Round Lake (in Maplewood)

Strategic Lake Management Plan

Prepared for
Ramsey-Washington Metro Watershed District

April 2007

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Executive Summary

The purpose of this SLMP is to determine appropriate water quality goals for Round Lake based on its current and desired recreational-uses as outlined in the *Ramsey-Washington Metropolitan Watershed Management Plan* (Barr, 1997; Barr, 2006 [Draft]) and to summarize and evaluate the available information and water quality data to determine if Round Lake is currently meeting those water quality goals.

Round Lake is directly connected to Lake Phalen and is surrounded entirely by Ramsey County parkland (Phalen-Keller Regional Park). It is used primarily for canoeing, fishing, picnicking, wildlife habitat, and aesthetic viewing and has been assigned a District recreational-use level of 3 (Barr, 2006 [Draft]).

Water quality in Round Lake is good and a trend analysis has shown that it has significantly improved over the past 2 decades. The average growing season concentrations of total phosphorus and chlorophyll *a* for the past decade were 48 µg/L and 16 µg/L, respectively; while the average growing season Secchi disc transparency was 6.4 feet (1.95 meters). These values indicate that Round Lake is a eutrophic lake.

Watershed pollutant load and in-lake water quality modeling suggests that watershed loading is the primary source of phosphorus to the lake although the results indicate that Round Lake does experience some internal loading, which is likely due to phosphorus release from anoxic sediments and potentially, resuspension of sediments due to benthivorous fish activity. There is no data available to suggest that macrophytes are contributing to the phosphorus concentrations in the lake.

The 2006 preliminary District water quality goals for Round Lake are aligned with the MPCA-proposed shallow lake criteria for lakes in the North Central Hardwood Forests ecoregion. Round Lake has consistently met these goals for the past decade. As a result, it seems that the preliminary District water quality goals seem reasonable for Round Lake and should be maintained. However, it is recommended that the District management class for Round Lake be changed from "Improvement" to "Prevent further degradation." Additionally, because of the significant improvement in water quality and the attainment of the MPCA water quality criteria, it is recommended that the District proceeds with the process of delisting Round Lake from the 303(d) Impaired Waters List.

Round Lake (in Maplewood)
Strategic Lake Management Plan

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1.0 Introduction

1.1 SLMP Objectives

One of the primary goals of the Ramsey-Washington Metropolitan Watershed District (District) is to maintain or improve the quality of surface waters to meet or exceed the water quality necessary to support the District's designated beneficial uses. In 1997, the District established beneficial use categories based on desired recreational activities for a waterbody in the *Ramsey-Washington Metropolitan Watershed Management Plan* (Plan) (Barr, 1997; Barr, 2006 [Draft]). The recreational-use levels are ranked from Level 1 through Level 5, with Level 1 water bodies having the highest number of recreational-uses and the best water quality.

In order to help achieve desired water quality goals established in the Plan many of the lakes within the District have been studied in Strategic Lake Management Plans (SLMPs). However, for many of the smaller lakes within the District, SLMPs have not yet been completed and official water quality goals have not been established, as is the case for Round Lake in Maplewood.

The purpose of this SLMP is to determine appropriate water quality goals for Round Lake based on its current and desired recreational-uses as outlined in the Plan and to summarize and evaluate the available information and water quality data to see if Round Lake is currently meeting those water quality goals. Figure 1-1 shows the location of Round Lake.

1.2 Overview of Round Lake's Recreational-uses

Round Lake is directly connected to Lake Phalen, an important recreational-body within the District, via two open channels. Round Lake is surrounded entirely by Ramsey County parkland (Phalen-Keller Regional Park) and is used primarily for canoeing, fishing, picnicking, wildlife habitat, and aesthetic viewing. Public access to Round Lake is available via a pier located on the northeast side of the lake. There is no direct boat launch access on Round Lake although unofficial access is possible from the shore by the parking lot on the eastside of the lake. Also, there is a concrete boat launch into Lake Phalen near the northern outlet from Round Lake into Lake Phalen which can provide canoe or paddle access to the lake as well. The District has assigned a recreational-use level of 3 to Round Lake (Barr, 2006 [Draft]).

In addition to the recreational-uses of Round Lake, there are a number of recreational-uses within the Round Lake watershed. The Minnesota Department of Natural Resources' (MDNR) Gateway State

Trail passes through the watershed just north of Round Lake. There are a number of other local and city trails that pass through the watershed or are part of the Phalen-Keller Regional Park.

1.3 Water Quality Goals

The Plan (Barr, 2006 [Draft]) includes preliminary water quality goals and management classes for each of the District-managed lakes. The water quality goals are defined in terms of total phosphorus (TP), chlorophyll *a* (Chl *a*), and Secchi disc (SD). For the water bodies part of this SLMP, the preliminary goals are consistent with either the Minnesota Pollution Control Agency's (MPCA) proposed draft criteria for lakes in the North Central Hardwood Forests (CHF) ecoregion (MPCA, 2005) or the goals listed in the *Watershed Management Plan* (Barr, 1997). These goals will remain preliminary until an SLMP or other similar study is completed and appropriate goals are determined.

The District management classes are identified as either "Prevent further degradation" or "Improvement". An "Improvement" class is warranted if the public perceives a need for water quality improvement and there are feasible management options that will accomplish water quality improvement. A "Prevent further degradation" class is assigned when current water quality meets the goals set for the lake. A "Prevent further degradation" classification does not, however, imply inaction. Rather, development requirements, fisheries, shoreline, and macrophyte management as well as water quality improvement projects should be implemented as opportunities and budgets allow.

Additional classification of the water bodies based on water quality includes listings as Impaired Waters under Section 303(d) of the federal Clean Water Act (CWA). Those water bodies that do not meet the water quality standards established under the CWA are included on this list and future development of total maximum daily loads (TMDL) is required. The MDNR has developed ecological management classification system for Minnesota lakes (Schupp, 1992) that is based on parameters such as lake size, depth, chemical fertility, and growing season length.

The various classifications of Round Lake, as well as the District's preliminary water quality goals, are summarized in Table 1-1. The District goals are consistent with the MPCA's water quality criteria for shallow lakes in the North Central Hardwood Forest ecoregion (MPCA, 2005). Round Lake is currently listed for "Improvement" under the District's management classification and is also on the CWA 303(d) Impaired Waters List with excess nutrients listed as the primary pollutant.

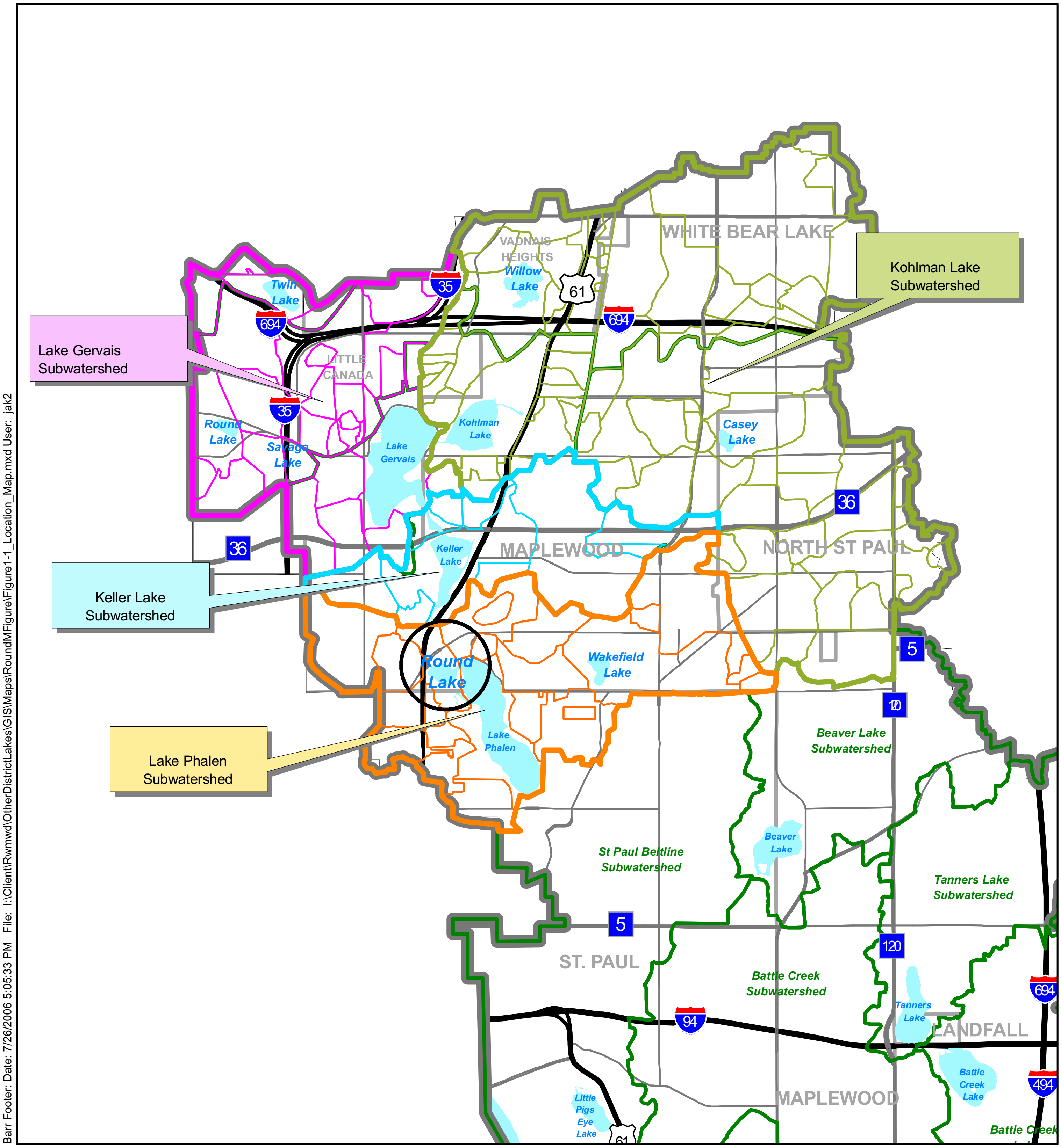
Table 1-1 Summary of RWMWD Recreational-Use Level, 2006 Preliminary Water Quality Goals, Proposed RWMWD Water Quality Goals and Management Class as well as 303(d) Impaired Waters and MDNR Ecological Management Class for Round Lake (in Maplewood)

Water Body	RWMWD Use Level	2006 Preliminary RWMWD Water Quality Goal	2006 Proposed RWMWD Water Quality Goal	Proposed RWMWD Management Class	CWA 303(d) Impaired Waters Pollutant	MDNR Ecological Class
Round Lake	3	60 µg/L TP[1,2] 20 µg/L Chl*a*[1,2] 3.3 ft SD[1,2]	60 µg/L TP[1] 20 µg/L Chl*a*[1] 3.3 ft SD[1]	Prevent further degradation[3]	Excess Nutrients	N/A

1- Water quality goals are consistent with the MPCA's draft criteria for shallow lakes in the North Central Hardwood Forests (CHF) ecoregion (Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria. Third Edition, September, 2005)

2- Goals remain preliminary until a SLMP or other similar study is completed and appropriate goals are determined

3- Proposed management class for Round Lake. Originally identified as Improvement.



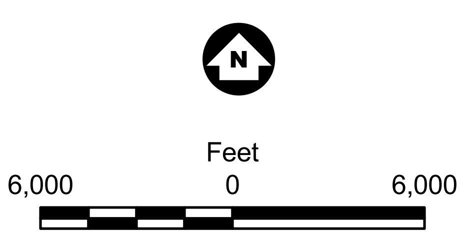


Figure 1-1

Location Map

Round Lake SLMP
Ramsey-Washington Metro Watershed District

2.0 Existing Lake and Watershed Conditions

2.1 Description of Round Lake

Round Lake is located in the city of Maplewood (Township 29, Range 22, Section 16). The lake is a 20-acre District-managed lake. It is also classified as Protected Public Water in the MDNR Public Waters Inventory (62-12P) and satisfies the criteria for shallow lake classification as outlined by MPCA, with nearly all of the lake (97.5%) being classified as littoral area.

According to data from the MDNR, Round Lake has a maximum depth of approximately 17 feet with a median depth of 6.4 feet. Approximate bathymetry information can be seen in Figure 2-1. Although classified as shallow, evaluation of the water quality data of Round Lake indicates that the lake does thermally stratify during the summer months. Therefore, Round Lake would be considered a dimictic lake, meaning it fully mixes twice per year (typically in the spring and fall).

There is no lake level data available specifically for Round Lake; however, there is data available for Lake Phalen from 1924 through the present. Round Lake is directly connected to Lake Phalen via two large open channels that enter on the northwest shore of Lake Phalen and because of these connections, it is often assumed, for modeling purposes, that the water surface elevation of Round Lake is the same as that of Lake Phalen. Figure 2-2 shows Round Lake and its two outlets to Lake Phalen. Using this assumption, the estimated normal water level (NWL) was 857.5 feet MSL. According to the Plan, the critical 100-year flood elevation for Round Lake was determined to be 861.4 feet MSL. Figure 2-3 maps the extent of the critical 100-year flood for Round Lake.

