Prepared by:
Capitol Region Watershed District
and Emmons & Olivier Resources, Inc.

Como Lake TMDL

October 2010

water | ecology | community

wq-iw11-05e

Cover Image
Como Lake

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TMDL SUMMARY TABLE

<table>
<tr><th>EPA/MPCA Required Elements</th><th colspan="3">Summary</th><th>TMDL Page #</th></tr>
<tr><td>Location</td><td colspan="3">Capitol Region Watershed District (CRWD) in the Upper Mississippi Basin, Ramsey County, MN (HUC 7010206).</td><td>2</td></tr>
<tr><td>303(d) Listing Information</td><td colspan="3">Describe the water body as it is identified on the State/Tribe’s 303(d) list:
• Como Lake (62-0055-00)
• Impaired Beneficial Use(s) - Aquatic recreation
• Indicator: Nutrient/Eutrophication Biological Indicators
• Target start/completion date: 2010/2014
• Original listing year: 2002</td><td>2</td></tr>
<tr><td>Applicable Water Quality Standards/ Numeric Targets</td><td colspan="3">Class 2B waters, MN Eutrophication Standards for shallow lakes, MN Rule 7050.0222 Subp. 4
• TP < 60µg/L
• Chlorophyll-a < 20 µg/L
• Secchi depth > 1.0</td><td>15</td></tr>
<tr><td>Loading Capacity (expressed as daily load)</td><td colspan="3">Loading Capacity: 0.83 lbs TP/day
Critical condition: in summer when TP concentrations peak and clarity is typically at its worst</td><td>31</td></tr>
<tr><td rowspan="11">Wasteload Allocation</td><td colspan="3"></td><td></td></tr>
<tr><td>Source</td><td>Permit #</td><td>WLA</td><td rowspan="10">33</td></tr>
<tr><td>Permitted Stormwater (St. Paul MS4)</td><td>MS400054</td><td rowspan="7">0.68 lbs/day
(categorical)</td></tr>
<tr><td>Permitted Stormwater (Falcon Heights MS4)</td><td>MS400018</td></tr>
<tr><td>Permitted Stormwater (Roseville MS4)</td><td>MS400047</td></tr>
<tr><td>Permitted Stormwater (CRWD MS4)</td><td>MS400206</td></tr>
<tr><td>Permitted Stormwater (Ramsey County MS4)</td><td>MS400191</td></tr>
<tr><td>Permitted Stormwater (construction)</td><td>Various</td></tr>
<tr><td>Permitted Stormwater (industrial)</td><td>No current sources</td></tr>
<tr><td>Permitted Stormwater (Mn/DOT MS4)</td><td>MS400170</td><td>0.00022 lbs/day</td></tr>
<tr><td>Reserve Capacity (and related discussion in report)</td><td>NA</td><td></td></tr>
<tr><td rowspan="5">Load Allocation</td><td colspan="3"></td><td rowspan="4">36</td></tr>
<tr><td>Source</td><td colspan="2">LA (lbs/day)</td></tr>
<tr><td>Internal load</td><td colspan="2">0.10</td></tr>
<tr><td>Atmospheric deposition</td><td colspan="2">0.05</td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td>Margin of Safety</td><td colspan="3">Implicit MOS: Conservative modeling assumptions</td><td>32</td></tr>
<tr><td>Seasonal Variation</td><td colspan="3">Seasonal variation: Critical conditions in these lakes occur in the summer, when TP concentrations peak and clarity is</td><td>37</td></tr>
</table>

	at its worst. The water quality standards are based on growing season averages. The load reductions are designed so that the lakes will meet the water quality standards over the course of the growing season (June through September).	
Reasonable Assurance	***Summarize Reasonable Assurance*** CRWD Rules CRWD Watershed Management Plan NPDES MS4 program Como Lake Strategic Management Plan	42
Monitoring	***Monitoring Plan included?*** Yes	38
Implementation	***1. Implementation Strategy included?*** Yes ***2. Cost estimate included?*** Yes	40
Public Participation	• Public Comment period (August 30, 2010 – September 29, 2010) • Comments received? Yes. • Summary of other key elements of public participation process	44

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ABBREVIATIONS

Atm	Atmospheric
BMP	Best management practice
CALM	Consolidation assessment and listing methodology
Chl	Chlorophyll-*a*
CLSMP	Como Lake Strategic Management Plan
CRWD	Capitol Region Watershed District
DNR	Minnesota Department of Natural Resources
EPA	United States Environmental Protection Agency
GSM	Growing season mean
LA	Load allocation
µg/L	Micrograms per liter
Mn/DOT	Minnesota Department of Transportation
MOS	Margin of safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal separate storm sewer system
NCHF	North Central Hardwood Forest
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
SD	Secchi depth
SPRWS	St. Paul Regional Water Services
SWPPP	Stormwater pollution prevention program
TMDL	Total maximum daily load
TP	Total phosphorus
TSI	Trophic state index
WLA	Wasteload allocation

EXECUTIVE SUMMARY

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

In 2002 the Capitol Region Watershed District developed a management plan for Como Lake. The Como Lake Strategic Management Plan (CLSMP) identified important management issues through input from key stakeholder groups, prioritized the issues and associated goals, and identified implementation activities. The CLSMP was used as the basis for this TMDL.

The Como Lake watershed is located in the north-central portion of the Capitol Region Watershed District (CRWD), which lies entirely within the North Central Hardwood Forest Ecoregion. Como Lake is located in the City of Saint Paul and the watershed is located within three municipalities in Ramsey County.

Phosphorus was identified as the main pollutant causing the impairment. The MN state eutrophication standards for shallow lakes were used to calculate the total maximum daily load (TMDL) for Como Lake.

Como Lake is a eutrophic lake, with relatively higher total phosphorus (TP) compared to chlorophyll-*a* concentrations and transparency. TP growing season means ranged from 100 to 400 µg/L. 2001 was the year with the poorest water quality. The same general pattern exists for chlorophyll-*a* and Secchi depth.

The sources of phosphorus loads to Como Lake are watershed runoff, internal loading, and atmospheric deposition. Phosphorus loads from each of these sources were estimated and used as input into the lake response model, which was used to estimate the assimilative capacity of the lake.

The watershed load to Como Lake represents approximately 34% of the total load to the lake, the internal load represents approximately 65% of the load to the lake, and atmospheric deposition represents the remaining 1% of the phosphorus load to the lake. A 60% reduction in watershed load and a 97% reduction in internal load is required in the TMDL. A categorical wasteload allocation is provided for all of the regulated sources, including communities regulated under a municipal separate storm sewer system (MS4) permit, construction stormwater, and industrial stormwater, with the exception of MNDOT, which has an individual allocation. The load reductions identified by the wasteload allocation will need to be met by this group as a whole. The load allocations for Como Lake consist of atmospheric deposition and internal loading.

A monitoring plan was outlined that lays out the different types of monitoring that will need to be completed in order to track the progress of implementation activities associated with Como Lake and of associated changes in water quality due to the management practices.

The implementation strategy lays out a subwatershed-based approach to reduce both the watershed load and the internal load in Como Lake.

1. BACKGROUND AND POLLUTANT SOURCES

1A. 303(d) Listings

Table 1. Impaired Waters Listing

Lake name:	Como Lake
DNR ID#:	62-0055-00
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):	2010/2014
CALM category[1]:	5B: Impaired by multiple pollutants and at least one TMDL study plans are approved by EPA*

*Como Lake has an aquatic consumption impairment due to mercury content in fish tissue. A statewide TMDL and implementation plan have been completed and approved.

1B. Background

Lake Management Plan

In 2002 the Capitol Region Watershed District (CRWD) developed a management plan for Como Lake. The Como Lake Strategic Management Plan (CLSMP) identified important management issues through input from key stakeholder groups, prioritized the issues and associated goals, and identified implementation activities. The CLSMP was used as the basis for this TMDL.

Watershed

The Como Lake watershed is located in the north-central portion of the CRWD and is within the Upper Mississippi Watershed. This area lies entirely within the North Central Hardwood Forest Ecoregion. Como Lake is located in the City of Saint Paul and the watershed is located within three municipalities (Table 2, Figure 1) in Ramsey County.

Como Lake has a 1783-acre watershed (not including the surface area of the lake) and is defined as a shallow lake according to the Minnesota Pollution Control Agency (MPCA). The majority of the watershed's water contribution to Como Lake is delivered through an extensive piped stormwater system consisting of twenty-two stormsewers discharging directly into the lake. A large portion of the northern runoff, including the golf course, runs through a series of two constructed wetland detention ponds. Gottfried's Pit collects the drainage from parts of Roseville, Falcon Heights, Ramsey County right-of-ways, and the City of Saint Paul. Gottfried's

[1] EPA's Consolidation Assessment and Listing Methodology [CALM] integrates the 305(b) Report with the 303(d) TMDL List. The primary purposes of the categorization are to determine the extent that all waters are attaining water quality standards, to identify waters that are impaired and need to be added to the 303(d) list, and to identify waters that can be removed from the list because they are attaining standards.

Pit is pumped to Como Lake. Como Lake discharges into the Trout Brook stormsewer and on to the Mississippi River.

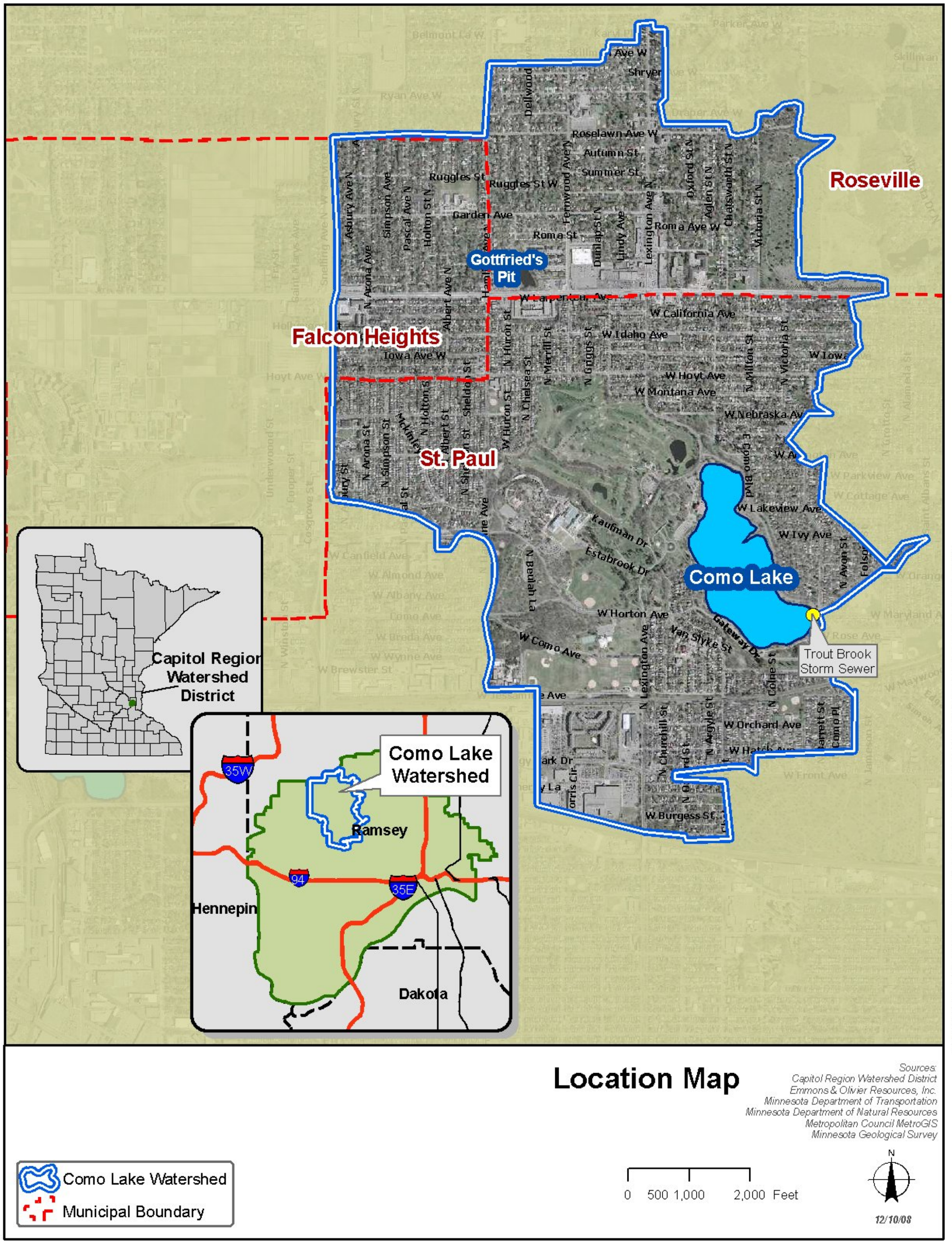

Figure 1. Como Lake Watershed Location

Table 2. Municipalities within Como Lake Watershed.

City	Area [acres]*
Saint Paul	1,205
Falcon Heights	230
Roseville	420
Total	**1,855**

*Areas include the watershed and the lake (72 ac.)

Land Use

The main land uses in the Como Lake watershed (Figure 2) are single family residential (54%), parks, recreation, and preserves (20.4%), institutional (7.5%), and commercial (6.7%). Open water makes up 4.3% of the total watershed.

Planned land use (Figure 3) shows increases in industrial, multi-family residential, and park, recreation, and preserves. Decreases are expected in railway, commercial, institutional, single family residential, and undeveloped lands (Table 3).

Table 3. Como Lake Watershed Land Use Summary.

Land Use Classification	2005 Area[1] [acres]	2020 Area[2] [acres]	% Change 2005-2020
Commercial[3]	112	104	-7%
Industrial	15	23	55%
Institutional	110	103	-7%
Mixed Use	-	6	-
Multi-Family Residential	63	96	53%[4]
Open Water	69	69	0%
Parks, Recreation, & Preserves	384	396	3%
Railway	19	20	4%
Single Family Residential	1070	1038	-3%
Undeveloped	13	-	-
Total	**1855**	**1855**	

[1]Data source: Generalized Land Use 2005 for the Twin Cities Metropolitan Area
[2]Data source: Regional Planned Land Use - Twin Cities Metropolitan Area
[3]Commercial includes 2020 land use classified as Limited Business
[4]The apparent conversion of single family residential to multi-family residential land use is due to a higher degree of resolution in the 2020 land use plans. The actual land use is not expected to change.

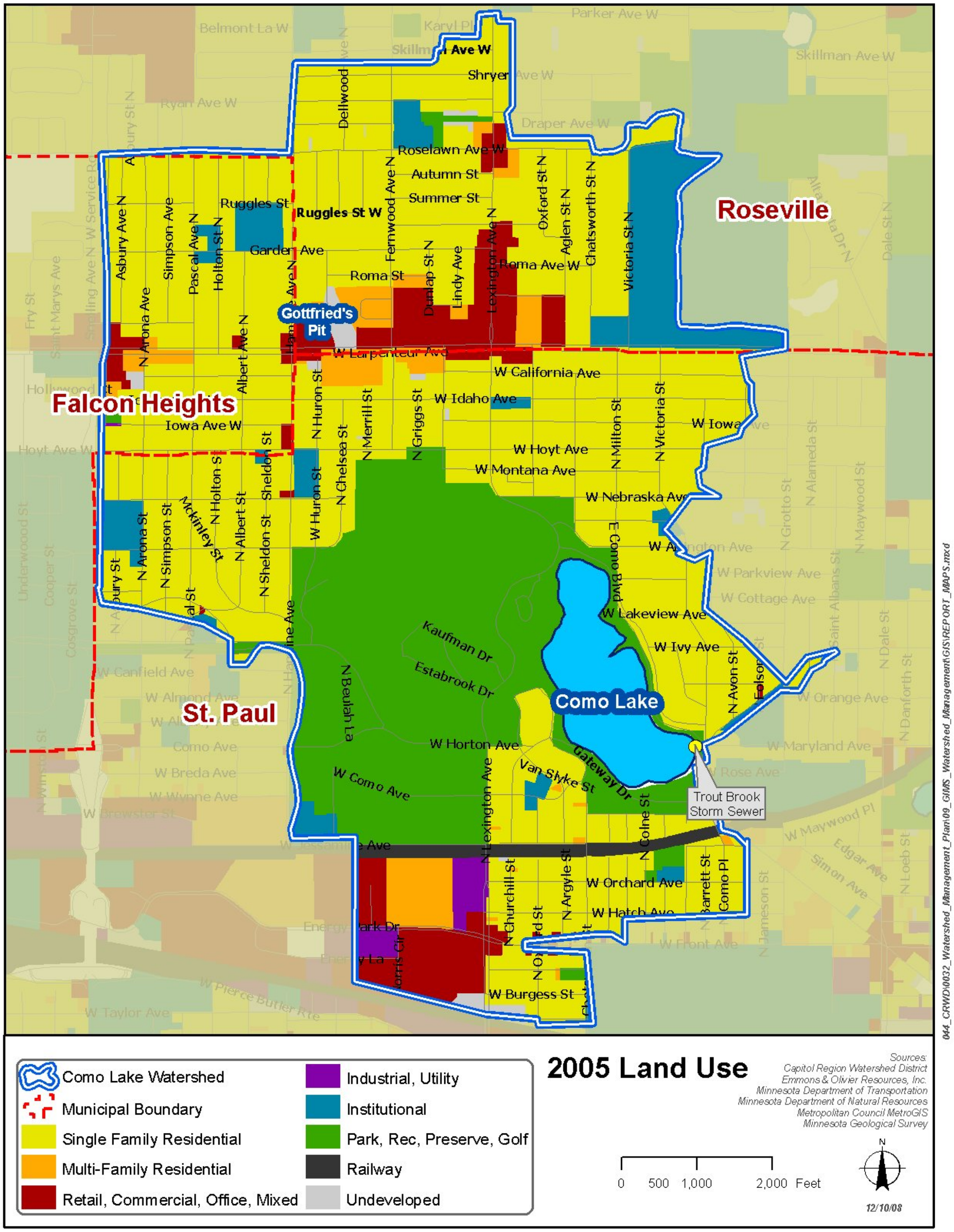

Figure 2. Land Use, 2005

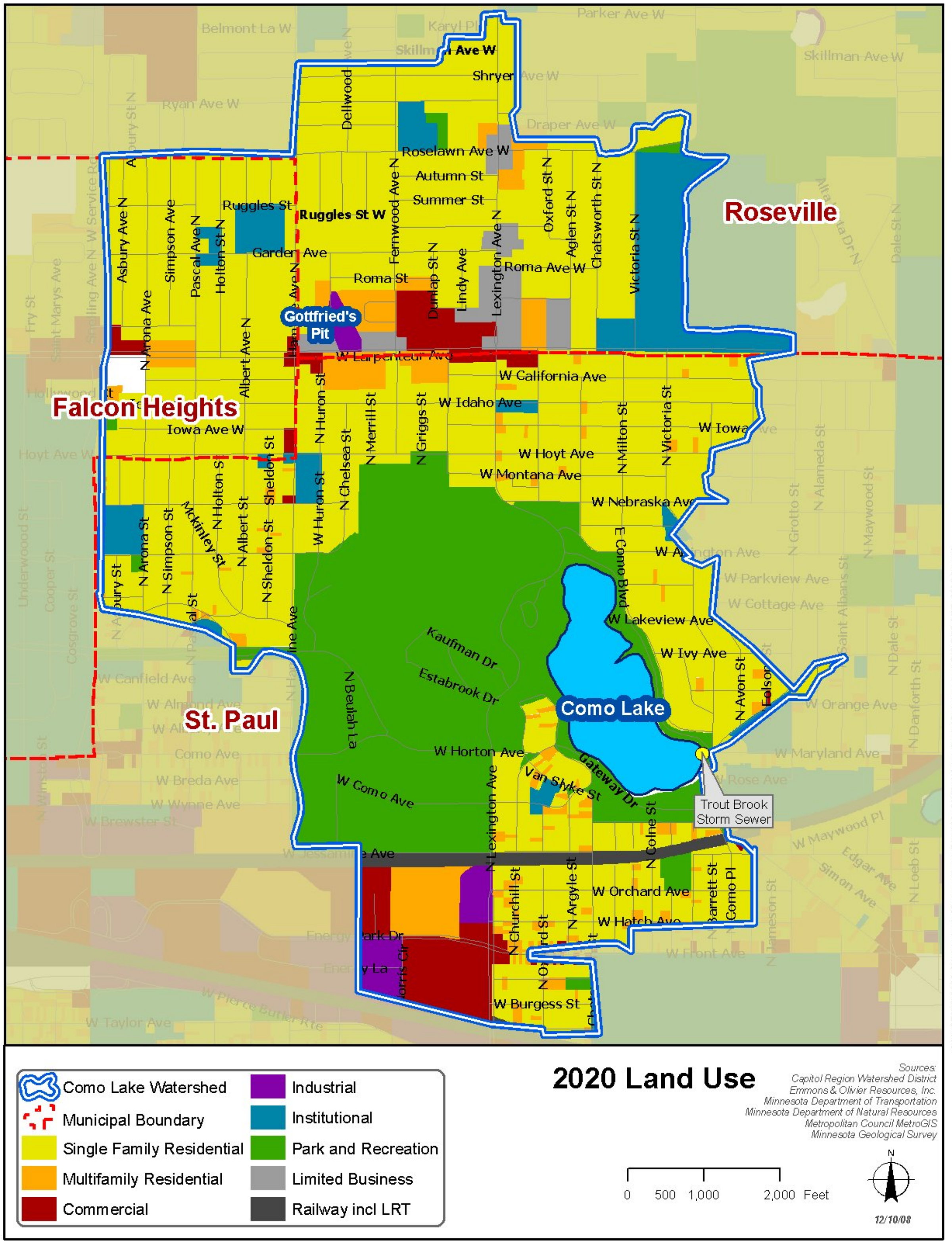

Figure 3. Planned Land Use, 2020

Population

Population is expected to increase in the cities that intersect the Como Lake watershed, with slightly greater percent increases projected to occur in St. Paul and Roseville (Table 4).

