Prepared by:
Emmons & Olivier Resources, Inc.
For the Rice Creek Watershed District

Silver Lake TMDL

May 2010

water | ecology | community

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Silver Lake TMDL

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• Impaired Beneficial Use(s) - Aquatic recreation
• Indicator: Nutrient/Eutrophication Biological Indicators
• Target start/completion date: 2008/2010
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</table>

	Reserve Capacity (and related discussion in report)	NA		46
Load Allocation	Identify the portion of the loading capacity allocated to existing and future nonpoint sources and to natural background if possible [40 CFR §130.2(g)]. ***Total LA = X/day, for each pollutant***			46
	Source		**LA**	
	Atmospheric		0.05 lbs/day	46
	Internal		0.15 lbs/day	46
	Natural Background?		NA	
Margin of Safety	Include a MOS to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality [CWA §303(d)(1)(C), 40 CFR §130.7(c)(1)]. ***Identify and explain the implicit or explicit MOS for each pollutant***			43
Seasonal Variation	Statute and regulations require that a TMDL be established with consideration of seasonal variation. The method chosen for including seasonal variation in the TMDL should be described [CWA §303(d)(1)(C), 40 CFR §130.7(c)(1)] ***Seasonal Variation Summary for each pollutant***			47
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Executive Summary

Silver Lake was listed as an impaired water by the Minnesota Pollution Control Agency (MPCA) on the 2002 303d list. The impaired use is aquatic recreation, with the stressor identified as “nutrient/ eutrophication biological indicators.”

Silver Lake has a 678.6-acre watershed and is defined as a shallow lake according to the Minnesota Pollution Control Agency (MPCA). The Silver Lake watershed is located in the southwest portion of the Rice Creek Watershed District (RCWD) and is within the Upper Mississippi Watershed which area entirely within the North Central Hardwood Forest Ecoregion. Portions of four cities and three counties are contained within the Silver Lake watershed.

Silver Lake is a eutrophic lake. TP concentrations have improved since the 1980s, with annual means ranging from approximately 48 to 70 µg/L within the last ten years. The improvement in TP does not appear to have led to improvements in chlorophyll-*a* concentrations and transparency has fluctuated up and down since the 1980s.

Phosphorus was identified as the main pollutant causing the impairment. The MN state eutrophication standards were used to calculate the total maximum daily load (TMDL). The categories of phosphorus loads to Silver Lake include watershed runoff, internal loading, and atmospheric deposition. Phosphorus loads from each of these sources were modeled and used as input into the lake response model.

Phosphorus Loading Summary

Source	Phosphorus Load (lbs/growing season)	Percent Total Load
Watershed	239.7	74%
Atmospheric Deposition	19	6%
Internal	65	20%

The lake response model (Bathtub) was used to estimate the assimilative capacity of the lake. The model was calibrated to observed in-lake water quality data using a 1997 through 2006 average. The combined watershed load to Silver Lake represents approximately 74% of the total load to the lake, and internal load represents approximately 20% of the phosphorus load to the lake.

The assimilative capacity is based on the lake meeting the TP standard, provided that either the chlorophyll-*a* or Secchi standard is also being met. The assimilative capacity was then divided up among the wasteload allocations (WLA) and the load allocations (LA).

Existing Loads and Assimilative Capacities

Model Scenario	Total Load to Lake during Growing Season (lbs)	Total Daily Load to Lake (lbs)	% Reduction Relative to Existing
Existing	325	0.89	--
Assimilative Capacity at Eutrophication Standard (60 µg/L)	308	0.84	5%

The TMDL allocations are summarizes below. The stormwater sources (municipal separate storm sewer systems (MS4s), construction stormwater, and industrial stormwater) were given a categorical WLA. The categorical WLA covers all stormwater sources; the load reductions identified by the WLAs will need to be met by this group as a whole, but individual WLAs are not specified. There are seven MS4s with WLAs in the Silver Lake TMDL. The load allocations for Silver Lake consist of atmospheric deposition and internal loading.

TMDL Allocation Summary

Source		% Allocation	TMDL (average lbs/day)
Load Allocation		24.4%	0.21
Wasteload Allocation - Stormwater		65.2%	0.55
MS4	Permit #		
Anoka County	MS400066		
Columbia Heights	MS400010		
Hennepin County	MS400138		
Minneapolis	MN0061018		
New Brighton	MS400038		
Ramsey County Public Works	MS400191		
St. Anthony Village	MS400051		
Construction stormwater	Various		
Industrial stormwater	No current permitted sources		
Margin of Safety (MOS)		10.4%	0.09
Total		**100%**	**0.84**

A monitoring plan is outlined that describes the different types of monitoring that will need to be completed in order to track the progress of implementation activities associated with Silver Lake, and of associated changes in water quality due to the management practices.

The implementation strategy lays out an approach to reduce both the watershed load and the internal load in Silver Lake.

Two local advisory meetings and one stakeholder meeting were held for this project.

1. Background and Pollutant of Concern

1A. 303(d) LISTINGS

Table 1. Impaired Waters Listings

Lake name:	Silver Lake
DNR ID#:	62-0083-00
Hydrologic Unit Code:	7010206
Pollutant or stressor:	Nutrient/Eutrophication Biological Indicators
Impairment:	Aquatic recreation
Year first listed:	2002
Target start/completion (reflects the priority ranking):	2008/2010
CALM category:	5C – Impaired by one pollutant and no TMDL study plan is approved by EPA

1B. BACKGROUND

Watershed

The Silver Lake watershed is located in the southwest portion of the Rice Creek Watershed District (RCWD) and is within the Upper Mississippi Watershed. This area lies entirely within the North Central Hardwood Forest Ecoregion. Silver Lake is located partially in the City of Columbia Heights and partially in the City of New Brighton, and the watershed is located within four municipalities (Table 2, Figure 1) and three counties (Anoka, Hennepin and Ramsey).

Silver Lake has a 678.6-acre watershed and is defined as a shallow lake according to the Minnesota Pollution Control Agency (MPCA). The Silver Lake subwatershed was delineated based on topographic data and stormsewer networks. Hart Lake drains to Silver Lake from the southwest and a series of natural wetlands are found northeast of the lake within Silverwood Park, previously a Salvation Army camp, but now owned by the Three Rivers Park District. Silver Lake outlets to Ramsey County Ditch (RCD) 3 which outlets into RCD 2 and eventually to Rice Creek and the Mississippi River.

Figure 1. Silver Lake Watershed Location

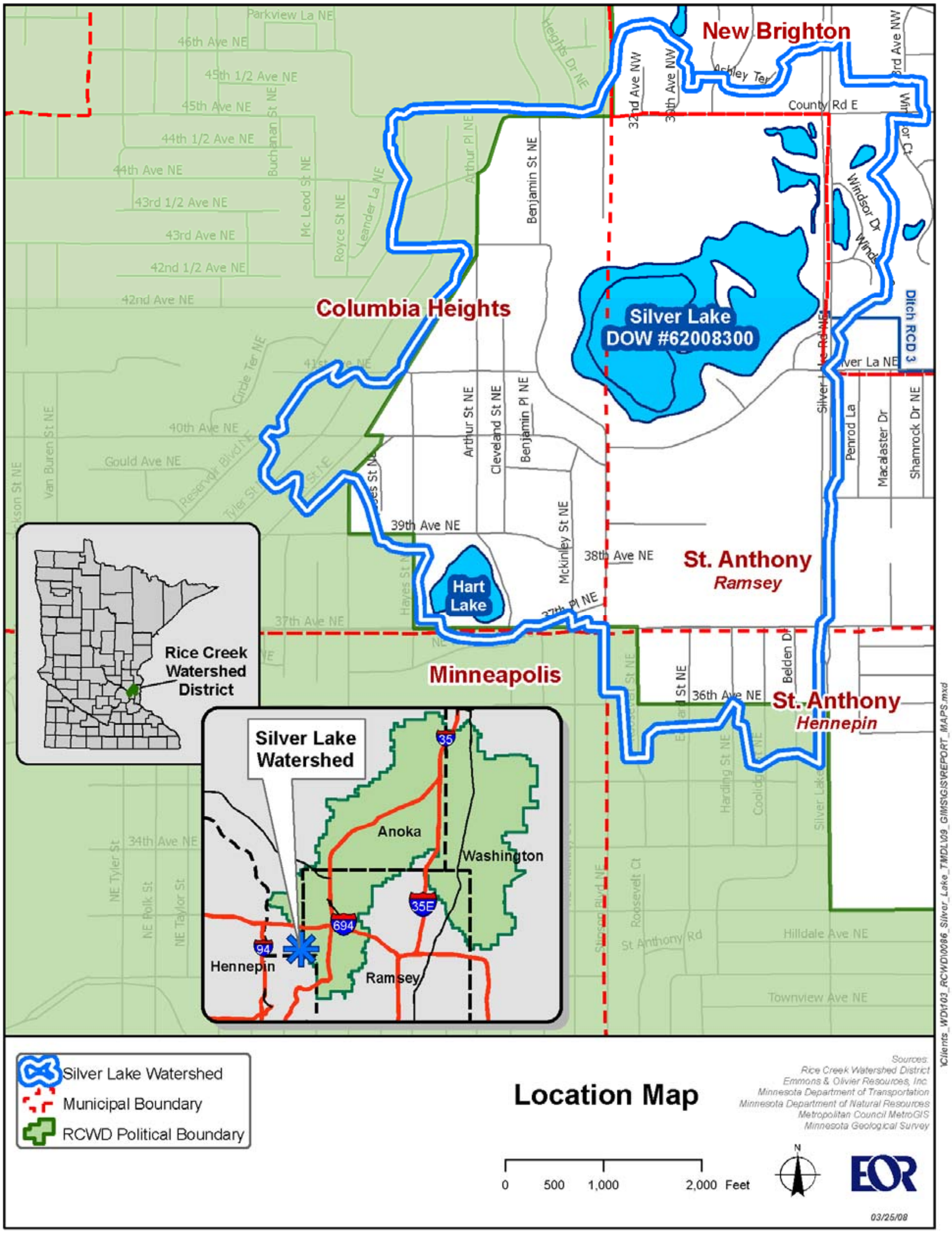


Table 2. Municipalities within Silver Lake Watershed.
Areas include the watershed and the lake.

Silver Lake Watershed	
City	**Area [acres]**
St. Anthony	328.3
Columbia Heights	281.3
New Brighton	67.5
Minneapolis	1.5
Total	678.6

Land Use

The main land uses in the Silver Lake watershed (Figure 2) are single family residential (40%), institutional (13%), multi-family (12%), and commercial (11%). Open water makes up 12% of the total watershed. Note that the large institutional area on the north side of the lake is mostly park land being developed as a regional park (Silverwood) by the Three Rivers Park District.

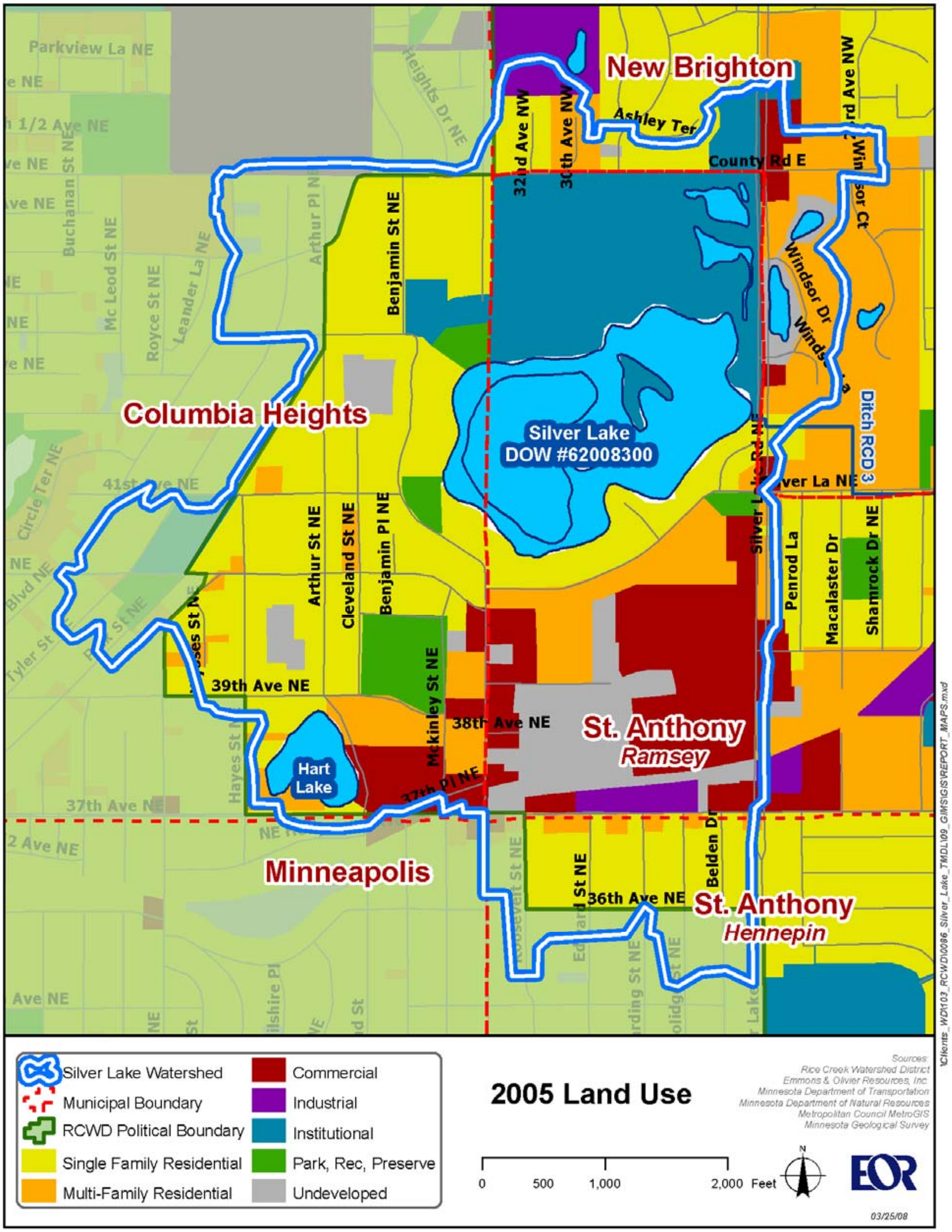
Planned land use (Metropolitan Council 2020 Land Use) (Figure 3) shows increases in commercial; industrial; park, recreation and preserves; and single family residential, with decreases in institutional; multi-family residential; and undeveloped lands. Proposed changes in land use between 2005 and 2020 are presented in Table 3. The large area designated as undeveloped within the Apache subwatershed south of the lake was previously Apache Plaza which was demolished in Spring 2004. Redevelopment in this area has been occurring for over 10 years.

Table 3. Silver Lake Watershed Land Use Summary

Land Use Classification	2005 [acres]	2020 [acres]	% Change 2005-2020
Commercial	73.21	94.53[1]	22.6%
Industrial	11.45	17.46[2]	34.4%
Institutional	90.88	81.61	-11.4%
Multi-Family Residential	83.28	61.19	-36.1%
Open Water	79.62	80.02	0.5%
Parks, Recreation, & Preserves	22.39	28.83	22.3%
Single Family Residential	269.54	314.92	14.4%
Undeveloped	48.18	0	-100.0%

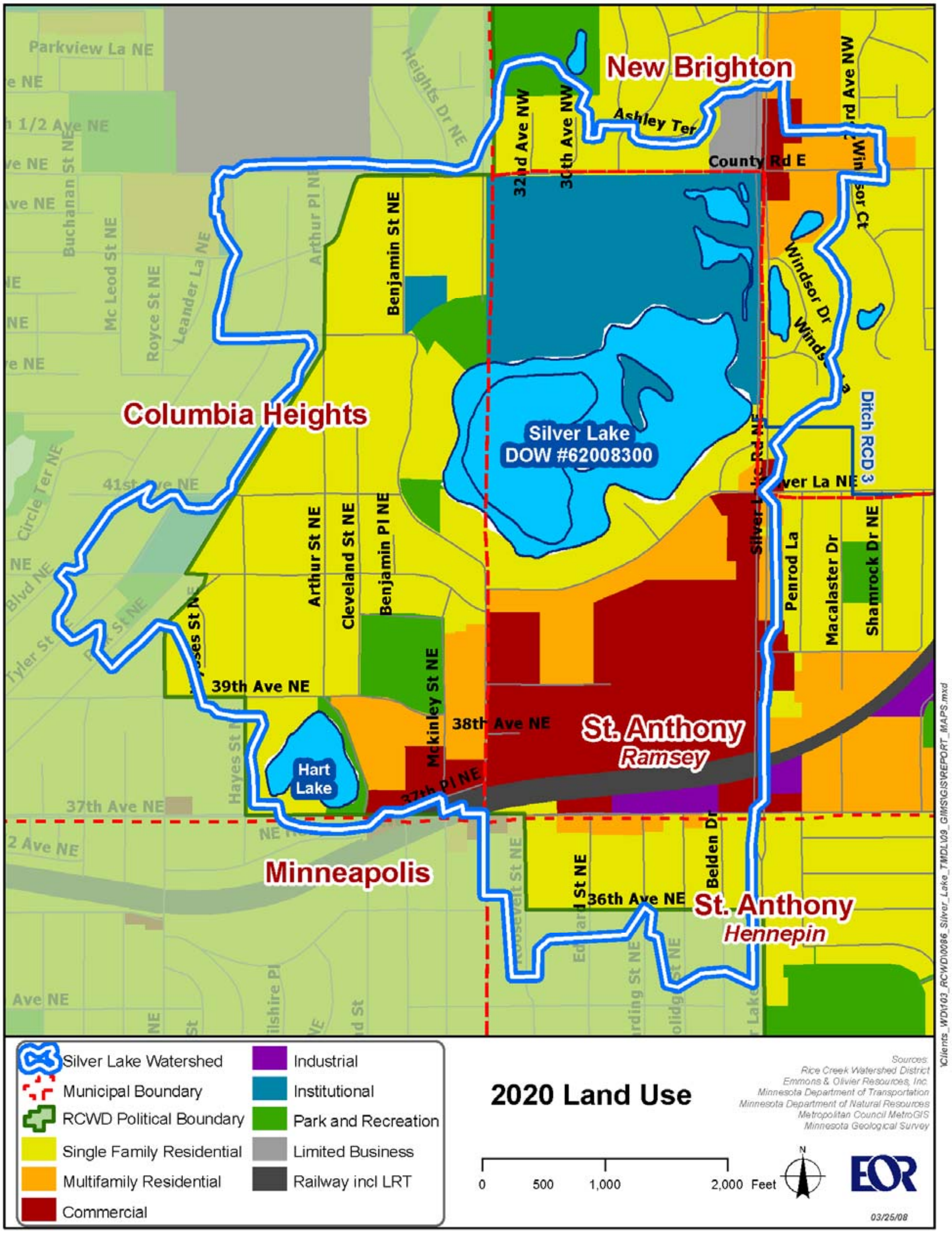
[1] Commercial includes 2020 land use classified as Limited Business
[2] Industrial includes 2020 land use classified as Railway including LRT

Figure 2. Land Use, 2005



Sources:
Rice Creek Watershed District
Emmons & Olivier Resources, Inc.
Minnesota Department of Transportation
Minnesota Department of Natural Resources
Metropolitan Council MetroGIS
Minnesota Geological Survey

Figure 3. Planned Land Use, 2020



Population

Population is expected to increase in the cities that intersect the Silver Lake watershed, with the greatest percent increase projected to occur in St. Anthony (Table 4).

Table 4. Current population and population forecasts for cities within the Silver Lake watershed

City	County	Population				% increase 2000-2030
		2000	2010	2020	2030	
New Brighton	Ramsey	22,206	22,700	22,500	22,800	3%
Minneapolis	Hennepin	382,747	402,000	423,000	435,000	12%
Columbia Heights	Anoka	18,520	20,000	21,400	21,700	15%
St. Anthony	Ramsey + Hennepin	8,012	9,150	9,400	10,000	20%

Data from the Metropolitan Council's 2030 Regional Development Framework - Revised Forecasts, January 9, 2008.

Wildlife Resources

The Silver Lake watershed contains many of the types of birds, amphibians, reptiles, and mammals typical of wetland and upland areas in this portion of the North Central Hardwood Forests ecoregion. Silverwood Park contains a significant 20-acre mature upload forest that includes white oaks, red oaks, burr oaks, cherry and aspen.

Lake Uses

Silver Lake is an important recreational resource for the area and the focal point for the Three Rivers Park District’s Silverwood Park, previously the Salvation Army's historic Silver Lake Camp and Conference Center that operated on the site from 1921-2004. The lake is used recreationally for fishing and swimming and motorized and non-motorized boating. The lake itself contains two islands, one of which is accessible via walking bridge.

The lakeshore consists of single family homes with lake access along the south and west shores, Silverwood Park on the north and part of the eastern shore, and Silver Lane on the eastern shore of the lake. Beach access is provided within the City of Columbia Heights, at the northwest corner of the lake and a public fishing pier is located along the western shore. Public access is also provided via Silver Lane on the southeastern shore of the lake and within Silverwood Park.

Soil and Groundwater

Soils within the Silver Lake subwatershed are mapped as Urban Land within the Soil Survey. Surficial geology can be used as a surrogate for the soils and can be used to determine the parent material for natural soils within the urban environment. In addition, soil boring data are available as part of the RCWD Permit Program that can be used to verify soil types. Surficial geology within the Silver Lake subwatershed consists of ice-contact stratified deposits of the Cromwell Formation, the Twin Cities Member of the New Ulm Formation, and till deposits of the New Ulm Formation. Both of the New Ulm Formation materials are very fine grained, typical parent materials for Hydrologic Soil Group C or D type soils. Cromwell Formation materials are much sandier; these ice-contact deposits will typically form HSG B type soils. Figure 4 summarizes the soil interpretation used in this study.