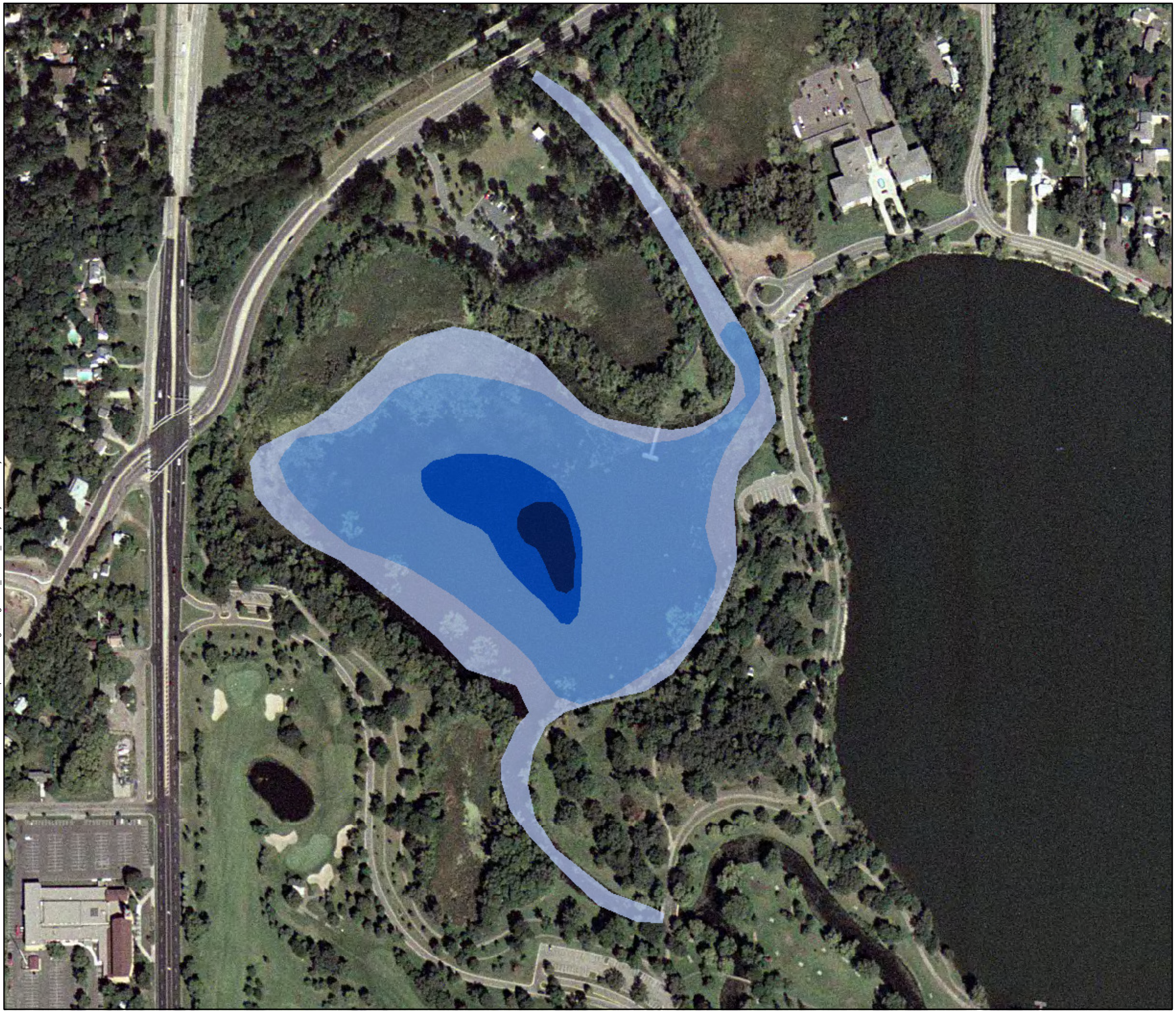


Figure 2-1

Round Lake
Approximate Bathymetry

Round Lake SLMP
Ramsey-Washington Metro Watershed District


(a)

(b)


(c)


(d)

Figure 2-2
(a) Round Lake (b) Northern outlet of Round Lake to Lake Phalen (c) Channel from Keller Lake to Lake Phalen located on the Northeastside of Round Lake (d) Keller Lake outlet weir (Photos taken 5/1/2006)

Legend

Flood Elevation = 861.4 ft MSL

Feet

250 0 250

Figure 2-3

Round Lake
Critical Flood Elevation

Round Lake SLMP
Ramsey-Washington Metro Watershed District

2.2 Watershed Characteristics

The Round Lake watershed has a total area of 242 acres, including the lake surface area, and drains a portion of the city of Maplewood. The lake is surrounded entirely by Ramsey County parkland. The dominant land uses in the watershed are natural/park/open space (44.5%) and low density residential development (31.9%). Other watershed land uses include: agriculture (0.7%), commercial (0.3%), high density residential (2.4%), institutional (5.3%), open water (9.8%), and wetland (5.1%). Round Lake is categorized as open water and wetland under the land use classification. Figures 2-4 and 2-5 summarize the land uses within the Round Lake watershed.

Drainage from the Round Lake watershed flows from the southwest and from the north into Round Lake. See Figure 2-6 for the general flow path through the Round Lake watershed. The watershed is part of the larger Lake Phalen watershed. There are no landlocked areas in the Round Lake drainage system. There is one stormwater pond modeled within the Round Lake watershed and runoff from the watershed typically enters the lake via storm sewer outfalls at various points along the lakeshore.

There is also an open channel that flows parallel to the northeast side of Round Lake that conveys water from Keller Lake upstream and discharges near the northern-most outlet to Lake Phalen. For modeling, it was assumed that there was no interaction between the water from Keller Lake and that of Round Lake. There is likely some interaction between the channel water and the water in Round Lake although a more detailed modeling effort would be required to quantify the extent of interaction between the these two sources as well as the impact of the upstream water on water quality within Round Lake.

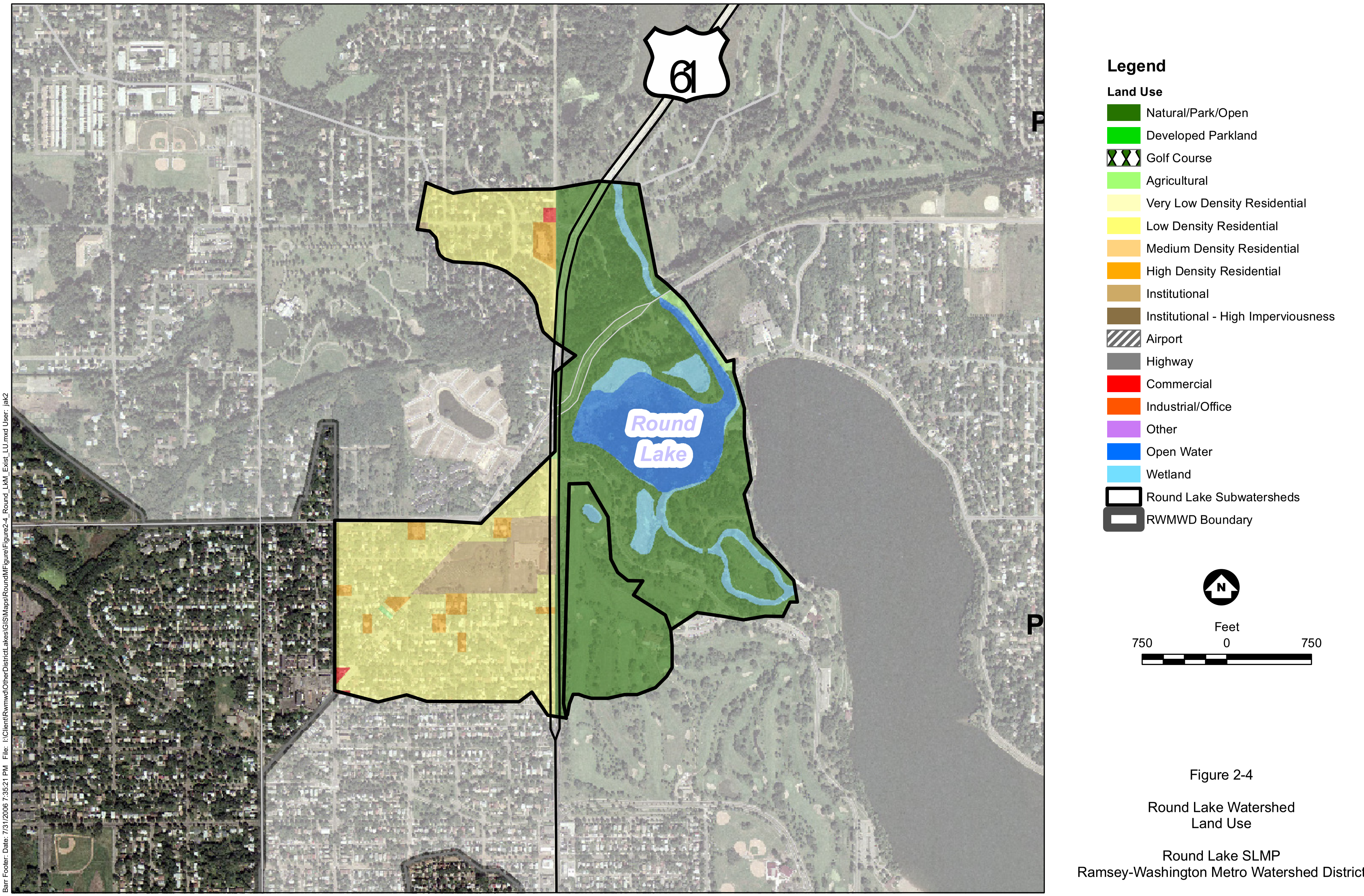


Figure 2-4

Round Lake Watershed
Land Use

Round Lake SLMP
Ramsey-Washington Metro Watershed District

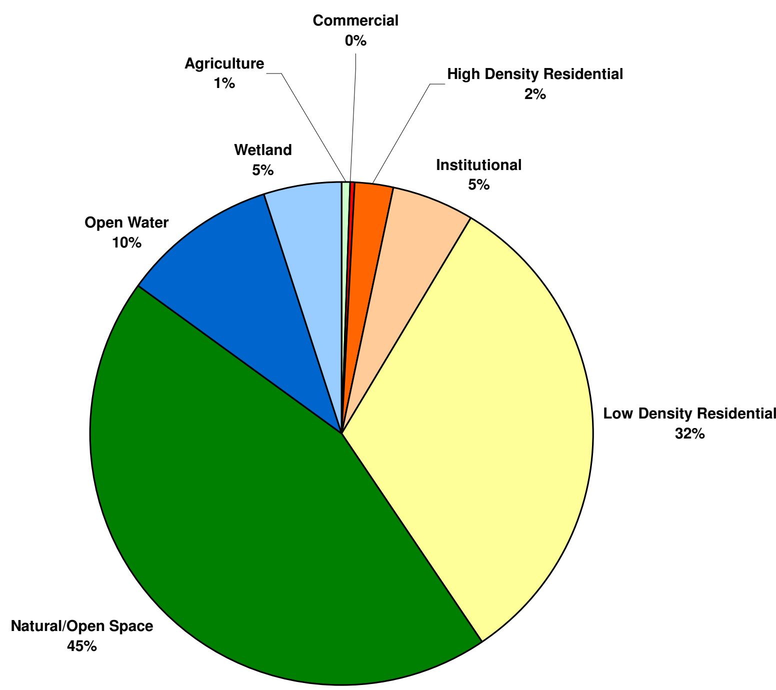
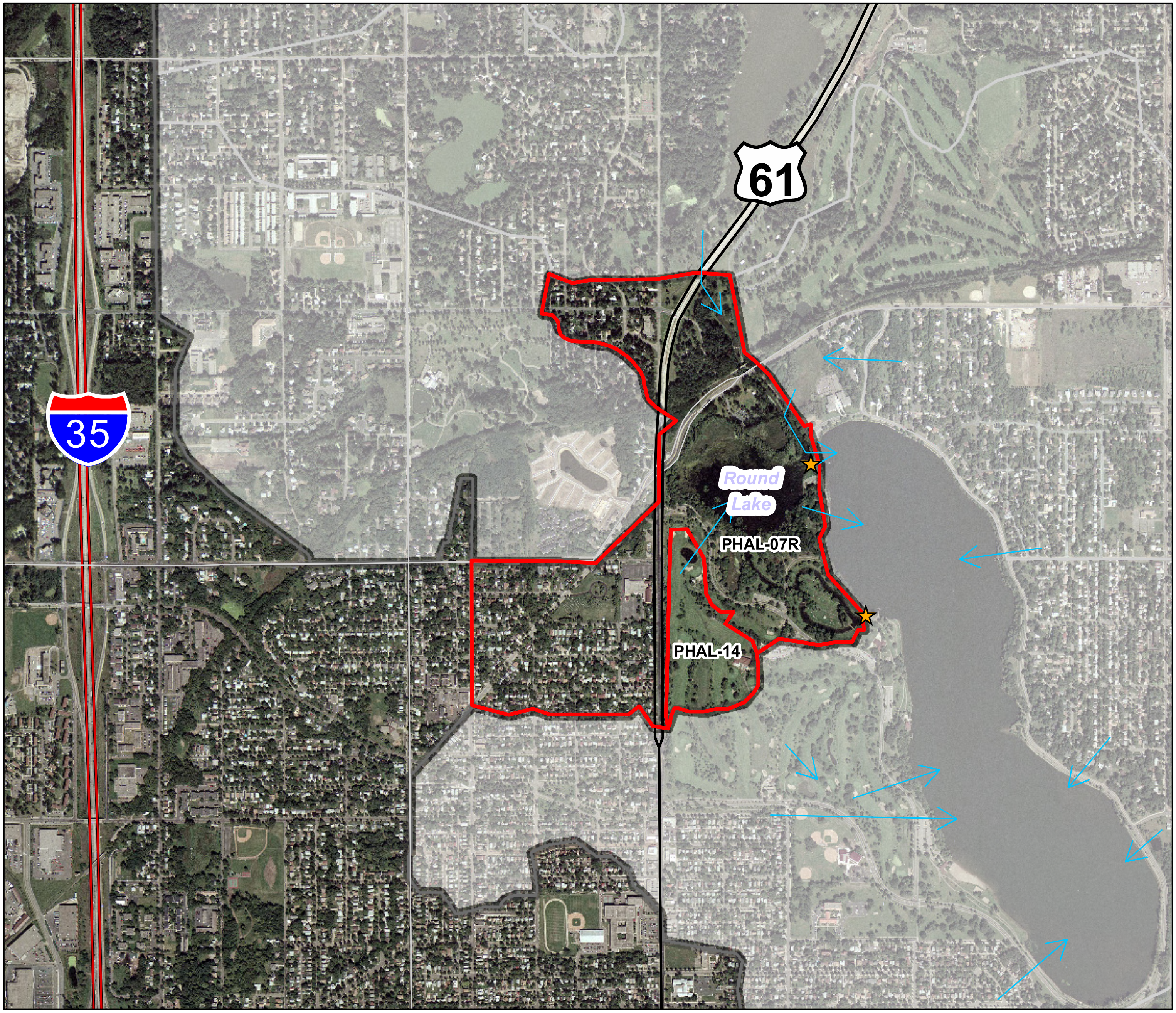


Figure 2-5
Round Lake Watershed
(214 Acres)
Land Use Summary



Legend

- Round Lake Subwatersheds
- RWMWD Boundary
- Flow Direction
- Primary Outlet

N

Feet

1,000 0 1,000

Figure 2-6

Round Lake Watershed
Subwatersheds & Drainage

Round Lake SLMP
Ramsey-Washington Metro Watershed District

2.3 Historic Water Quality

The following section evaluates and summarizes the historic water quality data available for Round Lake in Maplewood. Appendices A and B summarize the general concepts in water quality as well as the water quality evaluation methods used in this report.

2.3.1 Water Quality Parameters

There are more than 2 decades of water quality data available for Round Lake in Maplewood (from the early 1980s through 2004). This data includes TP and Chl *a* concentrations as well as SD transparencies, which are summarized below. There is also information available for many other water quality parameters, although this report will primarily focus on the three parameters mentioned above that are most commonly used to evaluate water quality.

The annual growing season averages (June through September) of the surface water data (samples collected within 0-2 meters of the water surface) were computed for TP, Chl *a*, and SD for the entire period of record and are shown in Figures 2-7 through 2-9. Each graph also includes the number of measurements (n) that were used to calculate the growing season average.

The average growing season TP concentration in Round Lake over the entire period of record was 66 µg/L; as compared to the average TP concentration over the past decade of 48 µg/L. The highest TP concentrations in Round Lake occurred in the early to mid-1980's, with the highest growing season average TP occurring in 1987.

Chl *a* concentrations followed a pattern similar to that of TP, with the highest concentrations occurring in the early to mid-1980's. The growing season epilimnetic average Chl *a* concentrations over the entire sampling record was 23 µg/L while for the past decade the average concentrations were 16 µg/L.