Table 4. Current population and population forecasts for cities within the Como Lake Watershed.

City	County	Population				% increase 2000-2030
		2000	2010	2020	2030	
Saint Paul	Ramsey	286,840	305,000	320,000	331,000	15.4 %
Falcon Heights	Ramsey	5,572	6,100	6,100	6,100	9.5 %
Roseville	Ramsey	33,690	36,000	37,000	38,300	13.7 %

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

Wildlife Resources

In 1995 the St. Paul Department of Parks and Recreation performed a Natural Resource Inventory for Como Park. The inventory cataloged the entire park. From the 1995 inventory and testimony from local residents cited in the Como Lake Strategic Management Plan, it is evident that the Como Lake watershed is home to 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. Como Park contains 90 acres of intermediate upland forest that includes various oak species, maple species, black cherry, basswood, elm, and aspen.

Lake Uses

Como Lake is an important recreational resource for the area and the centerpiece for Como Park, which is one of the most visited parks in the metropolitan area. Como Lake’s use for recreation dates back to 1857. The lake is used recreationally for fishing, boating, and aesthetic viewing from the extensive trail surrounding the lake.

Soils

The soils information for the Como Lake watershed was gathered from the 2006 NRCS county soil survey data for Ramsey County. Soils within the Como Lake watershed are mapped as urban/unknown, with some areas of group B hydric soils also present (Figure 4).

Permitted Sources

<u>Municipal Separate Storm Sewer Systems (MS4)</u>

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. Phase I of the NPDES Storm Water Program identified the City of St. Paul as a large MS4, and the city has an individual NPDES permit (on public notice as of June 2010). The MPCA has issued an MS4 general permit that regulates each Phase II MS4 and requires the owner or operator to develop a Stormwater Pollution Prevention Program (SWPPP) that incorporates best management practices applicable to their MS4. Roseville and Falcon Heights are covered under the Phase II MS4 general permit. In addition, Ramsey County and the Minnesota Department of Transportation (Mn/DOT) Metro District are regulated MS4s.

CRWD is also regulated by an MS4 permit, but does not currently have any regulated stormwater conveyances within the Como Lake watershed; it is included in this TMDL to cover the possibility that it could have regulated conveyances in the future. Table 5 includes each regulated MS4 and their NPDES permit number. There are no industrial stormwater permits issued within the Como 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	Area in Como Lake Watershed (ac)	Percent Area in Watershed
Capitol Region WD	MS400206	0	0%
City of Saint Paul	MS400054	1178	64%
City of Falcon Heights	MS400018	226	12%
City of Roseville	MS400047	408	22%
Ramsey County	MS400191	42	2.3%
Mn/DOT Metro District	MS400170	0.6	0.032%

Construction and Industrial Stormwater

Construction sites can contribute substantial amounts of sediment to stormwater runoff. The NPDES Stormwater Program requires that all construction activity disturbing areas equal to or greater than one acre of land must obtain a permit and create a Stormwater Prevention Pollution Plan (SWPPP) that outlines how runoff from the construction site will be minimized during and after construction. Construction stormwater permits cover construction sites throughout the duration of the construction activities, and the level of on-going construction activity varies.

The Industrial Stormwater General Permit applies to facilities with Standard Industrial Classification Codes in ten categories of industrial activity with significant materials and activities exposed to stormwater. Significant materials include any material handled, used, processed, or generated that when exposed to stormwater may leak, leach, or decompose and be carried offsite. The NPDES Stormwater Program requires that the industrial facility obtain a permit and create a Stormwater Prevention Pollution Plan (SWPPP) for the site outlining the structural and/or non-structural best management practices used to manage stormwater and the site's Spill Prevention Control and Countermeasure Plan. An annual report is generated documenting the implementation of the SWPPP.

There are no facilities with industrial stormwater permits within the boundaries of this project.

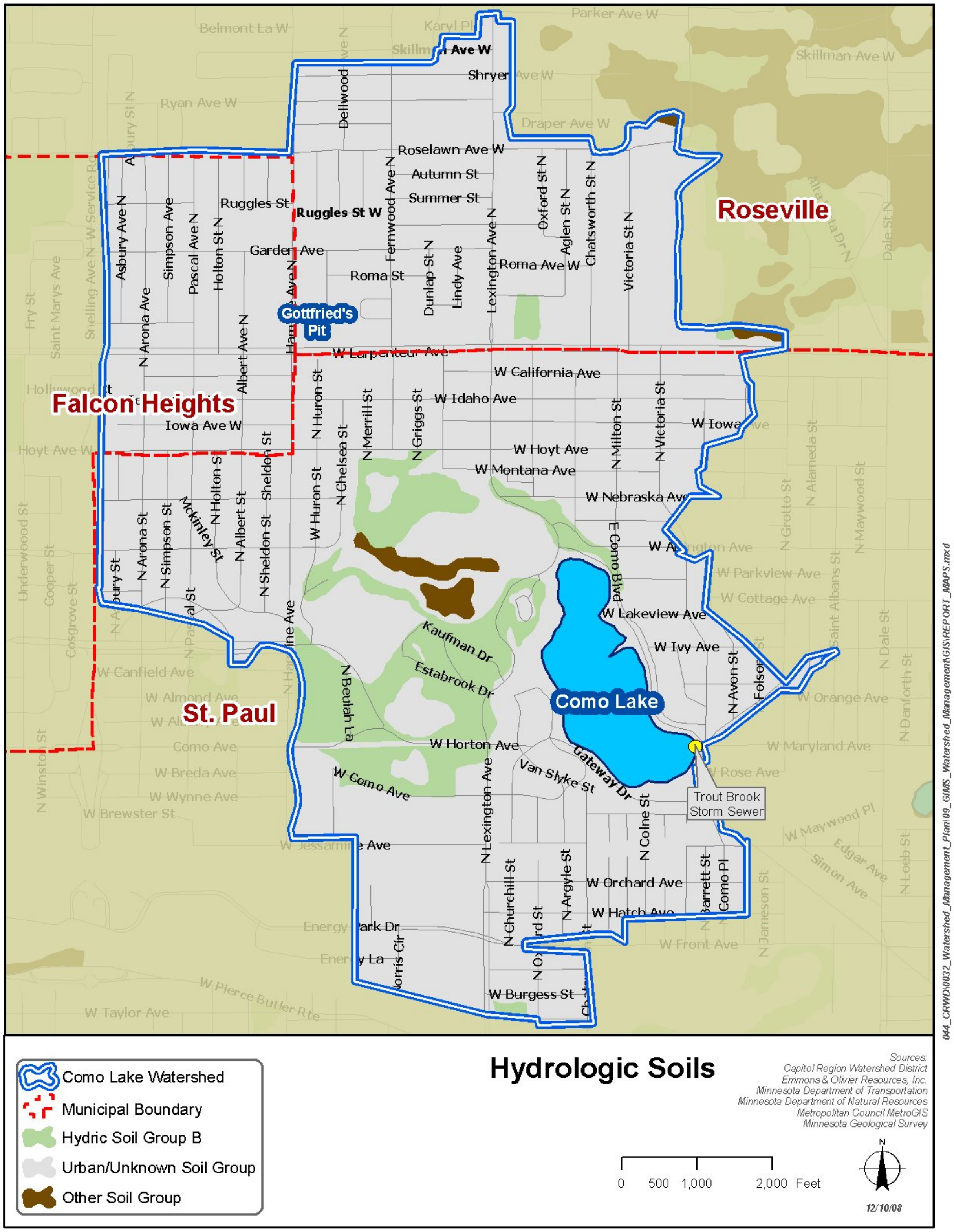

Figure 4. Soils

1C. Pollutant of Concern

Role of Phosphorus in Shallow Lakes

Como 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 Como Lake (Figure 5 and Figure 6). Similarly, a negative relationship is apparent between chlorophyll-*a* and Secchi depth (Figure 7).

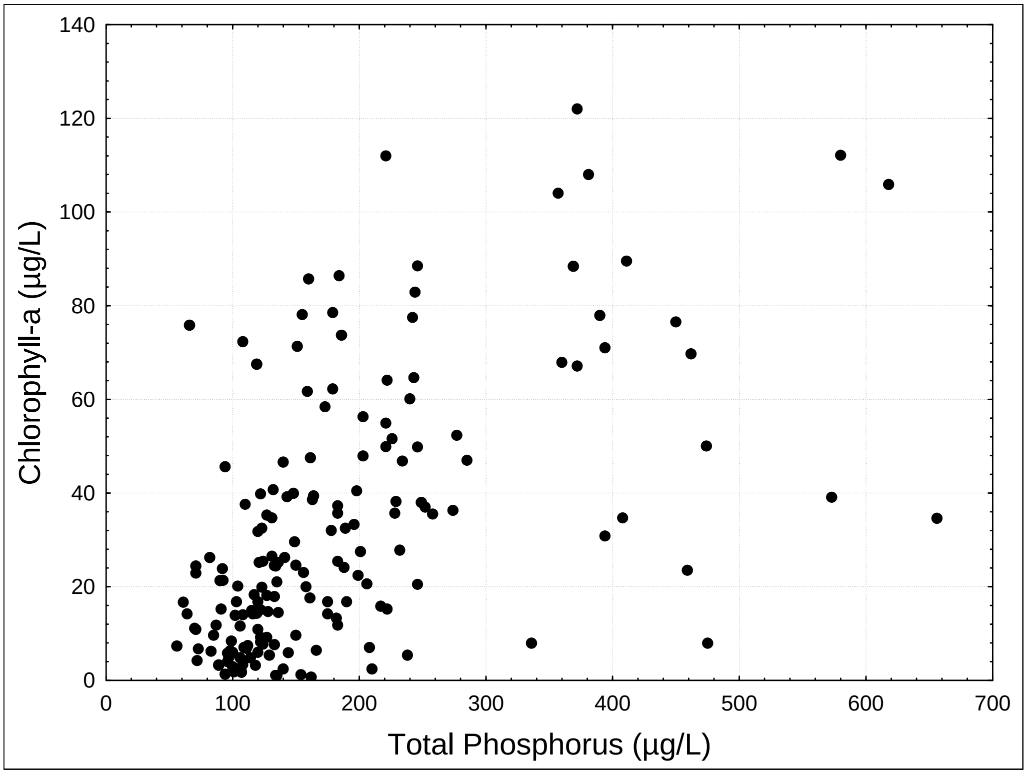

Figure 5. Relationship of Chlorophyll-*a* to TP in Como Lake, 1993-2007.

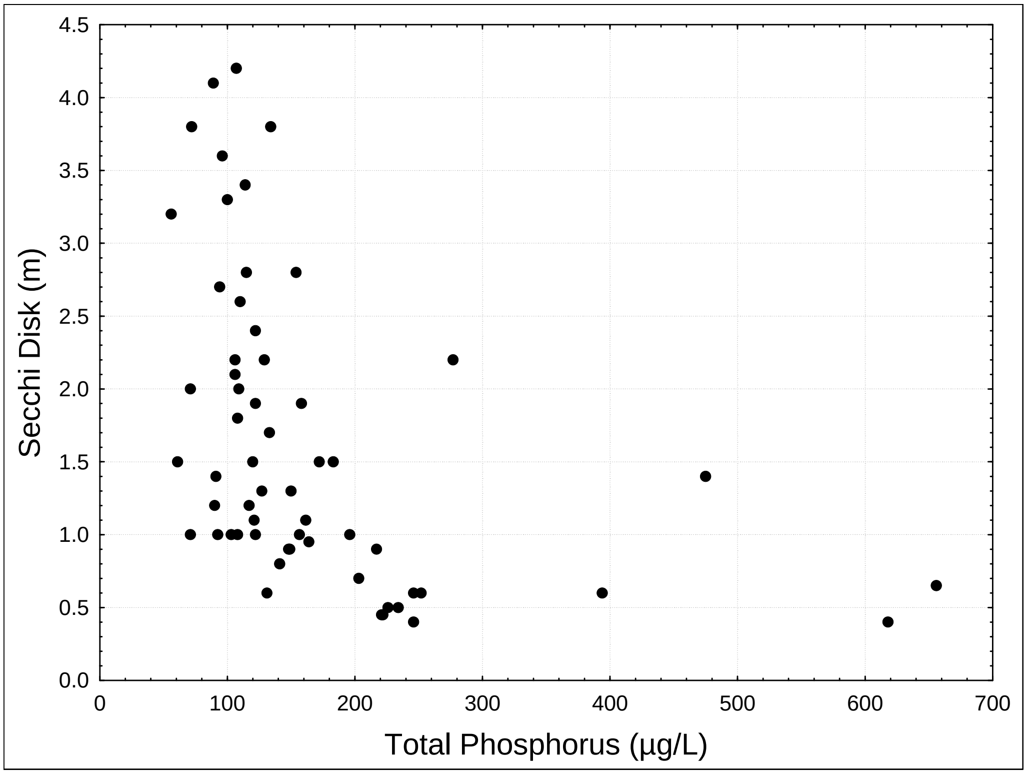

Figure 6. Relationship of Secchi Depth to TP in Como Lake, 1993-2007.

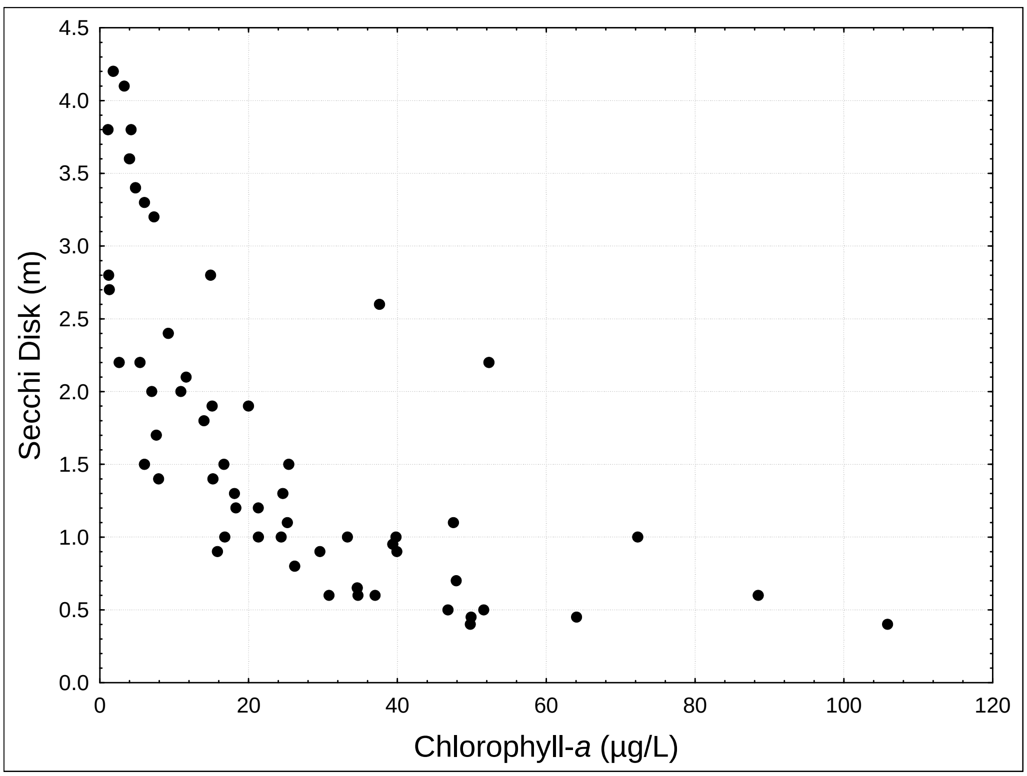

Figure 7. Relationship of Secchi Depth to Chlorophyll-a in Como Lake, 1993-2007.

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.

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.

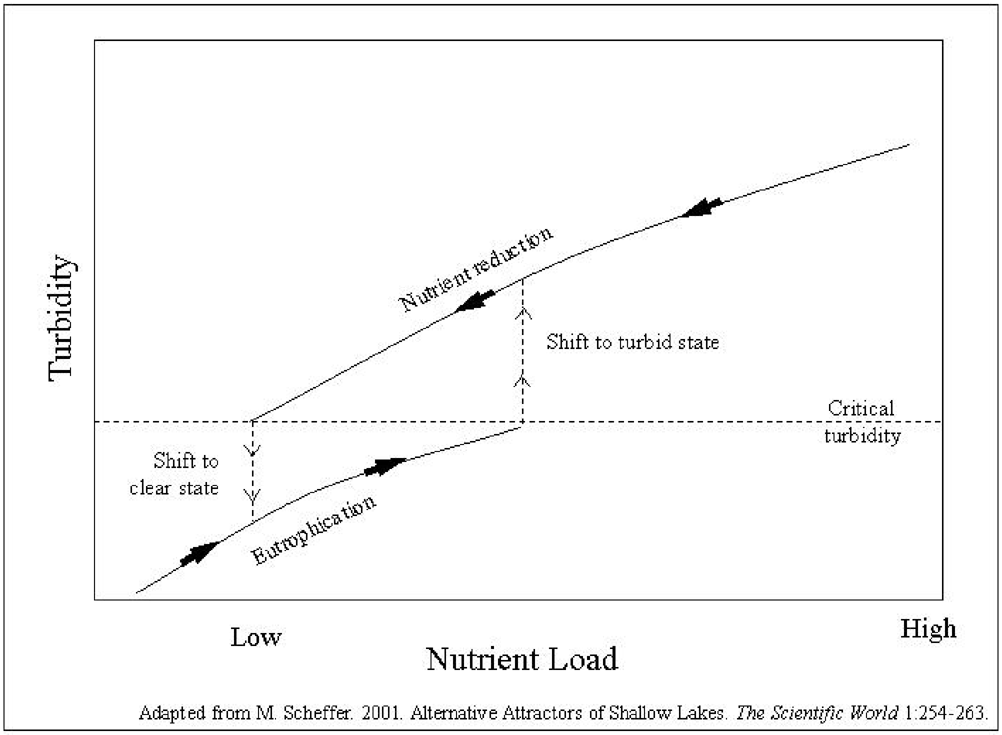

Figure 8. Alternative Stable States in Shallow Lakes.

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, zooplankton, and fish communities to the lake.

2. APPLICABLE WATER QUALITY STANDARDS AND NUMERIC WATER QUALITY TARGETS

2A. Designated Uses

Como 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. If a water body is meeting the applicable standards, then it is assumed that the designated uses of the water body are being attained. Amendments to Minnesota's Rule 7050, approved by the MPCA Board in December 2007 and approved by the EPA in May 2008, includes eutrophication standards for 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. 97% of the surface area of Como Lake is littoral, and the lake is therefore considered shallow.

A lake is considered to be meeting water quality standards when it is meeting the TP standard in addition to either the chlorophyll-*a* or Secchi depth standard. Under the TMDL allocations presented in Section 6, it is expected that the lake will meet at least the TP and the Secchi depth standards.

