Silver Lake Use Attainability Analysis

Prepared for
Riley-Purgatory-Bluff Creek Watershed District

May 2003

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Executive Summary

Overview

This report details the results of a Use Attainability Analysis (UAA) of Silver 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 protective measures to insure continued attainment of intended beneficial uses of Silver Lake. The analysis is based on the results of 1996 and 2000 lake water quality monitoring programs, and computer simulations of watershed runoff. Computer simulations estimated watershed runoff under varying climatic conditions. Because the lake's watershed is fully developed, existing and future land uses are assumed to be the same.

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 Silver Lake. These goals address recreation, water quality, aquatic communities, water quantity, and wildlife. Wherever possible, Riley-Purgatory-Bluff Creek Watershed District (RPBCWD) goals for Silver Lake have been quantified using a standardized lake rating system termed Carlson's Trophic State Index (TSI). 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 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**—[$20 \leq$ 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**—[$38 \leq$ 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**—[$50 \leq$ 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**—[$62 \leq$ 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 0.8 meters (less than 2.7 feet).

The 1996 District Water Management Plan indicated Silver Lake was unclassified by the MPCA, MDNR, and the City of Chanhassen. Hence, the lake's target water quality goals were based upon the RPBCWD policy of nondegradation of current lake water quality conditions. Current conditions were estimated from the Dillon and Rigler water quality model during a year of average precipitation. Primary data were not available for model calibration.

The RPBCWD goals for Silver Lake include the following:

1. The **Recreation Goal** is to provide water quality that supports canoeing and aesthetic viewing. The goal has been attained and nondegradation of the lake's current water quality will insure goal attainment in the future. Hence, the recreation goal is a TSI_{SD} 83 (Secchi disc water transparency of 0.2 meters).
2. The intended **Water Quality Goal** is protection of the lake's current water quality. The goal has been attained and nondegradation of the lake's current water quality will insure future goal attainment. The numeric goal stated in the District plan, however, has not been attained and is not attainable. The goal was established before the collection of primary data and was based upon uncalibrated modeling estimation. The average summer water transparency estimated by the model (i.e., 0.5 meters) differed from primary data collected during 1996 (0.4 meters) and 2000 (0.2 meters). Use of primary data from 2000 is recommended. Hence, a change from the current numeric water quality goal of TSI_{SD} 70 (Secchi disc water transparency of 0.5 meters) to a goal of TSI_{SD} 83 (Secchi disc water transparency of 0.2 meters) is recommended.
3. The **Aquatic Communities Goal** is preservation of the lake's wetland habitat. The habitat is used by seasonal waterfowl, such as ducks and geese, and other aquatic life. The goal has

been attained. However, nuisance non-native plants threaten future non-attainment of the goal. Management of non-native plants will insure continued goal attainment.

4. The **Water Quantity Goal** for Silver Lake is to manage surface water runoff from a regional flood, the critical 100-year frequency storm event. This goal has been achieved.
5. The **Wildlife Goal** for Silver Lake is to protect existing, beneficial wildlife uses. The wildlife goal has been achieved.

Current Water Quality

An evaluation of 1996 and 2000 Silver Lake water quality data was completed to determine the lake's current water quality. Results of this evaluation indicate the lake's water quality is poor and has remained relatively stable over the 4-year period. The 1996 and 2000 total phosphorus concentration data indicate the lake was hypereutrophic (very poor water quality) during all monitoring events. Chlorophyll measurements during 1996 and 2000 generally exceeded nuisance levels. Measurements indicated the lake was hypereutrophic (very poor water quality) during all but the April 30, 1998 sample event. Secchi disc measurements during 1996 and 2000 were hypereutrophic (very poor) during all but the spring sample events (i.e., April 30, 1998 and March 28, 2000). Severe recreational-use impairment occurred during the summer (Osgood, 1989). The lake's recreational-use impairment appears to be largely determined by algal abundance.

Water Quality Problem Assessment

The lake's poor water quality is related to excessive inputs of phosphorus. Sources of phosphorus include: (1) runoff-borne phosphorus from its urbanized watershed; (2) internal loading; and (3) atmospheric deposition.

Phosphorus Budget

The lake's phosphorus budget details phosphorus contributions from the lake's 251-acre watershed, internal loading, and atmospheric deposition. The lake's watershed includes the 67-acre lake, 11 acres of stormwater treatment ponds, and 173 acres of land with a low-density residential land use. Because the lake's watershed is fully developed, watershed phosphorus loading under existing and future land use conditions is assumed to be the same. Computer simulations of runoff water quality indicate that the annual total phosphorus load to Silver Lake from its watershed varies from 53 pounds under dry climatic conditions (i.e., 19-inches annual precipitation) to 118 pounds under wet climatic conditions (i.e., 41-inches annual precipitation). The rate of watershed phosphorus

Total Phosphorus Loads to Silver Lake Under Varying Climatic Conditions

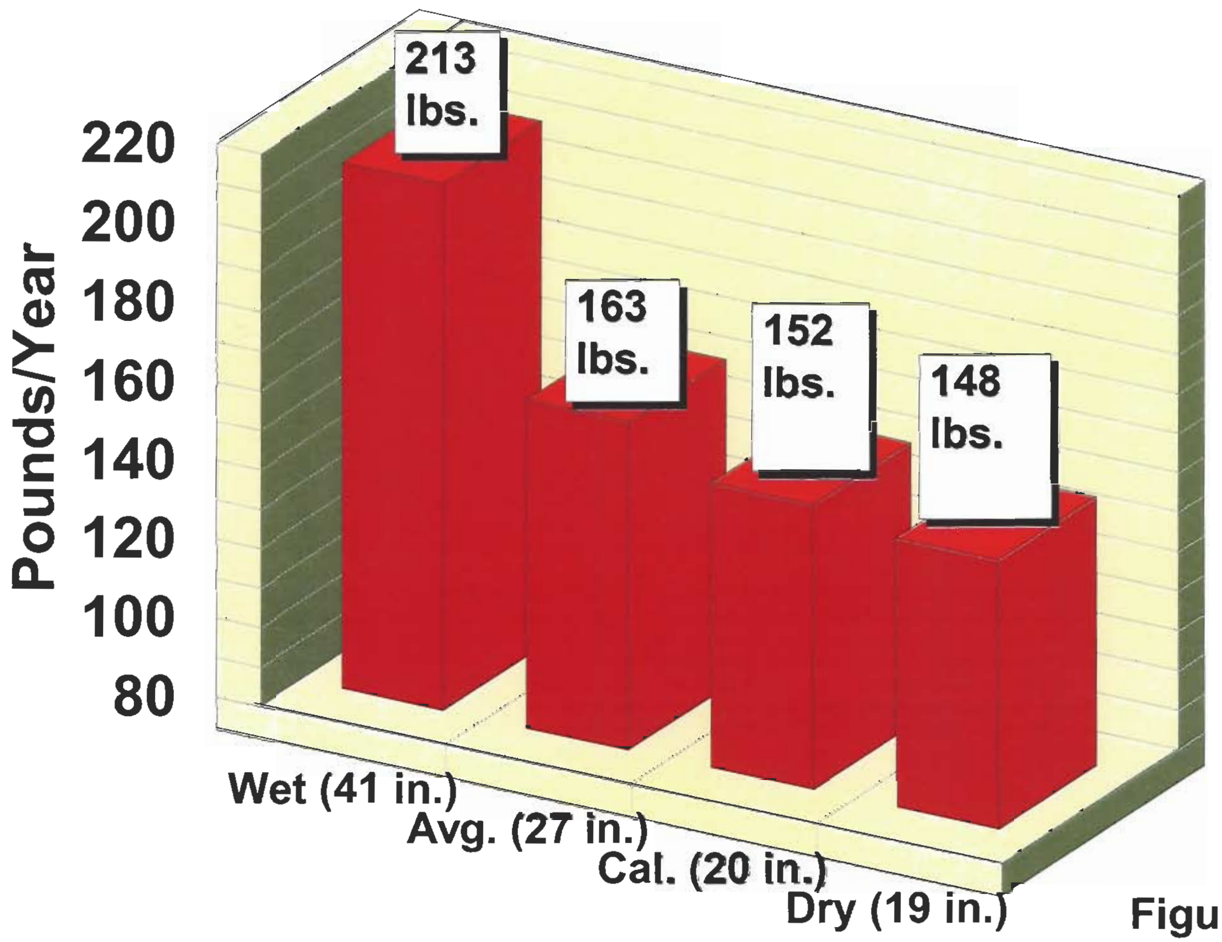


Figure EX-1

P:\23\27\053\rileyuaa\report\tploads.wb2:ult. Land use loading to the 67-acre lake during average precipitation conditions is approximately 1 pound of phosphorus per acre of lake per year (L = 0.112 $g/m^2/yr$). Internal phosphorus loading is estimated to total 62 pounds annually (L = 0.104 $g/m^2/yr$) during all climatic conditions. The lake's annual atmospheric deposition load is estimated to total 33 pounds annually (L = 0.055 $g/m^2/yr$) under all climatic conditions. Watershed and internal phosphorus loading are excessive and cause poor water quality.

Silver Lake's annual phosphorus budget for an average precipitation year (i.e., 27-inches of precipitation) indicates approximately 42 percent of the lake's annual phosphorus load enters the lake from its watershed. Atmospheric deposition and the lake's internal load represent 20 and 38 percent of the annual phosphorus load, respectively (See Figure EX-2).

Aquatic Plants

Macrophyte (i.e., aquatic plant) surveys were performed during 1996 and 2000. Plants were generally found to depths of 5 feet and the plant community was relatively stable. Two nuisance non-native species, curlyleaf pondweed and purple loosestrife, were observed in Silver Lake during 1996 and 2000. Non-native species typically follow an aggressive growth pattern and eliminate native species from a lake and from its shoreline. Reduction of the two nuisance species to the greatest extent possible is recommended to protect the lake's habitat and current beneficial uses.

Recommended Goal Changes

The District's lake management strategy has been "to protect" the resource. Protect means to avoid significant degradation from point and nonpoint pollution sources and from wetland alterations in order to maintain existing beneficial uses, aquatic and wetland habitats, and the level of water quality necessary to protect these uses in receiving waters. The District has established management goals for Silver Lake to facilitate protection from degradation. The lake's water quality goal is a TSI_{SD} of 70 (i.e., Secchi disc measurement of 0.5 meters).

An evaluation of the lake's water quality goal indicates a goal change is warranted. The lake's goal was based upon modeled predictions of the lake's current water quality. The modeled predictions were completed during preparation of the District's water management plan when primary data were not available. Primary data collected during 1996 and 2000 indicate the lake's average summer Secchi disc measurement was poorer than modeled estimates. Primary data indicate the goal is

Silver Lake Phosphorus Budget: Sources
Average Precipitation Year (27 Inches)

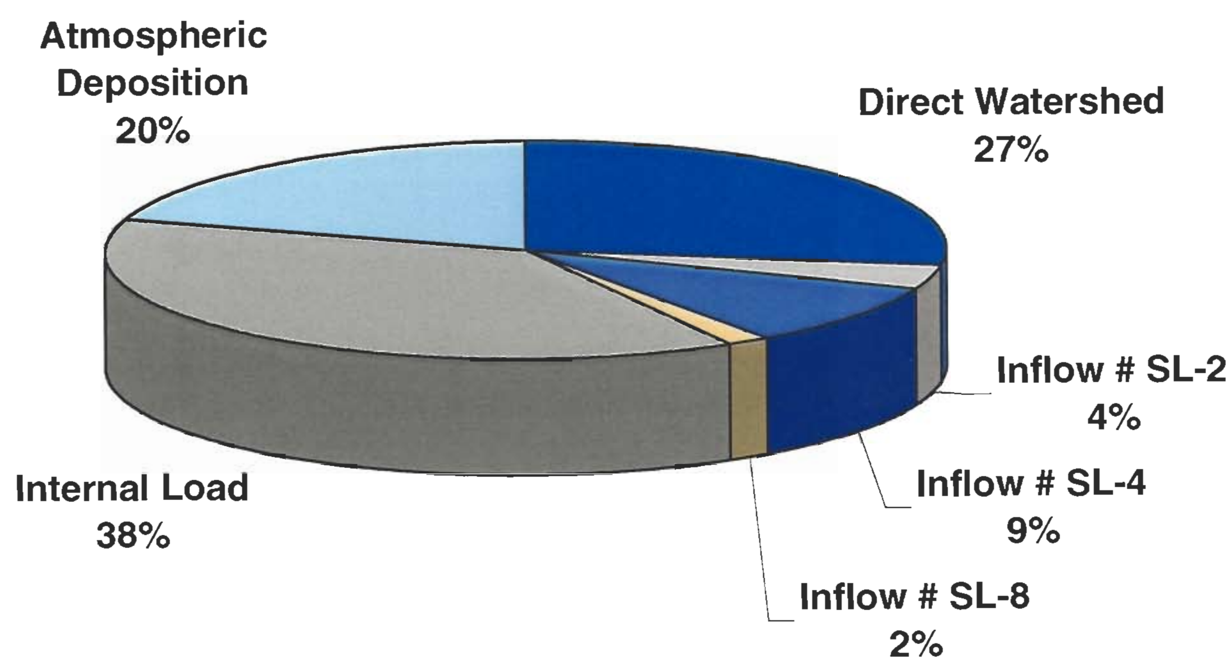


Figure EX-2

unreasonable and not attainable. Establishing a goal based upon current (i.e., 2000) water quality data would achieve the intent of the District nondegradation policy. Hence, a goal change to TSI_{SD} 83 (i.e., Secchi disc measurement of 0.2 meters) is recommended. The more reasonable water quality goal is attainable with no action.

Recommended Change to District Policy

District lake management policy is nondegradation of the lakes' current water quality and achievement of national and state goals and policies. The District policy assumes national and state goals and policies are both reasonable and attainable. 2001 changes in state lake management criteria are based upon the assumption that all waters of the state must achieve a full support of swimmable use. The criteria are both unreasonable and unattainable for Silver Lake. The state criteria change mandates a District policy change. The recommended change in District policy is to achieve national and state criteria deemed reasonable by the District and work to affect change in unreasonable criteria.

Recommended Exotic (Non-Native) Plant Management

The Silver Lake plant community is currently satisfactory for its lake type and use (i.e., a Type 25 wetland used for canoeing and aesthetic viewing). However, two nuisance non-native aquatic plant species, curlyleaf pondweed and purple loosestrife, threaten further degradation in the future. Non-native species typically follow an aggressive growth pattern and eliminate native species from a lake and from its shoreline. Hence, the following plant management projects are recommended to reduce non-native species to the greatest extent possible. A reduction in non-native species will insure continued attainment of the lake's aquatic communities goal.

Introduction of predator beetles along the shore of Silver Lake is recommended to reduce purple loosestrife coverage. Beetles are introduced each spring until a substantial reduction in purple loosestrife coverage has been achieved. The project is expected to span several years. Estimated cost of the management program is $3,000 annually for 3 to 6 years for a total cost of $9,000 to $18,000.

A whole-lake, low dose fluridone treatment is recommended to reduce curlyleaf pondweed coverage to the greatest extent possible. Treatment will occur in May. Fluridone will be evenly distributed at a concentration of 5 μg/L over the entire lake. The initial application will be followed in 2 to 3 weeks by a second booster application, designed to reestablish a whole-lake fluridone concentration of 5 μg/L. The booster application is necessary to maintain aqueous fluridone levels of at least 2 μg/L for more than 60 days, the exposure time required to control curlyleaf pondweed. Estimated treatment costs are $20,000 (2002 cost basis). A permit from the MDNR is required and, hence, must be obtained prior to treatment.

Water residue samples will be collected to insure fluridone levels of 5 μg/L are achieved following the initial and booster applications and to insure that fluridone levels are greater than 2 μg/L for at least 60 days. Six sample locations will be monitored one, four, and 10 days after the initial treatment and one, 10, 20, 30, and 60 days after the booster treatment. All samples will be analyzed for fluridone using the FasTEST technique (Getsinger et. al, 2001). Estimated cost of monitoring is $20,000 (2002 cost basis).