A groundwater assessment was conducted to determine the potential interaction of groundwater with the lake. Lake elevations relative to regional and local groundwater elevations and the hydrology of surrounding waters were examined. In addition, the local surficial geology was reviewed to determine the lake's dependence on groundwater. The groundwater investigation concluded that Silver Lake functions as groundwater flow-through lake which indicates that groundwater both discharges and recharges within the lake. While the lake has been determined to be a reflection of the water table, the interaction of groundwater with the lake is relatively small due to the fine grained nature of the surrounding soils and geology. In systems with substantial groundwater input, nutrients from the groundwater input need to be taken into account in the nutrient balance of the lake. In addition, the groundwater and surface water interaction is an important component to consider when planning restoration activities. Due to the lake's small interaction with groundwater, a total phosphorus load from groundwater was not calculated or included in the lake modeling.

Permitted Point Sources

Municipal Separate Storm Sewer Systems (MS4)

The Stormwater Program for Municipal Separate Storm Sewer Systems (MS4s) is designed to reduce the amount of sediment and pollution that enters surface and ground water from storm sewer systems to the maximum extent practicable. These stormwater discharges are regulated through the US EPA National Pollutant Discharge Elimination System (NPDES) program, which has been delegated to the MPCA. The MPCA has issued a MS4 General Permit that regulates each MS4 and requires the owner or operator of a MS4 to develop a stormwater pollution prevention plan (SWPPP) that incorporates best management practices applicable to their MS4. In addition, the MPCA also issues individual permits that are developed for a specific MS4 entity. All of the municipalities within the Silver Lake watershed except for Minneapolis are covered under the MS4 General Permit. Minneapolis is covered under an individual NPDES permit. In addition, Hennepin, Anoka, and Ramsey County Public Works are regulated MS4s. The RCWD is a regulated MS4 for the RCWD public ditch system, however there are no public ditches within the Silver Lake watershed and therefore the RCWD is not required to have a wasteload allocations within this TMDL. There are no State owned roads in the watershed and therefore Mn/DOT is not included as a regulated MS4. Table 5 includes each regulated MS4 and their NPDES Permit Number. There are no industrial stormwater permits issued within the Silver Lake watershed, construction permits are not listed as they are very time dependent and can change often.

Table 5. Permitted Point Sources

MS4	NPDES Permit Number
Anoka County	MS400066
Columbia Heights	MS400010
Hennepin County	MS400138
Minneapolis	MN0061018
New Brighton	MS400038
Ramsey County Public Works	MS400191
St. Anthony Village	MS400051

Traditional Point Sources

There are no non-MS4 NPDES-permitted point sources within the Silver Lake watershed.

Figure 4. Soils

Sources:
Rice Creek Watershed District
Emmons & Olivier Resources, Inc.
Minnesota Department of Transportation
Minnesota Department of Natural Resources
Metropolitan Council MetroGIS
Minnesota Geological Survey

1C. POLLUTANT OF CONCERN

Role of Phosphorus in Shallow Lakes

Silver Lake is classified by the MPCA as a shallow lake. The MPCA defines a lake as shallow if its maximum depth is less than 15 ft, or if the littoral zone covers at least 80% of the lake's surface area.

Total phosphorus is often the limiting factor controlling primary production in freshwater lakes. It is the nutrient of focus for this TMDL, and is sometimes referred to as the causal factor. As phosphorus concentrations increase, primary production also increases, as measured by higher chlorophyll-*a* concentrations. Higher concentrations of chlorophyll lead to lower water transparency. Both chlorophyll-*a* and Secchi transparency are referred to as response factors, since they indicate the ecological response of a lake to excessive phosphorus input.

There is often a positive relationship between TP and chlorophyll-*a,* and a negative relationship between TP and Secchi depth, as is the case with Silver Lake (Figures 5 and 6). Similarly, a negative relationship is apparent between chlorophyll-*a* and Secchi depth (Figure 7).

Figure 5. Relationship of Chlorophyll-*a* to TP in Silver Lake, 1997 - 2006

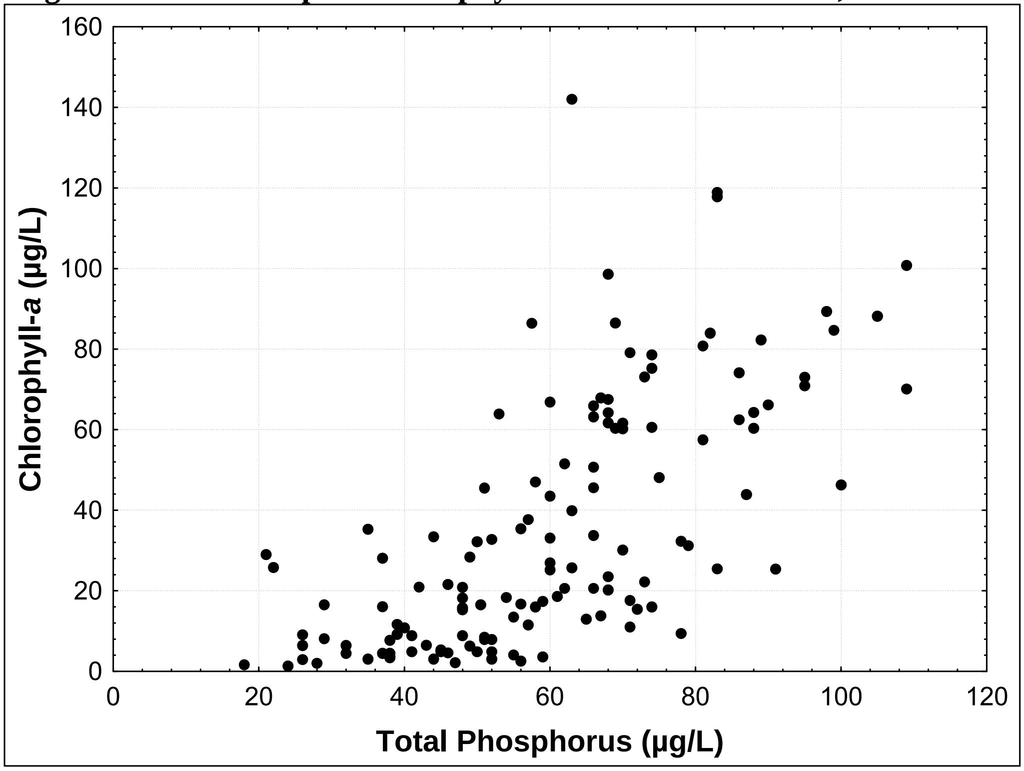


Figure 6. Relationship of Secchi Depth to TP in Silver Lake, 1997 - 2006

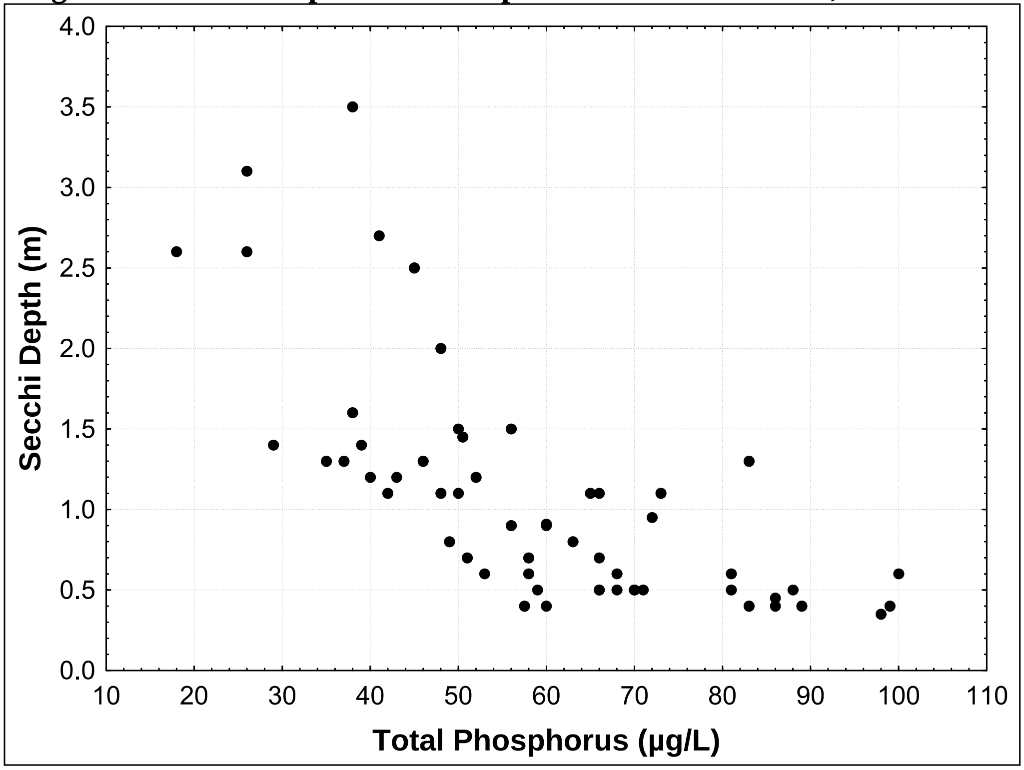
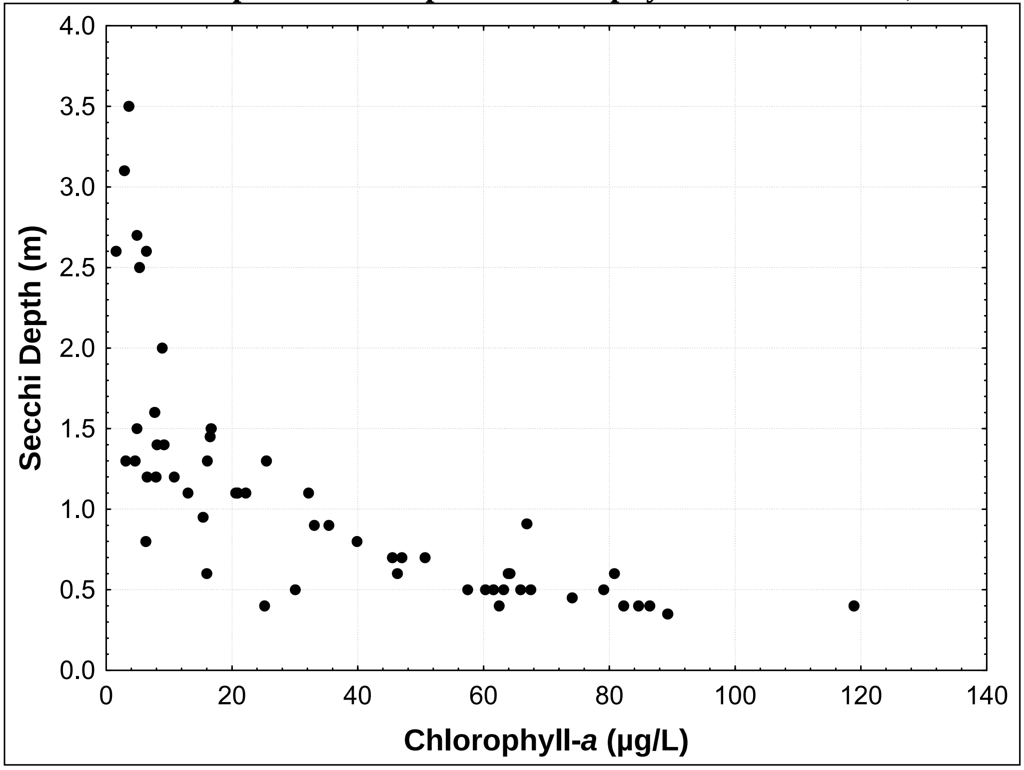


Figure 7. Relationship of Secchi Depth to Chlorophyll-*a* in Silver Lake, 1997 - 2006

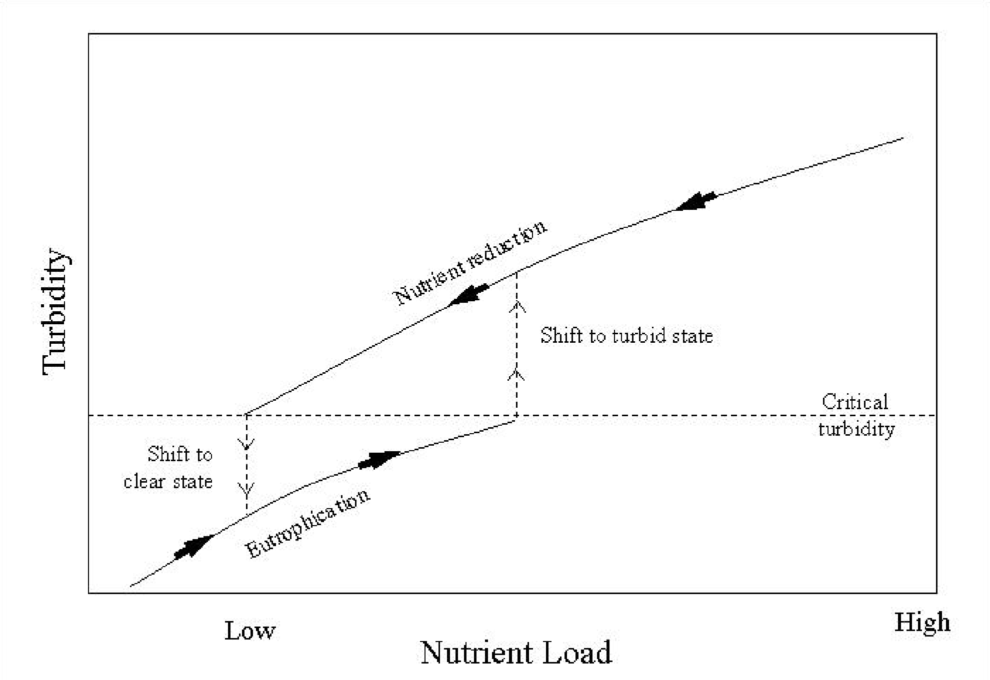


The relationship between phosphorus concentration and the response factors (chlorophyll and transparency) is often different in shallow lakes as compared to deeper lakes. In deeper lakes, primary productivity is often controlled by physical and chemical factors such as light availability, temperature, and nutrient concentrations. The biological components of the lake (such as microbes, algae, macrophytes, zooplankton and other invertebrates, and fish) are distributed throughout the lake, along the shoreline, and on the bottom sediments. In shallow lakes, the biological components are more concentrated into less volume and exert a stronger influence on the ecological interactions within the lake. There is a more dense biological community at the bottom of shallow lakes than in deeper lakes because of the fact that oxygen is replenished in the bottom waters and light can often penetrate to the bottom. These biological components can control the relationship between phosphorus and the response factors.

The result of this impact of biological components on the ecological interactions is that shallow lakes normally exhibit one of two ecologically alternative stable states (Figure 8): the turbid, phytoplankton-dominated state, and the clear, macrophyte (plant)-dominated state. The clear state is the most preferred, since phytoplankton communities (composed mostly of algae) are held in check by diverse and healthy zooplankton and fish communities. Fewer nutrients are released from the sediments in this state. The roots of the macrophytes stabilize the sediments, lessening the amount of sediment stirred up by the wind. Periodic winter fish kills are desirable, as they control the population of bottom feeders that also stir up bottom sediments and exacerbate internal loading. Bottom feeders also forage in the bottom sediments and release nutrients into the water column through excretion.

Nutrient reduction in a shallow lake does not lead to a linear improvement in water quality (indicated by turbidity in Figure 8). As external nutrient loads are decreased in a lake in the turbid state, slight improvements in water quality may at first occur. At some point, a further decrease in nutrient loads will cause the lake to abruptly shift from the turbid state to the clear state. The general pattern in Figure 8 is often referred to as “hysteresis”, meaning that when forces are applied to a system, it does not return completely to its original state nor does it follow the same trajectory on the way back.

Figure 8. Alternative Stable States in Shallow Lakes



Adapted from M. Scheffer. 2001. Alternative Attractors of Shallow Lakes. *The Scientific World* 1:254-263.

The biological response of the lake to phosphorus inputs will depend on the state that the lake is in. For example, if the lake is in the clear state, the macrophytes may be able to assimilate the phosphorus instead of algae performing that role. However, if enough stressors are present in the lake, increased phosphorus inputs may lead to a shift to the turbid state with an increase in algal density and decreased transparency. The two main categories of stressors that can shift the lake to the turbid state are:

- Disturbance to the macrophyte community, for example from wind, benthivorous (bottom feeding) fish, boat motors, or light availability (influenced by algal density or water depth)
- A decrease in zooplankton grazer density, which allows unchecked growth of sestonic (suspended) algae. These changes in zooplankton density could be caused by an increase in predation, either directly by an increase in planktivorous fish that feed on zooplankton, or indirectly through a decrease in piscivorous fish that feed on the planktivorous fish.

This complexity in the relationships among the biological communities in shallow lakes leads to less certainty in predicting the in-lake water quality of a shallow lake based on the phosphorus load to the lake. The relationships between external phosphorus load and in-lake phosphorus concentration, chlorophyll concentration, and transparency are less predictable than in deeper lakes, and therefore lake response models are less accurate.

Another implication of the alternative stable states in shallow lakes is that different management approaches are used for shallow lake restoration than those used for restoration of deeper lakes.

Shallow lake restoration often focuses on restoring the macrophyte and zooplankton communities to the lake. All of these factors will become important as a management strategy is developed for the shallow Silver Lake.

2. Applicable Water Quality Standards and Numeric Water Quality Targets

2A. DESIGNATED USES

Silver Lake is classified as Class 2B, 3B, 4A, 4B, 5, and 6 waters. The most protective of these classes is Class 2 waters, which are protected for aquatic life and recreation. MN Rules Chapter 7050.0140 Water Use Classification for Waters of the State reads:

> Subp. 3. Class 2 waters, aquatic life and recreation. Aquatic life and recreation includes all waters of the state which do or may support fish, other aquatic life, bathing, boating, or other recreational purposes, and where quality control is or may be necessary to protect aquatic or terrestrial life or their habitats, or the public health, safety, or welfare.

2B. WATER QUALITY STANDARDS

Water quality standards are established to protect the designated uses of the state's waters. Amendments to Minnesota's Rule 7050, approved by the EPA May 2008, include eutrophication standards for shallow lakes (Table 6). Eutrophication standards were developed for lakes in general, and for shallow lakes in particular. Standards are less stringent for shallow lakes, due to higher rates of internal loading in shallow lakes and different ecological characteristics.

To be listed as impaired, the monitoring data must show that the standards for both TP (the causal factor) and either chlorophyll-*a* or Secchi depth (the response factors) were violated. If a lake is impaired with respect to only one of these criteria, it may be placed on a review list; a weight of evidence approach is then used to determine if these lakes will be listed as impaired. For more details regarding the listing process, see the *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for the Determination of Impairment* (MPCA 2007).

According to the MPCA definition of shallow lakes, a lake is considered shallow if its maximum depth is less than 15 ft, or if the littoral zone (area where depth is less than 15 ft) covers at least 80% of the lake's surface area. Although Silver Lake has a maximum depth of 47 feet, its littoral area is 88% of the lake's total surface area, and therefore considered shallow. The eutrophication standards for shallow lakes apply to Silver Lake: 60 µg/L TP, 20 µg/L chlorophyll-*a*, and 1.0 m Secchi transparency (Table 6).

To be taken off of the impaired waters list, the lake must meet the TP standard and either the chlorophyll or Secchi transparency standard. Under the goal scenarios, Silver Lake is expected to meet the Secchi standard in addition to the TP standard.