Como Lake is a shallow lake that is in the turbid, phytoplankton-dominated state commonly seen in impaired shallow lakes. To improve water quality and meet the state eutrophication standards, the goal is to switch the lake to the clear, macrophyte (plant)-dominated state. If this were to occur, chlorophyll concentrations would decrease, water clarity would improve, and rooted macrophyte abundance would increase. While this clearwater phase improves water quality, it has the potential side effect of interfering with certain types of recreation.

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

Como Lake is 72 acres in size, with a watershed area to lake area ratio of 25 (Table 7). It has a maximum depth of 16 feet and a mean depth of 7.3 feet (Figure 9). Approximately 93% of the surface area of the lake is littoral (less than 15 feet depth). The 36-inch submerged outlet flows into a manhole with an eight-foot weir and stoplogs, which control the normal water level. The outlet discharges only periodically, during wet weather flows. Recent peak flows are approximately 6.5 cfs (2007) and 2.2 cfs (2008).

Table 7. Como Lake Characteristics.

Lake total surface area (ac)	72
Total littoral area (ac)	67[1]
Percent lake littoral surface area	92
Lake volume (ac-ft)	526
Mean depth (ft)	7.3[1]
Maximum depth (ft)	16[2]
Drainage area (acres)	1767[3]
Watershed area : lake area	25

[1]2006 DNR Fisheries report
[2]DNR LakeFinder
[3]Drainage area from CRWD P8 model; differs slightly from area calculated from updated watershed boundary file (1783 ac). This area (1767 ac) was used in the TMDL modeling, to be consistent with previous modeling efforts.

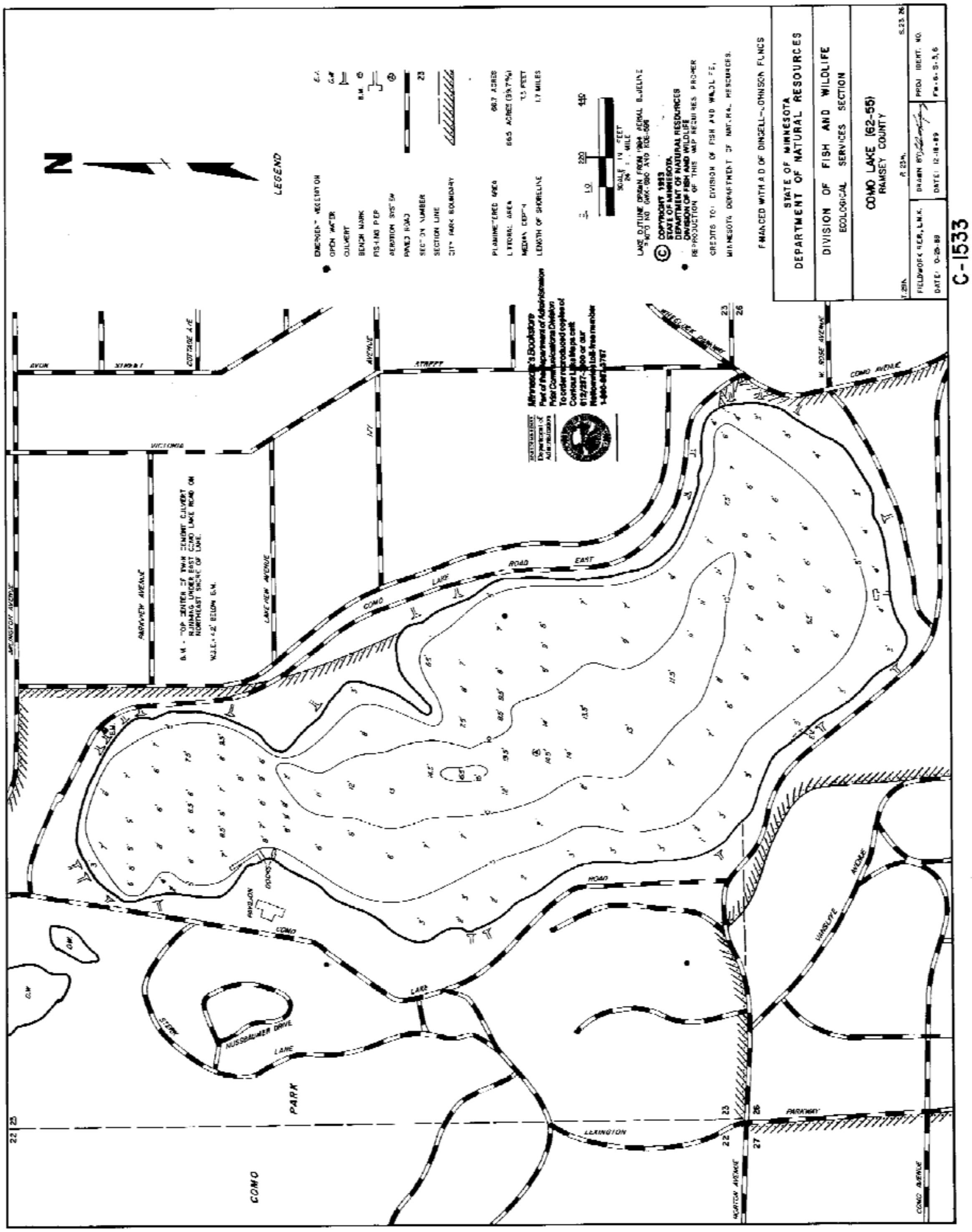

Figure 9. Como Lake Bathymetric Map

Monitoring data are available from as far back as 1946, although there were only one or two samples taken that year and conclusions should not be drawn from sampling at this low frequency. Sampling frequency increased in 1984 and has been conducted annually since then. The last ten years of data were used to calculate the water quality data means (Table 8). All in-lake data were collected by the Ramsey County Public Works Department.

Como Lake is a eutrophic lake, with TSI values for Secchi depths and chlorophyll-*a* in the eutrophic range and TP in the hypereutrophic range (Table 8). The high TP relative to the chlorophyll-*a* and the Secchi depths suggests that the lake has so much phosphorus in it that the algae are not limited by phosphorus, but by some other limiting factor. This does not mean that TP doesn't impact the water quality of the lake, but rather it means that phosphorus will have to be reduced by a substantial amount before improvements in the chlorophyll or Secchi depth are realized. While initial reductions in phosphorus loads to the lake may not translate into immediate improvements to water clarity, without these reductions the lake may never reach the point where algal concentrations will respond and lead to water clarity improvements.

The TP standard for shallow lakes in the North Central Hardwood Forest (NCHF) ecoregion is 60µg/L. TP concentration growing season means ranged from 100 to 400 µg/L in the years 1993 to 2007 (Figure 10), exceeding the ecoregion standard for shallow lakes each year. Chlorophyll-*a* concentration growing season means ranged from to 10 µg/L to 60 µg/L in 1993 to 2007 (Figure 11), only meeting the NCHF ecoregion shallow lakes standard of 20 µg/L in 1998, 1999, and 2004. The Secchi depth growing season means ranged from to 0.65 m to 3.5 m in 1993 to 2007 (Figure 12), meeting the NCHF ecoregion shallow lakes standard of 1.0 m in all years except 2005 and 2006. Water clarity measured by a Secchi disk can be relatively high even when chlorophyll concentrations are high; the relationship depends on the types of algae and their distribution. Without information on the types of algae in the lake, this relationship between chlorophyll concentrations and Secchi transparency can not be determined. One possible explanation is that, when there is a high concentration of blue-green algae, the Secchi disk can temporarily push aside the algae and lead to artificially high clarity measurements.

Water quality in Como Lake is generally poor throughout the growing season (Figure 13 through Figure 15).

Table 8. Surface Water Quality Means, 1998-2007.

	Growing Season Mean (June – September)	Trophic Status Index	Shallow Lakes Standard
TP	173 µg/L	78	< 60 µg/L
Chl-*a*	25 µg/L	62	< 20 µg/L
Secchi depth	1.6 m	53	> 1.0 m

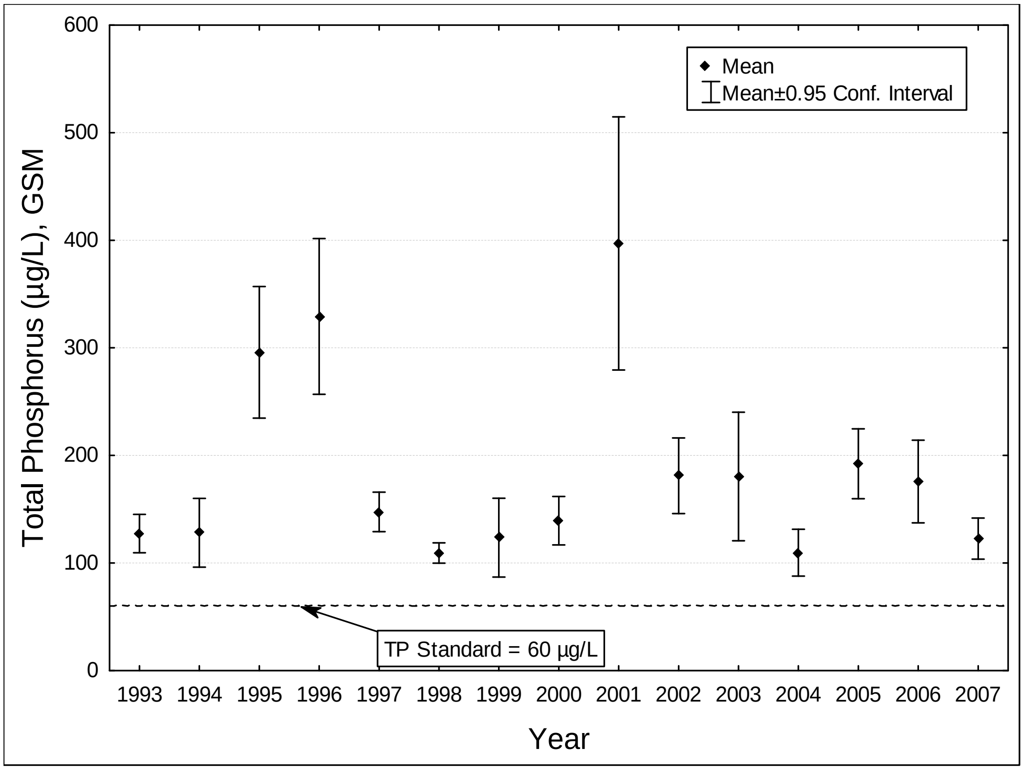

Figure 10. Total Phosphorus Monitoring Data, Como Lake, 1993-2007.

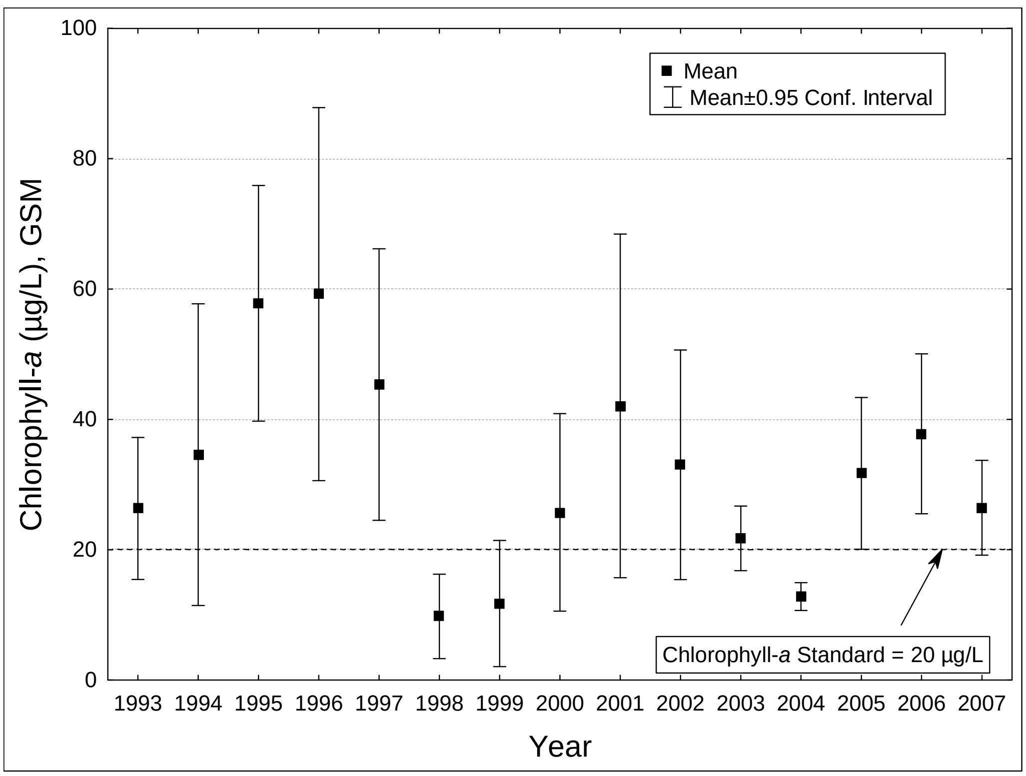

Figure 11. Chlorophyll-a Monitoring Data, Como Lake, 1993-2007.

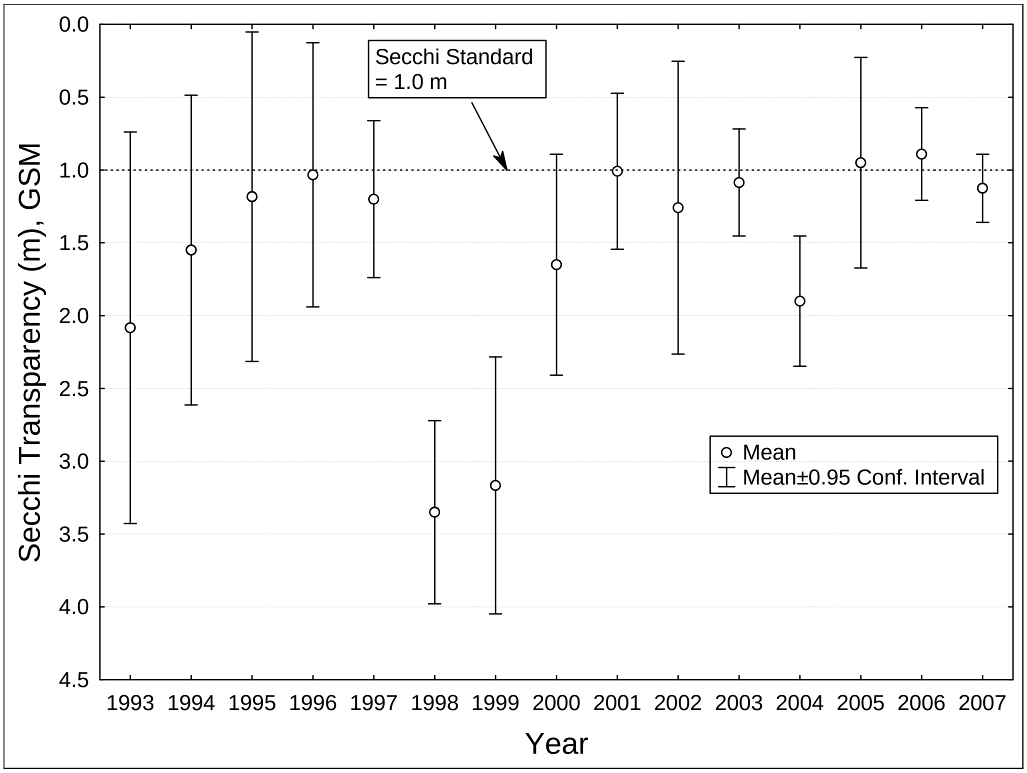

Figure 12. Secchi Depth Monitoring Data, Como Lake.

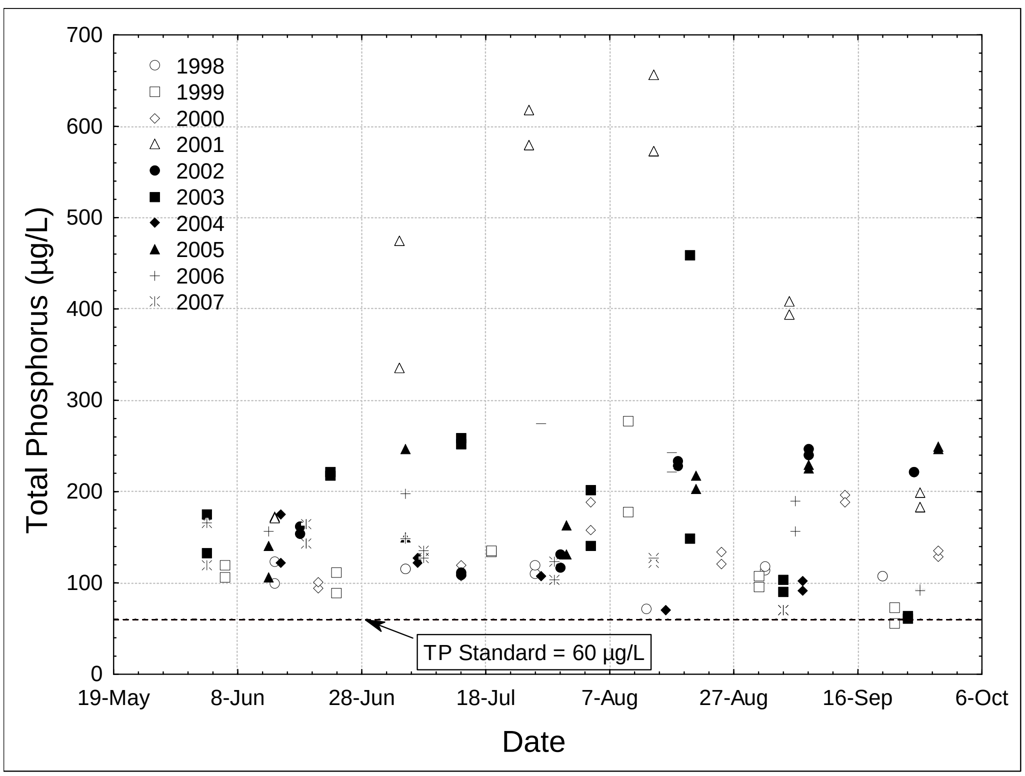

Figure 13. Como Lake Seasonal TP Patterns, 1998-2007.

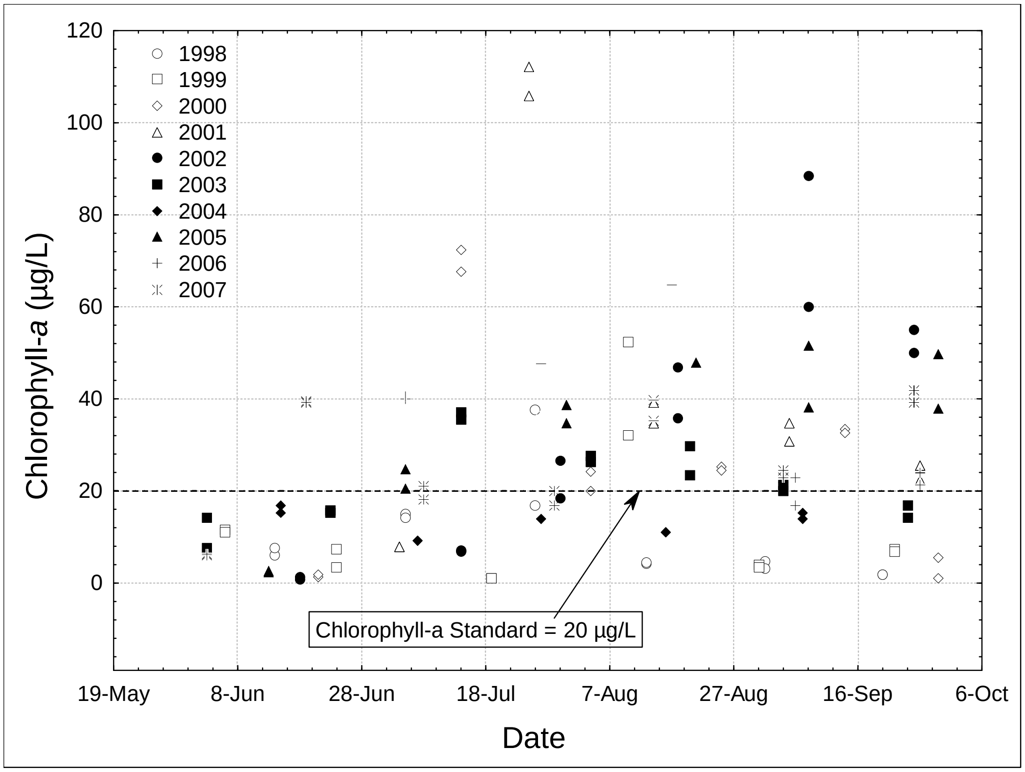

Figure 14. Como Lake Seasonal Chlorophyll-*a* Patterns, 1998-2007.