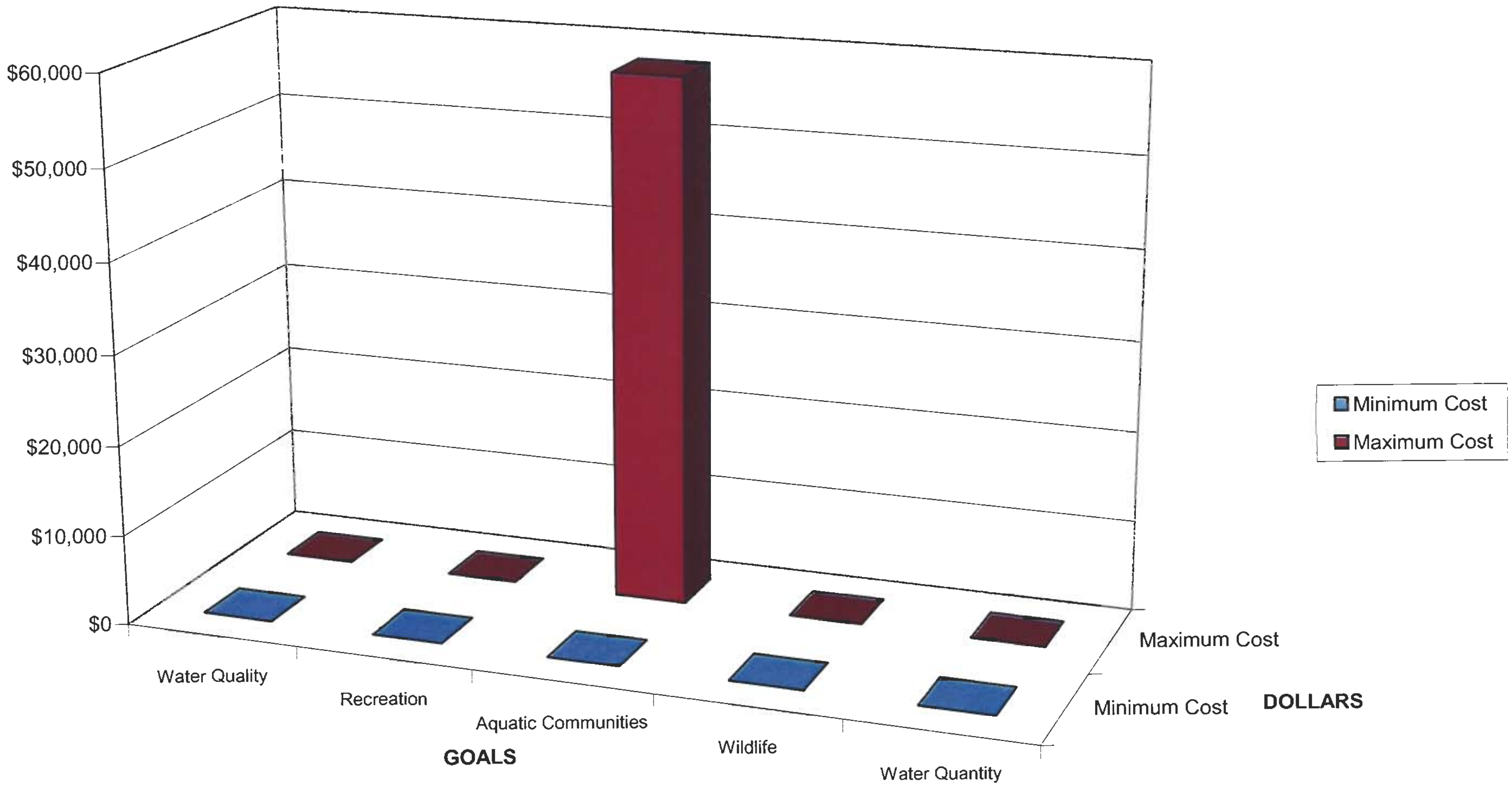
Benefits and Costs of Recommended Alternatives

Benefits and costs of recommended alternatives are shown in Table EX-1. Figure EX-3 graphically depicts program costs.

Table EX-1 Benefits and Costs of Recommended Alternatives

Treatment and Management Activities	Benefits	Estimated Cost (Dollars)
Goal Changes	Align numeric goal with nondegradation District policy.	No Cost.
Change District Policy to Achieve Reasonable National Goals and State Policy and Work to Affect Change in Unreasonable Criteria	Insure District policies are both reasonable and attainable.	No Cost.
Biological Control of Purple Loosestrife	Control purple loosestrife and protect native vegetation	$9,000 to $18,000
Whole Lake Fluridone Treatment to Control Curlyleaf Pondweed	Control curlyleaf pondweed and protect native vegetation	$20,000
Sampling Program Required by Fluridone Treatment	Insure fluridone levels are high enough to effectively control curlyleaf pondweed.	$20,000

Silver Lake
Costs to Meet or Exceed Goals



"Minimum Cost" is $0. All goals have been attained, assuming the water quality goal is changed based upon primary data.
"Maximum Cost" is the cost of the the non-native plant management program to prevent future habitat degradation.

Figure EX-3

Silver 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 Silver Lake. The plan articulated five specific goals for Silver Lake. These goals address recreation, aquatic communities, water quality, water quantity, and wildlife. This report: (1) evaluates the existing and potential beneficial uses intended in these goals; (2) and contains an analysis of the factors that potentially impair or limit those beneficial uses.

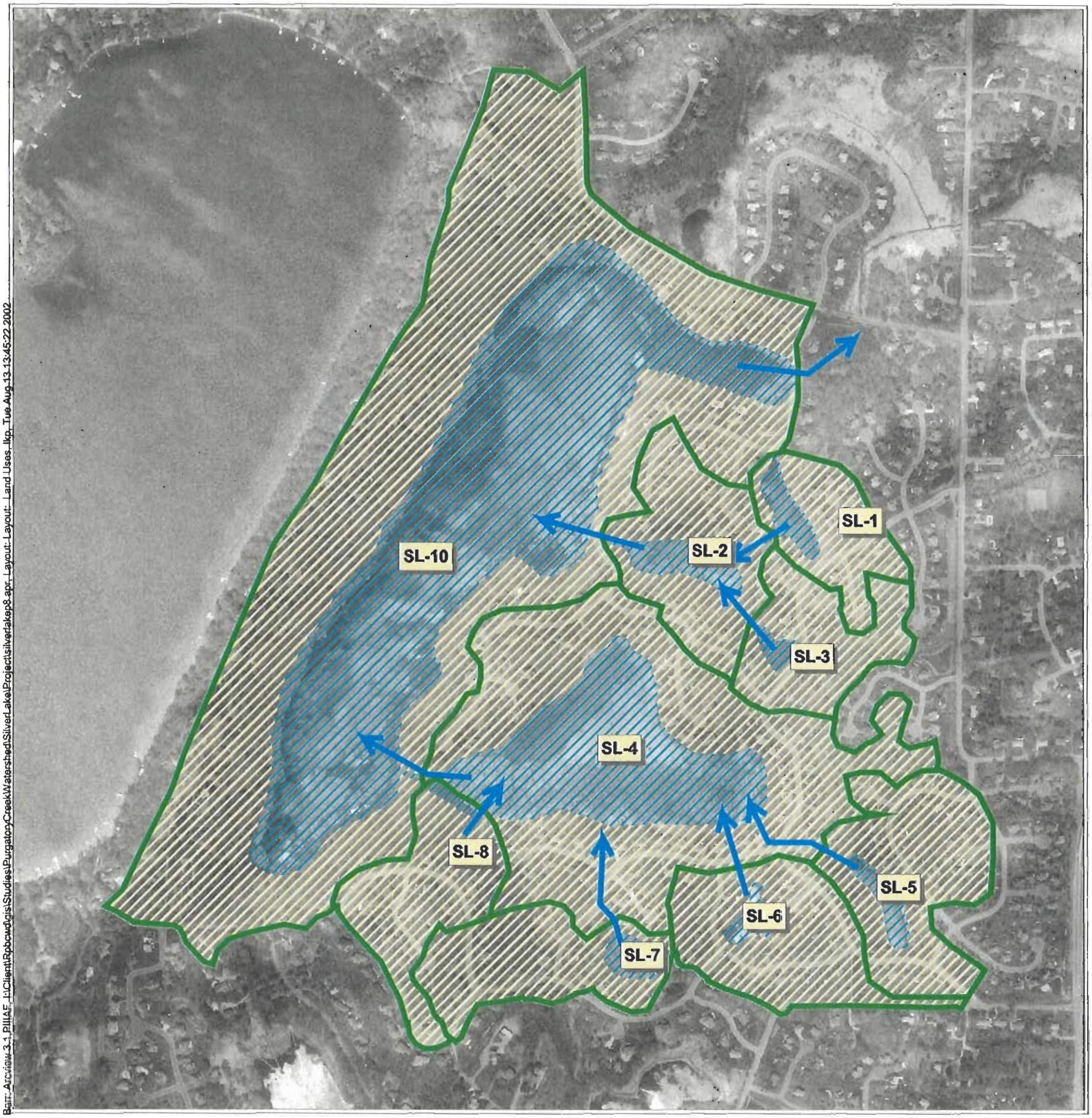
A use attainability analysis of Silver Lake was completed to provide the scientific foundation for a lake-specific best management plan that will maintain or attain the existing and potential beneficial uses of Silver Lake. A use attainability analysis evaluates existing and potential beneficial uses 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 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 tool for the technical analysis is an advanced water quality model that predicts the amount of pollutants that reach a lake via stormwater runoff. Calibrating the model to a lake requires an accurate determination of land use and measurement of the lake's water quality. Impacts of upland detention and treatment of stormwater are included in the model.

1.1 Land Use

All land use practices within a lake's watershed impact the lake and determine 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.

Silver Lake's watershed was evaluated from 2000 aerial photographs to determine its land uses. The lake's 251-acre watershed includes 78 acres of water and 173 acres of land. Water land uses include the 67-acre lake and 11 acres of stormwater treatment ponds. All of the watershed's land area is comprised of low density residential development (See Figure 1). The lake's watershed is fully developed. Hence, future land use changes are not anticipated.



Note: Device number and watershed designations are identical

Figure 1

2000 Silver Lake
Watershed Land Uses

1.2 Major Hydrologic Characteristics

Silver Lake has a surface area of 67 acres at normal water surface elevation (i.e., 898.0 feet), a maximum depth of approximately 13 feet, and a mean depth of approximately 3.0 feet. The lake's volume, outflow volume, and hydrologic residence time vary with climatic conditions (See Table 1).

Table 1 Silver Lake Estimated Volume, Outflow Volume, and Hydrologic Residence Time During Varying Climatic Conditions

Climatic Condition (Water Year,-inches of Precipitation)	Estimated Lake Volume in m^3 (Estimated Lake Volume in acre-ft)	Estimated Lake Outflow in m^3 (Estimated Lake Outflow in acre-feet)	Estimated Hydrologic Residence Time in Years
Wet Year (1983, 41-inches)	248,042 (201)	259,250 (210)	1
Average Year (1995, 27-inches)	248,042 (201)	76,328 (62)	3
Model Calibration Year (2000, 20-inches)	248,042 (201)	39,365 (32)	6
Dry Year (1988, 19-inches)	248,042 (201)	8,556 (7)	29

Of the thirteen major lakes in the District, Silver Lake is eleventh in surface area and thirteenth in volume.

The outlets to Silver and Lotus lakes are the beginning of Purgatory Creek. The two streams later merge to become a single stream.

1.3 Water Quality

1.3.1 Data Collection

Water quality data were collected from Silver Lake during 1996 and 2000. Data were collected during spring, approximately 2 weeks after ice-out, and five times during the summer period (i.e., June through early September).

1.3.2 Baseline/Current Water Quality

Baseline water quality data include data collected prior to 1988. Baseline water quality data are not available for Silver Lake because data were first collected in 1996. Data collected since 1988 comprise current water quality. A discussion of current water quality follows.

An evaluation of 1996 and 2000 Silver Lake water quality data 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.

Figures 2 and 3 summarize the seasonal changes in concentrations of total phosphorus and chlorophyll *a* and Secchi disc transparencies for Silver Lake during 1996 and 2000. The data are compared with a standardized lake rating system.

Total phosphorus data collected from Silver Lake during 1996 and 2000 indicate the lake's nutrient levels are consistently high enough to cause nuisance algal blooms. All data were in the hypereutrophic (very poor water quality) category. The lake's phosphorus levels were high following spring ice-out (i.e., 80 μg/L in 1996 and 84 μg/L in 2000) and concentrations doubled (1996) or tripled (2000) during the spring through late summer period.

During 1996, approximately 30 percent of the spring to summer phosphorus increase was attributed to internal loading. Internal loading includes macrophyte senescence (i.e., curlyleaf pondweed that dies out around July 1) and the release of phosphorus from the lake's sediments. Watershed loading (46%) and atmospheric deposition (24%) comprised the remaining seventy percent of the spring to summer phosphorus increase.

During 2000, approximately 56 percent of the spring to summer phosphorus increase was attributed to internal loading. Watershed loading (32 percent) and atmospheric deposition (12 percent) comprised the remaining 44 percent of the spring to summer phosphorus increase.

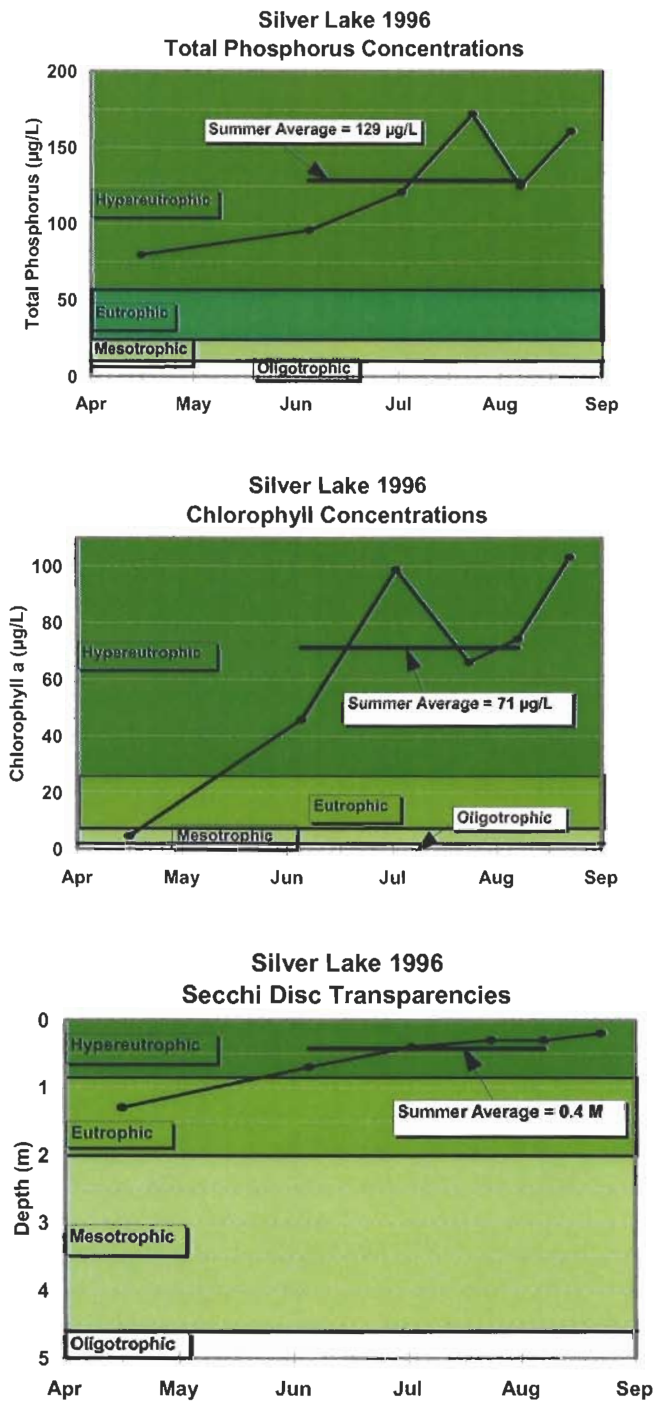
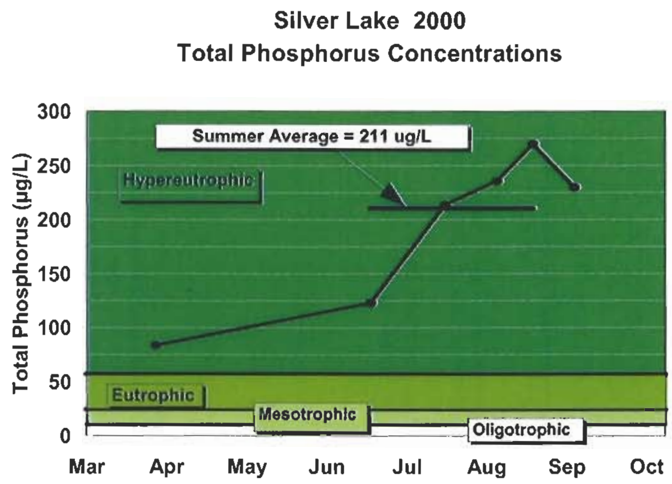
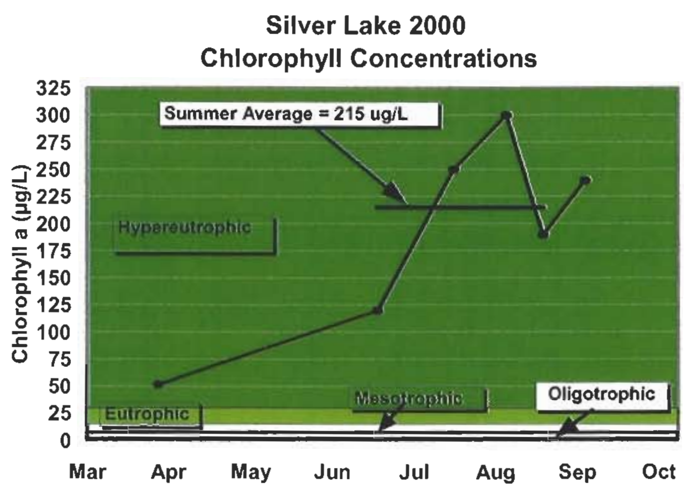


Figure 2. 1996 Seasonal Changes in Total Phosphorus and Chlorophyll a Concentrations and Secchi Disc Transparencies





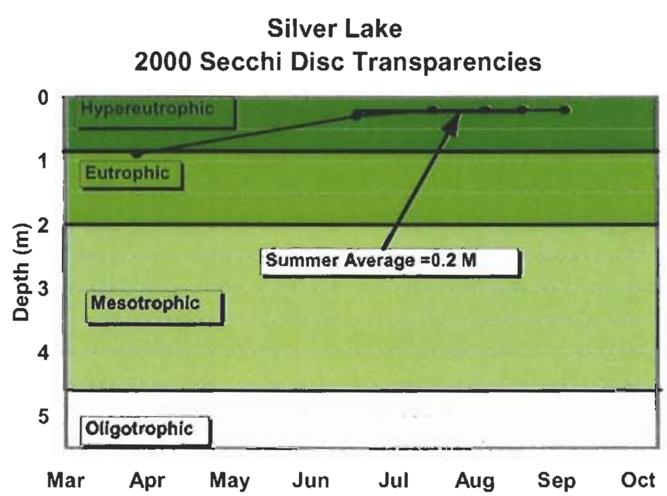


Figure 3. 2000 Seasonal Changes in Total Phosphorus and Chlorophyll a Concentrations and Secchi Disc Transparencies

The 1996 and 2000 Silver Lake average summer total phosphorus concentrations (measured at the 0- to 2-meter depth) were 129 μg/L and 211 μg/L, respectively. Between year differences are attributed to differences in phosphorus loading to the lake. The April through August phosphorus load to the lake during 2000 (50.3 kg) is estimated to be approximately double the 1996 load (25.1 kg). Loading differences resulted from differences in watershed loading and internal loading.

