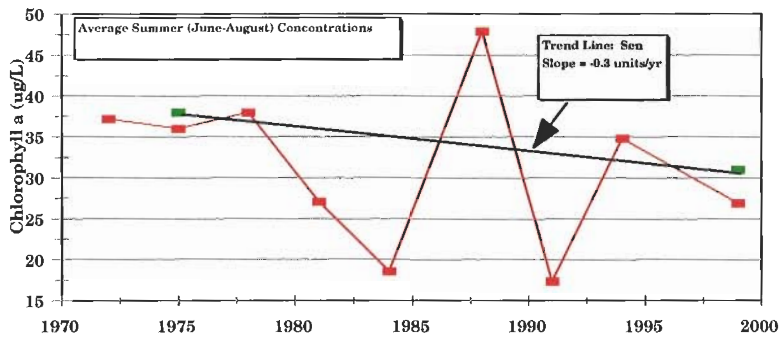
Two criteria must be met to conclude the lake's water quality has significantly improved or declined. First, the trend in a variable was considered significant if the slope of the regression was statistically significant at the 95 percent confidence level. Second, a conclusion of degraded water quality requires concurrent increases in total phosphorus and chlorophyll *a* concentrations, and a decrease in Secchi disc transparency; a conclusion of improvement requires the inverse relationship. The results for the three variables show that phosphorus and chlorophyll concentrations have significantly declined (i.e., water quality improvement) and Secchi disc transparency has significantly improved (i.e., water quality improvement). Hence, the analysis indicates the lake's water quality has improved significantly over time. Despite the significant improvement in water quality, the lake currently fails to meet MPCA-criteria for full support of swimmable-use and MDNR-criteria for full support of the lake's fishery.

The results of the regressions indicate that Secchi disc transparency has been increasing at an average rate of 0.004 meters per year (less than 0.2 inch); chlorophyll *a* concentration in the epilimnion (upper 6 feet) has decreased at the rate of 0.3 μg/L per year; total phosphorus concentration in the epilimnion (upper 6 feet) has been decreasing at a rate of 1.3 μg/L per year. The changes in Secchi disc, chlorophyll, and total phosphorus are significantly different from zero statistically. Despite the statistically significant changes, the slow rate of change indicates the lake is very stable. At the rate of change determined by the trend analysis, a 93-year time period would be required to achieve the District's water quality goal of TSI_{SD} equal to or less than 53. Hence, the data indicate the lake's current water quality problems are unlikely to change unless management practices are implemented to improve the lake's water quality.

Lotus Lake
Total Phosphorus - 1972 Through 1999



Lotus Lake
Chlorophyll a - 1972 Through 1999



Lake Lotus
Secchi Disc - 1972 Through 1999

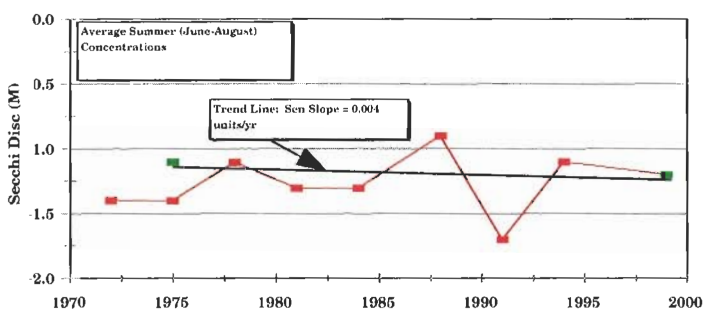


Figure 22 Lotus Lake Trend Analysis -- 1975-1999 Total Phosphorus and Chlorophyll *a* Concentrations and Secchi Disc Transparency

2.6.3 Water Quality Modeling Analysis

Water quality modeling was performed to better understand the phosphorus dynamics in the Lotus Lake watershed and in Lotus Lake, and to understand how phosphorus loading is affecting algal growth in the lake. Watershed modeling, which includes both hydrologic and phosphorus loading, was performed using the P8 (IEP, Inc. 1990) model. In-lake models (Vollenweider, 1976, and Thomann and Mueller 1987) were used to determine how external and internal phosphorus loading (loading within the lake) lead to the observed levels of phosphorus in Lotus Lake. Internal loading was from sediment phosphorus loading.

Modeling was performed for four climatic conditions (dry, average, model calibration, and wet year) and different management efforts to determine the potential effect of these management activities on phosphorus levels in Lotus Lake. A regression between phosphorus levels and Secchi disc transparency was developed by the Minnesota Pollution Control Agency from Minnesota lake monitoring data and was used to predict expected lake clarity improvements (Secchi disc transparency) with different management activities (Heiskary and Wilson, 1990; See Figure 4). A detailed description of model development, calibration, and validation is provided in Appendix B.

The modeling analysis confirms that the lake is unable to meet the District water quality goal under all climatic conditions, currently and in the future (Tables 6 and 12).

2.7 Major Hydrologic Characteristics

The major hydrologic characteristics of Lotus Lake have changed as the watershed has changed from primarily agricultural to urban. Although the watershed is nearly developed, some additional development will occur in the future. Park and open space areas will decline and residential and industrial areas will increase. Following these land use changes, the lake's annual water load is expected to increase by about 7 to 10 percent.

2.8 Land Use Assessment

Land use in the watershed has changed from the predevelopment period. The watershed's land use changed from wooded to agriculture to urbanized. Watershed urbanization is nearly complete. However, future redevelopment within the watershed could result in density increases and increased phosphorus loading to the lake. Increased density in residential development and increased commercial development are both possible in the future. Proposed land use changes within the lake's watershed should be analyzed to determine whether increased phosphorus loading to the lake would result from the land use changes. Management practices such as detention basins may be required to prevent phosphorus loading increases from future land use changes.

3.0 Lotus Lake Goals

3.1 Water Quantity Goal

The water quantity goal for Lotus Lake is to provide sufficient water storage during a regional flood. The water quantity goal has been achieved and no action is required.

3.2 Water Quality Goal

The water quality goal of Lotus Lake is predicated on the lake's recreational goal. The goal is to achieve a water quality that will fully support the lake's swimmable and fishable uses. The District goal is a $TSI_{SD} \leq 53$. Table 13 shows that the water quality goal is currently not being achieved, but with the implementation of the following management practice the water quality goal can be achieved or exceeded:

- WQ-1: Alum treatment of Lotus Lake.

The cost of the alternative is presented in Figure 23. It should be recognized that the management alternative is designed to meet or exceed the TSI_{SD} goal and reduce the fluctuations in dissolved oxygen levels in Lotus Lake that are the result of the summer algal blooms.

Table 13 Expected Water Quality with Water Quality Management Alternative

	Trophic State Index (TSI_{SD}) Value				
Management Approach	District Goal	Wet Year (41")	Model Calibration Year (34")	Average Year (27")	Dry Year (19")
Existing Land Use					
No Action	≤ 53	57	57	57	56
Lake Alum Treatment	≤ 53	39	38	37	34

Future Land Use

	Trophic State Index (TSI_{SD}) Value				
Management Approach	District Goal	Wet Year (41")	Model Calibration Year (34")	Average Year (27")	Dry Year (19")
No Action	≤ 53	58	57	57	57
Lake Alum Treatment	≤ 53	42	39	37	36

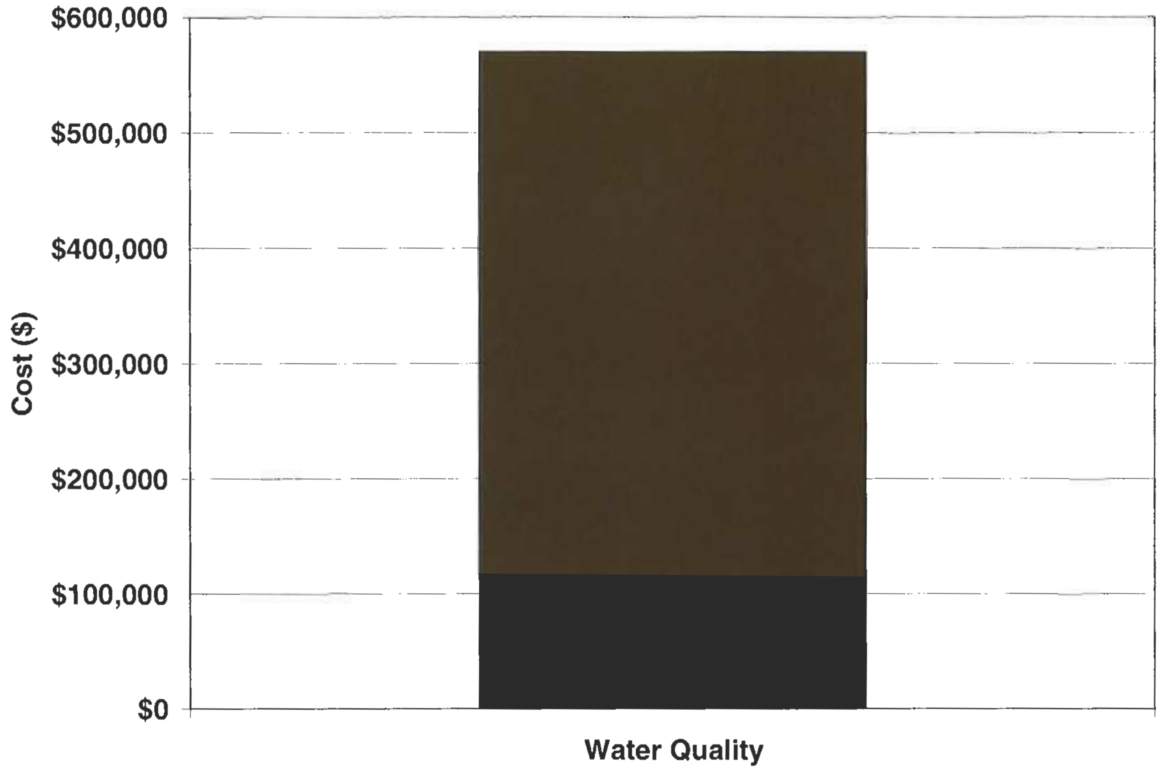


Figure 23 Cost of the Water Quality Management Alternative

3.3 Aquatic Communities Goal

The aquatic communities goal for Lotus Lake is the achievement and maintenance of a water quality and habitat that fully supports the lake's fisheries-use classification as determined by the MDNR (Schupp 1992). The goal is to maintain a $TSI_{SD} \leq 56$, reduce the fluctuations in dissolved oxygen levels in Lotus Lake that are the result of the summer algal blooms, and manage invasive non-native plant species, including curlyleaf pondweed, Eurasian watermilfoil, and purple loosestrife. The lake's current water quality and oxygen fluctuations do not provide the desired habitat for the lake's fishery. The lake's non-native species threaten further habitat degradation by problematic growths and displacement of native species. The alternative presented in Table 14 will allow Lotus Lake to achieve or exceed the District aquatic communities goal. The costs to implement the management alternative are presented in Figure 24.

Table 14 Expected Water Quality with Aquatic Communities Management Alternative

Management Approach	Trophic State Index (TSI_{SD}) Value				
	District Goal	Wet Year (41")	Model Calibration Year (34")	Average Year (27")	Dry Year (19")
Existing Land Use					
No Action	≤ 56	57	57	57	56
Lake Alum Treatment, Herbicide Treatment of Curlyleaf Pondweed and Eurasian Watermilfoil, Beetle Treatment of Purple Loosestrife	≤ 56	39	38	37	34
Future Land Use					
No Action	≤ 56	58	57	57	57
Lake Alum Treatment, Herbicide Treatment of Curlyleaf Pondweed and Eurasian Watermilfoil, Beetle Treatment of Purple Loosestrife	≤ 56	42	39	37	36

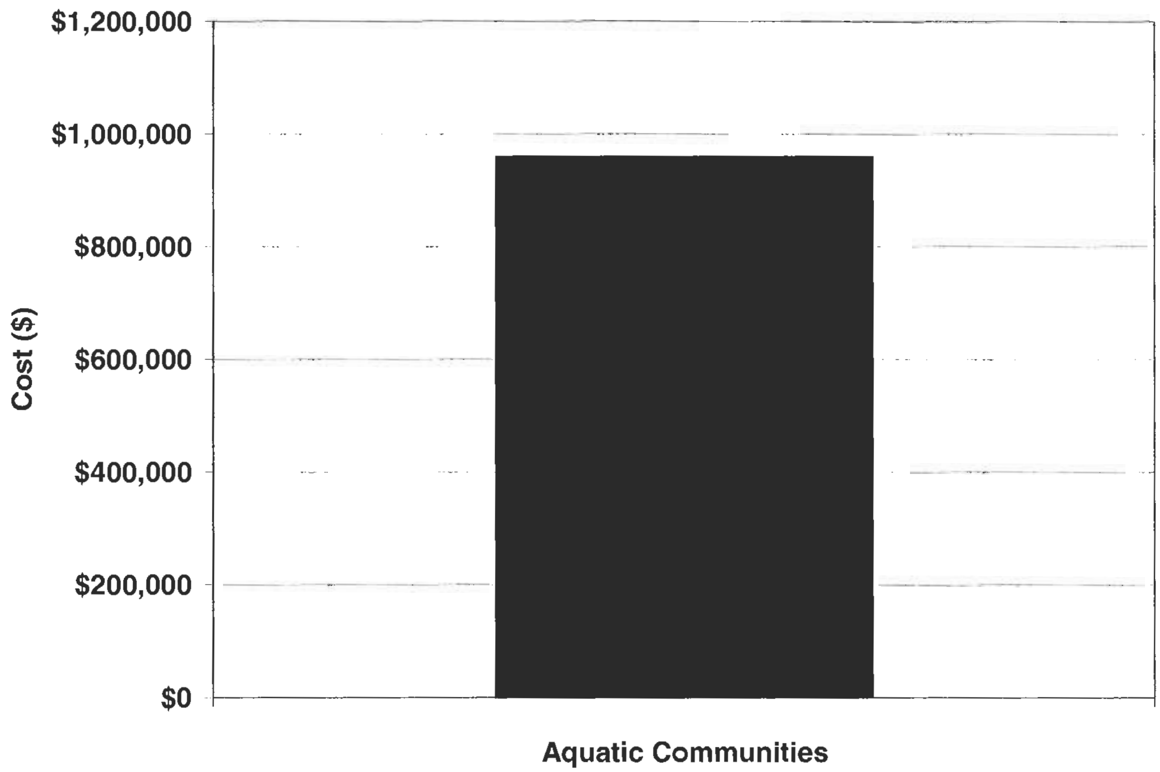


Figure 24 Cost of the Aquatic Communities Management Alternative

3.4 Recreation Goal

Because Lotus Lake has been designated a swimming lake by the Riley-Purgatory-Bluff Creek Watershed District, the recreational goal is to fully support the lake's swimmable-use. The lake has an excellent fishery and is managed by the MDNR as a walleye fishery. Hence, a second District goal is to maintain a $TSI_{SD} \leq 56$ (Schupp 1992), a water quality that fully supports the lake's MDNR ecological Class 24 rating. From the perspective of the TSI_{SD} goals for swimming and the lake's fishery and the problems with dissolved oxygen fluctuations resulting from excessive blue-green algae growth, the recreation goal is currently not being achieved. In addition, the lake's non-native species may cause problematic growths to further impair recreational-use of Lotus Lake. The alternative presented in Table 15 will allow Lotus Lake to achieve or exceed the District recreation goal. The cost to implement the management alternative is presented in Figure 25.

Table 15 Expected Water Quality with Recreation Management Alternative

Management Approach	Trophic State Index (TSI_{SD}) Value				
	District Goal	Wet Year (41")	Model Calibration Year (34")	Average Year (27")	Dry Year (19")
Existing Land Use					
No Action	≤ 53	57	57	57	56
Lake Alum Treatment, Herbicide Treatment of Curlyleaf Pondweed and Eurasian Watermilfoil, Beetle Treatment of Purple Loosestrife	≤ 53	39	38	37	34
Future Land Use					
No Action	≤ 53	58	57	57	57
Lake Alum Treatment, Herbicide Treatment of Curlyleaf Pondweed and Eurasian Watermilfoil, Beetle Treatment of Purple Loosestrife	≤ 53	42	39	37	36

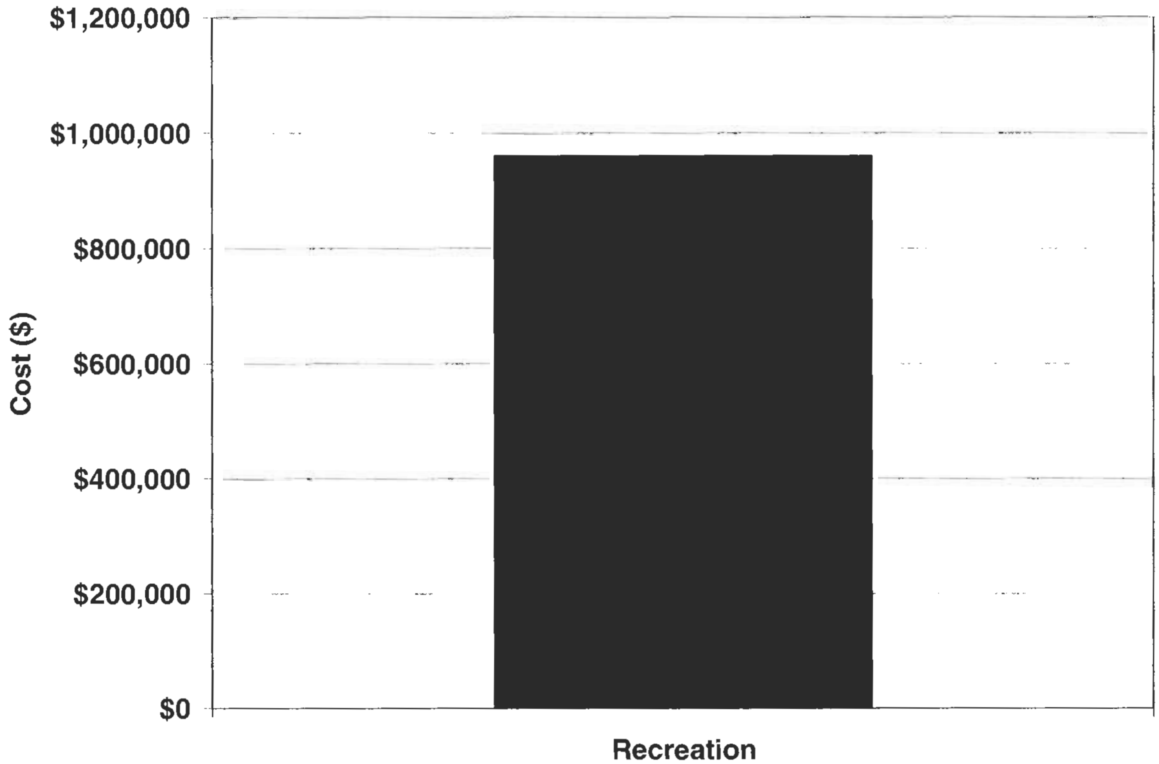


Figure 25 Cost of the Recreation Management Alternative

3.5 Wildlife Goal

The wildlife goal for Lotus Lake is to protect existing, beneficial wildlife uses. The wildlife goal has been achieved.