The average growing season SD transparencies for Round Lake has deepened from 4.8 feet over the entire record period to 6.4 feet for the last decade.

Using the growing season averages over the past decade (TP = 48 µg/L, Chl *a* = 16 µg/L, and SD = 6.4 feet), the Carlson TSI values for TP is 60, for Chl *a* is 58, and for SD is 50. Based on these indices, Round Lake would be classified as a eutrophic lake.

General evaluation of the temperature, dissolved oxygen (DO), and TP depth profiles of Round Lake indicate that the lake does thermally stratify during the summer months and that the hypolimnion does become anoxic with very low or no DO near the bottom of the lake. Often, the TP concentrations below the thermocline were much higher than the concentrations measured near the surface, supporting the idea that water quality in Round Lake is impacted by anoxic phosphorus release from the sediment.

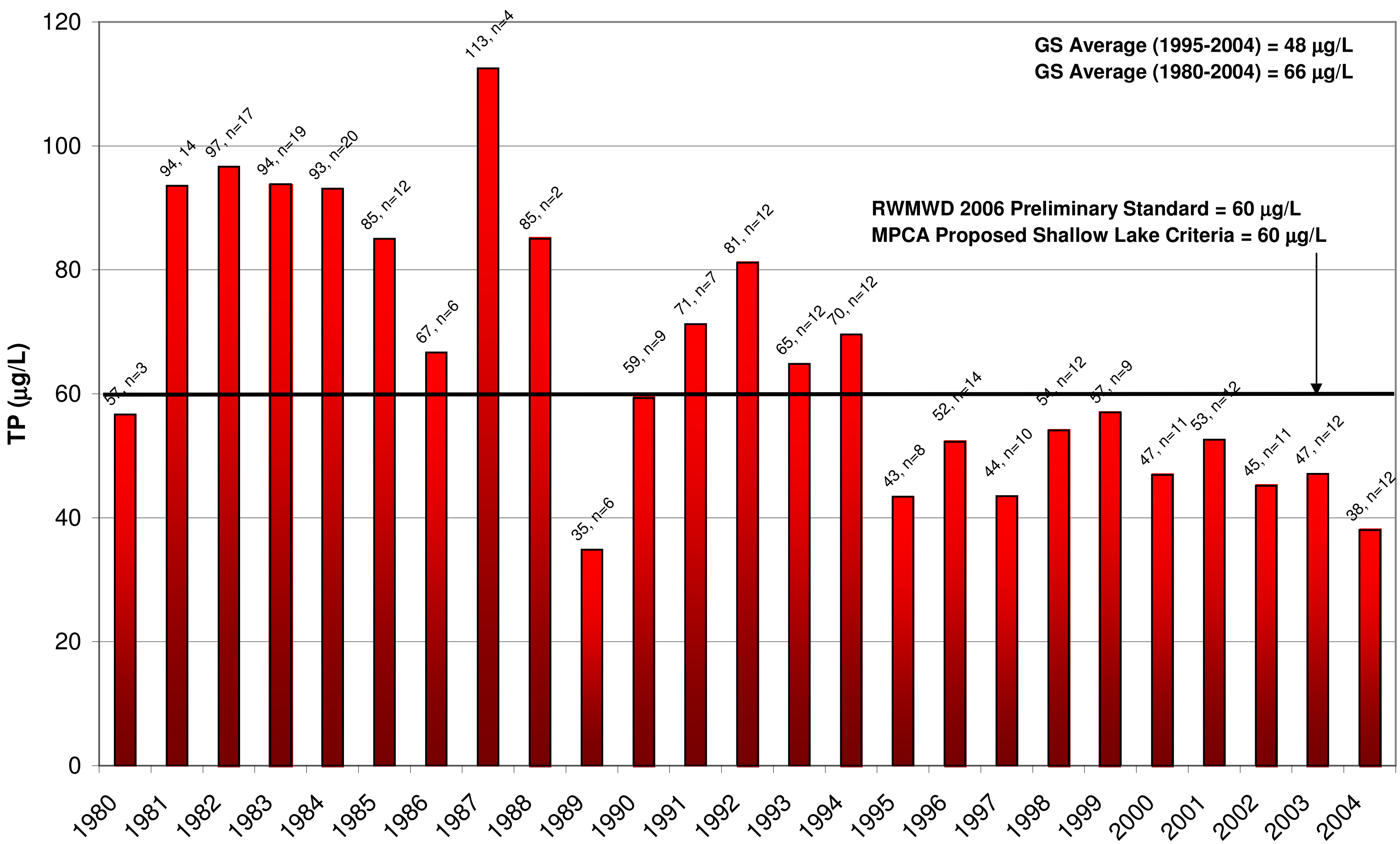


Figure 2-7
Round Lake (in Maplewood)
Growing Season (June through September) Average
Total Phosphorus Concentrations
1980-2004

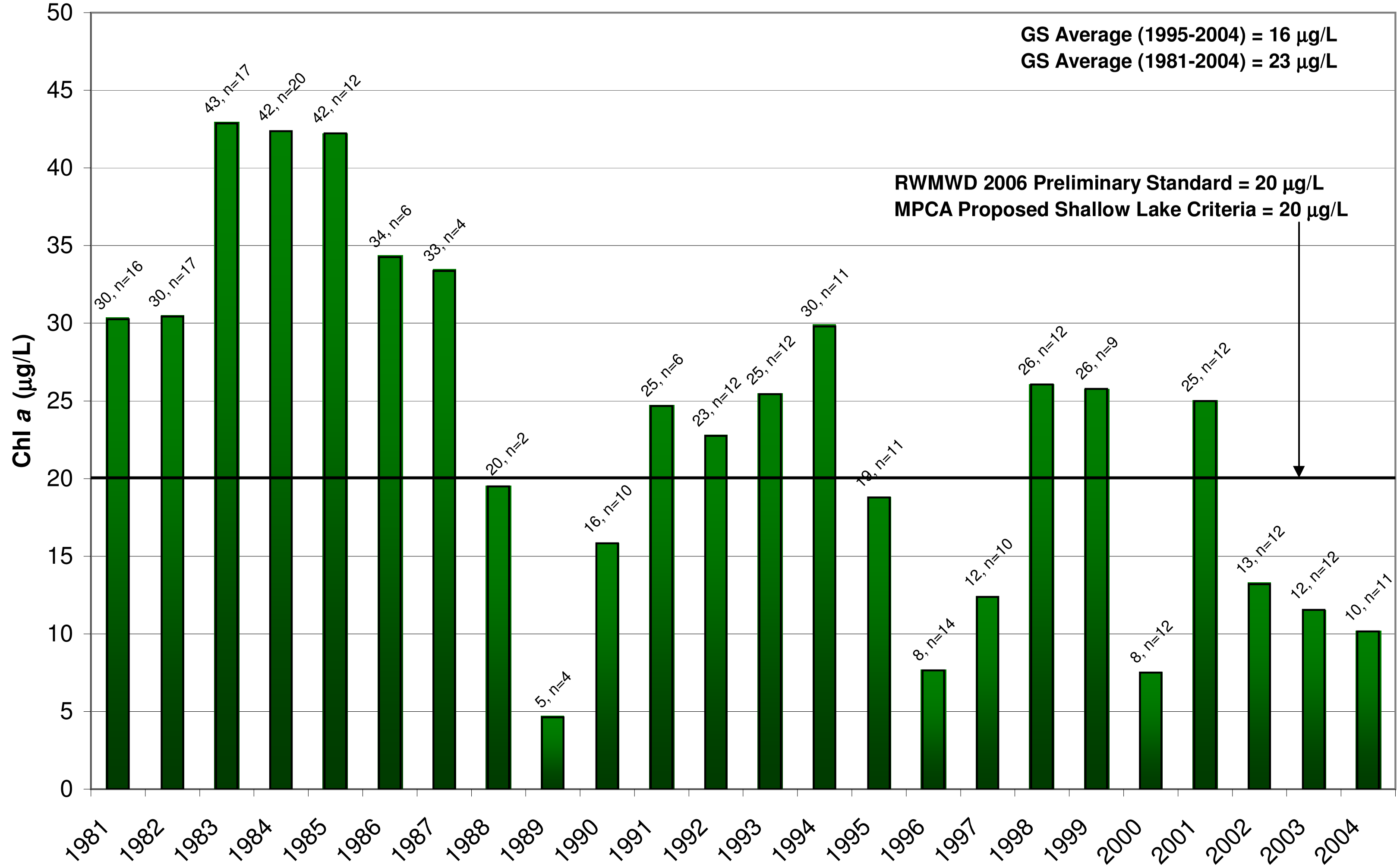


Figure 2-8
Round Lake (in Maplewood)
Growing Season (June through September) Average
Total Chlorophyll *a* Concentrations
1981-2004

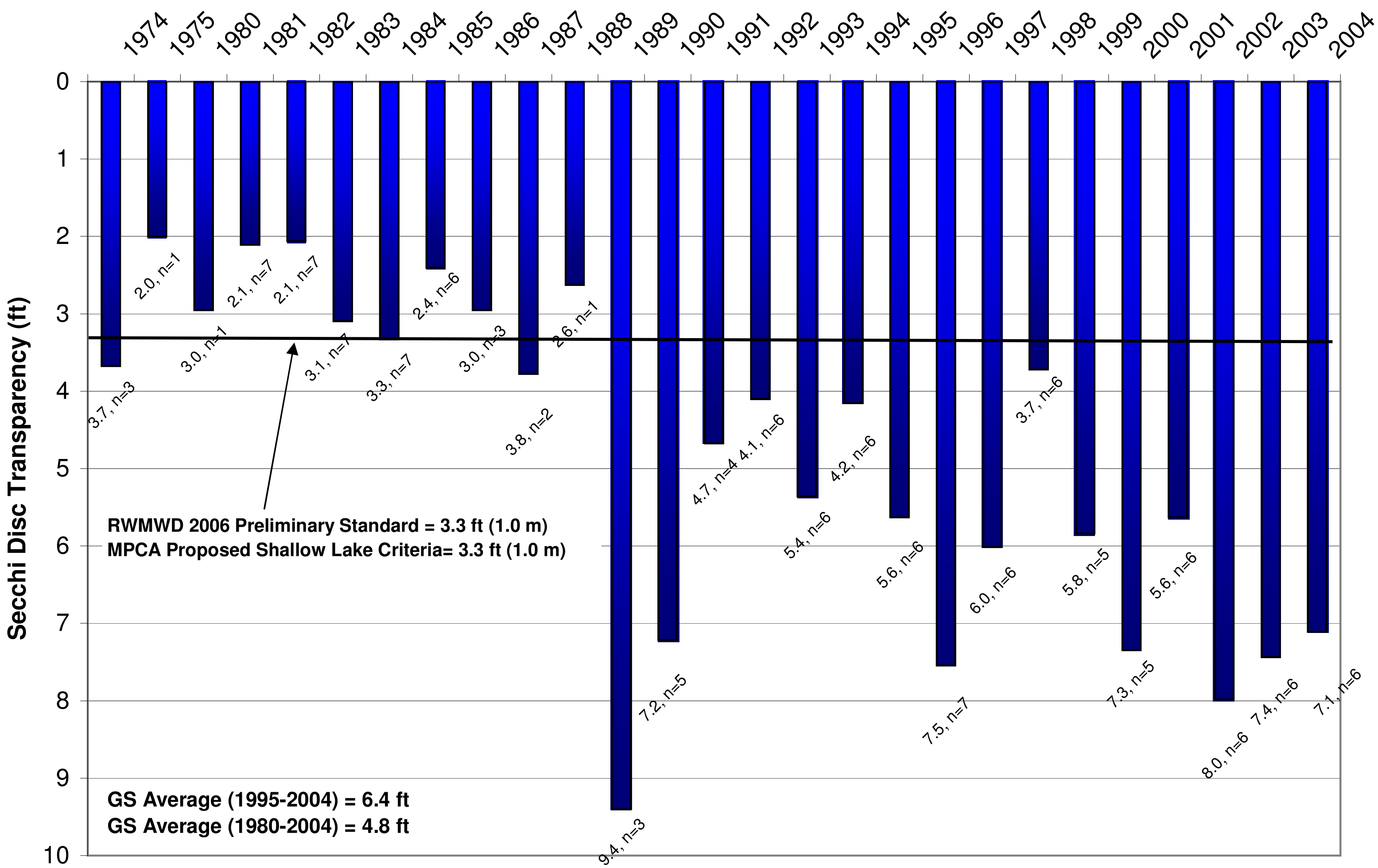


Figure 2-9
Round Lake (in Maplewood)
Growing Season (June through September) Average
Secchi Disc Transparencies
1974-1975,1980-2004

2.3.1.1 Historic Water Quality Alignment with Established Goals

This difference in the average TP and Chl *a* concentrations as well as the SD transparency over the entire period, as well as for the past decade, indicate improvements in Round Lake water quality. A trend analysis run on the data available for Round Lake confirms that the changes in all three water quality parameters are significant and that water quality in Round Lake has improved over the period of record.

The 2006 preliminary District water quality goals (Barr, 2006 [Draft]) for Round Lake are the same as the proposed water quality standards established by the MPCA for shallow lakes in the North Central Hardwood Forest ecoregion (See Table 1-1). Figures 2-7 through 2-9 shows the annual growing season averages for TP, Chl *a*, and SD as compared to the proposed water quality goals. The growing season average for the past decade for Round Lake for each of the water quality parameters has met the proposed standards and has been consistently meeting these goals for the past 10 years.

In addition to the significant improvement in lake water quality, the results of the MINLEAP analysis suggests that given Round Lake's watershed area, lake area, and mean depth, the expected TP and Chl *a* concentrations for a minimally impacted lake with similar characteristics would be 56.3 µg/L (standard error of 18.5) and 23.7 µg/L (standard error of 14.2), respectively and the predicted SD transparency being 1.2 m (3.9 feet) (standard error of 0.5 m). Comparing the summer average conditions within Round Lake for the past decade to these predicted ranges indicates that water quality in Round Lake falls within the expected water quality ranges and is actually better than the expected average value for a lake with similar basin and watershed characteristics in CHF ecoregion of Minnesota.

2.3.2 Biological Parameters

There are currently no macrophyte, zooplankton, phytoplankton, or fishery surveys available specifically for Round Lake. According to information from the MDNR, Eurasian watermilfoil, an invasive macrophyte, is currently present in Round Lake. Additionally, a study of the extended Phalen Chain of Lakes, which includes Kohlman Lake, Gervais Lake, Keller Lake, and Lake Phalen, indicates that a large number of carp have been observed in the lakes, especially during spawning season, although the actual magnitude of the benthivorous fish (bottom-feeding) has not been established (Barr, 2005b; Barr, 2005c). Benthivorous fish are known to resuspend sediment which can be related to increased phosphorus loads.