The 1996 and 2000 Silver Lake chlorophyll *a* measurements (i.e., measured at 0-2 meters) generally exceeded nuisance levels (>20 μg/L). With the exception of the 1996 spring measurement, chlorophyll measurements were consistently in the hypereutrophic (very poor water quality) category.

The lake's nuisance chlorophyll levels resulted from high spring concentrations and large increases throughout the spring and summer period. The lake's chlorophyll concentration increased by an order of magnitude during the 1996 spring to early summer period and doubled during the same period in 2000. In both years, the lake's chlorophyll concentration more than doubled from early to late summer. Concurrent increases in phosphorus and chlorophyll concentrations during both years indicated the lake's algal mass is determined by its phosphorus concentrations.

Poor water transparency resulted from the lake's nuisance chlorophyll levels. The 1996 and 2000 Secchi disc measurements in Silver Lake were in the hypereutrophic (very poor water quality) category during all but the spring sample events.

Increasing algal mass throughout the spring and summer period further reduced the lake's water transparency. The lake's Secchi disc transparency decreased by one half (1996) to two thirds (2000) during the spring to early summer period. The lake's water transparency then declined continually during the summer to a minimum of 0.2 meters. Upon reaching the minimum of 0.2 meters, the lake's water transparency remained stable for the duration of the summer period. The minimum value occurred in late summer during 1996 and by mid-summer during 2000.

The data indicate severe recreational-use impairment occurred throughout the summer (Osgood, 1989). The lake's poor water transparency and resultant recreational-use impairment appear to be largely determined by algal abundance.

1.4 Ecosystem Data

1.4.1 Aquatic Ecosystems

Ecosystem describes the community of living things within Silver Lake and their interaction with the environment in which they live. The interdependency of the ecosystem is best illustrated by the food web. The food web begins with the primary producers, which are green plants, such as phytoplankton (algae) and macrophytes (aquatic weeds). They take in carbon dioxide and water and use the sun's energy to produce their own food. Next in the chain are the primary consumers or herbivores, which eat plants. The most populous of these consumers is the zooplankton, which prey upon algae (phytoplankton). Succeeding the primary consumers are the secondary consumers or planktivores, which include sunfish and crappies. The diet of these fish includes zooplankton and other primary consumers. Tertiary consumers or predator fish occupy the next level of the food chain. This group includes bass and northern pike, which consume crappies and bluegill sunfish. At the top of the food chain are omnivores, such as humans, which eat bass and northern pike. A less visible component of the food chain, the decomposers, include bacteria living at the lake bottom, which break down dead and decaying organisms into nutrients and other essential elements (See Figure 4). All life in a food chain is interdependent. If any one group becomes unbalanced, all life in the food chain is adversely impacted. An aquatic ecosystem is managed to maintain balance between the phytoplankton, zooplankton, small fish (crappies and bluegill sunfish), and large fish (bass and northern pike).

Silver Lake ecosystem information is comprised of nutrient, phytoplankton, zooplankton, and macrophyte data. The data indicate the lake's ecosystem is typical of a hypereutrophic (very poor water quality) small, shallow lake in this region. Nutrient data were discussed previously in Section 1.3.2 Baseline/Current Water Quality. A discussion of phytoplankton, zooplankton, and macrophyte data follows.

1.4.1.1 Phytoplankton

The phytoplankton species in Silver Lake form the base of the lake's food web. Phytoplankton, also called algae, are small aquatic plants naturally present in all lakes. They derive energy from sunlight (through photosynthesis) and from dissolved-nutrients found in lake water. They provide food for several types of animals, including zooplankton, which are in turn eaten by fish. A phytoplankton population in balance with the lake's zooplankton population is ideal for fish production. An inadequate phytoplankton population reduces the lake's zooplankton population and adversely

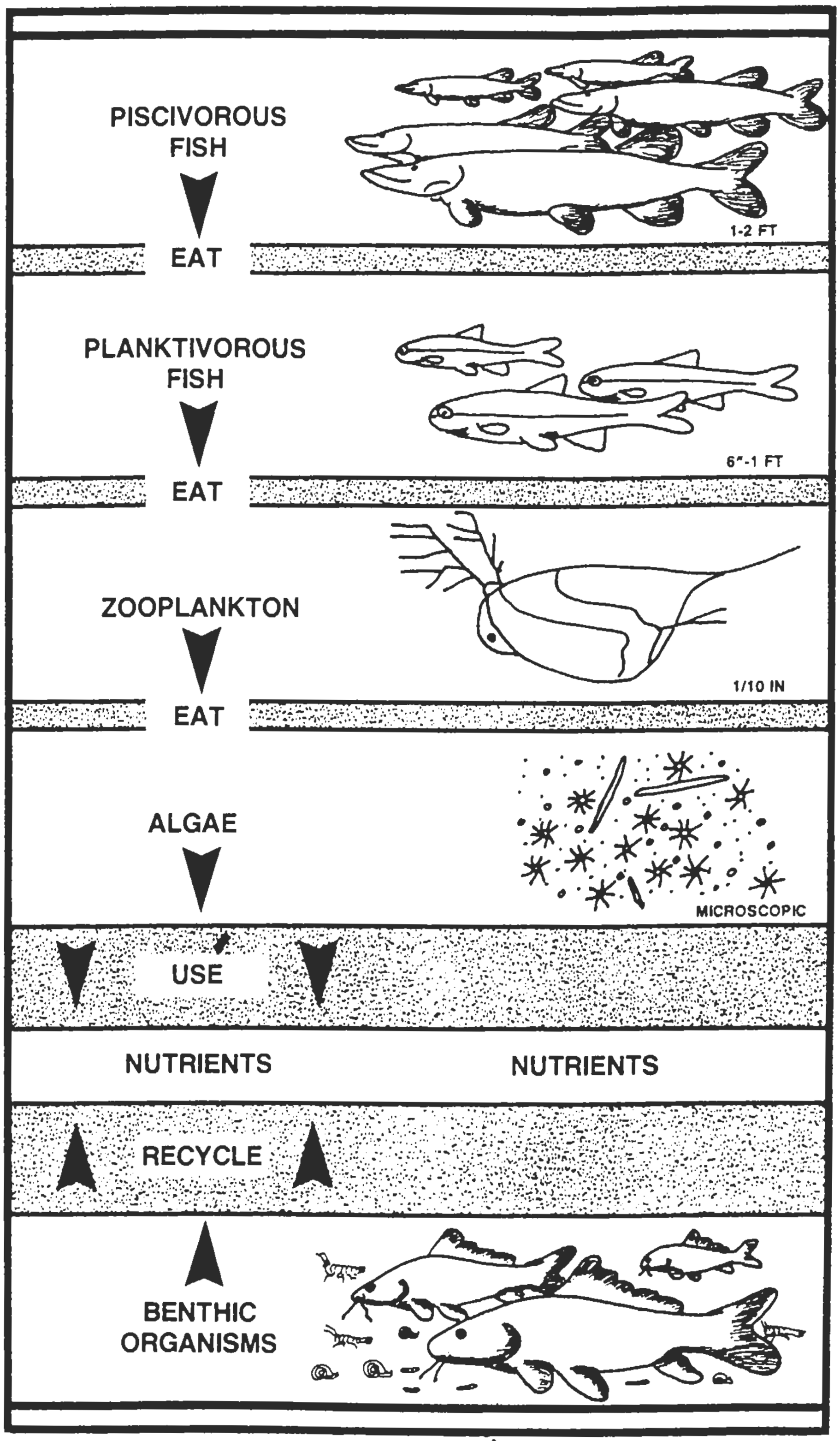


Figure 4
THE FOOD WEB

impacts the lake's fishery. Excess phytoplankton, however, reduce water clarity and reduced water clarity can interfere with the recreational usage of a lake.

Blue-green algae generally dominated the Silver Lake phytoplankton community during 1996 and 2000 (Figures 5 and 6). The lake's high algal numbers were consistent with the lake's high chlorophyll concentrations. Chlorophyll concentrations and algal numbers increased from spring through summer to a late summer maximum. Highest chlorophyll concentrations and algal numbers were observed during early September in 1996 and during early August in 2000. Higher chlorophyll concentrations and algal numbers were observed during 2000 than 1996.

The quantity of algae in a lake or algal volume is a function of the number of individual algae in the lake and the size of each individual. Algal sizes vary greatly. Green algae, cryptomonads, and diatoms are small in size and represent very low algal volumes. Blue-green algae are generally larger in size and, consequently, represent relatively high volumes. Silver Lake was generally dominated by blue-green algae. Because of the high numbers and blue-green dominance, the lake consistently noted high algal volumes (See Figures 7 and 8). Higher algal volumes were noted during 2000 than 1996. The seasonal high volume during both years occurred during early August. The excess numbers and high volumes of phytoplankton during the summers caused them to be out of balance with the other organisms in the lake's food web (See Figure 9).

Dominance by blue-green algae during the monitoring period was unfavorable for the following reasons:

- Blue-green algae are inedible to fish, waterfowl, and most zooplankters and, hence, not subject to biological control;
- Blue-green algae float at the lake surface in expansive algal blooms;
- Blue-green algae may be toxic to animals when occurring in large blooms;
- Blue-green algae disrupt lake recreation during the summer period.

Blue-green algal growth is stimulated by excess phosphorus loads. The growing conditions in summer are particularly favorable to blue-green algae, and they have a competitive advantage over the other algal species during this time. A reduction in phosphorus loads is required for a reduction in blue-green algal growth.

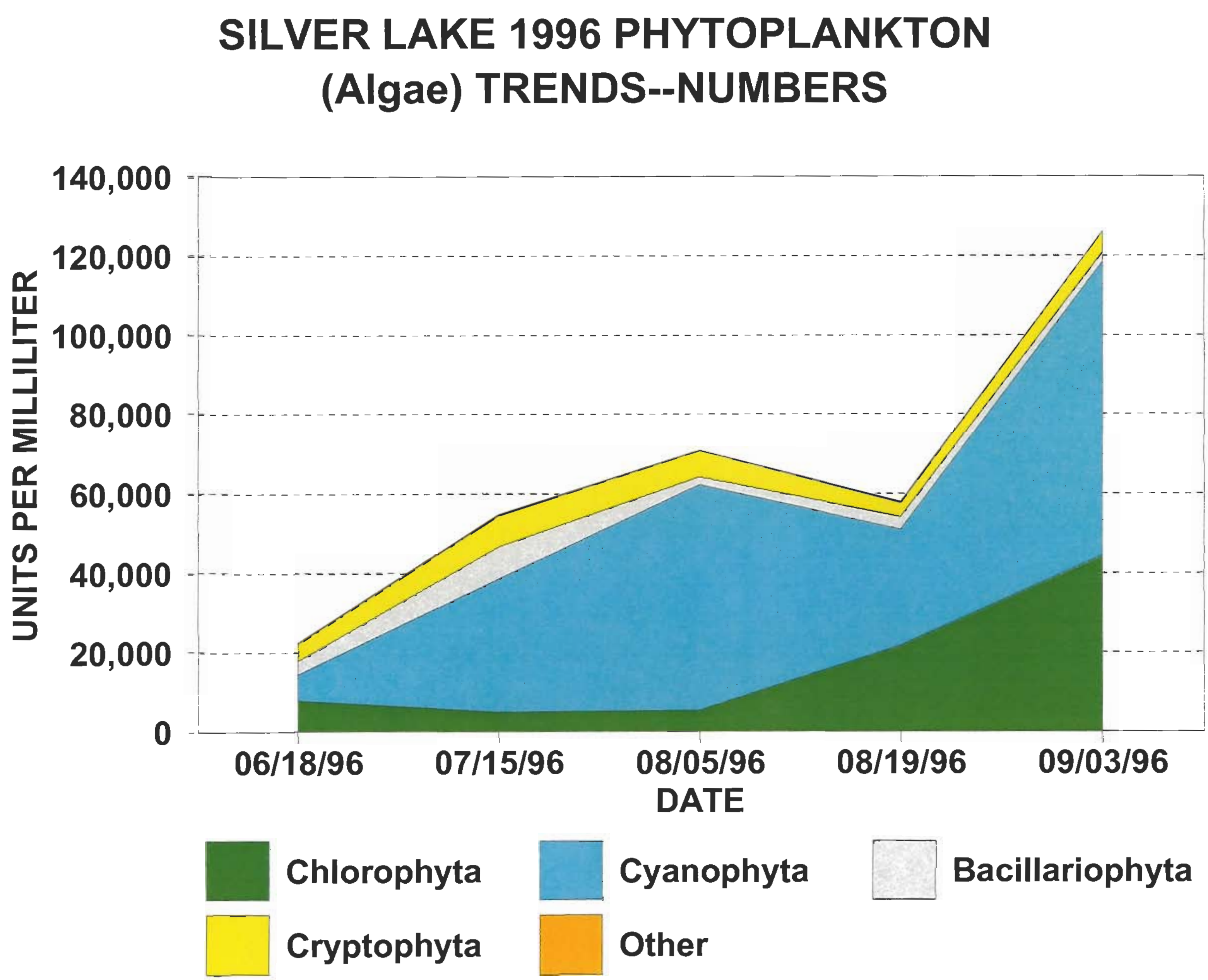

SILVER LAKE 1996 PHYTOPLANKTON
(Algae) TRENDS--NUMBERS
UNITS PER MILLILITER
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
06/18/96
07/15/96
08/05/96
08/19/96
09/03/96
DATE
Chlorophyta
Cyanophyta
Bacillariophyta
Cryptophyta
Other