3.6 Public Participation

The public participation goal is to encourage public participation as part of the use attainability analysis. This goal will be achieved through a public meeting to obtain comments on the use attainability analysis.

4.0 Selected Implementation Plan

4.1 Basis for Selected Implementation Plan

Lotus Lake is a complex aquatic system. Any management action must be taken with consideration of how the different components of the ecosystem fit together. Monitoring data and modeling results have been used to better understand the ecology of Lotus Lake and to estimate what the consequence may be from different management activities. The root of the imbalances that are observed at Lotus Lake (blue-green algae blooms and low dissolved oxygen in the summer) is a high level of phosphorus. Although it may appear that the solution is to immediately reduce phosphorus levels, simply reducing phosphorus in a non-systematic manner may not lead to expected improvements and may have some unintended consequences.

Curlyleaf pondweed and Eurasian watermilfoil, two nuisance non-native species, are presently found in Lotus Lake. Improvement in the lake's water clarity is expected to increase light availability to the plants and promote additional growth of both species. Failure to effectively manage these plant species before improving the lake's water clarity could result in the unintended consequence of problematic growths of both species. Additional curlyleaf pondweed growth could hamper lake improvement efforts. Curlyleaf pondweed would contribute phosphorus to Lotus Lake by growing quickly in the spring, extracting phosphorus from the sediments, and dying off in June, thus releasing phosphorus stored in plant tissue. Hence, the expected improvements in the lake's water quality may not occur because of additional phosphorus loading resulting from additional curlyleaf pondweed growth.

Management of both species should occur before the lake's phosphorus concentration is reduced and water clarity is improved. This should involve removing the species from Lotus Lake so that native plants can replace them.

Research has shown that the appropriate herbicide for curlyleaf pondweed control is endothall, and that this herbicide should be applied in the spring (when the water temperature is approximately 55°F to 60°F) and at a dose of 1 to 1.5 mg/L (Poovey et al. 2002, Skogerboe 2004 – personal communication). Preliminary results from studies in Eagan, Minnesota by John Skogerboe of the U.S. Army Corps of Engineers have shown that four subsequent years of endothall treatment have essentially eliminated curlyleaf pondweed from two of the study lakes and that after the 4th year of treatment no viable turions (pondweed seeds) remained in the sediment (Skogerboe 2004 – personal communication). To remove curlyleaf pondweed, treatment will need to continue until no viable turions remain after treatment is completed. Treatment is expected to continue for 4 years.

Current research is evaluating the effectiveness of lime to control curlyleaf pondweed. In a pilot study at Big Lake, Wisconsin, curlyleaf pondweed did not grow in 1-acre plots treated with lime, even though the plant continued to grow throughout the lake (Barr 2001). In whole lake studies, curlyleaf pondweed was not observed where lime had been applied in Clifford Lake and Faille Lake, located near Osakis in central Minnesota. The U.S. Army Corps of Engineers is currently conducting a lime slurry research project at the Eau Galle Aquatic Ecology Laboratory near Spring Valley, Wisconsin. Should the project results indicate lime would be the most effective tool to control curlyleaf pondweed in Lotus Lake, lime will be used rather than endothall to manage this plant.

Current research has shown that the appropriate herbicide for Eurasian watermilfoil control is 2,4-D, and that this herbicide should be applied in the spring as soon as Eurasian watermilfoil starts rapidly growing (April or May). Preliminary results from a study in Bloomington, Minnesota by John Skogerboe of the U.S. Army Corps of Engineers have shown that 2,4-D was effective in controlling Eurasian watermilfoil. Study results further indicate a synergistic benefit to Eurasian watermilfoil control when endothall and 2,4-D are used together (Skogerboe 2004 – personal communication). To remove Eurasian watermilfoil, treatment will need to continue until this plant species is no longer observed in the lake. Treatment is expected to continue for 4 years.

Annual herbicide treatment (endothall for curlyleaf pondweed and 2,4-D for Eurasian watermilfoil) should occur until curlyleaf pondweed and Eurasian watermilfoil are no longer observed in Lotus Lake and no viable curlyleaf turions are found (estimate 4 years of treatment).

Purple loosestrife along the lake's shoreline threatens to displace native vegetation and reduce the habitat quality of the lake's shoreline area. Introducing a natural predator will control purple loosestrife growth along the shore. Two beetle species, *Galerucella pusilla* and *Galerucella calmariensis*, effectively prey upon purple loosestrife, inhibit purple loosestrife growth, and greatly reduce flowering seed output. Introducing the beetles to infested areas of Lotus Lake will control purple loosestrife growth and promote the growth of native species.

Under varying climatic conditions, stormwater comprises from 19 to 35 percent of the lake's annual phosphorus load under existing land uses and from 20 to 37 percent under future land uses. Stormwater comprises a small fraction of the lake's total phosphorus load because wet detention ponds are removing a significant fraction of phosphorus loads (see Table 9) from the adjacent watershed. Few opportunities for additional removal of phosphorus from stormwater runoff are apparent. Upgrading eleven ponds in the lake's watershed to meet MPCA/NURP criteria, upgrading two dry detention ponds to wet detention ponds, and the addition of five wet detention ponds would have a negligible effect on the lake's water quality. Increasing infiltration of stormwater runoff to remove from ¼-inch to ¾-inches of runoff from the lake's direct watershed would have a negligible effect on the lake's water quality.

Phosphorus stored in sediment is the most treatable source of phosphorus to the water column of Lotus Lake. The concentration of phosphorus in Lotus Lake sediments that can release into the water column (i.e., mobile phosphorus) is very high (Figure 18) and corresponds to a potential phosphorus release rate of approximately 4.7 mg per square meter of lake surface per day. Approximately 10 percent of the phosphorus released from sediments during the summer and 1 percent of the phosphorus released from sediments during the winter is entrained in the lake's surface waters. An estimated 500 pounds of phosphorus is released from the lake's sediments and entrained in Lotus Lake's surface waters annually. This internal load comprises 53 to 66 percent of the lake's annual total phosphorus load under existing watershed land use conditions and varying climatic conditions. Treatment of the lake's sediments with alum will reduce phosphorus loading to the lake and improve its water quality. Alum treatment of the lake is the most effective method of improving the lake's water quality.

If applied in one treatment, the large dose of alum that is required to treat Lotus Lake's sediments may be too heavy for the sediments to bear. The sediments have a limited weight bearing capacity because the water content of the upper 6 centimeters of the lake's sediments is 86 to 94 percent. Hence, the weight of the alum may cause it to sink far below the sediment's surface.

Splitting the large dose into smaller doses applied annually for 3 consecutive years is recommended. The smaller annual doses are expected to remain in the upper 6 centimeters of lake sediment and effectively treat the sediment's mobile phosphorus. Treatment effectiveness is dependent upon the alum treating the upper 6 centimeters of the lake's sediments. If the alum sinks below the 6 centimeter depth, the treatment will have the unintended consequence of not treating the upper 6 centimeters of sediments that are releasing phosphorus into the lake's water column.

4.2 Manage Curlyleaf Pondweed and Eurasian Watermilfoil

The recommended treatment program for curlyleaf pondweed and Eurasian watermilfoil consists of annual spring herbicide treatment until they are removed from the lake. Treatment will occur in late-April or early-May when the water temperature is approximately 55°F to 60°F. Curlyleaf pondweed will be treated with the herbicide endothall at a dose of approximately 1 to 1.5 mg/L. Eurasian watermilfoil will be treated with the herbicide 2,4-D. To remove both species from Lotus Lake, treatment will need to continue annually until no curlyleaf pondweed, no viable turions, and no Eurasian watermilfoil remain. Treatment is expected to continue for 4 years.

The District will need a permit to implement the recommended non-native plant management program. Hence, the District should apply for an aquatic plant management permit (APM) from the MDNR (MN Rule 6280.0250).

Current research to determine the effectiveness of lime to manage aquatic plants, including non-native species, could potentially conclude that lime is a better management tool than herbicide for control of curlyleaf pondweed and/or Eurasian watermilfoil. Should lime prove to be a better tool, lime treatment will replace herbicide treatment for curlyleaf pondweed and/or Eurasian watermilfoil. A letter of support from the MPCA and MDNR must be obtained prior to treating the lake with lime.

4.3 Manage Purple Loosestrife

The recommended purple loosestrife treatment program includes introduction of beetles, natural predators, into shoreline areas infested with purple loosestrife. The MDNR will provide beetles to the District at no cost. However, introducing the beetles into purple loosestrife infested areas is the District's responsibility. Management of purple loosestrife generally spans several years (4 years estimated). During the treatment period, annual field surveys will measure beetle population establishment and persistence. Survey results will determine whether the collection and release of additional beetles are warranted.

The macrophyte survey in August, 1999 (See Figure 12) identified 10 sites with approximately 5.5 acres of purple loosestrife (*Lythrum salicaria*). The area of each of these sites is listed in Table 16. Recommended release sites are shown on Figure 26 and presented in Table 16.

Table 16 Acreage of Sites With Purple Loosestrife Infestations

Lotus Lake Purple Loosestrife	
Site	**Approximate Acres**
1	0.69
2	0.32
3	2.64
4	0.16
5	0.35
6	0.57
7	0.08
8	0.12
9	0.55
10	0.08

Biocontrol agents provide a viable long term management strategy. During the 1st year the biocontrol beetles are released there will be little sign of control. It may take 2 to 3 years before the biocontrol population builds up and becomes established. Factors such as weather and site type will also affect biocontrol populations.

The MDNR has released purple loosestrife biocontrol beetles at Lotus Lake in 1997 on the South end of the lake at South Lotus Lake Park. The MDNR has also released beetles in neighboring lakes. The MDNR has returned in subsequent years to monitor the beetle's survival at Lotus Lake, and in 2002, this site was highly rated for beetle occurrence, indicating persistence of local beetle populations. Some control of purple loosestrife is occurring in South Lotus Lake Park. A brief survey for existence of beetle populations around Lotus Lake due to historical releases is recommended in subsequent years. The survey would be included in surveys to evaluate new releases of biocontrol beetles.

4.4 Alum Treatment of Lotus Lake

The recommended treatment program to reduce the lake's phosphorus concentrations is a lake alum treatment. The recommended alum dose is 11 mg/m^2 by 1 centimeter deep or 1,204 gallons per acre to treat the top 6 centimeters of sediment in Lotus Lake. The dose will be administered in increments of one third the total dose. A dose of approximately 401 gallons per acre will be administered annually in the fall for 3 consecutive years to attain the recommended treatment dose of 1,204 gallons per acre. Annual monitoring of the lake and sediments will measure treatment

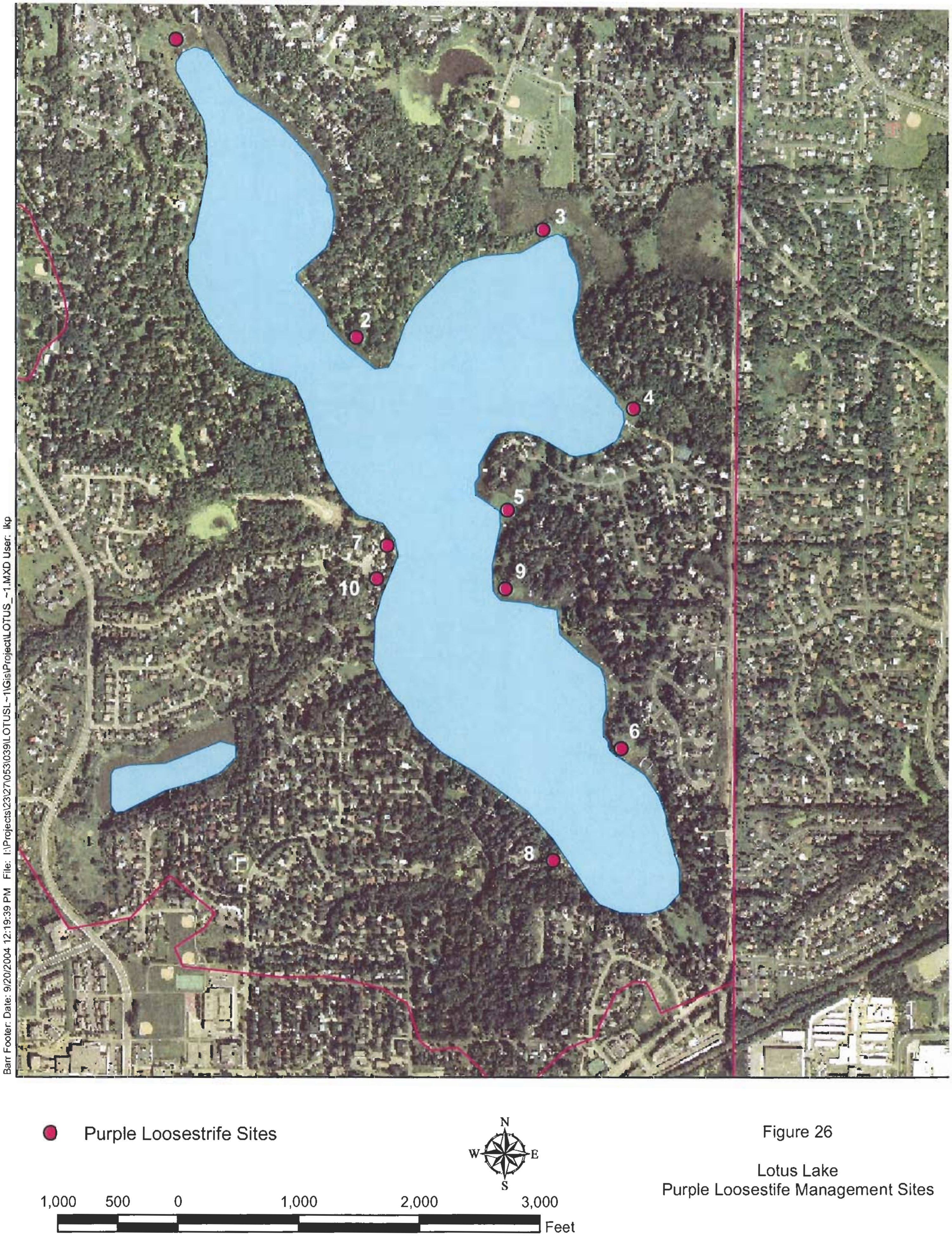


Figure 26

Lotus Lake
Purple Loosestrife Management Sites

effectiveness and the mobile phosphorus remaining in the lake's sediments. Dose adjustments will be made as warranted.

A letter of support must be obtained from the MPCA and MDNR prior to treating the lake with alum.

4.5 Expected Sequence of Implementation Plan

Below is the expected sequence of the lake management activities.

Year 1-3 Herbicide (endothall and 2,4-D) treatment of curlyleaf pondweed and Eurasian watermilfoil in the spring; beetle treatment of purple loosestrife in the spring; monitoring and evaluation of aquatic plants (transect surveys), including purple loosestrife; monitoring and evaluation will determine warranted changes in herbicide treatment and whether additional beetles need to be introduced into purple loosestrife infested areas.

Year 4 Continued herbicide treatment; monitoring and evaluation of sediments, lake water quality, and aquatic plants (transect surveys), including purple loosestrife (qualitative mapping); monitoring and evaluation will determine warranted changes in herbicide treatment and whether this is the final year of treatment; monitoring and evaluation will determine whether purple loosestrife control is complete or whether additional beetles need to be introduced to complete purple loosestrife control.

Years 5-7 Alum treatment in the fall; monitoring and evaluation of lake water quality, sediments, and aquatic plants (transect surveys), including purple loosestrife (qualitative mapping); monitoring and evaluation of lake water quality and sediments will determine warranted changes in alum dose and when the final alum treatment occurs.

Year 8-10 Monitoring and evaluation of lake water quality, sediments, and aquatic plants (qualitative mapping), including purple loosestrife (qualitative mapping);

Years 11 Completion of a final report which summarizes the treatment program and monitoring results.

The annual costs of the lake management activities for the 11-year period are shown in Figure 27.

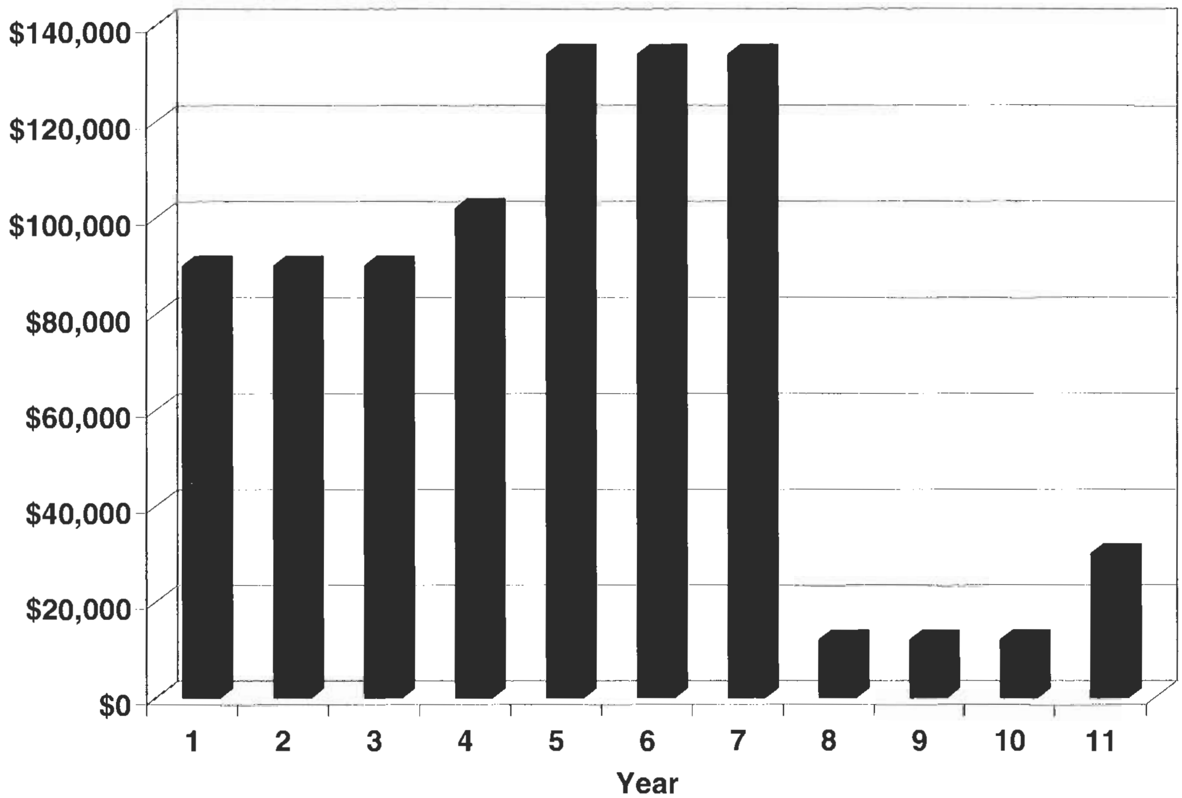


Figure 27 Annual Cost of Lotus Lake Management Alternative to Meet or Exceed Goals

4.6 Monitoring and Evaluation

An important part of this plan is monitoring and evaluation, including aquatic plant monitoring, purple loosestrife and beetle monitoring, water quality monitoring, and sediment monitoring.