Table 6. MN Eutrophication Standards, North Central Hardwood Forests Ecoregion

Parameter	Eutrophication Standard, Shallow Lakes
TP (µg/l)	TP < 60
Chlorophyll-*a* (µg/l)	chl < 20
Secchi depth (m)	SD > 1.0

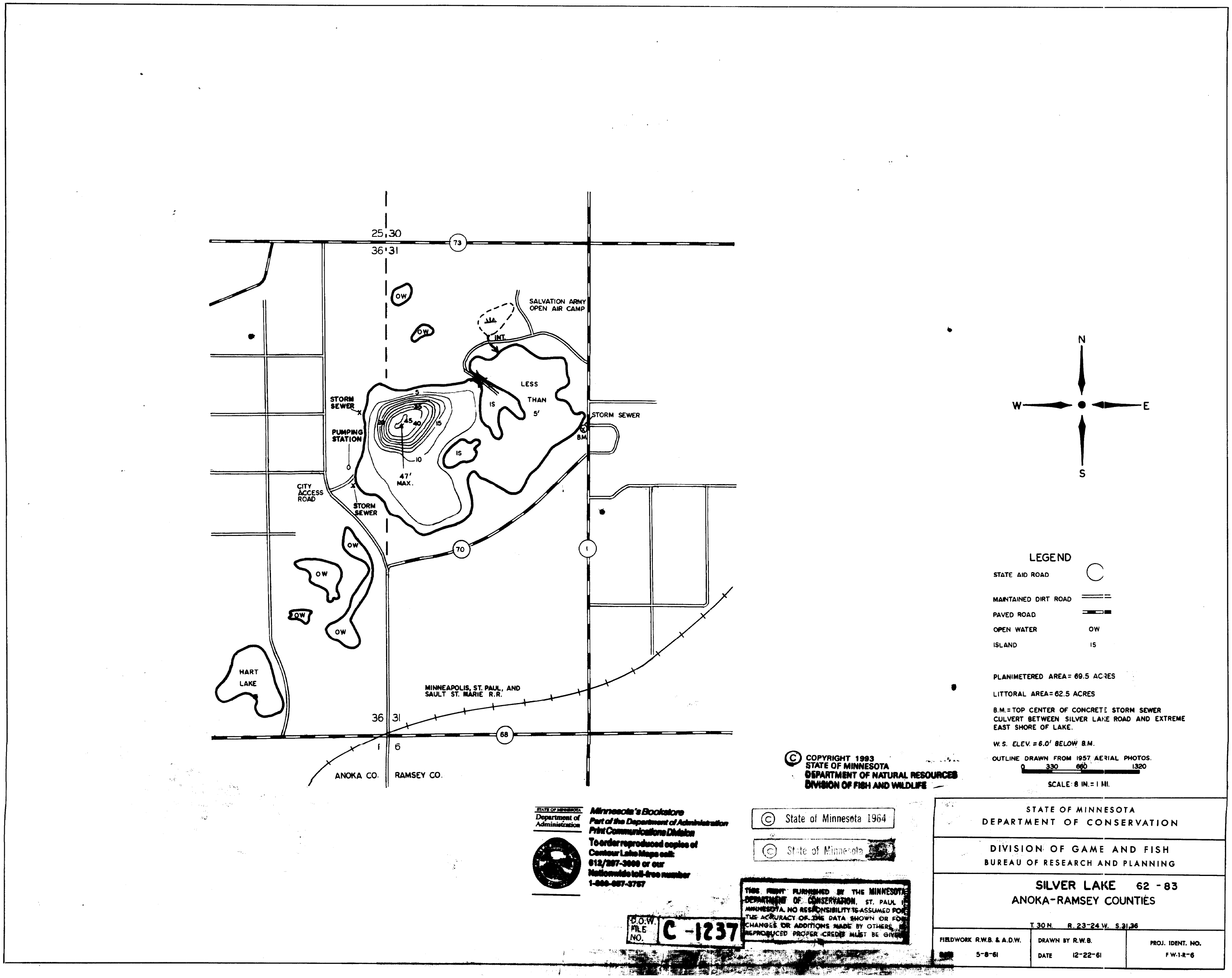
3. Impairment Assessment

Silver Lake is 72.5 acres in size, with a watershed area to lake area ratio of 9.4 (Table 7). Although it has a deep hole, with a maximum depth of 47 feet, overall the lake is shallow. Approximately 88% of the surface area of the lake is littoral (less than 15 feet depth), and the entire northeastern segment of the lake is less than five feet deep (Figure 9). The mean depth of the lake is 7.5 feet.

Table 7. Silver Lake Characteristics

Lake total surface area (ac)	72.5
Total littoral area (ac)	62.5
Percent lake littoral surface area	88%
Lake volume (ac-ft)	563
Mean depth (ft)	7.5
Maximum depth (ft)	47
Drainage area (acres)	678.6
Watershed area : lake area	9.4

Figure 9. Silver Lake Bathymetric Map



Monitoring data are available from as far back as the 1970s, although there were only one or two samples taken per year and conclusions should not be drawn from sampling at this low frequency. Sampling frequency increased in 1986, and has been conducted annually since then. The last ten years of data were used to calculate the water quality data means (Table 8).

Silver Lake is a eutrophic lake, with similar TSI values for the three standard monitoring parameters (Table 8). TP concentrations have improved since the 1980s (Figure 10), with annual means ranging from approximately 48 to 70 µg/L within the last ten years. Chlorophyll and transparency haves fluctuated up and down since the 1980s (Figure 11 and Figure 12).

Water quality in Silver Lake generally declines throughout the growing season (Figures 13 through 15), reaching the worst values in August.

Table 8. Surface Water Quality Means, Silver Lake, 1997 - 2006

	Growing Season Mean (June – September)	Coefficient of Variation	Trophic Status Index
TP (µg/L)	63	0.03	64
Chlor-*a* (µg/L)	40	0.07	67
Secchi depth (m)	0.94	0.06	61

Figure 10. Total Phosphorus Monitoring Data, Silver Lake

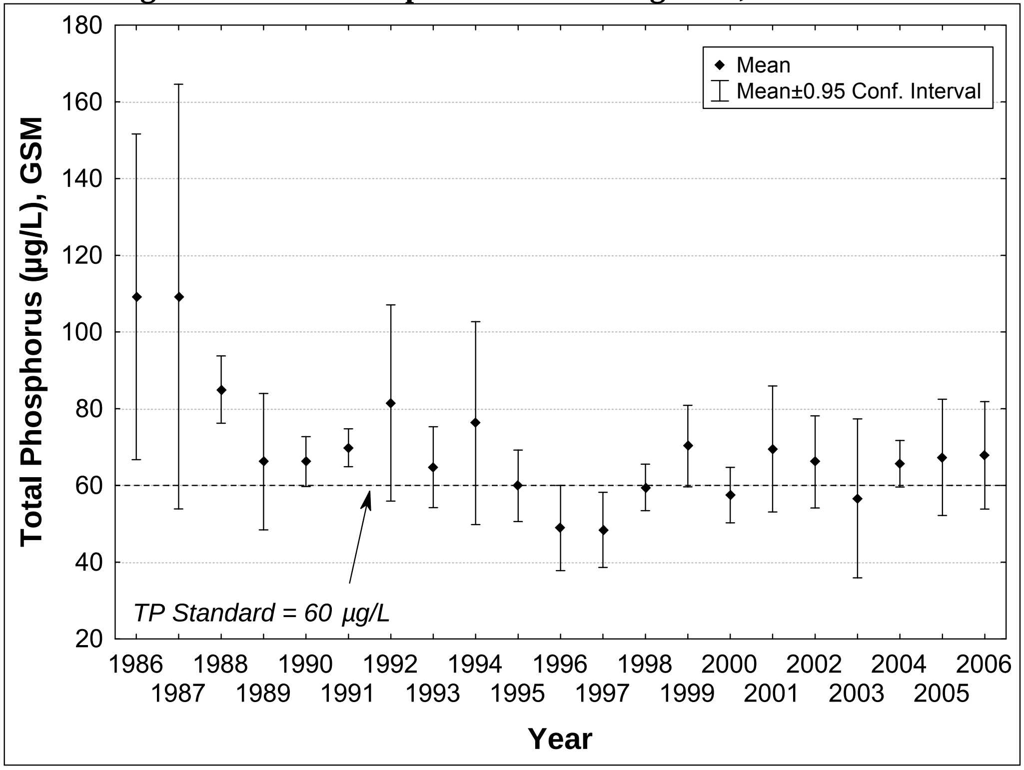


Figure 11. Mean Chlorophyll-*a* Monitoring Data, Silver Lake

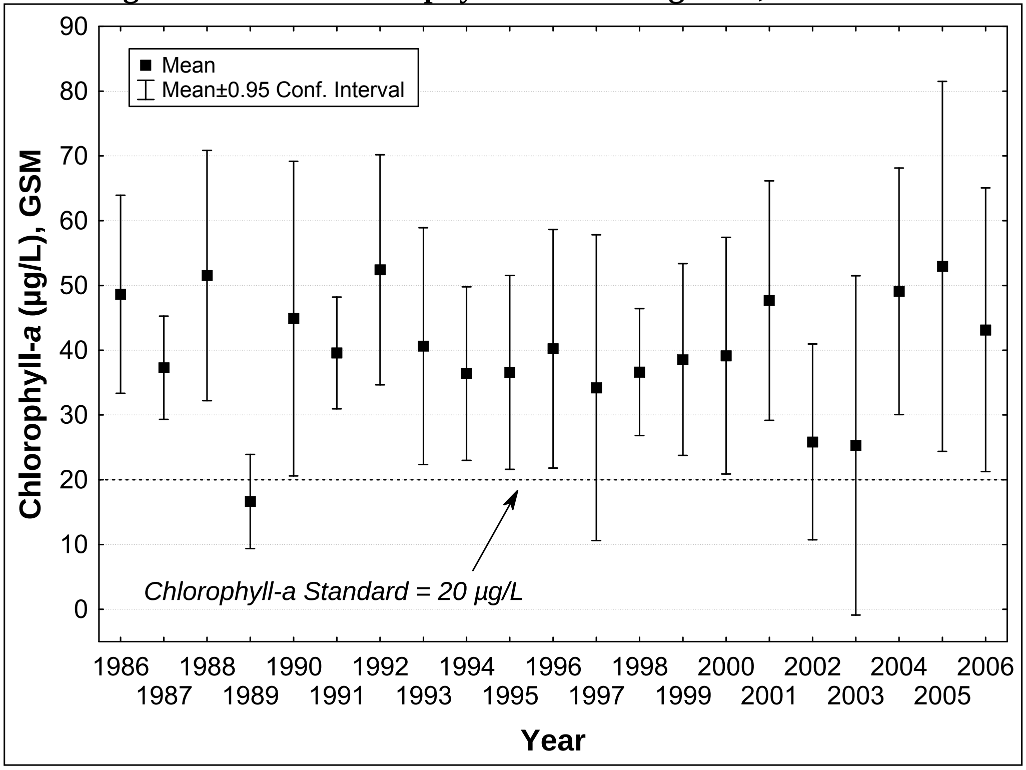


Figure 12. Secchi Depth Monitoring Data, Silver Lake

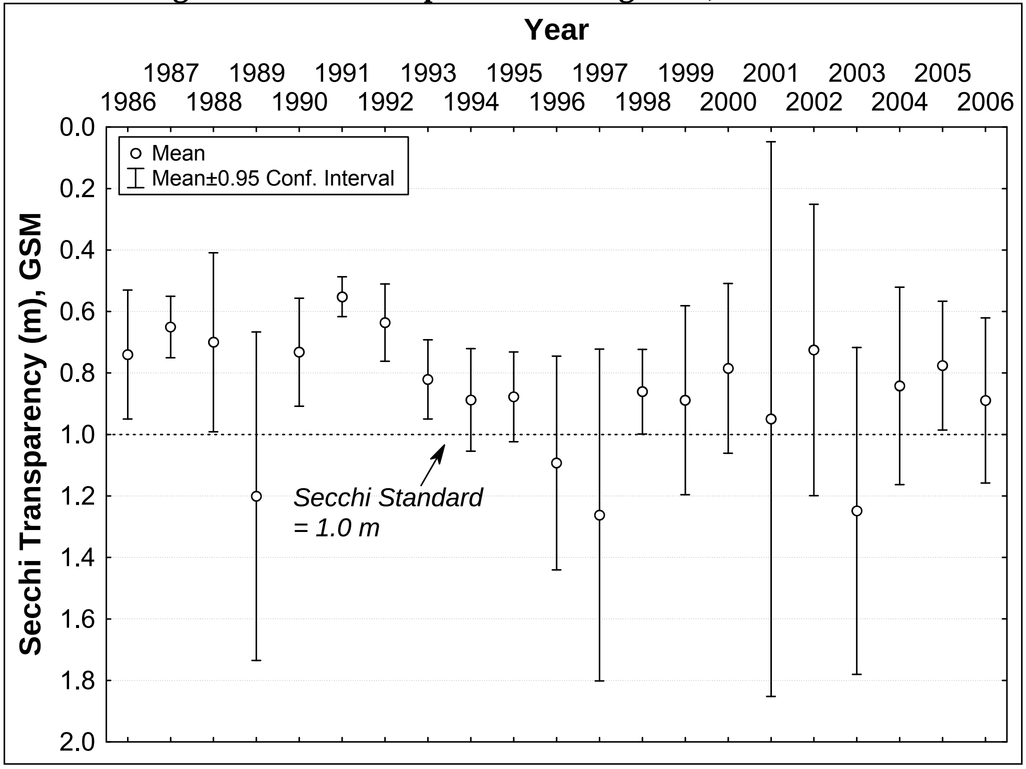


Figure 13. Silver Lake Seasonal TP Patterns, 1997-2006

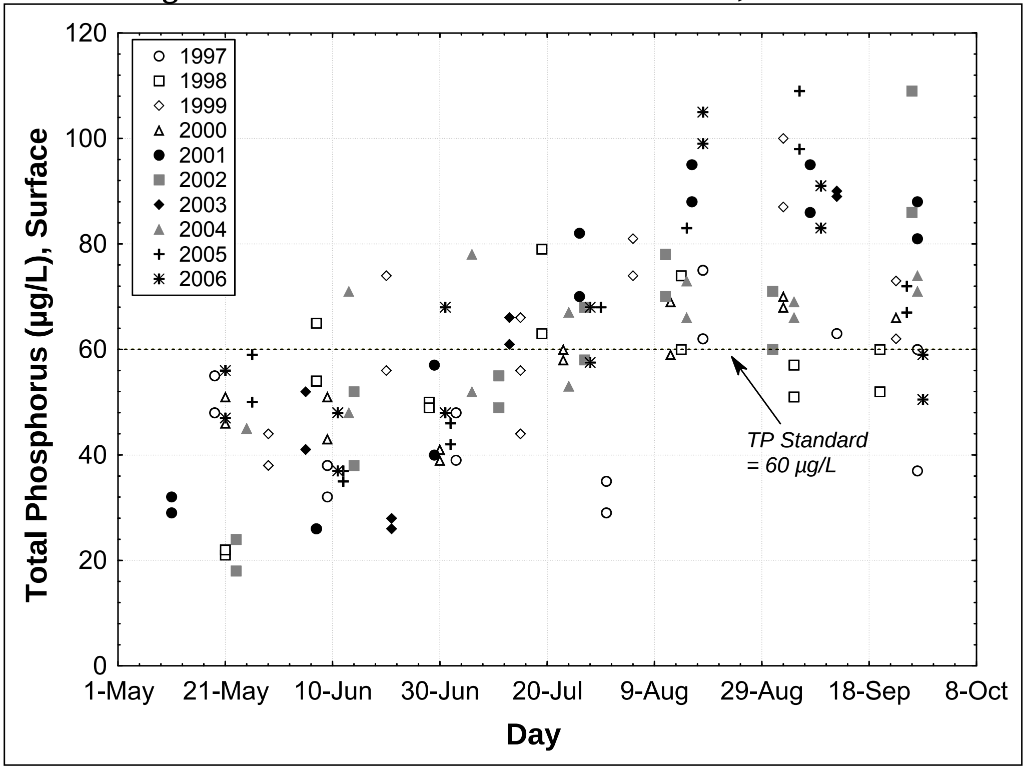


Figure 14. Silver Lake Seasonal Chlorophyll-*a* Patterns, 1997-2006

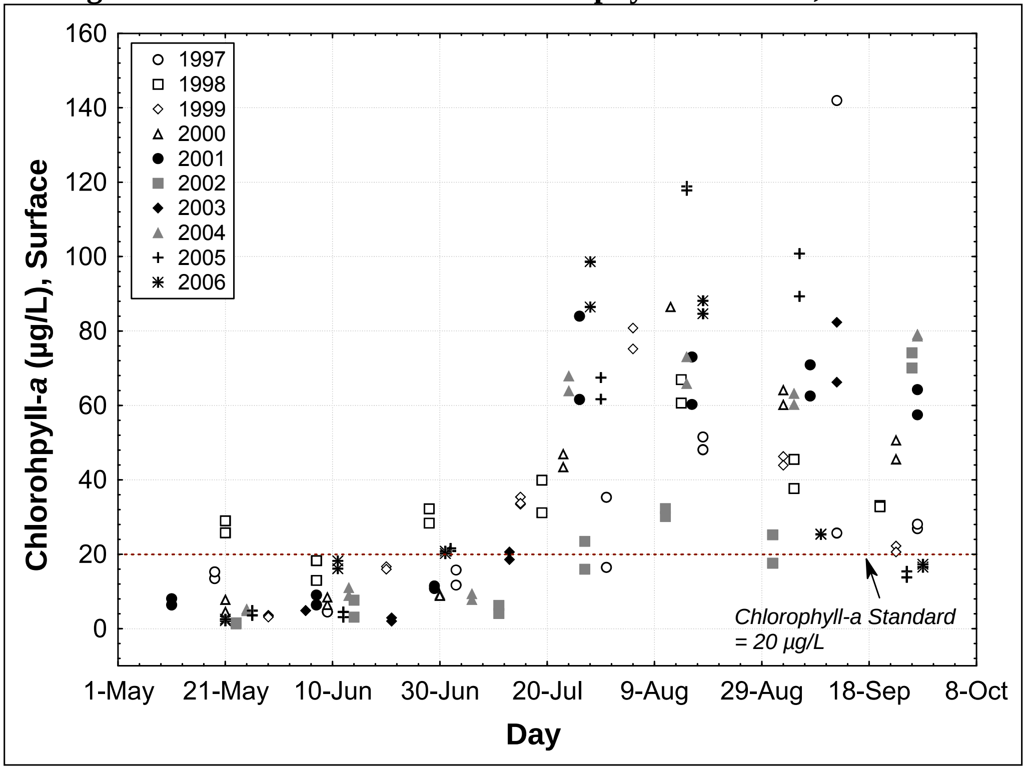
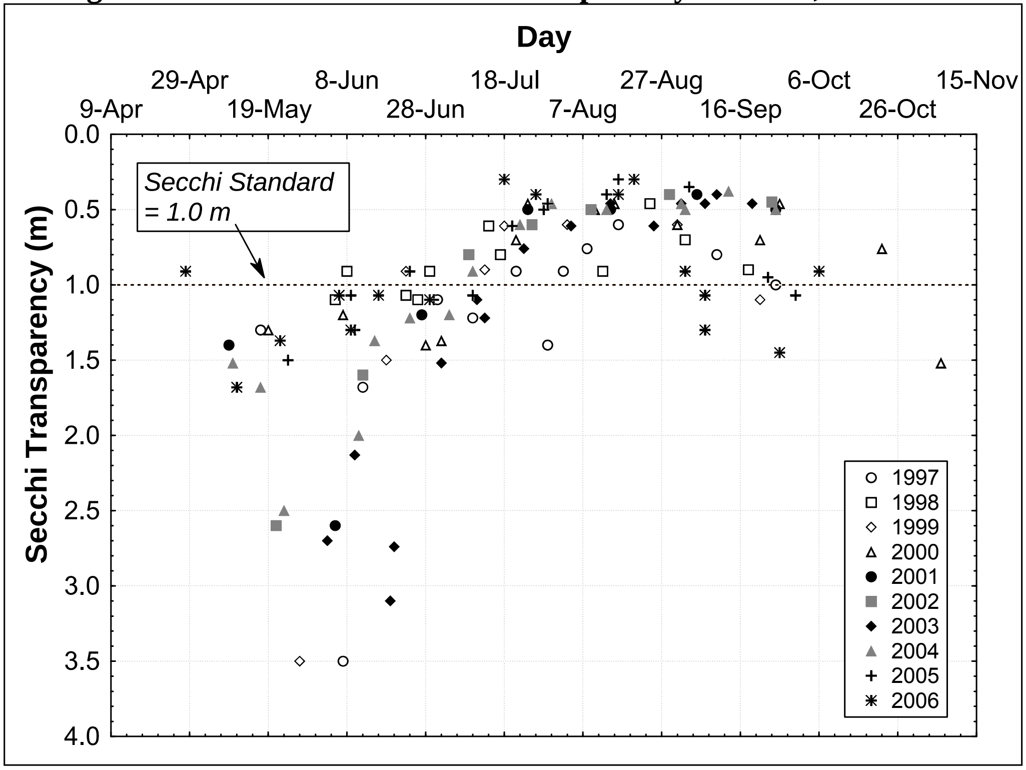


Figure 15. Silver Lake Seasonal Transparency Patterns, 1997-2006



Based on a 2006 DNR fish survey, black bullhead, black crappie, bluegill, channel catfish, carp, golden shiner, hybrid sunfish, largemouth bass, northern pike, pumpkinseed sunfish, walleye, white sucker, and yellow perch were found in Silver Lake. In addition, lakeshore residents noted a significant population of carp within the littoral zone of the lake.

Bluegills and black crappies were the most abundant species sampled within Silver Lake. Dense populations of planktivores such as these can lower zooplankton densities, lessening the grazing pressure on phytoplankton and thereby increasing the algal density. It is not certain if bullhead are considered a nuisance in Silver Lake, but in general bullhead, as well as carp, are benthivorous fish; they forage in the lake sediments, which physically disturbs the sediments and causes high rates of phosphorus release from the sediments to the water column. Northern pike populations are smaller than expected based on typical numbers compared to similar lakes. Channel catfish and walleye have been stocked in the lake over the last five years. Yellow perch and northern pike were also stocked in this lake during 2002. The City of Columbia Heights currently operates an aerator on behalf of the DNR to prevent fish winterkill.

A macrophyte survey was conducted on July 9, 2008, by Ramsey County Public Works and the Ramsey Conservation District. Very few macrophytes were found during this survey. The majority of plants were leaves or fragments of plants. In addition to filamentous algae, the following macrophytes were found:

- Muskgrass (*Chara* spp.);
- Sago pondweed (*Stuckenia pectinata*); and
- Horned pondweed (*Zannichellia palustris*).

4. Pollutant Sources

Phosphorus has been identified as the pollutant of concern for this TMDL (Section 1C). The three categories of phosphorus loads to Silver Lake include watershed runoff, internal loading, and atmospheric deposition. These sources of phosphorus were estimated and used as input into the lake response model (*Section 5: Loading Capacity*). This section describes the methods used to estimate the load from each phosphorus source category.