Figure 5

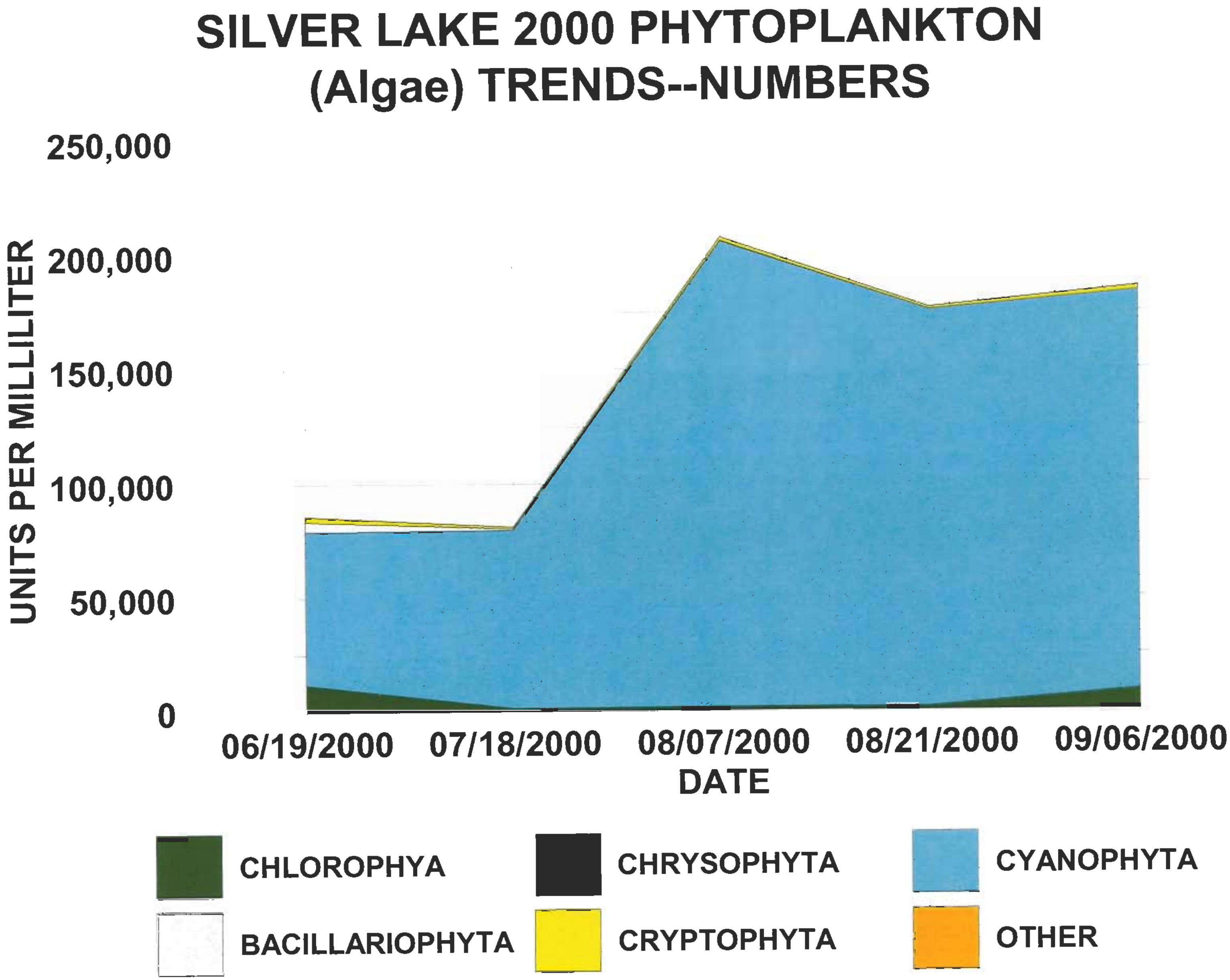

SILVER LAKE 2000 PHYTOPLANKTON
(Algae) TRENDS--NUMBERS
UNITS PER MILLILITER
250,000
200,000
150,000
100,000
50,000
0
06/19/2000
07/18/2000
08/07/2000
08/21/2000
09/06/2000
DATE
CHLOROPHYA
CHRYSOPHYTA
CYANOPHYTA
BACILLARIOPHYTA
CRYPTOPHYTA
OTHER

Figure 6

SILVER LAKE 1996 PHYTOPLANKTON (Algae) TRENDS--VOLUMES

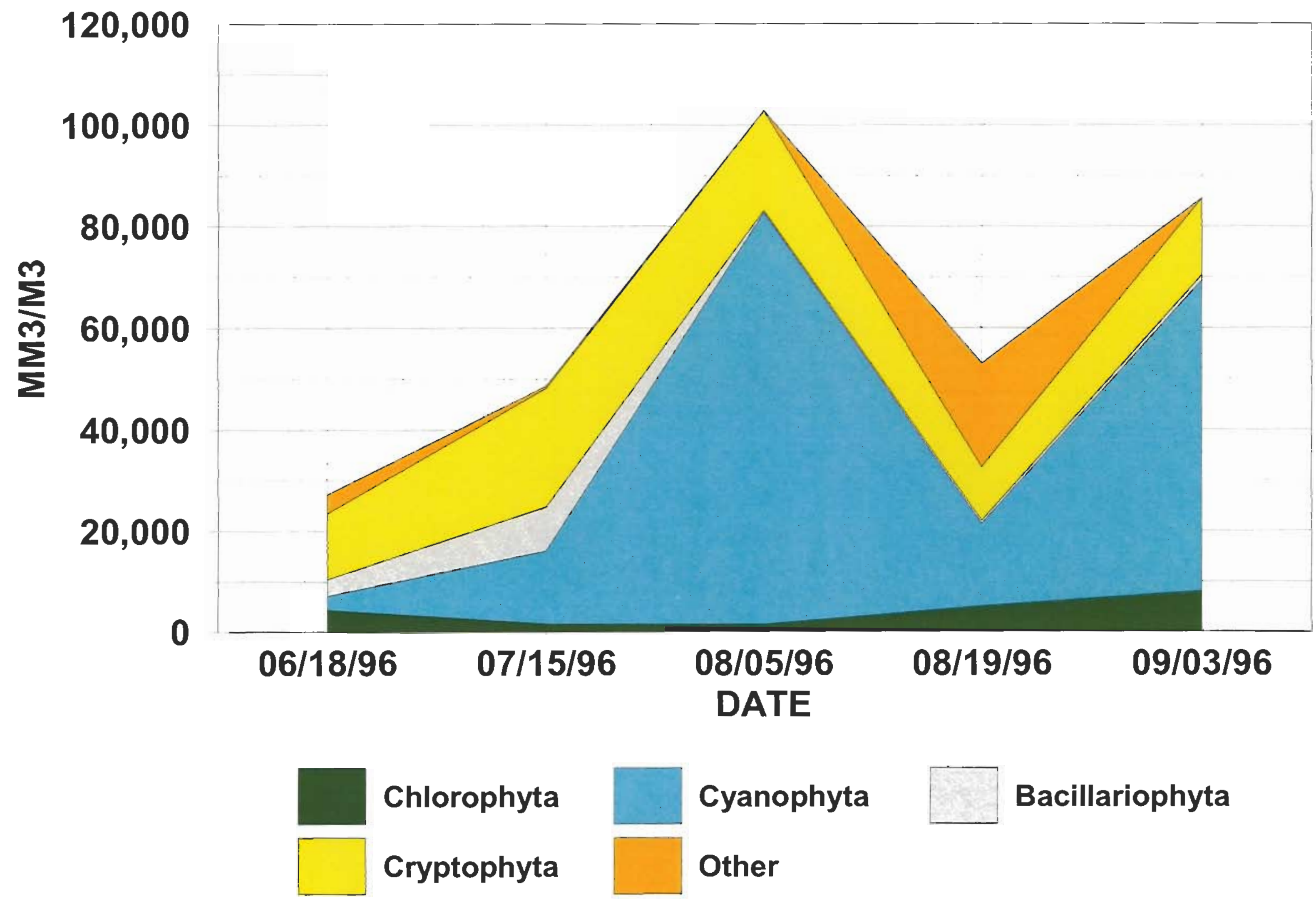


Figure 7

SILVER LAKE 2000 PHYTOPLANKTON (Algae) TRENDS--VOLUMES

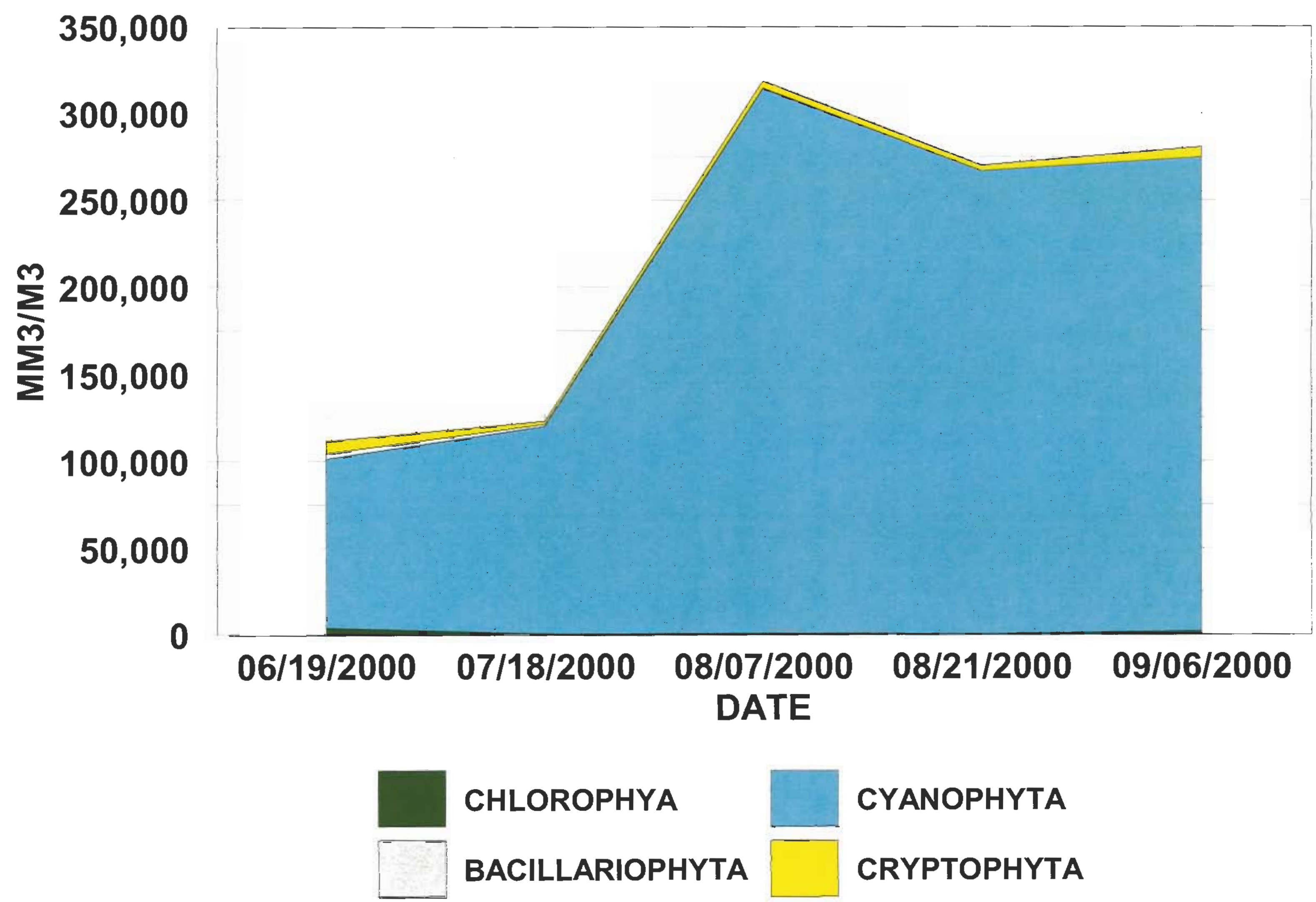


Figure 8

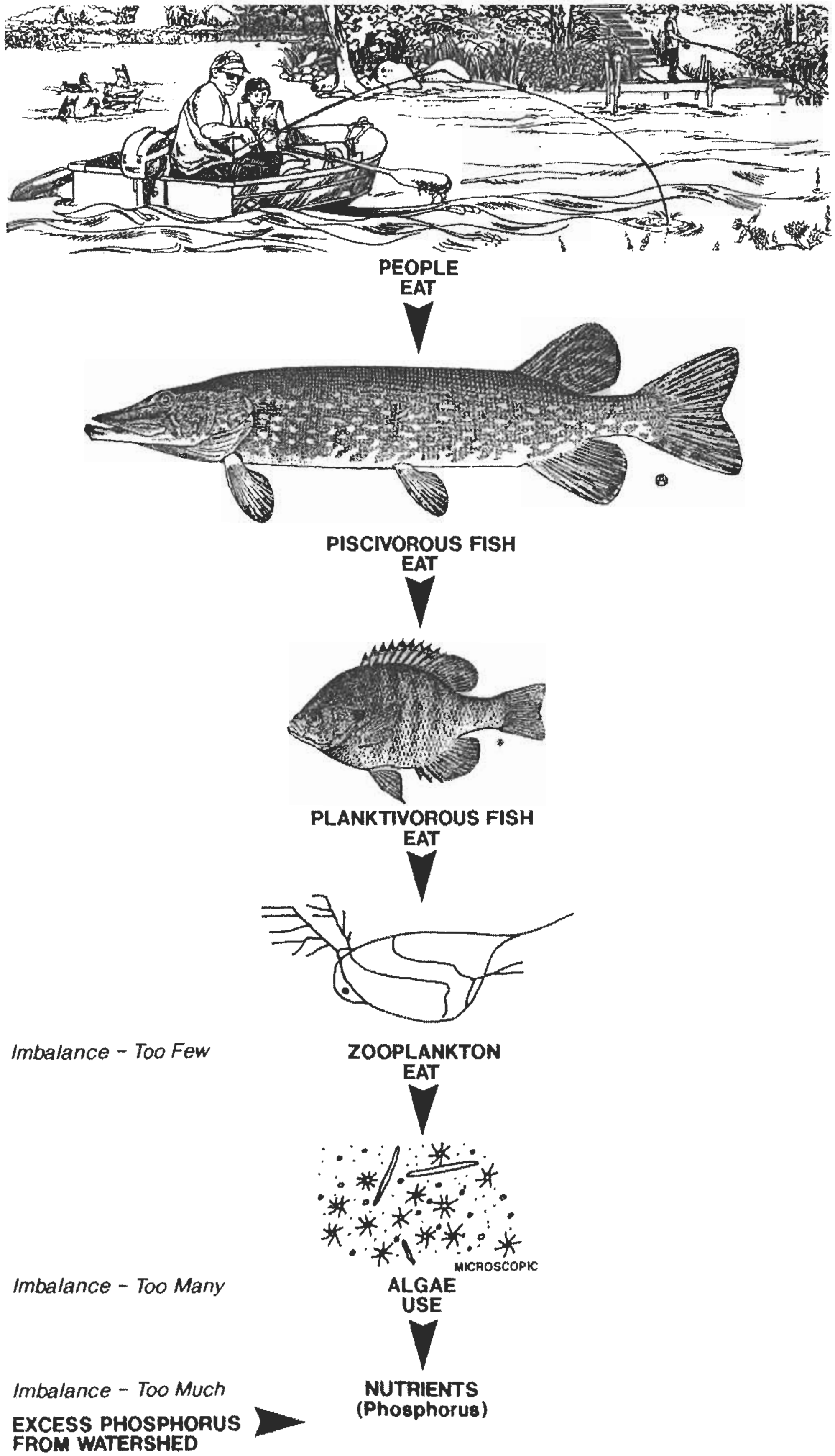


Figure 9

SILVER LAKE
IMBALANCED ECOSYSTEM

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1.4.1.2 Zooplankton

Zooplankton are the second step in the Silver Lake food web. They are microscopic animals that feed on particulate matter, including algae, and are, in turn, eaten by fish.

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).

Although the three groups were represented during 1996 and 2000, the zooplankton community in Silver Lake was dominated by small-bodied zooplankters (Figures 10 and 11). Large-bodied zooplankters (i.e., *Daphnia galeata mendotae*) comprised less than 1 percent of the zooplankton community during sample events. Fish predation of the larger-bodied zooplankters likely resulted in dominance by smaller-bodied zooplankters throughout the sample period. The low numbers of large-bodied zooplankters have minimized biological control of the lake's phytoplankton.