4.6.1 Aquatic Plant Monitoring

During each treatment year and for 3 years following treatment, aquatic plant surveys should be completed on three occasions: pre-treatment survey, late-spring survey, and late-summer survey. The three surveys will determine the locations and density of plants in Lotus Lake, including curlyleaf pondweed and Eurasian watermilfoil. Because treatment is expected to occur in late-April or early-May, the pre-treatment survey should be completed in either April or May, but before treatment occurs. The late-spring survey should be completed by late-June. The late-summer survey should be completed by late-August. During the late-spring survey, turions (curlyleaf pondweed "seeds") should be collected from 10 percent of sample locations.

Annual monitoring will be used to assess plant community changes and to determine treatment changes. It is anticipated that reduced curlyleaf pondweed (and turions) and Eurasian watermilfoil will occur annually during the treatment period. The treatment area is expected to decrease with decreased coverage. The treatment program will be adjusted annually based upon monitoring results and will be terminated when no curlyleaf pondweed or Eurasian watermilfoil plants are observed in Lotus Lake and no viable turions are collected.

4.6.2 Purple Loosestrife/Beetle Monitoring

Annual field surveys should determine purple loosestrife coverage and measure beetle population establishment and persistence.

4.6.3 Water Quality Monitoring

Monitoring should occur 1 year prior to the lake's alum treatment, during each year of alum treatment, and for 3 years following the final alum treatment. During each year of monitoring, water quality parameters (total phosphorus, chlorophyll *a*, Secchi disc transparency, dissolved oxygen, and pH) should be monitored every 2 weeks from April through September.

4.6.4 Sediment Monitoring

Sediment monitoring should occur before alum treatment, during each of the 3 years of treatment, and for 3 years following treatment. The monitoring will evaluate changes in the mobile phosphorus content of the lake's sediments. The monitoring following sediment treatment will also evaluate the location of the alum layer. If the layer is below the sediment's surface, the distance from the surface will be measured.

5.0 Proposed 7050 Rules For Lakes

The 1972 amendments to the federal Clean Water Act require the MPCA to assess the water quality of rivers, streams, and lakes in Minnesota (Code of Federal Regulations, title 40, part 130). Waters determined to be not meeting water quality standards and not supporting assigned beneficial uses are defined as "impaired." Impaired waters are listed and reported to the citizens of Minnesota and to the Environmental Protection Agency (EPA) in the 305(b) report and the 303(d) list. Both listings are named after the relevant sections of the Clean Water Act. The beneficial uses assessed in this context are aquatic life and recreation (swimming) and aesthetics.

Impaired water or impaired condition is defined in Minn. R. pt. 7050.0150 as follows:

> *... a water body that does not meet applicable water quality standards or fully support applicable beneficial uses, due in whole or in part to water pollution from point or nonpoint sources, or any combination thereof.*

The listing of a waterbody on the 303(d) list triggers a regulatory response on the part of the MPCA to address the causes and sources of the impairment. This process is called a Total Maximum Daily Load (TMDL) analysis. The purpose of the TMDL analysis is to focus attention and resources on impaired waters and ultimately bring them back into compliance with water quality standards. Current rules require that a TMDL analysis be completed after a water body is listed on the 303(d) impaired waters list to determine a water quality improvement program to bring the water body in compliance with MPCA standards. The rules also require implementation of the water quality improvement program to bring the water body in compliance with MPCA standards.

The MPCA has developed lake criteria to determine impaired waters. The criteria are found in *Guidance Manual for Assessing the Quality of Minnesota Surface Waters For Determination of Impairment.* 305(b) Report and 303(d) List (MPCA 2004). The MPCA used these criteria to assess Lotus Lake. Because the lake failed to meet these criteria (See Table 17), Lotus Lake had been listed on the 303(d) List as an impaired waters of the State.

Table 17 Eutrophication Criteria Used to List Lakes on the 303(d) List for 2004: Lakes in the North Central Hardwood Forests (NCHF) Ecoregion, including Lotus Lake

Parameter	Criteria*
Total Phosphorus (µg/L)	< 40
Chlorophyll *a* (µg/L)	< 15
Secchi Disc (m)	> 1.2

*Lakes meeting the criteria are not listed on the 303(d) list.

The criteria found in Table 17 were modified during the 2004 revision of Minnesota's 7050 Water Quality Standards. The 7050 Standards' revisions include the addition of eutrophication standards for lakes (i.e., total phosphorus, chlorophyll *a*, and Secchi disc standards) on a regional basis. Within each region, separate criteria were established for deeper lakes (depths greater than 15 feet) and shallow lakes (depth of 15 feet or less and/or 80 percent or more of the lake is littoral). Lotus Lake is located within the North Central Hardwood forests region and, because it is deeper than 15 feet and less than 80 percent of the lake is littoral, it is a deep lake. The proposed 7050 standards for Lotus Lake are the criteria shown in Table 18.

Table 18 Proposed 7050 Standards Under Consideration for North Central Hardwood Forests (NCHF) Lakes, including Lotus Lake

Parameter	Criteria*
Total Phosphorus (µg/L)	< 40
Chlorophyll *a* (µg/L)	< 13
Secchi Disc (m)	> 1.5

*Lakes meeting the proposed criteria will not be listed on the 303(d) list.

The proposed changes to the 7050 Standards are expected to be finalized during 2005. Once finalized, the 7050 standards will be used to assess lakes to determine lake impairment. Lakes not meeting the standards will be placed on Minnesota's 303(d) Impaired Waters List (List). Lakes currently on the List must attain the water quality of the 7050 standards to be removed from the List.

Lotus Lake's historical water quality has generally failed to meet the proposed 7050 Standards (Standards). During the 1972 through 2000 monitoring period, the lake's water quality failed to meet the proposed Standards for total phosphorus, chlorophyll *a*, and Secchi disc at a frequency of 91, 100, and 91 percent, respectively.

Following implementation of the recommended lake improvement plan, Lotus Lake's water quality is expected to meet the proposed Standards (See Table 18) during all climatic conditions, currently and in the future (See Table 19). Hence, Lotus Lake is expected to be delisted from the 303(d) impaired waters list.

Table 19 Comparison of Proposed 7050 Standards for Lotus Lake With Expected Water Quality Following Implementation of Recommended Plan

Parameter	Proposed 7050 Standard Goal	Wet Year (41")	Model Calibration Year (34")	Average Year (27")	Dry Year (19")
Existing land Use					
Total Phosphorus (µg/L)	< 40	13	13	11	9
Chlorophyll *a* (µg/L)	<13	2.7	2.7	2.1	1.6
Secchi Disc (m)	> 1.5	4.3	4.6	5.0	5.9
Future Land Use					
Total Phosphorus (µg/L)	<40	16	13	11	10
Chlorophyll *a* (µg/L)	<13	3.7	2.7	2.1	1.9
Secchi Disc (m)	>1.5	3.6	4.3	5.0	5.4

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Appendix A

Water Quality and Biological Data

Appendix A-1

1999 Water Quality and Biological Data

Lotus Lake

Date	Max Depth (m)	Sample Depth (m)	Secchi Depth (m)	Chl. a (mg/cu.m)	Turbidity (NTU's)	D. O. (mg/L)	Temp (°C)	Sp. Cond. (µmho/cm @ 25°C)	Total P (mg/L)	Ortho P (mg/L)	Total N (mg/L)	pH (S.U.)
04/09/99	9.8	0-2	1.2	23.4	--	--	--	--	0.057	<0.003	1.47	8.3
		0.0		--	--	11.2	9.0	445	--	--	--	--
		1.0		--	--	11.2	9.0	445	--	--	--	--
		2.0		--	--	11.4	9.0	445	--	--	--	--
		3.0		--	--	11.5	8.5	450	0.053	--	--	8.3
		4.0		--	--	11.5	8.5	450	0.053	--	--	8.3
		5.0		--	--	11.4	8.5	450	0.062	--	--	8.3
		6.0		--	--	11.2	8.5	452	0.059	--	--	8.3
		7.0		--	--	11.2	8.5	452	0.057	--	--	8.3
		8.0		--	--	11.0	8.5	452	0.057	--	--	8.3
		9.3		--	--	10.0	8.5	452	0.053	--	--	8.3
05/10/99	9.8	0-2	2.9	5.2	2.3	--	--	--	0.031	0.005	1.50	8.1
		0.0		--	--	7.6	15.0	460	--	--	--	--
		1.0		--	--	7.6	15.0	468	--	--	--	--
		2.0		--	--	7.4	14.7	468	--	--	--	--
		3.0		--	--	7.3	14.6	469	0.031	--	--	8.1
		4.0		--	--	7.0	14.6	469	0.033	--	--	8.1
		5.0		--	--	7.1	14.5	470	0.031	--	--	8.1
		6.0		--	--	6.6	14.2	470	0.035	--	--	8.1
		7.0		--	--	2.2	11.2	471	0.033	--	--	8.1
		8.0		--	--	0.1	10	478	0.044	--	--	8.0
		9.0		--	--	0.1	9.6	490	0.095	--	--	7.8
		9.3		--	--	0.1	9.6	491	0.084	--	--	7.7
06/08/99	9.4	0-2	2.1	3.8	3.0	--	--	--	0.033	<0.002	1.62	8.3
		0.0		--	--	7.5	23.0	466	--	--	--	--
		1.0		--	--	7.5	23.1	466	--	--	--	--
		2.0		--	--	6.8	22.9	468	--	--	--	--
		3.0		--	--	6.1	21.5	466	0.040	--	--	8.3
		4.0		--	--	5.40	20.7	467	0.035	--	--	8.3
		5.0		--	--	1.60	18.0	468	0.044	--	--	8.3
		6.0		--	--	0.0	16.8	472	0.046	--	--	8.2
		7.0		--	--	0.0	15.8	478	0.040	--	--	7.8
		8.0		--	--	0.0	14.4	493	0.100	--	--	7.7
		9.0		--	--	0.0	12.5	515	0.297	--	--	7.6

Lotus Lake

Date	Max Depth (m)	Sample Depth (m)	Secchi Depth (m)	Chl. a (mg/cu.m)	Turbidity (NTU's)	D. O. (mg/L)	Temp (°C)	Sp. Cond. (µmho/cm @ 25°C)	Total P (mg/L)	Ortho P (mg/L)	Total N (mg/L)	pH (S.U.)
06/22/99	9.1	0-2	1.7	8.2	5.0	--	--	--	0.037	<0.002	0.93	8.4
		0.0		--	--	8.6	21.3	461	--	--	--	--
		1.0		--	--	8.6	21.2	461	--	--	--	--
		2.0		--	--	8.3	21.1	461	--	--	--	--
		3.0		--	--	7.6	21.0	462	0.037	--	--	8.3
		4.0		--	--	6.7	20.6	463	0.046	--	--	8.3
		5.0		--	--	3.7	20.1	465	0.037	--	--	8.2
		6.0		--	--	2.2	19.5	470	0.031	--	--	8.1
		7.0		--	--	0.0	15.5	490	0.053	--	--	7.9
		8.0		--	--	0.0	14.0	510	0.182	--	--	7.7
		8.6		--	--	0.0	13.3	518	0.392	--	--	7.5
07/06/99	9.5	0-2	1.4	10.4	5.2	--	--	--	0.048	0.002	0.93	8.4
		0.0		--	--	6.6	25.4	448	--	--	--	--
		1.0		--	--	6.6	25.5	448	--	--	--	--
		2.0		--	--	6.5	25.5	448	--	--	--	--
		3.0		--	--	6.4	25.5	448	0.054	--	--	8.3
		4.0		--	--	6.4	25.3	448	0.054	--	--	8.4
		5.0		--	--	0.0	22.1	455	0.046	--	--	8.4
		6.0		--	--	0.0	18.5	482	0.054	--	--	7.9
		7.0		--	--	0.0	16.0	506	0.115	--	--	7.8
		8.0		--	--	0.0	14.9	520	0.337	--	--	7.6
		9.0		--	--	0.0	13.7	538	0.648	--	--	7.4
07/19/99	9.0	0-2	0.3	43.2	11.0	--	--	--	0.074	0.002	1.25	8.2
		0.0		--	--	6.0	25.4	451	--	--	--	--
		1.0		--	--	5.8	25.5	452	--	--	--	--
		2.0		--	--	5.8	25.6	451	--	--	--	--
		3.0		--	--	5.2	25.6	452	0.072	--	--	8.3
		4.0		--	--	4.7	25.5	456	0.068	--	--	8.3
		5.0		--	--	0.1	23.7	458	0.061	--	--	8.3
		6.0		--	--	0.0	20.1	480	0.088	--	--	7.9
		7.0		--	--	0.0	16.2	518	0.217	--	--	7.5
		8.0		--	--	0.0	14.8	535	0.435	--	--	7.4
		8.5		--	--	0.0	14.2	544	0.858	--	--	7.1
08/09/99	9.1	0-2	0.7	48.2	12.0	--	--	--	0.081	<0.002	1.59	7.9
		0.0		--	--	4.6	24.5	442	--	--	--	--
		1.0		--	--	4.5	24.5	442	--	--	--	--
		2.0		--	--	4.0	24.5	442	--	--	--	--
		3.0		--	--	4.0	24.5	439	0.078	--	--	8.0
		4.0		--	--	4.6	24.4	437	0.085	--	--	8.0
		5.0		--	--	4.2	24.2	430	0.078	--	--	8.0
		6.0		--	--	0.1	21.9	487	0.081	--	--	7.8
		7.0		--	--	0.0	18.9	513	0.400	--	--	7.5
		8.0		--	--	0.0	15.8	558	0.656	--	--	7.6
		8.6		--	--	0.0	15.5	561	0.647	--	--	7.1

(shaded) TP value is the average of two analyses

Lotus Lake

Date	Max Depth (m)	Sample Depth (m)	Secchi Depth (m)	Chl. a (mg/cu.m)	Turbidity (NTU's)	D. O. (mg/L)	Temp (°C)	Sp. Cond. (µmho/cm @ 25°C)	Total P (mg/L)	Ortho P (mg/L)	Total N (mg/L)	pH (S.U.)
08/23/99	9.7	0-2	0.8	47.8	13.5	--	--	--	0.075	<0.002	1.55	8.0
		0.0		--	--	5.3	23.0	429	--	--	--	--
		1.0		--	--	5.0	23.0	429	--	--	--	--
		2.0		--	--	4.3	22.9	431	--	--	--	--
		3.0		--	--	3.8	22.8	432	0.065	--	--	8.0
		4.0		--	--	3.8	22.8	432	0.073	--	--	8.0
		5.0		--	--	3.7	22.8	432	0.065	--	--	7.9
		6.0		--	--	0.6	22.5	438	0.061	--	--	7.9
		7.0		--	--	0.0	20.5	485	0.086	--	--	7.8
		8.0		--	--	0.0	17.8	560	0.144	--	--	7.6
		9.0		--	--	0.0	15.0	611	0.747	--	--	7.2
09/07/99	9.1	0-2	0.7	43.2	15.0	--	--	--	0.068	<0.002	1.41	8.1
		0.0		--	--	5.4	22.2	426	--	--	--	--
		1.0		--	--	5.3	22.3	425	--	--	--	--
		2.0		--	--	5.4	22.3	425	--	--	--	--
		3.0		--	--	5.6	22.3	425	0.064	--	--	8.1
		4.0		--	--	5.5	22.2	425	0.061	--	--	8.1
		5.0		--	--	5.4	22.3	425	0.059	--	--	8.1
		6.0		--	--	5.2	22.1	425	0.064	--	--	8.1
		7.0		--	--	0.1	20.7	500	0.064	--	--	8.0
		8.0		--	--	0.0	18.0	574	0.156	--	--	7.6
10/11/99	9.1	0-2	2.0	2.7	6.0	--	--	--	0.042	0.002	1.27	8.1
		0.0		--	--	7.1	14.1	431	--	--	--	--
		1.0		--	--	7.0	14.0	431	--	--	--	--
		2.0		--	--	6.9	14	432	--	--	--	--
		3.0		--	--	6.8	13.9	432	0.043	--	--	8.3
		4.0		--	--	6.8	13.8	432	0.038	--	--	8.2
		5.0		--	--	6.8	13.8	432	0.042	--	--	8.2
		6.0		--	--	6.7	13.8	432	0.043	--	--	8.1
		7.0		--	--	6.4	13.8	433	0.042	--	--	8.1
		8.0		--	--	6.3	13.8	433	0.040	--	--	8.1
		8.5		--	--	6.0	13.7	434	0.041	--	--	8.1

1999 PHYTOPLANKTON DATA SUMMARY (UNITS/ML)
LOTUS LAKE
SAMPLE: 0-2 METERS (INT. TUBE)
STANDARD INVERTED MICROSCOPE ANALYSIS METHOD