3.0 Water Quality Modeling

Phosphorus typically moves either in water as soluble phosphorus (dissolved in the water) or attached to sediments carried by water. Therefore, the determination of the volume of water discharged annually to each lake is integral to defining the amount of phosphorus loading. This section of the report provides a summary of the watershed and in-lake modeling results for Round Lake. These results help identify the major sources of TP in the lake and direct the development of management options that might help maintain and/or improve the water quality in Round Lake. Appendix B summarizes the water quality evaluation methods used in this report, including more detailed information on the P8 and in-lake models. A summary of the estimated annual water and phosphorus budgets for average climatic conditions for Round Lake can be seen in Figure 3-1.

3.1 Watershed Modeling (P8) Results

The P8 model was used to simulate loadings to Round Lake during the average (2000-01), wet (2001-02) and dry (1988-89) climatic conditions. These estimated loadings are based upon the flow and treatment of stormwater through the drainage system, including the effects of existing wetlands and detention ponds on water quality.

Table 3-1 summarizes the total water and phosphorus loads to Round Lake for the water years (October 1 to September 30) of the various climatic conditions. These loadings are based on existing land use conditions in the watershed.

Table 3-1 Summary of P8 Total Phosphorus Loads to Round Lake for Varying Climatic Conditions

Climatic Condition	Parameter		Load
Wet (10/1/01-9/30/02)	Flow	ac-ft	88.8
	TP	lbs	181.2
Average (10/1/00-9/30/01)	Flow	ac-ft	132.9
	TP	lbs	200.2
Dry (10/1/88-9/30/89)	Flow	ac-ft	70.6
	TP	lbs	130.8

It is important to note that under average conditions, the water load is actually slightly higher than under wet conditions while TP loads are similar. Climatic condition periods were selected based on depths of precipitation over a 17-month period that included the summer before the water year of interest. May through September of the summer before the water year is included in the in-lake modeling since it is assumed that the water and TP load to the lake during this period affects the following year's spring TP concentration. However, higher pollutant loading is often associated with smaller, more frequent storm events even though the resulting runoff volumes may be less.

Figure 3-2 summarizes the percent contribution of each of the Round Lake drainage districts to the total watershed phosphorus load during average climatic conditions. Round Lake is dominated by external phosphorus loads. A review of the annual water and phosphorus budgets for Round Lake during average climatic conditions shows that watershed loading accounts for 67 percent of the water load and 87 percent of the phosphorus load. Additionally, atmospheric deposition of phosphorus accounts for another 3 percent (6 lbs) of the external phosphorus load.

3.2 In-Lake Modeling Results

While the P8 model is a useful tool for evaluating runoff volumes and pollutant concentrations from a watershed, the in-lake model is needed to predict the resulting total phosphorus concentrations from the total phosphorus load to the lake as well as to quantify internal loading.

The estimated internal phosphorus load for Round Lake for the average climatic year (2001) was 19 lbs (with an estimated 12 lbs related to anoxic sediment release) which accounts for 10 percent of the total annual phosphorus load.

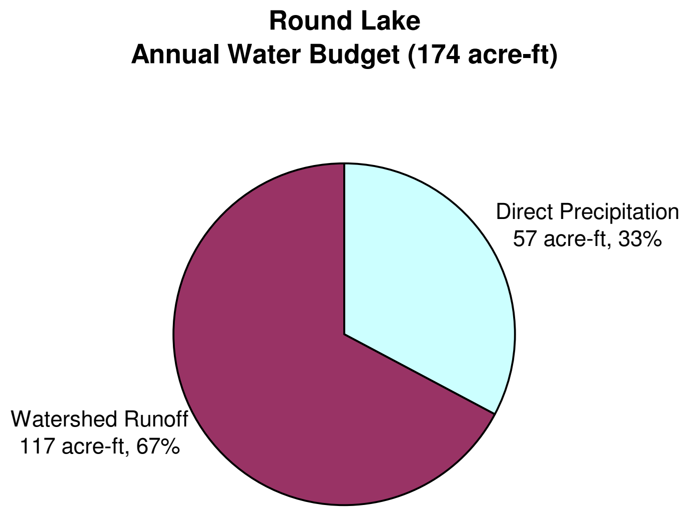
During 2001, the TP data demonstrates a pattern typical of dimictic lakes that are thermally stratified and experience phosphorus loading due to anoxic sediment release. Spring TP concentrations start low (spring steady-state) and gradually increase throughout the season. Near the end of summer (end of August), a sudden increase in the surface TP concentrations is observed due to the fall turn-over (mixing) of the lake that brings the water with high concentrations of TP from the hypolimnion to the surface. See Figure 3-3 for the observed in-lake TP concentrations for average climatic conditions.

During dry climatic conditions, it appears that watershed loading dominates the phosphorus budget in Round Lake with minimal internal loading. However, during wet conditions, it appears that internal loading plays a more significant role, similar to that occurs during average climatic conditions.

The in-lake model assumes that there is no interaction between the water in Round Lake and the channel on the northeast side of the lake that conveys discharge from Keller Lake into Lake Phalen. It is likely there is some interaction between these two water sources. Model results and historical water quality monitoring indicate that the lake's phosphorus concentration may be affected by Keller

Lake outflows through flushing flows and dilution of phosphorus concentrations, due to the fact that Round Lake's TP concentration often matches that of Keller Lake.

However, a much more detailed modeling effort would be required to quantify the actual interaction of between the flows from Keller Lake through the channel and the lake water in Round Lake. Additionally, the water quality model of Round Lake was developed without any fishery or macrophyte surveys which would provide information on estimated phosphorus loads due to benthivorous fish species and certain species of plants (such as Curlyleaf pondweed) that can contribute significantly to the internal phosphorus loading. However, because there is currently no information available, the current in-lake model assumes that the impacts of these potential sources are negligible.



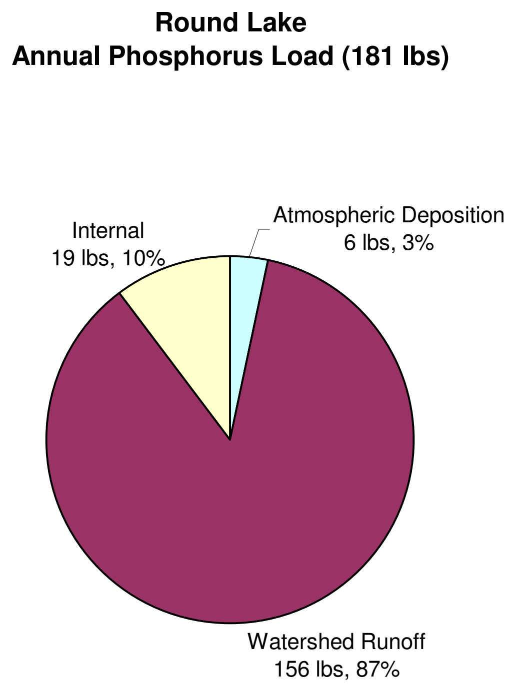


Figure 3-1
Round Lake
Annual Water and Phosphorus Budgets
for Average Climatic Conditions

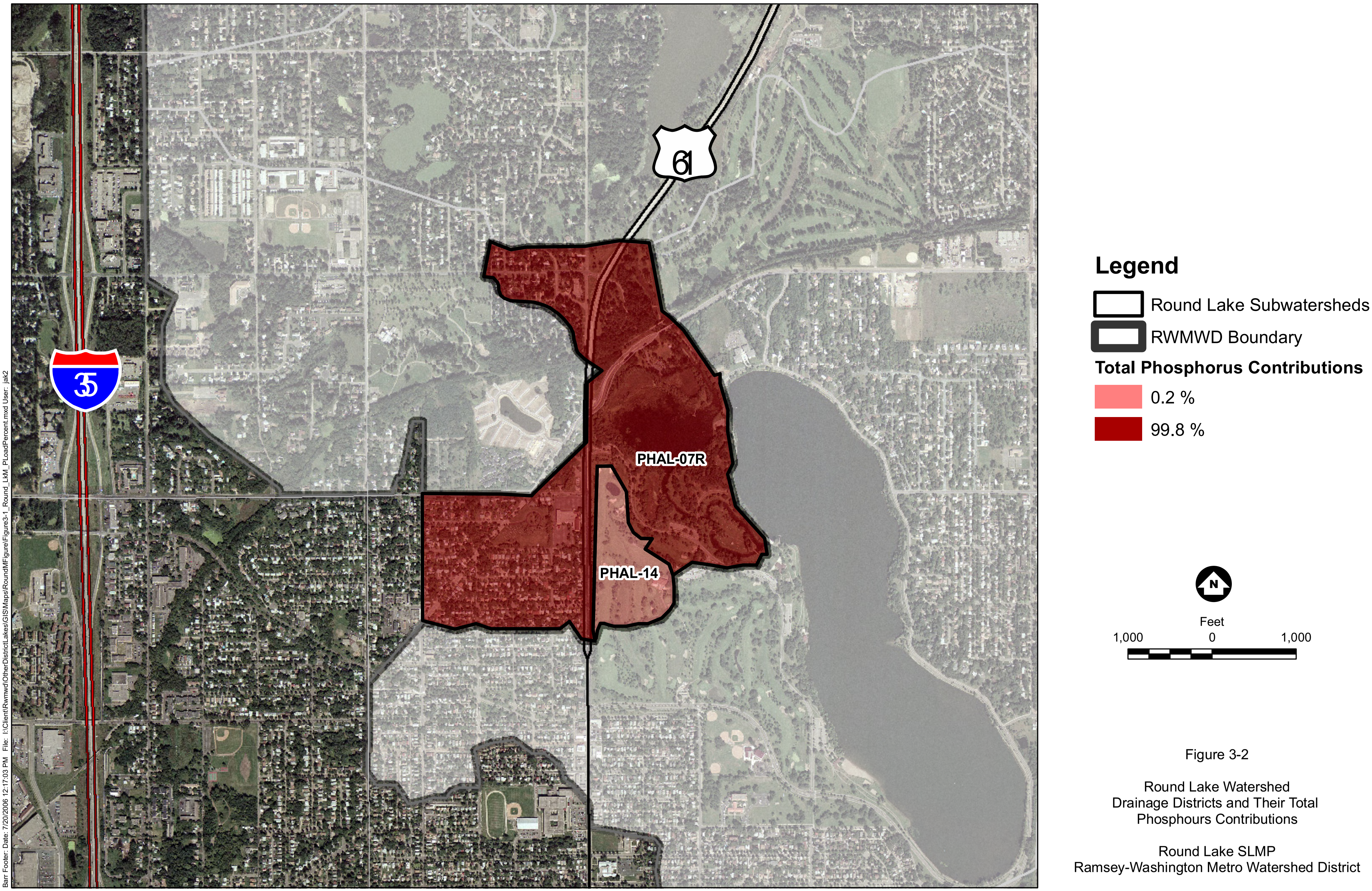


Figure 3-2

Round Lake Watershed
Drainage Districts and Their Total
Phosphours Contributions

Round Lake SLMP
Ramsey-Washington Metro Watershed District

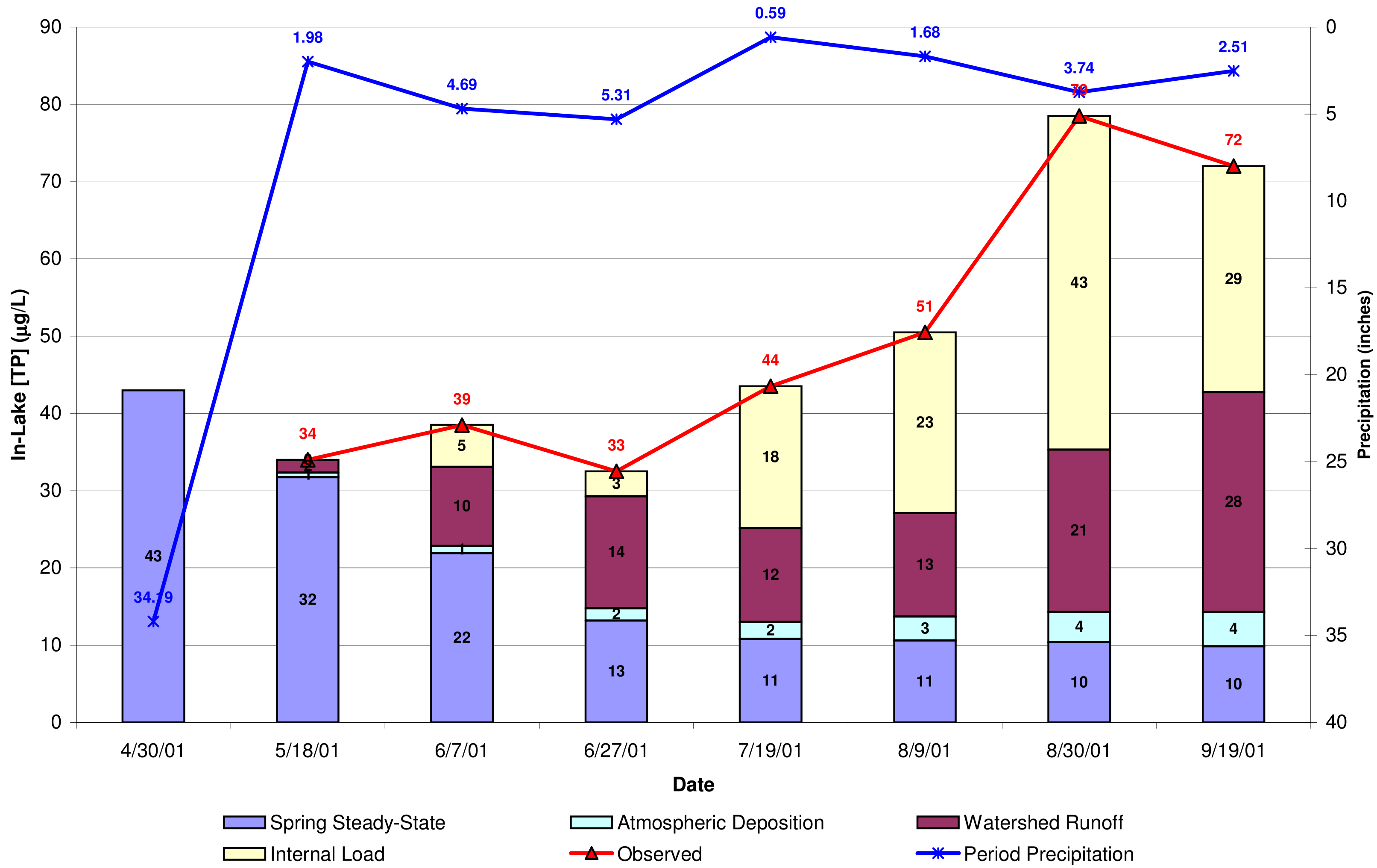


Figure 3-3
Round Lake
In-Lake Model Calibration Results for Average Climatic Conditions (2000-2001)
with Watershed and Spring Decay

4.0 Evaluation and Discussion of Management Options

4.1 Summary of Conditions in Round Lake

Based on the water quality data available, it appears that Round Lake has consistently met the 2006 preliminary District water quality goals for the past decade. These goals are aligned with the MPCA proposed shallow lake criteria for lakes in the North Central Hardwood Forests ecoregion. Additionally, a trend analysis indicates that water quality in Round Lake has significantly improved for all water quality parameters over the period of record.