SILVER LAKE 1996 ZOOPLANKTON TRENDS

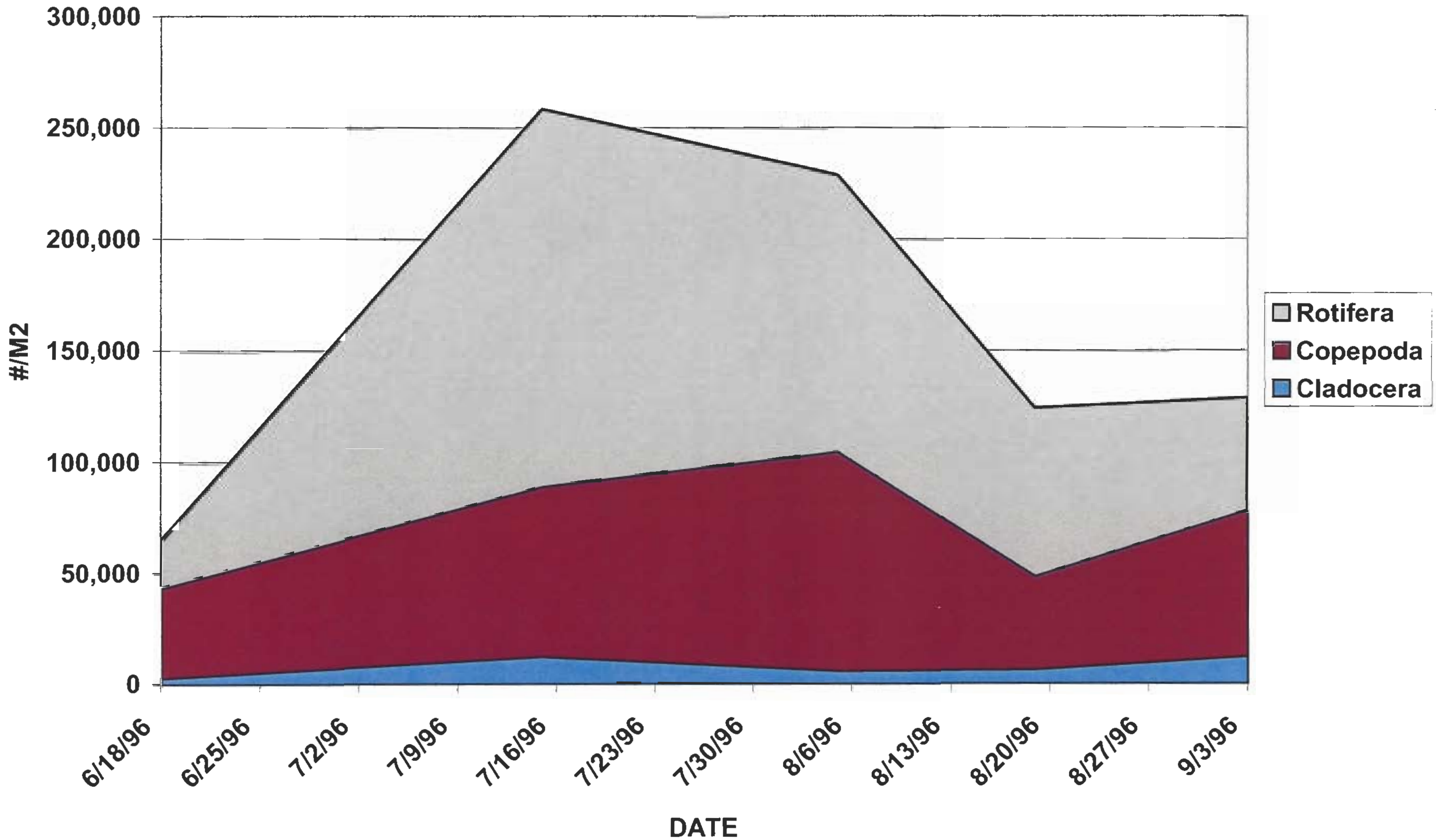
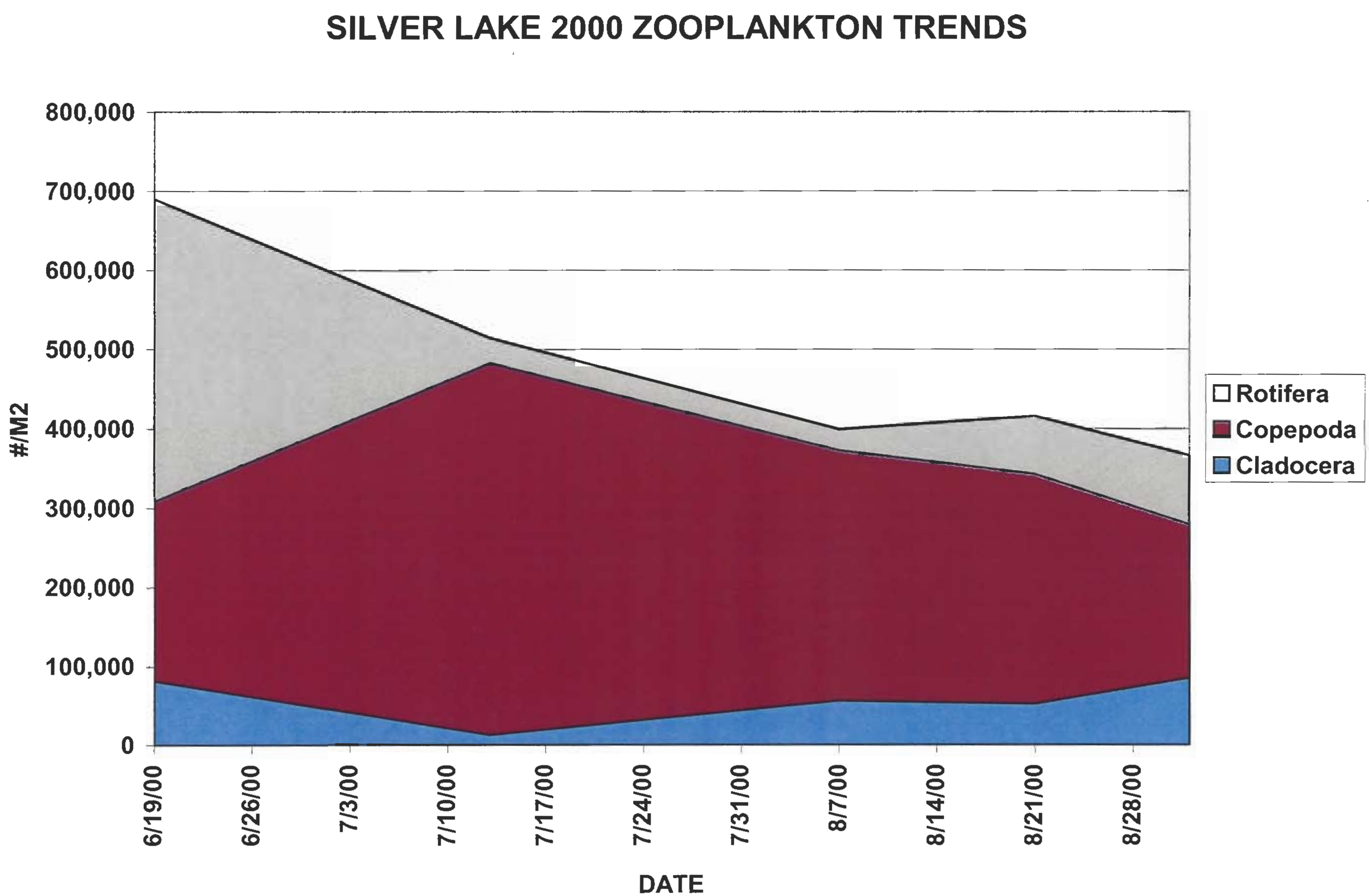


Figure 10



SILVER LAKE 2000 ZOOPLANKTON TRENDS
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
#/M2
6/19/00
6/26/00
7/3/00
7/10/00
7/17/00
7/24/00
7/31/00
8/7/00
8/14/00
8/21/00
8/28/00
DATE
Rotifera
Copepoda
Cladocera

Figure 11

1.4.1.3 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
- Provide food for waterfowl, fish, and wildlife
- Produce oxygen
- Provide spawning areas for fish in early-spring
- Help stabilize marshy borders and protect shorelines from wave erosion
- Provide nesting sites for waterfowl and marsh birds

Silver Lake's macrophytes were surveyed on June 20 (Figure 12) and August 22 (Figure 13) during 1996 and on June 12 (Figure 14) and August 23 (Figure 15) during 2000.

In 1996, submerged aquatic plants were found to depths of 5 to 6 feet during the June survey. Reduced water transparency during August limited aquatic plant growth to depths of 4 feet. The pattern of submerged, floating, and emergent plants did not change substantially between the two sampling periods, but there were species changes.

The 1996 Silver Lake macrophyte community had typical submerged aquatic plant species, as well as species that are rarely seen in this watershed district. Typical species included two nuisance non-native species. Curlyleaf pondweed (*Potamogeton crispus*) was identified at light to moderate densities along the northeast side of the lake in June and was not found in August (typical for this species). Purple loosestrife (*Lythrum salicaria*) has invaded both the south and north ends of Silver Lake, and was noted as dense in the north end. The unusual species were wild rice (*Zizania aquatica*) and bladderwort (*Utricularia sp.*). The wild rice was dispersed around the lake at a low density. Bladderwort growth was limited to the northern end of the lake.

In 2000, submerged aquatic plants were found to depths of 5 feet during the June and August surveys. The pattern of submerged and emergent plants did not change substantially between the two sampling periods. However, floating plants were more abundant during the August survey than the June survey. The 2000 macrophyte community was very similar to the community observed during 1996. Species changes between the two years include siting the species *Utricularia sp.* in 1996, but not in 2000. Similarly, *Potamogeton sp.* (a narrowleaf Potamogeton) was sited in 2000 and not in 1996. Other macrophyte species noted a similar coverage and density during the two surveys.

RILEY - PURGATORY- BLUFF CREEK WATERSHED DISTRICT
SILVER LAKE - MACROPHYTE SURVEY
JUNE 20, 1996

- No Macrophytes Found in Water >5.0' - 6.0'
- Macrophyte Densities Estimated as Follows: 1=light; 2=moderate; 3= heavy

Aquatic Vegetation: *Woffia Columbiana* (water meal), *Lemna trisulca* (star duckweed) and *Spirodela polyrhiza* (greater duckweed) were present on the lake surface.

	Common Name	Scientific Name
Submerged Aquatic Plants:	Sago pondweed	*Potamogeton pectinatus*
	Curly leaf pondweed	*Potamogeton crispus*
	Flatstem pondweed	*Potamogeton zosteriformis*
	Coontail	*Ceratophyllum demersum*
	Wild rice	*Zizania aquatica*
	Elodea	*Elodea canadenis*
	Bladderwort	*Utricularia spp.*
Emergent:	Cattail	*Typha spp.*
	Purple loosestrife	*Lythrum salicaria*
Floating Leaf:	See aquatic vegetation comments above.	
No Aquatic Vegetation Found:		

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Figure 12

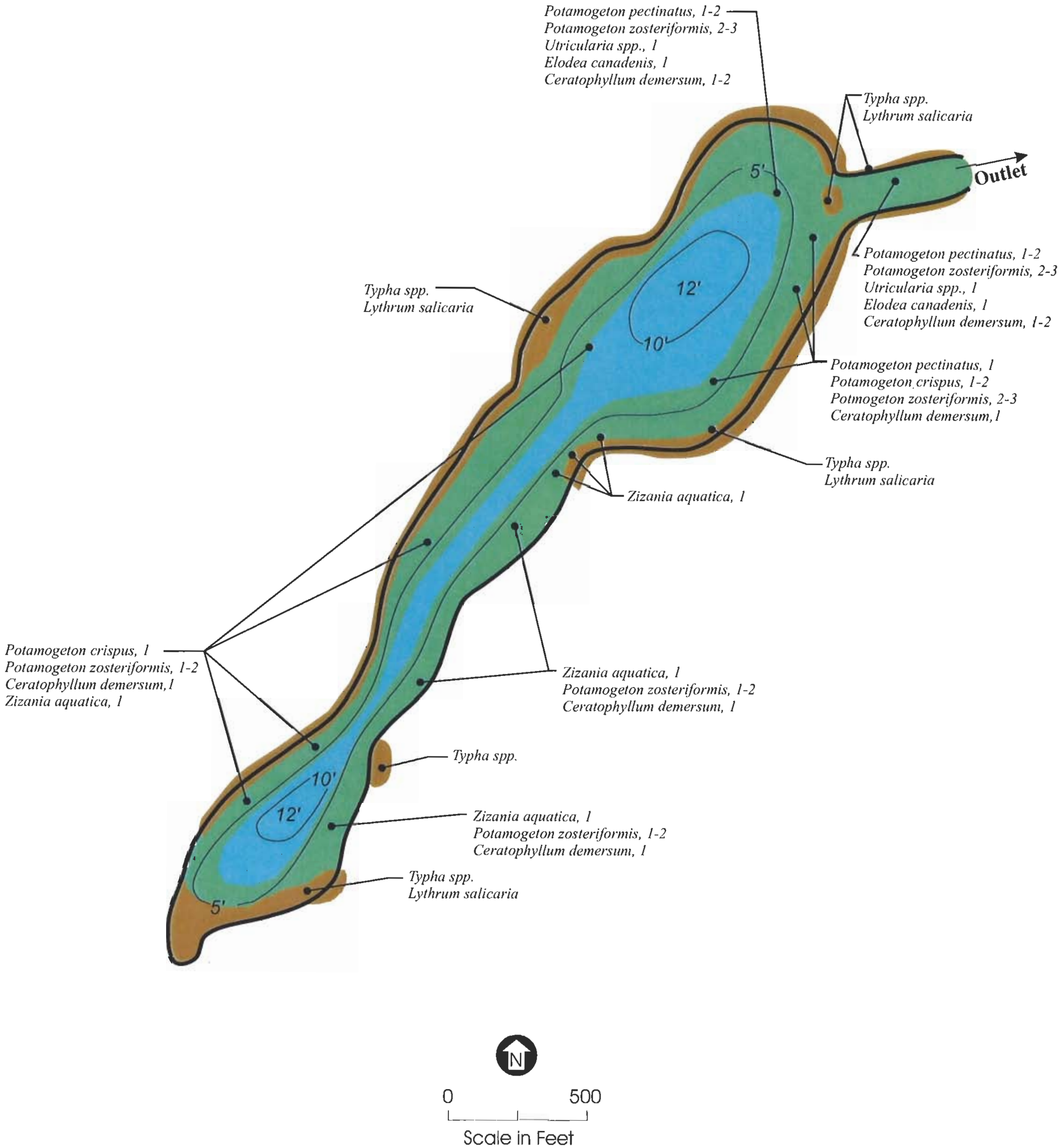

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Figure 12
(continued)

SILVER LAKE
June 20, 1996

RILEY - PURGATORY- BLUFF CREEK WATERSHED DISTRICT
SILVER LAKE - MACROPHYTE SURVEY
AUGUST 22, 1996

- No Macrophytes Found in Water >4.0'
- Macrophyte Densities Estimated as Follows: 1=light; 2=moderate; 3= heavy

Aquatic Vegetation: *Woffia columbiana* (water meal), *Lemna trisulca* (star duckweed) and *Spirodela polyrhiza* (greater duckweed) were present on the lake surface. Dense areas of *Lythrum salicaria* (purple loosestrife) around perimeter of lake.

	Common Name	Scientific Name
Submerged Aquatic Plants:	Sago pondweed	*Potamogeton pectinatus*
	Curly leaf pondweed	*Potamogeton crispus*
	Flatstem pondweed	*Potamogeton zosteriformis*
	Coontail	*Ceratophyllum demersum*
	Wild rice	*Zizania aquatica*
	Elodea	*Elodea canadenis*
	Bladderwort	*Utricularia spp.*
Emergent:	Cattail	*Typha spp.*
	Purple loosestrife	*Lythrum salicaria*
Floating Leaf:	See aquatic vegetation comments above.	
No Aquatic Vegetation Found:		

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Figure 13

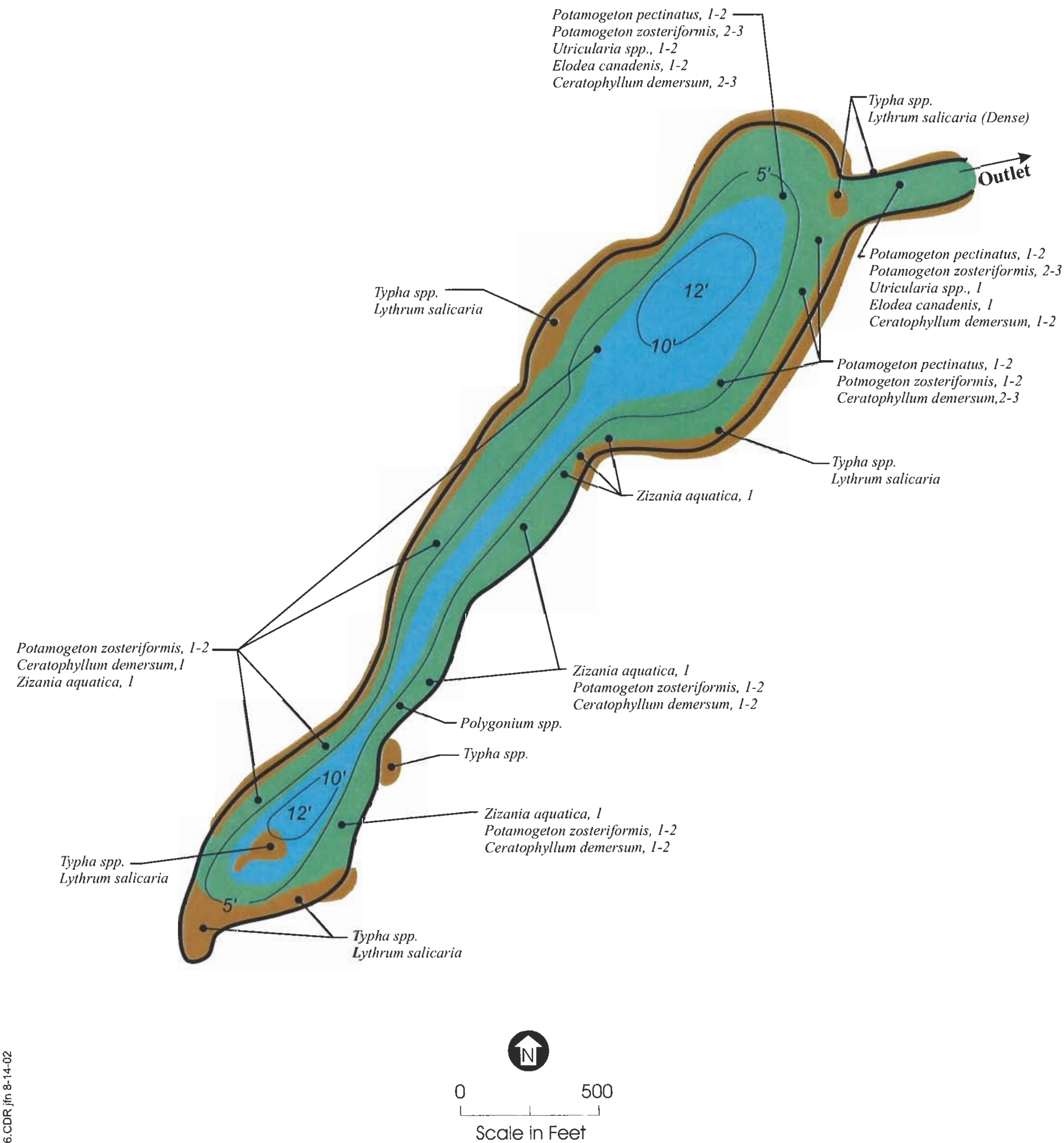

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Figure 13
(continued)

SILVER LAKE
August 22, 1996

SILVER LAKE MACROPHYTE SURVEY
June 12, 2000

- No Macrophytes Found in Water > 5.0'
- Macrophyte Densities Estimated As Follows: 1=Light; 2=Moderate; 3= Heavy
- *Spirodela polyrhiza* (greater duckweed) and *Lemna minor* (lesser duckweed) are present throughout the lake.