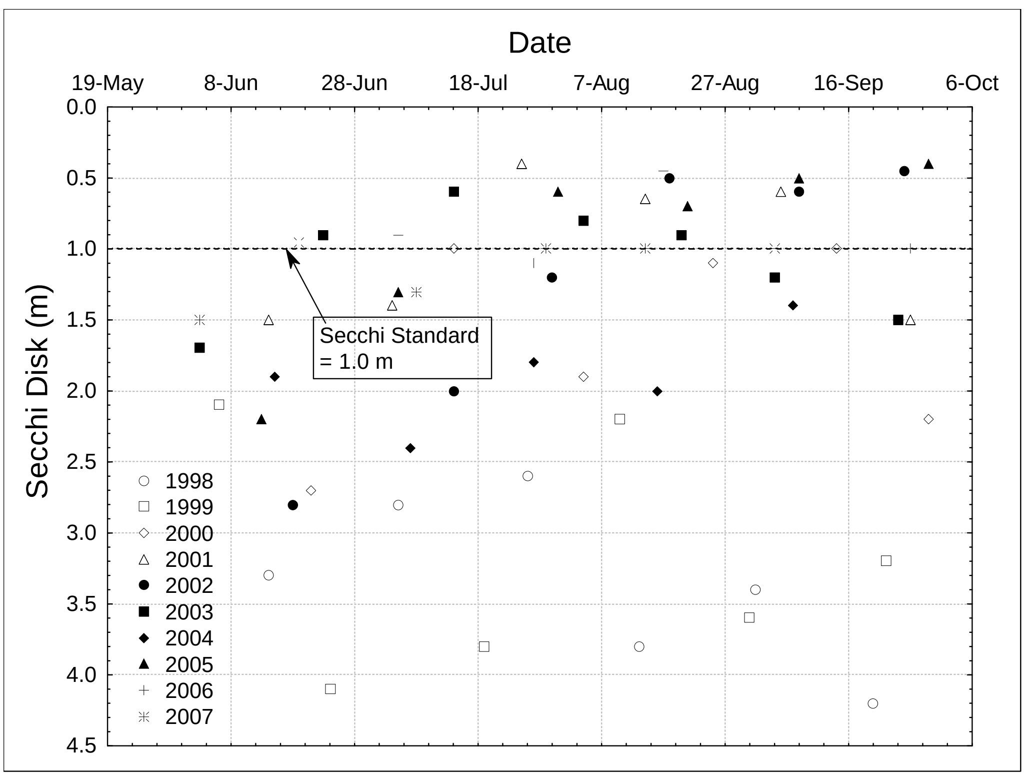

Figure 15. Como Lake Seasonal Transparency Patterns, 1998-2007

Como Lake's fishery is highly managed, and it is classified by the DNR as a bass panfish lake. Stocking took place as early as 1857. Winterkills have been frequent, and an aeration system was installed in 1985 to reduce the frequency of winterkills. The lake was treated in 1986 with rotenone. Following the rotenone treatment, the DNR began restocking fish with walleye, largemouth bass, and bluegill.

Based on a 2006 DNR fish survey, black bullhead, black crappie, bluegill, golden shiner, green sunfish, hybrid sunfish, northern pike, pumpkinseed sunfish, walleye, white sucker, yellow bullhead, and yellow perch were found in Como Lake. Black bullhead, bluegill, and northern pike were the most abundant species sampled within Como Lake. Channel catfish and largemouth bass were stocked in the lake in the 1990s but were not present in the 2006 sampling.

Bullhead abundance seems to be on the rise from low abundance in the 1990s. It is not certain if bullhead are considered a nuisance in Como Lake, but in general bullhead 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. Bluegills are abundant with 20% of the fish sampled over 6 inches. The northern pike population has increased since the 1990s and are considered abundant. The walleye population seems to have increased since the 1996 sampling with moderate numbers present and large, 17 to 22-inch fish sampled in 2006.

The vegetative community in Como Lake lacks diversity (CLSMP, CRWD 2002). It is primarily made up of submergent vegetation, including elodea, coontail, and northern water milfoil. Curly leaf pondweed and elodea have been known to reach nuisance densities during the growing season. The emergent and floating leaf vegetation is diminished to two stands of narrow leaf cattail.

4. POLLUTANT SOURCES

The three categories of phosphorus loads to Como Lake are watershed runoff, internal loading, and atmospheric deposition. These sources of phosphorus loads 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

Methods

The Como Lake Watershed was modeled (Appendix A: CRWD Stormwater Modeling, CRWD 2000), along with the entire Capitol Region Watershed District, in the P8 (Program Predicting Polluting Particle Passage thru Pits, Puddles & Ponds) water quality model developed by William Walker, Jr. P8 is used to predict pollutants (TSS, TP, TKN, copper, lead, zinc, and hydrocarbons) generated from a watershed as well as the removal provided within treatment devices (e.g., ponds, swales, infiltration basins, pipes). The model accounts for routing of water from one watershed to another. The driving input parameters required in P8 are watershed (slope, curve number and percent impervious), devices (e.g. ponds and lakes), climatology (precipitation and temperature) and pollutant characteristics [based on the United States Environmental Protection Agency's Nationwide Urban Runoff Program studies and median sites (USEPA, 1986; Athayede et al., 1983)]. Simulations are driven by continuous hourly rainfall and daily air temperature time series data. The P8 model has implicit limitations. Although it is regularly used for watershed-wide applications and can be validated with monitoring data, the program was designed to simulate runoff from urban catchments into NURP treatment ponds. In addition, the model does not utilize sophisticated routing methods for flow and pollutants. Model strengths include continuous simulation and moderate adaptability to a selection of treatment BMPs. It is also a valuable tool because model set-up (including data input), calibration, and validation requirements are moderate.

This model was chosen for its 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. The results of the P8 modeling work (calibrated to 1994 data) were used as input to the lake response model (WiLMS) described in Section 5.

Stormsewer maps from the cities were used to delineate subwatershed boundaries, which were then used to define inputs to the P8 model. Precipitation data were averaged across five nearby daily precipitation monitoring sites. Volume calibration consisted of computing runoff in the second antecedent moisture condition (AMC II) during the growing season and adjusting the impervious runoff coefficient and depressional storage parameters. The overall predicted volumes were within 10 perent of the observed volumes.

The P8 model was then calibrated to the average event flow-weighted TP concentraion. Calibration steps as described in *P8 Enhancements & Calibration to Wisconsin Sites* (Walker, 1997) were followed, with the following exceptions: 1) Monitored events greater than one inch of precipitation were not eliminated, and 2) Calibration of the dissolved fraction of water quality components differed. The NURP 50% particle file was used. For the median event, the predicted TP concentration was within seven percent of the observed concentration.

Results

The current (as of 1994) watershed phosphorus load to Como Lake is 625 lbs/yr, with an average loading rate of 0.35 lbs/ac-yr (Table 9). The subwatersheds to Como Lake are shown in Figure 16.

Table 9. Watershed Phosphorus Loads
Results from Como Lake P8 model, 2000 (CRWD)

Subwatershed	Area (ac)	TP Load (lbs/yr)	Average Surface Outflow (ac-ft/yr)	Runoff Depth (in/yr)	Areal Loading Rate (lbs/ac-yr)	Runoff TP Concentration (µg/l)
2	74	29	28	4.6	0.39	382
3	517	228	246	5.7	0.44	342
4	199	62	68	4.1	0.31	336
5	97	34	34	4.2	0.35	369
6	88	32	37	5.0	0.36	319
7	298	111	129	5.2	0.37	317
8	495	129	248	6.0	0.26	192
Total	***1767***	***625***	***790***	***5.36***	***0.35***	***292***

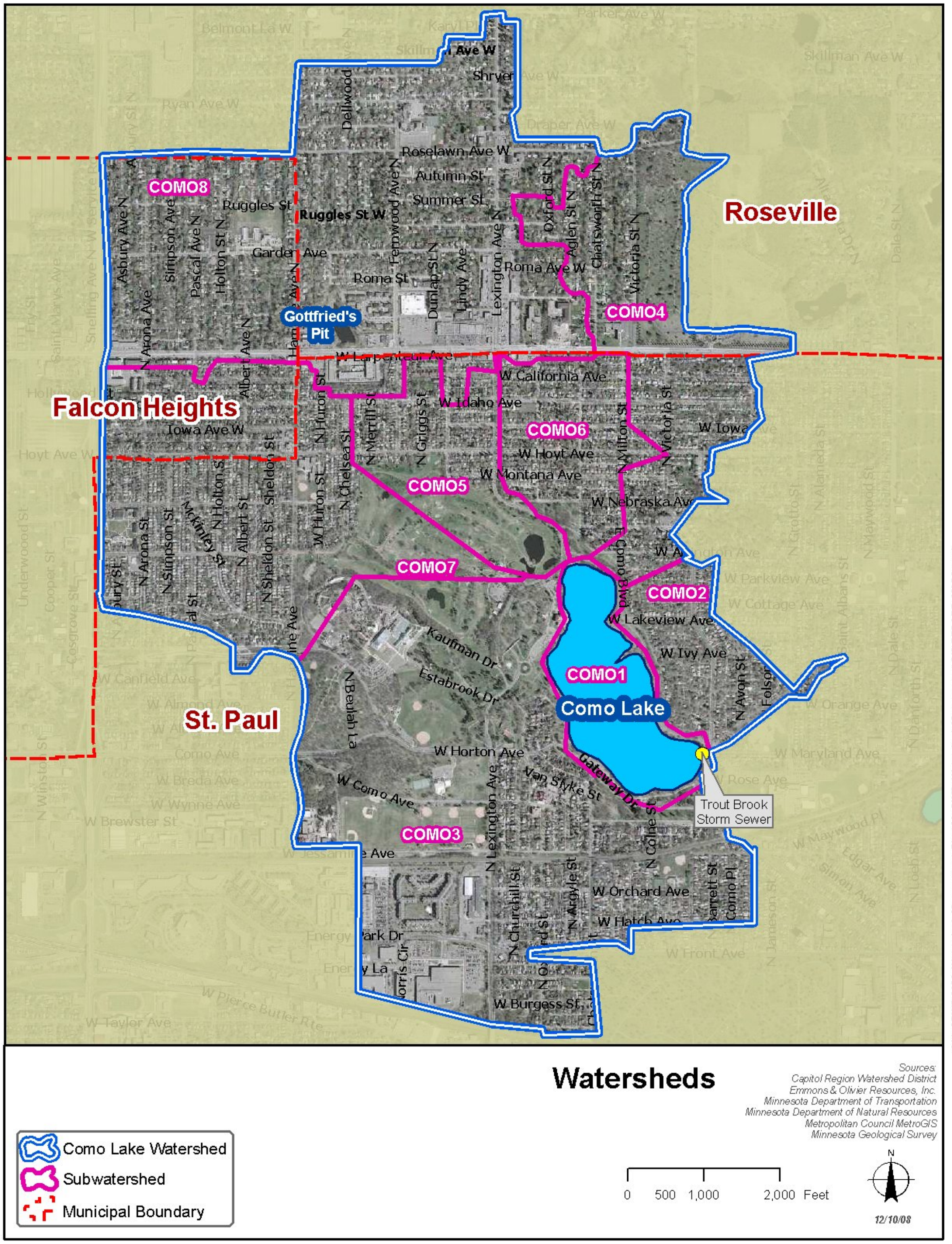

Figure 16. Como Lake Subwatersheds.

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 Como Lake. The dissolved oxygen depth profile from 2007 indicates that the lake temporarily stratifies during the growing season with periods of mixing occurring during the growing season. The hypolimnion is intermittently anoxic during the growing season (Figure 17). 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 when the lake is stratified (Figure 18). This suggests that internal loading is a source of phosphorus in Como Lake: the wind driven mixing causes phosphorus rich hypolimnetic water to be mixed with the surface waters and causes disturbance of the bottom sediments.

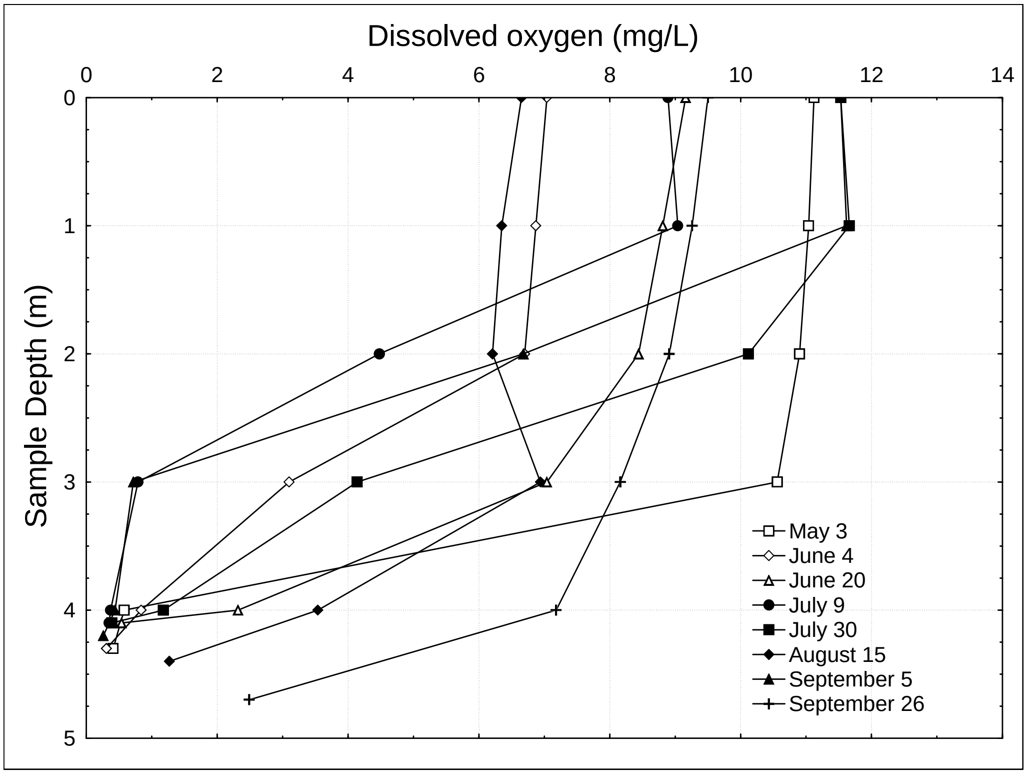

Figure 17. Como Lake Dissolved Oxygen Depth Profile, 2007

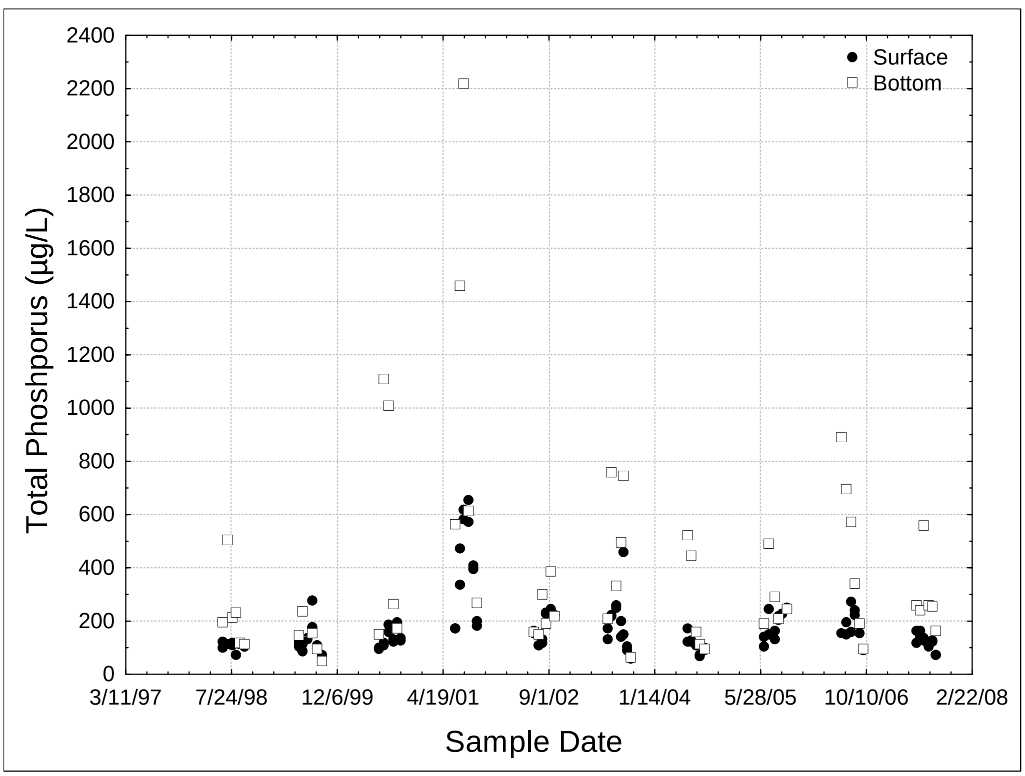

Figure 18. Como Lake Surface vs. Bottom Phosphorus Concentrations.

The internal load was calculated with the mass balance approach using the lake response model WiLMS (more details about WiLMS are included in Section 5: Loading Capacity). The watershed load was first input into the lake model. The additional load that was needed to calibrate the lake model to observed in-lake concentrations was assumed to be due to internal loading. This load was calculated to be 1,190 lbs/yr of TP (Table 11). If any unidentified watershed phosphorus sources exist, then the internal load estimated with the mass balance approach would be an overestimate.

4C. Atmospheric Deposition

Atmospheric deposition over the growing season was estimated to be 19 lbs/yr in Como Lake, calculated by using WiLMS default rate of 0.27 lbs/ac-yr. (See Section 5 for more information about WiLMS.) This rate falls within the range of rates reported by MPCA (2004), 0.09 to 0.5 lbs/ac-yr.

5. LOADING CAPACITY

This section describes the derivation of the TMDL for Como Lake. The year 2000 is the baseline year for the TMDL calculations.

5A. Methods

To estimate the assimilative capacity of the lake, an in-lake water quality model was developed using WiLMS (Wisconsin Lake Modeling Suite, Version 3.3.18), an empirical model of lake eutrophication developed by the Wisconsin Department of Natural Resources (Table 10). The model was selected based on its ability to predict how the in-lake total phosphorus concentration will respond to changes in phosphorus loading to the lake. An advantage of the model is its simplicity; model input parameters are miminal. WiLMS contains multiple phosphorus sedimentation models, but does not contain equations for modeling chlorophyll concentrations or transparency. The Walker 1987 Reservoir Model was used to model phosphorus sedimentation in Como Lake; this model was used to model in-lake TP concentrations in the development of the 2002 Como Lake Strategic Management Plan.

Input data consisted of the watershed load calculated by the P8 model (summarized in Section 4A), the internal load calculated using the mass balance approach (summarized in Section 4B), and the load from atmospheric deposition (summarized in Section 4C). Precipitation data are from the MN Climatology Working Group, and evaporation was estimated from rates published in the MN Hydrology Guide. No other inputs or changes to the model were made. The model was calibrated to the 1998 through 2007 average growing season mean (GSM, see Section 3: Impairment Assessment, and Table 8). In-lake TP concentrations had not changed substantially since the Como Lake Strategic Management Plan was finished (Figure 10); major BMPs implemented after the completion of the plan were completed in 2007. Practices implemented or initiated after 2000 can be used to achieve the load reduction requirements in Section 6 of this TMDL.

The mass balance approach in model calibration is a simple approach that assumes that the mass (load) of phosphorus that enters the lake is the same as the mass of phosphorus that leaves the lake. For the Como Lake model, the watershed load was input into the model and the predicted in-lake TP concentration was compared to the observed concentration. The observed concentration was substantially greater than the predicted concentration; it was assumed that the additional load to the lake needed to calibrate the predicted to the observed TP concentration is due to internal loading. This additonal load was then added to the model as internal loading.