4A. WATERSHED RUNOFF

Watershed runoff is the most significant source of phosphorus to Silver Lake. Phosphorus enters Silver Lake via MS4 discharges, regulated point sources. There are no other point sources of phosphorus within the watershed, and there is no non-regulated area within the watershed. Runoff from urban areas typically contains particulate matter and sediment. Phosphorus binds to sediments or is present in organic particulate matter, which is then transported downstream into Silver Lake. Phosphorus concentrations in runoff and associated loads can be predicted through watershed modeling exercises.

Methods

Watershed runoff was modeled using a combination of two models: P8 (Program Predicting Polluting Particle Passage thru Pits, Puddles and Ponds) and StormNET. These models were chosen for their ability to simulate flow conditions and pollutant transport in an urban environment. P8 was also chosen due to its ability to discretely model BMPs such as stormwater ponds, infiltration basins, and wetlands. A new P8 model was constructed based on available topographic data, stormwater BMP data, and stormwater routing information. StormNET was used to calibrate the volumes generated in P8, due to a lack of available data on stormwater flows. The results of the P8 modeling work were used as input to the lake response model described in *Section 5: Loading Capacity.*

The Silver Lake Watershed was modeled in Version 3.4 of the P8 Water Quality Model developed by William Walker, Jr. Ph.D. P8 is a model for predicting the generation and transport of stormwater runoff pollutants in urban watersheds. Continuous water-balance and mass-balance calculations are performed on a user-defined system consisting of watersheds, stormwater BMPs, particle classes and water quality components. Model output was used as input into the lake response model.

A hydrologic and hydraulic model was generated for the Silver Lake subwatershed to assist in development of the overall TMDL (Appendix A). Due to the urban nature of the watershed and lack of available flow data within the subwatershed, the model was used to assist with construction and calibration of the P8 watershed loading model. The hydrologic and hydraulic modeling was assembled and run using StormNET, a front-end software product using the EPA-SWMM 5.0 engine. Appendix A summarizes the StormNET modeling efforts and results.

A P8 model was constructed in 2000 by the Ramsey County Public Works Lake Management Program. Significant changes have occurred within portions of the Silver Lake watershed and additional data refinement available at this time warranted developing a new model. The 2000 model was used to calibrate the current model.

The parameters selected for the Silver Lake watershed P8 model are summarized in Table 9 and discussed in the following paragraphs. P8 parameters not discussed in the following paragraphs were left at the default model setting.

Table 9. Modified P8 Parameters

P8 Parameter	
Time Steps Per Hour	12
Minimum Inter-Event Time (hrs)	10
Maximum Continuity Error %	2
Rainfall Breakpoint (inches)	0.8
Precipitation Scale Factor	1
Air Temp Offset (deg-F)	0
Loops Thru Storm File	1
Max Snowfall Temperature (deg-f)	32.0
Snowmelt Temperature (deg-f)	32.0
Snowmelt Coef (in/degF-Day)	0.06
Soil Freeze Temp (deg-F)	32.0
Snowmelt Abstraction Factor	1.00
Evapo-Trans. Calibration Factor	1.00
Growing Season Start Month	5
Growing Season End Month	10

5-Day Antecedent Rainfall + Runoff (inches)		
CN Antecedent Moisture Condition	**AMC-II**	**AMC-III**
Growing Season	1.40	2.10
Non-growing Season	0.50	1.10

The precipitation file used is comprised of hourly precipitation measured at the Minneapolis-St. Paul International Airport for the 1995 water year (October 1st 1994 – September 30th 1995). This time period represents an average precipitation year locally (26.52 inches of precipitation). A corresponding temperature file was also used for the simulation. Table 11 is the particle class table for NURP 50 particle distribution used for the Silver Lake model.

In addition to the global data, the hydrologic characteristics of each individual subwatershed were characterized in the model according to Appendix B and Table 10. Appendix B includes the subwatershed specific data, as well as the routing information. Subwatershed areas were based on the StormNET model (Appendix A), although several subwatersheds were combined in the P8 modeling results figures and others were modified based on stakeholder input.

Table 10. Modeling Input Parameters

Pervious Curve Number	61
Depressional Storage [inches]	0.2
Load Factor	1
Runoff Coefficient	0.9

All the major stormwater treatment facilities within the Silver Lake watershed were included within the model, as well as Hart Lake. There are several small rain gardens within the SIL-003, SIL-004 and SIL-009 subwatersheds that, due to the scale of the modeling effort for this project, were not expressly modeled. Appendix B includes the physical characteristics of each stormwater pond included in the P8 model. P8 uses the traditional hydraulic loading rate method for dynamic settling to calculate pollutant removal efficiency within all ponding areas (US EPA, 2006). This method assumes that pollutant removal is by settling alone. The inflow rate and area of the pond are used to calculate the pollutant removal. Pollutant removal occurs when with settling velocities greater than the hydraulic loading rate, or overflow rate, are removed. Outflow data from the hydraulic model was used to generate the Hart Lake input data for P8.

Table 11. Global Modeling Parameters

Particle Class	P0%	P10%	P30%	P50%	P80%
Filtration Efficiency	90	100	100	100	100
Settling Velocity (ft/sec)	0	0.03	0.3	1.5	15
First Order Decay Rate	0	0	0	0	0
2nd Order Decay (1/day)	0	0	0	0	0
Impervious Runoff Conc	1	0	0	0	0
Pervious Runoff Conc	1	100	100	100	200
Pervious Conc Exponent	0	1	1	1	1
Accum. Rate (lbs-ac-day)	0	1.75	1.75	1.75	3.5
Particle Removal Rate	0	0.25	0.25	0.25	0.25
Washoff Coefficient	0	20	20	20	20
Washoff Exponent	0	2	2	2	2

Calibration and Verification

The P8 model was calibrated through comparison of volumes results of the StormNET hydraulic model (Appendix A) and annual TP loads were compared to the previously calibrated Ramsey County P8 model. The current P8 and StormNET models were run with a 24-hour, 1.0-inch storm event and volumes and high water levels within ponds were compared with results in general agreement. The annual TP loads between the previous P8 model and the current model were also compared, although several factors led to slightly different results. Those factors include differing measurements of impervious surface, changes in subwatershed delineation and additional stormwater treatment in place since the original model.

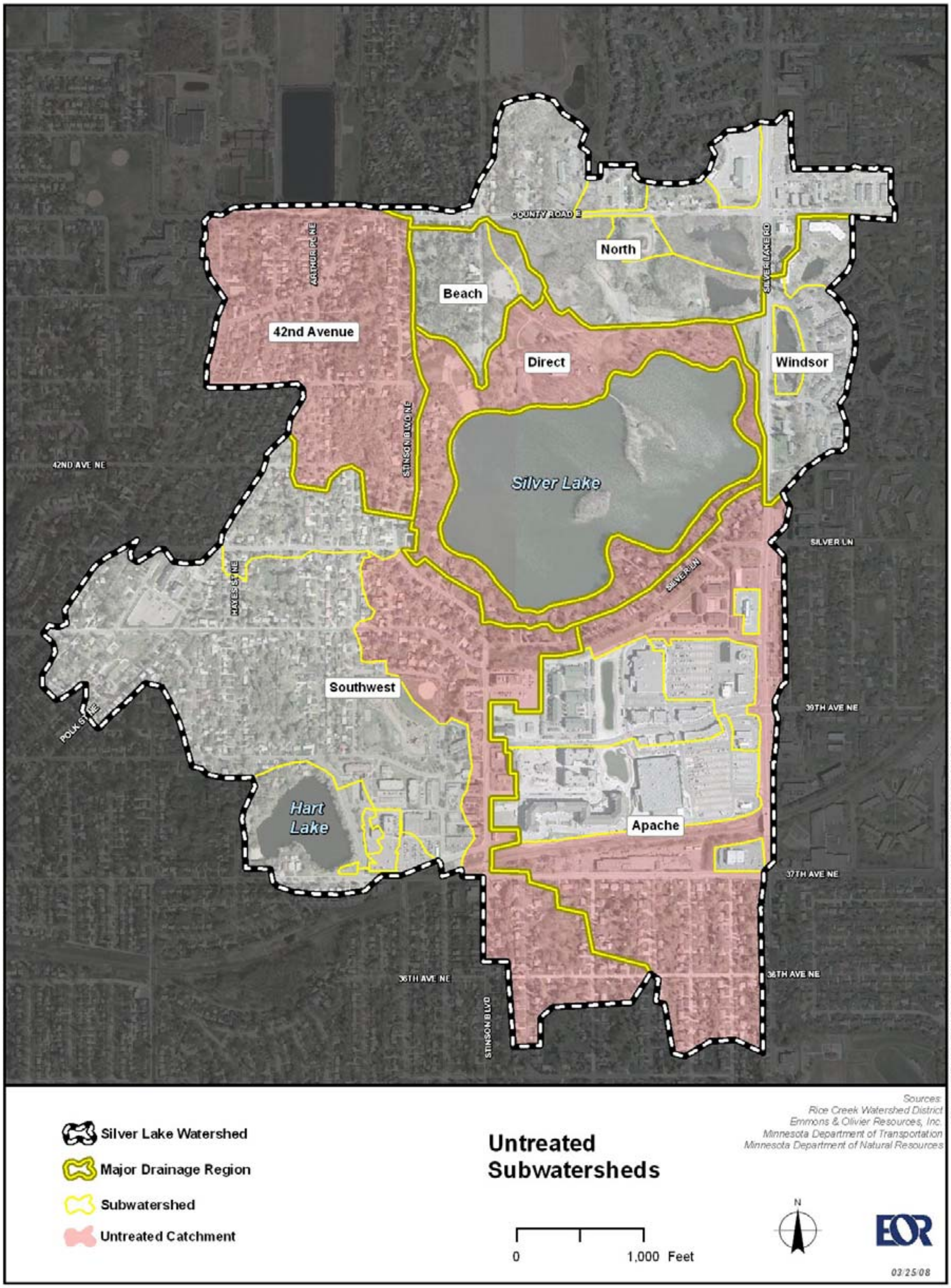
Results

There are six distinct major subwatersheds to Silver Lake in addition to the direct drainage area around the lake (Figure 16). Figure 16 also depicts the areas within the Silver Lake watershed that do not currently have any formal water quality treatment facilities. These areas could be the focus of future management practice installation. Results from the P8 model are summarized by major subwatershed in the following table.

Table 12. Watershed Runoff Phosphorus Loading

Major Subwatershed	Area [acres]	Annual Volume [acre-feet]	Annual TP Load [lbs/year]	Annual TP Loading Rate [lbs/acre]
Apache	148.05	171.74	101.33	0.68
Southwest	205.14	123.79	83.93	0.41
42nd Avenue	71.09	26.57	25.21	0.35
Beach	18.92	4.52	3.15	0.17
North	80.14	21.04	4.48	0.06
Windsor	30.65	21.76	7.03	0.23
Direct	52.1	15.23	14.53	0.27
Total to Silver Lake	*606.1*	*384.66*	239.7	*0.40*

Figure 16. Silver Lake Subwatersheds and Untreated Areas



Sources:
Rice Creek Watershed District
Emmons & Olivier Resources, Inc.
Minnesota Department of Transportation
Minnesota Department of Natural Resources

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Apache Subwatershed

The Apache subwatershed (Figure 17) is located south of Silver Lake and is a highly impervious retail area with some water quality treatment and large untreated areas. The area drains into the lake via a pipe that discharges on the east side and also serves as the outlet of the lake when lake levels rise. Much of this subwatershed is actively being redeveloped. Figure 17 depicts the drainage area TP generation, removal efficiencies within stormwater ponds and the contribution of each drainage area to downstream flow.

Southwest Subwatershed

The Southwest subwatershed (Figure 18) consists primarily of single family residential land with some parkland and high density residential land use. The area also contains Hart Lake (8.5 acres in size). There are two small stormwater ponds in the drainage area to Hart Lake, otherwise the main treatment in this subwatershed is within the Prestemon Park pond. There is also a small pond at the end of 41st Street that treats a portion of the subwatershed. Figure 18 depicts the drainage area TP generation, removal efficiencies within stormwater ponds and the contribution of each drainage area to downstream.

42nd Avenue and Beach Subwatersheds

The 42nd Avenue subwatershed (Figure 19) is northwest of the lake and is predominantly single family residential. It has no formal water quality treatment facilities. The Beach subwatershed is northwest of the lake and drains through to the beach on the lake. There is an infiltration basin and a small pond near the beach that provides water quality treatment. Figure 19 depicts the drainage area TP generation, removal efficiencies within stormwater ponds and the contribution of each drainage area to downstream.

North Subwatershed

This subwatershed consists largely of undeveloped land with some office buildings. There are significant natural ponding areas within this subwatershed which provide considerable water quality treatment. This is the part of the watershed currently being redeveloped as Silverwood Park by the Three Rivers Park District. Figure 20 depicts the drainage area TP generation, removal efficiencies within stormwater ponds and the contribution of each drainage area to downstream.

Windsor Subwatershed

The Windsor subwatershed is located northeast of the lake and consists of multi-family residential land use. There are large ponding areas within this subwatershed which provide water quality treatment. The pond within SIL-021 infiltrates virtually all runoff generated within its small watershed, and therefore has a 98% TP removal efficiency. Figure 21 depicts the drainage area TP generation, removal efficiencies within stormwater ponds and the contribution of each drainage area to downstream.

Direct Subwatershed

The Direct subwatershed includes all of the untreated area immediately adjacent to the lake. Land uses include single family residential and undeveloped. Figure 22 depicts the drainage area TP generation and total load to the lake from the Direct subwatershed.