	Common Name	Scientific Name
Submerged Aquatic Plants:	Narrowleaf pondweed	*Potamogeton spp. (narrowleaf)*
	Curly leaf pondweed	*Potamogeton crispus*
	Flatstem pondweed	*Potamogeton zosteriformis*
	Sago pondweed	*Potamogeton pectinatus*
	Coontail	*Ceratophyllum demersum*
	Elodea	*Elodea canadensis*
Floating Leaf:	White water lily	*Nymphaea tuberosa*
	Greater duckweed	*Spirodela polyrhiza*
	Lesser duckweed	*Lemna minor*
Emergent:	Cattail	*Typha spp.*
	Purple Loosestrife	*Lythrum salicaria*
	Wild rice	*Zizania aquatica*
No Aquatic Vegetation Found:		

Figure 14

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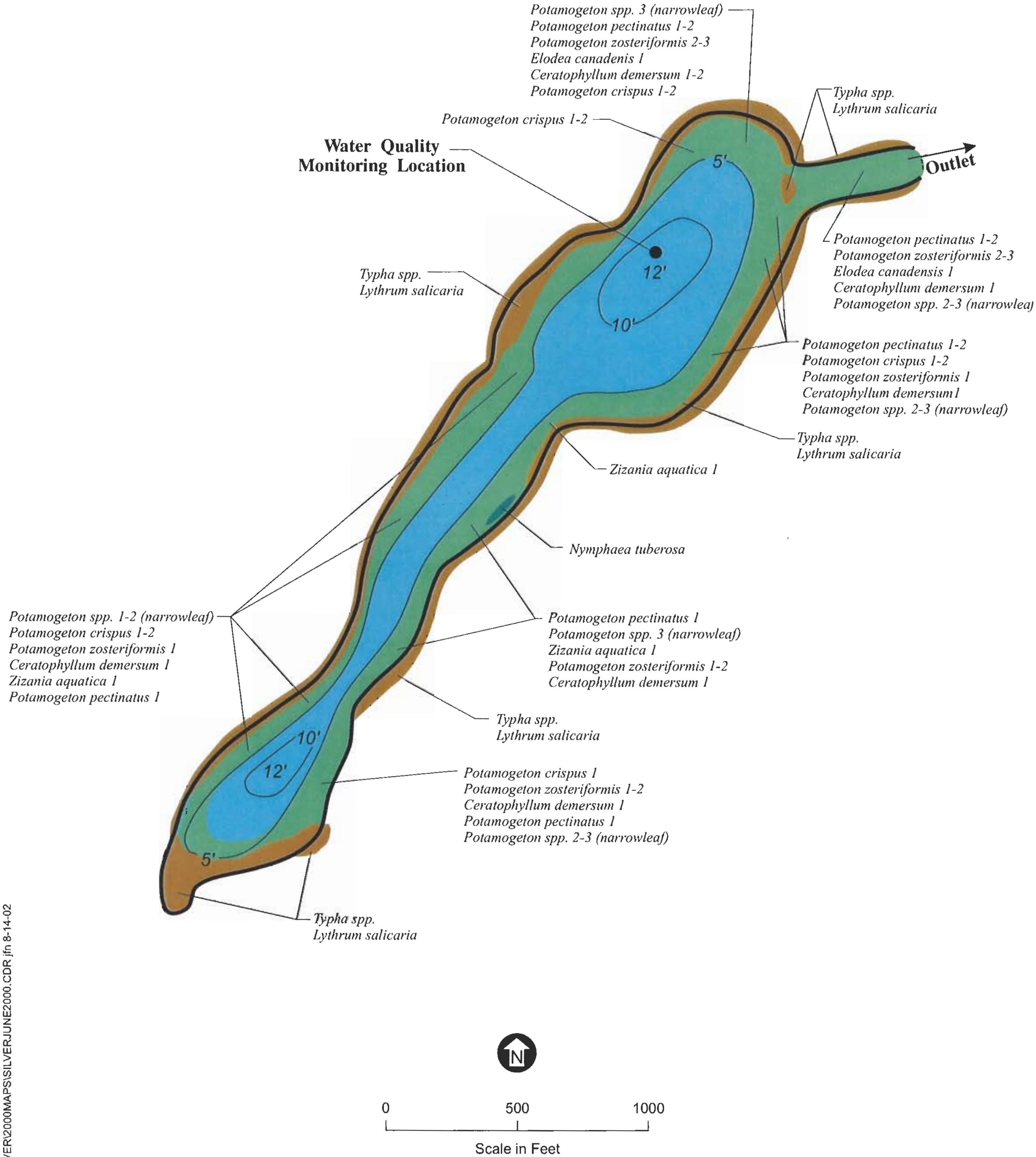

Figure 14
(continued)

SILVER LAKE
June 12, 2000

SILVER LAKE MACROPHYTE SURVEY
August 23, 2000

- No Macrophytes Found in Water > 5.0'
- Macrophyte Densities Estimated As Follows: 1=Light; 2=Moderate; 3= Heavy
- *Spirodela polyrhiza* (greater duckweed) and *Lemna minor* (lesser duckweed) are present throughout the lake.

	Common Name	Scientific Name
Submerged Aquatic Plants:	Narrowleaf pondweed	*Potamogeton spp. (narrowleaf)*
	Flatstem pondweed	*Potamogeton zosteriformis*
	Sago pondweed	*Potamogeton pectinatus*
	Coontail	*Ceratophyllum demersum*
	Elodea	*Elodea canadensis*
Floating Leaf:	White water lily	*Nymphaea tuberosa*
	Greater duckweed	*Spirodela polyrhiza*
	Lesser duckweed	*Lemna minor*
Emergent:	Cattail	*Typha spp.*
	Purple Loosestrife	*Lythrum salicaria*
	Wild rice	*Zizania aquatica*
No Aquatic Vegetation Found:		

Figure 15

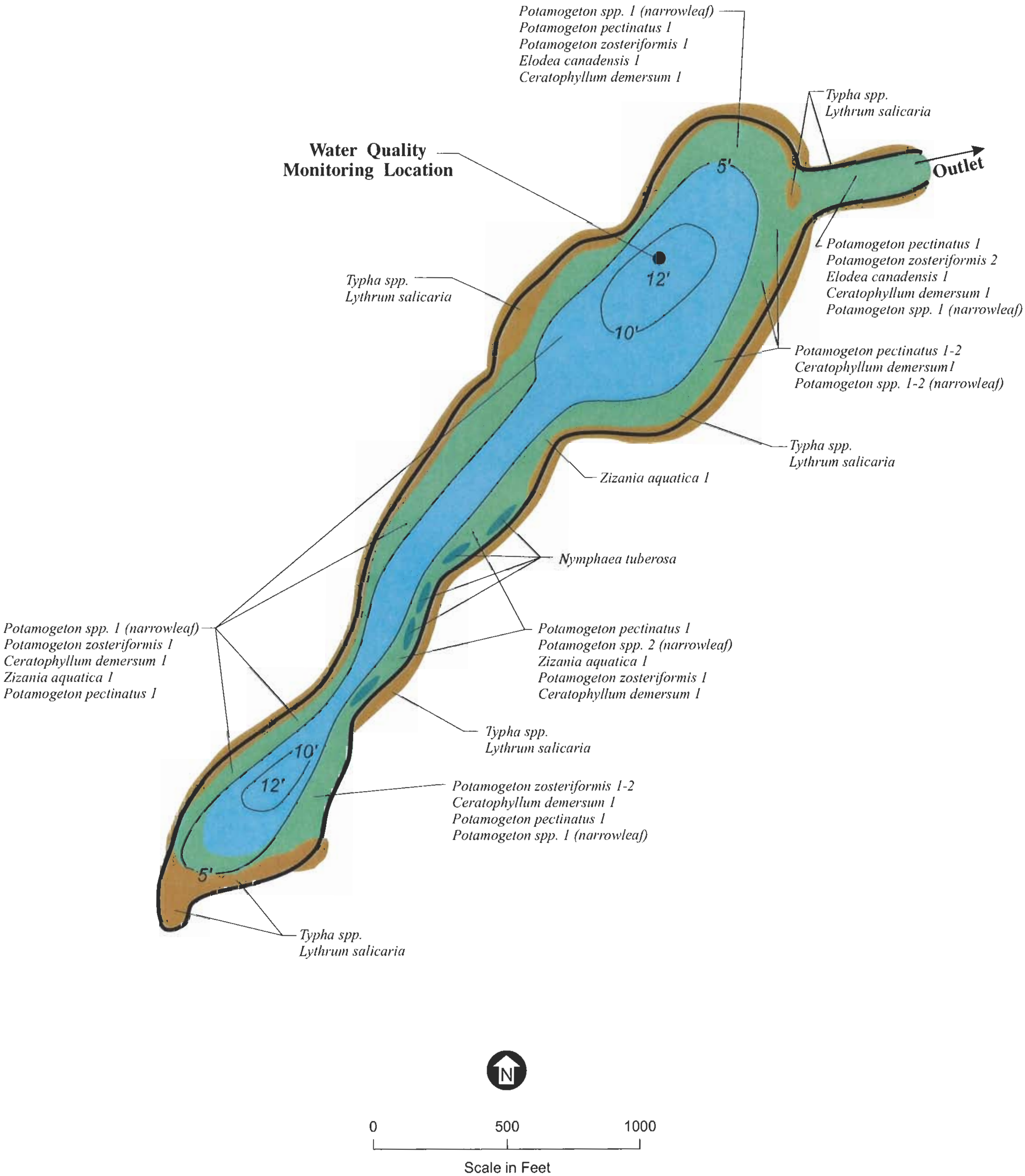

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Figure 15
(continued)

SILVER LAKE
August 23, 2000

1.5 Water Based Recreation

Silver Lake is used by riparian residents for canoeing and aesthetic viewing. Riparian residents report that snapping turtles living in the lake prevent swimming by creating unsafe conditions for swimmers (Melmer, 2002). The lake has no public access.

1.6 Fish and Wildlife Habitat

During the first half of the twentieth century, the Minnesota Department of Natural Resources (MDNR) believed Silver Lake could support a gamefish community. Hence, the MDNR actively managed the lake and stocked the lake with several gamefish species. MDNR records for the 1916 to 1943 period indicate MDNR stocked the lake with:

- 925 bass fingerlings
- 614,000 northern pike fry
- 2,600 sunfish fingerlings
- 100 sunfish yearlings
- 125 crappie yearlings

Stocking was discontinued in 1943. The MDNR currently believes the lake does not hold permanent gamefish and is unsuitable for gamefish. Silver Lake is classified by the US Fish and Wildlife Service as a Type 25 wetland, indicating it is comprised of shallow open water. Silver Lake provides habitat for seasonal waterfowl, such as ducks and geese. The MDNR recommends management of the lake to maintain or improve its wetland function. Hence, the recommended management focus of Silver Lake is the preservation of its current habitat and aquatic life community.

1.7 Discharges

1.7.1 Natural Conveyance Systems

The natural inflow to Silver Lake is comprised of stormwater runoff from its direct watershed (i.e., SL-10 on Figure 16) and groundwater discharge. There are no streams or rivers that convey flow to Silver Lake.

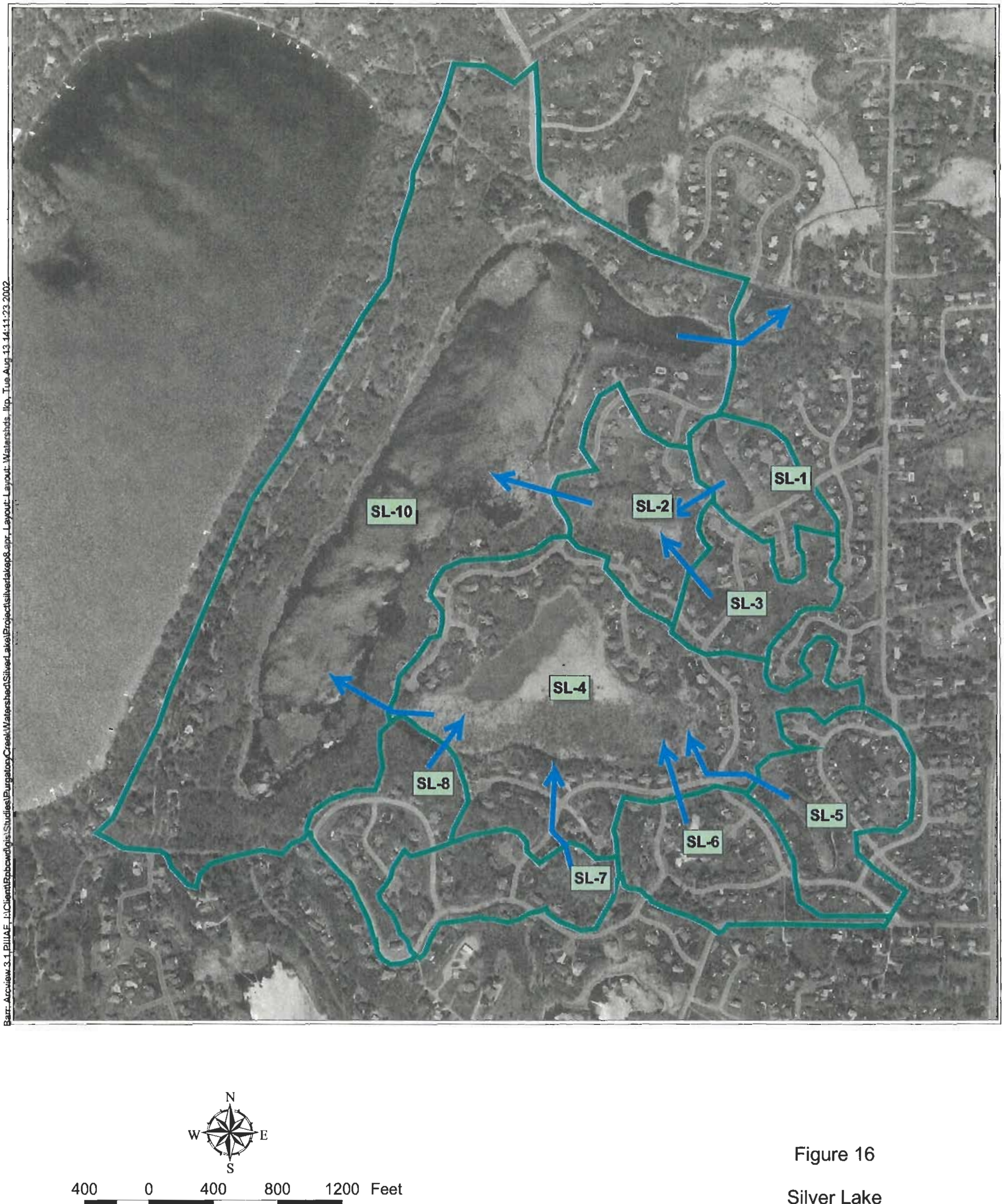

Figure 16

Silver Lake
Watershed

1.7.2 Stormwater Conveyance Systems

The Silver Lake stormwater conveyance system is comprised of a network of storm sewers and wet detention ponds within the watershed tributary to the lake. The wet detention ponds provide water quality treatment of stormwater runoff. Storm sewers convey stormwater runoff to and from the wet detention ponds, and eventually convey the runoff to Silver Lake.

Silver Lake receives runoff from three conveyance systems in the lake's watershed. Conveyance systems tributary to Silver Lake include (See Figure 16):

- **Pond SL-2**—Stormwater runoff from subwatershed/detention ponds SL-1, SL-2, and SL-3 is conveyed to pond SL-2, which discharges to Silver Lake.
- **Pond SL-4**—Stormwater runoff from subwatersheds/detention ponds SL-4, SL-5, SL-6, and SL-7 is conveyed to pond SL-4, which discharges to Silver Lake.
- **Pond SL-8**—Stormwater runoff from subwatershed SL-8 is conveyed to pond SL-8, which discharges to Silver Lake.