DIVISION	TAXON	4/9/99 units/mL	5/10/99 units/mL	6/8/99 units/mL	6/22/99 units/mL	7/6/99 units/mL	7/19/999 units/mL	8/9/99 units/mL	8/23/99 units/mL	9/7/99 units/mL	10/11/99 units/mL
CHLOROPHYTA (GREEN ALGAE)	*Ankistrodesmus falcatus*	1,353	21	0	0	0	0	0	39	0	0
	Ankistrodesmus Brauni	0	0	0	0	0	0	0	0	0	39
	Chlamydomonas globosa	27,914	105	1,913	703	3,514	1,796	273	664	1,640	1,210
	Closterium sp.	0	0	0	273	39	195	39	78	39	0
	Coelastrum microporum	0	21	39	0	0	0	0	0	39	0
	Oocystis parva	0	0	508	937	117	78	117	78	78	39
	Quadrigula sp.	0	0	39	156	39	0	0	0	0	0
	Pediastrum duplex v. clathratum	0	0	0	0	0	39	39	0	0	0
	Rhizoclonium hieroglyphicum	0	0	0	0	39	39	78	78	0	0
	Scenedesmus sp.	0	0	0	0	0	39	0	0	0	0
	Schroederia Judayi	592	105	2,303	468	312	39	39	156	39	39
	Schroederia sp.	423	0	0	0	0	0	0	0	0	0
	Selenastrum minutum	0	21	0	0	0	0	0	0	0	0
	Sphaerocystis Schroeteri (Colony)	0	21	0	156	0	0	0	0	0	0
	Staurastrum sp.	0	21	0	0	0	39	0	39	0	0
	Unidentified Green Filament	0	0	0	0	0	0	0	0	0	39
	CHLOROPHYTA TOTAL	30,282	316	4,802	2,694	4,060	2,264	586	1,132	1,835	1,366

1999 PHYTOPLANKTON DATA SUMMARY (UNITS/ML)
LOTUS LAKE
SAMPLE: 0-2 METERS (INT. TUBE)
STANDARD INVERTED MICROSCOPE ANALYSIS METHOD

DIVISION	TAXON	4/9/99 units/mL	5/10/99 units/mL	6/8/99 units/mL	6/22/99 units/mL	7/6/99 units/mL	7/19/999 units/mL	8/9/99 units/mL	8/23/99 units/mL	9/7/99 units/mL	10/11/99 units/mL
CHRYSOPHYTA (GOLDEN-BROWN ALGAE)	CHRYSOPHYTA TOTAL	0	0	0	0	0	0	0	0	0	0
CYANOPHYTA (BLUE-GREEN ALGAE)	*Anabaena affinis*	0	0	0	0	0	0	156	976	468	78
	Anabaena flos-aquae	0	0	0	0	0	0	312	39	0	0
	Anabaena spiroides v. crassa	0	0	0	39	0	0	0	0	0	0
	Anabaenopsis raciborski	0	0	0	0	117	2,342	13,469	16,280	17,997	351
	Aphanizomenon flos-aquae	423	0	156	351	2,030	12,180	2,577	1,952	2,225	429
	Coelosphaerium Naegelianum	0	0	0	156	586	234	78	0	0	0
	Merismopedia tenuissima	0	21	0	78	6,324	976	234	0	39	0
	Microcystis aeruginosa	0	0	0	351	195	39	39	39	39	0
	Microcystis incerta	0	0	0	39	0	0	234	429	0	156
	Oscillatoria Agardhii	0	0	0	0	39	0	547	273	3,553	0
	Oscillatoria limnetica	0	0	0	0	0	39	1,718	547	2,030	0
	CYANOPHYTA TOTAL	423	21	156	1,015	9,291	15,811	19,208	19,559	25,883	937

1999 PHYTOPLANKTON DATA SUMMARY (UNITS/ML)
LOTUS LAKE
SAMPLE: 0-2 METERS (INT. TUBE)
STANDARD INVERTED MICROSCOPE ANALYSIS METHOD

DIVISION	TAXON	4/9/99 units/mL	5/10/99 units/mL	6/8/99 units/mL	6/22/99 units/mL	7/6/99 units/mL	7/19/999 units/mL	8/9/99 units/mL	8/23/99 units/mL	9/7/99 units/mL	10/11/99 units/mL
BACILLARIOPHYTA (DIATOMS)	*Asterionella formosa*	0	337	0	39	0	0	0	0	0	39
	Cyclotella glomerata	0	0	0	0	39	0	0	0	0	0
	Fragilaria capucina	0	21	0	39	0	0	0	0	0	78
	Fragilaria crotonensis	0	0	0	0	39	39	0	0	0	0
	Navicula sp.	85	0	0	0	156	0	0	0	0	0
	Stephanodiscus Hantzschii	7,444	0	0	0	0	0	0	0	0	0
	Stephanodiscus sp.	0	0	0	0	0	0	0	0	0	117
	Synedra acus	0	21	0	0	0	0	78	0	0	0
	Synedra ulna	2,876	105	0	0	0	39	0	0	0	0
	BACILLARIOPHYTA TOTAL	10,404	485	0	78	234	78	78	0	0	234
CRYPTOPHYTA (CRYPTOMONADS)	*Cryptomonas erosa*	1,100	190	1,835	1,835	8,316	1,132	78	117	390	5,700
	CRYPTOPHYTA TOTAL	1,100	190	1,835	1,835	8,316	1,132	78	117	390	5,700
EUGLENOPHYTA (EUGLENOIDS)	CRYPTOPHYTA TOTAL	0	0	0	0	0	0	0	0	0	0
PYRRHOPHYTA (DINOFLAGELLATES)	*Ceratium hirundinella*	0	0	0	0	312	1,015	1,327	820	390	547
	Peridinium cinctum	423	0	0	0	0	0	0	0	0	0
	PYRROPHYTA TOTAL	423	0	0	0	312	1,015	1,327	820	390	547

1999 PHYTOPLANKTON DATA SUMMARY (UNITS/ML)
LOTUS LAKE
SAMPLE: 0-2 METERS (INT. TUBE)
STANDARD INVERTED MICROSCOPE ANALYSIS METHOD

DIVISION	TAXON	4/9/99 units/mL	5/10/99 units/mL	6/8/99 units/mL	6/22/99 units/mL	7/6/99 units/mL	7/19/999 units/mL	8/9/99 units/mL	8/23/99 units/mL	9/7/99 units/mL	10/11/99 units/mL
	TOTALS	42,632	1,011	6,793	5,622	22,214	20,301	21,277	21,628	28,499	8,784

LAKE: **LOTUS**

DIVISION	TAXON	SAMPLE DATE 4/9/1999	5/10/1999	6/8/1999	6/2/1999	7/6/1999	7/19/1999	8/9/1999	8/23/1999	9/7/1999	10/11/1999
CLADOCERA											
	Daphnia galeata mendotae	86,362	243,362	146,076	53,884	6,466	39,972	50,823	30,861	2,278	4,066
	Daphnia ambigua/parvula	0	0	0	0	0	9,405	0	0	0	0
	Daphnia retrocurva	0	0	0	0	4,311	0	38,625	92,583	13,667	24,395
	Bosmina sp.	10,532	27,040	74,067	47,418	21,554	35,270	12,197	8,817	13,667	56,922
	Chydorus sp.	4,213	4,507	0	0	4,311	11,757	6,099	2,204	4,556	4,066
	Diaphanosoma sp.	0	0	0	0	6,466	77,594	225,653	33,065	11,389	0
	Ceriodaphnia sp.	0	0	0	0	0	0	0	2,204	0	0
	Leptodora kindtii	0	0	0	0	0	0	0	2,204	0	0
	SUBTOTAL	101,107	274,908	220,142	101,303	43,108	173,998	333,398	171,940	45,557	89,448
COPEPODA											
	Nauplii	928,918	324,482	251,003	372,880	64,661	129,323	182,962	70,540	127,559	75,218
	Cyclops sp.	383,363	283,922	16,459	23,709	10,777	16,459	4,066	2,204	6,834	50,823
	Mesocyclops sp.	0	6,760	10,287	12,932	15,088	16,459	34,559	50,700	22,778	30,494
	Diaptomus sp.	8,426	2,253	26,746	43,108	86,215	51,729	44,724	8,817	11,389	8,132
	SUBTOTAL	1,320,707	617,417	304,496	452,629	176,741	213,970	266,311	132,262	168,560	164,666
ROTIFERA											
	Kellicottia sp.	42,128	101,401	14,402	28,020	4,311	28,216	10,165	22,044	216,395	20,329
	Conochilus sp.	4,213	0	0	19,398	49,574	56,432	0	0	0	0
	Keratella cochlearis	198,001	736,845	82,296	288,820	165,964	489,074	479,767	152,101	250,562	1,172,990
	Keratella quadrata	0	0	0	0	0	0	0	0	0	0
	Polyarthra vulgaris	204,320	6,760	2,057	0	0	0	85,382	0	4,556	8,132
	Ascomorpha sp.	0	0	0	8,622	15,088	157,538	89,448	52,905	45,557	42,691
	Brachionus sp.	0	0	0	0	0	0	0	0	2,278	0
	Filinia longiseta	18,958	78,867	4,115	0	0	2,351	22,362	0	0	0
	Aplanchna sp.	0	0	6,172	0	0	0	6,099	0	0	0
	Trichocerca sp.	0	0	8,230	0	4,311	2,351	34,559	4,409	18,223	0
	SUBTOTAL	467,619	923,873	117,272	344,860	239,247	735,963	727,782	231,458	537,570	1,244,142
	TOTAL	1,889,432	1,816,198	641,910	898,792	459,095	1,123,931	1,327,491	535,660	751,687	1,498,256

Appendix A-2

1994 Water Quality and Biological Data

Lotus Lake Water Quality

Date	Max. Depth (meters)	Secchi Disc (meters)	Depth (meters)	Chl a (ug/L)	Temp. (C)	D.O. (mg/l)	Specific Cond. (umho/cm @ 25 degrees C)	Total P (mg P/L)	Ortho P (mg P/L)	Total N (mg N/L)	TN:TP	pH (S. U.)
04/14/94	9.4	1.3	0-2	16.2	--	--	--	0.070	<0.010	0.97	14	8.0
			0.0	--	8.5	15.3*	400	--	--	--	--	--
			1.0	--	8.0	16.5*	398	--	--	--	--	--
			2.0	--	7.5	16.5*	403	--	--	--	--	--
			3.0	--	7.5	16.8*	403	--	--	--	--	--
			4.0	--	7.0	16.0*	409	--	--	--	--	--
			4.4	--	--	--	--	0.077	--	--	--	--
			5.0	--	7.0	16.0*	401	--	--	--	--	--
			6.0	--	6.5	15.0*	407	--	--	--	--	--
			7.0	--	6.0	14.4*	405	--	--	--	--	--
			8.0	--	6.0	13.4*	405	--	--	--	--	--
			8.9	--	6.0	12.9*	405	0.363	--	--	--	7.8
06/22/94	8.8	1.6	0-2	16.7	--	--	--	0.049	0.021	1.47	30	8.3
			0.0	--	26.5	10.4	414	--	--	--	--	--
			1.0	--	26.0	10.3	417	--	--	--	--	--
			2.0	--	26.0	9.1	417	--	--	--	--	--
			3.0	--	25.0	7.3	425	0.029	--	--	--	--
			4.0	--	24.0	2.3	433	--	--	--	--	--
			5.0	--	22.0	0.5	440	--	--	--	--	--
			6.0	--	20.0	0.2	446	--	--	--	--	--
			7.0	--	16.5	0.2	452	--	--	--	--	--
			8.0	--	14.5	0.2	453	--	--	--	--	--
			8.3	--	14.0	0.2	471	0.697	--	--	--	7.2

[shaded] denotes conditions unfavorable for the survival of gamefish

* Values were greater than saturation values.

Lotus Lake Water Quality

Date	Max. Depth (meters)	Secchi Disc (meters)	Depth (meters)	Chl a (ug/L)	Temp. (C)	D.O. (mg/l)	Specific Cond. (umho/cm @ 25 degrees C)	Total P (mg P/L)	Ortho P (mg P/L)	Total N (mg N/L)	TN:TP	pH (S. U.)
07/15/94	8.8	1.6	0-2	24.7	--	--	--	0.020	<0.010	1.68	84	8.2
			0.0	--	24.5	9.5*	419	--	--	--	--	--
			1.0	--	24.5	9.5*	419	--	--	--	--	--
			2.0	--	24.0	8.1	423	--	--	--	--	--
			3.0	--	23.5	6.4	422	0.022	--	--	--	--
			4.0	--	23.0	5.8	426	--	--	--	--	--
			5.0	--	23.0	5.2	426	--	--	--	--	--
			6.0	--	22.0	0.4	435	--	--	--	--	--
			7.0	--	16.0	0.4	494	--	--	--	--	--
			7.5	--	--	--	--	0.551	--	--	--	--
			8.0	--	15.0	0.4	508	--				
			8.3	--	14.5	0.4	515	0.903	--	--	--	7.2
08/11/94	9.1	0.8	0-2	40.1	--	--	--	0.063	<0.010	1.18	19	8.2
			0.0	--	22.0	7.5	402	--	--	--	--	--
			1.0	--	22.0	7.0	400	--	--	--	--	--
			2.0	--	21.0	5.3	408	--	--	--	--	--
			3.0	--	21.0	5.2	408	0.065	--	--	--	--
			4.0	--	21.0	4.8	408	--	--	--	--	--
			5.0	--	21.0	4.4	410	--	--	--	--	--
			6.0	--	21.0	4.3	410	--	--	--	--	--
			7.0	--	21.0	4.3	410	--	--	--	--	--
			7.5	--	--	--	--	0.079	--	--	--	--
			8.0	--	20.0	0.1	427	--	--	--	--	--
			8.6	--	17.0	0.1	522	1.335	--	--	--	7.0

(shaded) denotes conditions unfavorable for the survival of gamefish

* Values were greater than saturation values.

Lotus Lake Water Quality

Date	Max. Depth (meters)	Secchi Disc (meters)	Depth (meters)	Chl a (ug/L)	Temp. (C)	D.O. (mg/l)	Specific Cond. (umho/cm @ 25 degrees C)	Total P (mg P/L)	Ortho P (mg P/L)	Total N (mg N/L)	TN:TP	pH (S. U.)
08/26/94	8.8	0.5	0-2	57.6	--	--	--	0.070	<0.010	1.39	20	7.2
			0.0	--	23.0	7.8	385	--	--	--	--	--
			1.0	--	22.5	7.5	389	--	--	--	--	--
			2.0	--	22.5	6.2	389	--	--	--	--	--
			3.0	--	22.5	6.2	389		--	--	--	--
			4.0	--	22.0	6.2	392	--	--	--	--	--
			4.5	--	--	--	--	0.058	--	--	--	--
			5.0	--	22.0	5.6	397	--	--	--	--	--
			6.0	--	21.0	0.5	405	--	--	--	--	--
			7.0	--	20.5	0.2	425	--	--	--	--	--
			8.0	--	20.0	0.2	435	--	--	--	--	--
			8.3	--	20.0	0.2	435	0.227	--	--	--	7.0
09/08/94	9.1	0.6	0-2	66.9	--	--	--	0.063	<0.010	1.47	23	8.5
			0.0	--	23.5	15.2*	381	--	--	--	--	--
			1.0	--	22.0	15.2*	387	--	--	--	--	--
			2.0	--	20.5	7.5	398	--	--	--	--	--
			3.0	--	20.0	4.2	401	--	--	--	--	--
			4.0	--	20.0	3.4	401	--	--	--	--	--
			4.5	--	--	--	--	0.060	--	--	--	--
			5.0	--	19.5	3.2	405	--	--	--	--	--
			6.0	--	19.5	2.8	405	--	--	--	--	--
			7.0	--	19.5	2.8	405	--	--	--	--	--
			7.5	--	--	--	--	--	--	--	--	--
			8.0	--	19.5	0.6	405	--	--	--	--	--
			8.6	--	19.5	0.5	411	0.236	--	--	--	7.4

[shaded box] denotes conditions unfavorable for the survival of gamefish

PHYTOPLANKTON UNIT (CLUMP) COUNT

RILEY-PURGATORY-BLUFF CREEK WATERSHED DISTRICT

LAKE: LAKE LOTUS

SAMPLE DEPTH: 0-2 METERS

SAMPLE DATE: 06/22/94

DIVISION	TAXON	UNITS/ML
CHLOROPHYTA (GREEN ALGAE)	*Oocystis parva*	1,601
	Chlamydomonas globosa	468
	Sphaerocystis Schroeteri	195
	Schroederia Judayi	156
	Closterium sp.	78
	Coelastrum microporum	78
	Tetraedron minimum	78
	Crucigenia quadrata	39
	Lagerheimia sp.	39
	Scenedesmus sp.	39
CHRYSOPHYTA (GOLDEN-BROWN ALGAE)	--	--
CYANOPHYTA (BLUE-GREEN ALGAE)	*Merismopedia tenuissima*	1,015
	Coelosphaerium Naegelianum	312
	Microcystis aeruginosa	156
	Aphanocapsa delicatissima	78
	Microcystis incerta	78
BACILLARIOPHYTA (DIATOMS)	*Navicula sp.*	78
CRYPTOPHYTA (CRYPTOMONADS)	*Cryptomonas sp.*	1,327
EUGLENOPHYTA (EUGLENOIDS)	--	--
PYRROPHYTA (DINOFLAGELLATES)	*Ceratium hirundinella*	39
	TOTAL	5,856

PHYTOPLANKTON UNIT (CLUMP) COUNT

RILEY-PURGATORY-BLUFF CREEK WATERSHED DISTRICT

LAKE: LOTUS LAKE

SAMPLE DEPTH: 0-2 METERS

SAMPLE DATE: 07/15/94

DIVISION	TAXON	UNITS/ML
CHLOROPHYTA (GREEN ALGAE)	*Schroederia Judayi*	1,132
	Chlamydomonas globosa	468
	Closterium sp.	195
	Coelastrum microporum	195
	Oocystis parva	156
	Elakatothrix sp.	117
	Selenastrum minutum	117
	Sphaerocystis Schroeteri	117
	Ankistrodesmus Brauni	39
	Crucigenia quadrata	39
	Scenedesmus sp.	39
CHRYSOPHYTA (GOLDEN-BROWN ALGAE)	*Dinobryon sociale*	39
CYANOPHYTA (BLUE-GREEN ALGAE)	*Aphanizomenon flos-aquae*	742
	Anabaena affinis	312
	Merismopedia tenuissima	195
	Microcystis aeruginosa	156
	Coelosphaerium Naegelianum	117
	Anabaena spiroides v. crassa	78
	Anabaena flos-aquae	39
BACILLARIOPHYTA (DIATOMS)	*Synedra ulna*	39
CRYPTOPHYTA (CRYPTOMONADS)	*Cryptomonas sp.*	2,616
EUGLENOPHYTA (EUGLENOIDS)	--	--
PYRROPHYTA (DINOFLAGELLATES)	--	--
	TOTAL	6,949