Table 10. WiLMS Input Parameters

Lake Area (acres)	Volume (ac-ft)	Mean Depth (ft)	Drainage Area (ac)	Total Unit Runoff (inches)	Watershed TP Load to Lake (lbs/yr)	TP, GSM (µg/L)
72	525.6	7.3	1767	5.4	625	173

After the model was calibrated, the TP standard (60 µg/L) was used as the endpoint, and the TP loads to the lake were adjusted until the model predicted that the standard would be reached. This resultant load is the lake's assimilative capacity.

The TMDL was first determined in terms of annual loads. In-lake water quality models predict annual averages of water quality parameters based on annual loads. Symptoms of nutrient enrichment normally are the most severe during the summer months; the state eutrophication standards were established with this seasonal variability in mind. The annual loads were converted to daily loads by dividing the annual loads by 365.

5B. Results

Phosphorus Loads

The watershed load to Como Lake represents approximately 34% of the total load to the lake, the atmospheric load represents 1% of the total load to the lake, and internal load represents approximately 65% of the phosphorus load to the lake.

Table 11. Phosphorus Loads to Como Lake

Phosphorus Source	TP Load (lbs/yr)	% Total Load
Watershed	625	34%
Atmospheric	20	1%
Internal	1190	65%
Total	1835	

Assimilative Capacity

The TP assimilative capacity of Como Lake was calculated to be 306 lbs/yr (0.83 lbs/day), an overall reduction of 83% from the existing loading of 1835 lbs/yr. The assimilative capacity will be split up between the load allocation and the wasteload allocations in Section 6.

Critical Conditions

Critical conditions in Como Lake occur in the summer, often in July and August (see Figure 13, Figure 14, and Figure 15), when TP concentrations peak and clarity is at its worst. The water quality standards are based on growing season averages. The load reductions are designed so that the lakes will meet the water quality standards over the course of the growing season (June through September).

6. TMDL ALLOCATIONS

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. A MOS may be either explicitly calculated or implicitly included in the modeling assumptions and approach to calculating the TMDL.

An implicit MOS was incorporated into this TMDL by using conservative assumptions. These were used to account for an inherently imperfect understanding of the lake system and to ultimately ensure that the nutrient reduction strategy is protective of the water quality standard.

Conservative modeling assumptions included applying sedimentation rates that likely under-predict the sedimentation rate for shallow lakes. Impaired lakes are often in the ecologically turbid phase, as opposed to the clear-water phase. In this case, the lake water quality models are calibrated to the turbid phase and estimate a loading capacity that reflects the lake meeting the phosphorus standard while still in the turbid phase. (While a lake with 60 µg/L TP is more likely to be in the clear-water phase than the turbid phase, it is possible for a lake to meet the standard and still exhibit characteristics of a lake in the turbid phase (Moss et al., 1996)). However, as the phosphorus loads to the lake decrease and the lake is restored, the goal is to switch the lake from the turbid phase to the clear-water phase; this switch can be reached before the lake achieves the phosphorus goal. In this clear-water phase, the zooplankton community is healthier and is able to better control algal densities. The loading capacity for this TMDL (based on the turbid phase) is an underestimate of the lake's loading capacity under the clear-water phase, since the lake should be able to assimilate more phosphorus while continuing to maintain the clear-water phase. This applies to shallow lake systems.

6B. TMDL Allocations

The final TMDL equation for Como Lake is as follows:

TMDL = Load Allocation + Wasteload Allocation

306 lbs/yr = 57 lbs/yr + 249 lbs/yr
0.83 lbs/day = 0.15 lbs/day + 0.68 lbs/day

The WLA represents the permitted phosphorus sources to Como Lake, which comprise the watershed load. During the development of the 2002 Como Lake Strategic Management Plan, the Data Collection and Management Work Group identified that a 60% reduction to the watershed TP load was the most aggressive achievable reduction possible. This 60% reduction in watershed load was used to calculate the total WLA to be 249 lbs/yr (Table 12).

After accounting for the 60% reduction in the watershed load, the remaining load reductions needed are required from the sources that constitute the LA: internal load and atmospheric deposition. An overall reduction of 95% is needed from these sources (Table 12). This high reduction needed is quite aggressive. However, smaller reductions in external and/or internal loads may shift the lake from the turbid phase to the clear-water phase, and the more aggressive load reductions may not be needed.

Table 12. Overall Load Reductions

Source	Existing Load (lbs/yr)	Allocated Load (lbs/yr)	% Reduction
Permitted sources (watershed runoff)	625	249	60%
Non-permitted sources (atmospheric deposition and internal load)	1210	57	95%
Total	*1835*	*306*	*83%*

6C. Wasteload Allocations

The wasteload allocation is that portion of the total TMDL that is allocated to permitted point sources. The permitted sources in the watershed were identified as regulated MS4 stormwater and construction stormwater (Section 1B). In the case of Como Lake, the entire watershed load is regulated under the NPDES program and is considered a point source (Figure 19). There are no other permitted point sources in the watershed; therefore the entire wasteload allocation will be shared by regulated entities under the NPDES program.

The majority of the stormwater sources (MS4, construction stormwater, and industrial stormwater) were given a categorical WLA for Como Lake. An individual WLA was given to Mn/DOT. Mn/DOT's required load reductions have already been achieved through the implementation of BMPs since the TMDL baseline year of 1994 by other regulated MS4s. These BMPs will need to be documented in Mn/DOT's SWPPP to show WLA achievement.

The load reductions identified by the categorical WLA will need to be met by the group as a whole. The regulated MS4 communities that are part of the categorical WLA will need to document progress towards meeting the WLA in their SWPPPs. Although there are no NPDES-regulated industrial stormwater sources, it is included in the categorical WLA to cover future industrial stormwater sources. Table 13 summarizes the wasteload allocations and includes each of the regulated MS4s within the Como Lake subwatershed.

Table 13. Wasteload Allocations

Permit Name	Permit Number	Existing (1994) TP Load (lbs/year)	WLA (lbs/year)	WLA (lbs/day)	Percent Reduction
City of Saint Paul	MS400054	624.80	248.92	0.68	60%
City of Falcon Heights	MS400018				
City of Roseville	MS400047				
Ramsey County	MS400191				
Capitol Region Watershed District	MS400206				
Construction stormwater	Various				
Industrial stormwater	No current permitted sources				
Mn/DOT	MS400170	0.20	0.08	0.00022	60%*

* Mn/DOT’s load reductions have already been achieved through the implementation of BMPs by other regulated MS4s

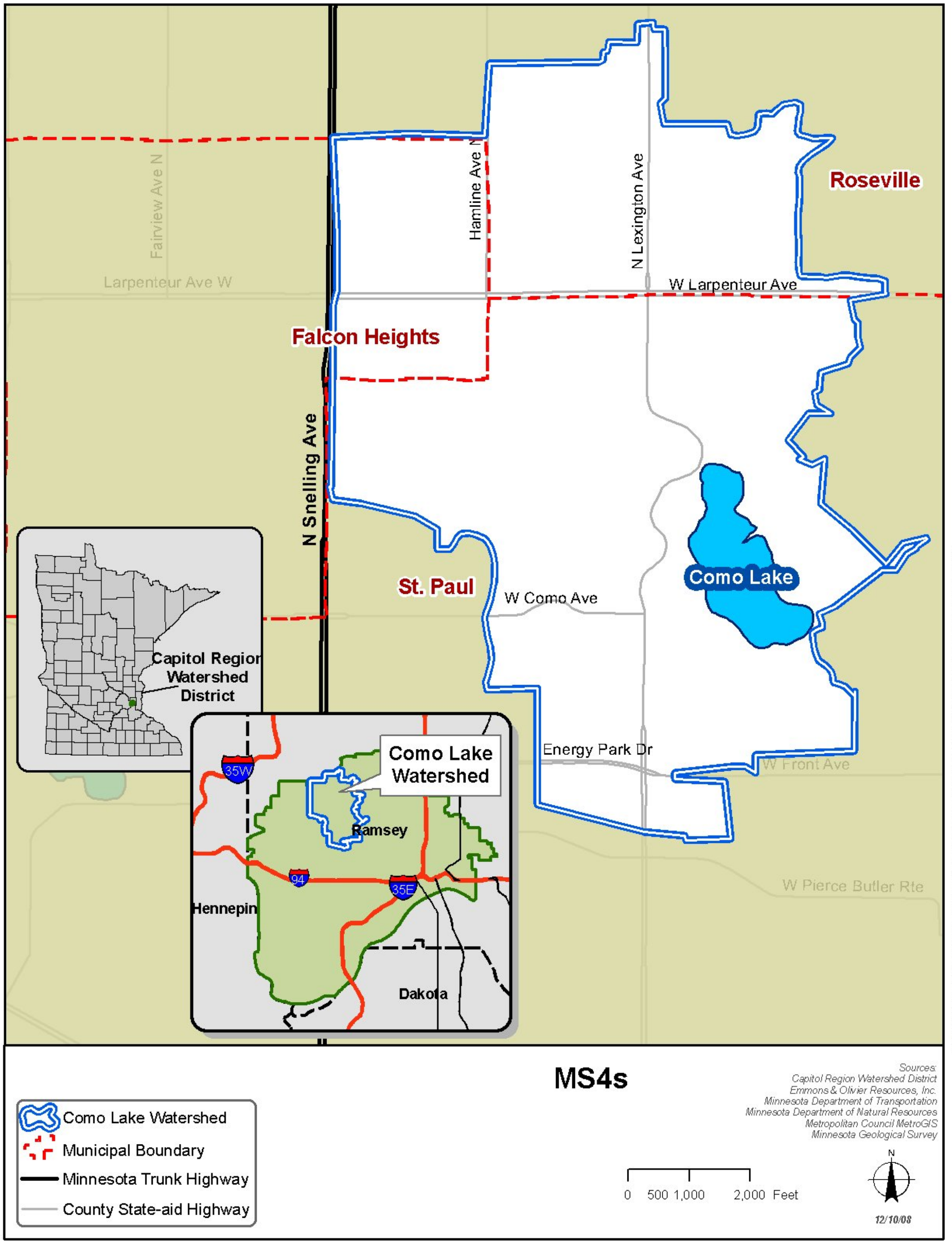

Figure 19. Regulated MS4s in the Como Lake Watershed

6D. Load Allocations

The atmospheric and internal sources of TP are considered under the load allocation. Since reductions in atmospheric loading are not expected, atmospheric deposition was held constant at 20 lbs/yr, and the internal load needs to be reduced by 97% to 37 lbs/yr (Table 14).

Table 14. Load Allocations, Annual and Daily

Source	Existing Load (lbs/yr)	Load Allocation (lbs/yr)	Required Load Reduction (lbs/yr)	Percent Reduction
Internal Load	1190	37	1153	97%
Atmospheric Load	20	20	0	0%
Total	1210	57	1153	95%

Source	Existing Load (lbs/day)	Load Allocation (lbs/day)	Required Load Reduction (lbs/day)	Percent Reduction
Internal Load	3.26	0.10	3.16	97%
Atmospheric Load	0.05	0.05	0	0%
Total	3.31	0.15	3.16	95%

6D. Reserve Capacity

Reserve capacity, an allocation for future growth, was not explicitly calculated for this TMDL, but rather was included as part of the WLAs and LAs. The watershed for Como Lake reached its development potential; therefore any further development that does take place will be redevelopment and is already included in the WLA.

6E. TMDL Allocation Summary

Table 15. TMDL Allocation Summary

<table>
<tr><th colspan="2">Source</th><th>TMDL (lbs/yr)</th><th>TMDL (lbs/day)</th></tr>
<tr><td colspan="2">Load Allocation</td><td>57</td><td>0.15</td></tr>
<tr><td colspan="4">Wasteload Allocations</td></tr>
<tr><td>MS4 or other source</td><td>NPDES Permit #</td><td></td><td></td></tr>
<tr><td>City of Falcon Heights</td><td>MS400018</td><td rowspan="7">248.92</td><td rowspan="7">0.68</td></tr>
<tr><td>City of Saint Paul</td><td>MS400054</td></tr>
<tr><td>City of Roseville</td><td>MS400047</td></tr>
<tr><td>Ramsey County</td><td>MS400191</td></tr>
<tr><td>Capitol Region Watershed District</td><td>MS400206</td></tr>
<tr><td>Construction stormwater</td><td>Various</td></tr>
<tr><td>Industrial site stormwater</td><td>No current permitted sources</td></tr>
<tr><td>Minnesota Department of Transportation</td><td>MS400170</td><td>0.08</td><td>0.00022</td></tr>
<tr><td colspan="2">Total TMDL</td><td>306</td><td>0.83</td></tr>
</table>

7. SEASONAL VARIATION AND CRITICAL CONDITIONS

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

This is the case for Como Lake; critical conditions occur during the summer (Figure 13), when TP concentrations peak.

8. MONITORING PLAN

The following monitoring plan lays out the different types of monitoring that will need to be completed in order to track the progress of implementation activities associated with Como Lake and of associated changes in water quality due to the management practices.

Monitoring should occur after implementation activities are initiated in order to evaluate the effectiveness of the BMPs, and should continue throughout the implementation period until water quality standards are attained. CRWD, in partnership with the regulated MS4s and Ramsey County Public Works, will ensure that the monitoring is completed.

The following parameters should be part of the in-lake monitoring plan:

- TP, soluble reactive phosphorus, nitrogen, chlorophyll-*a*, and transparency should be monitored biweekly during the growing season.
- At least one year of winter nitrate data should be obtained in Como Lake. Winter nitrate has been shown to be an indicator of plant species richness in shallow lakes and can provide information on nitrogen loading and the potential for aquatic macrophyte restoration (James et al. 2005). This information can help target future management practices aimed at reducing nitrogen loading to the lake.
- Depth profiles of temperature and dissolved oxygen should be taken biweekly during the growing season at the deepest portion of the lake.
- Zooplankton monitoring should be undertaken for a full season every five years. Monitoring should start in early spring (March or April), when large zooplankton peak; zooplankton community dynamics during this period influence the water quality during the remainder of the growing season.
- A fish survey should be completed once every five years to obtain data on fish population abundance, size distribution, and year class strength as well as to evaluate management activities. Surveys should be conducted following the *Manual for Instruction of Lake Survey*, Special Publication No. 147 from the Minnesota Department of Natural Resources (DNR).
- Spring and summer aquatic macrophyte surveys should be completed every five years, during the same years as the zooplankton and fish monitoring. The spring survey is important to monitor the abundance of curly-leaf pondweed and to understand its role in the overall lake phosphorus dynamics, and the summer survey tracks the presence and establishment of native macrophytes in the lake.

The following parameters should be part of the subwatershed monitoring plan:

- At the outlet of each subwatershed, TP, soluble reactive phosphorus, nitrogen, and TSS should be monitored during storm events causing discharge.
- At the outlet of each subwatershed, TP, soluble reactive phosphorus, nitrogen, TSS, and turbidity should be monitored biweekly during the growing season under baseflow conditions.

- At the outlet of each subwatershed, flows should be monitored to verify the modeled loadings.

9. IMPLEMENTATION STRATEGY

It is widely recognized that restoration of shallow lakes, particularly those in highly urbanized areas, can be a significant challenge. 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. This discussion separates the management strategies into practices addressing watershed load and internal load. In shallow lake restoration, the first step is to reduce the watershed load, after which management practices aimed at the internal load and in-lake ecological interactions should be addressed. If the watershed load is not brought under control first, there is a lower chance that the efforts aimed at the in-lake sources will be successful.

The initial five-year implementation program of priority activities for the restoration of Como Lake is anticipated to cost approximately $2.5 million. The implementation program and priority activities for restoration of Como Lake will be determined as part of development of the Como Lake TMDL Implementation Plan. The implementation plan will be developed through a process led by a stakeholder advisory group made up of all the MS4s. Projects that are not included in the implementation plan, yet achieve equivalent outcomes, can be implemented. The implementation plan will be built upon an adaptive management approach. Implementation activities will be continually monitored and evaluated to determine effectiveness in reaching the in-lake goals for Como Lake. The in-lake goal as well as the subwatershed TP reduction goals may need to be reevaluated at a future date as a result of the monitoring and evaluation.

CRWD will coordinate the implementation activities through a stakeholder process with all of the regulated MS4s within the Como Lake watershed, along with other stakeholders. The watershed district will annually report on progress made towards meeting the WLAs and LA, and, if necessary, will evaluate the goals set forth in this TMDL report.

9A. Watershed Load

Watershed load reduction planning will occur on a subwatershed basis (subwatersheds are indicated in Figure 16). Subwatershed evaluations were completed as part of the CLSMP, and potential projects were identified, including approximate costs. The implementation plan for the Como Lake TMDL will refine the projects identified and the estimated costs. The plan will contain a range of options for implementation; implementation partners can select from this range of options the practices that best suit local resources, needs, and constraints. Future evaluation, likely to be completed after development of the implementation plan, will include BMP siting and design.

The watershed load reduction activities will focus on programs (such as good housekeeping), regulatory controls, and projects. Due to the urban nature of the watershed, the majority of the projects will be retrofits and redevelopment projects. Opportunities within each subwatershed will be identified for retrofits including small and large scale water quality treatment practices. Opportunities for water quality treatment should be investigated on public and private property located in key areas.

Regulatory controls include construction and industrial stormwater permits. Construction stormwater activities are 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 Appendix A of 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.

Industrial stormwater activities are also 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, or meet local industrial stormwater requirements if they are more restrictive than requirements of the State General Permit.

9B. Internal Load

The focus of internal load management will be to shift Como Lake from the current turbid, algal-dominated state to a clear state dominated by aquatic macrophytes (plants). This will be done through management activities designed to stabilize the lake-bottom sediments, improve aquatic macrophyte species composition and abundance, and increase the density of zooplankton. Strategies may include fisheries management to control populations of benthivorous fish and to prevent overgrazing on zooplankton through increasing the relative abundance of piscivorous fish (fish that eat other fish) relative to planktivorous fish (fish that eat organisms that float in the water). Other approaches will include shoreline management, waterfowl management, and investigation into operation of the current aerator.

10. REASONABLE ASSURANCES

There are federal, state, watershed, and local authorities in place to provide a reasonable assurance that the implementation efforts within this TMDL study will go forward. This TMDL report recommends that the CRWD work with the many stakeholders involved in lake management to implement a series of improvement measures for the lake. The District will serve as the 'aggregator' or TMDL coordinator to assist each of the MS4s, in coordination, in meeting their individual TMDL requirements. This role will include completing an annual inventory and accounting for reductions in the watershed, serving as a technical resource for the MS4s, providing monitoring to determine implementation effectiveness, and providing documentation to collectively meet the annual reporting requirements of the MS4 permits.

CRWD Rules

On March 5, 2008 the CRWD adopted revisions to the watershed rules adopted September 6, 2006. Under the CRWD rules the district reviews projects within the watershed. CRWD has successfully implemented these rules since adoption.

Specific rules expected to contribute to water quality improvement in Como Lake include stormwater management (Rule C), wetland management (Rule E), erosion and sediment control (Rule F), and illicit discharge and connection (Rule G).

CRWD Watershed Management Plan

The Como Lake TMDL, as well as other TMDLs within the watershed district, is referenced in CRWD's draft 2010 Watershed Management Plan. The plan describes the process by which the watershed district will coordinate the implementation of the TMDLs.

NPDES MS4 Program

The Como Lake watershed has MS4 permit programs in place for Capitol Region Watershed District, Mn/DOT, St. Paul, Falcon Heights, Roseville, and Ramsey County.

Under the MS4 program, each permitted community must develop a SWPPP that lays out the ways in which the community will actively and effectively manage its stormwater. SWPPPs are required to incorporate the results of any approved TMDLs within their area of jurisdiction, subject to review by the MPCA.

Given implementation of the various rules and programs noted above, reasonable assurance can be given that communities within the subject watershed will be properly managing their stormwater.

Como Lake Strategic Management Plan

The CLSMP was completed in 2002. The CLSMP was developed though a high level of public participation with strong technical guidance. This plan lays out the implementation strategy needed to accomplish the TMDL.

The framework in the CLSMP lays out a logical approach, under the leadership of the CRWD, for an existing group of district cooperators to accomplish the implementation of the management activities needed to meet to meet the TMDL. Members of this group include all of the regulatory and planning stakeholders committed to the success of the implementation plan. These entities will continue to work together to implement the program to accomplish it.

11. PUBLIC PARTICIPATION

Public participation for the Como Lake TMDL study was the public participation process for the Como Lake Strategic Management Plan.