Eight wet detention ponds treat runoff prior to conveyance to Silver Lake (i.e., SL-1, SL-2, SL-3, SL-4, SL-5, SL-6, SL-7, and SL-8). Detention ponds are shown in Figure 16 and basin details are presented in Appendix B.

Wet detention ponds consist of a permanent pool of water and have the capacity to hold runoff and release it at lower rates than incoming flows. Wet detention ponds are one of the most effective methods available for treatment of nutrient-rich runoff. Wet detention ponds are used to interrupt the transport phase of sediment and pollutants associated with it, such as trace metals, hydrocarbons, nutrients, and pesticides.

During a storm event, polluted-runoff enters the detention basin and displaces "clean water" until the plume of polluted-runoff reaches the basin's outlet structure. When the polluted-runoff reaches the basin outlet, it has been diluted by the water previously held in the basin. This dilution further reduces the pollutant concentration of the outflow. In addition, the course sediments being transported by the polluted runoff and the pollutants associated with these sediments are trapped in the detention basin.

As storm flows subside, finer sediments suspended in the basin's pool will have a relatively longer period of time to settle out. These finer sediments, eventually trapped in the basin's permanent pool, will continue to settle until the next storm flow occurs. In addition to efficient settling, this long detention time allows some removal of dissolved nutrients through biological activity (Walker, 1987). These dissolved nutrients are mainly removed by algae and aquatic plants. After the algae die, the dead algae can settle to the bottom of the pond, carrying with them the dissolved nutrients that were consumed, to become part of the bottom sediments.

The wet detention process results in good pollutant removal from small storm events. Runoff from larger storms will experience pollutant removal, but not with the same high efficiency levels as the runoff from smaller storms. Studies have shown that because of the frequency distribution of storm events, good control for more frequent small storms (wet detention's strength) is very important to long-term pollutant removal.

1.7.3 Public Ditch Systems

There are no public ditch systems that affect Silver Lake.

1.8 Appropriations

There are no known water appropriations from Silver Lake.

2.0 Assessment of Silver Lake Problems

2.1 Appropriations

There are no known water appropriations from Silver Lake.

2.2 Discharges

The discharge of excess phosphorus to Silver Lake has resulted in poor water quality. A detailed analysis of discharges was completed to determine phosphorus sources. Since phosphorus typically moves either in water as soluble phosphorus dissolved in the water or attached to sediments carried by water, the determination of the volume of water discharged to Silver Lake annually was an important step in defining the amount of phosphorus discharged to the lake.

During development of the District Water Management Plan, literature export rate coefficients were used to estimate the annual water and phosphorus loads to the lake. The District Plan recommended using the water quality model XP-SWMM, XP-Stormwater and Waste Water Model, in the completion of the Use Attainability Analysis to provide a more precise estimate of water and phosphorus loads. Because the P8 model (Program for Predicting Polluting Particle Passage through Pits, Puddles, and Ponds; IEP, Inc., 1990) provides more accurate predictions of phosphorus loads to a lake than the XP-SWMM model, the P8 model was selected instead of the XP-SWMM model. The Use Attainability Analysis used the P8 model to estimate the volume of water and phosphorus mass entering the lake. Details of phosphorus discharges to the lake and management opportunities follow.

2.2.1 Natural Conveyance Systems

The direct watershed to Silver Lake contributes stormwater runoff to the lake via overland flow. Runoff from the direct watershed does not receive treatment before entering the lake. The annual amount of phosphorus added to Silver Lake from its direct watershed was estimated for four climatic conditions, previously shown to affect the lake's volume, outflow volume, and hydrologic residence time (See Section 1.2 Major Hydrologic Characteristics):

- **Wet year**—an annual precipitation of 41-inches, the amount of precipitation occurring during the 1983 water year

- **Average year**—an annual precipitation of 27-inches, the amount of precipitation occurring during the 1995 water year

- **Model calibration year**—an annual precipitation of 20-inches, the amount of precipitation occurring during the 2000 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).

- **Dry year**—an annual precipitation of 19-inches, the amount of precipitation occurring during the 1988 water year.

The amount of phosphorus added to the lake from the direct watershed under these climatic conditions is estimated to range from 34 to 72 pounds per year. This amount represents between 23 and 34 percent of the lake's annual load (See Table 2). The data indicate watershed phosphorus loading was precipitation dependent. Hence, the annual total phosphorus load and the percent of total annual Silver Lake total phosphorus load both increased with increasing precipitation.

Table 2 Estimated Total Phosphorus Loads from Silver Lake Direct Watershed Under Varying Climatic Conditions

Climatic Condition (inches of precipitation)	Annual Total Phosphorus Load From Direct Watershed (Pounds)	% of Total Annual Silver Lake Total Phosphorus Load*
Wet ('83) (41" pptn)	72	34
Average (27")	45	27
Model Calibration (20")	39	26
Dry (19")	34	23

*Annual Silver Lake total phosphorus load includes watershed load, atmospheric deposition, and internal load.

2.2.2 Stormwater Conveyance Systems

Stormwater conveyance systems, located on the east side of the lake, add less than one third of the annual phosphorus load to Silver Lake. Stormsewers add from 17 to 46 pounds of phosphorus to Silver Lake annually. This amount represents from 11 to 22 percent of the lake's annual load (See Table 3).

Table 3 Estimated Total Phosphorus Loads from Silver Lake Stormwater Conveyance Systems Under Varying Climatic Conditions

Climatic Condition (Inches of precipitation)	Annual Total Phosphorus Load From Stormwater Conveyance Systems (Pounds)	% of Silver Lake Annual Total Phosphorus Load*
Wet ('83) 41" pptn.	46	22
Avg. ('95) 27" pptn.	24	15
Model Calibration ('00) 20" pptn.	17	11
Dry ('88) 19" pptn.	19	12

*Annual Silver Lake total phosphorus load includes watershed load, atmospheric deposition, and internal load.

Each of the three storm sewer systems discharging into Silver Lake (See Figure 16) adds a different amount of phosphorus to the lake. Phosphorus loading is 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. As shown in Table 4, inflow locations SL-2, SL-4, and SL-8 each contribute from 1 to 14 percent of the lake's annual total phosphorus load.

Individual subwatershed contributions vary with watershed size. SL-8 notes a watershed size of 15 acres and contributes from 1 to 2 percent of the lake's annual total phosphorus load. SL-2 notes a watershed size of 38 acres and contributes from 3 to 6 percent of the lake's annual total phosphorus load. SL-4 notes a watershed size of 98 acres and contributes from 7 to 14 percent of the lake's annual total phosphorus load.

Table 4 A Comparison of Estimated Total Phosphorus Loads from Three Silver Lake Stormwater Conveyance Systems Under Varying Climatic Conditions

	Annual Total Phosphorus Load From Stormwater Conveyance Systems in pounds (% of Silver Lake Annual Total Phosphorus Load)			
Stormwater Conveyance System	**Wet ('83) 41" pptn.**	**Avg. ('95) 27" pptn.**	**Model Calibration ('00) 20" Pptn.**	**Dry ('88) 19" pptn.**
SL-2	12 (6)	6 (4)	4 (3)	5 (3)
SL-4	29 (14)	15 (9)	11 (7)	12 (8)
SL-8	5 (2)	3 (2)	2 (1)	2 (1)
Total Annual Load from Stormwater Conveyance Systems	**46 (22)**	**24 (15)**	**17 (11)**	**19 (12)**

The watershed load from the lake's direct watershed (See Table 2) is higher than the collective total of the three stormwater conveyance systems (See Tables 3 and 4). Removal of pollutants by wet detention ponds within the stormwater conveyance systems reduces watershed phosphorus loading to the lake. Runoff from the lake's direct watershed is not treated prior to entering Silver Lake. Consequently, the rate of phosphorus loading from the lake's direct watershed is 5 to 10 times higher than the rate of phosphorus loading from the lake's stormwater conveyance systems. The differences in direct watershed and stormwater conveyance system phosphorus loading rates are shown in Table 5. The phosphorus loading rates shown in Table 5 were determined by dividing watershed annual phosphorus loads in pounds by contributing subwatershed land areas in acres.

Table 5 A Comparison of Estimated Total Phosphorus Loading Rate from Three Silver Lake Stormwater Conveyance Systems and the Lake's Direct Watershed Under Varying Climatic Conditions

	Annual Total Phosphorus Loading Rate in pounds/acre			
	Wet ('83) 41" pptn.	Avg. ('95) 27" pptn.	Model Calibration ('00) 20" Pptn.	Dry ('88) 19" pptn.
Stormwater Conveyance System:				
SL-2	0.4	0.2	0.1	0.1
SL-4	0.3	0.2	0.1	0.1
SL-8	0.3	0.2	0.1	0.1
Direct Watershed	2.1	1.3	1.2	1.0

Individual watershed detention basins are effective in the reduction of watershed phosphorus loading to the lake. Basins SL-1, SL-3, SL-5, SL-6, SL-7, and SL-8 are estimated to remove more than 50 percent of the annual subwatershed phosphorus load under varying climatic conditions. Basin SL-2 is estimated to remove from 38 to 50 percent of the annual subwatershed phosphorus load. Basin SL-4 is estimated to remove from 43 to 54 percent of the annual subwatershed phosphorus load (See Table 6). Hence, individual basins remove from 38 to 70 percent of the annual subwatershed phosphorus load.

Table 6 Estimated Total Phosphorus Removal Efficiency of Silver Lake Watershed Detention Ponds

Stormwater Conveyance System	Pond Name	Total Phosphorus Removal Efficiency (% Removed)			
		Wet ('83) 41" pptn.	Avg. ('95) 27" pptn.	Model Calibration ('00) 20" pptn.	Dry ('88) 19" pptn.
SL-2	SL-1	59	66	70	64
	SL-2	38	46	50	42
	SL-3	52	61	64	58
SL-4	SL-4	43	50	54	47
	SL-5	51	59	64	58
	SL-6	58	65	69	63
	SL-7	53	61	64	59
SL-8	SL-8	51	59	62	58

The lower removal efficiencies of Ponds SL-2 and SL-4 apparently result from routing cleaner, treated water from upstream ponds through these downstream ponds. The cleaner, treated water contains fewer particles for removal by the downstream ponds. Hence, during stormwater events, the removal efficiencies of the downstream ponds are poorer than the upstream ponds, which receive untreated, particle-laden waters from their watersheds. An evaluation of the particulate phosphorus content of watershed pond inflow waters confirms the reduction in particles entering ponds SL-2 and SL-4. The estimated particulate phosphorus content of waters flowing into ponds SL-2 and SL-4 ranged from 43 to 59 percent, compared with 62 to 73 percent for waters flowing into upstream watershed ponds (See Table 7).

Table 7 Estimated Particulate Phosphorus Content of Waters Flowing Into Silver Lake Watershed Detention Ponds

Stormwater Conveyance System	Pond Name	Particulate Phosphorus Content of In-Flowing Waters (% Particulate P)			
		Wet ('83) 41" pptn.	Avg. ('95) 27" pptn.	Model Calibration ('00) 20" Pptn.	Dry ('88) 19" pptn.
SL-2	SL-1	62	69	73	66
	SL-2	43	51	55	47
	SL-3	62	69	73	66
SL-4	SL-4	48	55	59	52
	SL-5	62	69	73	67
	SL-6	62	69	73	67
	SL-7	63	70	73	67
SL-8	SL-8	63	70	73	67

Two of the eight ponds in the lake's watershed fail to meet current MPCA- and NURP-criteria. Current criteria by the MPCA (i.e., Protecting Water Quality in Urban Areas, 1989) and NURP (i.e., based upon results from the Nationwide Urban Runoff Program) require a minimum permanent pool or dead storage volume for each pond based upon its watershed size. The dead storage volume criteria is required because a pond's treatment effectiveness is directly related to its dead storage volume. Pond surveys were completed during 2001 to estimate current dead storage volume for all ponds in Silver Lake's watershed. Six of the 8 watershed ponds meet MPCA/NURP-criteria. Two ponds nearly meet MPCA/NURP criteria, but require from 27 to 81 cubic yards of increased dead storage volume to satisfy the criteria.

- **No Upgrade** — No upgrade to two basins not meeting MPCA/NURP criteria is recommended because no water quality benefit is expected to result. Model simulations were completed to estimate the reduction in phosphorus loading to Silver Lake if two treatment basins (SL-3 and SL-7 shown in Figure 16) were upgraded to meet MPCA/NURP-criteria. Because a relatively small increase in volume is required (i.e., 27 cubic yards for SL-2 and 81 cubic yards for SL-7) to satisfy MPCA/NURP-criteria, the upgrade will not result in a change in the lake's annual watershed phosphorus load. Upgrading these treatment basins is estimated to cost approximately $1,100.

2.2.3 Public Ditch Systems

There are no known ditch systems affecting Silver Lake.

2.3 Fish and Wildlife Habitat

The Silver Lake fish and wildlife habitat is currently satisfactory for its uses. Specific fish and wildlife habitat criteria have not been established for Silver Lake. The lake has been classified by the US Fish and Wildlife Service as a Type 25 wetland. The MDNR recommends continued management of the lake to maintain or improve its wetland function.

2.4 Water Based Recreation

Water based recreation uses of Silver Lake include canoeing and aesthetic viewing. The lake is not used for swimming because snapping turtles living within the lake create unsafe conditions for swimmers (Melmer, 2002).

District management policy for the lake's recreation uses includes achievement of national goals and state policies and nondegradation of the lake's current water quality. The District policy assumes national goals and state policies are both reasonable and attainable. Prior to 2001, state criteria were both reasonable and attainable. 2001 changes in state lake management criteria are based upon the assumption that all waters of the state must achieve a full support of swimmable use. The criteria are both unreasonable and unattainable for Silver Lake. A discussion of the policy change and associated problems follows.

Prior to 2001, state criteria for managing lakes were based upon a lake's swimmable use. MPCA swimmable use lake classification and criteria for each lake class are shown in Table 8. The criteria indicate the appropriate classification for Silver Lake is non-supporting of swimming. Hence, criteria for non-support of swimmable use are applicable to the management of Silver Lake. The criteria are both reasonable and achievable.

Table 8 MPCA Criteria for State Lakes Based Upon Swimmable Uses, by Category*

Water Quality Category	Desired TSI	Desired Total Phosphorus Concentration (μg/L)	Desired Chlorophyll *a* Concentration (μg/L)	Desired Secchi Disc Transparency (meters)
Level I: Full Support of Swimmable Use	TSI≤53	[TP]≤30	[Chl*a*]≤10	SD≥1.6
Level II: Full Support of Swimmable Use, But Threatened	57≥TSI>53	40≥[TP]>30	15≥[Chl*a*]>10	1.2≤SD<1.6
Level III: Partial Support of Swimmable Use	63≥TSI>57	60≥[TP]>40	27≥[Chl*a*]>15	0.8≤SD<1.2
Level IV: Non-Support of Swimmable Use	TSI>63	[TP]>60	[Chl*a*]>27	SD<0.8

*MPCA Use Support Classification for Swimming (MPCA Method) Relative to Carlson's Trophic State Index by Ecoregion. The classification is for the Central Hardwood Forests Region (MPCA 1998 and MPCA 1990).

MPCA criteria do not require a specific TSI value for waters that are non-supporting of swimming. Instead, MPCA criteria state that lakes non-supporting of swimming within the North Central Hardwood Forests (NCHF) ecoregion (i.e., the region in which Silver Lake is located) have a TSI > 63 (MPCA, 1998). Hence, Silver Lake's water quality meets state criteria for a lake classified as non-support of swimmable use. Silver Lake noted a summer average TSI of 82 during 2000 and 73 during 1996 (See Table 9). Under varying climatic conditions, the lake's summer average TSI is estimated to range from 76 to 82 (See Table 10).

Table 9 1996 and 2000 Silver Lake Trophic State Index Values

Parameter	1996	2000
Total Phosphorus	74	81
Chlorophyll *a*	72	83
Secchi disc	73	83
Average TSI	73	82

Table 10 Silver Lake Estimated Trophic State Index Values Under Varying Climatic Conditions

	Wet Year (1983, 41")	Average Year (1995, 27")	Dry Year (1988, 19")
Total Phosphorus	81	78	76
Chlorophyll *a*	81	78	76
Secchi disc	83	77	75
Average TSI	82	78	76

Prior to 2001, the lake's water quality was satisfactory for its water based recreation uses. The lake was not used for swimming because resident snapping turtles created unsafe swimming conditions. The lake's water quality met state criteria for a water body not used for swimming.