PHYTOPLANKTON UNIT (CLUMP) COUNT

RILEY-PURGATORY-BLUFF CREEK WATERSHED DISTRICT

LAKE: LOTUS LAKE

SAMPLE DEPTH: 0-2 METERS

SAMPLE DATE: 08/11/94

DIVISION	TAXON	UNITS/ML
CHLOROPHYTA (GREEN ALGAE)	*Chlamydomonas globosa*	1,175
	Coelastrum microporum	448
	Oocystis parva	280
	Closterium sp.	112
	Pediastrum simplex	56
CHRYSOPHYTA (GOLDEN-BROWN ALGAE)	--	--
CYANOPHYTA (BLUE-GREEN ALGAE)	*Aphanizomenon flos-aquae*	21,260
	Anabaena affinis	2,462
	Merismopedia tenuissima	448
	Microcystis aeruginosa	392
	Coelosphaerium Naegelianum	336
	Oscillatoria limnetica	224
	Anabaena flos-aquae	56
	Microcystis incerta	56
BACILLARIOPHYTA (DIATOMS)	*Melosira sp.*	112
	Navicula sp.	56
	Synedra ulna	56
CRYPTOPHYTA (CRYPTOMONADS)	*Cryptomonas sp.*	1,846
EUGLENOPHYTA (EUGLENOIDS)	*Phacus sp.*	56
PYRROPHYTA (DINOFLAGELLATES)	--	--
	TOTAL	29,428

PHYTOPLANKTON UNIT (CLUMP) COUNT

RILEY-PURGATORY-BLUFF CREEK WATERSHED DISTRICT

LAKE: LOTUS LAKE

SAMPLE DEPTH: 0-2 METERS

SAMPLE DATE: 08/26/94

DIVISION	TAXON	UNITS/ML
CHLOROPHYTA (GREEN ALGAE)	*Chlamydomonas globosa*	3,638
	Closterium sp.	171
	Oocystis parva	171
	Scenedesmus quadricauda	171
	Selenastrum sp.	171
	Schroederia Judayi	114
	Crucigenia quadrata	57
	Dictyosphaerium sp.	57
CHRYSOPHYTA (GOLDEN-BROWN ALGAE)	*Dinobryon sociale*	57
CYANOPHYTA (BLUE-GREEN ALGAE)	*Aphanizomenon flos-aquae*	15,347
	Anabaena affinis	3,865
	Oscillatoria Agardhii	3,183
	Oscillatoria limnetica	1,307
	Coelosphaerium Naegelianum	568
	Anabaena flos-aquae	171
	Merismopedia tenuissima	114
	Microcystis incerta	114
BACILLARIOPHYTA (DIATOMS)	*Navicula sp.*	57
CRYPTOPHYTA (CRYPTOMONADS)	*Cryptomonas sp.*	1,705
EUGLENOPHYTA (EUGLENOIDS)	--	--
PYRROPHYTA (DINOFLAGELLATES)	*Ceratium hirundinella*	57
	TOTAL	31,093

PHYTOPLANKTON UNIT (CLUMP) COUNT

RILEY-PURGATORY-BLUFF CREEK WATERSHED DISTRICT

LAKE: LOTUS LAKE

SAMPLE DEPTH: 0-2 METERS

SAMPLE DATE: 09/08/94

DIVISION	TAXON	UNITS/ML
CHLOROPHYTA (GREEN ALGAE)	*Chlamydomonas globosa*	1,236
	Closterium sp.	88
	Coelastrum microporum	88
	Oocystis parva	88
	Schroederia Judayi	88
	Scenedesmus sp.	44
CHRYSOPHYTA (GOLDEN-BROWN ALGAE)	--	--
CYANOPHYTA (BLUE-GREEN ALGAE)	*Anabaena affinis*	6,576
	Aphanizomenon flos-aquae	4,899
	Oscillatoria Agardhii	2,560
	Coelosphaerium Naegelianum	662
	Oscillatoria limnetica	485
	Anabaena flos-aquae	177
BACILLARIOPHYTA (DIATOMS)	*Melosira sp.*	88
	Stephanodiscus sp.	44
CRYPTOPHYTA (CRYPTOMONADS)	*Cryptomonas sp.*	4,987
EUGLENOPHYTA (EUGLENOIDS)	--	--
PYRROPHYTA (DINOFLAGELLATES)	*Ceratium hirundinella*	177
	TOTAL	22,287

ZOOPLANKTON COUNT
VERTICAL TOW (BOTTOM TO SURFACE)

Lake: **Lotus**
Sample Date: **6/22/94**

Division	Taxon	#/M2	Avg Body Length (mm)
Cladocera	*Daphnia retrocurva*	36,429	0.74
	Daphnia galeata mendotae	68,304	0.76
	Bosmina longirostris	22,768	0.39
	Diaphanosoma sp.	40,982	0.65
	Chydorus sphaericus	4,554	0.21
	Ceriodaphnia sp.	4,554	0.34
Copepoda	*Nauplii*	95,626	--
	Cyclops sp.	18,214	--
	Mesocyclops edax	13,661	--
	Diaptomus sp.	154,822	--
Rotifera	*Polyarthra vulgaris*	100,179	--
	Keratella cochlearis	578,307	--
	Conochilus sp.		
	Ascomorpha sp.	27,078	--
	Kellicottia longispina	42,552	--
	Total:	1,208,030	

ZOOPLANKTON COUNT
VERTICAL TOW (BOTTOM TO SURFACE)

Lake: **Lotus**
Sample Date: **7/15/94**

Division	Taxon	#/M2	Avg Body Length (mm)
Cladocera	*Daphnia galeata mendotae*	58,025	0.84
	Daphnia retrocurva	54,157	0.75
	Bosmina longirostris	317,205	0.43
	Diaphanosoma sp.	69,630	0.90
	Chydorus sphaericus	96,709	0.25
	Ceriodaphnia sp.		
Copepoda	*Nauplii*	313,336	--
	Cyclops sp.	7,737	--
	Mesocyclops edax	19,342	--
	Diaptomus sp.	108,314	--
	Tropocyclops sp.		
Rotifera	*Polyarthra vulgaris*	23,210	--
	Keratella cochlearis	143,129	--
	Conochilus sp.	549,306	--
	Filinia longiseta	3,979	--
	Ascomorpha sp.	27,078	--
	Kellicottia longispina	42,552	--
	Total:	1,833,708	

ZOOPLANKTON COUNT
VERTICAL TOW (BOTTOM TO SURFACE)

Lake: **Lotus**
Sample Date: **8/11/94**

Division	Taxon	#/M2	Avg Body Length (mm)
Cladocera	*Daphnia retrocurva*	198,944	0.81
	Daphnia galeata mendotae	39,789	0.96
	Bosmina longirostris	11,937	0.37
	Diaphanosoma sp.	55,704	0.62
	Chydorus sphaericus	119,366	0.27
	Leptodora kindtii	3,979	--
	Nauplii	274,542	--
Copepoda	*Cyclops sp.*	35,810	--
	Mesocyclops edax	67,641	--
	Diaptomus sp.	95,493	--
	Polyarthra vulgaris	3,979	--
Rotifera	*Keratella cochlearis*	417,782	--
	Conochilus sp.	3,979	--
	Ascomorpha sp.	206,901	--
	Kellicottia longispina	262,606	--
	Filinia longiseta	123,345	--
	Total:	1,921,796	

ZOOPLANKTON COUNT
VERTICAL TOW (BOTTOM TO SURFACE)

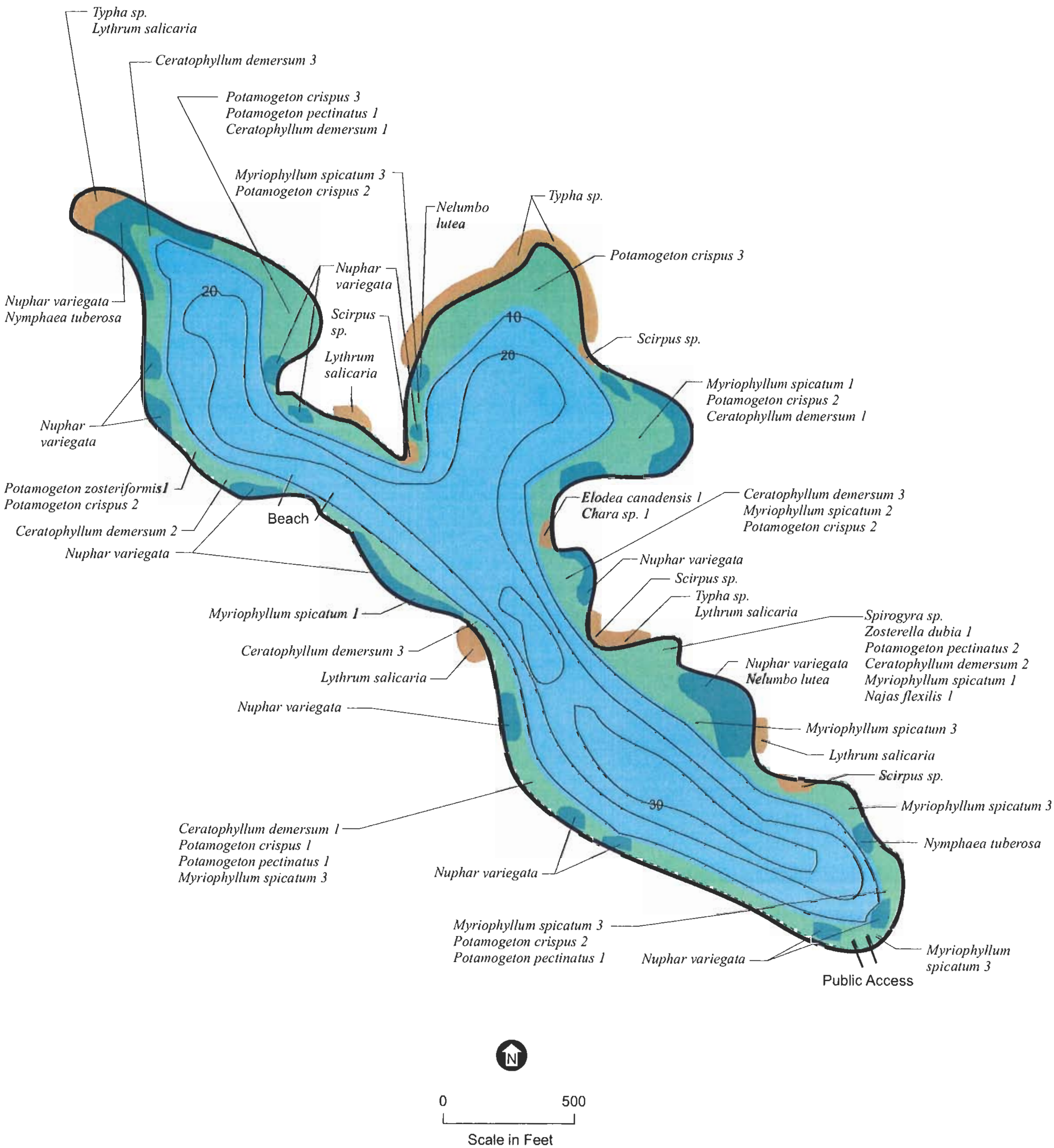
Lake: **Lotus**
Sample Date: **9/8/94**

Division	Taxon	#/M2	Avg Body Length (mm)
Cladocera	*Daphnia retrocurva*	115,741	0.86
	Bosmina longirostris	16,534	0.45
	Diaphanosoma sp.	74,405	0.87
	Chydorus sphaericus	8,267	--
	Ceriodaphnia sp.	4,134	0.52
Copepoda	*Nauplii*	347,223	--
	Cyclops sp.	41,336	--
	Mesocyclops edax	8,267	--
	Diaptomus sp.	128,142	--
	Tropocyclops sp.	16,534	--
Rotifera	*Polyarthra vulgaris*	8,267	--
	Keratella cochlearis	194,280	--
	Conochilus sp.	33,069	--
	Ascomorpha sp.	20,668	--
	Kellicottia longispina	95,073	--
	Total:	1,111,940	

ZOOPLANKTON COUNT
VERTICAL TOW (BOTTOM TO SURFACE)

Lake: **Lotus**
Sample Date: **8/26/94**

Division	Taxon	#/M2	Avg Body Length (mm)
Cladocera	*Daphnia retrocurva*	4,134	0.69
	Daphnia galeata mendotae	115,741	0.92
	Bosmina longirostris	12,401	0.38
	Diaphanosoma sp.	45,470	0.79
	Chydorus sphaericus	86,806	0.26
	Leptodora kindtii	3,979	--
	Nauplii	177,745	--
Copepoda	*Cyclops sp.*	8,267	--
	Mesocyclops edax	70,271	--
	Diaptomus sp.	74,405	--
	Polyarthra vulgaris		
Rotifera	*Keratella cochlearis*	326,555	--
	Conochilus sp.	12,401	--
	Ascomorpha sp.	8,267	--
	Kellicottia longispina	16,534	--
	Filinia longiseta	57,871	--
	Total:	1,020,846	

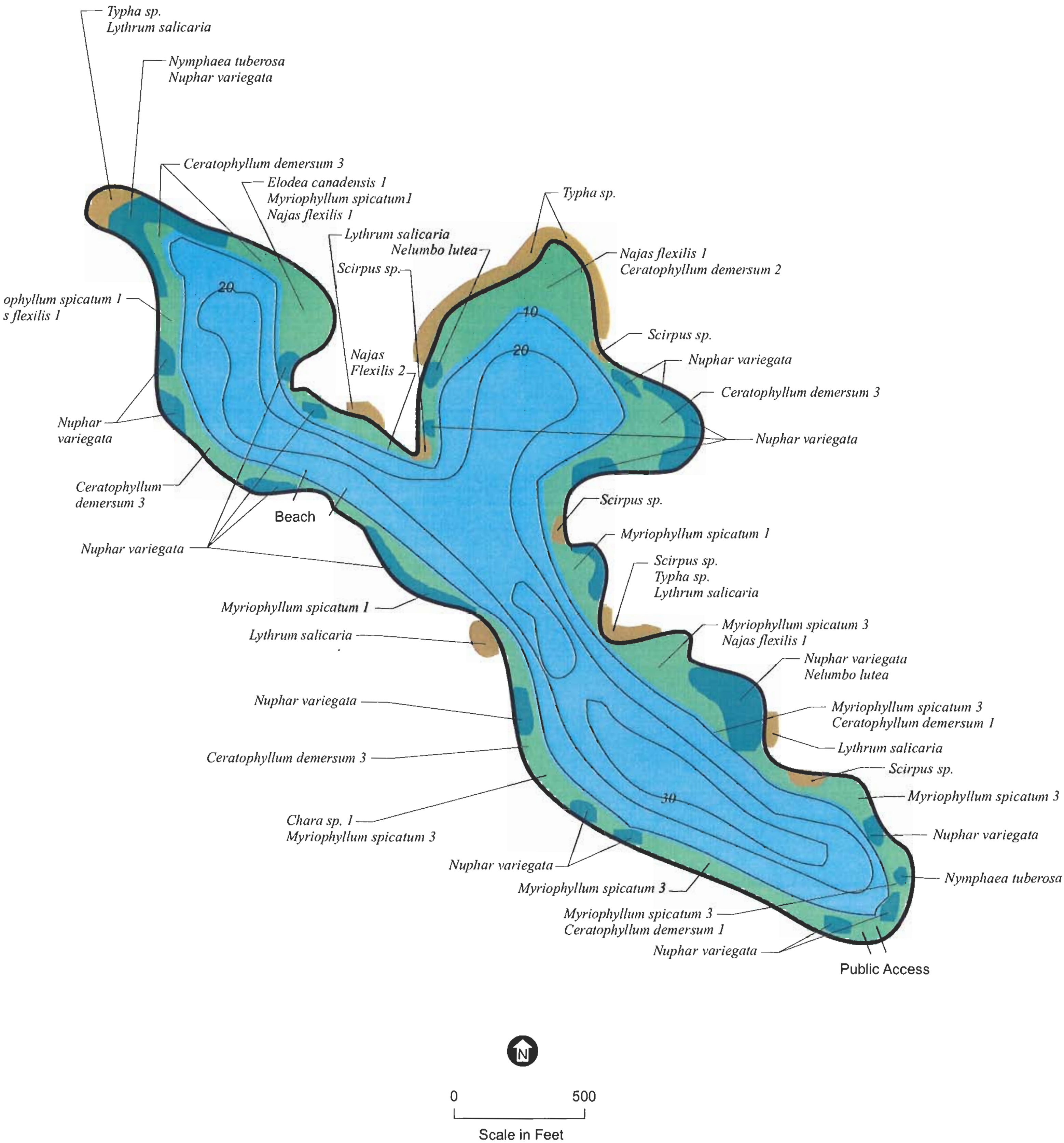


LOTUS LAKE
MACROPHYTE SURVEY
JUNE 22, 1994

- No Macrophytes Found In Water > 8.0'.
- Macrophyte Densities Estimated As Follows: 1 = light; 2 = moderate; 3 = heavy

	Common Name	Scientific Name
Submerged Aquatic Plants:	Eurasian watermilfoil	*Myriophyllum spicatum*
	Coontail	*Ceratophyllum demersum*
	Muskgrass	*Chara sp.*
	Bushy pondweed and naiad	*Najas flexilis*
	Elodea	*Elodea canadensis*
Floating Leaf Plants:	Yellow waterlily	*Nuphar variegata*
	White waterlily	*Nymphaea tuberosa*
	Lotus	*Nelumbo lutea*
Emergent Plants:	Bulrush	*Scirpus sp.*
	Cattail	*Typha sp.*
	Purple loosestrife	*Lythrum salicaria*
No Aquatic Vegetation Found:		

P:23\271053\LakeMacrophyteMaps\Lotus\1994\AUGUST1994.CDR RLG 05-27-04



LOTUS LAKE
MACROPHYTE SURVEY
AUGUST 26, 1994

Appendix B

Lake Modeling

B-1 Modeling Approach

The purpose of developing a watershed and in-lake model for Lotus Lake was to determine how different phosphorus sources contribute to the observed levels of phosphorus in the lake. Modeling was performed for a range of climatic conditions (dry, average, model calibration and wet years). The in-lake model was calibrated using lake monitoring data from 1999.

The in-lake model was then run for a wet year (1983), an average year (1995), and a dry year (1988) to determine the expected average summer total phosphorus concentration for years with wet, average, and dry precipitation levels.

One of the first steps in developing the in-lake model was the determination of water and phosphorus loads from different potential sources. The three phosphorus sources evaluated in this modeling study include: the Lotus Lake watershed, phosphorus release and migration from sediment, and atmospheric deposition.

The in-lake model was run under varying climatic conditions (dry, average, model calibration, and wet year) to determine expected average summer phosphorus levels under a range of precipitation conditions. The model was also run under different management approaches to assess their benefits. From the predicted total phosphorus levels, average expected summer chlorophyll concentration and Secchi disc transparency were predicted from a relationship between total phosphorus and chlorophyll concentration and from a relationship between total phosphorus and Secchi disc transparency (see Figure 4 of this report). Data used to develop these relationships were from Minnesota Lakes. The relationships were developed by the MPCA (Heiskary et al., 1990).