Review of the phosphorus budget for average climatic conditions indicates that external phosphorus loads (mainly watershed runoff) dominate the loading to Round Lake. Internal loading comprises approximately 10 percent of the total load. More than half of the internal load appears to occur as the result of anoxic sediment release. Because of a lack of biological data, most specifically macrophyte and fishery surveys, the potential impact of rough fish and various aquatic weeds, cannot be evaluated. Presently, the impact of Keller Lake discharges on in-lake water quality cannot be quantified.

Unless the District feels that a more significant improvement in water quality in Round Lake is of high priority, implementation of additional management practices beyond what is already required by the District for new and redevelopment is not necessary. A general discussion of BMPs can be found in Appendix C.

4.2 Discussion of Internal Loads in Round Lake

In-lake modeling suggests that Round Lake does experience internal phosphorus loading to some degree. Because there is limited information about many of the typical sources of internal phosphorus loads, such as benthivorous fish activity, the presence of certain macrophytes such as Curlyleaf pondweed, and anoxic release from sediments, it is difficult to estimate how specific in-lake treatments would impact the water quality in Round Lake. However, the water quality data and the in-lake modeling indicate that Round Lake thermally stratifies during the summer months, the hypolimnion becomes anoxic, and there is a release of phosphorus from the sediments during this period. Additionally, benthivorous fish have been observed in other lakes in the Phalen Chain of Lakes.

Benthivorous fish, such as carp and bullhead, can have a direct influence on the phosphorus concentration in a lake (LaMarra, 1975) as these fish typically feed on decaying plant and animal matter and other organic particulates found at the sediment surface and convert these nutrients into a soluble form that is then available for algal uptake. Additionally, they cause resuspension of sediments that reduce water clarity as well as high phosphorus concentrations (Cooke et al., 1993). The predicted water quality improvement following removal of the bottom-feeding fish is difficult to estimate, and will require permitting and guidance from the MDNR. In addition, using fish barriers to prevent benthivorous fish from spawning may adversely affect the spawning of game fish, such as northern pike, which is undesirable.

Round Lake is directly connected to the Phalen Chain of Lakes including Lake Phalen and Keller Lake. Review of the MDNR fishery reports available for lakes in the chain indicate the presence of benthivorous fish, though not in significant numbers. However, large numbers of carp have been observed by anglers and District staff, especially during spawning season (Barr, 2005b; Barr, 2005c). Quantifying the impact of benthivorous fish management on water quality in the lake at this point is very uncertain. Additionally, because of the direct connections between the lakes on the Phalen Chain, rough fish management would most likely have to be “Chain-wide.”

4.3 Diversion of Keller Lake Discharge through Round Lake

Currently, Keller Lake discharges into the open channel that runs parallel to the northeast side of Round Lake and outlets to Lake Phalen via the north outlet of Round Lake. Although the channel bypasses Round Lake, there is some interaction between the channel water and water in Round Lake. However, the extent of mixing has not been quantified. The District was interested in evaluating a management scenario that routes all of Keller Lake’s discharge through Round Lake and determining the impact it would have on the water quality in Lake Phalen.

The outlet from Keller Lake is a 36-foot rectangular weir with an invert elevation of 858 feet MSL. Because there is very little difference in the lake levels of Keller Lake and the downstream Lake Phalen, the flow over this structure is often submerged. Based on a lake level analysis, the estimated average discharge from Keller Lake during the period of 2001 through was approximately 20 cfs. Discharge volumes from Keller Lake were estimated for wet climatic conditions (2001-2002) for each time period between Round Lake water quality sampling events. These volumes, along with actual water quality data available for Keller Lake for those same periods, were incorporated into the Round Lake in-lake model developed for wet climatic conditions.

Model results suggest that routing Keller Lake discharges through Round Lake will have minimal improvement on the water quality before the water reaches Lake Phalen as much of the water volume will be flushed through Round Lake and will not receive additional treatment from the Round Lake basin. Modeling of existing land use under wet climatic conditions shows that under the diversion scenarios, Round Lake would receive several times the volume of water than it currently receieves under the existing conditions.

Also, by closing the northern outlet from the channel and Round Lake to Lake Phalen, all flows from Keller Lake, as well as Round Lake, would have to discharge to Lake Phalen via the channel on the south side of Round Lake. Because of increased flows moving through the channel, erosion, channel stability, and flooding may become issues of concern.

5.0 Recommendations

5.1 Attainment of Goals

Based on the water quality data available, it appears that Round Lake has consistently met the 2006 preliminary District water quality goals for the past decade. These goals are aligned with the MPCA proposed shallow lake criteria for lakes in the North Central Hardwood Forests ecoregion. As a result, it seems that the preliminary District water quality goals seem reasonable for Round Lake and should be maintained. However, it is recommended that the District management class for Round Lake be changed from "Improvement" to "Prevent further degradation."

Additionally, Round Lake is listed on the MPCA Draft 2006 Impaired Waters List, with Excess Nutrients identified as its primary pollutant. Because there has been a significant improvement in water quality and the average summer growing season, TP concentration has been consistently meeting the MPCA proposed shallow lakes water quality criteria for the past decade, a case to have Round Lake delisted from the Impaired Waters List could be made. Therefore, it is recommended that the District proceed with the 303(d) delisting process for Round Lake.

Table 5-1 summarizes the proposed changes to the District classifications of Round Lake based on the results of this study.

Table 5-1 Summary of Proposed RWMWD Recreational-use Level, Water Quality Goals, Management Class as well as 303(d) Impaired Waters for Round Lake (in Maplewood)

Water Body	RWMWD Use Level	2006 Proposed RWMWD Water Quality Goal	2006 Proposed RWMWD Management Class	CWA 303(d) Impaired Waters List
Round Lake	3	60 µg/L TP[1] 20 µg/L Chl*a*[1] 3.3 ft SD[1]	Prevent further degradation[2]	Delisting[3] (Excess Nutrients)

1- Water quality goals are consistent with the MPCA's draft criteria for shallow lakes in the North Central Hardwood Forests (CHF) ecoregion (Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria. Third Edition, September, 2005)

2- Proposed management class for Round Lake. Originally identified as Improvement.

3- Recommended delisting from the 303(d) Impaired Waters List as Round Lake has been consistently meeting the MPCA criteria for the past decade.

5.2 Management Recommendations and Further Studies

Because water quality in Round Lake has improved and meets the proposed MPCA water quality criteria, specific structural and in-lake BMPs are not recommended at this time. Instead, a "Prevent further degradation" management approach for this lake is appropriate.

"Prevention of further degradation" recommendations for Round Lake would include:

- Development of rules to ensure that new developments do not increase the sediment and phosphorus leaving their sites.
- Monitoring of the fishery, specifically focusing on the presence of benthivorous fish such as carp.
- Monitoring of macrophytes within the lake to determine the presence of invasive species such as Curlyleaf pondweed and Eurasian water milfoil and the creation and implementation of a macrophyte management plan that targets these species.
- Creation and implementation of a shoreline study that seeks restoration opportunities around Round Lake.

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Appendix A

General Concepts in Lake Water Quality

Appendix A: General Concepts in Lake Water Quality

There are a number of concepts and terminology that are necessary to describe and evaluate a lake's water quality. This section is a brief discussion of those concepts, divided into the following topics:

- Eutrophication
- Trophic states
- Limiting nutrients
- Stratification
- Nutrient recycling and internal loading

To learn more about these five topics, one can refer to any text on limnology (the science of lakes and streams).

A.1 Eutrophication

Eutrophication, or lake degradation, is the accumulation of sediments and nutrients in lakes. As a lake naturally becomes more fertile, algae and weed growth increases. The increasing biological production and sediment inflow from a lake's watershed eventually fill the lake's basin. Over a period of many years, the lake successively becomes a pond, a marsh and, ultimately, a terrestrial site. This process of eutrophication is natural and results from the normal environmental forces that influence a lake. Cultural eutrophication, however, is an acceleration of the natural process caused by human activities. Nutrient and sediment inputs (i.e., loadings) from wastewater treatment plants, septic tanks, and stormwater runoff can far exceed the natural inputs to the lake. The accelerated rate of water quality degradation caused by these pollutants does result in unpleasant consequences. These include profuse and unsightly growths of algae (algal blooms) and/or the proliferation of rooted aquatic weeds (macrophytes).

A.2 Trophic States

Not all lakes are at the same stage of eutrophication; therefore, criteria have been established to evaluate the nutrient status of lakes. Trophic state indices (TSIs) are calculated for lakes on the basis of total phosphorus, Chlorophyll *a* concentrations, and Secchi disc transparencies. TSI values range upward from 0, describing the condition of the lake in terms of its trophic status (i.e., its degree of fertility). All three of the parameters can be used to determine a TSI. However, water transparency is typically used to develop the TSI_{SD} (trophic state index based on Secchi disc transparency) because people's perceptions of water clarity are often directly related to recreational-use impairment. The TSI rating system results in the placement of a lake with high fertility in the hypereutrophic status category. Water quality trophic status categories include oligotrophic (i.e., excellent water quality), mesotrophic (i.e., good water quality), eutrophic (i.e., poor water quality), and hypereutrophic (i.e., very poor water quality). Water quality characteristics of lakes in the various trophic status categories are listed below with their respective TSI ranges:

1. **Oligotrophic** – [$20 \leq TSI_{SD} \leq 38$] clear, low productive lakes, with total phosphorus concentrations less than or equal to 10 µg/L, Chlorophyll *a* concentrations of less than or equal to 2 µg/L, and Secchi disc transparencies greater than or equal to 4.6 meters (15 feet).
2. **Mesotrophic** – [$38 \leq TSI_{SD} \leq 50$] intermediately productive lakes, with total phosphorus concentrations between 10 and 25 µg/L, Chlorophyll *a* concentrations between 2 and 8 µg/L, and Secchi disc transparencies between 2 and 4.6 meters (6 to 15 feet).
3. **Eutrophic** – [$50 \leq TSI_{SD} \leq 62$] high productive lakes relative to a neutral level, with 25 to 57 µg/L total phosphorus, Chlorophyll *a* concentrations between 8 and 26 µg/L, and Secchi disc measurements between 0.85 and 2 meters (2.7 to 6 feet).
4. **Hypereutrophic** – [$62 \leq TSI_{SD} \leq 80$] extremely productive lakes which are highly eutrophic and unstable (i.e., their water quality can fluctuate on daily and seasonal basis, experience periodic anoxia and fish kills, possibly produce toxic substances, etc.) with total phosphorus concentrations greater than 57 µg/L, Chlorophyll *a* concentrations of greater than 26 µg/L, and Secchi disc transparencies less than 0.85 meters (2.7 feet).

Determining the trophic status of a lake is an important step in diagnosing water quality problems. Trophic status indicates the severity of a lake's algal growth problems and the degree of change needed to meet its recreational-use goals. Additional information, however, is needed to determine the cause of algal growth and a means of reducing it.

A.3 Limiting Nutrients

The quantity or biomass of algae in a lake is usually limited by the water's concentration of an essential element or nutrient "the limiting nutrient". (For rooted aquatic plants, the nutrients are derived from the sediments.) The limiting nutrient concept is a widely applied principle in ecology and in the study of eutrophication. It is based on the idea that plants require many nutrients to grow, but the nutrient with the lowest availability, relative to the amount needed by the plant, will limit plant growth. It follows then, that identifying the limiting nutrient will point the way to controlling algal growth.

Nitrogen (N) and phosphorus (P) are generally the two growth-limiting nutrients for algae in most natural waters. Analysis of the nutrient content of lake water and algae provides ratios of N:P. By comparing the ratio in water to the ratio in the algae, one can estimate whether a particular nutrient may be limiting. Algal growth is generally phosphorus-limited in waters with N:P ratios greater than 12. Laboratory experiments (bioassays) can demonstrate which nutrient is limiting by growing the algae in lake water with various concentrations of nutrients added. Bioassays, as well as fertilization of in-situ enclosures and whole-lake experiments, have repeatedly demonstrated that phosphorus is usually the nutrient that limits algal growth in freshwaters. Reducing phosphorus in a lake, therefore, is required to reduce algal abundance and improve water transparency. Failure to reduce phosphorus concentrations will allow the process of eutrophication to continue at an accelerated rate.

A.4 Stratification

The process of internal loading is dependent on the amount of organic material in the sediments and the depth-temperature pattern, or "thermal stratification," of a lake. Thermal stratification profoundly influences a lake's chemistry and biology. When the ice melts and air temperature warms in spring, lakes generally progress from being completely mixed to stratified with only an upper warm well-mixed layer of water (epilimnion), and cold temperatures in a bottom layer (hypolimnion). Because of the density differences between the lighter warm water and the heavier cold water, stratification in a lake can become very resistant to mixing. When this occurs, generally in mid-summer, oxygen from the air cannot reach the bottom lake water and, if the lake sediments have sufficient organic matter, biological activity can deplete the remaining oxygen in the hypolimnion. The epilimnion can remain well-oxygenated, while the water above the sediments in the hypolimnion becomes completely devoid of dissolved oxygen (anoxic). Complete loss of oxygen changes the chemical conditions in the water and allows phosphorus that had remained bound to the sediments to reenter the lake water.

As the summer progresses, phosphorus concentrations in the hypolimnion can continue to rise until oxygen is again introduced (recycled). Dissolved oxygen concentration will increase if the lake sufficiently mixes to disrupt the thermal stratification. Phosphorus in the hypolimnion is generally not available for plant uptake because there is not sufficient light penetration to the hypolimnion to allow for growth of algae. The phosphorus, therefore, remains trapped and unavailable to the plants until the lake is completely mixed. In shallow lakes this can occur throughout the summer, with sufficient wind energy (polymixis). In deeper lakes, however, only extremely high wind energy is sufficient to destratify a lake during the summer and complete mixing only occurs in the spring and fall (dimixis). Cooling air temperature in the fall reduces the epilimnion water temperature, and consequently increases the density of water in the epilimnion. As the epilimnion water density approaches the density of the hypolimnion water very little energy is needed to cause complete mixing of the lake. When this fall mixing occurs, phosphorus that has built up in the hypolimnion is mixed with the epilimnion water and becomes available for plant and algal growth.

A.5 Nutrient Recycling and Internal Loading

The significance of thermal stratification in lakes is that the density change in the metalimnion (i.e., middle transitional water temperature stratum) provides a physical barrier to mixing between the epilimnion and the hypolimnion. While water above the metalimnion may circulate as a result of wind action, hypolimnetic waters at the bottom generally remain isolated. Consequently, very little transfer of oxygen occurs from the atmosphere to the hypolimnion during the summer.

Shallow water bodies may circulate many times during the summer as a result of wind mixing. Lakes possessing these wind mixing characteristics are referred to as **polymictic** lakes. In contrast, deeper lakes generally become well-mixed only twice each year. This usually occurs in the spring and fall. Lakes possessing these mixing characteristics are referred to as **dimictic** lakes. During these periods, the lack of strong temperature/density differences allows wind-driven circulation to mix the water column throughout. During these mixing events, oxygen may be transported to the deeper portions of the lake, while dissolved phosphorus is brought up to the surface.