Figure 17. Apache Subwatershed

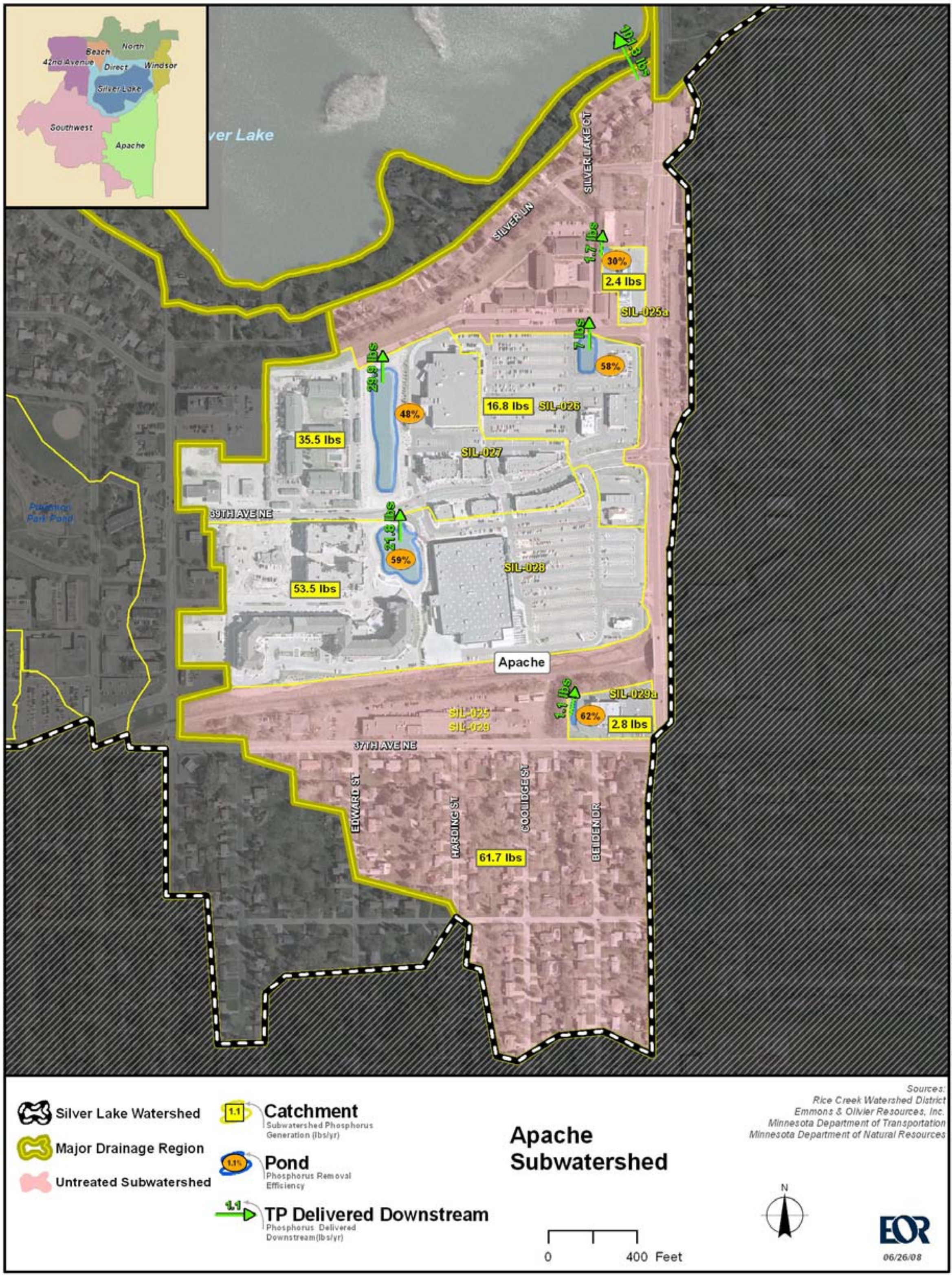


Figure 18. Southwest Subwatershed

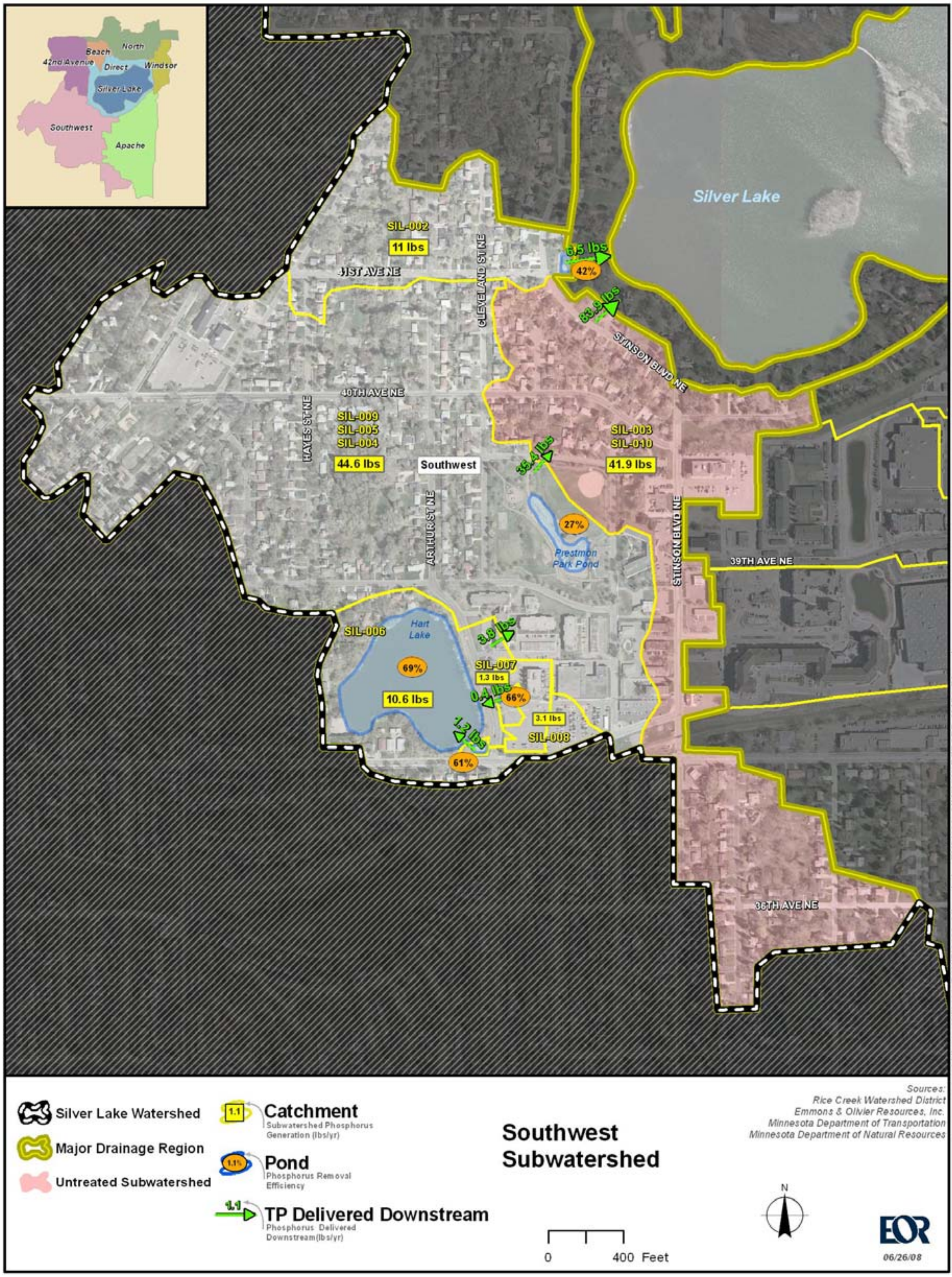


Figure 19. 42nd Avenue and Beach Subwatersheds

Figure 20. North Subwatershed

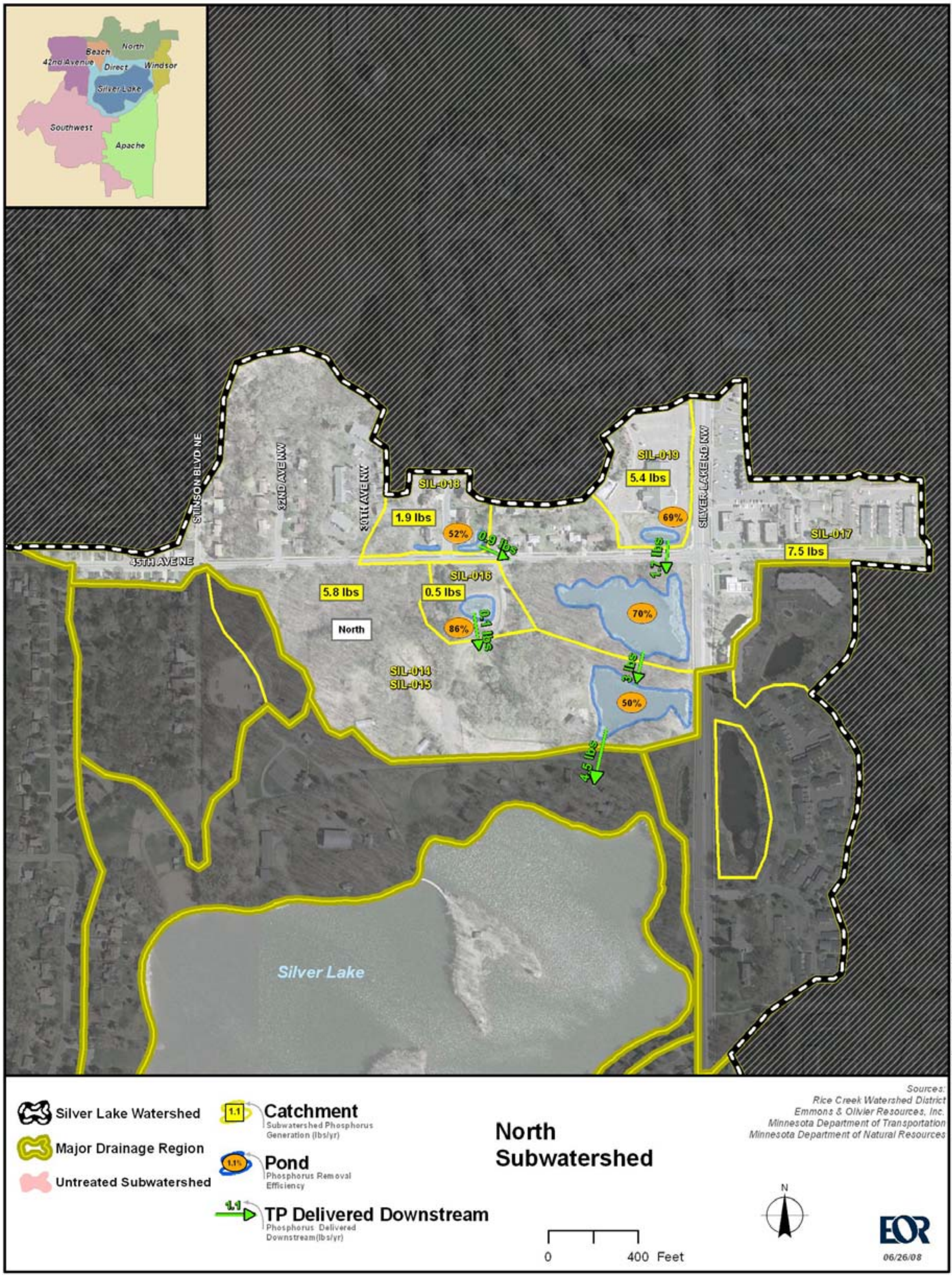
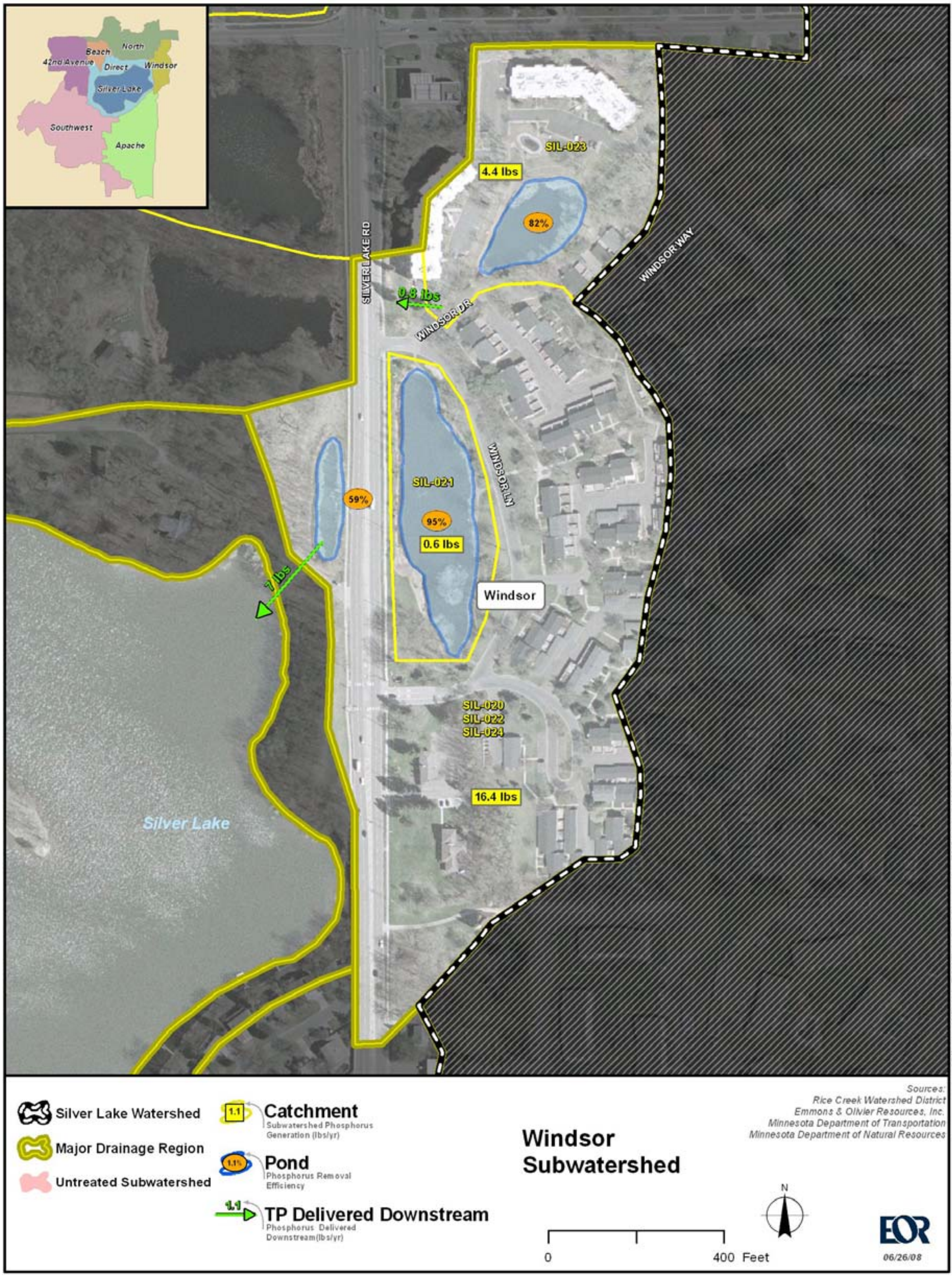
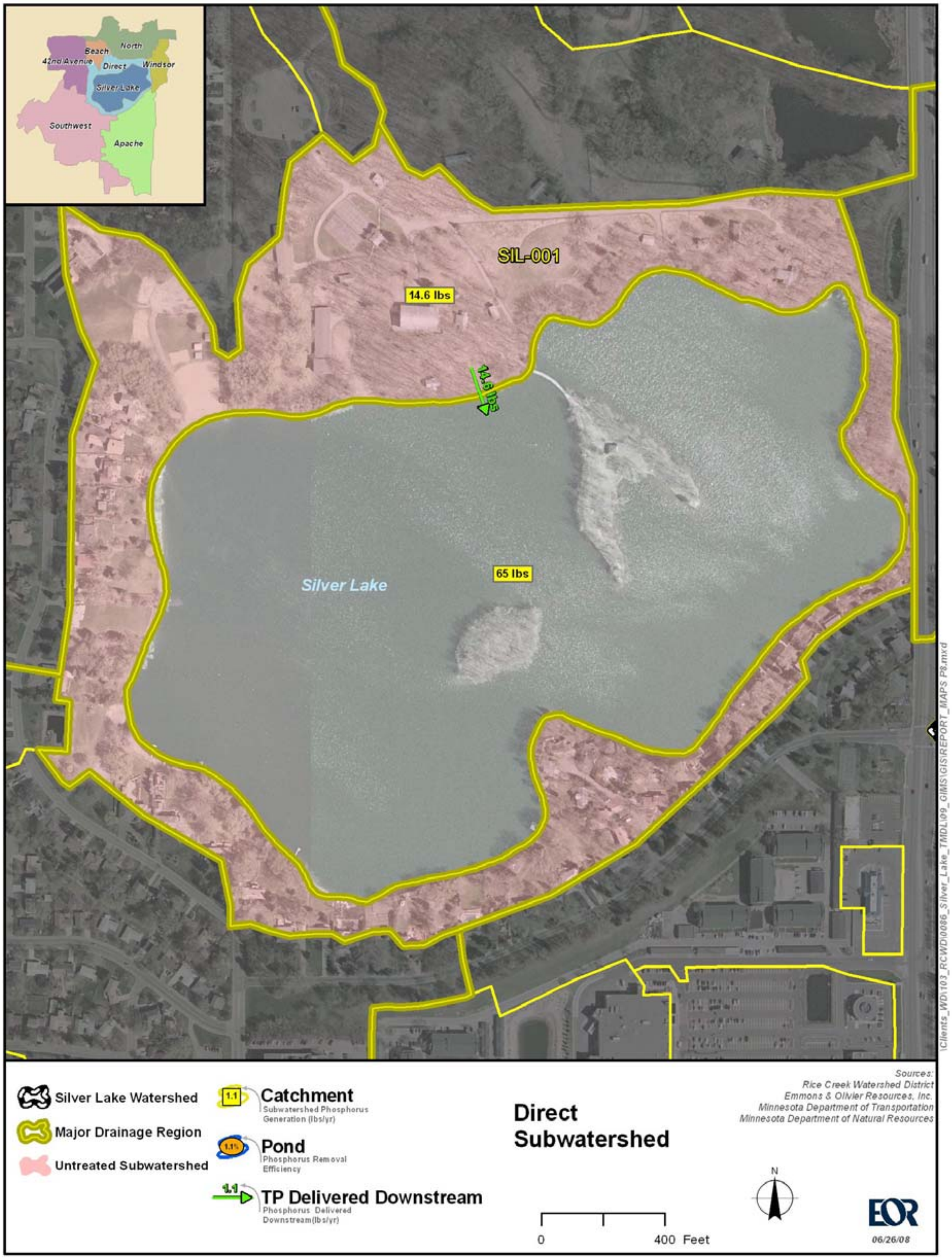


Figure 21. Windsor Subwatershed



Sources:
Rice Creek Watershed District
Emmons & Olivier Resources, Inc.
Minnesota Department of Transportation
Minnesota Department of Natural Resources

Figure 22. Direct Subwatershed



4B. INTERNAL LOADING

Internal loading in lakes refers to the phosphorus load that originates in the bottom sediments and is released back into the water column. The phosphorus in the sediments was originally deposited in the lake sediments through the settling of particulates (attached to sediment that entered the lake from watershed runoff, or as phosphorus incorporated into biomass) out of the water column. Internal loading can occur through various mechanisms:

- Anoxic (lack of oxygen) conditions in the overlying waters: Water at the sediment-water interface may remain anoxic for a portion of the growing season, and low oxygen concentrations result in phosphorus release from the sediments. If a lake's hypolimnion (bottom area) remains anoxic for a portion of the growing season, the phosphorus released due to anoxia will be mixed throughout the water column when the lake loses its stratification at the time of fall mixing. Alternatively, in shallow lakes, the periods of anoxia can last for short periods of time; wind mixing can then destabilize the temporary stratification, thus releasing the phosphorus into the water column.
- Physical disturbance by bottom-feeding fish such as carp and bullhead. This is exacerbated in shallow lakes since bottom-feeding fish inhabit a greater portion of the lake bottom than in deeper lakes.
- Physical disturbance due to wind mixing. This is more common in shallow lakes than in deeper lakes. In shallower depths, wind energy can vertically mix the lake at numerous instances throughout the growing season.
- Phosphorus release from decaying curly-leaf pondweed (*Potamogeton crispus*). This is more common in shallow lakes since shallow lakes are more likely to have nuisance levels of curly-leaf pondweed.

Water quality sampling and dissolved oxygen depth profiles were taken at the deep hole in Silver Lake (see Figure 9). The dissolved oxygen depth profile from 2006 indicates that this portion of the lake stratifies and the hypolimnion remains anoxic during the growing season (Figure 23). Total phosphorus data from that site also show that the concentration in the hypolimnion is higher than the surface water samples taken at the same time (Figure 24). This suggests that internal loading is a source of phosphorus in Silver Lake as the hypolimnetic waters high in phosphorus are mixed with the surface waters during the fall turnover event.

Figure 23. Silver Lake Dissolved Oxygen Depth Profile, 2006

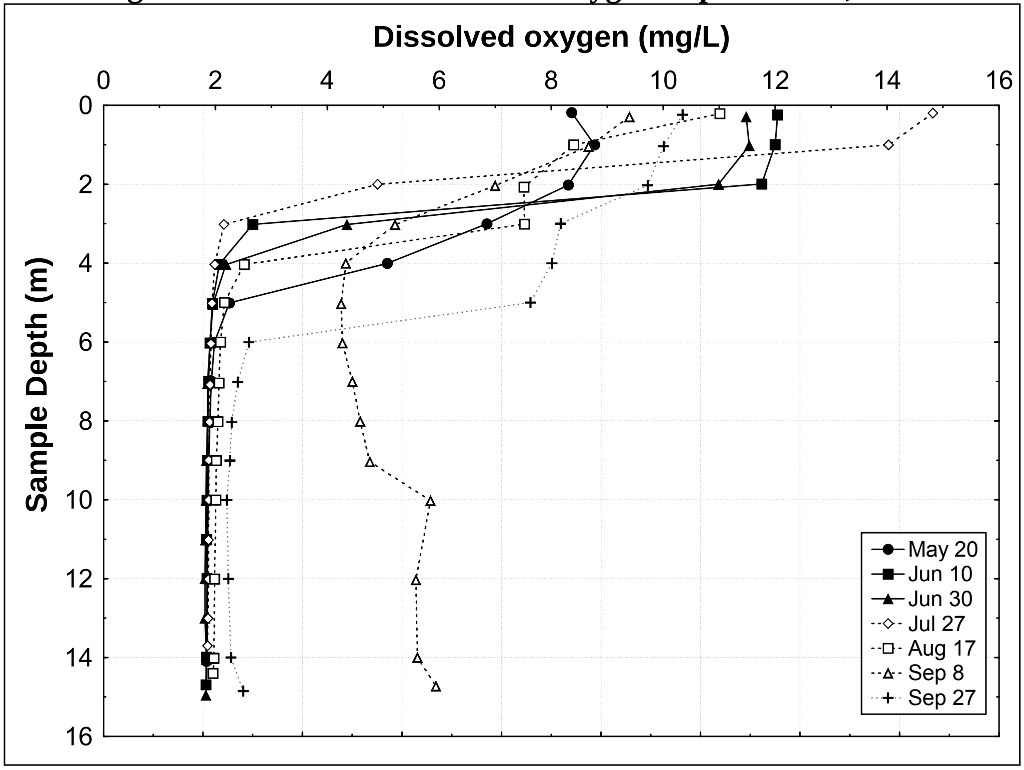
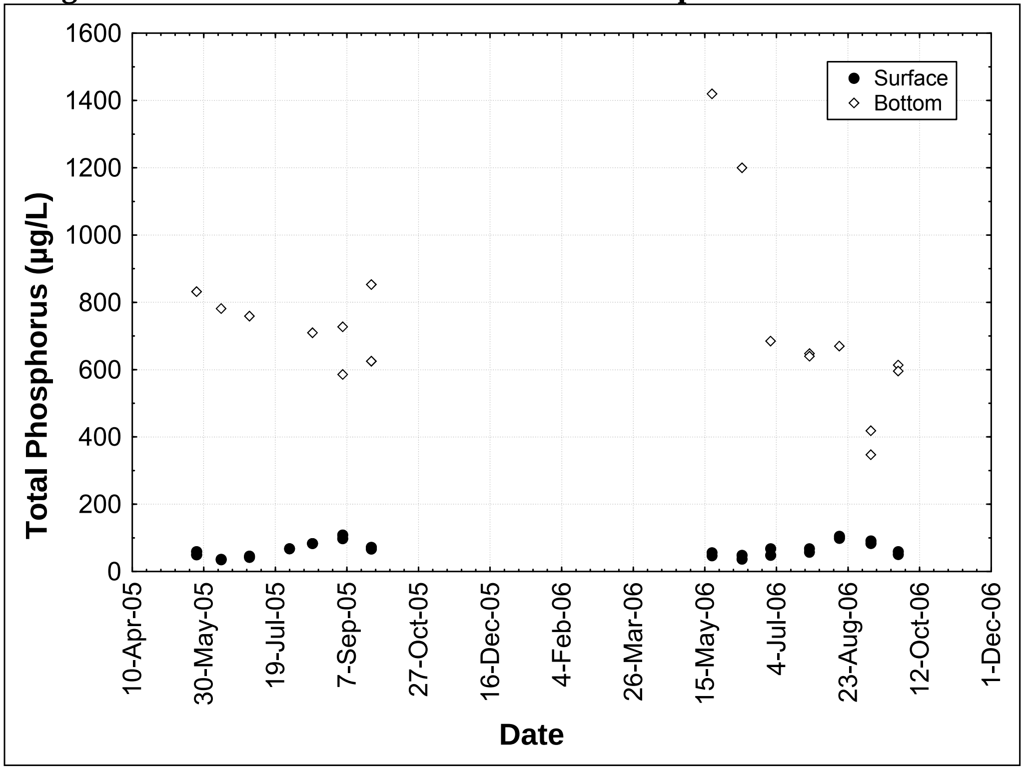


Figure 24. Silver Lake Surface vs. Bottom Phosphorus Concentrations



Internal loads due to anoxic release in the hypolimnion were calculated based on an approach developed by Nürnberg (1988, 1995) in which an anoxic factor is calculated based on in-lake TP concentrations, lake surface area, and lake mean depth, and a sediment phosphorus release rate is calculated based on sediment phosphorus concentrations (Appendix C). Using these equations, the internal loading rate in Silver Lake was estimated to be 0.89 lb/ac-yr, or an internal load of 65 lbs/yr.

This internal loading rate was calculated independently of the lake model (Bathtub model) and was not input into the lake model (described in Section 5A). An average rate of internal loading is implicit in Bathtub since the model is based on empirical data and internal loading rates were not directly estimated in the development of the equations used in Bathtub. Since adjustments to the model (e.g. additional internal loading) were not necessary for model calibration, it was assumed that Silver Lake does not have excessive internal loading relative to the lakes that were used in the development of the Bathtub model. The internal loading estimate calculated from the lake sediment data was used to represent internal loading in the overall lake nutrient balance.

Additional internal loading due to bottom-feeding fish, wind mixing in shallow areas, and the release of phosphorus from curly-leaf pondweed was not added to the estimate. Since it had been determined that Silver Lake does not have excessive internal loading, it was assumed that the internal load due to these additional sources is not excessive. This does not mean that internal loads in Silver Lake are due only to anoxia, but rather that the internal load is not substantially higher than the Bathtub model predicts based on inherent relationships and datasets within the model itself.

4C. ATMOSPHERIC DEPOSITION

Atmospheric deposition over the growing season was estimated to be 19 lbs/yr in Silver Lake, calculated by Bathtub, using the Bathtub default rate of 0.27 lbs/ac-yr.

5. Loading Capacity

This section describes the derivation of the TMDL for Silver Lake.

5A. METHODS

To estimate the assimilative capacity of Silver Lake, the Bathtub (Version 6.1) model was selected to link phosphorus loads with in-lake water quality. A publicly available model, Bathtub was developed by William W. Walker for the U.S. Army Corps of Engineers (Walker 1999). Bathtub has been used successfully in many lake studies in Minnesota and throughout the United States. Bathtub is a steady-state annual or seasonal model that predicts a lake's summer (June through September) mean surface water quality. Bathtub's time-scales are appropriate because watershed phosphorus loads are determined on an annual or seasonal basis, and the summer season is critical for lake use and ecological health. Bathtub has built-in statistical calculations that account for data variability and provide a means for estimating confidence in model predictions. The heart of Bathtub is a mass-balance phosphorus model that accounts for water and phosphorus inputs from tributaries, watershed runoff, the atmosphere, sources internal to the lake, and (if appropriate) groundwater; and outputs through the lake outlet, groundwater (if appropriate), water loss via evaporation, and phosphorus sedimentation and retention in the lake sediments. Bathtub allows choice among several different mass balance phosphorus models. For lakes in Minnesota, the option of the Canfield-Bachmann lake formulation has proven to be appropriate in many cases and was used to model Silver Lake. Bathtub's in-lake water quality predictions include two response variables, chlorophyll-*a* concentration and Secchi depth, in addition to total phosphorus concentration. Empirical relationships between in-lake total phosphorus, chlorophyll-*a*, and Secchi depth form the basis for predicting the two response variables.