B-2. Watershed Modeling

Phosphorus loading from the Lotus Lake watershed was determined using the P8 model (IEP, Inc. 1990). Water and phosphorus loading were estimated using input from land use maps, soils maps, aerial photos with elevation contours, and storm sewer maps. Phosphorus removal by detention basins was also calculated with the P8 model. Daily phosphorus and water loading outputs from this model were used as inputs to an in-lake model.

An atmospheric wet and dry deposition rate of 0.56 kg/ha/yr. (Tetra Tech. 1982) was applied to the surface area of Lotus Lake to determine annual phosphorus loading. An annual total phosphorus load of 120 pounds from atmospheric deposition was estimated for Lotus Lake.

B-3 Lake Modeling

The first step in lake modeling was the identification and evaluation of different phosphorus sources. Both external phosphorus sources and internal phosphorus sources were considered for this model. Sediment cores were collected in 2003 and analyzed for total and potentially releasable (mobile) phosphorus. Results of the sediment analysis indicated that sediment was a potentially significant source of phosphorus loading to Lotus Lake (see Figure 18 of this report). Because of the significant increases in phosphorus that are observed in the Lotus Lake water column from June through mid-September, and the fact that this increase was not associated with stormwater inputs, internal phosphorus loading was identified early in this study as a significant source of phosphorus loading (see Figure B-1).

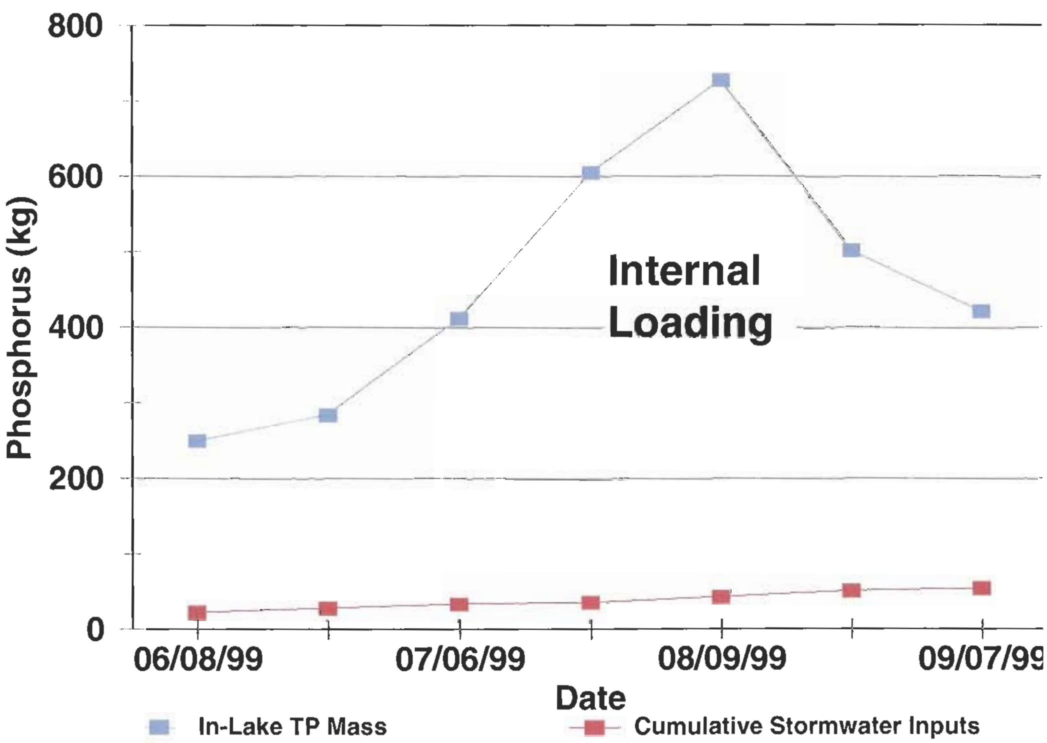


Figure B-1 In-Lake Phosphorus Mass Compared to Cumulative Stormwater Inputs (Includes Watershed Inputs and Atmospheric Deposition)

B-3.1 Sediment

Total phosphorus monitoring data for Lotus Lake (see Figure 5 of this report) shows that the concentration of phosphorus in the water column can increase significantly during the summer period. It appears that the phosphorus release from the lake sediments is contributing to observed phosphorus levels. Lotus Lake sediment is relatively high in phosphorus that can release into the lake column (see Figure 18 of this report). From the sediment phosphorus data it was estimated that the phosphorus release rate is 4.7 mg per square meter per day (Pilgrim, 2002). Only a portion of the phosphorus released from the sediments is entrained in the lake's surface waters. An estimated 10 percent of the phosphorus released from the sediments during the summer and 1 percent of the phosphorus released from the sediments in the winter is entrained in the lake's surface waters. An estimated 500 pounds of phosphorus is released from the lake's sediments and entrained in Lotus Lake's surface waters annually (see Figure B-2).

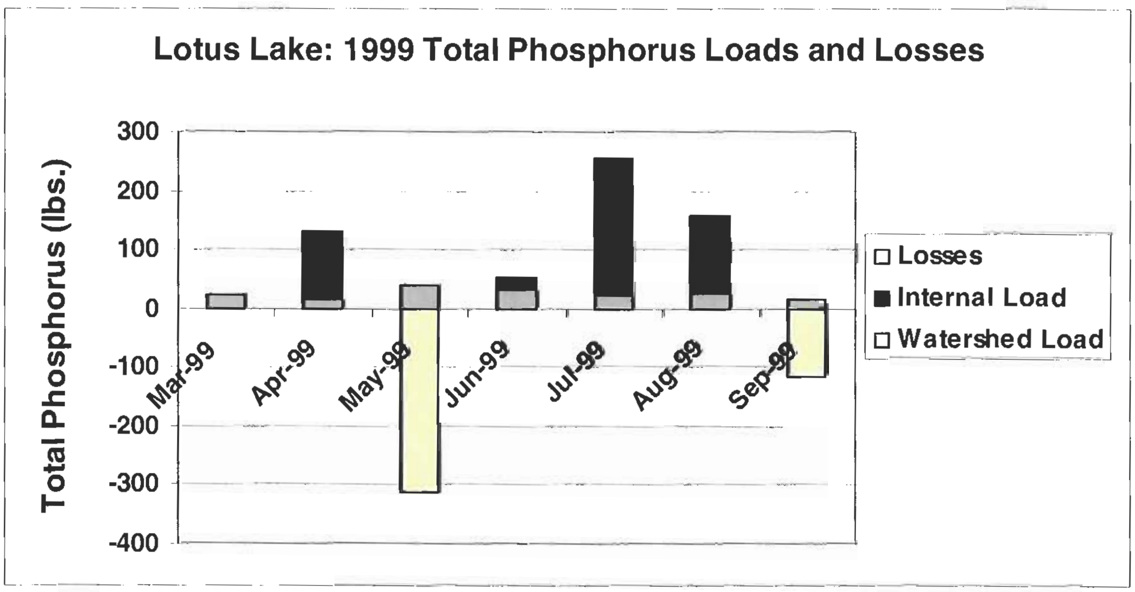


Figure B-2 Lotus Lake: Modeled Phosphorus Loads from Stormwater and Internal (Sediments) Sources and Net Losses (Settling and Zooplankton Grazing) for Calibration Year Climatic Conditions and Existing Watershed Land Uses

B-3.2 Calibration

Three parameters were used to calibrate the lake model: (1) phosphorus settling velocity, (2) the rate of phosphorus release from sediments, and (3) net losses (settling and zooplankton grazing).

The phosphorus settling velocity was calculated using an equation from Vollenweider (1976) and lake characteristics such as lake volume and mean depth, watershed phosphorus and water loading from the spring of one year to the spring of the next year (1 year of phosphorus loading), outflow discharge volume, and outflow concentration. The phosphorus settling velocity was calculated such that the model-predicted a phosphorus concentration that was equal to the concentration of phosphorus monitored in the spring (calibrated with 1999 monitoring data, 57 µg/L on April 9, 1999). The settling velocity calculated for Lotus Lake was 2.26 meters per year.

The phosphorus released from sediments and entrained in the lake's epilimnion (surface waters) was used as an input to a second mass balance model (adapted from Thomann and Mueller 1987) to develop a calibrated model. The net phosphorus loading from sediments was adjusted to minimize the difference between model-predicted and monitored phosphorus concentrations.

The net loss of phosphorus from the lake's epilimnion (surface waters) was used as an input to the lake's mass balance model (adapted from Thomann and Mueller 1987) to develop a calibrated model. The net phosphorus loss from the settling of dead algal cells and from zooplankton grazing was adjusted to minimize the difference between model-predicted and monitored phosphorus concentrations.

The equations used in this study follow.

B-3.2.1 Vollenweider

There are two equations for the Vollenweider model.

$$Ks = Vp/Z$$

and

$$P = \frac{W}{Q + Ks * V}$$

where:

- Ks = first order settling loss rate per year,
- Vp = net apparent settling rate,
- Z = average lake depth,
- P = Epilimnetic Phosphorus Concentration,
- W = Total Phosphorus Loading Rate (mg/yr),
- Q = Outflow (m^3/yr), and
- V = Lake Volume (m^3)

The first equation was solved for variable Ks, the first order settling loss rate per year. The net apparent settling rate used to determine Ks was 2.26 meters per year (see Figure B-3), the lake's average depth was 4.9 meters, and Ks was 0.46. This variable was then input in the second equation. The second equation was used to estimate the concentration of phosphorus that will occur in the spring.

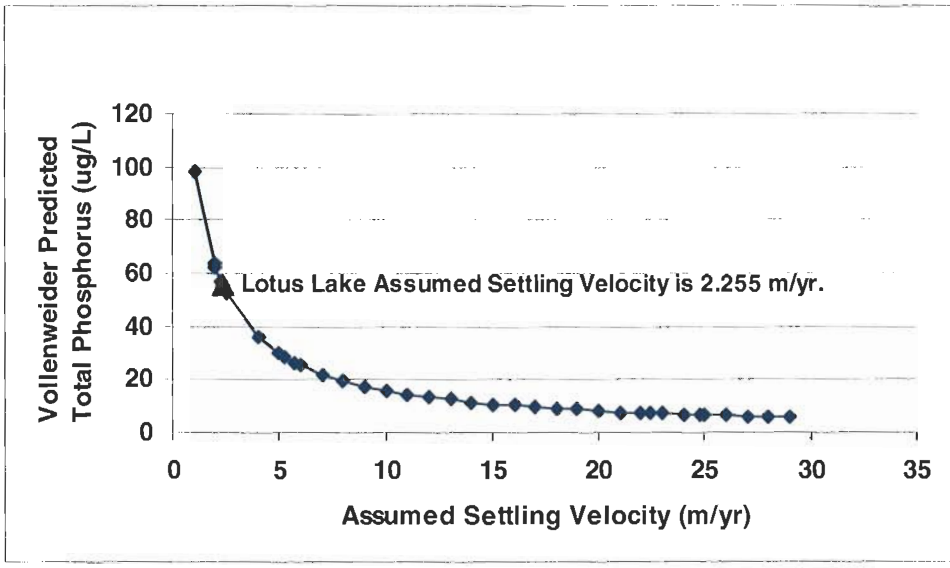


Figure B-3 Lotus Lake: Assumed Settling Velocity and Observed Total Phosphorus Value (April 9, 1999)

B-3.2.2 Mass Balance Equation Adapted from Thomann and Mueller

$$P_{Watershed} \equiv \frac{(P_{previousmonth} * (V - WL)) + WC_{SRP} + (WC_{P10} * 0.2)}{V}$$

$$P_{Total} \equiv P_{Watershed} + P_{NetInternalLoad} - P_{NetLosses}$$

where:

$P_{Watershed}$ = concentration of total phosphorus in the lake's epilimnion from watershed loading (monthly time step),

$P_{previousmonth}$ = concentration of total phosphorus in the lake's epilimnion on the last day of the previous month,

V = volume of the lake's epilimnion,

WL = water load into the lake for t (month),

WC_{SRP} = concentration of total phosphorus in the lake's epilimnion from watershed loading of soluble reactive phosphorus into the lake for t (month) = SRP load into lake for t (month)/WL,

$WC_{P10}*0.2$ = concentration of total phosphorus in the lake's epilimnion from 20 percent of the watershed loading of P10 particles into the lake for t (month) (i.e., 20 percent of P10 particles estimated to be entrained in the lake's epilimnion) = (P10 load into lake for t (month)/WL)*0.2,

P_{Total} = total phosphorus concentration of lake's epilimnion for t (month),

$P_{Watershed}$ = phosphorus concentration of lake's epilimnion from watershed phosphorus load for t (month),

$P_{NetInternalLoad}$ = phosphorus concentration of lake's epilimnion from net internal load for t (month), and

$P_{NetLosses}$ = quantity to subtract from phosphorus concentration of lake's epilimnion from net losses (zooplankton grazing and settling) for t (month).

This model was used with a monthly time step.

The mass balance model was used to estimate the lake's phosphorus concentration under four climatic conditions (wet, average, model calibration, and dry) and two watershed land use conditions (existing and future).

The model calibration scenario used watershed phosphorus loading from the period May 1, 1998 through April 30, 1999 to estimate the 1999 spring (April) lake concentration, using the Vollenweider model. The wet, dry, and average climatic scenarios used watershed phosphorus loading from the 1983, 1988, and 1995 water years, respectively, to estimate the spring (April) lake concentration using the Vollenweider model. The mass balance models (adapted from Thomann and Mueller) for the calibration, wet, dry, and average scenarios each used the starting value for April estimated by their respective Vollenweider models. Each mass balance model then estimated monthly lake concentrations beginning in April and concluding in September. Water and phosphorus inputs from the water year were then used to repeat the model ten times to model the lake's response to ten consecutive years of each precipitation condition (wet, model calibration, average, and dry).

B-3.3 Management Estimates

The effect of different management actions on phosphorus loading to Lotus Lake was estimated for:

- Upgrading eleven wet detention ponds, upgrading two dry detention ponds to wet detention ponds, and adding five wet detention ponds (all ponds would meet MPCA- and NURP-criteria).
- Infiltration of ¼-inch, ½-inch, and ¾-inch of runoff in the lake's direct watershed (LL-1, shown on Figure 17 of this report).
- Alum treatment of Lotus Lake.

For each management scenario, the Vollenweider model was used to estimate the spring (April) lake concentration. The mass balance model was used to estimate monthly lake concentrations for a 10-year period. The average summer total phosphorus concentration (June through August) was then determined for each year.

B-4 WATBUD Modeling

The WATBUD model was used to evaluate the water load estimate for Lotus Lake by a P8 model of the Lotus Lake watershed. The P8 model calculates the water flux into the lake from watershed runoff, including both direct runoff and flow through storm sewers. The P8 model does not, however, take into account groundwater seepage, nor the direct precipitation to or evaporation from the lake surface. Because of this, the WATBUD model was needed to evaluate the lake's water budget.

WATBUD is a lake water balance model produced by the Minnesota Department of Natural Resources (MDNR 1996, 1998). The model calculates daily lake level changes based on daily inputs of precipitation and temperature, optional daily inputs of runoff, evaporation or groundwater exchange and optional internal sub models which estimate runoff, evaporation or groundwater exchange. The model is capable of optimizing various water balance parameters using known lake level data as calibration targets.

B-4.1 Water Budget Components

The WATBUD model was run to simulate conditions for the 1995 through 2002 water years (October 1, 1994 to September 30, 2002) with the 1999 water year being the primary period of interest.

B-4.1.1 Precipitation

The WATBUD model requires daily rainfall records. Precipitation for the Lotus Lake watershed was calculated using monthly grids created from State Climatologist data. The monthly precipitation amounts were compared with hourly precipitation amounts recorded by a gage in Eden Prairie to determine the adjustment factor that would convert the Eden Prairie data to equal the monthly Lotus Lake watershed data. Then the adjustment factor was applied to the hourly Eden Prairie rainfall amounts to adjust them so that the monthly Eden Prairie rainfall would equal the monthly Lotus Lake watershed rainfall amounts.

B-4.1.2 Evaporation

Daily lake evaporation rates were calculated from monthly evaporation rates taken from a Meyer Model simulation of the Minneapolis Chain of Lakes. Evaporation rates for the Minneapolis' lakes are assumed to be applicable to lakes within the Riley-Purgatory-Bluff Creek Watershed District, which are at a similar latitude and experience similar climatic conditions. The Meyer Model was developed by Barr Engineering Company, based on work by Adolf Meyer (Meyer, 1947; Barr Engineering, undated), as a tool to estimate watershed net yield. Within the Meyer Model, monthly evaporation is calculated using average monthly water temperature, relative humidity and wind speed, as well as a site specific water temperature adjustment parameter. The Meyer Model simulation for the Minneapolis Chain of Lakes calculated two sets of monthly evaporation rates: one set for shallow lakes and one set for deep lakes. Because Lotus Lake is a deep lake, the deep lake rates were used.

B-4.1.3 Runoff

Daily runoff rates (which include both overland flow and flow through storm sewers) from the P8 model of the Lotus Lake watershed were modified and used as input in the WATBUD model. Because the P8 model does not simulate groundwater seepage, it is not able to accurately predict surface water outflow from a lake in which there is significant groundwater interaction. This is true for Lotus Lake. The calibration of the Lotus Lake model is discussed in detail below.

B-4.1.4 Groundwater Exchange

A groundwater exchange sub model (Lake Level Dependence) was used to calculate groundwater seepage into the pit. This sub model can be used to calculate groundwater exchange using lake level data under the assumption that there is a direct relationship between lake level and seepage, independent of the groundwater heads. In this sub model, seepage is calculated using the following equation:

$$\textbf{Seepage} = \textbf{a} * (1+\textbf{b}*\textbf{Llake}),$$

where:

a (inches) and **b** are arbitrary constants, and
Llake is the level of the lake.

The constants **a** and **b** can be user specified or fit during calibration. It is worth noting that the WATBUD model is not able to estimate total groundwater inflow and outflow, just the net groundwater exchange.

B-4.1.5 Surface Water Outlet

A man-made outlet structure drains Lotus Lake during high water periods. The WATBUD model calculated outflow on a daily time step using user defined stage-outflow relationships. Initially, an outlet rating curve for the outlet was developed based on the design specifications of the outlet. However, use of this rating curve produced a poor match between simulated and measured lake stages. In 2002, the outlet was found to be blocked (Dave Melmer, 2002, personal communications). Based on the assumption that the outlet is typically blocked, a hypothetical blocked-outlet rating curve was developed and used for the WATBUD calibration.