Phosphorus enters a lake from either watershed runoff or direct atmospheric deposition. It would, therefore, seem reasonable that phosphorus in a lake can decrease by reducing these external loads of phosphorus to the lake. All lakes, however, accumulate phosphorus (and other nutrients) in the sediments from the settling of particles and dead organisms. In some lakes this reservoir of phosphorus can be reintroduced in the lake water and become available again for plant uptake. This resuspension or dissolution of nutrients from the sediments to the lake water is known as “internal loading”. As long as the lake’s sediment surface remains sufficiently oxidized (i.e., dissolved oxygen remains present in the water above the sediment), its phosphorus will remain bound to sediment particles as ferric hydroxy phosphate. When dissolved oxygen levels become extremely low at the water-sediment interface (as a result of microbial activity using the oxygen), the chemical reduction of ferric iron to its ferrous form causes the release of dissolved phosphorus, which is readily available for algal growth, into the water column. The amount of phosphorus released from internal loading can be estimated from depth profiles (measurements from surface to bottom) of dissolved oxygen and phosphorus concentrations. Even if the water samples indicate the water column is well oxidized, the oxygen consumption by the sediment during decomposition can restrict the thickness of the oxic sediment layer to only a few millimeters. Therefore, the sediment cannot retain the phosphorus released from decomposition or deeper sediments, which result in an internal phosphorus release to the water column. Low-oxygen conditions at the sediments, with resulting phosphorus release, are to be expected in eutrophic lakes where relatively large quantities of organic material (decaying algae and macrophytes) are deposited on the lake bottom.

If the low-lying phosphorus-rich waters near the sediments remain isolated from the upper portions of the lake, algal growth at the lake's surface will not be stimulated. Shallow lakes and ponds can be expected to periodically stratify during calm summer periods, so that the upper warmer portion of the water body is effectively isolated from the cooler, deeper (and potentially phosphorus-rich) portions. Deep lakes typically retain their stratification until cooler fall air temperatures allow the water layers to become isothermal and mix again. Deep lakes are, therefore, frequently dimictic, typically mixing only twice a year. However, relatively shallow lakes are less thermally stable and may mix frequently during the summer periods.

The pH of the water column can also play a vital role in affecting the phosphorus release rate under oxic conditions. Photosynthesis by macrophytes and algae during the day tend to raise the pH in the water column, which can enhance the phosphorus release rate from the oxic sediment. Enhancement of the phosphorus release at elevated pH ($pH > 7.5$) is thought to occur through replacement of the phosphate ion (PO_4^{-3}) with the excess hydroxyl ion (OH^-) on the oxidized iron compound (James, et al., 2001).

Another potential source of internal phosphorus loading is the die-off of Curlyleaf pondweed, which is an exotic (i.e., non-native) lake weed is present in many of the lakes in Minnesota.

Appendix B

Water Quality Data Analysis

Appendix B: Water Quality Evaluation

Below is a discussion of the evaluation techniques used in the analysis of Round Lake water quality data and pollutant load modeling to determine current conditions in the lake and water quality goal attainability.

B.1 Lake Water Quality Data Analysis

Historical water quality data was evaluated to determine at which stage of eutrophication each lake is currently at. Secchi disc (SD) transparency, total phosphorus (TP) concentration, and chlorophyll *a* (Chl *a*) concentration are the parameters typically considered when discussing the trophic state and overall water quality of a lake. These are the 3 parameters used in this study to evaluate the current water quality of lakes in this study.

B.1.1 Trophic State

Determining the trophic status of a lake is an important step in diagnosing water quality problem as it is an indicator the severity of a lake's algal growth problems and the degree of change needed to meet its recreational goals. To assign a tropic state to each lake, available water quality data was analyzed using the Carlson Trophic State Index, (Carlson, 1977), which assigns a trophic state index ("TSI") to a lake based on the TP and Chl *a* concentrations as well as SD transparency. The lake classification index is summarized below in Table B-1.

Table B-1 Carlson Trophic State Index Classification

Lake Classification	TSI Values	TP Concentration (µg/L)	Chl *a* Concentration (µg/L)	SD Transparency (m)
Oligotrophic	<38	<10.5	<2.0	>4.6
Mesotrophic	38–50	10.5–24.5	2.0–7.5	4.6–2.01
Eutrophic	50–62	24.5–57.0	7.5–26.0	2.01–0.85
Hypereutrophic	>62	>57.0	>26.0	<0.85

In general, oligotrophic classification indicates low productivity (nutrients) and high water clarity. Hypereutrophic status is on the other end of the spectrum with extremely high nutrients levels and very poor water quality that result in severely reduced recreational-use.

B.1.2 Trend Analysis

Trend analysis of lake water quality data are completed to determine if a lake has experienced significant degradation or improvement during all (or a portion) of the years for which water quality data are available. Water quality data from the "summer" growing season (June-September) are compiled from previous investigations for each analysis. The summer averages of the water quality data are used to determine water quality trends. Long term trends are typically determined using standard statistical methods (i.e., linear regression and analysis of variance).

For this report, the District used the Mann-Kendall/Sen's Slope Trend Test to determine water quality trends and their significance. To complete the trend test, the calculated summer average must be based on at least four measured values during the sampling season, and at least five years of data are required. The District considers a lake's water quality to have significantly improved or declined if the Mann-Kendall/Sen's Slope Trend Test is statistically significant at the 95 percent confidence interval. Also, to conclude an improvement requires concurrent decreases in total phosphorus and chlorophyll *a* concentrations, and increases in Secchi disc transparencies; a conclusion of degradation requires the inverse relationship.

B.1.3 Lake Water Quality Goal Attainability

The Minnesota Lake Eutrophication Analysis Procedure (MINLEAP) is an empirical model intended to be used as a screening tool for estimating lake conditions and for identifying "problem" lakes. MINLEAP is particularly useful for identifying lakes requiring "protection" versus those requiring "restoration" (Heiskary and Wilson, 1990). MINLEAP uses relationships between water quality parameters, watershed areas, and basic lake basin morphometry for each ecoregion of the state to estimate typical ranges in water quality for "minimally" impacted lakes. This modeling has been done in the past to identify Minnesota lakes which may be in better or worse condition than they "should be" based on their location, watershed area and lake basin morphometry (Heiskary and Wilson, 1990). This can be useful in the establishment of realistic water quality goals for lakes.

B.1.4 Biological Data

Any available biological data was compiled and evaluated for this SLMP. The type and distribution of aquatic communities are impacted by each other and water quality; thus macrophyte (aquatic weeds), phytoplankton, zooplankton, and fisheries data provides insight into the health of the aquatic ecosystem associated within a water body as well as the overall water quality. Information of fisheries and macrophytes can also help identify internal sources of phosphorus loading to the lake.

B.2 Pollutant Load Modeling

B.2.1 Watershed Pollutant Load Modeling (P8)

The P8 (Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds; IEP, Inc., 1990) Urban Catchment Model was used to estimate flow and water quality constituent loadings to each of the lakes from its contributing watersheds (the "external" load). P8 uses long-term climatic data so that watersheds and BMPs can be evaluated for varying hydrologic conditions.

The P8 models used to evaluate each lake and watershed in this LSR were originally developed and calibrated as part of the development of the larger Phalen Chain of Lakes SLMP (Barr Engineering Co., 2004). It was assumed that the P8 model parameters (flow and water quality) that were calibrated during the development of the Phalen Chain SLMP apply to each of the smaller, individual subwatersheds of the model and that the results of this P8 modeling will still provide general insight into the water volume and water quality loads to each lake. However, if the water quality within these specific lakes becomes a very high priority for the District, we would recommend a more detailed modeling effort be done for each lake.

The P8 models were run for wet (5/1/2001-9/30/2002), dry (5/1/1988-9/30/1989), and average (5/1/2000-9/30/2001) climatic conditions. Temperature data from the Minneapolis-St. Paul International Airport (MSP) and precipitation data combined from several area gages (MSP, Eden Prairie, Hopkins, and H.B. Fuller) were used for modeling the wet, dry and average years. The 2000 MetCouncil land use in the tributary watersheds was updated by comparing the land use classification (used in the Phalen Chain SLMP modeling) with 2004 areal photographs of the Metro area. This resulted in new runoff curve numbers and percentages of impervious surface within each watershed. However, since there were no major changes in the land use classifications, it was assumed that the original calibration of the P8 model would still be applicable, even with changed land use parameters.

When evaluating the results of the modeling, it is important to consider that the results provided are more accurate in terms of relative differences than in absolute results. The model provides a realistic estimate of the relative differences in phosphorus and water loadings from the various subwatersheds and major inflow points to the lake. However, since runoff quality is highly variable with time and location, the values for phosphorus loadings given from the model for a specific watershed may not necessarily reflect the actual loadings. Various site-specific factors, such as lawn care practices, illicit point discharges and erosion due to construction or streambank failure are not accounted for in the model. The model provides values that are considered to be "typical" of the region for the watershed's respective land uses.

B.2.2 Internal Pollutant Load Modeling

While the P8 model is a useful tool for evaluating runoff volumes and pollutant concentrations from a watershed, another method is needed to predict the in-lake phosphorus concentrations that are likely to result from the combination of external and internal phosphorus loads. Internal loading is often a significant source of phosphorus in lakes that have a history of high phosphorus loads from their watershed. Phosphorus released from the sediments is typically in a dissolved form, which can be quickly utilized by algae, leading to intense algae blooms. Internal loading is influenced by the lake's mixing and stratification patterns, macrophyte growth, and the presence of certain fish species.

For evaluating the resultant in-lake phosphorus concentrations in Round Lake, a mass balance spreadsheet model based on the empirical equation set forth by Dillion and Rigler (1974) was used. Phosphorus loads for each climatic period were predicted using the P8 model and then used along with the available in-lake water quality data from that time period to estimate the internal phosphorus load.

Water quality sample data for Round Lake, which consisted of total phosphorus, chlorophyll *a*, and Secchi disk data from the MPCA, were used to calibrate and verify the lake water quality mass balance model for the lake. There is data for Round Lake also available for a number of other water quality parameters.

For the average climatic period, water quality (total phosphorus) data from 2001 were used to determine the best in-lake water quality model to use for this analysis. The best fit proved to be the Dillon and Rigler model (Dillon and Rigler, 1974) with Chapra's 1975 retention term. Therefore, this model was used for predicting the spring total phosphorus concentration of the lake. The following steady-state mass balance equation, originally developed by Dillon and Rigler (Dillon and Rigler, 1974), was used for modeling the springtime total phosphorus concentration of Round Lake:

$$P_{SPRING} = \frac{L(1-R)}{z\rho}$$

where:

P_{SPRING} = spring total phosphorus concentration (µg/L)
L = areal total phosphorus loading rate ($mg/m^2/yr$)
R = retention coefficient
= Chapra (1975) = $v_s/(v_s+q_s)$
vs = apparent settling velocity (m/yr)
= $qs*t_d^{0.5}$ (Thomann and Mueller, 1987)
q_s = annual areal water outflow load (m/yr)
= Q/A
z = lake mean depth (m)
ρ = hydraulic flushing rate (1/yr)
= $1/(t_d)$
t_d = hydraulic residence time = (V/Q)
Q = annual outflow (m^3/yr)
V = lake volume (m^3)
A = lake surface area (m^2)

While this model, supplied with the total phosphorus loads predicted by P8 for the various climatic conditions for existing land use conditions, adequately predicted the spring steady-state concentration of phosphorus in lake, early-summer, summer average and fall overturn concentrations were not accounted for in the above model. It was determined after analyzing historical water quality data that the phosphorus concentrations varied significantly during the summer time. These variations were the result of watershed runoff, atmospheric deposition, and internal loading.

B.2.3 Accounting for Internal Loading

Most of the empirical phosphorus models (including that of Dillion and Rigler) assume that the lake to be modeled is well-mixed, meaning that the phosphorus concentrations within the lake are uniform. This assumption is useful in providing a general prediction of lake conditions, but it does not account for the seasonal changes in phosphorus concentrations that can occur in a lake. Such changes occur in dimictic lakes when phosphorus is removed by settling from the epilimnion. As has been discussed, these changes can also occur seasonally as a result of internal loading. Extensions of the Vollenweider model are therefore needed to allow the use of the P8-generated TP loads to provide reasonable predictions of summer average epilimnetic lake phosphorus concentrations.

Analysis of water quality data for Round Lake demonstrates that the lake thermally stratifies during the summer months. The thermocline develops during the beginning of summer and typically stabilizes throughout the season, usually becoming deeper near the end of the summer before fall turnover. Because of this data, it can be concluded that Round Lake is most likely a "dimictic" (mixing twice per year).

During periods of stratification the bottom waters can become anoxic (devoid of oxygen), even for short periods, and internal phosphorus load from the lake sediments may occur. At this time, the phosphorus released from the sediments can build up in the hypolimnion, especially during periods of high temperatures and low wind. This internal load of phosphorus can be transported to the entire water column as wind increases and causes lake circulation or as fall approaches and mixing typically begins to occur. Dissolved oxygen profiles for Round Lake suggest that the hypolimnion typically has little or no dissolved oxygen and that anoxic sediment P-release is likely for much of the summer. Other sources of internal phosphorus loads include resuspension of sediments due to rough fish activities or wind-driven waves (in shallow lakes) as well as the die-back of certain macrophyte species such as Curlyleaf pondweed.

The internal loading of phosphorus was calculated from the following mass balance equation:

$$\text{Internal P} = \text{Observed P} + \text{Outflow P} - \text{Runoff P} - \text{Atmospheric P}$$

The phosphorus mass balance was calculated for the lake basin based on existing land use conditions and phosphorus concentrations measured in during the average climatic year.

Large internal loads will delay the lake's response to phosphorus loading reduction in the watershed. Large reductions in phosphorus loading from the watershed would eventually lead to reduced internal loading of phosphorus, although internal loading can be treated in the interim to achieve water quality goals.

B.2.4 Atmospheric Deposition

An atmospheric deposition rate of 0.2615 kg/ha/yr (MPCA, 2004) was applied to the surface area of Round Lake to determine annual phosphorus loading. The estimated atmospheric and watershed runoff phosphorus loads were used to determine the amount of internal loading within Round Lake by fitting the model to observed water quality data for the various climatic periods. The calibrated models were used to predict in-lake phosphorus concentrations under various management scenarios.

B.3 Use of the P8/In-lake Model

The in-lake model, adjusted to account for internal loading and calibrated to measured in-lake TP concentrations, was subsequently used to estimate phosphorus loads and concentrations under a variety of management scenarios and climatic conditions.

The annual water and watershed phosphorus loadings to Round Lake under existing land use conditions was estimated for three different years, each representing a distinct climatic pattern. The varying climatic conditions affect the lake's volume and hydrologic residence time, and thereby affect the phosphorus concentrations in the lake. The precipitation totals during the 3 climatic conditions (years) modeled are summarized in Table B-2.