The Bathtub model was calibrated to data representing an average year (Table 13):

- The watershed load was estimated with P8 using an average water year (see Section 4a) – October 1, 1994 to September 30, 1995 precipitation data.
- Evaporation was estimated based on long-term evaporation rates published in the MN Hydrology Guide.
- Change in storage was estimated with water level data from October 1, 1994 to September 30, 1995.
- The model was calibrated to observed in-lake water quality data using a 1997 through 2006 average.

Table 13. Bathtub Input Parameters

Parameter	Bathtub Input
Precipitation	0.66 m
Evaporation	0.91 m
Increase in storage	-0.12 m
Atmospheric precipitation TP load rate	30 mg/m^2-yr
Averaging period	1 year

An average rate of internal loading is implicit in Bathtub since the model is based on empirical data. Adjustments to the model (e.g. additional internal loading, changes to the calibration coefficients) were not necessary for model calibration. The internal loading estimate calculated from the lake sediment data (see Section 4B) was therefore not directly entered into the model, but was used to represent internal loading in the overall lake nutrient balance.

Table 14. Bathtub Model Input

Bathtub Model Selection	
Phosphorus balance	9 – Canfield & Bachmann, General
Chlorophyll-*a*	2 – P, light, turbidity
Secchi depth	1 – vs. chl-*a* & turbidity
Phosphorus calibration	1 – decay rates

After the model was calibrated to all parameters (TP, chlorophyll-*a*, and Secchi transparency), the TP goal was then used as an endpoint, and the TP loads were adjusted until the model predicted that the in-lake TP goal would be reached. The model output also includes predictions of chlorophyll-*a* concentration and Secchi depth at the TP goal, in addition to predicted algal bloom frequencies, which are based on chlorophyll-*a* concentration.

All inputs used in the Bathtub model are presented in Appendix D.

5B. MODEL CALIBRATION

The Canfield-Bachmann General Lakes model was selected because it best predicted the in-lake TP concentration without additional adjustments to the model. This model calculates the phosphorus sedimentation rate as a function of the total phosphorus loading to the lake and the lake's total volume.

After the TP model was calibrated, the model 2 chlorophyll equation was selected, as it best predicted the observed concentration. Lastly, the Secchi depth model 1 was selected based on the model that best predicted the observed Secchi depth (Table 15). Additional statistics on the model calibration are presented in Appendix D.

Table 15. Bathtub Calibration- Existing Conditions

Water Quality Parameter	**Silver Lake**	
	Observed	**BATHTUB Predicted**
TP (µg/L) mean	63	63
Chl-*a* (µg/L) median	40	35
SD (m) mean	0.94	1.06

5C. RESULTS

Existing Conditions

The watershed load to Silver Lake represents approximately 74% of the total load to the lake, and internal load represents approximately 20% of the phosphorus load to the lake (Table 16).

Table 16. Volume and TP Load Source Contributions: Existing Conditions

Source	Volume (ac-ft/yr)	% Volume	TP Load (lbs/yr)	% TP Load
Watershed	385	71%	241*	74%
Atmospheric precipitation	158	29%	19	6%
Internal	0	0%	65	20%

*The watershed TP load generated from Bathtub is 1.3 lbs/yr higher than the P8 modeled watershed load of 239.7 lbs/year used as input to the Bathtub model

Assimilative Capacity

To reach the long-term in-lake water quality goal of 60 µg/l TP, the total annual phosphorus load to the lake must not exceed 308 lbs/yr (Table 17), a reduction of 5%. At this concentration, both the chlorophyll-*a* and the Secchi depth will also improve (Table 18). This load is the lake's TMDL, and will be split up among a load allocation, waste load allocations, and a margin of safety (Section 6):

$$\text{TMDL} = \text{LA} + \text{WLA} + \text{MOS}$$

Table 17. Existing Load and Assimilative Capacity

Model Scenario	Total Load to Lake (lbs/yr)
Existing	325
In-Lake Water Quality Standard (60 µg/L)	308
Reduction needed to meet standard	17

The assimilative capacity is based on the lake meeting the TP standard, provided that either the chlorophyll-*a* or the Secchi standard is also being met. Under the modeled scenario for the water quality standard (60 µg/L TP), the chlorophyll-*a* standard is not met, but the Secchi improves slightly (Table 18). This improvement is expected to lead to the Secchi depth standard of 1.0 m being met. Management practices aimed at reducing the phosphorus load to the lake should lead to lower algal production and therefore improved clarity. Management pratices aimed at shifting the ecological interactions (aquatic macrophytes and fisheries) within the lake are also expected to improve clarity – the goal of these practices is to support a more healthy zooplankton community that can effectively graze down the algae and improve clarity (see *Section 9C – Implementation Strategy, Internal Load*).

Table 18. Predicted In-Lake Water Quality under Observed Conditions and Achievement of Standards, Compared to Actual Standards

Scenario	Scenario TP (µg/L)	Standard TP (µg/L)	Scenario Chlor-a (µg/L)	Standard Chlor-a (µg/L)	Scenario Secchi (m)	Standard Secchi (m)
Existing, observed	63	60	40	20	0.94	1.0
60 µg/L TP Modeled Scenario	60		34		1.09	

6. TMDL Allocations

The TMDL for Silver Lake was apportioned between the wasteload allocation (WLA) and the load allocation (LA). The WLAs and LAs are presented in terms of phosphorus loading per day, in addition to phosphorus loading per year. The modeling and load estimates were based on average year loads, and these loads were divided by the number of days in a year (365 days) to determine the daily loads.

6A. MARGIN OF SAFETY

The margin of safety (MOS) is included in the TMDL equation to account for both the inability to precisely describe current water quality conditions and the unknowns in the relationship between the load allocations and the in-lake water quality.

Methods

The MOS was calculated using the method described in Walker (2003). With this approach, the MOS is composed of a margin of variability (MOV) and a margin of uncertainty (MOU). The MOV is based on annual variability in lake TP concentrations, and is directly related to the compliance rate, or the frequency of meeting the water quality goal. The MOU is based on the uncertainty in predicting the TP concentration (current conditions as well as the effects of implementation activities on the TP concentration), and is directly related to the confidence level, or the probability of meeting the goal at the desired frequency. Both the compliance rate and the confidence level were set at 60%.

After the MOS was determined, the remaining load was apportioned between the load allocations and the waste load allocations according to the same proportion as the distribution of the loads in the modeled goal scenario.

Results

The MOS was calculated to be 32 lbs/yr (Table 19).

Table 19. Margin of Safety

Parameter	Water Quality Goal 60 µg/l TP
Compliance Rate (β)	0.6
Margin of Variability (MOV) (lbs/yr)	3
Confidence level (α)	0.6
Margin of Uncertainty (MOU) (lbs/yr)	12
TMDL (lbs/yr)	308
MOS (lbs/yr)	32
TMDL – MOS = LA + WLA (lbs/yr)	278

6B. TMDL ALLOCATIONS

The final TMDL equation for Silver Lake is as follows:

TMDL = Load Allocation + Wasteload Allocation + Margin of Safety

308 lbs/yr = 75 lbs/yr + 201 lbs/yr + 32 lbs/yr

The difference between the TMDL and the margin of safety represents the total load that can be allocated between the load allocation (LA) and the wasteload allocations (WLA). The TMDL allocations are divided between LAs (internal loading and atmospheric deposition) and WLAs (permitted stormwater runoff). There are required reductions in both the stormwater runoff and the internal loading. No reductions in atmospheric deposition are required.

Based on this allocation, a 17% reduction in watershed loads and a 14% reduction in internal loads are necessary for the lake to achieve the water quality goal, relative to current conditions (Table 20).

Table 20. Phosphorus Sources and Required Reductions

	Existing		TMDL Goal		Reduction Needed	
TP Source	**TP Load (lbs/yr)**	**% Total Load**	**TP Load (lbs/yr)**	**% Total Load**	**TP Load (lbs/yr)**	**% Reduction**
Watershed	241	74%	201	73%	40	17%
Atmospheric	19	6%	19	7%	0	0%
Internal	65	20%	56	20%	9	14%
Total	325		276		49	15%

6C. WASTELOAD ALLOCATIONS

The wasteload allocation is that portion of the total TMDL that is allocated to permitted point sources. In the case of Silver Lake, the entire watershed load is regulated under the NPDES program and is considered a point source. Within the Silver Lake watershed, there are no other permitted point sources; therefore the entire wasteload allocation will be shared by regulated entities under the NPDES program.

The stormwater sources (MS4, construction stormwater, and industrial stormwater) were given categorical WLAs for Silver Lake (Table 21). The categorical WLA covers all stormwater sources; the load reductions identified by the WLAs will need to be met by this group as a whole.
Table 21 summarizes the categorical wasteload allocation and includes each of the regulated MS4s within the Silver Lake subwatershed. The categorical wasteload allocation includes allocations for Construction General Permit applicants and Industrial Stormwater General Permit applicants.

Table 21. Waste Load Allocations

Permit Type	Permit Name	% of Total Area	Permit Number	Existing TP Load (lbs/year)	WLA (lbs/year)	WLA (lbs/day)	Percent Reduction
MS4 Stormwater	Anoka County	0.5	MS400066	241	201	0.55	17%
MS4 Stormwater	Columbia Heights	40.6	MS400010				
MS4 Stormwater	Hennepin County	0.1	MS400138				
MS4 Stormwater	Minneapolis	0.3	MN0061018				
MS4 Stormwater	New Brighton	9.1	MS400038				
MS4 Stormwater	Ramsey County Public Works	2.6	MS400191				
MS4 Stormwater	St. Anthony Village	46.9	MS400051				
Construction stormwater	Various	--	Various				
Industrial stormwater	No current permitted sources	--	NA				

Loads from construction stormwater are considered to be a small percent of the total WLA and are difficult to quantify. Construction stormwater activities are therefore considered in compliance with provisions of the TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install, and maintain all BMPs required under the permit, including any applicable additional BMPs required in the Construction General Permit for discharges to impaired waters, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit.

There are currently no industrial activities subject to the Industrial Stormwater General Permit in the watershed. Industrial storm water activities are considered in compliance with provisions of the TMDL if they obtain an industrial stormwater general permit or General Sand and Gravel general permit (MNG49) under the NPDES program and properly select, install and maintain all BMPs required under the permit.

Stormwater activities from individually permitted, non-MS4 NPDES/SDS stormwater discharges will be considered in compliance with provisions of the TMDL if they follow conditions of the individual permit and implement the appropriate BMPs. As additional data become available after U.S. EPA approval of the TMDL, WLAs for individual permitted sources may be modified, provided the overall WLA does not change. Modifications in individual WLAs will be public noticed.

6D. LOAD ALLOCATIONS

The atmospheric and internal sources of TP are considered under the load allocation. The atmospheric load is assumed to be constant, and the required load reduction is in the internal loading only (Table 22).

Table 22. Load Allocations

	Existing TP Load (lbs/yr)	Load Allocation (lbs/yr)	Load Allocation (lbs/day)	Percent Reduction
Internal Load	65	56	0.15	14%
Atmospheric Load	19	19	0.05	0%
Total	84	75	0.21	14%

6E. RESERVE CAPACITY

No portion of the loading is being explicitly set aside as reserve capacity to account for growth beyond the current boundaries of permitted MS4 communities. This is based on the entire watershed already being designated as MS4 authorities and the RCWD's existing permit program that requires water quality treatment for redeveloped sites. The RCWD Rules will prevent new phosphorus loads from entering the lake as a result of redevelopment.

6F. TMDL SUMMARY

Table 23. TMDL Allocation Summary

Source		% Allocation	TMDL (average lbs/day)
Load Allocation		24.4%	0.21
Wasteload Allocation - Stormwater		65.2%	0.55
MS4	Permit #		
Anoka County	MS400066		
Columbia Heights	MS400010		
Hennepin County	MS400138		
Minneapolis	MN0061018		
New Brighton	MS400038		
Ramsey County Public Works	MS400191		
St. Anthony Village	MS400051		
Construction stormwater	Various		
Industrial stormwater	No current permitted sources		
Margin of Safety (MOS)		10.4%	0.09
Total		**100%**	**0.84**

7. Seasonal Variation

In-lake water quality models used for this TMDL predict growing season or annual averages of water quality parameters based on growing season or annual loads, and the MPCA’s nutrient criteria are based on growing season averages. Symptoms of nutrient enrichment normally are the most severe during the summer months; the nutrient standards set by the MPCA were set with this seasonal variability in mind.

8. Monitoring Plan

Ramsey County has been monitoring Silver Lake since 1986. Their program has focused on providing nutrient and solids sampling and profiles for dissolved oxygen, specific conductance, temperature and pH. Sampling is conducted bi-weekly May-September. Silver Lake is also monitored by private citizens as part of the Citizen Lake Monitoring Program.

Efforts should be made to continue monitoring the lake bi-weekly into the future. Adaptive management may require additional monitoring when different BMPs are implemented. Spring and fall aquatic macrophyte surveys should be completed periodically to understand the role of curly-leaf pondweed in overall lake phosphorus dynamics and track the presence of macrophytes in the lake.

9. Implementation Strategy

9A. APPROACH TO LAKE RESTORATION

Lake restoration activities can be grouped into two main categories: those practices aimed at reducing external nutrient loads, and those practices aimed at reducing internal loads. The focus of restoration activities depends on the lake's nutrient balance and opportunities for restoration. In a shallow lake such as Silver Lake, the first step in the restoration is to control the external loads. This discussion separates the management strategies into practices addressing watershed load and internal load. An estimated cost is included for each activity.

9B. WATERSHED LOAD

The watershed strategies being used to meet the TMDL include urban retrofitting and redevelopment, management, and regulatory controls. The watershed loading goal requires the removal of 40 pounds of total phosphorus, annually.

Urban Retrofitting and Redevelopment

Retrofits are proposed within the Silver Lake subwatershed to assist in achieving the TMDL. As redevelopments are presented, additional improvements will be explored by the communities and Watershed District.

Columbia Heights Boat Ramp Improvements
A boat ramp, owned by the City of Columbia Heights, currently includes a regional water quality pond. This pond currently provides 42% removal of total phosphorus for the contributing drainage area (northern portion of the Southwest Subwatershed). Modifications to the existing pond design could include a ponding or filtration component that will allow the site to remove 80% of the total phosphorus.

Cost: $150,000

Silverwood Park Improvements
Three Rivers Park District is planning the redevelopment of Silverwood Park, located on the north and east shores of Silver Lake, to include a variety of water quality treatment features. Runoff from the visitor center, associated parking and the greater site area will drain via a treatment train of stormwater features prior to discharge to Silver Lake. The treatment train includes pervious pavers, cistern, 7 biofiltration basins, 1 stormwater pond, and the existing eastern wetlands and stormwater pond. In addition, casual water quality benefits will be realized from parallel swales seeded with deep-rooted native vegetation that treat runoff from the entrance drive prior to discharge to biofiltration basins.

Cost: $300,000

Silver Lake Beach Park Improvements
The City of Columbia Heights has plans for site improvements to Silver Lake Beach Park. Water quality improvements include two infiltration basins and a vegetated swale with ponding. The large central infiltration basin will treat runoff from the proposed entrance drive and parking area as well as runoff from small storm events over 12.5 acres of residential development. The second infiltration basin will receive overflow from the large basin and will treat runoff from contributing areas. The vegetated swale will provide intermittent water quality ponding for an additional small drainage area. In addition, casual water quality benefits will be provided by overall impervious surface reduction and conversion of portions of mowed turf to native plants. The improvement will result in TP removal from the Beach and Direct subwatersheds.

Cost: $70,980

Shoreland Buffers and Restoration
Shoreland buffers can be used to treat direct drainage from properties adjacent to the lake. Buffers provide for wildlife habitat and filtering of stormwater pollutants and act as a filter for stormwater runoff from shoreland properties. These practices are targeted toward homes on the west and south shores of the lake where lawns extend down to the lakeshore. Shoreline areas were also identified where erosion was taking place along the east shore and on portions of the islands. Shoreland restoration work in these areas can stabilize the shores and prevent sediment from entering the lake and reduce the associated nutrients.

Cost: $100,000

Apache Redevelopment
Existing ponding facilities within the Apache redevelopment area were designed to treat an additional four properties located east of Stinson Boulevard between the railroad tracks on the south and 40th Avenue NE on the north. These four properties are currently untreated and flow to the north along Stinson Boulevard, directly to the lake. As these properties redevelop, runoff will be directed to the existing Apache stormwater facilities and additional TP will be removed annually from watershed runoff in this area.

Cost: $0

Rain Garden or Small Water Quality Treatment Facility Retrofits
The Cities of St. Anthony and Columbia Heights contain many untreated residential areas. Urban retrofits including rain gardens are a simple and cost effective method of achieving water quality treatment in fully urbanized areas. This activity assumes that rain gardens or small water quality treatment facilities can be installed either in conjunction with road reconstruction activities (Stinson Avenue and Silver Lane) or as part of a neighborhood retrofit project. Opportunities may exist to divert and treat a portion of flow within existing storm sewers along Stinson Blvd and Silver Lake Road. This implementation activity assumes the construction of 22 rain gardens or small water quality treatment facilities.

Cost: $355,000

Management

Existing P-free Fertilizer Laws
Minnesota Statute (Chapter 18C) has been updated to include the Phosphorus Lawn Fertilizer Law (SF 1555), which went into effect in 2004 and restricts the use of fertilizer containing phosphorus in non-cropped land. Since this is a recent law, its full effect has not yet been observed. It is likely to decrease phosphorus concentrations in residential runoff according to an unpublished study done by the Three Rivers Park District.

Cost: $0

Education Program
A targeted education program could be used to provide information to residents near the lake on good housekeeping practices such as keeping lawn clippings and leaves off impervious areas, fertilizer management, the importance of aquatic macrophytes in the health of shallow lakes, and how homeowners can protect the lake. This education program could be coordinated by the RCWD.

Cost: $3,000/year

Regulatory Controls

It is anticipated that existing regulatory controls will provide additional TP removal requirements needed to meet the TMDL as additional sites redevelop over the next 10-20 years.

RCWD Rules
Due to the fully developed nature of this watershed, improvements will be typically made during redevelopment projects. The existing RCWD Rules, adopted on February 13, 2008, include a stormwater management Rule (Rule C) that requires volume control to achieve District water quality goals. The RCWD will continue to permit new development and redevelopments into the foreseeable future and should result in no new phosphorus loadings to the lake

Rule C requires, among other things:

- Use of Better Site Design techniques from the MN Stormwater Manual
- Best management practices sized to infiltrate and/or retain the runoff volume generated within the contributing area by a two-year (2.8-inch) storm under the developed condition, or 0.8-inch for any undisturbed contributing impervious areas on the site (special provisions are made for roadways)

The complete watershed rules can be found on the Rice Creek Watershed District Website (http://www.ricecreek.org).

Cost: Variable, dependent on future development type, scale, and location

9C. INTERNAL LOAD

The internal load to Silver Lake was estimated at 65 pounds per year, or 20% of the total annual load. Although this percentage is relatively low, utilizing in-lake treatment strategies will help to meet the water quality goals for the lake.

Fisheries Management

Due to the abundance of benthic fish, specifically carp, within Silver Lake, a fisheries management plan should be developed and implemented to consider carp removal from the lake. Carp are benthic feeders that forage in the lake bottom sediments, thus releasing phosphorus into the water column. Carp removal practices in Silver Lake could be a reasonable management strategy as the lake is not connected upstream or downstream through natural waterways, creating an impediment to migration of carp from other sources.

Cost: $50,000

Aquatic Macrophyte Management

Almost no aquatic macrophtyes were found within the lake during the summer of 2008. In addition, lakeshore owners noted a significant change in the macrophyte community within the past 5 years. Previously, macrophytes were present within the littoral zone, but more recently all of the macrophytes appeared to die off. Shallow lakes depend on the aquatic macrophyte community to provide refuge for zooplankton and fish. A study of the recent shifts within the macrohphyte community should be undertaken and macrophyte management should be conducted to aid in the establishment of a healthy macrophyte community.

Cost: $100,000

Chemical Treatment

Aluminum sulfate (alum) is a chemical addition that binds with phosphorus to form a non-toxic precipitate (floc). Alum removes phosphorus from the lake system so that is not available for algal growth by forming a barrier between lake sediments and the water to restrict phosphorus release from the sediments. An in-lake alum treatment is proposed to treat the 47 feet deep area of the lake within the northwest portion of the lake. The hypolimnion in this area remains anoxic during the growing season and has measured concentrations of TP that are significantly higher than surface TP concentrations. The proposed alum treatment is not intended as a management step to reduce annual loading, but rather as a one time addition to get immediate in-lake results for a moderate cost if a funding entity is identified. Increased short-term water clarity can help long-term restoration efforts through increasing the light available to aquatic macrophytes.

Cost: $9,000 (one time treatment of 7 acres)

10. Reasonable Assurances

As part of an implementation strategy, reasonable assurances provide a level of confidence that the TMDL allocations will be implemented by federal, state, or local authorities. Implementation of the Silver Creek TMDL will be accomplished by both state and local action on many fronts. State implementation of the TMDL will be through action on NPDES permits for both point sources and stormwater. In addition, potential state funding of TMDL implementation projects includes Clean Water Legacy Act grants and the Clean Water Partnership program. At the federal level, funding can be provided through Section 319 grants that provide cost share dollars to implement voluntary activities in the watershed.