B-4.2 Model Calibration

The WATBUD model was calibrated using 363 lake stage measurements from Lotus Lake as calibration targets. During the automated calibration process the groundwater seepage parameters **a** and **b** (discussed above) were allowed to vary until there was an acceptable match between simulated and measured lake levels.

Figure B-4 shows the resulting lake stages estimated by WATBUD. WATBUD does a good job of matching lake stages throughout the calibration period, in particular the lake stages in the latter half of the calibration period. Because actual land use changes are not captured by the model, it is more critical to match the late time data. By varying the groundwater flux components, the simulation is able to match measured heads.

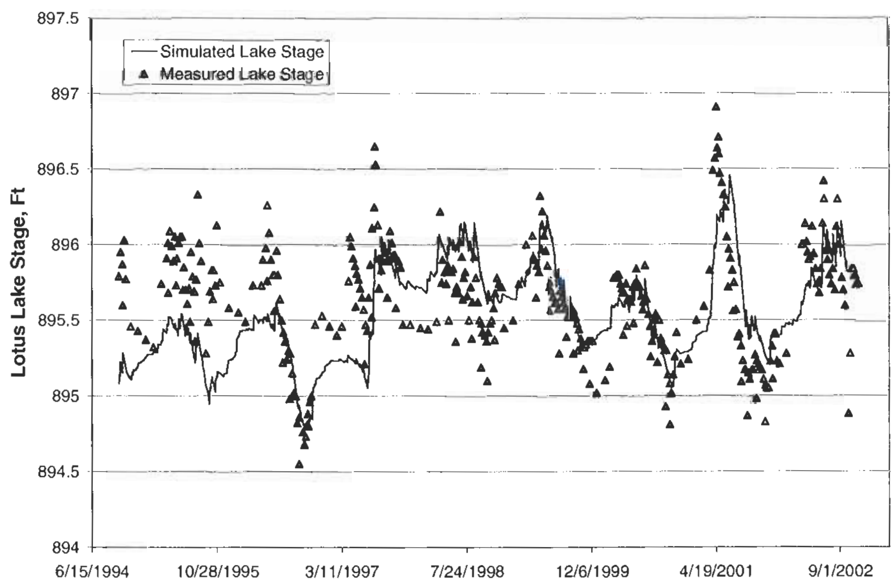


Figure B-4 Measured and simulated Lotus Lake stages assuming a partially blocked outlet.

B-4.3 Results

Table B-1 show the Lotus Lake water balance for the 1999 water year as calculated by WATBUD.

Table B-1 Lotus Lake 1999 Water Balance in acre-ft as Calculated by WATBUD

Precipitation	Runoff	Evaporation	Seepage	Stream Outflow
676	703	715	569	175

These values are approximate due to the fact that WATBUD reports some data as change in lake level which were multiplied by an average lake area (which in reality changes with stage) to get a volume. It should be noted that the reported seepage volume is a net seepage (groundwater flow in minus groundwater flow out) and the different components of seepage are unknown.

B-5 Lake Model Calibration

A graphical presentation of the lake model calibration results are shown below in Figure B-5. The Vollenweider lake model was calibrated by calculating a lake specific settling velocity for Lotus Lake (see Figure B-3). The mass balance lake model was calibrated by changing the time-distributed input of phosphorus from sediments and the time-distributed losses from zooplankton grazing and settling (see Figure B-2). The modeled in-lake total phosphorus concentrations closely matched the 1999 observed lake phosphorus concentrations. The summer average total phosphorus concentration estimated by the in-lake model was the same as the observed value.

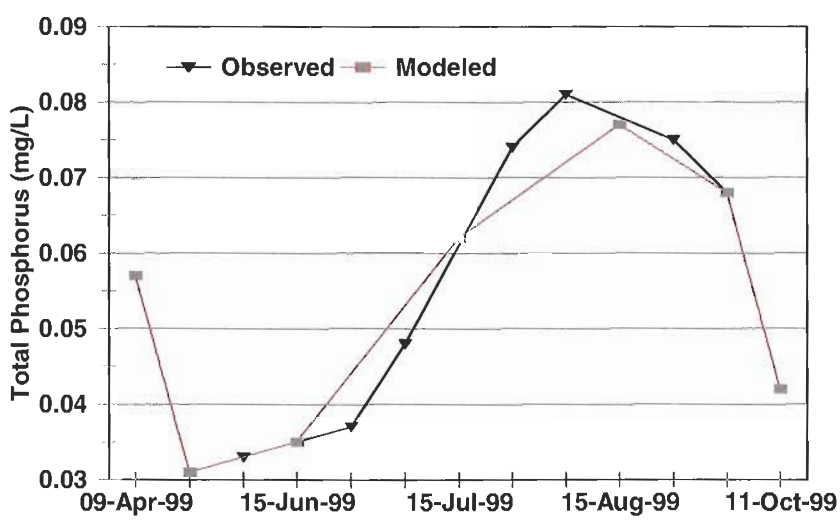


Figure B-5 Calibrated Lake Model

B-6 Lake Model Validation

For validation, the calibrated model was used with 1994 hydrology (e.g., water inputs) and watershed phosphorus loading inputs to see how closely the model- predicted in-lake total phosphorus concentration matched the monitored total phosphorus concentration. The validation results (Figure B-6) show good agreement between the model-predicted total phosphorus summer concentrations and the monitored summer concentrations. However, the validation model underestimated the lake's spring phosphorus concentration. Apparently, a higher percentage of the winter internal load was entrained in the lake's surface waters during the spring of the validation year than during the spring of the calibration year (Calibration Year Internal Load Shown in Figure B-2 of this report).

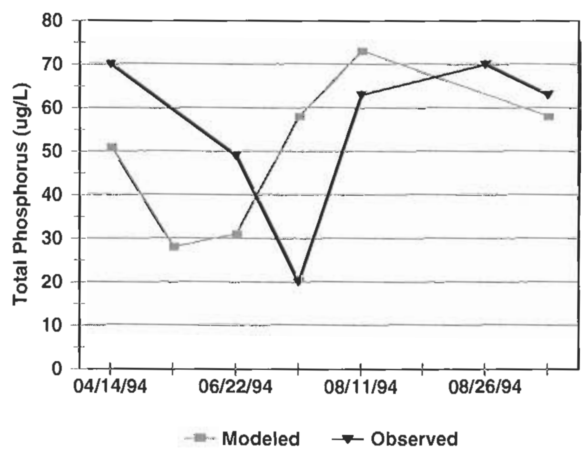


Figure B-6 Validation of the Calibrated Lake Model

The timing of zooplankton grazing losses differed between the calibration year (1999) and validation year (1994). Losses occurred during the spring and early-summer during the calibration year and occurred through mid-summer during the validation year (see Figure B-7). Hence, the validation model predicted that zooplankton grazing losses would occur during May through June (period in which losses occurred during the calibration year) when in actuality the losses occurred through July. Although the timing of the validation model differs from the timing of the observed results, the summer concentrations are similar.

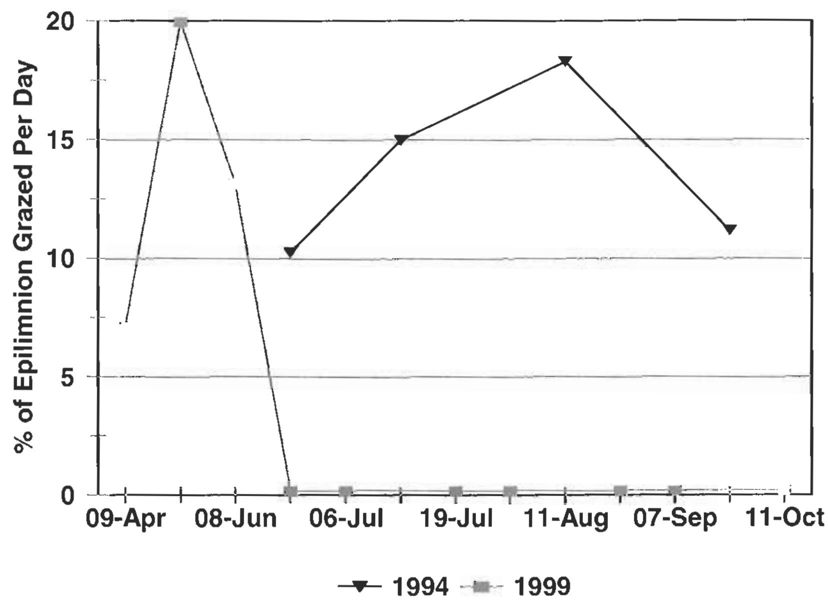


Figure B-7 Comparison of 1994 and 1999 Zooplankton Grazing Rates

B-7 Management Modeling Results

The expected outcome of several alternative management actions was modeled using the calibrated model for dry, average, calibration, and wet years. The expected outcome of each management activity is presented as the average summer total phosphorus concentration (Table B-2), the expected Secchi disc transparency given the average total phosphorus concentration (Table B-3), and the TSI that corresponds to the Secchi disc transparency (Table B-4). The expected Secchi disc transparency presented in Table B-3 was calculated using a logarithmic relationship between measured summer phosphorus levels in Lotus Lake and corresponding Secchi disc transparency (see Figure 4 of this report). The relationship was determined by the MPCA and is based upon data from Minnesota lakes (Heiskary et al., 1990).

Table B-2 Expected Mean Summer Total Phosphorus Concentrations Under Varying Climatic Conditions and Management Approaches

Management Approach	Mean TP Concentration (µg/L)			
	Wet Year (41 Inches)	Model Calibration Year (34 Inches)	Avg. Year (27 Inches)	Dry Year (19 Inches)
Existing Watershed Land Use Conditions				
No Action	58	58	56	54
NURP Upgrade*	58	58	56	54
One Fourth-Inch Infiltration LL-1	57	58	56	54
One Half Inch Infiltration LL-1	57	56	55	53
Three Fourths Inch Infiltration LL-1	56	56	55	53
Lake Alum Treatment**	13	13	11	9
Future Watershed Land Use Conditions				
No Action	61	59	57	55
NURP Upgrade*	61	59	56	55
One Fourth Inch Infiltration LL-1	61	58	56	55
One Half Inch Infiltration LL-1	60	57	56	54
Three Fourths Inch Infiltration LL-1	60	57	55	54
Lake Alum Treatment**	16	13	11	10

*Upgrade Wet Detention Ponds LL-2A, LL-3A, LL-4A, LL-6A, LL-6B, LL-8B1, LL-8D, LL-8E, LL-10B, LL-11B, and LL-11C and Dry Detention Ponds LL-8H and LL-8I to Meet MPCA- and NURP-Criteria and add Wet Detention Ponds LL-1, LL-1A, LL-8A, LL-8F, and LL-11A (New Ponds will meet MPCA/NURP Criteria)

**Lake phosphorus concentration estimate is following the third consecutive year of alum treatment (i.e., after full dose has been administered)

Table B-3 Expected Mean Summer Secchi Disc Transparencies Under Varying Climatic Conditions and Management Approaches

Management Approach	Mean Summer Secchi Disc (m)			
	Wet Year (41 Inches)	Model Calibration Year (34 Inches)	Avg. Year (27 Inches)	Dry Year (19 Inches)
Existing Watershed Land Use Conditions				
No Action	1.2	1.2	1.3	1.3
NURP Upgrade*	1.2	1.2	1.3	1.3
One Fourth Inch Infiltration LL-1	1.2	1.2	1.3	1.3
One Half Inch Infiltration LL-1	1.2	1.2	1.3	1.3
Three Fourths Inch Infiltration LL-1	1.2	1.2	1.3	1.3
Lake Alum Treatment**	4.3	4.6	5.0	5.9
Future Watershed Land Use Conditions				
No Action	1.1	1.2	1.2	1.3
NURP Upgrade*	1.1	1.1	1.2	1.3
One Fourth Inch Infiltration LL-1	1.2	1.2	1.3	1.3
One Half Inch Infiltration LL-1	1.2	1.2	1.3	1.3
Three Fourths Inch Infiltration LL-1	1.2	1.2	1.3	1.3
Lake Alum Treatment**	3.6	4.3	5.0	5.4

*Upgrade Wet Detention Ponds LL-2A, LL-3A, LL-4A, LL-6A, LL-6B, LL-8B1, LL-8D, LL-8E, LL-10B, LL-11B, and LL-11C and Dry Detention Ponds LL-8H and LL-8I to Meet MPCA- and NURP-Criteria and add Wet Detention Ponds LL-1, LL-1A, LL-8A, LL-8F, and LL-11A (New Ponds will meet MPCA/NURP Criteria)

**Lake Secchi disc transparency estimate is following the third consecutive year of alum treatment (i.e., after full dose has been administered)

Table B-4 Expected Trophic State Index Values Under Varying Climatic Conditions and Management Approaches

Management Approach	Trophic State Index (TSI_{SD}) Value				
	District Goal	Wet Year (41 Inches)	Model Calibration Year (34 Inches)	Avg. Year (27 Inches)	Dry Year (19 Inches)
Existing Watershed Land Use Conditions					
No Action	≤56	57	57	57	56
NURP Upgrade*	≤56	57	57	57	56
One Fourth Inch Infiltration LL-1	≤56	57	57	57	56
One Half Inch Infiltration LL-1	≤56	57	57	57	56
Three Fourths Inch Infiltration LL-1	≤56	57	57	57	56
Lake Alum Treatment**	≤56	39	38	37	34
Future Watershed Land Use Conditions					
No Action	≤56	58	57	57	57
NURP Upgrade*	≤56	58	58	57	57
One Fourth Inch Infiltration LL-1	≤56	58	57	57	57
One Half Inch Infiltration LL-1	≤56	58	57	57	57
Three Fourths Inch Infiltration LL-1	≤56	58	57	57	57
Lake Alum Treatment**	≤56	42	39	37	36

*Upgrade Wet Detention Ponds LL-2A, LL-3A, LL-4A, LL-6A, LL-6B, LL-8B1, LL-8D, LL-8E, LL-10B, LL-11B, and LL-11C and Dry Detention Ponds LL-8H and LL-8I to Meet MPCA- and NURP-Criteria and add Wet Detention Ponds LL-1, LL-1A, LL-8A, LL-8F, and LL-11A (New Ponds will meet MPCA/NURP Criteria)

**Lake TSI_{SD} estimate is following the third consecutive year of alum treatment (i.e., after full dose has been administered)

B-8 Conclusions

This lake model was used to estimate the relative phosphorus loading from watershed inputs and lake sediment, and how management of these different sources would affect phosphorus levels in Lotus Lake. An important part of this modeling study was the identification of the relative contribution of watershed loading and internal phosphorus loading from lake sediment to the lake's annual phosphorus loading. The phosphorus contribution by watershed loading was estimated from P8 modeling results. Internal loading from lake sediment was based upon the releasable phosphorus content of the top 6 centimeters of Lotus Lake sediment and a relationship between the phosphorus content and the expected release rate (Pilgrim 2002).

The prescribed management activities should be completed according to the management plan presented in Section 4.5. By following this management plan the relative contribution by the lake sediment to phosphorus levels in Lotus Lake can be confirmed because alum treatment of lake sediments should reduce phosphorus contributed by internal loading by approximately 80 percent. Controlling nuisance non-native species before improving the lake's water clarity will protect the lake's native vegetation and prevent problematic growths by non-native species.

Appendix C

Monitoring and Analysis Methods

Appendix C Monitoring and Analysis Methods

The Lotus Lake UAA included the collection of lake water quality data and ecosystem data.

C.1 Lake Water Quality Data Collection

In 1999, samples were collected from a representative Lotus Lake sampling station (i.e., located at the deepest location in the lake basin, see Figure C-1). Samples were collected from April through mid-October. A total of ten water quality parameters were measured at the Lotus Lake sampling station. Table C-1 lists the water quality parameters and specifies at what depths the samples or measurements were collected. Dissolved oxygen, temperature, specific conductance, turbidity, and Secchi disc transparency were measured in the field, water samples were analyzed in the laboratory for total phosphorus, soluble reactive phosphorus, total nitrogen, chlorophyll *a*, and pH. The procedures for chemical analyses of the water samples are shown in Table C-2. Generally, the methods can be found in Standard Methods for Water and Wastewater Analysis.

C.2 Ecosystem Data Collection

Ecosystem data collected from April to October 1999 included:

- **Phytoplankton**—A composite 0-2 meter sample was collected during each water quality sampling event during the period April 1999 thorough October 1999.
- **Zooplankton**—A zooplankton sample was collected (i.e., bottom to surface tow) during each water quality sample event during the period April 1999 through October 1999.
- **Macrophytes**—Macrophyte surveys were completed during June and August 1999.

Phytoplankton and zooplankton samples were identified and enumerated to provide information on species diversity and abundance. The macrophyte community was surveyed to determine species locations, composition, and abundance.