The public participation process for the CLSMP was carefully designed to balance technical needs with those of the Como Lake watershed communities. It was determined that three work groups were needed: a technical committee to analyze the data and make recommendations, a public relations/communications committee that could provide the neighborhood perspective, and a steering committee that managed the entire process.

Three work groups were formed around the identified needs. These work groups were the Advisory Group, Data Collection and Management, and Public Outreach. Participants for each of the groups were recruited from government, organizations, businesses, and citizens active in the Como Lake watershed communities including St. Paul, Roseville, Falcon Heights, and Ramsey County. Some of the members were participating as staff members for their respective organizations and some of the members were volunteers. All three of the committees were designed to work independently but to continually feed information to each other so both their individual and project goals could be realized.

Sixteen meetings were held from July 2000 through June 2001. The general format for the meetings was to meet together at the beginning of the meetings and then to break out into the work groups afterwards.

Advisory Group

The Advisory Group was the steering committee of the entire strategic planning process. Members represented key governmental agencies, the Minnesota State Legislature, business, non-profit organizations, and citizen-based groups. The Advisory Group identified key objectives for each of the work groups, coordinated the development of a list of issues to be addressed, prioritized issues, analyzed and selected options for addressing those issues, and assisted in creating an implementation and monitoring process. It also reviewed the draft CLSMP and recommended changes based upon the committees' feedback and their own analysis.

Data Collection and Management Work Group

This committee reviewed and evaluated existing watershed and water quality information and provided educational presentations to the Advisory Group and the Public Outreach Work Group. It provided feedback to the Advisory Group regarding issues, management concerns, options and implementation scenarios. Members had a technical background and represented local and state government and non-profit organizations.

Public Outreach Work Group

This committee assisted the Advisory Group in the development and prioritization of issues, and developed a communications plan that identified short and long-term projects. The short-term projects were designed to build the public's awareness regarding the CLSMP, the state of Como Lake, and current and future water quality enhancement activities. The long-term projects were designed to create ongoing interest and commitment to improve the water quality of the lake through the media, stewardship activities, and outreach to schools and local governments.

Members represented community organizations and citizens. Generally, volunteers facilitated the meetings, determined the work plan, and used staff and consultants to assist and generate work products recommended at the meetings.

Attendee organizations of these meetings:

City of Falcon Heights
City of Roseville
City of Saint Paul
City of Saint Paul, Div. of Parks and Recreation
City of Saint Paul Public Works
CRWD Board of Managers
CRWD Citizens Advisory Committee
Community Council District 6
Community Council District 10
Como Northtown Credit Union
Como Shoreline Interests
Emmons & Olivier Resources
Lynch Associates
Neighborhood Energy Consortium
Metropolitan Council Environmental Services
Minnesota Department of Natural Resources
Minnesota Pollution Control Agency
Minnesota State Legislature
Ramsey County
Ramsey County Public Works
Ramsey Soil and Water Conservation District
University of Minnesota Water Resources Center

Stakeholder Meetings during TMDL Process

Regulated MS4s were provided the opportunity to review the draft TMDL report in early 2010. Individual meetings were held with the municipalities in February 2010 to discuss the TMDL and its derivation from the CLSMP. A meeting with all regulated MS4s was held on February 17, 2010 to further discuss the TMDL, the form of the WLA (categorical vs. individual), and the implementation strategies. Regulated MS4s were provided another opportunity to review and comment on the draft report before preliminary review by the MPCA and EPA and the public comment period.

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APPENDIX A. CRWD STORMWATER MODELING

Capitol Region Watershed District
Stormwater Modeling

May 16, 2000

BARR

Capitol Region Watershed District Stormwater Modeling

May 16, 2000

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Capitol Region Watershed District
Stormwater Modeling

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1.0 Background

Barr Engineering was asked by Capitol Region Watershed District (CRWD) to complete a stormwater modeling project for the entire District using the P8 Urban Catchment Model (IEP, Inc., 1990 and Walker, 1990). In this project, subwatersheds tributary to the Mississippi River, District Lakes, and public stormwater detention ponds were evaluated. Stormwater monitoring information for four minor subwatershed areas obtained by the City of St. Paul in 1994 (Montgomery Watson, 1994) was used to calibrate the P8 model. Calibrated P8 model parameters for the monitored subwatersheds were utilized to model the unmonitored portions of the District based on impervious area and land use information for the remaining District subwatersheds. Modeling simulations of the entire District were performed for recent (1999), wet, dry, and average climatic conditions.

1.1 Land Use Information

The land use information provided by the District contained the following eight categories: (1) Commercial, (2) Industrial, (3) Institutional, (4) Parks and Open Space, (5) Residential High Density, (6) Residential Low Density, (7) Water, and (8) Undeveloped. The land use shapefile provided was based on parcel data and therefore, was missing all of the roadways throughout the District. As a result the missing roadway data was filled in using ArcView to create a ninth land use type, "Roads".

1.2 Impervious Surface Information

Impervious surface information is considered to be a basic measurement unit of an urbanized watershed. As such, the CRWD completed a project to create an ArcView shapefile for the major impervious surfaces throughout the District, including roads, alleys, structures, tennis courts, and parking lots. The impervious surface GIS data layer from the District did not contain polygons for all the sidewalks and driveways within the District. To overcome the lack of information for sidewalks and driveways, Barr Engineering determined the areal extent of sidewalks and driveways for representative areas within each of the various land use categories. To accomplish this, the 1997 Metropolitan Council Aerial Photographs of the District were used to digitize the sidewalks and driveways at six different, but representative, locations throughout the District. Whenever possible the location was selected to correspond to the stormwater monitoring sites. This was done to aid in model calibration. Table 1 summarizes the results of the sidewalk and driveway areal extent analysis.

Table 1 Sidewalk and Driveway Areal Extents

Land Use Category	Sidewalk Extent (%)	Driveway Extent (%)
Commercial	4.67	1.83
Industrial *	0.00	21.32
Institutional	5.78	7.18
Parks and Open Space	1.21	0.21
Residential High Density	6.74	1.70
Residential Low Density	3.62	2.81
Roads	6.61	2.14
Undeveloped	11.07	9.83
Water	N/A	N/A

* The extent of sidewalk for industrial land use was estimated to be 0% because sidewalk could not be differentiated from driveways, parking lots, or other impervious surfaces on the 1997 Metropolitan Council Aerial Photos.

Connectivity estimation of the various impervious surface types was accomplished by associating each surface type with a land use category. Using the 1997 aerial photos, the connectivity percentages of representative impervious surfaces were visually estimated. A minimum of four locations of various land use types were observed, including the monitoring sites and downtown areas. It was discovered that the Downtown and Urban subwatershed had higher connected impervious percentages, as indicated in Table 2. Table 2 provides the connected percent impervious for the various surface and land use types. Roads, alleys, parking lots, and driveways were assumed to be 100 percent connected to the storm sewer network. The connectivity of structures was estimated based on the number of sides of the structure that were in close proximity or adjacent to a connect impervious surface (i.e., if the structure was surrounded by a parking lot, the structure was assumed to be 100 percent connected, while if a structure had roads or alleys adjacent to two sides, the structure was assumed to be 50 percent connected). One exception to this methodology was structures in low density residential areas. The impervious areas of these structures were assumed to not be directly connected to the storm sewers. The assumption is based on the fact the runoff from these impervious surfaces typically must flow through pervious areas, such as lawns, prior to reaching the storm sewers.

Table 2. Connected Percent for Various Impervious Surface and Land Use Types

Impervious Surface Type	Apply to Watersheds	Land Use Type								
		Commercial	Industrial	Institutional	Low Density Residential	High Density Residential	Parks & Open Space	Undeveloped	Water	Road
Alley	All	100	100	100	100	100	100	100	N/A	100
Parking Lot	All	100	100	100	100	100	100	100	N/A	100
Structure	Downtown & Urban	100	100	100	0	100	50	100	N/A	100
	Others	80	100	50	0	50	50	75	N/A	100
Tennis Court	All	0	0	0	0	0	0	0	N/A	0
Road	All	100	100	100	100	100	100	100	N/A	100
Driveway	All	100	100	100	100	100	100	100	N/A	100
Sidewalk	Downtown & Urban	100	100	100	0	100	25	0	N/A	100
	Others	75	100	50	0	50	25	0	N/A	100

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1.3 Monitoring Site Watershed Data

The land use types, impervious surface areas, and soils data were determined for each monitoring site. Based on the various land uses in each monitored watershed, the areal extent of sidewalks and driveways were determined. Using the impervious surface data and the respective connectivity percentages of each land use type, the connected impervious fraction was determined. Based on consultation with the SCS National Engineering Handbook (SCS, 1964), the pervious curve number was selected for each site based upon soil types, land use, and hydrologic conditions (i.e., if watershed soils are type B and pervious areas are comprised of grassed areas with 50% to 75% cover, then a Curve Number of 69 would be selected). A composite pervious curve number was estimated for each site based on the area and hydrologic soil group (HSG) of each soil type within the site subwatersheds. This pervious curve number was then weighted with indirect (i.e., unconnected) impervious areas in each subwatershed. Table 3 lists the various watershed characteristics for each site.

Table 3. Monitoring Site Subwatershed Characteristics

Watershed Characteristic	Monitoring Site			
	Lawson	**Vandalia**	**Charles**	**Hartford**
Major Land Use Type	Low Density Residential	Industrial	Mixed	Low Density Residential
Subwatershed Area (acres)	53.8	82.0	61.6	72.5
Pervious Curve Number	78	81	75	77
Connected Impervious Fraction	0.400	0.882	0.444	0.355

2.0 Water Volume Calibration

After compiling volunteer, University of Minnesota, St. Paul Campus, (UofM), and Minneapolis-St. Paul International Airport rainfall data and looking at the various monitoring site locations in relation to the precipitation sites, it was decided to average the daily total precipitation amounts from the UofM and the four volunteer sites. This averaging was done because the precipitation-monitoring site bordered the stormwater monitoring locations. This enabled one precipitation file to be developed for calibration. At this point it is important to mention that if the flow volumes predicted by P8 were dramatically different from observed, one possible explanation is that the precipitation file does not represent site specific rainfall events. The rainfall hyetographs were developed for each event based on either the UofM or Airport hourly precipitation observations. The average event precipitation totals were compared to the event totals recorded at the UofM and the Airport. The hyetograph from which ever of the two sites provided the closest event precipitation total to the average of the four volunteer and UofM sites was used to develop a PCP file for P8. The selected hyetograph was adjusted to reflect the average precipitation totals.

Based on the observed monitoring event periods and the overlap of some events for one site and not for the others, as well as the large difference between observed and predicted flow volumes, independent precipitation files had to be developed for each site. The monitoring site locations are shown in Figure 1.

- **Vandalia** – The UofM rain gage is located in relatively close proximity to this site. Therefore, the precipitation charts from the UofM rain gage, as supplied as part of the City of St. Paul 1994 Stormwater Monitoring Report, were used to develop the PCP file for the Vandalia monitoring site. For other unmonitored events, the Airport rainfall data were used. (Vandcal.pcp)

- **Hartford** – The volunteer rainfall monitoring site 28-23-9 is located in relatively close proximity to this site. Therefore, the event precipitation total observed by this volunteer were used in conjunction with the hyetographs for the same events from the Airport. (Hartcal.pcp)

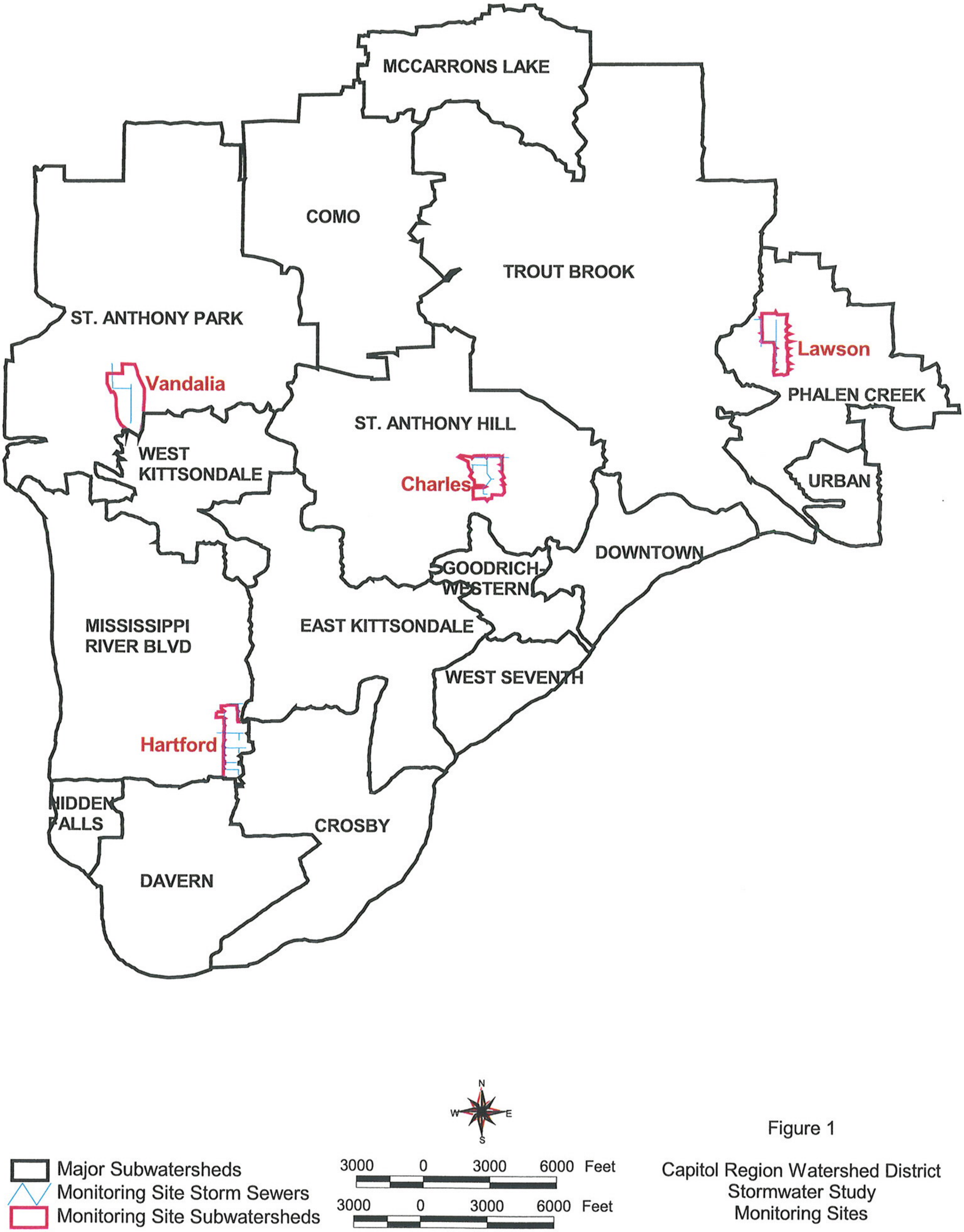

Figure 1

Capitol Region Watershed District
Stormwater Study
Monitoring Sites

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- **Lawson** – This stormwater monitoring site is closest to volunteer sites 29-22-23 and 29-22-26. Therefore, the average observed event precipitation total from these sites was used with either the UofM or Airport hyetographs. The appropriate hyetograph was selected based on which location provided the closest match to the average volunteer site rainfall total for the respective event. (Lawscal.pcp)

- **Charles** – This site is centrally located within the area of the precipitation monitoring sites listed in the 1994 Stormwater Report. Therefore the average precipitation amount, from the four volunteers and the UofM sites, was used with either the UofM or Airport hyetograph to develop the precipitation file for this site. The appropriate hyetograph was selected based on which location provided the closest match to the overall average rainfall total for the respective event. (Charcal.pcp)

Model calibration was based on observed runoff totals for the monitoring events at a given site, as reported in the 1994 Stormwater Monitoring Report. Model calibration was based on the overall arithmetic mean of the individual site total estimated runoff volume divided by the observed runoff volume for all of the representative events at all of the monitoring sites. The models were considered calibrated when the average of the individual site ratios was 100 percent, meaning the models were predicting 100 percent of the observed runoff volume for the analyzed events. Early on in the calibration process it became evident that observed runoff volumes for all of the events at Hartford, the first event at Charles, and the second event at the Lawson monitoring sites were unrealistic, given the watershed characteristics and the best estimate of rainfall volumes. The difference between observed and predicted runoff volumes could be caused by several factors, including inaccurate precipitation data, flow monitoring data, impervious surface data, storm sewer data, or any combination of this type of information. The Hartford site was closely examined using aerial photos, storm sewer maps, and topographic information to try and explain the large difference between observed and predicted runoff volumes. Because no physical explanation could be found, the monitored flow rates were placed in doubt for the above mentioned sites and events. To facilitate model calibration, those events in question (Event 2 at Lawson, Event 1 at Charles, and Events 1, 2, and 3 at Hartford) were eliminated from the calibration procedure.

The initial model run for each site was conducted using the models default watershed parameters. Model runs with the default watershed parameters resulted in an over prediction of runoff volumes for the majority of the observed events. The initial model runs also revealed the majority of the runoff was from the impervious surfaces only. This is unrealistic for the larger observed events (precipitation > 1-inch). Examination of the events file revealed that the models were generally computing pervious runoff using antecedent moisture condition (AMC) I. The default P8 model parameters used to determine pervious runoff are set such that the model will utilize curve numbers from one of three different antecedent moisture conditions based on the 5-day antecedent precipitation total. An examination of the observed runoff volumes versus the total 5-day antecedent precipitation amounts showed that a significant relationship did not exist between these variables. As a result, the model was forced to compute runoff in the second antecedent moisture condition (AMC II). This was accomplished by setting the cut off between AMC I and AMC II equal to 0 while the division between AMC II and AMC III was set equal to 100. This forced the model to compute runoff in the second AMC as long as the pervious 5-day rainfall plus snowmelt was between 0 and 100-inches. Because the monitoring data were only collected during the growing season (May through September), the model was only forced to run in the AMC II during that period. Based on the aerial photos of the monitoring it was assumed the grassed areas were in fair condition. Because of soil compaction due to urbanization it was assumed that soil group A would produce runoff volumes similar to group B. This was also done to produce pervious runoff to aid in the calibration process. The following pervious CN's were selected for the various HSG's:

Table 4. Modeled CN's for Various HSG's

HSG	CN
A	69
B	69
C	79
D	84

In addition to forcing the model to compute runoff in AMC II, the impervious runoff coefficient and depression storage parameters were adjusted to aid in model calibration of runoff from the impervious surfaces. Initial model runs indicated that the models were over predicting the runoff volumes for small events (precipitation total <0.5-inches). Based on this, the depression storage was increased from the default value of 0.02-inches to 0.1-inch. Even after the above adjustments, the models were over-predicting the runoff volumes. Therefore, the impervious runoff coefficient was reduced until the overall runoff observed and predicted runoff volumes were equal (This is essentially Step 13 of Walker's report, *P8 Enhancements & Calibration to Wisconsin Sites*). The resulting impervious runoff coefficient, 0.9, produced an overall predicted to observed ratio of 100 percent. In addition, the individual sites had ratios ranging between 93 and 110 percent. The best fit was at Vandalia where the overall average ratio was 100 percent for the three monitoring events. The remaining variation in individual events is likely due to inaccurate site specific rainfall data. Table 5 shows the difference between the model runs with the default parameters and the calibrated model. It also lists the calibration parameters.

An impervious area watershed runoff coefficient equal to 0.9, a depression storage amount of 0.1 inches, running the model in the second AMC during the growing season, and using pervious CN's for grassed areas with fair cover conditions produced the best calibration with respect to water volumes. This is supported by the fact that the overall predicted volumes for each site were all within 10 percent of the observed volumes.

Table 5. Water Volume Calibration Results

	Charles	Lawson	Hartford	Vandalia
Initial Results				
Impervious Runoff Coefficient	1	1	1	1
Depression Storage (inches)	0.02	0.02	0.02	0.02
Weighted Pervious CN (Good Condition)	58	73	71	76
Growing Season AMC I – AMC II Divide	1.4	1.4	1.4	1.4
Growing Season AMC I – AMC II Divide	2.1	2.1	2.1	2.1
Individual Site Predicted/Observed Volume Ratios*	76%	122%	449%	118%
Overall Arithmetic Mean Predicted/Observed Volume Ratios	191%			
Calibrated Results				
Impervious Runoff Coefficient	0.9	0.9	0.9	0.9
Depression Storage (inches)	0.1	0.1	0.1	0.1
Weighted Pervious CN (Fair Condition)	75	78	77	81
Growing Season AMC I – AMC II Divide	0	0	0	0
Growing Season AMC I – AMC II Divide	100	100	100	100
Individual Site Predicted/Observed Volume Ratios*	110%	93%	N/A	97%
Overall Arithmetic Mean Predicted/Observed Volume Ratios	100%			

* For representative storm events considered for this analysis.