The RCWD is currently updating its overall watershed management plan. This plan will be well poised to evaluate and implement TMDL recommendations through a locally driven process. In addition, the RCWD also has cost-share and grant programs to assist with funding water quality improvement projects within the overall watershed. The RCWD is currently funding a portion of the Columbia Heights Beach improvement project. The RCWD Rules are also in place and watershed permitting is expected to continue into the future. The RCWD also reviews and provides comments, when appropriate, on municipal Storm Water Pollution Prevention Programs (SWPPPs) and will continue to review and comment as relates to applicable TMDL studies within the watershed.

The Three Rivers Park District is also funding the improvements to Silverwood Park, as described in the Implementation Strategy section. The Park District also reviews and comments, as appropriate, on municipal SWPPPs.

The regulated MS4s within the watershed must review the adequacy of their SWPPP to ensure that it meets the TMDL’s WLA set for stormwater sources. If the SWPPP from any regulated MS4 does not meet the applicable requirements, schedules, and objectives of the TMDL, the MS4 will be required to modify their SWPPP, as appropriate, within 18 months after the TMDL is approved by the US EPA.

Local water plans for each of the cities within the Silver Lake subwatershed can also be used to identify implementation actions specific to their City with associated costs and schedule. This will allow the cities to implement measures to protect the lake.

11. Public Participation

Public participation for the Silver Lake TMDL began in 2007 with the development of a local advisory group consisting of watershed, municipal, county, and Three Rivers Park District representatives. This group met twice, August 8, 2007 and April 9, 2008. The purpose of the meetings was to gather available data, provide background on the TMDL process and obtain input in the early stages of TMDL development, specifically on the watershed modeling results and potential implementation strategies. Local advisory group representatives are identified in Table 24.

Table 24. Local Advisory Group Members

Matt Kocian	RCWD Lake and Stream Specialist
Doug Fischer	Anoka County
Kathy Young	Columbia Heights
Kevin Hansen	Columbia Heights
Carolyn Fackler	Hennepin County
Lois Eberhart	Minneapolis
Beth Neuendorf	MN Department of Transportation
Kerry Thorne	New Brighton
Grant Wyffels	New Brighton
Jay Hartman	St. Anthony Village
Todd Hubmer	St. Anthony Village and WSB
Terry Noonan	Ramsey County
Brian Grundtner	Ramsey County
Molly Churchich	Ramsey County
John Barten	Three Rivers Park District
Michael Horn	Three Rivers Park District
Randy Lehr	Three Rivers Park District
Jennifer Olson	EOR
Marcey Westrick	EOR and BWSR
Gary Oberts	EOR
Tom Miller	EOR
Brooke Asleson	MN Pollution Control Agency

A stakeholder meeting was held on June 27, 2008. Meeting attendees included staff from various agencies, city and county staff, lakeshore residents part of the Silver Lake Homeowners Association, RCWD, Three Rivers Park District, and the project technical team.

At a minimum, one public meeting will be held after release of the draft TMDL report, anticipated in 2010.

References

Minnesota Pollution Control Agency (MPCA). 2007. Guidance Manual for Assessing the Quality of Minnesota Surface Waters for the Determination of Impairment. MPCA Environmental Outcomes Division, St. Paul, MN. 116 p.

Nürnberg, G.K. 1988. Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. *Can. J. Fish. Aquat. Sci*. 45:453-462.

Nürnberg, G.K. 1995. Quantifying anoxia in lakes. *Limnol. Oceanogr*. 40(6):1100-1111.

US EPA, 2006. BMP Modeling Concepts and Simulation. Office of Research and Development, Washington DC. EPA/600/R-06/033.

Walker, W. W., Jr. 2003. Consideration of variability and uncertainty in phosphorus total maximum daily loads for lakes. *Journal of Water Resources Planning and Management* 129(4):337-344.

Walker, W. W., 1999. Simplified Procedures for Eutrophication Assessment and Prediction: User Manual. Prepared for Headquarters, U.S. Army Corps of Engineers, Waterways Experiment Station Report W-96-2. http://wwwalker.net/bathtub/, Walker 1999 (October 30, 2002).

Appendix A
StormNET Model Summary

A hydrologic and hydraulic model was generated for the Silver Lake subwatershed to assist in development of the overall TMDL. Due to the urban nature of the watershed and lack of available flow data within the subwatershed, the model was used to assist with construction and calibration of watershed loading models. The model was also constructed to complement work by the RCWD to develop a watershed-wide hydrologic and hydraulic model.

The hydrologic and hydraulic modeling was assembled and run using StormNET, a front-end software product using the EPA-SWMM 5.0 engine. StormNET is a FEMA-approved modeling software that uses the hydrodynamic wave routing methodology to accurately approximate complex drainage networks. Dynamic wave routing solves the complete St. Venant equations throughout the drainage network and includes modeling of backwater effects, flow reversal, surcharging, looped connections, pressure flow, and interconnected ponds.

There are two primary analysis blocks in the model that influence the accuracy of the model results. The hydrologic, or runoff, portion of the model approximates the volume of runoff that occurs for the selected precipitation event. The hydraulic portion of the model conveys the stormwater generated in the hydrologic block through the Silver Lake conveyance system consisting of primarily pipes and ponds.

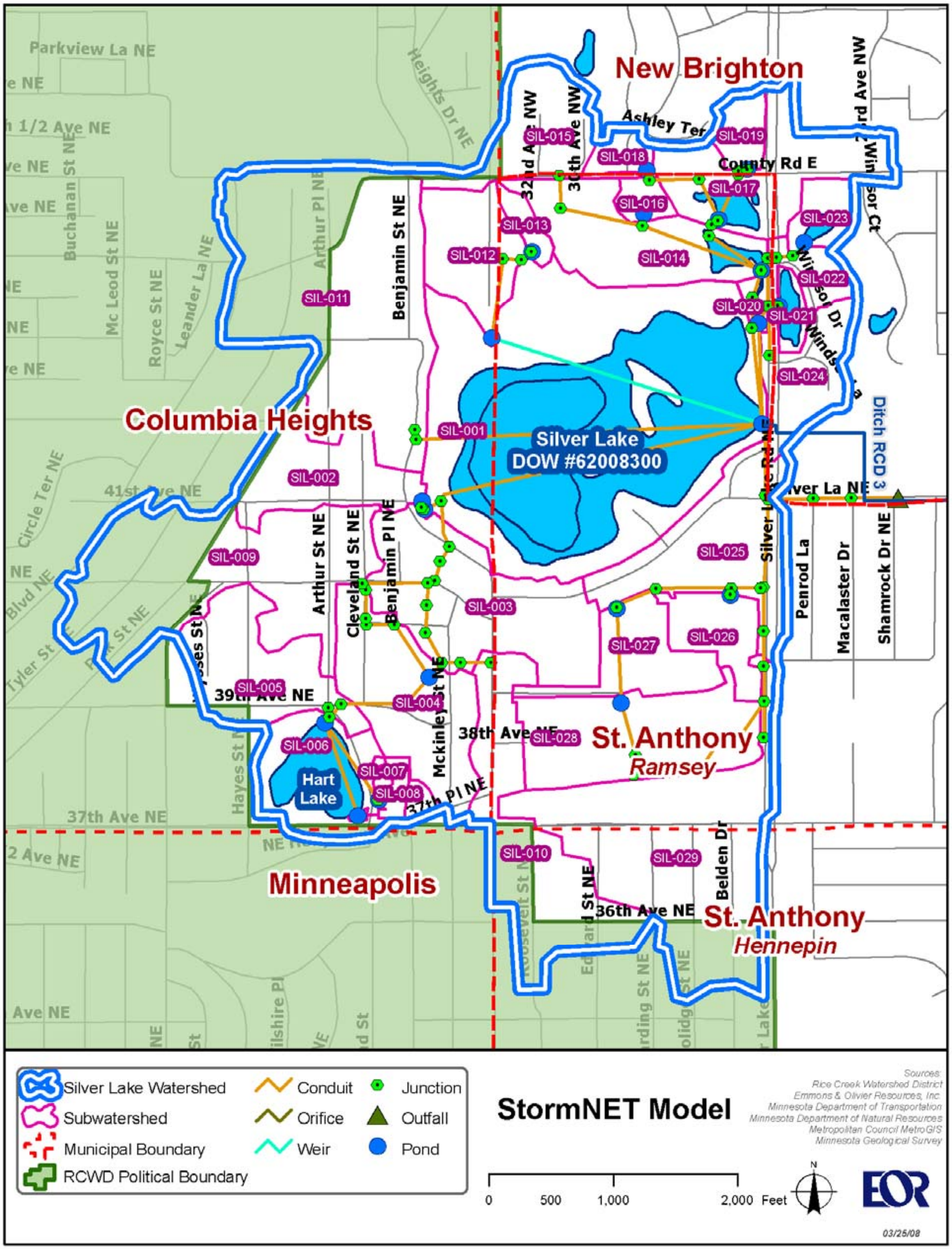
HYDROLOGY

Catchment Boundaries

Delineation of catchment boundaries for the Silver Lake TMDL relied upon previously defined boundaries as delineated by adjacent municipalities and RCWD permit applicants. However, each boundary was subsequently reviewed and split, combined with other boundaries, or modified where necessary. The majority of the subwatershed is fully developed and relies on storm sewer to convey storm drainage to and from Silver Lake.

The final subwatershed boundaries are the result of review of all available data, assessment of quality and usefulness, determination of appropriate locations for boundary breaks and new delineations based on the approved RCWD permit files through 2007 in conjunction with the highest resolution contours available. Two-foot topography was available for the majority of the Silver Lake subwatershed in either electronic format or hard-copy maps. The two-foot contours were used to delineate the drainage to storm sewer infrastructure. The pertinent storm sewer infrastructure was surveyed as part of the data collection for hydraulic modeling and used to verify catchment boundaries.

Figure A-1: Silver Lake Catchment Boundaries



Sources:
Rice Creek Watershed District
Emmons & Olivier Resources, Inc.
Minnesota Department of Transportation
Minnesota Department of Natural Resources
Metropolitan Council MetroGIS
Minnesota Geological Survey

03/25/08

Rainfall

The primary single event simulation analyzed for the TMDL purposes was the 1-inch, 24-hour rainfall. The rainfall distribution is defined by the SCS Type II synthetic distribution, typical for this region of Minnesota.

Continuous simulation performed for model calibration used historic local rainfall data available from the Climatology Working Group (www.climate.umn.edu). Historic daily rainfall recordings from Soil and Water Conservation District monitoring gauges located within two miles of Silver Lake provided data for 2006 and 2007. The closest gauge readings were used and converted into a SCS Type II rainfall distribution.

Infiltration

The Green-Ampt continuous soil infiltration methodology was used. Application of the Green-Ampt equation within StormNET required definition of three parameters:

- Initial soil moisture deficit;
- Soil capillary suction; and
- Saturated hydraulic conductivity.

The three infiltration parameter values were calculated as a weighted average unique to each subwatershed through GIS spatial analysis. Due to the importance of using accurate infiltration values, an extensive effort was made to refine the assignment of these parameters. The values used for the Silver Lake TMDL model have been through a rigorous review process as part of the modeling process for the Minnehaha Creek Watershed District. This methodology underwent extensive review and received approval from the Technical Advisory Council members (including United States Army Corps of Engineers (USACE); Federal Emergency Management Agency (FEMA); Metropolitan Council; Minnesota Department of Natural Resources (MDNR); Minnesota Department of Transportation (Mn/DOT); Minnesota Pollution Control Agency (MPCA); local city, county and watershed staff and representatives; and other water resource engineer consultants).

Percent Impervious

The percent impervious surface area (%ISA) is the key hydrologic parameter that affects the accuracy of the volume of stormwater that drains off of the ground surface for small storm events. For this reason, an extremely precise method was used to calculate the percentage of each catchment comprised of impervious surface.

The steps for estimating %ISA based on remotely sensed imagery are described in the following list and graphically in Figure A-2:

1. Evaluate study area and acquire appropriate imagery (may require multiple images).
2. Rectify and geo-reference the imagery (if necessary).
3. Classify imagery into four-high level classes of urban, vegetation, water, shadow.
4. Generate an appropriate vegetation index for each image.
5. Create a set of ground samples representing degrees of imperviousness.

6. Run regression based on impervious samples and average vegetation index.
7. Apply regression to vegetation index and rescale values to 0-100% impervious.
8. Mask out non-urban areas and merge imagery (if necessary).
9. Manual review/update areas for seasonal or “date-difference” effects.
10. Generate zonal statistics for each subwatershed.

The impervious surface used in StormNET includes both urban (roads, buildings, etc.) impervious surfaces as well as open water surfaces.

Depression Storage

The depression storage is defined for both pervious and impervious areas. Default values for depressional storage were applied as 0.1 inches from the pervious area and 0.02 inches from the impervious area.

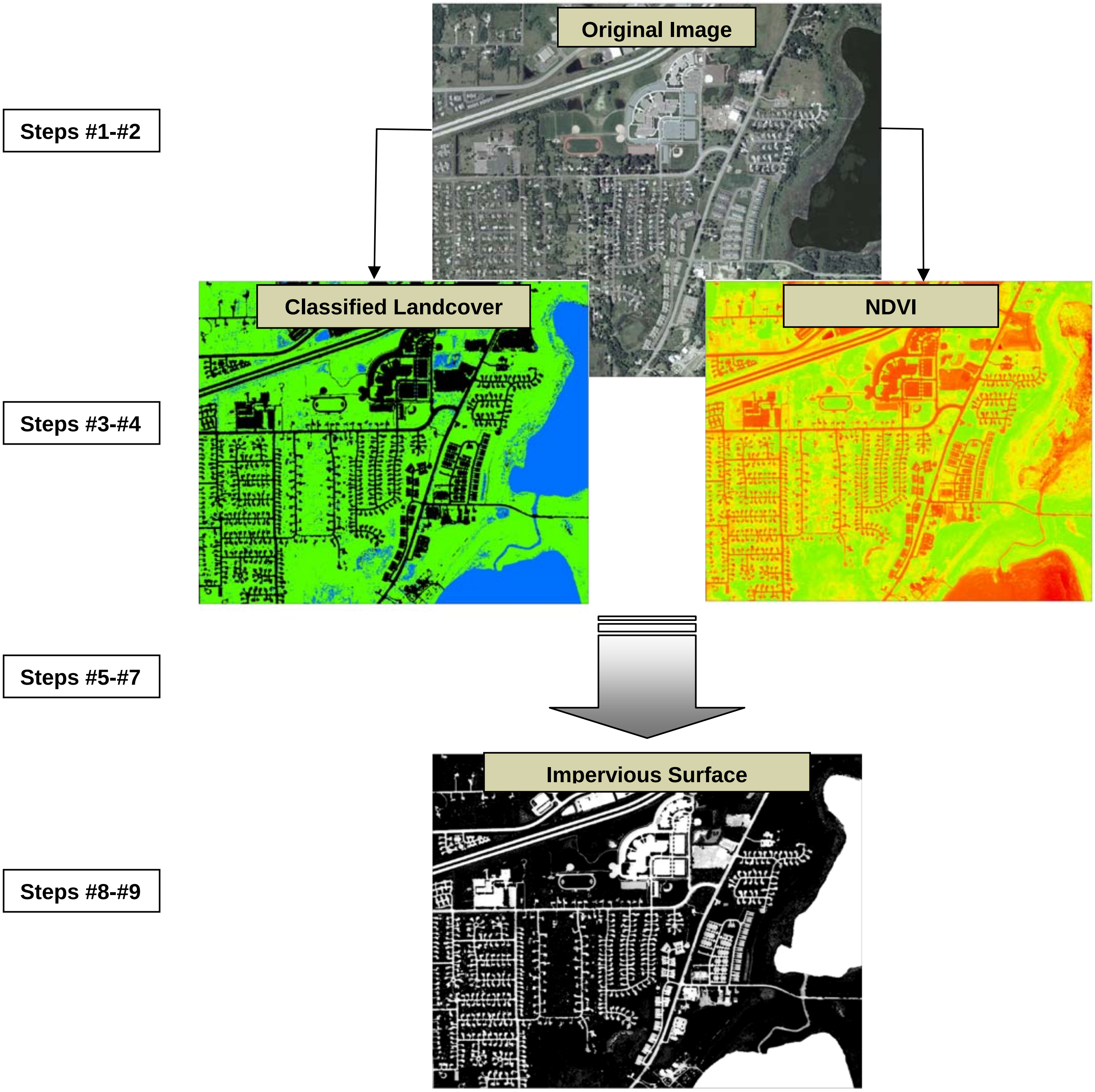
No Depression

The depression storage depths are applied to all impervious surfaces excluding the percentage of impervious surface defined in the “no depression” category. The “no depression” application is appropriate where a portion of the impervious surface consists of the waterbody to which all of the runoff is directed. The area of the waterbody is included in the quantity of the impervious surface, however, because the rain falls directly on the waterbody, it will not have the depressional losses that would occur in the small depressions or voids found in pavement or roofs.

Time of Concentration

The time of concentration is simulated in StormNET (when using infiltration hydrology) by defining a theoretical catchment width and slope from catchment area and flow path properties.

Figure A-2: Deriving Impervious Surface Estimates (see text for definition of steps)



HYDRAULICS

Storage

Lakes, larger ponds, wetlands, and some channel segments are included explicitly in the model as a storage node in which the shape and amount of storage available are defined by a stage/storage rating curve. The stage/storage curves are defined using as-built or design plans from RCWD permit files wherever applicable. When plans were not available, or for Hart and Silver Lakes, two-foot contours were used to generate the stage/storage curves.

All defined storage is also given a defined outlet. The outlets range from sophisticated multi-stage or multi-structure constructed outlets, to a simple culvert outlet.

Structures

A wide range of infrastructure types are located within the relatively small Silver Lake subwatershed. Structures described and modeled explicitly include: culverts, weirs, orifices, swales, drop structures, and storm sewer pipes. Approximately 100 structures were surveyed in 2007 and modeled. All of the listed structures are easily and accurately modeled within StormNET.

Channel Routing

The channels defined in the model are typically a combination of both trapezoidal cross sections and storage nodes. Because the number of open channels is limited, and the flow through these channels is small, the size and shape of the swales was approximated using two-foot contours.

Infiltration

No infiltration is assumed to occur in the ponds or the floodplains associated with the ponds.

Figure A-3: StormNET Model.

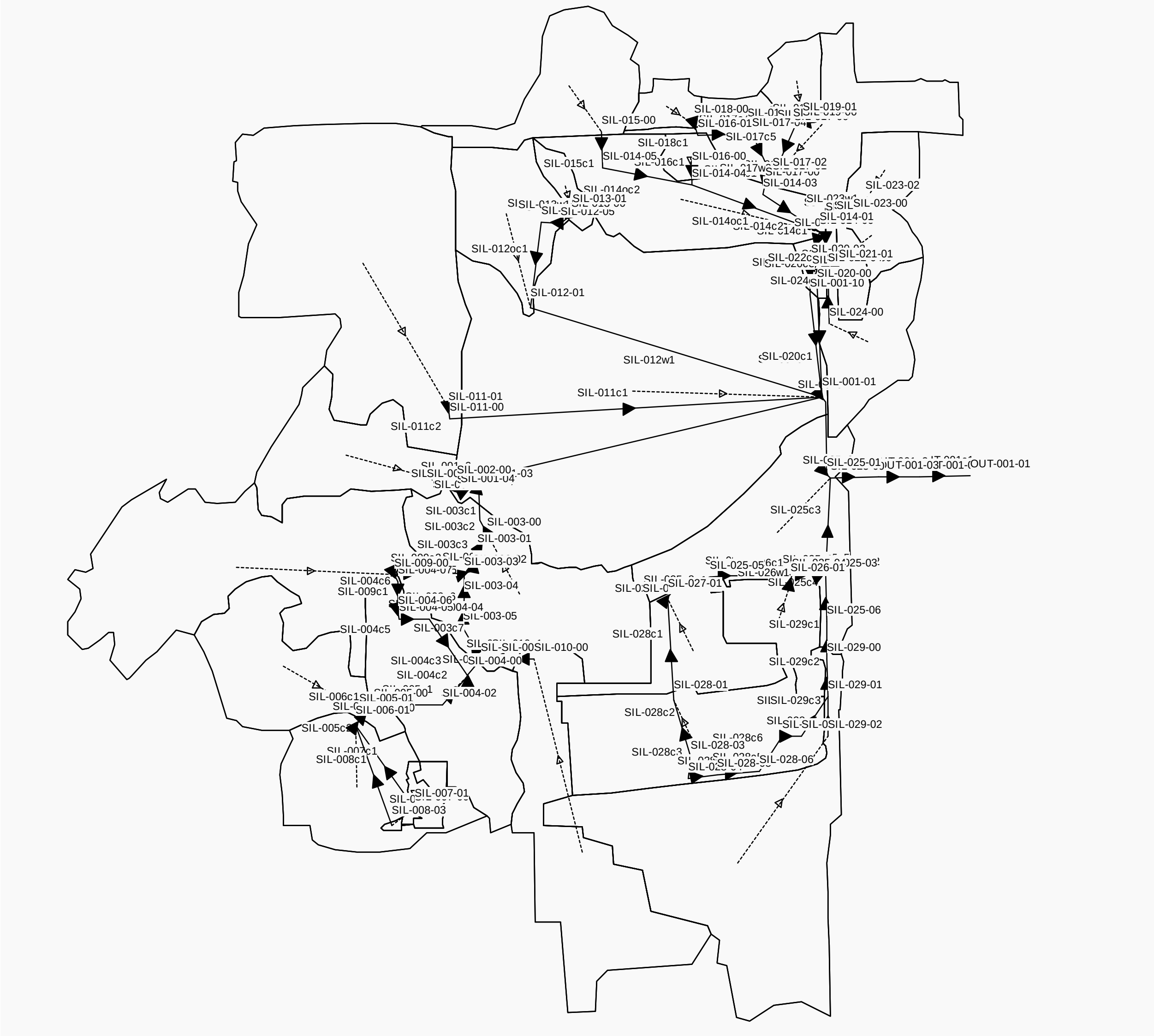


Figure A-3 Legend:
Green nodes control hydrologic functions.
Blue nodes represent lakes or detention ponds with defined stage storage curves.
Red nodes are junctions where manholes exist or pipe sizes change.