Table B-2 Precipitation Amounts for Various Climatic Conditions used for Modeling Water and TP Loading to Round Lake

Climatic Condition	May 1 through April 30 Precipitation (inches)	May 1 through September 30 Precipitation (inches)
Dry (1988-1989)	23.82	16.61
Average (2000-2001)	34.19	22.3
Wet (2001-02)	31.91	31.88

As previously discussed, the internal loading for each lake varies drastically during different climatic conditions. Therefore, this variability was included in the in-lake modeling by utilizing different internal release rates for each condition. The estimation of the internal release rates for each of the conditions was able to be determined because water quality data was available for each of the climatic conditions.

B.3.1 Modeling Chlorophyll *a* and Secchi Disc Transparency

The P8 model used for the analysis predicts phosphorus loads to the lakes, and the in-lake model used to determine water quality in the lake itself only estimates phosphorus loads and concentrations. To estimate Chl *a* concentrations and SD transparencies, it was necessary to develop additional models (i.e., regression relationships).

Because there was several decades of water quality data available for Round Lake, developing reliable lake-specific relationships between summer average TP and Chl *a* and between summer average Chl *a* and SD transparency was successful. All surface water quality data collected from the lake was used to estimate Chl *a* concentrations and from modeled TP concentrations and SD transparencies were from the estimated Chl *a* concentrations. Figure B-1 depicts the numerical water quality models used to estimate Chl *a* and SD values for Round Lake.

For Round Lake, the equations are:

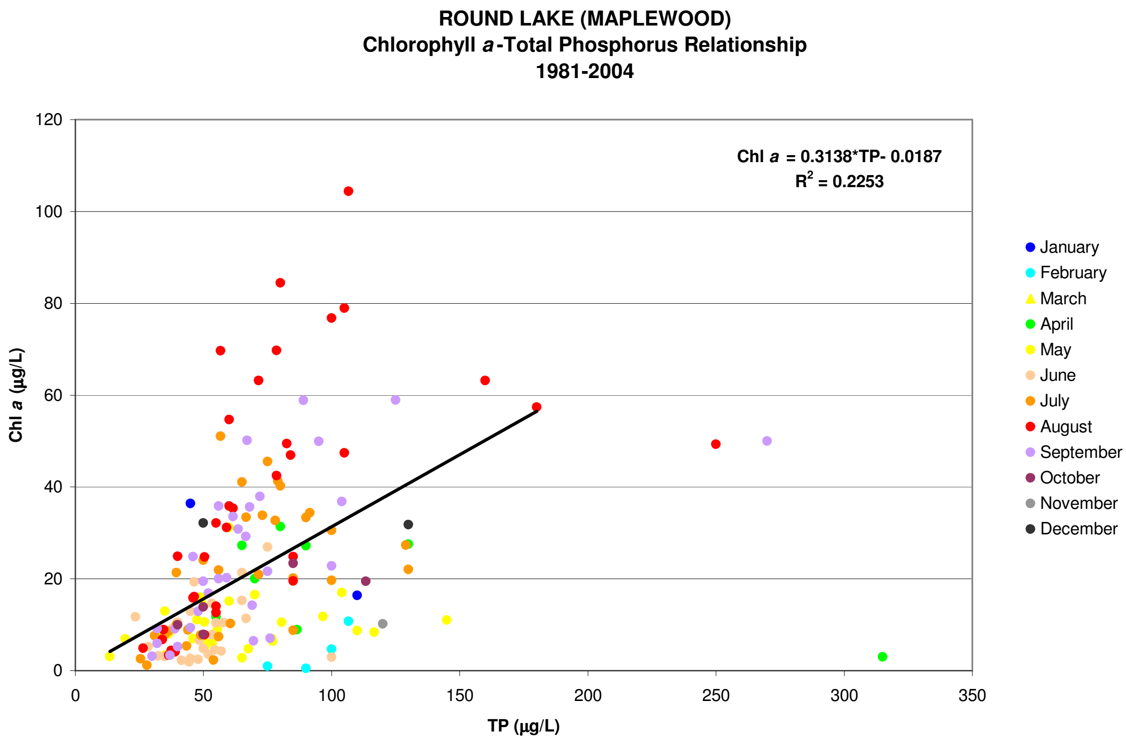
$$[\text{Chl } a] = 0.3138*[\text{TP}] - 0.0187 \qquad R^2 = 0.2253$$

$$\text{SD} = 144.8*[\text{TP}]^{-0.8698} \qquad R^2 = 0.4418$$

Where:

[TP]	=	measured or estimated epilimnetic (mixed surface layer) mean summer TP concentration (µg/L)
[Chl *a*]	=	estimated epilimnetic mean summer Chl *a* concentration (µg/L)
SD	=	estimated mean summer Secchi disc transparency (ft)

These equations were subsequently used to give indications of what may be expected with respect to Chl *a* and transparency, given the P8/in-lake model results for TP. It should be noted that the responses of these parameters to the others is highly variable. Due to this variability, the regression equations therefore can be expected only to allow a general indication of the lake response to changing TP, and the predicted Chl *a* and transparency values should not be construed as absolute.



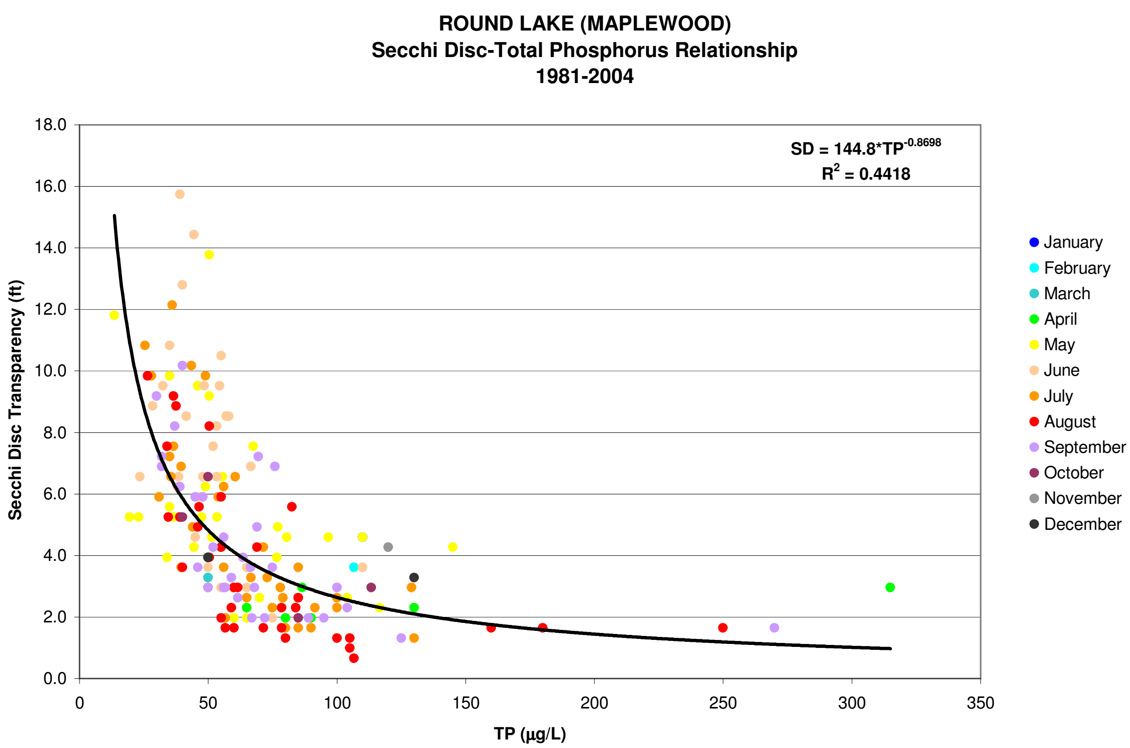


Figure B-1
Round Lake
Relationships between Total Phosphorus and Chlorophyll *a* Concentrations and Secchi Disc Transparencies

Appendix C

General Discussions of Best Management Practices (BMPs)

Appendix C: General Discussion of Best Management Practices (BMPs)

This section discusses improvement options and general BMPs considered for Round Lake and its watershed to remove phosphorus and/or reduce sediment loads entering a lake. Three types of BMPs were considered during the preparation of this report: structural, nonstructural, and in-lake. However, it is important to note that this is not a complete list but rather a select list of BMPs most applicable to the conditions specific to the watersheds and lakes of this study.

1. Structural BMPs remove a fraction of the pollutants and sediment loads contained in stormwater runoff prior to discharge into receiving waters.

2. Nonstructural BMPs (source control) eliminate pollutants at the source and prevent pollutants from entering stormwater flows.

3. In-Lake BMPs reduce phosphorus already present in a lake, and/or prevent the release of phosphorus from anoxic lake sediments.

C.1 Structural BMPs

Structural BMPs temporarily store and treat urban stormwater runoff to reduce flooding, remove pollutants, and provide other amenities (Schueler, 1987). Water quality BMPs are specifically designed for pollutant removal. The effectiveness of the various BMPs is summarized in Table C-1. Structural BMPs control total suspended solids and total phosphorus loadings by slowing stormwater and allowing particles to settle in areas before they reach the stream. Settling areas can be ponds, storm sewer sediment traps, or vegetative buffer strips. Settling can be enhanced by treatment with a flocculent prior to entering the settling basin.

When choosing a structural BMP, the ultimate objective must be well understood. The BMP should accomplish the following (Schueler 1987):

1. Reproduce, as nearly as possible, the stream flow before development.
2. Remove at least a moderate amount of most urban pollutants.
3. Require reasonable maintenance.
4. Have a neutral impact on the natural and human environments.
5. Be reasonably cost-effective compared with other BMPs.

Table C-1 General Effectiveness of Stormwater BMPs at Removing Common Pollutants from Runoff

Best Management Practice (BMP)	Suspended Sediment	Total Phosphorus	Total Nitrogen	Oxygen Demand	Trace Metals	Bacteria	Overall Removal
Wet Pond	5	3	2	3	4	?	4
Infiltration Trench or Basin	5	3	3	4	5	4	4
Porous Pavement	4	4	4	4	4	5	4
Water Quality Inlet (Grit Chamber)	1	?	?	?	?	?	?
Filter Strip	2	1	1	1	1	?	1

Percent Removal	Score
80 to 100	5
60 to 80	4
40 to 60	3
20 to 40	2
0 to 20	1
Insufficient Knowledge	?

Source: Schueler 1987

Examples of structural BMPs commonly installed to improve water quality include:

- Wet detention ponds
- Infiltration
- Vegetative buffer strips
- Oil and grit separators

Each of the BMPs is described below and their general effectiveness is summarized in Table C-1.

C.1.1 Wet Detention Ponds

Wet detention ponds (sometimes called “NURP” ponds after the Nationwide Urban Runoff Program) are impoundments that have a permanent pool of water and also have the capacity to hold runoff and release it at slower rates than incoming flows. Wet detention ponds are one of the most effective methods available for treatment of stormwater 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. When designed properly, wet detention ponds can also provide some removal of dissolved nutrients. Detention ponds have also been credited with reducing the amount of bacteria and oxygen-demanding substances as runoff flows through the pond.

During a storm, 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 does reach the 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, much of the total suspended solids and total phosphorus being transported by the polluted runoff and the pollutants associated with these sediments are trapped in the detention basin. A well-designed wet detention pond could remove approximately 80 to 95 percent of total suspended solids and 40 to 60 percent of total phosphorus entering the pond (MPCA, 1989).

As storm flows subside, finer sediments suspended in the pond’s pool will have a relatively longer period of time to settle out of suspension during the intervals between storm events. These finer sediments eventually trapped in the pond’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.

C.1.2 Infiltration

Infiltration is the movement of water into the soil surface. For a given storm event, the infiltration rate will tend to vary with time. At the beginning of the storm, the initial infiltration rate is the maximum infiltration that can occur because the soil surface is typically dry and full of air spaces. The infiltration rate will tend to gradually decrease as the storm event continues because the soil air spaces fill with water. For long duration storms the infiltration rate will eventually reach a constant value, the minimum infiltration rate (the design infiltration rate). The infiltrated runoff helps recharge the groundwater and mitigate the impacts of development. Stormwater flows in, ponds on the surface, and gradually infiltrates into the soil bed. Pollutants are removed by adsorption, filtration, volatilization, ion exchange, and decomposition. Therefore, infiltration is one of a few BMPs that can reduce the amount of dissolved pollutant in stormwater. Infiltration BMP devices, such as porous pavements, infiltration trenches and basins, and rainwater gardens, can be utilized to promote a variety of water management objectives, including:

- Reduced downstream flooding
- Increased groundwater recharge
- Reduced peak stormwater discharges and volumes
- Improved stormwater quality

An infiltration basin collects and stores stormwater until it infiltrates to the surrounding soil and evaporates to the atmosphere. Infiltration basins remove fine sediment, nutrients (including dissolved nutrients), trace metals, and organics through filtration by surface vegetation, and through infiltration through the subsurface soil. Deep-rooted vegetation can increase infiltration capacity by creating small conduits for water flow. Infiltration basins are designed as a grass-covered depression underlaid with geotextile fabric and coarse gravel. A layer of topsoil is usually placed between the gravel layer and the grassed surface. Pretreatment is often required to remove any coarse particulates (leaves and debris), oil and grease, and soluble organics to reduce the potential of groundwater contamination and the likelihood of the soil pores being plugged. Infiltration can also be promoted in existing detention ponds by excavating excess sediments (typically the fines that have seal the bottom of the pond) and exposing a granular sub-base (assuming one was present prior to the original construction of the detention pond).

Rainwater gardens (a form of bio-retention) are shallow, landscaped depressions that channel and collect runoff. To increase infiltration, the soil bed is sometimes amended, such as with mulch. Vegetation takes up nutrients, and stored runoff is reduced through evapotranspiration. Bio-retention is commonly located in parking lot islands, or within small pockets in residential areas.
Bio-retention is primarily designed to remove sediment, nutrients, metals, and oil and grease. Secondary benefits include flow attenuation, volume reduction, and removal of floatables, fecal coliform, and BOD.

C.1.3 Vegetated Buffer Strips

Vegetative buffer strips are low sloping areas that are designed to accommodate stormwater runoff traveling by overland sheet flow. Vegetated buffer strips perform several pollutant attenuation functions, mitigating the impact of development. Urban watershed development often involves disturbing natural vegetated buffers for the construction of homes, parking lots, and lawns. When natural vegetation is removed, pollutants are given a direct path to the lake -- sediments cannot settle out; nutrients and other pollutants cannot be removed. Additional problems resulting from removal of natural vegetation include streambank erosion and loss of valuable wildlife habitat (Rhode Island Department of Environmental Management, 1990).

The effectiveness of buffer strips is dependent on the width of the buffer, the slope of the site, and the type of vegetation present. Buffer strips should be 20-feet wide at a minimum, however 50- to 75 feet is recommended. Many attractive native plant species can be planted in buffer strips to create aesthetically pleasing landscapes, as well as havens for wildlife and birds. When properly designed, buffer strips can remove 30 to 50 percent of total suspended solids from lawn runoff. In addition, well-designed buffer strips will discourage waterfowl from nesting and feeding on shoreland lawns. Such waterfowl can be a significant source of phosphorus to the pond, by grazing turfed areas adjacent to the water and defecating in or near the water's edge where washoff into the pond is probable.