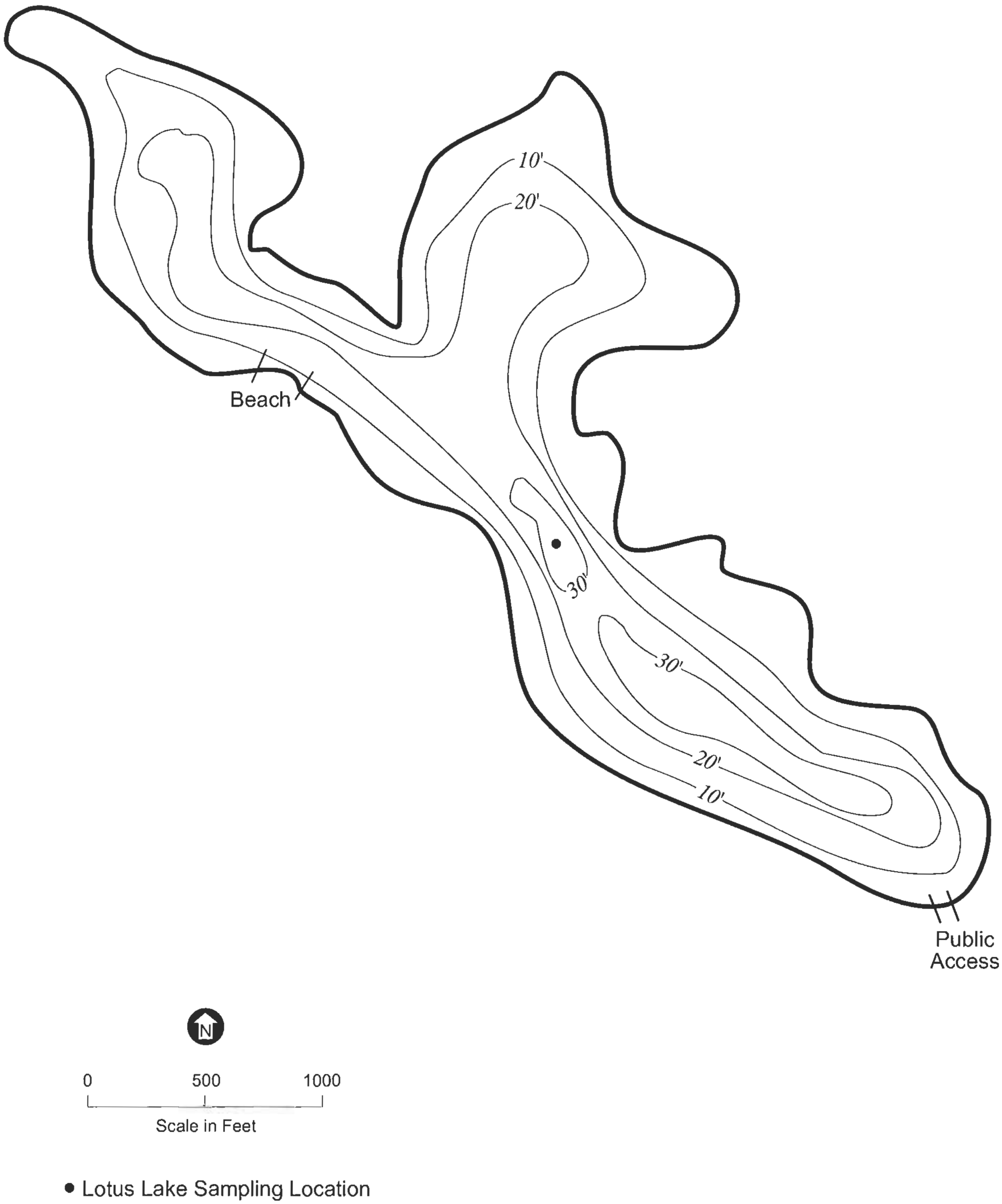


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Figure C-1

LOTUS LAKE BASIN
MORPHOLOGY AND SAMPLE LOCATION

Table C-1 Lotus Lake Water Quality Parameters

Parameters	Depth (Meters)	Sampled or Measured During Each Sample Event
Dissolved Oxygen	Surface to bottom profile	X
Temperature	Surface to bottom profile	X
Specific Conductance	Surface to bottom profile	X
Secchi Disc	—	X
Total Phosphorus	0-2 Meter Composite Sample	X
Total Phosphorus	Profile at 1 meter intervals from 3 meters to 0.5 meters above the bottom	X
Soluble Reactive Phosphorus	0-2 Meter Composite Sample	X
Total Nitrogen	0-2 Meter Composite Sample	X
pH	0-2 Meter Composite Sample	X
pH	Profile at 1 meter intervals from 3 meters to 0.5 meters above the bottom	X
Chlorophyll *a*	0-2 Meter Composite Sample	X
Turbidity	0-2 Meter Composite Sample	X

Table C-2 Procedures for Chemical Analyses Performed on Water Samples

Analysis	Procedure	Reference
Total Phosphorus	Persulfate digestion, manual ascorbic acid	Standard Methods, 18th Edition (1992) modified per Eisenreich, et al., Environmental Letters 9(1), 43-53 (1975)
Soluble Reactive Phosphorus	Manual ascorbic acid	Standard Methods, 18th Edition modified per Eisenreich, et al., Environmental Letters 9(1), 43-53 (1975)
Total Nitrogen	Persulfate digestion, scanning spectrophotometric	Bachman, Roger W. and Daniel E. Canfield, Jr., 1991. A Comparability Study of a New Method for Measuring Total Nitrogen in Florida Waters. Report submitted to the Florida Department of Environmental Regulation.
Total Kjeldahl Nitrogen	Digestion, treatment with sodium hypochlorite and sodium phenolate, run of Technicon Autoanalyzer II	USEPA Methods of Chemical Analysis of Water and Wastes, 351.1
Nitrate + Nitrite Nitrogen	Copperized reduction column and Lachat Flow Injection Ion Analyzer	USEPA Methods of Chemical Analysis of Water and Wastes, 353.2
Chlorophyll *a*	Spectrophotometric	Standard Methods, 18th Edition, 1992, 10200 H
pH	Potentiometric measurement, glass electrode	Standard Methods, 16th Edition, 1985, 423
Specific Conductance	Wheatstone bridge	Standard Methods, 16th Edition, 1985, 205
Temperature	Thermometric	Standard Methods, 16th Edition, 1985, 212

Analysis	Procedure	Reference
Dissolved Oxygen	Electrode	Standard Methods, 16th Edition, 1985, 421F
Phytoplankton Identification and Enumeration	Inverted Microscope	Standard Methods, 16th Edition, 1985, 1002F (2-d), 1002H (2)
Zooplankton Identification and Enumeration	Sedgewick Rafter	Standard Methods, 16th Edition, 1985, 1002F (2-d), 1002H
Transparency	Secchi disc	

C.3 Watershed Pond Survey

During 2001, 25 wet detention ponds and two "dry" ponds (temporarily hold stormwater and then drain dry) in the Lotus Lake watershed were surveyed. The ponds' bathymetry was determined in the survey. This work was completed to help establish the current conditions of water bodies that affect the flow of storm water runoff from the Lotus Lake watershed. The survey of each wet detention pond began by recording the type and size of the outlet and estimating the height to the low overflow point. A Global Positioning System (GPS) was then used to record the perimeter of the pond. Staff walked the pond perimeter and used the GPS to record the longitude and latitude of selected points along the perimeter. A grid was then marked off on the resultant map of the pond with points approximately 20 feet apart. A depth gage was dropped to the bottom to get the water depth at each survey point. The grid points and associated water depths were then recorded on a map of the pond. The maps were then placed in the Geographical Information System (GIS) and pond volumes, both dead and live storage, were determined. Pond data are summarized in Appendix D. The information was used for P8 modeling of the Lotus Lake watershed to determine the lake's watershed phosphorus load.

Appendix D

Lotus Lake Watershed Pond Data

Lotus Lake Watershed Ponds
Summary

WS ID	Pond ID	Primary Outlet Elev. (ft.)	Water Elev. (ft.)	Overflow Elev. (ft.)	Average Pond Slope (outlet to overflow)	Primary Outlet Size/Type	Secondary Outlet Elev.	Secondary Outlet Size /Type	D.S.S. Volume (Acre/Feet)	L.S.S. Volume (Acre/Feet)	D.S.S. Area (Acres)	L.S.S. Area (Acres)
LL-2B	34	0	-0.50	101.5 (1.5)	--	12"x8" oval	None	None	0.221	0.244	0.125	0.145
LL-2A	33	0	0.2	102.8 (2.8)	3 to 1	17" CMP	None	None	0.41	0.628	0.192	0.276
LL-3A	29	0	0.1	109.7 (9.7)	4 to 1	12" RCP	None	None	0.007	4.621	0.453	1.084
LL-4C	20	0	-0.50	101.5 (1.5)	--	27" RCP	None	None	0.688	0.379	0.234	0.296
LL-4B	23	0	0.2	103.0 (3.0)	--	12" RCP	None	None	1.675	2.244	0.646	0.886
LL-4A	55	0	0.1	101.9 (1.9)	5 to 1	8" PVC	None	None	0.325	3.394	2.541	2.814
LL-5C	1	0	0	103.7 (3.7)	3 to 1	15" RCP	None	None	0.16	0.474	0.101	0.176
LL-5B	16	0	0	103.0 (3.0)	--	15" RCP	None	None	0.2	0.472	0.111	0.149
LL-5A	18	0	0	102.0 (2.0)	--	18"	None	None	4.364	12.232	5.685	6.937
LL-6B	14	0	0	101.9 (1.9)	--	18"	None	None	0.63	0.863	0.331	0.58
LL-6A	LLN	0	1.5	107.7 (7.7)	4 to 1	24" RCP	None	None	0.113	3.718	0.459	0.949
LL-7A	13	0	0	102.7 (2.7)	--	15"	None	None	0.954	2.834	0.559	1.131

Lotus Lake Watershed Ponds
Summary

WS ID	Pond ID	Primary Outlet Elev. (ft.)	Water Elev. (ft.)	Overflow Elev. (ft.)	Average Pond Slope (outlet to overflow)	Primary Outlet Size/Type	Secondary Outlet Elev.	Secondary Outlet Size /Type	D.S.S. Volume (Acre/Feet)	L.S.S. Volume (Acre/Feet)	D.S.S. Area (Acres)	L.S.S. Area (Acres)
LL8J	53	None	0	104.0 (4.0)	--	None	None	None	2.606	9.889	2.076	9.889
LL8K	3	0	0.1	103.0 (3.0)	--	24" RCP	None	None	0.794	1.955	0.372	0.499
LL-8L	8	0	0	106.0 (6.0)	--	12" RCP	None	None	0.747	7.494	0.407	1.849
LL-8I	56	0	--	101.0 (1.0)	--	None	None	None	0	--	--	--
LL-8H	57	0	No Water	107.3 (7.3)	5 t0 1	18-20" RCP	None	None	0	--	--	--
LL-8G	4	None	0	103.3 (3.3)	--	None	None	None	7.939	N/A	8.414	None
LL-8E	5	0	0.4	106.6 (6.6)	5 to 1	2' x 2' round	None	None	0.043	3.354	0.367	0.967
LL-8D	5a	0	1	113.8 (13.8)	3 to 1	44" RCP	None	None	0.052	6.513	0.318	0.953
LL-8B1	12	0	0.1	107.2 (7.2)	3 to 1	12" RCP	None	None	0.061	3.08	0.446	0.77
LL-8C	7	0	0.02	101.5 (1.5)	--	18" RCP	None	None	3.06	3.07	1.581	2.128
LL-8B	6	0	0	102.5 (2.5)	--	14'(L)x0.5'(H) beam	None	None	4.633	7.043	1.978	3.712
LL-10B	44	None	0	101.0 (1.0)	--	None	None	None	0.347	N/A	0.139	None
LL-10A	46	0	0.01	101.5 (1.5)	--	12" RCP	None	None	46.003	10.696	9.991	11.417
LL-11C	42	0	0.1	105.5 (5.5)	--	5' diameter horizontal RCP	None	None	0.861	2.84	0.116	0.206
LL-11B	41	0	0.2	104.5 (4.5)	--	42" RCP	None	None	0.102	0.355	0.06	0.097

Summary

WS ID	Comments	WS ID	Comments
LL-2B	outlet at adverse angle	LL8K	Island near center
LL-2A	Outlet to south. Trash rack (3' x 2') to CMP.	LL-8L	--
LL-3A	Pond slope: used 4/1 because 5/1 in notes created buffer to houses. Field notes: Pond full of cattails, pipe is lower than pond. Overflow if pipe was closed.	LL-8I	No dead storage space. Open scrub area. No Primary outlet.
LL-4C	--	LL-8H	No dead storage space. No water. Pipe outlet is to East under Powers Blvd. Outlet below ground elevation.
LL-4B	--	LL-8G	--
LL-4A	Field notes: Natural channel to outlet. Overflow at same location. Full of cattails and no open water.	LL-8E	--
LL-5C	--	LL-8D	--
LL-5B	Unable to find outlet, but likely 15" RCP	LL-8B1	Field Notes: No dead storage space. 100 percent cattails.
LL-5A	City Plan indicates 15" outlet	LL-8C	--
LL-6B	City Plan indicates 18" outlet	LL-8B	--
LL-6A	Pond slope 3/1 (north) and 5/1 (south) so used 4/1 in calculations	LL-10B	No outlet found. Very minimal overflow to Pond 46.
LL-7A	City Plan indicates 15" outlet	LL-10A	--
LL8J	--	LL-11C	--
		LL-11B	--

Appendix E

P8 Model Parameter Selection

Appendix E P8 Model Parameter Selection

P8 version 2.4 was used for Lotus Lake watershed modeling. The parameters selected for the Lotus Lake P8 model are discussed in the following paragraphs. P8 parameters not discussed in the following paragraphs were left at the default setting.

Time Step, Snowmelt, and Runoff Parameters (Case-Edit-Other)

- **Time Steps Per Hour (Integer)—2.** Selection was based upon the number of time steps required to eliminate continuity errors greater than 2 percent.
- **Minimum Inter-Event Time (Hours)—10**. The selection of this parameter was based upon an evaluation of storm hydrographs to determine which storms should be combined and which storms should be separated to accurately depict runoff from the lake's watershed.
- **Snowmelt Factors—Melt Coef (Inches/Day-Deg F)—0.06**. The selection was based upon the snowmelt rate that provided the best match between the observed and predicted snowmelt.
- **Snowmelt Factors—Scale Factor For Max Abstraction—1**. This factor controls the quantity of snowmelt runoff (i.e., controls losses due to infiltration). Selection was based upon the factor that resulted in the closest fit between modeled and observed runoff volumes.
- **Growing Season/Non-Growing Season AMC II = 1.4/0.5 and AMC III = 2.1/1.1**. This indicates that AMC-II is used if the 5 day antecedent moisture is 1.4 (growing season) or 0.5 (non-growing season) inches or greater and that AMC-III is used if antecedent moisture is 2.1 (growing season) or 1.1 (non-growing season) inches or greater.

Particle Scale Factor (Case-Edit-Components)

- **Scale Fac.—tp—1.00.** The particle scale factor adjusts phosphorus loading for site specific factors. A factor of 1.00 indicates no adjustment was needed.

Particle File Selection (Case—Read—Particles)

- **NURP50PAR.** The NURP 50 particle file was used to predict phosphorus loading and settling in wet detention ponds.

Precipitation File Selection (Case—Edit—First—Prec. Data File)

- **MS4902II.PCP.** The precipitation file MS490211.PCP is comprised of hourly precipitation data during the period 1949 through 2002. Data were obtained from the Minneapolis-St. Paul International Airport prior to 1998. During 1998 through 2002, precipitation for the Lotus Lake watershed was calculated using monthly grids created from State Climatologist data. The monthly precipitation amounts were compared with hourly precipitation amounts recorded by a gage in Eden Prairie to determine the adjustment factor that would convert the Eden Prairie data to equal the monthly Lotus Lake watershed data. Then the adjustment factor was applied to the hourly Eden Prairie rainfall amounts to adjust them so that the monthly Eden Prairie rainfall would equal the monthly Lotus Lake watershed rainfall amounts.

Air Temperature File Selection (Case—Edit—First—Air Temp. File)

- **MSP4902.TMP.** The temperature file was comprised of temperature data from the Minneapolis—St. Paul International airport during the period 1949 through 2002.

Devices Parameter Selection (Case—Edit—Devices—Data—Select Device)

- **Pond Bottom—**The surface area of the pond bottom of each detention pond was determined and entered here.
- **Detention Pond—Permanent Pool—Area and Volume—**The surface area and dead storage volume of each detention pond was determined and entered here.
- **Detention Pond—Flood Pool—Area and Volume—**The surface area and storage volume under flood conditions (i.e., the storage volume between the normal level and flood elevation) was determined and entered here.
- **Detention Pond—Orifice Diameter and Weir Length—**The orifice diameter or weir length was determined for each detention pond and entered here.
- **Detention Pond or Generalized Device—Particle Removal Scale Factor—**0.3 for ponds less than 2 feet deep, 0.6 for ponds from 2 to 3 feet deep, and 1 for all ponds 3 feet deep or greater. The particle removal factor for watershed devices determines particle removal by devices.
- **Detention Pond or Generalized Device—Outflow Device No's—**The number of the downstream device receiving water from the detention pond outflow was entered for infiltration, normal, and spillway.
- **Generalized Device—Infiltration Outflow Rates (cfs)—**0 for all ponds.
- **Detention Pond—Infiltration Rate (in/hr)—**0 for all ponds.
- **Pipe/Manhole—Time of Concentration—**The time of concentration for most pipe/manhole devices was determined and entered here. A "dummy" pipe/manhole device was placed immediately upstream of most ponds and a time of concentration of 0.5 hours per "dummy" pipe was selected to enable the model to accurately time the release of waters from each pond. Failure to use a "dummy" pipe/manhole for this purpose will result in a much faster release of waters from ponds and resultant reductions in treatment than actually occurs. Finally, a "dummy" pipe called Lotus Lake was used in each of the three models. The Lotus Lake pipe received all water and phosphorus loads that enter Lotus Lake. A time of concentration of 0.5 hours was used for the Lotus Lake pipe. Use of the pipe forced the model to total the water and phosphorus loads entering the lake, thus avoiding hand tabulation.

Watersheds Parameter Selection (Case—Edit—Watersheds—Data—Select Watershed)

- **Outflow Device Number—**The device number of the device receiving runoff from the watersheds was selected.
- **Pervious Curve Number—**A weighted SCS curve number was used as outlined in the following procedure. The P8 Pre-Processor (GIS algorithm) was used to compute a SCS curve number for each watershed. The computation was based upon soil types in the watershed, land use, and hydrologic conditions. The computation also weighted the pervious curve number with indirect (i.e., disconnected) impervious areas in each sub watershed as follows:

WCN = {[(Indirect Impervious Area) * (98)] + [(Pervious Area) * (Pervious Curve Number)]}/(Total Area)

The assumptions for direct, indirect, and total impervious areas were based upon measurements from representative areas within the District for land uses found within the Lotus Lake watershed.

- **Swept/Not Swept—**An "unswept" assumption was made for the entire impervious watershed area. A sweeping frequency of 0 was selected for swept. Hence, selected parameters were placed in the unswept category, including impervious fraction, depression storage, impervious runoff coeff, and scale factor for particle loads.
- **Impervious Fraction—**The direct or connected impervious fraction for each subwatershed was determined and entered here. The direct or connected impervious fraction includes driveways and parking areas that are directly connected to the storm sewer system. The P8 pre-processor performed the computations to determine impervious fractions for the subwatersheds. The direct impervious fraction for each subwatershed was based upon measurements from representative areas within the District for land uses found within the Lotus Lake watershed. The direct impervious fraction for each land use type was weighted with the acres of each land use to obtain a weighted average for each subwatershed.
- **Depression Storage**—0.03
- **Impervious Runoff Coef**.—0.94

Passes Through the Storm File (Case—Edit—First—Passes Thru Storm File)

- **Passes Thru Storm File—20**. The number of passes through the storm file was determined after the model had been set up and a preliminary run completed. The selection of the number of passes through the storm file was based upon the number required to achieve model stability. Multiple passes through the storm file were required because the model assumes that dead storage waters contain no phosphorus. Consequently, the first pass through the storm file results in lower phosphorus loading than occurs with subsequent passes. Stability occurs when subsequent passes do not result in a change in phosphorus concentration in the pond waters. It was determined that the four P8 models (i.e., wet, average, calibration, and dry) achieved stability at 20 passes.