USE OF GIS/XP-SWMM INTERFACE

The GIS/StormNET interface was integral to create and simplify the generation of data and the data input process. The interface has expedited the data input of the following variables for existing conditions:

- Storm sewer pipes;
- Outlet structures;
- Pond/lake stage-storage curves;
- Subwatershed area;

- Impervious acreage;
- No depression area;
- Watershed slope;
- Watershed width;
- Weighted average capillary suction;
- Initial soil moisture deficit; and
- Weighted average saturated hydraulic conductivity.

MODEL CALIBRATION

Continuous Simulation Calibration Process

Calibration was performed using lake level data provided by Ramsey County Environmental Services as provided on the DNR Lake Finder website. Lake level data from Silver (West) Lake has been recorded since the 1930s. The data are recorded in an outdated vertical datum that originated in 1912. However, the modeling datum uses survey data taken in 2007 using NGVD 88 datum, the most accurate vertical datum in use. For this reason, the Silver Lake levels recorded in the 1912 datum were shifted to a level where the general lake level patterns matched.

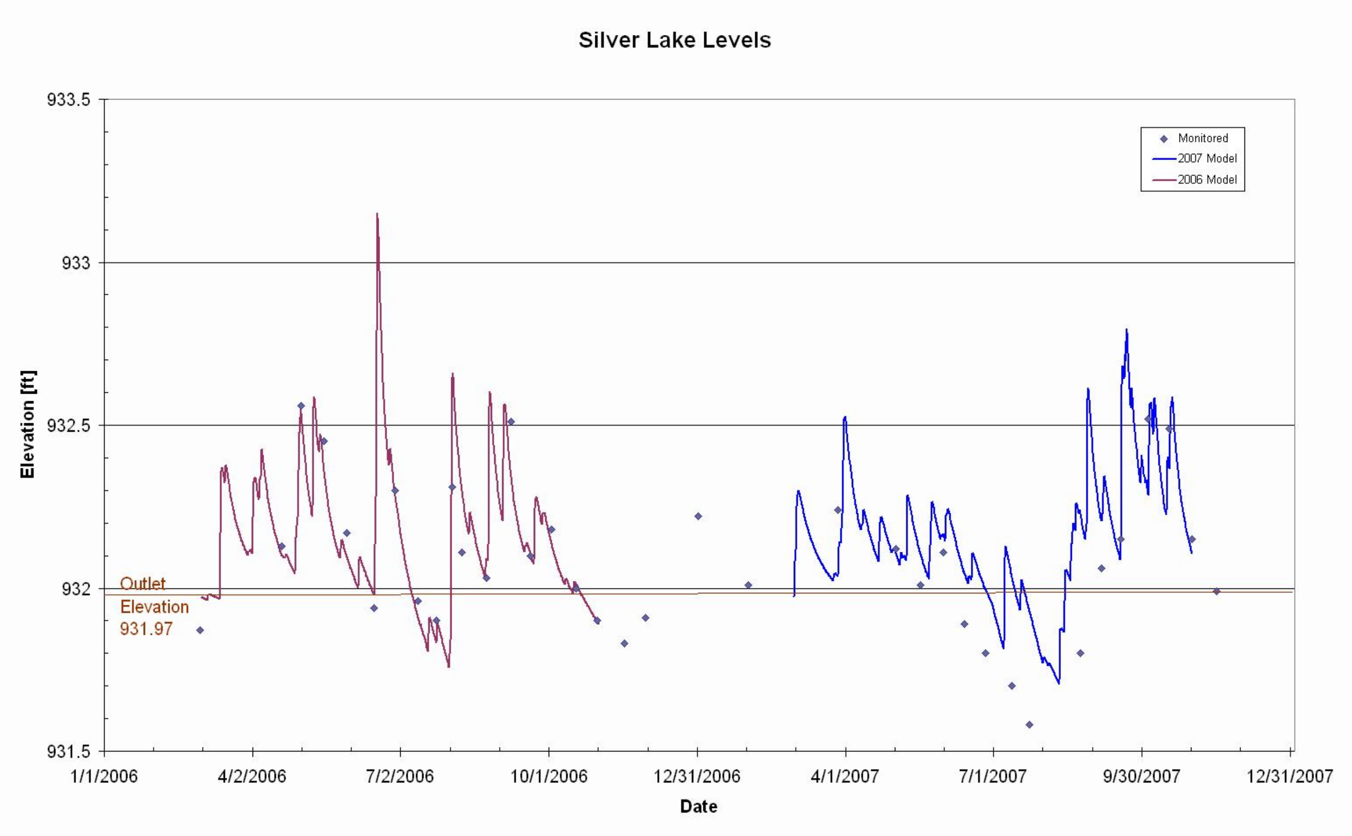
The lake level observations were recorded on a bi-weekly to monthly basis for 2006 and 2007. This data is too coarse to allow for a definitive calibration of a StormNET model. Additionally, the location and distribution of the precipitation data and the SCS Type II distribution previously described make the model calibration less precise.

However, the methodology for generating the parameters used in the model has been refined through previous modeling efforts and extensive calibration processes. For the Silver Lake model, these previous modeling efforts paid off as the initial model run was quite accurate when compared to the recorded Silver Lake level readings. No calibration of the parameters was required. The discrepancies from the Ramsey County data may be related to the average monthly evaporation rates defined in the model. Using a temperature file or other means to approximate the actual evaporation that occurred in 2007 may be a way to obtain an annual simulation that matched the recorded values even better.

Groundwater contribution to Silver Lake was not included as part of the model calibration. A sensitivity analysis was performed and groundwater flow was not found to have a significant impact on event or annual flows into Silver Lake.

Despite these small discrepancies, the results, shown in Figure A-4, indicate with a limited certainty that the model is fairly accurate for the approximation of small to large storm events.

Figure A-4: Silver Lake Levels as Modeled in StormNET.



Appendix B
P8 Data

Table B-1. Subwatershed Input Data

Subwatershed Name	Area	Outflow Device	Impervious Area	Indirectly Connected Area	Directly Connected Area
	[acres]		[%]	[%]	[%]
SIL-001	52.1	Into_Lake	17%	15%	85%
SIL-002	19.06	Sil-002P	36%	15%	85%
SIL-003	30.31	Into_Lake	41%	15%	85%
SIL-004	27.85	Sil-004P	49%	35%	65%
SIL-005	22.01	Sil-004P	31%	15%	85%
SIL-006	12.72	Sil-006GD	47%	15%	85%
SIL-007	0.85	Sil-007P	93%	15%	85%
SIL-008	2.33	Sil-008P	83%	15%	85%
SIL-009	51.64	Sil-004P	39%	15%	85%
SIL-010	29.86	Into_Lake	47%	15%	85%
SIL-011	71.09	Into_Lake	28%	35%	65%
SIL-012	16.09	Sil-012IB	19%	35%	65%
SIL-013	2.83	Sil-013P	4%	15%	85%
SIL-014	24.68	Sil-014P	11%	75%	25%
SIL-015	17.79	Sil-014P	28%	50%	50%
SIL-016	3.11	Sil-016P	9%	15%	85%
SIL-017	25.68	Sil-017P	56%	75%	25%
SIL-018	3.69	Sil-018P	32%	15%	85%
SIL-019	5.19	Sil-019P	65%	15%	85%
SIL-020	1.82	Sil-020P	22%	15%	85%
SIL-021	1.42	Sil-021P	18%	15%	85%
SIL-022	5.85	Sil-020P	52%	15%	85%
SIL-023	5.93	Sil-023P	47%	15%	85%
SIL-024	13.87	Sil-020P	51%	15%	85%
SIL-025	26.93	Into_Lake	60%	15%	85%
SIL-025a	1.35	SIL-025a	97%	0%	100%
SIL-026	10.16	Sil-026P	89%	0%	100%
SIL-027	22.69	Sil-027P	84%	0%	100%
SIL-028	31.37	Sil-028P	92%	0%	100%
SIL-029	53.57	Into_Lake	42%	15%	85%
SIL-029a	1.98	SIL-029aP	76%	0%	100%

Table B-2. Stormwater Pond Input Parameters

	Bottom Elevation	Bottom Area	Permanent Pool			Flood Pool			Outlet	
			Area	Volume	Inf. Rate	Area	Volume	Inf. Rate		
	[Feet]	[acres]	[acres]	[ac-ft]	[in/hr]	[acres]	[ac-ft]	[in/hr]	Type	Size
Sil-002P	951.5	0.023	0.09	0.18	0	0.204	0.179	0.2	Orifice	12”
Sil-004P	942.3	0.082	0.26	0.186	0	1.327	3.774	0.2	Orifice	24”
Sil-007P	948.3	0.001	0.1	0.163	0	0.105	0.02	0.2	Orifice	24”
Sil-008P	944.3	0.031	0.12	0.242	0	0.178	0.24	0.2	Orifice	24”
Sil-012IB	938.8	0.009	0.02	0.006	0	0.026	0.008	0.5	Weir	15’
Sil-013P	967	0.047	0.19	0.166	0	0.25	0.164	0.2	Orifice	24”
Sil-014P	934	0.295	1.18	2.662	0	2.315	2.629	0.2	Weir	6’
Sil-016P	946.7	0.116	0.46	0.5	0	0.751	0.106	0.2	Orifice	12”
Sil-017P	936.5	0.538	2.15	6.3	0	3.189	3.3	0.05	Orifice	4”
Sil-018P	966	0.016	0.06	0.049	0	0.216	0.335	0.2	Weir	9’
Sil-019P	949	0.076	0.3	1.064	0	0.44	1.314	0.2	Orifice	6”
Sil-020P	930	0.156	0.62	2.165	0	0.93	1.998	0.2	Weir	8’
Sil-021P	944	0.275	1.1	2.2	0	1.809	1.058	0.2	Orifice	24”
SIL-023P	931	0.399	1.6	2.946	0	1.683	0.656	0.2	Weir	4’
Sil-025a	A structural stormwater treatment system (V2B1) received 30% TP removal									
Sil-026P	940	0.071	0.28	1.538	0	0.312	0.267	0.2	Orifice	24”
Sil-027P	942	0.304	1.28	5.925	0	1.655	5.923	0.2	Weir	0.5’
Sil-028P	943	0.221	0.89	5.435	0	1.788	7.177	0.2	Orifice	30”
Sil-029aP	956	0.029	0.13	0.225	0	0.183	0.409	0.2	Orifice	15”

Appendix C
Internal Load

The internal load of a lake can be estimated by the following equation:

$$\text{Internal P loading rate} = AF \times RR$$

Where AF = anoxic factor, and RR = release rate (Nürnberg 1987). These two parameters were calculated as follows.

ANOXIC FACTOR

The anoxic factor describes the length of time (in days) that a sediment area equal to the lake's surface area is anoxic (Nürnberg 1995). The correction for lake surface area makes the anoxic factor comparable among lakes of different sizes. The anoxic factor can be calculated by knowing the spatial extent and duration of anoxia. Nürnberg (1996) estimated the anoxic factor with the following equation, developed from a data set of lakes in central Ontario and eastern North America:

$$AF_{summer} = -36.2 + 50.1 \log(TP) + 0.762z / A^{0.5},$$

where Af_{summer} = summer anoxic factor (days/yr), TP = average summer in-lake TP concentration (µg/L), z = lake mean depth (m), and A = lake surface area (km^2).

Applying this equation to Silver Lake:

Total phosphorus, growing season = 63 µg/L
Mean depth, z = 2.3 m
Lake surface area, A = 0.304 km^2
Anoxic factor = 57.1 days/yr

RELEASE RATE

The release rate of phosphorus from lake sediments can be predicted by the phosphorus concentrations within the sediments (Nürnberg 1988) with the following equation:

$$RR = -0.58 + 13.72(BD\text{-}P),$$

where RR = release rate (mg/m^2-day), and BD-P = bicarbonate dithionite extractable phosphorus (mg/g dry weight). BD-P analyzes iron-bound phosphorus, and has a better predictive ability than $TP_{sediment}$.

Lake sediment samples were collected on October 30, 2007 from 3 locations within Silver Lake using a WaterMark Universal Core Head sediment corer. Three samples at each location were taken from the top 5 cm of sediment and were all mixed together for the analysis. The average BD-P was 0.170 mg/g dry weight, resulting in a predicted release rate (RR) of 1.75 mg/m^2-day.

INTERNAL LOAD

Using the equation described above, the internal load in Silver Lake was calculated as follows:

Internal loading rate = AF x RR = 57.1 days/yr x 1.75 mg/m^2-day = 100 mg/m^2-yr

With a surface area of 72.5 ac (293,395 m^2), the internal load is:

RR x area = internal load
100 mg/m^2-yr x 293,395 m^2 = 65 lbs/yr

REFERENCES

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Appendix D
Bathtub Data

Model Input: Existing Conditions

Description:
Existing conditions

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.66	0.2
Evaporation (m)	0.91	0.3
Storage Increase (m)	-0.12	0.0

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	9	CANF& BACH, GENERAL
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	1	NOTEPAD

Segment Morphometry

													Internal Loads (mg/m2-day)					
		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Silver Lake	0	1	0.294	2.3	0.64	2.3	0.12	0	0	0.08	3.74	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	63	0.08	0	0	40	0.23	0.94	0.18	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Watershed	1	1	2.75	0.474	0	0	0	231	0	0	0	0	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Model Input: Goal Scenario

Description:

Existing conditions

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.66	0.2
Evaporation (m)	0.91	0.3
Storage Increase (m)	-0.12	0.0

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	9	CANF& BACH, GENERAL
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	1	NOTEPAD

Segment Morphometry

													Internal Loads (mg/m2-day)					
		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Silver Lake	0	1	0.294	2.3	0.64	2.3	0.12	0	0	0.08	3.74	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	63	0.08	0	0	40	0.23	0.94	0.18	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Watershed	1	1	2.75	0.474	0	0	0	215	0	0	0	0	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Bathtub Output: Model Calibration

T Statistics Compare Observed and Predicted Means Using the Following Error Terms:

1 = Observed Water Quality Error Only
2 = Error Typical of Model Development Dataset
3 = Observed & Predicted Error

Segment:	**1**	**Silver Lake**						
	Observed		**Predicted**		**Obs/Pred**	**T-Statistics ---->**		
Variable	**Mean**	**CV**	**Mean**	**CV**	**Ratio**	**T1**	**T2**	**T3**
TOTAL P MG/M3	63.0	0.08	62.7	0.35	1.00	0.06	0.02	0.01
CHL-A MG/M3	40.0	0.23	34.6	0.41	1.16	0.63	0.42	0.30
SECCHI M	0.94	0.18	1.06	0.42	0.89	-0.66	-0.42	-0.26
ANTILOG PC-1	1045.9	0.27	817.0	0.72	1.28	0.91	0.70	0.32
ANTILOG PC-2	15.5	0.21	15.4	0.25	1.01	0.03	0.02	0.02

Overall Water & Nutrient Balances

Overall Water Balance **Averaging Period = 1.00 years**

				Area	**Flow**	**Variance**	**CV**	**Runoff**
Trb	**Type**	**Seg**	**Name**	**km^2**	**hm^3/yr**	**$(hm3/yr)^2$**	**-**	**m/yr**
1	1	1	Watershed	2.8	0.5	0.00E+00	0.00	0.17
PRECIPITATION				0.3	0.2	1.51E-03	0.20	0.66
TRIBUTARY INFLOW				2.8	0.5	0.00E+00	0.00	0.17
***TOTAL INFLOW				3.0	0.7	1.51E-03	0.06	0.22
ADVECTIVE OUTFLOW				3.0	0.4	7.95E-03	0.20	0.14
***TOTAL OUTFLOW				3.0	0.4	7.95E-03	0.20	0.14
***EVAPORATION					0.3	6.44E-03	0.30	
***STORAGE INCREASE					0.0	0.00E+00	0.00	

Overall Mass Balance Based Upon **Predicted** **Outflow & Reservoir Concentrations**
Component: **TOTAL P**

				Load		**Load Variance**			**Conc**	**Export**
Trb	**Type**	**Seg**	**Name**	**kg/yr**	**%Total**	**$(kg/yr)^2$**	**%Total**	**CV**	**mg/m^3**	**$kg/km^2/yr$**
1	1	1	Watershed	109.5	92.5%	0.00E+00		0.00	231.0	39.8
PRECIPITATION				8.8	7.5%	1.94E+01	100.0%	0.50	45.5	30.0
TRIBUTARY INFLOW				109.5	92.5%	0.00E+00		0.00	231.0	39.8
***TOTAL INFLOW				118.3	100.0%	1.94E+01	100.0%	0.04	177.1	38.9
ADVECTIVE OUTFLOW				27.3	23.1%	1.08E+02		0.38	62.7	9.0
***TOTAL OUTFLOW				27.3	23.1%	1.08E+02		0.38	62.7	9.0
***STORAGE INCREASE				-2.2		3.16E-02		0.08	63.0	
***RETENTION				93.2	78.8%	1.23E+02		0.12		

Overflow Rate (m/yr)	1.4	Nutrient Resid. Time (yrs)	0.3584
Hydraulic Resid. Time (yrs)	1.6884	Turnover Ratio	2.8
Reservoir Conc (mg/m3)	63	Retention Coef.	0.788

Bathtub Output: Goal Scenario

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Silver Lake

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	60.4	0.35	60.2%	63.0	0.08	62.0%
CHL-A MG/M3	33.5	0.42	95.1%	40.0	0.23	97.0%
SECCHI M	1.09	0.43	50.4%	0.9	0.18	42.8%
ORGANIC N MG/M3	927.9	0.36	90.6%			
TP-ORTHO-P MG/M3	57.5	0.44	75.3%			
ANTILOG PC-1	772.0	0.72	81.0%	1045.9	0.27	86.6%
ANTILOG PC-2	15.5	0.26	95.2%	15.5	0.21	95.3%
TURBIDITY 1/M	0.1	3.74	1.1%	0.1	3.74	1.1%
ZMIX * TURBIDITY	0.2	3.74	0.0%	0.2	3.74	0.0%
ZMIX / SECCHI	2.1	0.43	8.1%	2.4	0.21	12.6%
CHL-A * SECCHI	36.5	0.35	96.4%	37.6	0.29	96.7%
CHL-A / TOTAL P	0.6	0.30	94.9%	0.6	0.24	96.8%
FREQ(CHL-a>10) %	95.0	0.07	95.1%	97.3	0.02	97.0%
FREQ(CHL-a>20) %	70.0	0.33	95.1%	79.0	0.13	97.0%
FREQ(CHL-a>30) %	44.8	0.59	95.1%	56.1	0.26	97.0%
FREQ(CHL-a>40) %	27.6	0.81	95.1%	37.8	0.37	97.0%
FREQ(CHL-a>50) %	17.0	1.00	95.1%	25.1	0.47	97.0%
FREQ(CHL-a>60) %	10.6	1.16	95.1%	16.7	0.56	97.0%
CARLSON TSI-P	63.3	0.08	60.2%	63.9	0.02	62.0%
CARLSON TSI-CHLA	65.1	0.06	95.1%	66.8	0.03	97.0%
CARLSON TSI-SEC	58.8	0.11	49.6%	60.9	0.04	57.2%

Overall Water & Nutrient Balances

Overall Water Balance **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Watershed	2.8	0.5	0.00E+00	0.00	0.17
PRECIPITATION				0.3	0.2	1.51E-03	0.20	0.66
TRIBUTARY INFLOW				2.8	0.5	0.00E+00	0.00	0.17
***TOTAL INFLOW				3.0	0.7	1.51E-03	0.06	0.22
ADVECTIVE OUTFLOW				3.0	0.4	7.95E-03	0.20	0.14
***TOTAL OUTFLOW				3.0	0.4	7.95E-03	0.20	0.14
***EVAPORATION					0.3	6.44E-03	0.30	
***STORAGE INCREASE					0.0	0.00E+00	0.00	

Overall Mass Balance Based Upon **Predicted** **Outflow & Reservoir Concentrations**
Component: **TOTAL P**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Watershed	101.9	92.0%	0.00E+00		0.00	215.0	37.1
PRECIPITATION				8.8	8.0%	1.94E+01	100.0%	0.50	45.5	30.0
TRIBUTARY INFLOW				101.9	92.0%	0.00E+00		0.00	215.0	37.1
***TOTAL INFLOW				110.7	100.0%	1.94E+01	100.0%	0.04	165.8	36.4
ADVECTIVE OUTFLOW				26.3	23.8%	9.91E+01		0.38	60.4	8.6
***TOTAL OUTFLOW				26.3	23.8%	9.91E+01		0.38	60.4	8.6
***STORAGE INCREASE				-2.2		3.16E-02		0.08	63.0	
***RETENTION				86.6	78.2%	1.13E+02		0.12		

Overflow Rate (m/yr)	1.4	Nutrient Resid. Time (yrs)	0.3688
Hydraulic Resid. Time (yrs)	1.6884	Turnover Ratio	2.7
Reservoir Conc (mg/m3)	60	Retention Coef.	0.782