During November 2001, the MPCA published new lake management criteria in *Draft Guidance Manual For Assessing the Quality of Minnesota Surface Waters For Determination of Impairment, 305(b) Report and 303(d) List*. The new criteria are based upon the assumption that all waters of the state must achieve a full support of swimmable use. The criteria do not consider whether or not a lake has ever been used for swimming or circumstances that prevent its use for swimming. The water quality criteria for full support of swimmable use within the NCHF ecoregion are total phosphorus concentrations <40 μg/L, chlorophyll *a* concentrations <15 μg/L, and Secchi disc transparency values ≥1.2 meters. The MPCA intends to place lakes not meeting the criteria on an impaired waters of the state list and submit the list to the Environmental Protection Agency (EPA). Placement on the impaired waters list will occur when the MPCA obtains twelve or more lake data measurements collected from June through September over the past 10 years that indicate two of the three criteria outlined above are not met. Removal from the impaired waters list will not occur until monitoring data indicate the lake's water quality meets MPCA criteria for full support of swimmable use. The same data requirements for listing a lake as impaired are required to de-list the lake.

Because only 10 measurements of each of the required three parameters (total phosphorus, chlorophyll *a*, and Secchi disc) have been collected from Silver Lake, the lake cannot be listed on the impaired waters of the state list. However, if two additional measurements of the 3 parameters were made and the state were to obtain the data, the lake would be listed on the impaired waters of the state list. The lake's name could not be removed from the list until its water quality met MPCA criteria for full-support of swimming.

Achievement of 2001 state criteria for full support of swimming is not feasible for Silver Lake. Modeling estimates indicate 75 percent of the lake's current phosphorus watershed load and 90 percent of the lake's internal phosphorus load must be removed to achieve a water quality that meets 2001 MPCA criteria under a range of climatic conditions (See Table 11). Removal of 75 percent of the lake's watershed load would require (1) the construction of additional wet detention basins to treat runoff waters not treated by current detention basins and (2) alum treatment of runoff waters to enhance phosphorus removal by detention basins. The lake's watershed is fully developed and land is unavailable for the construction of additional detention basins. Alum treatment is cost prohibitive. Therefore, it is not feasible to meet the 2001 state criteria.

Table 11 Estimated Silver Lake Water Quality Following 75 percent Watershed Phosphorus Loading Reduction and 90% Internal Phosphorus Loading Reduction Under Varying Climatic Conditions

	Average Summer Conditions		
Climatic Condition	**Wet Year (1983, 41")**	**Average Year (1995, 27")**	**Dry Year (1988, 19")**
Total Phosphorus µg/L (TSI_{TP})	37 (56)	26 (51)	22 (49)
Chlorophyll *a* µg/L (TSI_{Chl})	12.4 (55)	7.4 (50)	5.8 (48)
Secchi disc m (TSI_{SD})	2.5 (47)	4.0 (40)	5.1 (37)

Criteria requiring water quality improvement to support swimmable use are unreasonable for Silver Lake. The 2001 MPCA criteria neither consider circumstances causing a lake's impaired waters classification nor the feasibility of water quality improvement. In addition, the criteria do not consider whether swimming would ever occur in the lake if water quality changes resulted in criteria attainment. As mentioned previously, snapping turtles prevent swimming in Silver Lake by creating unsafe conditions for swimmers. The 2001 state policy change mandates a change in District policy.

- **Change District policy** – The recommended change to District policy is to achieve national goals and state policies deemed reasonable by the District and work to affect change in unreasonable criteria.

The District's lake management strategy has been "to protect" the resource. Protect means to avoid significant degradation from point and nonpoint pollution sources and from wetland alterations in order to maintain existing beneficial uses, aquatic and wetland habitats, and the level of water quality necessary to protect these uses in receiving waters. The District has established a management goal for Silver Lake to facilitate protection from degradation. The lake's water quality goal is a TSI_{SD} not to exceed 70 (i.e., Secchi disc measurement equal to or greater than 0.5 meters).

An evaluation of the lake's water quality goal indicates a goal change is warranted. The lake's goal was based upon modeled predictions of the lake's current water quality. The modeled predictions were completed during preparation of the District's water management plan when primary data were not available. Primary data collected during 1996 and 2000 indicate the lake's water quality is poorer than its modeling estimate. 1996 and 2000 water transparency data indicate the lake's average summer transparency ranged from 0.2 to 0.4 meters. The lake's average summer water transparency, expressed as Carlson's Trophic State Index (TSI), was 73 to 82 (See Table 9).

The goal stated in the District Water Management Plan is unreasonable and not attainable. Reduction of both watershed phosphorus loading and internal phosphorus loading is required for goal achievement. Although internal load reduction is possible, the lack of opportunity for watershed load reduction prevents goal attainment. A previous discussion detailed the lack of opportunity to reduce watershed phosphorus loading. Table 12 shows that it is not possible to attain the District goal solely through internal load reduction. The table shows the lake's estimated water quality if it were possible to remove its entire internal phosphorus load. Typically, a 90 percent removal is estimated. Hence, the need to change the District lake water quality goal is evident.

Table 12 Silver Lake Estimated Trophic State Index Values Following 100 percent Reduction of the Lake's Internal Phosphorus Load Under Varying Climatic Conditions

	Trophic State Index (TSI) Value			
Parameter	District Goal	Wet Year (1983, 41")	Average Year (1995, 27")	Dry Year (1988, 19")
Total Phosphorus	≤ 70	78	74	76
Chlorophyll *a*	≤ 70	79	78	72
Secchi disc	≤ 70	74	72	69
Average TSI	≤ 70	77	75	72

- **Change Silver Lake Water Quality Goal** — The recommended Silver Lake water quality goal is a TSI_{SD} 83 (i.e., Secchi disc transparency of 0.2 meters). The goal is based on 2000 primary data.

2.5 Ecosystem Data

Silver Lake's current ecosystem is satisfactory for its lake type and use (i.e., a type 25 wetland used for canoeing and aesthetic viewing). However, the presence of two nuisance non-native macrophyte species, curlyleaf pondweed and purple loosestrife, threatens future ecosystem degradation. Non-native species typically follow an aggressive growth pattern and eliminate native species from a lake (i.e., curlyleaf pondweed) and from its shoreline (i.e., purple loosestrife). Increased coverage of curlyleaf pondweed may impair the lake's canoeing and aesthetic viewing uses and degrade the lake's aquatic life habitat. Purple loosestrife may eliminate native species and degrade the lake's shoreline habitat. Hence, reduction of the two nuisance species to the greatest extent possible is recommended to protect the lake's habitat and current uses.

Manage—Introduction of a natural predator to control the purple loosestrife growth along the shore of Silver Lake is recommended. Two beetle species effectively prey upon purple loosestrife. They include *Galerucella pusilla* and *Galerucella calmariensis*. It is recommended that the District work with the MDNR to introduce the beetles in purple loosestrife infested areas of Silver Lake. The MDNR will provide the beetles and guidance at no cost. Raising the beetles and introducing the beetles to infested areas of Silver Lake is the District's responsibility. Management of purple loosestrife generally spans several years. Estimated cost of the management program is approximately $3,000 per year for 3 to 6 years or a total cost of $9,000 to $18,000.

Treat—A whole-lake, low dose fluridone treatment is recommended to control curlyleaf pondweed. When using low doses of fluridone to selectively control curlyleaf pondweed, it is important to treat the plant during early growth, since it is more difficult to control mature plants with low herbicide rates. Also, it is important to treat the plants prior to the formation of the reproductive turions to prevent the growth of successive generations. Hence, the treatment will occur in May. Fluridone will be evenly distributed at a concentration of 5 μg/L over the entire lake. The initial application will be followed in 2 to 3 weeks by a second booster application, designed to reestablish a whole-lake fluridone concentration of 5 μg/L. The booster application is necessary to maintain aqueous fluridone levels of at least 2 μg/L for more than 60 days, the exposure time required to control curlyleaf pondweed. The treatment method has been termed the 5-bump-5 treatment. Treatments will be conducted from boats using various conventional liquid herbicide application equipment designed to deliver fluridone at, or slightly below, the water surface. The spray boat will be piloted across Silver Lake in a manner to insure even distribution of the herbicide throughout the lake. Even distribution of fluridone is important to avoid residue "hot-spots" in the water column, ensuring that non-target plants do not receive a high initial dose. Estimated treatment costs are $20,000 (2002 cost basis). A permit from the MDNR is required and hence, must be obtained prior to treatment.

Sample—Water residue samples will be collected to insure fluridone levels of 5 µg/L are achieved following the initial and booster applications and to insure that fluridone levels >2 µg/L occur for at least 60 days. Six water residue sampling locations will be established at regular intervals throughout the lake. The stations will be positioned to determine lake-wide coverage of fluridone residues. Sampling stations will be established through the use of a global positioning system (GPS) unit and a GPS unit will be used to locate the stations during each sample event. Samples will be collected from all stations one, four, and 10 days after the initial treatment and one, 10, 20, 30, and 60 days after the booster treatment. All samples will be analyzed for fluridone using the FasTEST technique (Getsinger et. al, 2001). Estimated cost of monitoring is $20,000 (2002 cost basis).

2.6 Water Quality

Silver Lake's water quality is poor, but satisfactory for its use as a type 25 wetland. A water quality modeling analysis was completed to (1) evaluate the lake's water quality under varying climatic conditions and (2) evaluate management practices to improve the lake's water quality. A detailed discussion of modeling results pertinent to water based recreation is presented in Section 2.4 Water Based Recreation. Tables 10 through 12 present modeling results. Additional modeling analysis details follow.

2.6.1 Water Quality Modeling Analysis

An empirical model, such as the Dillon and Rigler phosphorus model (1974), is generally used to reconcile a lake's phosphorus loadings with its in-lake phosphorus concentrations. During preparation of the District water management plan, the Dillon and Rigler model was used to estimate Silver Lake's total phosphorus concentrations. However, primary data were not available to calibrate the model.

During the preparation of this UAA, a calibrated Dillon and Rigler model was used to estimate Silver Lake's spring total phosphorus concentration. Watershed phosphorus loadings for the model were predicted using the P8 model. Because in-lake phosphorus loading from sediments and from decaying plants play a vital role in the lake's phosphorus concentration during the summer period, a mass balance model was used to estimate monthly in-lake phosphorus concentrations during the summer months. Details concerning estimation of phosphorus loads from decaying plants and from sediments are found in Appendix A. The estimated monthly concentrations during June through August were used to determine the average summer total phosphorus concentration. The modeled average summer total phosphorus concentrations agreed well with measured values during 1996 and 2000, differing from measured values by less than 1 percent.

Chlorophyll concentrations were estimated using an empirical regression model for Minnesota lakes, developed by Heiskary and Wilson (1990). The modeled average summer chlorophyll concentrations agreed well with measured values during 1996 and differed from measured values by less than 1 percent. In 2000, modeled values differed from measured values by 26 percent.

Secchi disc values were estimated using an empirical model developed from Silver Lake data collected during 1996 and 2000. The model, detailed in Appendix A, estimates Secchi disc transparency from the lake's total phosphorus concentration. No differences between modeled and observed values were observed in 1996 and 2000.

The modeling analysis indicates the lake currently has very poor water quality under all climatic conditions. A comparison of the lake's modeled total phosphorus and chlorophyll concentrations and Secchi disc transparency measurements with a standardized lake rating system indicates the average summer values were within the hypereutrophic (i.e., very poor water quality) category during all climatic conditions.

The modeling analysis confirms the need for a Silver Lake water quality goal change. A previous discussion detailed the lack of opportunity for goal attainment and the need for a change to a Silver Lake goal that is based upon 2000 primary data.

2.7 Major Hydrologic Characteristics

The major hydrologic characteristics of the lake have changed from the pre-development period. Change continued throughout the development of the watershed. The watershed is fully developed and the major hydrologic characteristics are now stabilized.

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 complete. However, future redevelopment within the watershed could result in density increases and increased phosphorus loading to the lake. 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 changes. Management practices to prevent phosphorus loading increases should be required of land use changes to prevent degradation of the lake's water quality.

3.0 Lake Riley Goals

The approved water management plan of the Riley-Purgatory-Bluff Creek Watershed District articulated five specific goals for Silver Lake. These goals address recreation, aquatic communities, water quality, water quantity, and wildlife. A discussion of the goals follows.

3.1 Water Quantity Goal

The water quantity goal for Silver 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 intended water quality goal of Silver Lake is protection of the lake's current water quality. The intended goal has been attained and nondegradation of the lake's current water quality will insure future goal attainment.

The numeric water quality goal of Silver Lake (i.e. TSI_{SD} 70) has not been attained and is not attainable. Hence, a numeric goal change is warranted. The goal was established before the collection of primary data and was based upon uncalibrated modeling estimation. Use of 2000 primary data for the lake's numeric water quality goal is recommended. Hence, a change from the current water quality goal of TSI_{SD} 70 to TSI_{SD} 83 is recommended.

2001 changes in state lake management criteria mandate a District policy change. The criteria changes are based upon the assumption that all waters of the state must achieve a full support of swimmable use. The criteria are both unreasonable and unattainable for Silver Lake. The recommended change is a District policy to achieve national goals and state policy deemed reasonable by the District and work to affect change in unreasonable criteria.

- **WQ-1** -- Change Water Quality Numeric Goal to TSI_{SD} 83.
- **WQ-2** – Change District Policy to achieve national goals and state policies deemed reasonable by the District and work to affect change in unreasonable criteria.

3.3 Aquatic Communities Goal

The aquatic communities' goal of Silver Lake is preservation of the lake's wetland habitat. The lake provides habitat for seasonal waterfowl, such as ducks and geese, and other aquatic life. The goal has been attained. However, nuisance non-native plants threaten future non-attainment of the goal. Management of the non-native plants will insure continued goal attainment.

- AC-1--Manage purple loosestrife and curlyleaf pondweed.

3.4 Recreation Goal

The recreation goal is to provide a water quality that supports canoeing and aesthetic viewing. The goal has been attained and nondegradation of the lake's current water quality will insure goal attainment in the future. 2000 data indicate the lake's average summer water transparency is 0.2 meters. Hence, a recreation goal of TSI_{SD} 83 (Secchi Disc water transparency of 0.2 meters) is recommended.

3.5 Wildlife Goal

The wildlife goal for Silver 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 a 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 Recommended Goal Changes

It is recommended that the lake's numeric water quality goal be changed to a TSI_{SD} 83 (Secchi Disc water transparency of 0.2 meters). Corresponding total phosphorus and chlorophyll concentrations are 211 μg/L and 215 μg/L, respectively. Corresponding TSI values are TSI_{TP} 81 and TSI_{Chl} 83.

4.2 Recommended District Policy Change

The recommended change to District policy is to achieve national goals and state policy deemed reasonable by the District and work to affect change in unreasonable criteria.

4.3 Recommended Exotic (Non-Native) Plant Management

Reduction of the two nuisance exotic (non-native) species to the greatest extent possible is recommended to protect the lake's habitat and current uses. The following projects are recommended.

4.3.1 Purple Loosestrife Management

Introduction of a natural predator to control the purple loosestrife growing along the shore of Silver Lake is recommended. Two beetle species effectively prey upon purple loosestrife. They include *Galerucella pusilla* and *Galerucella calmariensis*. It is recommended that the District work with the MDNR to introduce the beetles to purple loosestrife infested areas along the shore of Silver Lake. The MDNR will provide the beetles and guidance at no cost. Raising the beetles and introducing the beetles to infested areas along the shore of Silver Lake is expected to cost approximately $3,000 per year. Management of purple loosestrife generally spans several years. Estimated cost of the management program is approximately $3,000 per year for 3 to 6 years or a total cost of $9,000 to $18,000.

4.3.2 Curlyleaf Pondweed Management

A whole-lake, low dose fluridone treatment is recommended to control curlyleaf pondweed. The treatment will occur in May. Fluridone will be evenly distributed at a concentration of 5 μg/L over the entire lake. The initial application will be followed in 2 to 3 weeks by a second booster application, designed to reestablish a whole-lake fluridone concentration of 5 µg/L. The booster application is necessary to maintain aqueous fluridone levels of at least 2 µg/L for more than 60 days, the exposure time required to control curlyleaf pondweed. The treatment method has been termed the 5-bump-5 treatment. Treatments will be conducted from boats using various conventional liquid herbicide application equipment designed to deliver fluridone at, or slightly below, the water surface. The spray boat will be piloted across Silver Lake in a manner to insure even distribution of the herbicide throughout the lake. Even distribution of fluridone is important to avoid residue "hot-spots" in the water column ensuring that non-target plants do not receive a high initial dose. Estimated treatment costs are $20,000 (2002 cost basis). A permit from the MDNR is required and hence, must be obtained prior to treatment.

4.3.3 Water Sampling Program

Water residue samples will be collected to insure fluridone levels of 5 µg/L are achieved following the initial and booster applications and to insure that fluridone levels >2 µg/L occur for at least 60 days. Six water residue sampling locations will be established at regular intervals throughout the lake. The stations will be positioned to provide a balanced coverage of lake-wide residues. Sampling stations will be established through the use of a global positioning system (GPS) unit and a GPS unit will be used to locate the stations during each sample event. Samples will be collected from all stations one, four, and 10 days after the initial treatment and one, 10, 20, 30, and 60 days after the booster treatment. All samples will be analyzed for fluridone using the FasTEST technique (Getsinger et. al, 2001). Estimated cost of monitoring is $20,000 (2002 cost basis).

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