3.0 Pollutant Calibration

The P8 model was calibrated to the average event flow-weighted concentration for total suspended solids (TSS), total phosphorus (TP), total copper, and total zinc. With two exceptions, Barr Engineering's calibration steps followed those discussed in the report "P8 Enhancements & Calibration to Wisconsin Sites", Walker (1997). The first exception relates to identifying calibration events. Since many of the monitored events for the four subwatersheds occurred during rainfall events that received more than 1-inch of precipitation, those events were not eliminated as recommended by Step 12 of Walker's report. The second exception relates to calibrating the dissolved fraction of the remaining water quality components, as outlined in Step 15 of Walker's report.

Barr Engineering performed an extensive review of the monitored water quality data and its relationship to the loadings from the pervious and impervious areas of the various land use types. It was determined that significant differences do not exist between the major land use types and therefore the calibration parameters can be optimized such that one particle file with one set of scale factors can be used for all subwatersheds.

Review of observed water quality data revealed that several of the events were not sampled over the entire storm event. Therefore, the concentrations listed in the 1994 Stormwater Monitoring Report do not represent the event flow weighted mean concentrations. As a result, modeling output was identified over the water quality sampling period (i.e., for Event 1 the sampling period was only the first 1.75 hours. Therefore, P8 model only the output data for just the first 1.75 hours of the event was compared to the observed data.). When possible, the flow volumes over the water quality sampling period were estimated from the flow data in the 1994 Stormwater Report. The flow volumes predicted by the calibrated P8 model for the Hartford site were used for pollutant calibration because the Hartford site's observed flow volumes were eliminated from the water volume calibration (See Section 2.0 Water Volume Calibration).

The pollutant calibration process started with the NURP50% particle file as developed by Walker for the median NURP monitoring site. The pollutant calibration process was conducted in a manner similar to the water volume calibration process (i.e., when the arithmetic mean of the individual site overall flow weighted mean predicted concentration to observed concentration ratio equaled 100 percent, the constituent was considered calibrated).

3.1 Total Suspended Solids Calibration

Following Walker's calibration steps, suspected monitored outliers were eliminated from the calibration process (Step 5). The 1994 Stormwater Report states "the Lawson watershed is fully developed with residential and older commercial areas and contains a number of gravel parking lots. It was also noted during the monitoring period that several inches of sediment generally accumulated in the manhole at the Lawson site." Because anomalous sedimentation was not observed at all of the sites, the Total Suspended Solids (TSS) concentrations at the Lawson site are likely not representative of the rest of the watersheds. As a result, the Lawson site was removed from the calibration process.

After completing the water volume calibration, Walker recommends calibrating the TSS (Step 14). Because all other pollutant concentrations are dependent on the amount of solids, TSS calibration is a critical step. The P8 model results using the NURP50% particle file indicated that P8 was over predicting TSS concentrations from impervious areas and under predicting concentrations from pervious areas, based on the relative magnitude of impervious and pervious area runoff volumes taken from the model calibrated for water volume.

To address the runoff TSS concentration from the pervious areas the pervious runoff concentration and the pervious runoff exponent were adjusted for the various particle classes. According to *P8 Urban Catchment Model Program Documentation, Version 1.1*, Walker 1990, based on typical sediment rating curves the pervious runoff exponent ranges between 0.1 and 1.6 for rivers. Other particle files supplied with the P8 model (NURP90.par, Monroe.par, and Lincoln.par) were reviewed to determine a range for the pervious runoff concentration since no pervious area monitoring data were available. Based on this review the P10% to P50% concentrations were found to range between 100 and 400 mg/L while the P80% concentration ranged between 200 and 800 mg/L. Numerous combinations of the pervious runoff concentration and exponent were examined. A pervious runoff concentration for the P10%-P50% of 100 mg/L and 200 mg/L for the P80% with a runoff exponent of 0.1 produced the best results for pervious runoff concentrations.

According to *P8 Urban Catchment Model Program Documentation, Version 1.1*, Walker 1990, any of the buildup/washoff parameters can be adjusted for calibration. Rescaling the impervious area particle loading for the different particle classes (P10% - P80%) as recommended in Step 14 of Walker's report was done to reduce the impervious runoff concentration. The NURP50% accumulation rates (1.75 and 3.5 lb/ac/day for P10%-P50% and P80% respectively) were reduced to 1 lb/ac/day for the P10%-P50% particle classes and 2 lb/ac/day for the P80% particle class. These adjustments alone did not sufficiently reduce the impervious runoff concentration. The P8 documentation states that the exponential washoff relationship used by the model is similar to that employed by the EPA's Stormwater Management Model (SWMM). Therefore, documentation for SWMM (Huber et al., 1987) was reviewed to determine acceptable values for the washoff parameters. The documentation revealed that the impervious washoff coefficient could range between 1 and 10. It also mentions that this coefficient can vary by almost five orders of magnitude. The SWMM documentation also indicates that the impervious washoff exponent typically ranges between 1.1 and 2.6, with most values near 2.0. The SWMM documentation states that both of the parameters can be varied to calibrate the model to observed data. In addition to the ranges supplied by the SWMM documentation, the other particle files supplied with P8 were reviewed for typical ranges in the buildup/washoff parameters. Again various combinations for the buildup/washoff parameters were simulated with the best results produced from the following parameters:

- Accumulation rates : 1 lb/ac/day (P10%-P50%) and 2 lb/ac/day (P80%)
- Accumulation Decay Rate : 0.3 day^{-1}
- Impervious Washoff Coefficient : 10.5
- Impervious Washoff Exponent : 2.1

Using the buildup/washoff and pervious runoff parameters listed above resulted in the overall arithmetic mean predicted to observed ratio of the flow weighted mean TSS concentration to equal 100 percent based on the representative monitoring site data. Table 6 summarizes the results of the TSS calibration procedure.

Table 6. TSS Calibration Results

	Charles	Lawson	Hartford	Vandalia
Initial Results (using NURP50.par)				
Accumulation Rate (lb/ac/day) (P10%-P50%/P80%)	1.75/3	1.75/3	1.75/3	1.75/3
Accumulation Decay Rate (1/day)	0.25	0.25	0.25	0.25
Impervious Runoff Coefficient	20	20	20	20
Impervious Runoff Exponent	2	2	2	2
Pervious Runoff Concentration (mg/L) (P10%-P50%/P80%)	100/200	100/200	100/200	100/200
Pervious Runoff Exponent	1	1	1	1
Individual Site Predicted/Observed Volume Ratios	449%	N/A	118%	286%
Overall Arithmetic Mean Predicted/Observed Volume Ratios	284%			
Calibrated Results (CRWDPart.par)				
Accumulation Rate (lb/ac/day) (P10%-P50%/P80%)	1/2	1/2	1/2	1/2
Accumulation Decay Rate (1/day)	0.3	0.3	0.3	0.3

	Charles	Lawson	Hartford	Vandalia
Impervious Runoff Coefficient	10.5	10.5	10.5	10.5
Impervious Runoff Exponent	2.1	2.1	2.1	2.1
Pervious Runoff Concentration (mg/L) (P10%-P50%/P80%)	100/200	100/200	100/200	100/200
Pervious Runoff Exponent	0.1	0.1	0.1	0.1
Individual Site Predicted/Observed Volume Ratios	144%	N/A	82%	74%
Overall Arithmetic Mean Predicted/Observed Volume Ratios	100%			

3.2 Total Phosphorus Calibration

The total dissolved fractions for many of the monitored water quality components are not known, so for phosphorus, we set the "Particle Content" for the dissolved fraction (P0%) such that the concentration was not less than the observed flow-weighted mean dissolved reactive phosphorus concentration for any of the monitoring sites. This is consistent with Step 15 of Walker's 1997 report. The total phosphorus (TP) particle composition for the P0% particle fraction was set equal to the largest observed dissolved reactive phosphorus concentration of any of the sites (0.16 mg/L) times 10^6, or 160000mg TP/kg TSS. The remaining TP particle compositions for the other particle fractions (P10%-P80%) were then reduced until the overall arithmetic mean predicted to observed ratio was 100 percent. The results of the TP calibration procedure are listed in Table 6. While the overall ratio was 100 percent, the median ratio of the individual events was 93 percent indicating that for the median event the predicted TP is within 7 percent of the observed.

Table 7. TP Calibration Results

	Charles	Lawson	Hartford	Vandalia
Calibrated Results (CRWDPart.par)				
TP P0% Particle Composition (mg TP/kg TSS)	160000	160000	160000	160000
TP P10%-P80% Particle Composition (mg TP/kg TSS)	2625	2625	2625	2625
TP Scale Factor	1	1	1	1
Individual Site Predicted/Observed Volume Ratios	119%	N/A	73%	107%
Overall Arithmetic Mean Predicted/Observed Volume Ratios	100%			

3.3 Trace Metal Calibration

Since no total dissolved fractions for the monitored trace metal water quality components were determined, the NURP50% speciation was retained during the calibration process. Based on the data presented in the 1994 Stormwater Monitoring Report, only copper (Cu) and zinc (Zn) had sufficient data for calibration. Only the sample data that were above the detection limits were used for calibration. The calibration of these parameters was accomplished by adjusting the respective scale factor in the "Components" screen of P8.

The default Cu scale factor caused the P8 model to under-predict the Cu concentrations. Therefore, the Cu scale factor was increased until the overall arithmetic mean predicted to observed Cu concentration ratio was 100 percent. A Cu scale factor of 1.37 produced the best calibration.

The default Zn scale factor caused the P8 model to over-predict the Zn concentrations. Therefore, the Zn scale factor was decreased until the overall arithmetic mean predicted to observed Zn concentration ratio was 100 percent. A Zn scale factor of 0.67 produced the best calibration.

3.4 Pollutant Calibration Summary

Because no significant differences in the pervious and impervious loadings exists between the major land use types, a single particle file (CRWDPart.par) was developed. Table 8 summarizes the resulting parameters in the "CRWDPart.par" file that were adjusted to calibrate the various P8 models to representative observed data. The resultant particle file was considered to be applicable to the entire Capitol Region Watershed District.

Table 8. Pollutant Calibration Results

Parameter Adjusted	Calibrated Value
Accumulation Rate (lb/ac/day) (P10%-P50%/P80%)	1 / 2
Accumulation Decay Rate (1/day)	0.3
Impervious Runoff Coefficient	10.5
Impervious Runoff Exponent	2.1
Pervious Runoff Concentration (mg/L) (P10%-P50%/P80%)	100/200
Pervious Runoff Exponent	0.1
TP P0% Particle Composition (mg TP/kg TSS)	16000
TP P10%-P80% Particle Composition (mg TP/kg TSS)	2625
TSS Scale Factor	1
TP Scale Factor	1
Cu Scale Factor	1.37
Zn Scale Factor	0.67

4.0 P8 Modeling of Entire CRWD

With the calibration process described in Sections 2.0 and 3.0 completed, the unmonitored areas of the District could now be modeled. Due to the large extent of the District, six individual P8 models were created. The models were developed in order to keep the number of devices at or below the maximum allowable of 48. Figure 2 illustrates the areas combined for a given model. Figure 3 illustrated the various subwatersheds and their flow direction modeled for this study. Table 9 lists the various major subwatersheds that were combined into one P8 model, explains any connections between models, and describes any unique modeling techniques.

Table 9. CRWD P8 Models

P8 Model Identifier	Major Subwatersheds Containing in Model	Comment
CRWD1	Lake Como and McCarrons Lake	Como and McCarrons Lakes were modeled as pipes so the total water and pollutant loads into the lakes could be easily determined. Devices 4, 5, 6, and 7 were setup as general devices with no particle removal to simulate diversion structures in the existing storm sewer system.
CRWD2	Trout Brook	Como and McCarrons Lakes discharge into Trout Brook. The generalized representation of these lakes and their tributary area were entered into this model (See Section 4.2 for further description). Due to the limited number of devices allowed in P8, runoff from subwatersheds TRT18, TRT19, TRT20, & TRT22 was combined and routed to device TRT20. Similar routing was done for subwatersheds TRT 14 & TRT16. Devices 18 and 19 were setup as general devices with no particle removal to simulate diversion structures in the existing storm sewer system.
CRWD3	Phalen Creek and Urban	
CRWD4	Downtown, St. Anthony Hill, Goodrich-Western, West Seventh, East Kittsondale, Croby, Davern, and Hidden Falls	A generalized representation of the Crosby Lake and its tributary area were entered into this model (See Section 4.2 for further description). To determine the loadings into Crosby Lake a separate watershed and device were entered into the model ("CrosbyLK")
CRWD5	Mississippi River Boulevard and West Kittsondale	
CRWD6	St. Anthony Park	

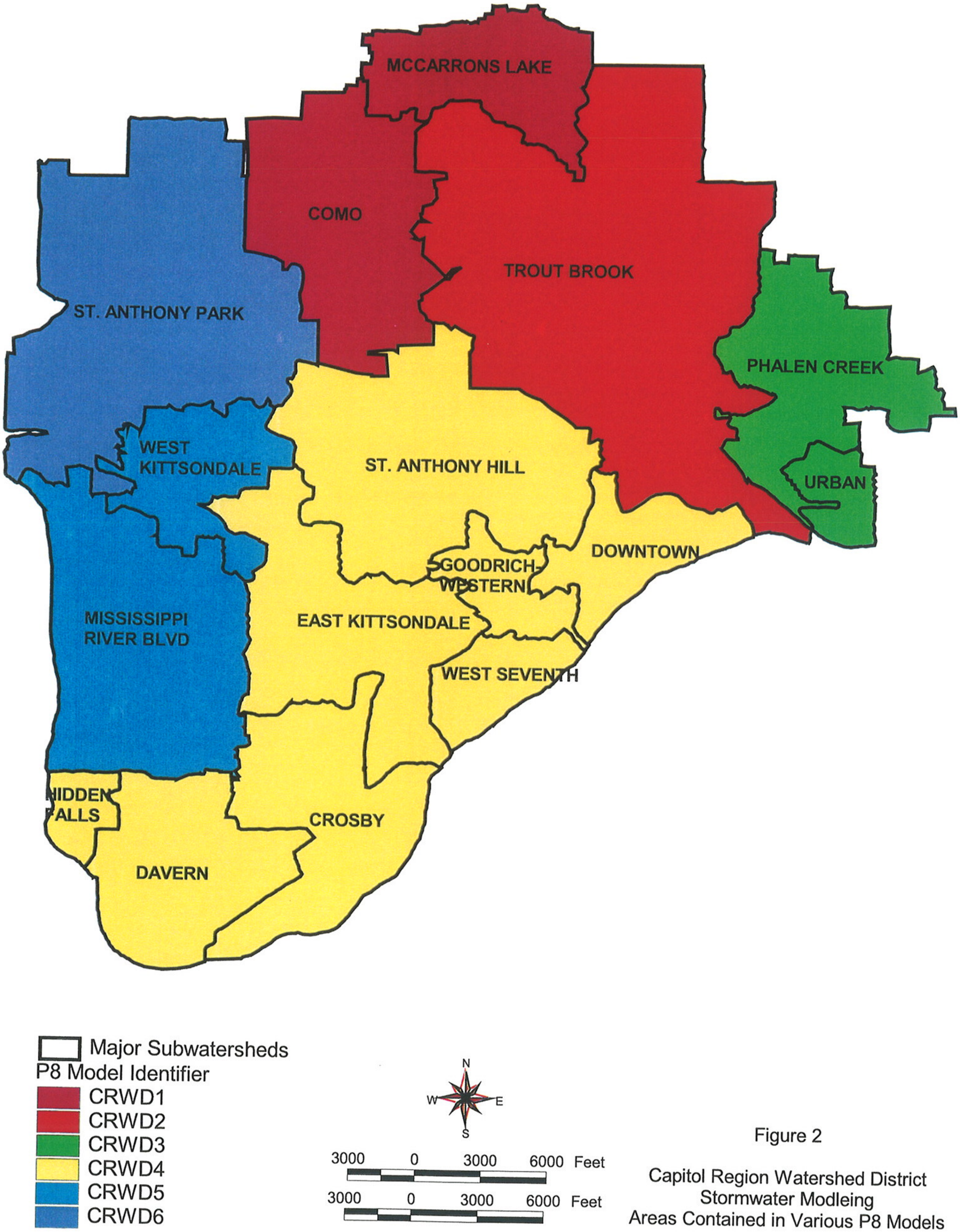

Figure 2

Capitol Region Watershed District
Stormwater Modleing
Areas Contained in Various P8 Models

Barr: Arcview 3.1,PIIDE, i:\projects\23\62\695\gis\project\capitol_deliver.apr, Layout: Layout1:Figure2, SAS, Thu May 18 17:54:48 2000

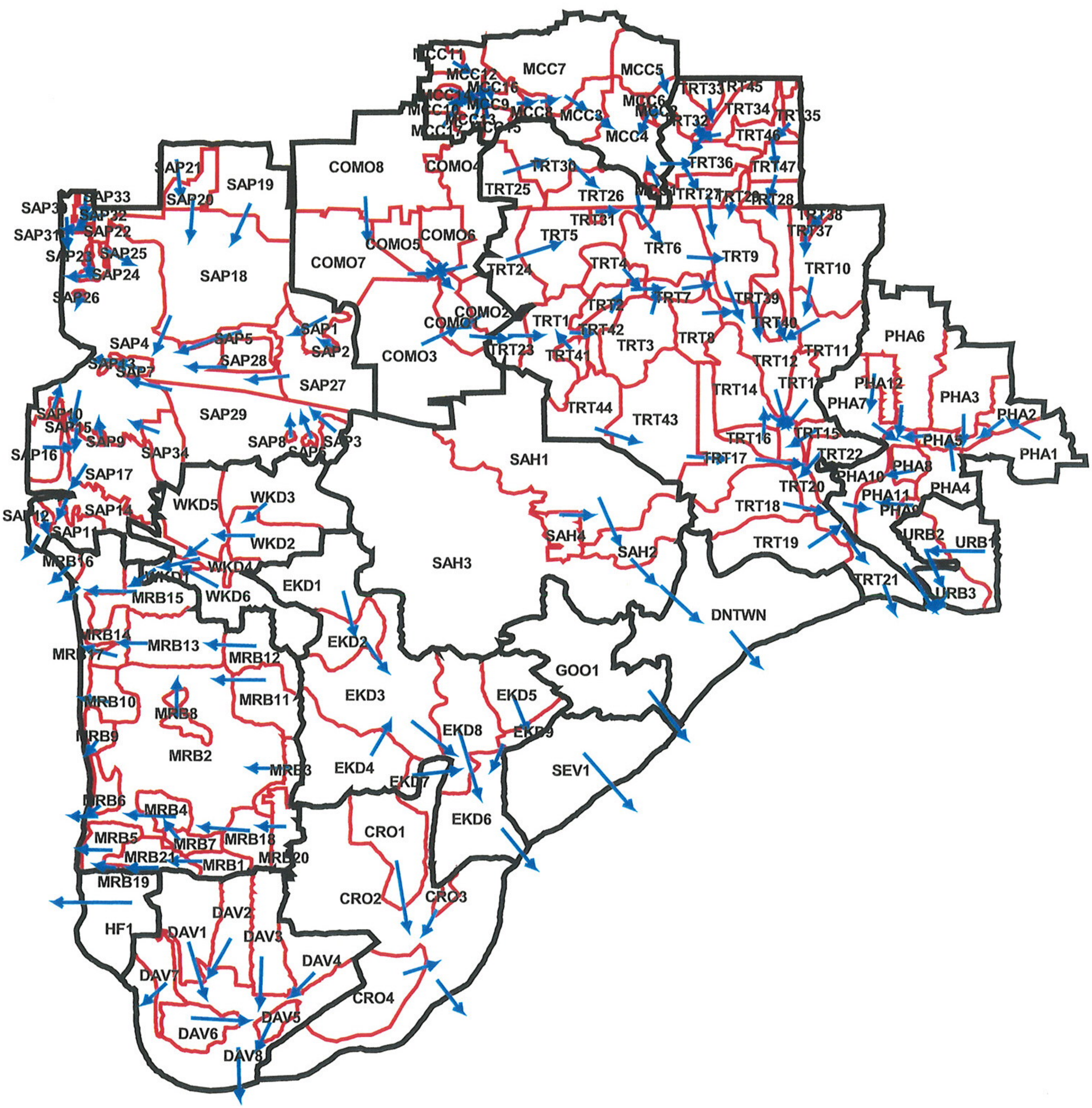

Figure 3

Capitol Region Watershed District
Stormwater Modeling
Watershed Divides and Flow Directions

Barr: Arcview 3.1,PIIDE, i:\projects\23\62\695\gis\project\capitol_deliver.apr, Layout: Layout:Figure3, SAS, Thu May 18 17:54:13 2000

4.1 P8 Model Parameter Selection

From the data that were collected for the 1994 Stormwater Monitoring Report, model calibration afforded the opportunity to select P8 parameters that resulted in a good fit between modeled and observed data. The parameters selected for the CRWD P8 models are discussed in the following paragraphs. P8 parameters not discussed in the following paragraphs were left at the default setting. P8 version 2.3 was used for the modeling.