C.1.4 Oil and Grit Separators

Oil-grit separators (e.g., StormCeptors) are concrete chambers designed to remove oil, sediments, and floatable debris from runoff, and are typically used in areas with heavy traffic or high potential for petroleum spills such as parking lots, gas stations, roads, and holding areas. A three-chamber design is common; the first chamber traps sediment, the second chamber separates oil, and a third chamber holds the overflow pipe. The three-chambered unit is enclosed in reinforced concrete. They are good at removing coarse particulates, but soluble pollutants probably pass through. In order to operate properly, they must be cleaned out regularly (at least twice a year). The major benefit of a water oil-grit separator is as a pre-treatment for an infiltration basin or pond. They can also be incorporated into existing stormwater system or included in an underground vault detention system when no available land exists for a surface detention basin. Only moderate removals of total suspended solids can be expected; however, oil and floatable debris are effectively removed from properly designed oil and grit separators.

C.2 Nonstructural BMPs

Nonstructural ("Good Housekeeping") BMPs discussed below include:

1. Public Education
2. City Ordinances
3, Street Sweeping
4. Deterrence of Waterfowl

Good housekeeping practices help reduce the pollutant at its source.

C.2.1 Public Education

Public education regarding proper lawn care practices, such as fertilizer use and disposal of lawn debris, would result in reduced organic matter and phosphorus loadings to the lake. A public information and education program may be implemented to teach residents within the watershed how to protect and improve the quality of the lake. The program would include distribution of fliers to all residents in the watershed and placement of advertisements and articles in the city's newsletters and the local newspapers. Information could also be distributed through organizations such as local schools, Girl Scouts and Boy Scouts and other local service clubs, or lake associations.

Initiation of a stenciling program to educate the public would help reduce loadings to the storm sewer system. Volunteers could place stenciled messages (i.e., "Dump No Waste, Drains to Round Lake") on all storm sewer catch basins within the watershed to promote environmental stewardship.

C.2.2 Ordinances

Water quality problems can be addressed through legislative methods, such as a watershed-wide ban on the use of phosphorus fertilizers or a commercial lawn care ordinance to control content of mixture and ensure that no phosphorus is present in the case of a complete phosphorus ban. A new legislated fertilizer phosphorus limitation has become effective in 2004, which bans the use of fertilizers containing phosphorus on lawns in the Twin Cities metro area (Anoka, Carver, Dakota, Hennepin, Ramsey, Scott and Washington counties). Exceptions to such a ban would be granted in cases where a resident was able to demonstrate, by means of soil analyses, that phosphorus was required. Other ordinances pertaining to littering, pet feces, and buffer strips adjacent to lakes and other water bodies could be strengthened or created.

C.2.3 Street Sweeping

Most often, street sweeping is performed only in the spring, after the snow has melted and in the fall, after the leaves have fallen, to reduce this potential source of phosphorus from entering the storm sewer. For most urban areas, street sweeping has relatively low effectiveness from late-spring (after the streets are cleaned of accumulated loads) until early-fall (prior to the onset of leaf fall) (Bannerman, 1983). In addition, the use of vacuum sweepers is preferred over the use of mechanical, brush sweepers. The vacuum sweepers are more efficient at removing small phosphorus-bearing particles from impervious surfaces within the watershed. Fall street sweeping is particularly important in the watershed directly tributary to the lake, where treatment of stormwater is not available.

C.2.4 Deterrence of Waterfowl

The role of waterfowl in the transport of phosphorus to lakes is often not considered. However, when the waterfowl population of a lake is large relative to the lake size, a substantial portion of the total phosphorus load to the lake may be caused by the waterfowl. Waterfowl tend to feed primarily on plant material in or near a lake; the digestive processes alters the form of phosphorus in the food from particulate to dissolved. Waterfowl feces deposited in or near a lake may result in an elevated load of dissolved phosphorus to the lake. One recent study estimated that one Canada goose might produce 82 grams of feces per day (dry weight) while a mallard may produce 27 grams of feces per day (dry weight) (Scherer et al., 1995). Waterfowl prefer to feed and rest on areas of short grass adjacent to a lake or pond. Therefore, shoreline lawns that extend to the water's edge will attract waterfowl. The practice of feeding bread and scraps to waterfowl at the lakeshore not only adds nutrients to the lake, but attracts more waterfowl to the lake and encourages migratory waterfowl to remain at the lake longer in the fall.

Two practices often recommended to deter waterfowl are construction of vegetated buffer strips, and prohibiting the feeding of waterfowl on public shoreline property. As stated above, vegetated strips along a shoreline will discourage geese and ducks from feeding and nesting on lawns adjacent to the lake, and may decrease the waterfowl population.

C.3 In-Lake BMPs

In-lake BMPs reduce phosphorus already present in a lake or prevent the release of phosphorus from the lake sediments and macrophyte die-off.

C.3.1 Application of Alum (Aluminum Sulfate)

Areal application of alum has proven to be a highly effective and long-lasting control of phosphorus release from the sediments, especially where an adequate dose has been delivered to the sediments and where watershed sediment and phosphorus loads have been minimized (Moore and Thorton, 1988). Alum will remove phosphorus from the water column as it settles and then forms a layer on the lake bottom that covers the sediments and prevents phosphorus from entering the lake as internal load. Lakes with soft sediment bottoms will typically need a higher alum dose than those with consolidated sediments due to the ease of sediment resuspension and settling that can result in the coverage of the alum over time. An application of alum to the lake sediments will decrease the internal phosphorus load by 80 percent (*Effectiveness and Longevity of Phosphorus Inactivation with Alum*, Welch and Cook, 1999) and will likely be effective for approximately 10 years, depending on the control of external nutrient loads.

C.3.2 Removal of Benthivorous (Bottom-feeding) Fish

Benthivorous fish, such as carp and bullhead, can have a direct influence on the phosphorus concentration in a lake (LaMarra, 1975). These fish typically feed on decaying plant and animal matter and other organic particulates found at the sediment surface. The fish digest the organic matter, and excrete soluble nutrients, thereby transforming sediment phosphorus into soluble phosphorus available for uptake by algae at the lake surface. Depending on the number of benthivorous fish present, this process can occur at rates similar to watershed phosphorus loads. Benthivorous fish can also cause resuspension of sediments in shallow ponds and lakes, causing reduced water clarity and poor aquatic plant growth, as well as high phosphorus concentrations (Cooke et al., 1993). In some cases, the water quality impairment caused by benthivorous fish can negate the positive effects of BMPs and lake restoration. Depending on the numbers of fish present, the removal of benthivorous fish may cause an immediate improvement in lake water quality. The predicted water quality improvement following removal of the bottom-feeding fish is difficult to estimate, and will require permitting and guidance from the Minnesota Department of Natural Resources (MDNR). In addition, using fish barriers to prevent benthivorous fish from spawning may adversely affect the spawning of game fish, such as northern pike.

The MDNR fisheries reports do not indicate that carp are a significant part of the lakes' fisheries. They indicate that the carp and bullhead populations in the Phalen Chain of Lakes are an older population, dominated by smaller numbers of large carp. Conversely, anecdotal evidence suggests that there is a large carp population in Kohlman and Keller Lakes. It is possible that the surveying techniques employed by the MDNR in these lakes do not adequately sample the carp populations—gill nets, for example, are known to select against these species. Therefore, the true extent of the carp population in the Phalen Chain of Lakes is currently unknown.

C.3.3 Winter Drawdown

Lake level control has been shown to be an effective means of controlling growth of certain macrophyte species and reducing the spatial distribution of these plants over the lake area. By reducing water levels in the winter, the sediments and plants are exposed to freezing and drying conditions which can impact the growth of the plant the following spring (Helsel *et al*., 2003a; Helsel *et al*., 2003b). Drawdown has been successfully coupled with chemical treatment in some lakes in southeast Wisconsin and resulted in the establishment of a more native plant community (Helsel *et al*., 2003a; Helsel *et al*., 2003b). Additionally, lake drawdowns have been used for the control of sediment resuspension as well as the eradication of rough fish populations. With drawdowns, loose bottom sediments are consolidated and resuspension is less likely (Helsel *et al*., 2003a; Helsel *et al*., 2003b). Studies have shown that during these periods of low water levels, rough fish populations have effectively been removed with the use of a rotenone solution (Helsel *et al*., 2003a; Helsel *et al*., 2003b).

Because lake level drawdown may potentially impact the fishery within a lake, restocking may be necessary after lake levels have returned to normal conditions. However, drawdown is most economical and feasible in lakes with surface outlets and control structures that allow for increased discharge. Land-locked basins would require the use of pumps to lower lake levels, which may be a costly option.

C.3.3 Mechanical Harvesting

Harvesting of lake macrophytes is typically used to remove plants that are interfering with uses such as boating, fishing, swimming, or aesthetic viewing. Mechanical control involves macrophyte removal via harvesting, hand pulling, hand digging, rotovation/cultivation, or diver-operated suction dredging. Small-scale harvesting may involve the use of the hand or hand-operated equipment such as rakes, cutting blades, or motorized trimmers. Individual residents frequently clear swimming areas via small-scale harvesting or hand pulling or hand digging. Large-scale mechanical control often uses floating, motorized harvesting machines that cut the plants and remove them from the water onto land, where they can be disposed. Mechanical harvesters consist of a barge, a reciprocating mower in front of the barge that can cut up to a depth of roughly 8 feet, and an inclined porous conveyer system to collect the cuttings and bring them to the surface.

Removal of aquatic vegetation through mechanical harvesting has not been shown to be an effective nutrient control method (Cooke et al, 1993). However, none of this research was focused on the internal phosphorus load reduction due to mechanical harvesting of Curlyleaf pondweed. Blue water Science's 2000 Orchard Lake Management Plan suggests that there is up to 5.5 pounds of phosphorus per acre of Curlyleaf pondweed. Additional research mentions that harvesting can reduce the extent of nuisance Curlyleaf pondweed growth if harvesting occurs for several years and reduce stem densities by up to 80 percent (McComas and Stuckert, 2000). Therefore, harvesting of Curlyleaf pondweed may significantly reduce the phosphorus in the water column of a lake assuming enough biomass can be removed from the lake. This assumes that enough time and equipment would be available to harvest the Curlyleaf prior to die-back in early-July.

While mechanical harvesting is more acceptable to the MDNR than chemical methods it would still require an MDNR permit and provide only temporary benefits and must be repeated annually. The MDNR regulations state that the maximum area that can be harvested is 50 percent of the littoral zone.

C.3.4 Application of Herbicides

Controlling Curlyleaf pondweed can be done by herbicide treatments applied from a barge or boat or by mechanical harvesting, or by a combination of these methods. Early to mid-springtime herbicide treatments are most effective at eradicating the plant by reducing the shoot and root biomass as well as suppressing turion production (Poovey, Skogerboe, and Owens, 2002).

MDNR regulations limit the extent of the lake that can be treated in any year. Aquatic herbicides are among the most closely scrutinized compounds known, and must be registered for use by both the U.S. EPA and the State of Minnesota. Registration of an aquatic herbicide requires extensive testing. Consequently, all of the aquatic herbicides currently registered for use are characterized by excellent toxicology packages, are only bio-active for short periods of time, have relatively short-lived residuals, and are not bioconcentrated (*The Lake Association Leader's Aquatic Vegetation Management Guidance Manual*, Pullmann, 1992).

Examples of two aquatic herbicides appropriate for use in controlling the Curlyleaf pondweed growth in Arrowhead Lake are Reward (active ingredient = Diquat) and Aquathol-K (active ingredient = Endothall). The use of low-level Sonar application has recently been found to selectively control exotic weed species such as Eurasian watermilfoil and Curlyleaf pondweed (*Whole-Lake Applications of Sonar for Selective Control of Eurasian Watermilfoil*, Getsinger *et al*, 2001). Due to past history of Sonar applications and the limited research on the new low level applications, the use of Sonar is not feasible at this time. It is also important to note that the MDNR will currently only permit 15 percent of the littoral zone of a given lake to be treated with herbicides.

C.3.5 Application of Copper Sulfate

Application of copper sulfate can be a highly effective algaecide in some cases, but the application is always temporary (days) and can have high annual costs. In addition, care must be taken to limit the impacts on none target organisms, such as invertebrates, and possible sediment contamination with copper. The primary effects on algae include inhibition of photosynthesis and cell division as a result of the additional cupric ion, the form of copper toxic to algae, present in the water column (Cooke *et al*, 1993). Blue-green algae are particularly sensitive to copper sulfate treatments. As a result, after a copper sulfate treatment is made the blue-green algae concentration is knocked back. However, after a few days the green algae (fast growers) take control and within a few weeks the Chlorophyll *a* concentration is back to pretreatment levels (Swain, et al., 1986). As the algae die and settle out of the water column they take with them the nutrients they used for growth. Therefore, copper sulfate application may temporarily reduce the total phosphorus concentration in a water body by removing the phosphorus that is associated with algal biomass. Once the algae have settle out of the water column and start to decompose, soluble phosphorus is released back into the water column that can be used for future algal growth. As a result, copper sulfate treatments are typically not considered a long-term solution to nutrient loading problems.

C.3.6 Diffused Aeration

The mobile P sediment fraction consists of iron bound and loosely sorbed phosphorus. If enough iron is present and the sediment remains oxic, the iron bound and loosely sorbed phosphorus sediment fractions will remain stable and bound to the sediment. However, phosphorus release, from the mobile phosphorus sediment fraction, occurs when sediments become anoxic.

Diffused aeration is intended to destratify the lake and is used as a means of maintaining oxic conditions in the sediment. Diffused aeration/destratification works by injecting compressed air into the water from a diffuser on the lake bottom resulting in circulation of the lake and increased oxygenation. This option can reduce or eliminate the release of phosphorus from sediments during anoxic periods in the hypolimnion. Additionally, aeration would likely result in improved habitat for fish and zooplankton in the bottom waters of the lake, since it would increase the dissolved oxygen concentrations. The development of scum-forming algal species is highly dependent on the stability of the water column (World Health Organization, 1999). In water without vertical mixing, blue-green algae can migrate up and down by changing their buoyancy. Interrupting this vertical migration of blue-greens by artificial mixing can prevent rapid development of surface scums (World Health Organization, 1999). This will also reduce the growth rate of blue-green algae by limiting optimum light conditions, enabling other phytoplankton species that can't regulate their buoyancy to better compete under fully mixed conditions. The species that would likely benefit from these conditions include green algae and diatoms, which do not form surface scums and are preferred food sources for zooplankton.

Holdren et al. (2001) noted that the results of destratification have varied. Some of the results include the following:

- Problems with low dissolved oxygen have typically been solved
- Where small water column temperature differences have been maintained all summer, algae blooms seem to decline
- Phosphorus and turbidity have increased, and in some cases, transparency has decreased
- Surface scums have been prevented, although total biomass may not decline
- Systems that bring deep water to the surface must move enough water to prevent anoxia at the sediment-water interface, or the quality of the bottom water may cause the surface water conditions to deteriorate