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

- Time Steps Per Hour (Integer)— 10. Selection was based upon the number of time steps required to eliminate continuity errors greater than two percent.

- Growing Season AMC—II = 0 and AMC—III = 100. Selection of this factor was based upon the observation that the model accurately predicted runoff water volumes from monitored watersheds when the Antecedent Moisture Condition II was selected (i.e., curve numbers selected by the model are based upon antecedent moisture conditions). Modeled water volumes from pervious areas were less than observed volumes when Antecedent Moisture Condition I was selected, and modeled water volumes exceeded observed volumes when Antecedent Moisture Condition III was selected. The selected parameters tell the model to only use Antecedent Moisture Condition I when less than 0 inches of rainfall occur during the five days prior to a rainfall event and to only use Antecedent Moisture Condition III if more than 100 inches of rainfall occur within five days prior to a rainfall event. (See Section 2.0 Water Volume Calibration for further discussion)

4.1.2 Particle Scale Factor (Case-Edit-Components)

- Scale Fac.—Cu—1.37. The particle scale factor determines the copper load generated by the particles predicted by the model in watershed runoff. The factor for copper was selected as 1.37 . (See Section 3.3 Trace Metal Calibration for more discussion on the selection of trace metal scale factors)

- Scale Fac.—Zn—0.67. The particle scale factor determines the zinc load generated by the particles predicted by the model in watershed runoff. The factor for zinc was selected as

0.67. (See Section 3.3 Trace Metal Calibration for more discussion on the selection of trace metal scale factors)

4.1.3 Particle File Selection (Case—Read—Particles)

- CRWDPart.PAR. The particle file developed during the calibration process was applied to the entire CRWD. (See Section 3.0 for discussion on how this particle file was developed)

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

- MSP4999.PCP. The precipitation file MSP4999.PCP is comprised of hourly precipitation measured at the Minneapolis–St. Paul International Airport were used for the period between 1949 and the end of September 1999.

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

- MSP4999.tmp. The temperature file was comprised of temperature data from the Minneapolis–St. Paul International Airport during the period from 1949 through 1999.

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

- Detention Pond— Permanent Pool— Area and Volume— The surface area and dead storage volume of each detention pond was determined and entered here. Where available, Barr used outlet stage-discharge relationships or other rating information and pond volume information supplied by the District. If limited information was supplied, Barr assumed an average depth of 4-feet and estimated the surface area information (based on USGS quad maps or aerial photos) to determine the pond permanent pool volume.

- Detention Pond— Flood Pool— Area and Volume— The surface area and storage volume under flood conditions (i.e., the storage volume between the normal level and flood elevation) was determined and entered here. The areas and volumes were estimated based on information provided by the District.

- Detention Pond— Infiltration Rate (in/hr)— Infiltration rates were only entered for landlocked basins. This was done to simulate no surface outflow from those areas. It was assumed that the soils under the basin would act similar to SCS group D soils. Therefore, an infiltration rate between 0 and 0.05 in/hr (recommended range for group D soils in P8) was selected.

- Detention Pond— Orifice Diameter and Weir Length— The orifice diameter or weir length was determined from field surveys or development plans of the area for each detention pond and entered here.

- Detention Pond or Generalized Device— Particle Removal Scale Factor— Particle Removal Scale Factor— 0.3 for ponds less than two feet deep (including dry ponds) and 1.0 for all ponds three feet deep or greater.

- Detention Pond or Generalized Device— Outflow Device Nos.— The number of the downstream device receiving water from the detention pond outflow was entered.

- Pipe/Manhole— Time of Concentration— Because detailed topographic information was not available for the entire District the time of concentration for each pipe/manhole device was entered as 0 hrs. A pipe device was entered for most watersheds in the District unless (1) there were more than 48 watersheds or (2) a given watershed contained a detention pond. A "dummy" pipe/manhole was installed in the network to represent District Lakes. This forced the model to total all loads (i.e., water, nutrients, etc.) entering the lake. Failure to enter the "dummy" pipe requires the modeler to manually tabulate the loads entering the lake.

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

- Outflow Device Number— The Device Number of the device receiving runoff from the watersheds was selected to match the watershed number. For example, subwatershed COMO3 (watershed No. 3) flows into device 3 (labeled COMO3).

- Pervious Curve Number— A weighted SCS Curve number was used, as outlined in the following procedure. The Ramsey County soil information was provided by the District. It was discovered that this coverage was missing the hydrologic soil group (HSG) classifications for several soil types. To fill in the missing data the individual soil descriptions for each soil type was consulted from the *1980 Soil Survey of Washington and*

Ramsey Counties, Minnesota, SCS. Several of the soil types that were missing the HSG had a HSG listed in the soil survey. In this case the information from the soil survey was added to the soils layer coverage. For areas where the unknown HSG was consistently surrounded by a uniform soil type or HSG, the missing HSG was assumed to be the same as the adjacent soil. Soils in the downtown area of St. Paul were assumed to behave similar to D type soils due to their non-native and compacted nature. For udorthents, undorthents (wet subsratum), pits (gravel), udifluvents, and aquolls and histosols (pond) the soil drainage description given in the text of the soil survey was used to estimate a HSG. Table 10 lists the HSG's assumed for this study.

Table 10. Modeled Hydrologic Soil Group

Soil Type	Description	Modeled HSG
Udorthents	Moderately to Mostly Well Drained	C
Undorthents (wet subsratum)	Very Poorly to Poorly Drained	D
Pits (gravel)*	Variable	A or B
Udifluvents	Somewhat Poorly Drained	D
Aquolls and histosols	Very Poorly Drained	D
B/D	HSG Drained/Undrained	D
C/D	HSG Drained/Undrained	D
A/D	HSG Drained/Undrained	D

* Dependent on surrounding soil types

Based on consultation with the SCS National Engineering Handbook (SCS, 1964), a pervious curve number was selected for each subwatershed based upon soil types, land use, and hydrologic conditions (e.g., if watershed soils are type B and pervious areas are comprised of grassed areas with 50% to 75% cover, then a Curve Number of 69 would be selected). An overall composite pervious curve number was determined by weighting the areas for the given soil groups within the subwatershed. This composite pervious curve number was then weighted with indirect (i.e., unconnected) impervious areas in each subwatershed as follows:

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

The direct, indirect, and total impervious areas were based upon measurements from the CRWD impervious shapefile.

- Swept/Not Swept—An "Unswept" assumption was made for the entire impervious watershed area. A Sweeping Frequency of 0 was selected. Selected parameters were placed in the "Unswept" column since a sweeping frequency of 0 was selected.

- Impervious Fraction—The direct or connected impervious fraction for each subwatershed was determined and entered here. The direct or connected impervious fraction includes driveways and parking areas that are directly connected to the storm sewer system. CRWD completed a project to create an ArcView shapefile for the major impervious surfaces throughout the District, including roads, alleys, structures, tennis courts, and parking lots. The impervious surface GIS data layer from the District did not contain polygons for all the sidewalks and driveways within the District. To overcome the lack of information for sidewalks and driveways, Barr Engineering determined the areal extent of sidewalks and driveways for representative areas within each of the various land use categories. Connectivity estimation of the various impervious surface types was accomplished by associating each surface type with a land use category. (See Section 1.2 Impervious Surface Information for additional information)

- Depression Storage— 0.1 (See Section 2.0 Water Volume Calibration for further discussion)

- Impervious Runoff Coefficient— 0.9 (See Section 2.0 Water Volume Calibration for further discussion)

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

- Passes Through Storm File— The number of passes through the storm file was determined after the model had been set up and a preliminary run completed. The selection of the number of passes through the storm file was based upon the number required to achieve model stability. Multiple passes through the storm file were required because the model assumes that dead storage waters contain no pollutants. Consequently, the first pass through the storm file results in lower pollutant loading than occurs with subsequent passes. Stability occurs when subsequent passes do not result in a change in pollutant concentration in the pond waters. To determine the number of passes to select, the model was run with three passes, five passes, and ten passes. A comparison of pollutant predictions for all devices was evaluated to determine whether changes occurred between the three scenarios. If there is no difference between three and five passes, three passes are sufficient to achieve model stability. If differences are noted between three and five passes and no differences are noted between five and ten passes, then five passes are sufficient to achieve model stability and so on. This parameter was determined for all six of the CRWD P8 model areas. No differences were noted between five and ten passes for CRWD1, CRWD3, CRWD4, CRWD5, and CRWD6. Therefore, it was determined that five (5) passes through the storm file resulted in model stability for the those models. Therefore, all the models associated with CRWD1, CRWD3, CRWD4, CRWD5, and CRWD6 are setup with 5 passes through the storm file. It was determined that model stability for CRWD2 (the Trout Brook major subwatershed) required twenty (20) passes through the storm file. Therefore, all the models associated with CRWD2 are setup with 20 passes through the storm file.

4.2 P8 Modeling of District Lakes

In the event that subwatershed areas possess a network of stormwater detention ponds downstream of lakes and other large water bodies, the following steps were taken to ensure that the downstream portions of the major subwatersheds were more accurately modeled:

- The lake and its tributary watershed were generalized and added to the P8 model for the overall watershed
- The generalized representation of the lake and its tributary watershed, in the P8 model, was setup (by adjusting scale factors) to match the average annual water and pollutant (TP) export concentration for the most recent year of record (1999).

These steps ensured an accurate representation of the flushing effect that takes place in stormwater detention ponds downstream of lakes. Because water quality data were only provided for Como Lake, McCarrons Lake, and Crosby Lake, they were the only lakes generalized in the P8 models. During the monitoring site calibration process the P0% particle fraction for TP was set so the minimum dissolved phosphorus concentration would be 160 μg/L. The lakes were entered into the P8 model as large detention basins. Adjustments to the "Particle Removal Scale Factor" had little impact on the outflow TP concentrations for the lakes, thus indicating that essentially all the phosphorus leaving the lakes is in the dissolved form with an annual flow weighted mean concentration of

160 μg/L. In some cases, this concentration is greater than 4 times the observed annual in-lake concentration. In order to reduce to TP concentration leaving the lakes the watershed "Scale Factor for Pervious Area Loads" and unswept "Scale Factor for Particle Loads" were reduced to a value less than 1. Table 11 summarizes the variables used to calibrate the generalized representation of the District Lakes.

Table 11. P8 Parameters for Generalized Lakes

Parameter	Como Lake	McCarrons Lake	Crosby Lake
P8 Model Containing the Generalized Lake Representation	CRWD2	CRWD2	CRWD4
P8 Watershed Number/Label	22 / COMOLK	16 / MCCARLK	15 / CRO4
Scale Factor for Pervious Area Loads	0.665	0.227	0.2
Unswept Scale Factor for Particle Loads	0.665	0.227	0.2
Observed 1999 Annual TP Concentration (μg/L)	112	37	32
Modeled Outflow 1999 Annual TP Concentration (μg/L)	112	37	32

4.3 P8 Modeling Summary

Modeling simulations of the entire District were performed for recent (1998-99 water year), wet (1982-83 water year), dry (1987-88 water year), and average (1994-95 water year) climatic conditions. The models developed for the various climatic conditions were named by the a combination of the P8 model identifier and the given water year (i.e., model simulation of average climatic conditions for the Trout Brook major subwatershed are contained in the "CRWD295.cas" P8 case file).

The annual and snowmelt inflow loadings and export for water, TSS, TP, Cu, and Zn are summarized in a database file ("All_crwd_models.dbf"). Also included in this database file are the subwatershed characteristics (subwatershed name, drainage area, impervious area, unconnected impervious area, pervious curve number, impervious fraction, relative area of major land use classes, and downstream subwatershed name) used in the various P8 models. All of this information has been entered into ArcView and is associated with the shapefile named "All_crwd_models.shp".

As previously mentioned, several subwatersheds had to be routed to a single device in the P8 model for Trout Brook. As a result, the individual watershed loadings were combined into a single watershed load. Runoff from subwatersheds TRT14 and TRT16 was combined and routed to device TRT14 in the P8 model. Therefore, the loadings associated with the runoff from subwatershed TRT16 were combined with those from TRT14 and listed in the database file for subwatershed TRT14. Similarly, TRT18, TRT19, TRT20, and TRT22 were routed to a single device (TRT20) in the P8 model. Therefore, the loadings listed for subwatershed TRT20 are a combination of the individual loadings from subwatersheds TRT18, TRT19, TRT20, and TRT22. Because runoff from several subwatersheds was routed to a single device, the individual loadings could not be determined. Therefore, the database files does not contain estimated loading results for subwatersheds TRT16, TRT18, TRT19, and TRT22 (i.e., the data field are blank for these subwatersheds).

5.0 Lake Modeling

The District provided summer average water quality data for Como Lake, McCarrons Lake, and Crosby Lake within the District. Water and pollutant export from District lakes, that could not be reliably modeled in P8, were estimated based on their annual modeled inflow loading and the predicted assimilation from a lake water quality mass balance model. The calibrated P8 computer model was used to estimate annual water and phosphorus inflow loadings to those lakes. Volumes and surface areas for the individual lakes were estimated based on the Minnesota Department of Natural Resources lake map for the respective lake.

5.1 In-Lake Modeling

The mass balance models for the above mentioned lakes were optimized to match, as closely as possible, the observed TP concentration data, based on the same climatic conditions. The Wisconsin DNR's WiLMS 3.0 (the Wisconsin Lake Modeling Suite is a screening level land use management/lake water quality evaluation tool) lake modeling tool was utilized for in-lake water quality calibration. This model can evaluate numerous mass balance models simultaneously, allowing the selection of the model with the closest fit to observed data. A copy of WiLMS 3.0 is provided on the enclosed CD. In addition, the lake water quality data files developed as part of this study are also included on the CD.

5.1.1 Como Lake

The District provided data for numerous years for Como Lake. Table 12 lists the lake and watershed input data as well as the predicted in-lake TP concentration for the various climatic conditions analyzed for this study. The in-lake mass balance model was calibrated to 1999 data. Based on the WiLMS modeling, the Vollenweider 1982 OECD model fit the data within 3 percent. Another model within this suite, Walker 1987 Reservoir, fit the observed data within 8 percent. Because several models could be selected based on 1999 conditions, the in-lake modeling result were verified using 1998 data and climatic conditions. Based on the 1998 WiLMS modeling results the Walker 1987 Reservoir model produced the closest fit. This model predicted the average summer TP concentration (107 μg/L) within 3 percent of the observed (104 μg/L). Since the Walker 1987 Reservoir model consistently produced results within 10 percent of the observed TP concentrations, it provides the best fit based on 1998 and 1999 climatic conditions. Therefore, this model was used to assess in-lake TP concentrations for other conditions.

Table 12. Como Lake Modeling Results

	Climatic Condition				
Parameter	**1998**	**1999**	**Wet**	**Dry**	**Average**
Tributary Area (ac)	1783.2	1783.2	1783.2	1783.2	1783.2
Lake Surface Area (ac)	66.7	66.7	66.7	66.7	66.7
Lake Volume (ac-ft)	477.6	477.6	477.6	477.6	477.6
Total Unit Runoff (in)	6.52	5.8	10.69	4.22	5.36
Precipitation – Evaporation (in)	2.0	-0.8	5.9	-24.9	-4.8
Watershed TP Yield (kg/ha/yr)	0.561	0.47	0.91	0.341	0.398
Atmospheric Deposition (kg/ha/yr)	0.56	0.56	0.56	0.56	0.56
Observed In-Lake TP (□g/L)	104	112	N/A	N/A	N/A
Predicted In-Lake TP (□g/L)	107	103	112	115	100

Since individual sampling event TP data were not provided, estimates and impacts due to internal loadings (from anoxic sediment release, curlyleaf pondweed die-back, or other sources of TP) could not be determined or considered separately in the in-lake modeling for Como Lake.

5.1.2 McCarrons Lake

The District provided data for numerous years for McCarrons Lake. Table 13 lists the lake and watershed input data as well as the predicted in-lake TP concentration for the various climatic conditions analyzed for this study. The in-lake mass balance model was calibrated to 1999 data. Based on the WiLMS modeling, the Reckhow 1979 General model provides the best fit to observed data. This model predicted the average summer TP concentration (34 μg/L) within 8 percent of the observed (37 μg/L). The 1999 in-lake modeling results were verified using 1998 data and climatic conditions. Based on the 1998 WiLMS modeling results the Reckhow 1979 General model produced the closest fit (within 10 μg/L). Since the Reckhow 1979 General model consistently produced the best fit for TP concentrations for recent climatic conditions, this model was used to assess in-lake TP concentrations for other conditions. Similar to Como Lake, the impacts due to any internal TP loading could not be determined or considered separately in the in-lake modeling because individually sampled TP data were not supplied.

Table 13. McCarrons Lake Modeling Results

	Climatic Condition				
Parameter	**1998**	**1999**	**Wet**	**Dry**	**Average**
Tributary Area (ac)	1048.9	1048.9	1048.9	1048.9	1048.9
Lake Surface Area (ac)	75.7	75.7	75.7	75.7	75.7
Lake Volume (ac-ft)	1661.6	1661.6	1661.6	1661.6	1661.6

	Climatic Condition				
Parameter	1998	1999	Wet	Dry	Average
Total Unit Runoff (in)	4.89	4.28	8.21	3.19	3.94
Precipitation – Evaporation (in)	2.0	-0.8	5.9	-24.9	-4.8
Watershed TP Yield (kg/ha/yr)	0.35	0.29	0.57	0.21	0.25
Atmospheric Deposition (kg/ha/yr)	0.56	0.56	0.56	0.56	0.56
Observed In-Lake TP (□g/L)	29	37	N/A	N/A	N/A
Predicted In-Lake TP (□g/L)	39	34	55	28	30

5.1.3 Crosby Lake

The District only provided water quality data for 1999. Therefore, the in-lake mass balance model was calibrated to 1999 data and not verified based on water quality data from other growing seasons. Based on the WiLMS modeling, the Reckhow 1979 General model provides the best fit to observed data. This model predicted the 1999 average summer TP concentration (31 µg/L) within 3 percent or 1 µg/L of the observed (32 µg/L). Since only one year of water quality data were provided, this model was used to assess in-lake TP concentrations for other climatic conditions. Table 14 lists the lake and watershed input data as well as the predicted in-lake TP concentration for the various climatic conditions analyzed for this study.

Table 14. Crosby Lake Modeling Results

	Climatic Condition			
Parameter	1999	Wet	Dry	Average
Tributary Area (ac)	160.2	160.2	160.2	160.2
Lake Surface Area (ac)	46.5	46.5	46.5	46.5
Lake Volume (ac-ft)	111.2	111.2	111.2	111.2
Total Unit Runoff (in)	8.33	14.81	5.83	7.65
Precipitation – Evaporation (in)	-0.8	5.9	-24.9	-4.8
Watershed TP Yield (kg/ha/yr)	0.96	1.74	0.65	0.82
Atmospheric Deposition (kg/ha/yr)	0.56	0.56	0.56	0.56
Observed In-Lake TP (µg/L)	32	N/A	N/A	N/A
Predicted In-Lake TP (µg/L)	31	49	24	28

5.1.4 Loeb and Sandy Lakes

No water quality data were available for these lakes during this study. Therefore, no in-lake water quality model was developed for either Loeb Lake or Sandy Lake. Loeb Lake likely has minimal impact on downstream water bodies because it is landlocked, according to St. Paul storm sewer information.

6.0 References

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